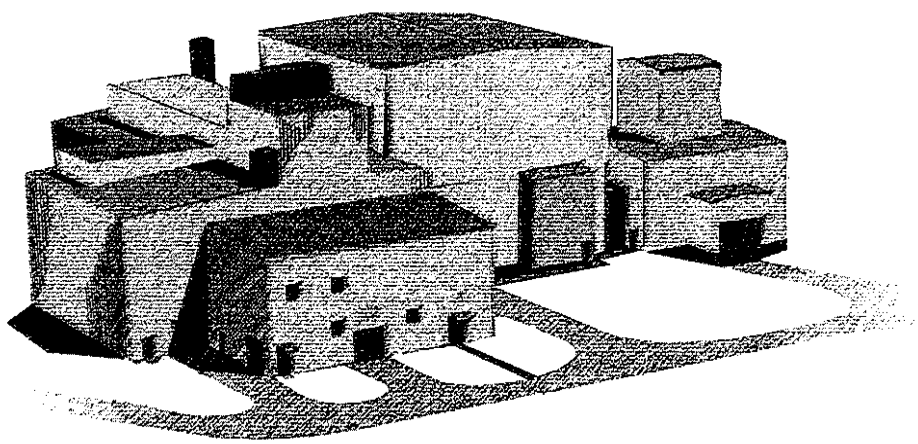
Safety Analysis Report

Idaho Spent Fuel Facility

Docket No. 72-25



Volume II

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FOSTER WHEELER ENVIRONMENTAL CORPORATION

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4.0 INSTALLATION DESIGN

This chapter describes the design of the Idaho Spent Fuel (ISF) Facility, including the installation layout, facility structures, storage vaults, major components, handling equipment, and auxiliary systems. Each major area and component is described and evaluated with emphasis on those features that perform functions important to safety (ITS). In particular, special design features are described and evaluated to indicate those used to withstand environmental and accident conditions associated with the ISF Facility.

This chapter also summarizes the analyses performed, to demonstrate compliance with design requirements presented in Chapter 3, *Principal Design Criteria.*

4.1 SUMMARY DESCRIPTION

This section summarizes the location and layout of the ISF Facility site, including the site boundary and controlled area boundary. It also describes the principal features of the ISF Facility site relating to site utility supplies, systems, and storage facilities. This includes information relating to potable water, sanitary wastewater, fire service water, electricity, and communications and alarm systems.

4.1.1 Location and Layout of Installation

The ISF Facility site is in the U.S. Department of Energy (DOE) Idaho National Engineering and Environmental Laboratory (INEEL). The INEEL site is in southeastern Idaho and consists of an 890-square-mile reservation 32 miles west of Idaho Falls, Idaho, as shown in Figure 2.1-3. Figure 2.1-5 shows the location and layout of the ISF site relative to the Idaho Nuclear Technology and Engineering Center (INTEC). INTEC is 53 miles west of Idaho Falls on 200 acres of the INEEL. Nearby structures, roadways, and railways are shown on these figures. The ISF Facility site is outside of and adjacent to the southeast side of INTEC area.

4.1.2 Principal Features

The principal features of the ISF Facility site and facilities are summarized in Chapter 1, *Introduction and General Description of Installation*. As described in Chapter 1, the ISF Facility is a fully enclosed building complex that allows for year-round operations to receive, repackage, and store SNF. It consists of three principal areas: the Cask Receipt Area, Transfer Area, and Storage Area. A common Transfer Tunnel provides for the movement of SNF throughout the facility via rail-mounted trolleys. Figure 1.2-1 shows the external appearance of the facility.

The general layout of the major areas of the ISF Facility is shown in Figure 1.2-2. The Cask Receipt Area provides the equipment necessary to transfer incoming spent nuclear fuel (SNF) transportation casks from truck-mounted transporters to a rail-mounted cask trolley for subsequent movement into other areas of the ISF Facility. The Cask Receipt Area incorporates a single-failure-proof cask receipt crane to lift the transport cask from its transport vehicle and place it on the cask trolley. The cask trolley moves within the enclosed Transfer Tunnel that connects the Cask Receipt Area with the Transfer Area and Storage Area. The Transfer Area and Storage Area are described below.

The Transfer Area provides the facilities for unloading the SNF from the DOE transfer cask and repackaging it into specifically designed ISF canisters. The ISF canisters are constructed of stainless steel and are vacuum dried, backfilled with helium, and welded closed to provide an inert storage atmosphere for the SNF.

Within the Fuel Packaging Area (FPA), a sub-area of the Transfer Area, SNF is handled by remote manipulation. SNF is manipulated using a specially designed fuel handling machine (FHM) that includes a single-failure-proof hoist and a power manipulator system (PMS). The FHM hoist is used to lift and move SNF. Master/slave manipulators (MSMs) and the PMS are used to perform required remote manual operations. The FPA also features shielded windows and a closed-circuit television (CCTV) system to aid operator viewing from the operating gallery outside of the FPA.

The Storage Area provides for interim dry storage of the SNF. The Storage Area consists of a passively cooled concrete vault housing 246 metal storage tubes, as shown in Figure 1.2-3. The area above the concrete vault is an enclosed, metal-sided building that provides weather protection and permits year-round SNF loading operations. Each storage tube provides interim storage for a single ISF canister. A canister handling machine (CHM) moves individual ISF canisters from the Transfer Tunnel to their storage-tube location, and inserts the ISF canisters into the storage tubes. As shown in Figure 1.2-4, the CHM consists of a single-failure-proof bridge crane with an integral shielded transfer cask. After an ISF canister is lowered into a storage tube and a shield plug is installed, the storage tube is sealed with a cover plate with dual metallic seal rings to provide the redundant, outer confinement barrier during storage. Storage tubes are filled with an inert atmosphere to reduce potential corrosion of the ISF canisters during storage. Figure 1.2-5 shows a storage tube assembly loaded with an ISF canister, whose internal configuration is presented in Figure 1.2-6.

The following sections further describe the ISF Facility site boundary and controlled area, as well as nearby utilities, storage facilities, and stacks.

4.1.2.1 Site Boundary

The ISF Facility site boundary is shown in Figure 4.1-1. The ISF Facility site comprises an area of approximately 8 acres on the southeast side of INTEC.

4.1.2.2 Controlled Area

In accordance with Title 10, Code of Federal Regulations (CFR), Part 72.106, Subpart E, *Siting Evaluation Factors*, Foster Wheeler Environmental Corporation (FWENC) has established a controlled area boundary as shown in Figure 2.1-3 (Ref. 4-1). This controlled area boundary coincides with the INEEL site boundary and is consistent with the controlled area boundary established by the DOE for the nearby Three Mile Island-2 (TMI-2) Independent Spent Fuel Storage Installation (ISFSI). FWENC exercises control over this area via agreements with the DOE.

4.1.2.3 Site Utility Supplies and Systems

The ISF Facility design relies on the natural circulation of air through the storage vaults to provide cooling for the SNF. This passive design eliminates the need for active cooling systems or utilities to support safe storage of the SNF. The ISF Facility site utility and supply systems are considered not important to safety (NITS). ITS classifications for the ISF Facility are described in Section 3.4.

Potable water, sanitary wastewater, fire water supply, electrical, and communications and alarm utility connections from the adjacent INTEC area are provided to the ISF Facility site. There are no groundwater test wells in the ISF Facility site.

4.1.2.3.1 Potable Water Supply

The DOE provides potable water via a 2-inch water line to the ISF Facility from existing INTEC utilities. The tie-in location is a valve vault on the western edge of the ISF Facility site, as shown in Figure 4.1-1. The available flow rate of 37 gallons per minute (gpm) of potable water is adequate to support ISF Facility operations. The potable water system is discussed in Section 4.3.5, *Water Supply System*.

4.1.2.3.2 Sanitary Wastewater

An existing 8-inch INTEC sanitary wastewater line supports the ISF Facility. This line is near the western edge of the ISF Facility site. An ISF Facility line will interface with the existing INTEC line at the tie-in location as shown in Figure 4.1-1. The sanitary wastewater system is described in Section 4.3.6, *Sewage Treatment System*.

4.1.2.3.3 Fire Water Supply

Fire water is supplied by INTEC utilities through two existing 10-inch water lines at the tie-in locations shown in Figure 4.1-1. The fire protection system, including anticipated fire water usage at the ISF Facility, is described in Section 4.3.8, *Fire Protection Systems*.

4.1.2.3.4 Electrical Supply

Electrical power is supplied to the ISF Facility site at 13.8 kilovolts (kV) and up to 5000 kilovolt-amps (kVA). The electrical power tie-in location and substation for the ISF Facility are shown in Figure 4.1-1. The electrical system is described in Section 4.3.2, *Electrical Systems*.

4.1.2.3.5 Communications and Alarm Systems

Communications to the ISF Facility are provided by telephone lines and local area network (LAN) connections. Voice and data communication lines are tied into existing INTEC telephone lines and the broadband LAN at the tie-in location shown in Figure 4.1-1. Emergency voice paging and alarm systems are also tied into existing systems at INTEC. The communications and alarm systems are described in Section 4.3.7, *Communications and Alarm Systems*, and Section 4.3.8, *Fire Protection Systems*.

4.1.2.4 Storage Facilities

Within the ISF Facility site boundary, limited amounts of chemicals and compressed gas bottles are used for facility operations and are stored at various locations at the ISF Facility site. There are no wastewater holding ponds or open-air chemical storage tanks on the ISF Facility site. Several storage facilities and wastewater holding ponds exist outside the ISF Facility site boundary as part of INTEC operations.

4.1.2.5 Stacks

The exhaust stack from the heating, ventilation, and air conditioning (HVAC) system is located as shown in Figure 4.1-1. The ISF Facility stack is described in Section 4.3.1, *Ventilation and Off-Gas Systems*. Within the INTEC area an exhaust stack from a nearby shutdown fossil power plant is approximately 300 feet from the southwest corner of the ISF Facility site. Additional stacks are in the INTEC area, and are further away from the ISF Facility site.

4.2 STORAGE STRUCTURES

The ISF Facility uses a fixed location storage vault system consisting of two vaults for the monitored and retrievable interim dry storage of SNF. Figure 4.2-1 and Figure 4.2-2 depict the general arrangement of the ISF Facility and relative location of the storage vaults in relationship to the spent fuel receipt and packaging areas. The storage vaults are aboveground, reinforced concrete structures as shown in Figure 4.2-3, Figure 4.2-4 and Figure 4.2-5. The storage vaults contain an array of carbon-steel storage tube assemblies, as shown in Figure 4.2-6. Each mechanically sealed storage tube assembly contains an SNF-loaded stainless steel canister. Shielding is provided by the storage vault concrete structure that surrounds the storage tube assembly array. Decay heat is vented directly to the atmosphere by natural air convection. Outside air flows into the vaults via inlet vents cast into the concrete structure on the north and south walls, and flows along the exterior of each storage tube assembly, discharging through an annulus between the storage tubes and the charge face structure.

This section describes the ISF Facility's storage vaults and major storage components, including associated design criteria, materials of construction, fabrication summary, and Quality Assurance (QA) activities. Structural, thermal, and criticality evaluations under normal and off-normal storage conditions are also summarized.

Structures and components relied upon for SNF receipt, handling and packaging, including the building above the storage vaults, are described and evaluated in Section 4.7. The shielding analysis is in Chapter 7, and the accident analysis is in Chapter 8.

4.2.1 Structural Specification

The design criteria of the storage vault and major components account for both normal and off-normal conditions, including a range of credible and postulated accidents. The principal design criteria for the ISF Facility are in accordance with 10 CFR 72 (Ref. 4-1) and ANSI/ANS 57.9 (Ref. 4-2).

4.2.1.1 ISF Storage Vault

The storage vaults consist of reinforced-concrete walls, floor, and charge face structure. Integral with the storage vault structure is the south section of the Transfer Tunnel. A support stool assembly is located at the bottom of each storage tube to provide vertical and lateral support of the storage tube. The support stool is bolted to the floor of the storage vaults. Thick concrete walls provide radiation shielding for the SNF. The storage vaults are classified ITS as they provide tornado missile protection for the stored fuel and the vault structure maintains the criticality array. This includes the Transfer Tunnel that forms part of the west wall of storage vault 1. The steel Storage Area building that covers the storage vaults and Transfer Tunnel is classified NITS, but was designed with additional features to ensure safe storage of the SNF.

Codes and Standards

The design of the storage vault including the charge face and Transfer Tunnel complies with the following principal codes and standards:

- ANSI/ANS 57.9, *Design Criteria for an Independent Spent Fuel Storage Installation–Dry Type*
- ACI 349, *Code Requirements for Nuclear Related Concrete Structures* (Ref. 4-3) (as modified by NUREG 1567 Paragraph 5.4.3.2 [Ref. 4-4] when using ACI-318 for construction [Ref. 4-5])
- ANSI A58.1, *Minimum Design Loads for Buildings and Other Structures* (Ref. 4-6)
- ASCE 7, *Minimum Design Loads for Buildings and Other Structures* (Ref. 4-7)

Materials of Construction

Materials for the storage vaults and Transfer Tunnel comply with ACI 349 as modified by NUREG 1567, paragraphs 5.4.3.2 and 5.4.3.3 when using ACI-318 for construction. The following materials are used in the construction of these concrete structures:

- Cement – ASTM C150, *Specification for Portland Cement*
- Aggregate – ASTM C33, *Specification for Concrete Aggregates*
- Reinforcing Steel – ASTM A615, *Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement*
- Reinforcing Steel – ASTM A706, *Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement*
- Embedments – ASTM A36, *Standard Specification for Structural Steel*

Fabrication/Inspection

The storage vaults and Transfer Tunnel will be constructed and inspected in accordance with the following codes:

- ACI-349, *Code Requirements for Nuclear Related Concrete Structures* (as modified by NUREG 1567 paragraph 5.4.3.2 when using ACI-318 for construction)
- ACI-318, *Code Requirements for Reinforced Concrete Structures*
- AWS D1.4, *Structural Welding Code – Reinforcement* (Ref. 4-8)

Features Covered by QA Program

The design and construction of the storage vaults and Transfer Tunnel structural concrete will be performed in accordance with the ISF Facility *Quality Program Plan* (Ref. 4-9).

4.2.1.2 ISF Storage Tube Assembly

The ISF storage tube assembly consists of the storage tube body, storage tube lid and seals, and the internal storage tube plug. The pressure boundary components of the storage tube assembly are classified ITS. The storage tubes are the ISF canister storage vessels that are installed within the storage vaults. A support stool that is bolted to the vault floor locates the base of each storage tube and the upper ends of the storage tubes are located by the penetrations through the charge face structure. ISF canisters are loaded into the ISF storage tubes using the CHM. An inert helium atmosphere is established within the

ISF storage tube after ISF canisters are loaded, in order to provide a dry inert atmosphere around the ISF canister and thereby prevent degradation of the canister during its residence in the storage facility. Metal seal rings are used to create redundant seals between the ISF storage tube body and lid. Test ports on the ISF storage tube lid are provided to facilitate testing of the seals during the initial inert fill process and during storage. The ISF storage tube is protected from tornado missile strike by the charge face structure and the charge face cover plate that is positioned directly above the storage tube. The charge face cover plate is bolted to the charge face encast to resist tornado wind pressure uplift. The support stool and the charge face cover plate are classified ITS.

Codes and Standards

The ISF storage tube pressure boundary components (confinement barrier) are an N-stamped Section III, Division 1, Class 2 component in accordance with the *ASME Boiler & Pressure Vessel Code* (Ref. 4-10).

The storage tube body, lid, bolts, and seals are designed in accordance with Article NC-3000 of the *ASME Boiler & Pressure Vessel Code*, Section III, Division 1, Subsection NC (Class 2 Components).

The support stool, charge face encast, and the charge face cover plate are designed in accordance with the *AISC Manual of Steel Construction, Ninth Edition* (Ref. 4-11).

Materials of Construction

Materials of construction of the storage tube assembly, support stool, charge face encast, and charge face cover plate are provided in Section 4.2.3.2.2.

Fabrication/Inspection

The storage tube body, lid, bolts, and seals are fabricated and inspected in accordance with the *ASME Boiler & Pressure Vessel Code*, Section III, Division 1, Subsection NC (Class 2 Components).

The support stool, charge face encast, and the charge face cover plate are fabricated and inspected in accordance with the *AISC Manual of Steel Construction, Ninth Edition.*

Features Covered by QA Program

Design, fabrication, testing, and inspection of the storage tube assembly is performed in accordance with the ISF Facility *Quality Program Plan* (Ref. 4-9).

4.2.1.3 ISF Canister

The ISF canister consists of the canister body assembly and the canister lid assembly. The ISF canister is classified ITS. The canister body consists of a formed head welded to a pipe section that creates the body cavity. A short length of pipe is welded to the lower formed head to form a base for the canister to stand upon. The canister lid consists of a formed head welded to a short length of pipe that provides the upper lifting feature for the canister. Integral impact plates are secured to the inside of the upper and lower formed heads. The impact plates support the internal baskets and transfers loads from the baskets to the canister shell. The ISF canister lid is welded to the canister body when the ISF canister is in the canister closure area.

Codes and Standards

The ISF canister (confinement barrier) is N-stamped as a Section III, Division 1, Class 1 component in accordance with the *ASME Boiler & Pressure Vessel Code.*

The ISF canister is designed in accordance with Article NB-3000 of the *ASME Boiler & Pressure Vessel Code*, Section III, Division 1, Subsection NB (Class 1 Components); including Code Case N-595-2.

Materials of Construction

Materials of construction of the ISF canister are provided in Section 4.2.3.2.3.

Fabrication/Inspection

The ISF canister is fabricated and inspected in accordance with the *ASME Boiler & Pressure Vessel Code*, Section III, Division 1, Subsection NB (Class 1 Components); including Code Case N-595-2.

Features Covered by QA Program

Design, fabrication, testing, and inspection of the ISF canister is performed in accordance with the ISF Facility *Quality Program Plan* (Ref. 4-9).

4.2.1.4 ISF Canister Basket

The ISF canister baskets consist of tubes, spacer discs and plates, tie bars, lids and locking plates assembled into structure that provides location and support for the spent fuel elements within the ISF canister. The ISF canister baskets that provide criticality control features are classified ITS. There is a specific basket design for each fuel type, as the basket must accommodate the different physical and radiological parameters of the fuel. The Peach Bottom, TRIGA, and Shippingport loose rod baskets are used for lifting and handling the fuel elements within the FPA as they are transferred from bench vessels into the ISF canister.

Codes and Standards

The ISF canister baskets that provide criticality control features are designed in accordance with Article NG-3000 of the *ASME Boiler & Pressure Vessel Code*, Section III, Division 1, Subsection NG (Core Support Structures).

Materials of Construction

Materials of construction of the ISF canister basket are provided in Section 4.2.3.2.4.

Fabrication/Inspection

The ISF canister basket is fabricated and inspected under the ISF Facility *Quality Program Plan* using the *ASME Boiler & Pressure Vessel Code*, Section III, Division 1, Subsection NG (Core Support Structures) as guidance.

Features Covered by QA Program

Design, fabrication, testing, and inspection of the ISF canister basket is performed in accordance with the ISF Facility *Quality Program Plan* (Ref. 4-9).

4.2.1.5 ISF Canister Impact Plate and Shield Plug

The impact plates are located inside the ISF canister upper and lower formed heads. They are flat steel plates that create perpendicular end faces inside the canister for the shield plug and canister basket to react against. The impact plates are fixed to the formed heads by a welded ring that holds the impact plates in their required position. The shield plug is a steel disc that is placed above the basket within the ISF canister. The shield plug is used to reduce the dose from the canister during canister closing operations. As each fuel type has different radiological parameters, there are different thickness requirements for the shield plugs to suit each fuel type. The ISF canister impact plate and shield plug are classified ITS.

Codes and Standards

The ISF canister impact plate and shield plug are designed to the requirements of Article NF-3000 of the *ASME Boiler & Pressure Vessel Code*, Section III, Division 1, Subsection NF (Supports).

Materials of Construction

Materials of construction of the ISF canister impact plate and shield plug are provided in Section 4.2.3.2.3

Fabrication/Inspection

The ISF canister impact plate and shield plug are fabricated and inspected under the ISF Facility *Quality Program Plan*, using the *ASME Boiler & Pressure Vessel Code*, Section III, Division 1, Subsection NF (Supports) as guidance.

Features Covered by QA Program

Design, fabrication, testing, and inspection of the ISF canister impact plate and shield plug are performed in accordance with the ISF Facility *Quality Program Plan* (Ref. 4-9).

4.2.1.6 ISF Storage Tube Plug

A shield plug is located in the top of each ISF storage tube, known as the ISF storage tube plug. The tube plug consists of a concrete filled tubular steel body. The upper end of the tube plug is stepped so that it sits inside the stepped upper forging of the ISF storage tube. The ISF storage tube plug is classified NITS as it provides shielding and does not form part of the storage tube pressure boundary. A lifting pintle is screwed into the tube plug to allow it to be handled by the CHM during ISF storage tube loading operations. The CHM also has the ability to exchange a tube plug using a lifting adapter that permits the canister grapple to lift the tube plug. The lifting adapter screws into the tapped hole in the tube plug that is normally used by the tube plug lifting pintle.

The tube plug provides shielding above the canisters which completes the overall shielding of the charge face structure. Stepped joints between the tube plug and the storage tube, and between the storage tube and charge face, prevent direct vertical streaming dose from the storage vault into the Storage Area.

Codes and Standards

The ISF storage tube plug is designed in accordance with the *AISC Manual of Steel Construction, Ninth Edition* and ACI 349, *Code Requirements for Nuclear Related Concrete Structures.*

The tube plug lifting pintle and the tube plug lifting adapter are designed in accordance with Crane Manufacturers Association of America (CMAA), Specification No. 70, *Specifications for Top Running Bridge and Gantry Type Multiple Girder Electric Overhead Traveling Cranes* (Ref. 4-12).

Materials of Construction

Materials of construction of the ISF storage tube plug are provided in Section 4.2.3.2.2.

Fabrication/Inspection

The ISF storage tube plug is fabricated and inspected in accordance with the *AISC Manual of Steel Construction, Ninth Edition* and ACI 349, *Code Requirements for Nuclear Related Concrete Structures.*

The tube plug lifting pintle and the tube plug lifting adapter are fabricated and inspected in accordance with Crane Manufacturers Association of America (CMAA), Specification No. 70, *Specifications for Top Running Bridge and Gantry Type Multiple Girder Electric Overhead Traveling Cranes.*

Features Covered by QA Program

Design, fabrication, testing, and inspection of the ISF storage tube plug is performed in accordance with the ISF Facility *Quality Program Plan* (Ref. 4-9).

4.2.2 Installation Layout

This section focuses on the Storage Area vaults and storage components. Installation layout figures for SSCs used in SNF receipt, handling and packaging operations are provided in Section 4.7.

4.2.2.1 Building Plans

Figure 4.2-3 is a plan view of the storage vaults showing the storage tube array in the two storage vaults.

4.2.2.2 Building Sections

Figure 4.2-4 is a section looking west through the Storage Area showing the vertically standing storage tubes, CHM, and steel building that covers the vaults and Transfer Tunnel.

Figure 4.2-5 is a section looking north through the two storage vaults showing the relative location of the storage vaults, storage tubes, Transfer Tunnel, and CHM positioned over the Storage Area load/unload port.

4.2.2.3 Confinement Features

Confinement features in the Cask Receipt Area and Transfer Area are described in Section 4.7.

Within the ISF storage vault, two independent confinement barriers between the SNF and the environment ensure safe storage during design basis conditions. The welded ISF canister provides the primary SNF confinement barrier. After the ISF canister is placed in the ISF storage tube, the mechanically sealed storage tube assembly functions as a secondary confinement barrier. The SNF cladding is not credited to function as a confinement barrier.

Regulations in 10 CFR 72.122(h) permit alternatives to the typical dry cask storage system approach. The general design criteria for the confinement barrier requires (in part) that:

> "(1) The spent fuel cladding must be protected during storage against degradation that leads to gross ruptures or the fuel must be otherwise confined such that degradation of the fuel during storage will not pose operational safety problems with respect to its removal from storage. This may be accomplished by canning of consolidated fuel rods or unconsolidated assemblies or other means as appropriate."

The "canning" alternative provided in 10 CFR 72.122(h)(1) is incorporated into the ISF Facility design. The ISF canister confines the SNF so that degradation of fuel cladding or the fuel matrix during storage will not pose operational safety problems with respect to its removal from storage.

The ISF storage tube assembly provides the outer (secondary) confinement barrier and the dual mechanical seals of the ISF storage tube closure lid are credited for meeting the redundant sealing requirement imposed by 10 CFR 72.236(e). The confinement barrier design for the ISF Facility is compared to a typical SNF cask design below.

	Primary Confinement Barrier	Secondary Confinement Barrier	Redundant Closure per 10 CFR 72.236(e)
Typical SNF Cask Design	Fuel cladding	Storage canister perimeter	Double seal welds on canister closure lid
ISF Facility Design	Welded ISF canister	ISF storage tube assembly	Double metallic seal rings on ISF storage tube assembly lid

The ISF canister does not function as a stand-alone storage system component during interim storage. SNF is first loaded into an ISF canister and welded closed. Each sealed ISF canister is then loaded into an ISF storage tube assembly sealed with double metallic seal rings to prevent the release of radioactive material. This design meets the requirements and the intent of 10 CFR 72.

After regulatory authority approval, which is not being requested by the ISF Facility License Application, the ISF canisters are expected to be:

- Removed from the storage tube assemblies in the ISF Facility storage vaults, loaded into a transportation cask and shipped to an authorized repository.
- Loaded into repository waste packages for permanent disposal at an authorized repository without opening the ISF canisters and directly handling the SNF.

4.2.3 Individual Fuel Storage System Unit Description

The ISF Facility uses a fixed location vault structure for interim dry storage of the ISF canisters. The fuel storage system of the ISF Facility consists primarily of the vault structure and the storage tube assemblies. The ISF canisters (with their internal ISF baskets) placed inside the storage tube assemblies in the storage vaults are considered the fuel storage system.

The storage vaults are enclosed over their top surface by the Storage Area building, which provides a weatherproof enclosure for canister transfer operations using the CHM. Section 4.7 describes the Storage Area building and CHM.

The storage vaults consist of the following main structures and components:

- foundation slab, vertical walls, and charge face structure
- charge face encasts and cover plates
- storage tube support stools
- cooling air inlet and outlet ducts

The storage tube assembly consists of the following main components:

- storage tube body
- storage tube lid and bolts
- metallic seal rings
- storage tube plug

The ISF canister assembly consists of the following main components:

- ISF canister assembly
- ISF basket structure
- shield plug assembly
- spacers

Figure 4.2-4 shows a north-south section through the storage vault showing the storage tubes standing vertically in the vault and the Storage Area building, including the CHM.

Figure 4.2-5 shows an east-west section through the two storage vaults showing the relative location of the storage vaults, storage tubes, and transfer tunnel.

Figure 4.2-3 shows a plan view of the storage vaults depicting the storage tube array in the two storage vaults.

Figure 4.2-6 shows a section through the storage tube assembly.

Figure 4.2-7 and Figure 4.2-8 show the ISF canister and basket assemblies used to store the various SNF types at the ISF Facility.

4.2.3.1 Function

The overall function of the spent fuel storage system at the ISF Facility is to provide confined, shielded, and criticality safe interim dry storage of the ISF canisters and their fuel contents for up to 40 years at the ISF Facility. Specific functions for each storage system component are provided below.

The storage vault:

- provides radiological shielding from the stored SNF
- provides tornado missile protection to the stored SNF
- provides a seismically stable structure to support the storage tubes
- provides labyrinth shielded inlet and outlet ducts as part of the passive natural convection cooling system for the stored SNF
- maintains the storage tubes in a fixed subcritical array
- transmits the loads from the storage tubes to the soil

The storage tube and tube plug:

- provide a secondary confinement barrier for the stored SNF
- provide a dry, inert atmosphere that will prevent degradation of the stored ISF canister
- complete the vault shielding by incorporating a tube plug
- provide a heat transfer interface between the ISF canister and the vault cooling air system in order to remove the decay heat from the stored SNF
- maintain the stored ISF canisters in a fixed subcritical array during normal, off-normal, and accident conditions of storage
- transfer the loads from the ISF canister to the storage vault structure

During storage, the ISF canister, impact plate, and ISF basket assembly:

- provide the primary confinement barrier for the stored SNF
- provide a dry, inert atmosphere that will prevent degradation of the stored SNF
- provide a means of handling the stored SNF into and out of the storage tube
- provide a heat transfer interface between the stored SNF and the storage tube in order to remove the decay heat and thereby maintain the stored SNF at acceptable temperatures
- maintain the stored SNF in a fixed subcritical array in all conditions of storage
- transmit the loads from the SNF to the storage tube

4.2.3.2 Components

4.2.3.2.1 Description of the Storage Vault

The storage vault is a reinforced concrete structure between the Cask Receipt Area and the Transfer Area as shown on Figure 4.2-9. There are two separate storage vault modules in the vault structure, designated vault 1 and vault 2. Vault 1 is positioned west of vault 2. The adjacent Transfer Tunnel is structurally part of the vault structure, but is not considered a functional part of the vault storage system.

The storage vault modules are enclosed over their top surface by the Storage Area building, which provides a weatherproof enclosure for canister transfer operations using the CHM. The Storage Area building is described in Section 4.7.3.1.5.

The storage vault system provides storage for 18-inch and 24-inch diameter ISF canisters placed in storage tubes. The storage tubes are designated 18-inch and 24-inch diameter because they are sized to accept the 18-inch or 24-inch diameter ISF canisters, but the actual internal diameters of the storage tubes are larger than their designated labels. The tube arrays are shown in Figure 4.2-3. Table 4.2-1 provides the number and size of the storage tube assemblies in each vault module.

The vertical loads from the storage tubes are transmitted through the base of the storage tube to support stools bolted to the vault floor slab. Storage tube vertical loads include dead weight of the storage tube and canister, and dynamic loads due to canister handling and seismic effects. The storage tubes do not apply any vertical loads to the charge face structure. The lateral loads from the storage tubes are transmitted at the top end through the charge face encast into the charge face structure, and at the bottom end through the support stool into the vault floor slab. Storage tube lateral loads are primarily due to seismic events. The charge face structure transmits the storage tube lateral loads to the vault walls and from there into the vault foundation.

The spacing of the storage tube array is determined by the structural requirements of the charge face structure. The ligament between adjacent storage tubes provides the beam section properties needed for the charge face structure to span the vault. The charge face and the support stool provide the upper and lower positioning for the storage tube creating a fixed array, which is used in the thermal, shielding and criticality analyses.

The foundation slab under the vault modules, and both the external and internal dividing walls, are nominally 3 feet thick. The charge face structure is 2 feet, 6 inches thick. A parapet wall runs above the north and south edges of the vault to form the runway beam structure for the CHM and a foundation for the structural steel of the Storage Area building.

The vault structural elements are designed of reinforced concrete to provide:

- radiation shielding (see Section 7.0 for the vault shielding assessment)
- structural and seismic stability without loss of function
- tornado protection for the stored SNF

The vault foundation slab is designed to support the load of the vault modules, including structural weight, facility operations, and off-normal and accident conditions.

Cooling-air inlet ducts are formed in the north and south walls of the vault nominally at charge face level, using the additional thickness of the CHM parapet wall for shielding. The inlet ducts have an offset path to prevent direct radiation streaming out from the storage tube assemblies. Mesh screens and a weather canopy over each inlet duct prevent debris, birds, vermin, etc., from getting into the vault. The inlet duct mesh screen has nominally 70 percent open area.

Cooling air exits the vault through the charge face structure into the Storage Area building, and is exhausted via louvers placed high in the building walls. A radial gap in the annulus between the charge face encast and the storage tube assembly and charge face cover plate, as shown in Figure 4.2-10, permits cooling air to flow up from the vaults and into the Storage Area building. The storage tube and charge face encast include matching shielding steps that prevent direct radiation from streaming through the charge face. Storage vault cooling is passive and self-regulating. The decay heat from the SNF warms the air, thus creating the convection flow to remove decay heat.

The outside surfaces of the storage tubes are sealed and radiologically clean. Therefore, no contamination is transferred to the cooling airflow or to the inside surface of the vault modules.

The charge face structure has steel encasts that locate the top end of the storage tubes. A 2.25-inch-thick steel charge face cover plate is bolted to each charge face encast to provide a tornado missile protective cover over each storage tube. This arrangement is shown in Figure 4.2-11. The charge face cover plates are bolted down to resist tornado wind suction forces.

4.2.3.2.2 Description of the Storage Tube Assembly and Associated Interfacing Equipment

The storage system provides two sizes of storage tube assembly: the 18-inch diameter storage tube, which accepts 18-inch diameter ISF canisters, and the 24-inch diameter storage tube, which accepts 24-inch diameter ISF canisters. As noted in the previous section, the ISF storage tubes are designated based on the diameter canister that they are sized to accept.

The storage tube assembly consists of the following main components:

- storage tube body
- storage tube lid (incorporating evacuating and inert fill port), bolts, and metal seal rings
- storage tube plug

The storage tube assembly interfaces with the following components and equipment:

- charge face cover plate
- storage tube support stool
- tube plug lifting pintle
- guide ring
- lifting adapter
- charge face encast and charge face structure

- ISF canister
- storage tube monitoring system

The component parts of the storage tube assemblies and associated interfacing equipment and their individual functional requirements are described below.

Storage Tube Assembly

The storage tube assembly (confinement barrier) is an N-stamped ASME Code Section III Division 1, Subsection NC (Class 2) vessel. The overall length of the storage tube is approximately 20 feet. The 18-inch and 24-inch storage tubes have nominal outside diameters of 20 inches and 26 inches, respectively.

The design parameters for the storage tube are:

design life:	40 years
design pressure:	50 psig
design temperature:	300°F
design basis leak rate:	10^{-4} cc/sec

Structural calculations are performed to analyze the storage tube for the effects of dead weight, pressure, handling, thermal, earthquake, and drop cases.

The storage tube consists of a carbon-steel tube welded to a forged flat closure plate at its bottom end. An annular forging is welded to the top end, and to this a flat closure lid is bolted. Metallic double seal rings between the flat closure lid and the top forging complete the pressure boundary. Figure 4.2-11 shows the detail of the storage tube seal rings and the inter-space leak check port used to verify that the storage tube lid is properly sealed.

A central port through the closure lid facilitates access to the storage tube for evacuation, leak testing, and inerting with helium, as shown in Figure 4.2-11. A check valve fitted in the lid port assists in the helium fill operation. The check valve is held open during helium filling operations by the connection tool that connects between the storage tube and the tube monitoring system. After completion of helium filling, a lid cover plate is installed with cap screws over the lid port and sealed by a pair of metallic seal rings. An inter-space leak checkpoint allows leak checking the seal rings of the lid cover plate.

The storage tube top forging has an internally stepped shoulder that supports an internal shield plug that is used to maintain the overall charge face shielding. The external stepped diameters of the top forging also provide a shielding interface with the charge face encast.

The top end of the storage tube is laterally centered by four equally spaced pads that are part of the charge face encast tube. An engineered annular gap between the outside diameter of the storage tube and the bore of the encast tube enables natural convection cooling flow to pass around the outside of the tube and up to the Storage Area building, as shown in Figure 4.2-10. The annular gap is nominally 0.25 inches wide.

The weight of the storage tube assembly rests on the steel support stool that is secured to the vault floor, and provides both lateral and vertical location and support. The height of the stool is set during construction to provide sufficient axial clearance at the top end of the storage tube so that seismic and differential thermal movements do not introduce axial loads in the storage tube assembly.

Storage Tube Plug

The storage tube plug is shown in Figure 4.2-11. It is positioned in the storage tube at charge face height and provides vertical shielding directly above the stored ISF canister, thereby completing the shielding continuity of the charge face structure. The tube plug is constructed from steel and concrete, and is designed to withstand the temperature variations, external pressures, and vacuum experienced while the storage tube internals are subjected to operating pressure, evacuation, or leak testing. A spiral vent tube is embedded in the concrete plug to provide a vent path between the storage tube closure lid and the storage tube area below the plug to facilitate evacuation and inerting the storage tube assembly. A lifting pintle is fitted to the tube plug to facilitate handling by the CHM during canister loading operations. The tube plug lifting pintle is removed from the tube plug before fitting the storage tube closure lid.

Storage Tube Assembly Materials

The storage tube assembly is fabricated from the following materials:

- storage tube body – ASME SA333 Grade 6
- storage tube top forging – ASME SA350 Grade LF2
- storage tube flat closure plate – ASME SA350 Grade LF2
- storage tube lid – ASME SA516 Grade 55
- storage tube lid cap screws – ASME SA193 Grade B7
- storage tube lid cover plate – ASME SA516 Grade 55
- storage tube lid cover plate cap screws – ASME SA193 Grade B7
- metal seal rings – Inconel Alloy 718, silver plated
- storage tube plug body – ASTM A333 Grade 6 and ASTM A36
- storage tube plug concrete fill – minimum density 140 pounds per cubic foot
- lifting pintle – ASTM A434 Grade 4340 Class BC
- storage tube and lid external surface coating is aluminum spray
- storage tube and lid internal surface coating is etch primer

The aluminum spray coating is used to prevent corrosion of the storage tube external surface for the required 40-year design life. Refer to Section 4.2.3.3.8 for additional information on corrosion prevention of the storage tube and ISF canister.

Charge Face Cover Plate

The charge face cover plate is a 2.25-inch thick steel disc located in a recess inside the charge face encast. Its top surface is level with the charge face surface, as shown in Figure 4.2-11. An annular gap between the outside diameter of the cover plate and the bore of the charge face is established by four equally spaced pads in the encast to provides a flow passage for the storage tube cooling air. The cover plate is bolted to a shoulder on the encast but is raised off it by 0.75-inch thick spacers below the cover plate at each cap screw location to maintain the required cooling airflow passageway.

Although the charge face cover plates contribute to overall charge face shielding performance, their primary function is to protect the top of the storage tube from tornado missile impact. Four cap screws hold the charge face cover plate down against the suction pressure resulting from the maximum tornado wind speed.

The charge face cover plates remain in place over the storage tubes except while the following operations take place:

- ISF canister loading into a storage tube
- ISF canister unloading from a storage tube
- inspection of a storage tube during storage

There are two sizes of charge face cover plates, sized for the 18-inch and 24-inch storage tube locations. The charge face cover plate is made from the following materials:

- charge face cover plate – ASTM A36
- charge face cover plate cap screws – ANSI B18.3, ASTM A574
- charge face cover plate coating is two-part epoxy paint

Each charge face cover plate is removed and installed by using a portable hoist that is rolled across the charge face structure. The hoist attaches to three eyebolts that are threaded into holes in the cover plate.

Charge Face Encast

The charge face encast is a steel fabrication cast into the charge face concrete structure to create the storage tube penetrations as shown in Figure 4.2-11. It is structurally tied into the charge face concrete and reinforcement by steel bars welded to the external diameters of the encast tubes. There are two sizes of charge face encasts, sized for the 18-inch storage tube and 24-inch storage tube locations.

The charge face encast provides a clean internal bore that locates and provides lateral (but not vertical) support for the storage tube assembly. The bore of the encast is stepped to provide matching shielding with the storage tube profile. Features are provided at the top end of the encast for locating and fastening the charge face cover plate and the funnel-shaped guide ring that is used when loading or unloading canisters to/from the storage tubes as shown in Figure 4.2-12.

The internal bore of the encast is designed with centering pads to provide a radial clearance gap around the storage tube top forging so that the vault cooling air flow can flow up through the charge face structure into the charge hall. The charge face encasts are made from the following materials:

- encast pipe sections – ASTM A333 Grade 1
- encast plate and bar sections – ASTM A36
- charge face encast internal surface coating-aluminum spray

- surfaces of encast in contact with concrete are uncoated

Storage Tube Support Stool

The storage tube support stool assembly is a flat plate with four alignment guides positioned on a pitch circle diameter so that the storage tube can fit inside these and be laterally located and supported by them, as shown in Figure 4.2-6 and Figure 4.2-13. The support stool provides structural support for the bottom end of the storage tube assembly. The support stool is positioned directly below the charge face encast and is anchor-bolted and grouted to the floor of the vaults. Jacking screws on the support stool base plate are provided to set the height and level of each individual support stool before being grouted in position during installation. There are two sizes of support stool, sized for the 18-inch and 24-inch storage tube locations.

The support stool transmits the vertical and lateral loads from the base of the storage tube into the vault floor. Storage tube vertical static and dynamic loads are transmitted through the support stool. Vertical loads from the storage tube assemblies are not transmitted to the charge face structure. Seismic events may generate lateral loads from the storage tube assembly. The support stool is designed to withstand these lateral loads from the base of the storage tube and to keep the storage tube in position so that the geometry of the storage array does not change. The charge face encast provides lateral support for the upper end of the storage tube assembly during a seismic event. The lateral support function of the support stool and the charge face encast work together to ensure that the storage tube array does not change during a seismic event.

The storage tube rests on the support stool. The support stool alignment guides are designed to be tall enough to restrain the storage tube during a seismic event. A guide ring is bolted into the charge face encast, which protrudes over the storage tube top forging, as shown in Figure 4.2-12. With the guide ring bolted in position there is insufficient clearance between the guide ring and the top of the storage tube assembly to lift the storage tube off its base. The support stool assembly is made from the following materials:

- support stool plate sections – ASTM A572 Grade 42, type 1
- support stool alignment guides – ASTM A6, ASTM A572 Grade 42, type 1
- support stool anchor bolts – ASTM 193, Grade B7
- support stool external surface coating – aluminum spray
- surfaces of support stool in contact with grout – paint with primer

Tube Plug Lifting Pintle

The tube plug lifting pintle is a removable lifting component screwed into the top of the tube plug to facilitate handling by the CHM, as shown in Figure 4.2-12. Because the lifting pintle does not remain permanently attached to the storage tube plug, the overall height of the storage tube assembly is reduced.

During canister loading operations the charge face cover plate and storage tube lid are removed from the designated storage location. The tube plug lifting pintle is then screwed into the top of the exposed tube plug. A painted spot on the top surface of the lifting pintle is used as the sighting target for the CHM navigation camera. The CHM aligns itself onto the pintle center spot as the starting position for the canister loading operation. After the canister has been loaded into the storage tube and the tube plug replaced, the tube plug pintle is removed to allow the storage tube lid to be installed. The lifting pintle is made from the following materials:

- tube plug lifting pintle – ASTM A434, Grade 4340, Class BC
- tube plug lifting pintle coating is etch primer

Guide Ring

The guide ring is a funnel-shaped annular steel ring, shown in Figure 4.2-12, which bolts to the top end of the charge face encast after the charge face cover plate and storage tube closure lid are removed. It provides a smooth lead-in guide during installation of the ISF canister and grapple as these are lowered into or out of the storage tube. It also protects the storage-tube sealing surface against which the storage tube closure lid seal rings engage.

The guide ring is bolted down, using the charge face cover plate bolts, to prevent the storage tube from being inadvertently lifted out by the canister or plug hoist if obstructions were to result between these and the storage tube.

There are two sizes of guide ring, sized for the 18-inch and 24-inch storage tube locations. The Storage Area ancillary handling equipment hoist and trolleys move and position the guide rings. The guide ring is made from the following materials:

- guide ring – ASTM A36
- guide ring coating is etch primer

Tube Plug Lifting Adapter

The CHM has a hoist and grapple to handle the storage tube plug, and a hoist and grapple to handle the ISF canister. A faulty tube plug would be rare, but could potentially occur due to a mishap, such as if it were dropped. In this case, it would be necessary to configure the CHM to exchange the faulty tube plug. Installing the tube plug lifting adapter on a new tube plug enables it to be handled by the CHM canister grapple. The CHM can then lift a new tube plug into the canister cavity of the CHM, traverse to the storage tube location with the faulty tube plug, use the CHM tube plug hoist to remove the faulty tube plug, and use the canister hoist to place the new plug in the storage tube.

The tube plug lifting adapter, shown in Figure 4.2-14, can be bolted to the top of a tube plug to enable the CHM's canister grapple to engage and lift it. For this reason, the lifting adapter replicates the geometry of the top of the ISF canister. Exchanging a tube plug should be an infrequent operation.

There are two sizes of tube plug lifting adapter, sized for the 18-inch storage tube and 24-inch storage tube locations. The lifting adapter assembly is made from the following materials:

- lifting adapter pipe sections – ASTM A333 Grade 1
- lifting adapter plate sections – ASTM A36
- bolt – ANSI B18.2.1, ASTM A325 type 1

- lifting adapter coating is etch primer

4.2.3.2.3 Description of the ISF Canister Assembly

ISF Canister

The ISF canister (confinement barrier) is an N-stamped ASME Code, Section III, Division 1, Subsection NB (Class 1) vessel. The ISF canister design is based on the DOE Standardized Spent Nuclear Fuel Canister Specification, summarized in Table 4.2-2. Several aspects of the original DOE canister design have been augmented in the ISF canister design to comply with ASME code requirements. The general arrangement of an ISF canister is shown in Figure 4.2-15.

The design life of the ISF canister assembly under 10 CFR 72 requirements is 40 years.

Fuel-specific ISF baskets and an internal shield plug are used with the ISF canister to provide a storage and transfer system vessel for SNF at the ISF Facility. Fuel-specific ISF baskets are provided for Peach Bottom, TRIGA, and Shippingport fuel assemblies. The various arrangements of ISF canister and basket assemblies designed to store SNF at the ISF Facility are shown in Figure 4.2-7 and Figure 4.2-8.

The ISF canister consists of two main sub-assemblies: the body assembly and the lid assembly. These two assemblies are welded together in the Canister Closure Area (CCA) after being loaded with SNF to complete the canister assembly.

The ISF canister body assembly consists of the following components:

- canister body
- lower head
- impact limiter with a welded lifting ring
- lower internal impact plate secured to the lower head by a welded retaining ring

The ISF canister lid assembly consists of the following components:

- upper head incorporating a vent plug and a flange for interfacing with the vacuum connection tool
- impact limiter with welded lifting ring
- upper internal impact plate secured to the upper head by a welded retaining ring

The top and bottom impact limiters with their associated lifting rings serve as energy absorbers if the canister is accidentally dropped. Contoured impact plates that match the interior surface of the upper and lower heads are used to protect the dished heads from internal impacts during a canister drop accident. Each plate provides a flat surface for supporting the ISF basket inside the canister. The impact plates, captured by a retaining ring welded to upper and lower head, do not provide a pressure retaining function in the canister. However, as they are in the ISF basket handling load path, the impact plates are designed to the requirements of the ASME Code, Section III, Division 1, Subsection NF.

The ISF facility uses three canister configurations:

- 18-inch outside diameter, long (15 feet)

- 18-inch outside diameter, short (10 feet)
- 24-inch outside diameter, long (15 feet)

Table 4.2-3 identifies the canister configuration used for each fuel type. The ISF canister is fabricated from standard pipe sections subject to tolerances as shown in Table 4.2-4, that affect internal cavity dimensions that can be used to accommodate ISF baskets. For an 18-inch pipe, the combined tolerance effects of diameter, thickness, ovality, and straightness over a 144-inch length of pipe reduce the internal diameter to approximately 16.9 inches. For a 24-inch pipe, the internal diameter is reduced to approximately 22.6 inches. This tolerance stack-up is provided in Table 4.2-5.

The ISF canister assembly is fabricated from the following materials:

- canister body – SA-312, type 316L
- upper and lower heads – SA-240, type 316L
- upper and lower impact plates – SA-240, type 316L, or SA 351, CF3M or CF3MN
- impact plate retaining ring – SA-240, type 316L
- shield plug retaining ring – SA-240, type 316L, or SA-479, type 316L
- upper and lower impact limiter – SA-312, type 316L
- upper and lower lifting ring – SA-240, type 316L
- canister stainless steel components are left uncoated

Canister Shield Plug

The canister shield plug is placed in the ISF canister between the upper impact plate and the top of the ISF basket, as shown in Figure 4.2-16. This shield plug reduces radiation doses to workers during canister welding, inspection, vacuum drying, and inerting operations in the CCA. The internal shield plug is supported directly by the ISF basket, or by a retaining ring welded to the ISF canister wall.

The shield plug does not provide a pressure retaining function in the canister. However, it is part of the ISF basket handling load path and is designed to the requirements of the ASME Code, Section III, Division 1, Subsection NF.

The top surface of the shield plug is positioned so that when the canister is in the canister cask, the shield plug and the canister cask collet system form a shielding barrier around the fuel. The radial gap between the shield plug and the canister is sized to provide shielding attenuation and to facilitate removal and insertion of the shield plug when the canister is at the FPA.

A lifting pintle is fitted to the top of the shield plug to facilitate handling in the FPA. The shield plug lifting pintle is similar to the pintle fitted to the ISF baskets, thereby permitting the same type of lifting tool in the FPA to handle both components.

When the canister shield plug is first loaded into the empty canister (i.e., empty of SNF) inside the CCA, the shield plug is handled by a unique lifting tool that engages in a tapped hole in the lifting pintle. Figure 4.2-17 shows the lifting tool engaged in a basket assembly, which is handled in a similar manner inside the CCA. After the shield plug has been placed in the canister and checked for proper fit, the tapped hole in the shield plug lifting pintle is filled with a grub screw that prevents further lifting of the shield plug in the CCA. This radiological safety feature mitigates against an inadvertent attempt to lift the shield plug out of the canister after it returns to the CCA after being loaded with SNF in the FPA.

The canister shield plug is fabricated from the following materials:

- lifting pintle – ASME SA479 316L
- shield plug – ASME SA479 316L or SA 351 CF3M or CF3MN
- spacer – ASME SA312 316L
- dowel pin – ASME SA479 316L

4.2.3.2.4 Description of ISF Basket Assembly

Internal baskets are required inside the ISF canisters during handling and storage, to support, protect, and limit movement of the SNF assemblies, to maximize canister content, and to maintain the geometry of the arrays if required for criticality. These structures are designated "ISF baskets"' to differentiate them from other baskets contained in DOE transfer casks used to transport SNF to the ISF Facility.

The ISF baskets provide the structural support for the fuel assemblies in the ISF canister and ensure that the SNF remains subcritical during normal, off-normal, and accident conditions at the ISF Facility. The ISF baskets are open on top to allow SNF to be inserted, in the FPA. Among the three configurations of ISF canister sizes used at the ISF Facility, different ISF basket designs are used to accommodate different types of SNF.

A basket lid (except for Shippingport reflector module ISF baskets) is securely attached to the top of the ISF baskets to limit fuel movement inside the basket compartment and prevent ejection of fuel assemblies during a drop accident. For the Shippingport reflector modules the internal ISF basket guides remain inside the canister to support and protect the fuel assembly as it is lowered inside.

ISF baskets and support structures are designed to fit inside the 18-inch and 24-inch ISF canisters. Removable ISF baskets are designed to fit interchangeably into any canister of the appropriate size. Canister configurations for each specific SNF type are listed in Table 4.2-3.

The functions of the ISF baskets are to:

- withstand the static loads due to the ISF basket weight, SNF weight, and canister shield plug weight (ISF baskets are vertical during interim storage)
- facilitate fuel loading in the FPA
- facilitate handling in the FPA
- provide a heat transfer path for the SNF decay heat to the canister
- maintain the fuel in a subcritical array in the canister during normal, off-normal, and accident conditions

In addition, the ISF basket provides features required for compliance with future transportation and repository disposal. Features specifically provided for compliance with transportation and/or repository disposal, but which are not necessary for 10 CFR 72 storage requirements (e.g., increased structural strength for transportation accidents and long term neutron poisons for repository storage) have been described here for purposes of completeness.

There are several configurations of ISF baskets relating to the three fuel types. The specific descriptions of each ISF basket type are given below against each fuel type.

Peach Bottom ISF Baskets

There are three variations of ISF baskets for Peach Bottom fuel:

- Peach Bottom core 1 fuel ISF basket (Figure 4.2-18)
- Peach Bottom core 2 fuel ISF basket (Figure 4.2-18)
- Peach Bottom core 1 fuel Attached Removal Tool (ART) ISF basket (Figure 4.2-19)

Peach Bottom ISF baskets are designed to be interchangeable with any 18-inch diameter, long ISF canister. This is necessary because the ISF canister that transfers the unloaded ISF basket into the FPA is not the same canister that brings the loaded ISF basket out of the FPA to the CCA.

Peach Bottom Core 1 Fuel and Core 2 Fuel ISF Basket

The Peach Bottom 1 and 2 ISF baskets use "tube-and-spacer-plate" design, where the individual fuel element is housed in a longitudinal support tube and the tubes are supported by a number of spacer plates. The outside diameters of the spacer plates of the ISF basket bear against the side of the canister to transmit ISF basket loads to the canister shell under accident conditions.

The Peach Bottom 1 and 2 ISF baskets are similar. Both ISF baskets hold 10 fuel elements, 2 near the center of the basket and 8 around the periphery. The fuel tubes are 4-inch outside diameter and run the length of the ISF basket. A total of 9 spacer plates along the length of the ISF basket provide the lateral location and support for the fuel tubes. Each spacer plate is made from stainless steel plate, with holes for the 10 fuel tubes bored through the plate to create the tube array.

In addition to the 10 fuel tubes, 2 other tubes run the length of the ISF basket. These tubes are filled with gadolinium phosphate and are sealed closed. Holes bored through the spacer plates carry the gadolinium phosphate tubes in a similar way to the fuel tubes. The gadolinium phosphate tubes provide long-term neutron absorber capability that is required for future geological repository of the ISF canister. This SAR does not take credit for the presence of the gadolinium phosphate tubes in the interim storage criticality analyses.

Tie bars are used to set the spacing for the spacer plates. Four tie bars around the periphery of the ISF basket support the ISF basket's axial loads, which are tensile when the ISF basket is being lifted in the FPA, and compressive when the shield plug weight bears onto the ISF basket inside the ISF canister. Each end of each tie bar segment is threaded or tapped so that each one can be screwed onto the next segment of tie bar and thereby clamp the spacer plates into position. The screwed-end connection of the tie bars permits the full diameter of the tie bar to be used for carrying the axial loads (as opposed to using spacer tubes over a continuous tie bar). This arrangement also provides the required rigidity at the spacer plates to withstand buckling loads.

A base plate is attached to the ends of the four tie bars by special screws, at the lower end of the ISF basket directly below the end spacer plate. The fuel tubes and gadolinium phosphate tubes rest on this plate. Peach Bottom 2 SNF is shorter than Peach Bottom 1 SNF; therefore, a spacer is placed in the bottom of the Peach Bottom 2 ISF basket fuel tube to reduce the fuel support tube cavity length. Peach Bottom 1 SNF rests directly on the lower base plate; Peach Bottom 2 SNF rests on this spacer that is in contact with the lower base plate. Holes in the base plate, in the spacer, and in the base of the fuel tubes ensure that moisture is not trapped in the ISF basket during fuel drying and inerting operations.

A top plate is clamped above the upper end spacer to trap the fuel tubes within the spacer plates. A thermal expansion gap is left between the top of the fuel tubes and the underside of the top plate. The top plate is machined to provide a chamfered lead-in to each fuel tube, so that the SNF elements will not snag during loading operations. Four securing pins are screwed into the four tie bars to clamp the top plate to the ISF basket structure. The securing pins complete the tie bar lifting load path and are machined to provide a recess used to attach the ISF basket lid, which will be described later in this section.

The nominal outside diameter of the Peach Bottom 1 and 2 ISF basket is 16.75 inches. The nominal inside diameter of the 18-inch diameter ISF canister is 17.25 inches, but when the combined tolerance effects of ISF canister diameter, thickness, ovality, and bow are taken into account, the effective internal envelope diameter to accommodate the ISF basket is approximately 16.9 inches, as shown in Table 4.2-5. The effect of bow along the length of the Peach Bottom 1 and 2 ISF basket is taken into account and its outside diameter is sized to be a clearance fit within the ISF canister internal envelope diameter.

Peach Bottom Core 1 Fuel (ART) ISF Basket

The designation ART refers to the attached removal tool (ART) on Peach Bottom core 1 SNF elements. These elements were removed from the reactor using an extraction tool that surrounded the element and lifted it from underneath with fingers. The outside envelope diameter of the removal tool is nominally 4.25 inches around the lower pawls and as the removal tool will be stored together with the elements, the ART ISF basket fuel tube must be larger in diameter than the regular Peach Bottom 1 fuel tubes. The ART ISF basket fuel tubes are 4.5-inch nominal outside diameter, and expand to a 5.5-inch nominal diameter section at the lower end of the tube. The larger diameter section at the base of the fuel tube accommodates the larger diameter of the removal tool that houses the element lifting fingers. The larger diameter section of the fuel tube provides clearance so that when the canister is transported in a horizontal position to a future repository, the SNF element will rest flat on its side and not on the expanded end of the removal tool.

The Peach Bottom 1 ART ISF basket uses the same general configuration as the Peach Bottom 1 and 2 ISF basket described in the previous section, except that there are only seven fuel element positions. One ART element is located in the center of the ISF basket and six are arranged around the periphery. The fuel tubes are supported by a total of seven spacer plates that provide the lateral location and support for the fuel tubes. At the junction between the 4.5-inch and 5.5-inch fuel tubes, the spacer plate is counter-bored from both sides to form a location for each of the two tube sizes.

In addition to the seven fuel support tubes, three other tubes run the length of the ISF basket. These tubes are filled with gadolinium phosphate and are sealed closed. Holes bored through the spacer plates carry the gadolinium phosphate tubes in a similar way to the fuel tubes. These tubes and their contents provide a long-term neutron absorber capability that is required when the canister is placed in the future geological repository.

Three tie bars around the periphery of the ART ISF basket are used to set the spacing of the spacer plates. Three securing pins are screwed into these tie bars, clamping the top plate to the ISF basket structure. The securing pins complete the tie bar lifting load path and are machined to provide a recess used to attach the ISF basket lid.

The nominal outside diameter of the Peach Bottom 1 ART ISF basket is 16.75 inches. The nominal inside diameter of the 18-inch diameter ISF canister is 17.25 inches, but when the combined tolerance effects of ISF canister diameter, thickness, ovality, and bow are taken into account, the effective internal envelope diameter to accommodate the ISF basket is approximately 16.9 inches, as shown in Table 4.2-5. The effect of bow along the length of the Peach Bottom 1 ART ISF basket is taken into account and its outside diameter is sized to be a clearance fit within the ISF canister internal envelope diameter.

Peach Bottom ISF Basket Lids

The ISF basket lid assemblies for the Peach Bottom core 1 fuel and core 2 fuel ISF baskets are identical. The ART ISF basket lid is similar, except that there are only three tie bars to engage, instead of the four on the Peach Bottom 1 and 2. The Peach Bottom ISF basket lid assembly consists of the following components:

- lid
- lid locking plate
- lifting pintle
- lid locking bolt

Details of the ISF basket lid assembly are shown on Figure 4.2-18.

The lid locking plate is captured by the lifting pintle and can rotate around the central boss on the lid plate. Four holes (three for ART lid) in the lid plate and lid locking plate align over the top of the securing pins. The lid is attached to the securing pins by rotating the locking plate to engage the keyhole slot in the locking plate under the recess machined into the pins. The lid locking bolt is located close to the lifting pintle and controls the locking plate rotation. When the lid locking bolt is screwed down, the locking plate is locked in either "open" or "locked" position. When the lid locking bolt is unscrewed, the locking plate can rotate between the open and locked positions. When the locking bolt is unscrewed it protrudes above the surface of the lid locking plate and prevents the ISF basket lifting device from engaging the lifting pintle. This mechanical interlock prevents attempting to lift the ISF basket unless the ISF basket lid is fully closed and locked. It also prevents the ISF basket lid from being removed unless the lid locking plate is fully opened and locked open.

The ISF basket lid is released from the top of the ISF basket by unscrewing the lid locking bolt to release the locking plate. The power manipulator system, attached to the FHM, is used to perform this operation, which then permits the locking plate to be rotated to its open position. After the lid locking bolt is screwed closed, the ISF basket lifting device can engage the lifting pintle and raise the lid clear of the ISF basket. Replacement of the ISF basket lid is the reverse of the above sequence. Because the lifting features of the ISF basket lifting pintle and the canister shield plug lifting pintle are identical, both components are handled by the same lifting device in the FPA.

Peach Bottom ISF Basket Assembly Materials

ISF basket assembly materials are stainless steel. Coatings are not used for corrosion protection. Peach Bottom ISF baskets are fabricated from the following materials:

- lid, locking plate, base plate (ART), and top plate (ART) – ASME SA240 316L
- lifting pintle – ASME SA479 316L
- spacer plate, base plate, and top plate – ASME SA693 type 630 (17-4 Ph)
- tie bar, lid securing pin, and special screw – ASME SA564 type 630 (17-4 Ph)
- fuel tube – ASME SA213 316L
- gadolinium phosphate container tube – ASME SA213 316L
- repository neutron absorber material – gadolinium phosphate

TRIGA ISF Basket

Two types of TRIGA SNF are to be stored at the ISF Facility. The same ISF basket design is used for both, as shown in Figure 4.2-20. Because of the short length of TRIGA SNF, two TRIGA ISF baskets can be stacked into a canister, one on top of the other. The lower ISF basket rests on the canister lower impact plate, and the upper ISF basket rests on the lid of the lower ISF basket. Spacers on the two ISF baskets minimize the axial free space within the canister.

The TRIGA ISF baskets are designed to be interchangeable with any 18-inch diameter, short ISF canister. This is necessary because the ISF canister that transfers the unloaded ISF basket into the FPA is not the same canister that brings the loaded ISF basket out of the FPA to the CCA.

The TRIGA ISF basket is also a tube-and-spacer-plate design, where the individual fuel elements are housed in longitudinal fuel tubes supported by spacer plates. The outside diameters of the spacer plates bear against the side of the canister to transmit ISF basket loads to the canister shell under accident conditions.

The TRIGA ISF basket holds 54 elements using 1.75-inch nominal outside diameter fuel support tubes that run the length of the ISF basket. Two spacer plates, one at each end of the fuel tube, provide lateral location and support for the fuel tubes. The holes for the 54 fuel support tubes are bored through the spacer plates to create the tube array within the ISF basket.

In addition to the 54 fuel tubes, one gadolinium phosphate tube in the center of the spacer plate runs the length of the ISF basket. The gadolinium phosphate tube provides long-term neutron absorber capability required for future geological repository. This SAR does not take credit for the presence of the gadolinium phosphate tube in the interim storage criticality analyses.

Tie bars are used to set the spacing for the spacer plates similar to the Peach Bottom ISF baskets. A total of six tie bars around the periphery of the ISF basket carry the ISF basket's axial loads. Three of the tie bars are configured to carry tensile loads when the ISF basket is being lifted in the FPA. The other three tie bars are configured to carry compressive loads when the shield plug and/or upper ISF basket weight bears onto the ISF basket.

A base plate is attached to the ends of the six tie bars at the lower end of the ISF basket, directly below the bottom spacer plate. The TRIGA elements, fuel tubes, and gadolinium phosphate tube rest on this plate. Holes in the base plate, offset from the center of the fuel tube positions, and holes in the base of the fuel tubes ensure that moisture is not trapped in the ISF basket during fuel drying and inerting operations. A spacer is attached to the underside of the base plate to occupy the free space in the ISF canister not occupied by the two TRIGA ISF baskets and the shield plug.

A top plate is clamped above the upper spacer plate to trap the fuel tubes within the spacer plates. A thermal expansion gap is left between the top of the fuel tubes and the underside of the top plate. The top plate is machined to provide a chamfered lead-in to each fuel tube, to eliminate the potential to snag during loading operations. Three lid support pins are screwed into the compression tie bars to clamp the top plate to the ISF basket structure. The lid support pins form a three-point feature that supports the lid. In addition, three lid securing rods thread into the base plate and extend the length of the basket assembly. These rods have a machined recess at the top to facilitate the lid locking plate in the same manner as the Peach Bottom baskets.

The nominal outside diameter of the TRIGA ISF basket is 16.85 inches. The nominal inside diameter of the 18-inch diameter ISF canister is 17.25 inches, but when the combined tolerance effects of ISF canister diameter, thickness, ovality, and bow are taken into account, the effective envelope diameter to accommodate the ISF basket is approximately 16.9 inches, as shown in Table 4.2-5. Because the TRIGA ISF basket is shorter in length than the Peach Bottom ISF baskets, its outside diameter can be larger than the Peach Bottom ISF basket, as the effects of canister and ISF basket bow on the internal canister envelope diameter are reduced. The TRIGA ISF basket outside diameter is a clearance fit within the ISF canister internal envelope diameter.

TRIGA ISF Basket Lids

The ISF basket lid assembly for the TRIGA fuel ISF baskets consists of the following components:

- lid
- lid locking plate
- lifting pintle
- lid locking bolt

The TRIGA ISF basket lid is attached to the three lid securing rods, as shown in Figure 4.2-20.

The lid locking plate is captured by the lifting pintle and can rotate around the central boss on the lid plate. Three holes in the lid plate and lid locking plate align over the top of the securing pins. The lid is attached to the securing pins by rotating the locking plate to engage the keyhole slot in the locking plate under the recess machined into the pins. The lid locking bolt is located close to the lifting pintle and controls the locking plate rotation. When the lid locking bolt is screwed down, the locking plate is locked in either "open" or "locked" position. When the lid locking bolt is unscrewed, the locking plate can rotate between the open and locked positions. When the locking bolt is unscrewed it protrudes above of the surface of the lid locking plate and prevents the ISF basket lifting device from engaging the lifting pintle. This mechanical interlock prevents attempting to lift the ISF basket unless the ISF basket lid is fully closed and locked. It also prevents the ISF basket lid from being removed unless the lid locking plate is fully opened and locked open.

The ISF basket lid is released from the top of the ISF basket by unscrewing the lid locking bolt to release the locking plate. The power manipulator system, attached to the FHM, is used to perform this operation, which then permits the locking plate to be rotated to its open position. After the lid locking bolt is screwed closed, the ISF basket lifting device can engage the lifting pintle and raise the lid clear of the ISF basket. Replacement of the ISF basket lid is the reverse of the above sequence. Because the lifting features of the ISF basket lifting pintle and the canister shield plug lifting pintle are identical, both components are handled by the same lifting device in the FPA.

TRIGA ISF Basket Materials

TRIGA ISF basket materials are stainless steel. Coatings are not used for corrosion protection. The TRIGA ISF baskets are fabricated from the following materials:

- lid, and locking plate – ASME SA240 316L
- lifting pintle – ASME SA479 316L
- spacer plate, base plate, and top plate – ASME SA693 type 630 (17-4 Ph)
- compressive tie bar, lid support pin, and special screw – ASME SA564 type 630 (17-4 Ph)
- Lid securing rod – ASME SA479 316L
- fuel tube – ASME SA213 316L
- spacer – ASME SA312 316L
- gadolinium phosphate container tube – ASME SA213 316L
- repository neutron absorber material – gadolinium phosphate

Shippingport ISF Baskets

The ISF Facility will store complete reflector IV and V modules, partially dismantled reflector modules, and loose reflector module rods. Type IV and V designations refer to a specific geometric configuration of reflector module. Section 3.1.1.3 provides a detailed description of the Shippingport SNF to be stored at the ISF Facility. Three ISF basket configurations are required to store the Shippingport SNF:

- Shippingport reflector IV module ISF basket, shown in Figure 4.2-21
- Shippingport reflector V module ISF basket, shown in Figure 4.2-22
- Shippingport reflector rods ISF basket, shown in Figure 4.2-23

Reflector IV and V Modules ISF Baskets

The Shippingport reflector modules have low fissile content, and only one complete module can be placed in a canister due to size limitations. Therefore, the Shippingport modules do not require structural supports within the canister, but guide rails are provided to aid loading the module into the canister.

The ISF basket for the reflector IV and V modules is built into the ISF canister and is not removed from the ISF canister when loading the SNF. These ISF baskets rely on the ISF canister for structural stability. Because there is no removable ISF basket structure for the Shippingport reflector modules, a ring is welded to the inside of the canister shell to provide a ledge for the shield plug to rest on. This ring carries the weight of the shield plug and prevents the shield plug from applying any load onto the reflector module. The ring also holds the basket guide bars in position in the canister and maintains the axial and angular alignment of the baskets. The internal shapes and materials of the reflector IV and V baskets are different, but the principle by which they guide and support the reflector modules is the same.

The reflector IV ISF basket, shown in Figure 4.2-21, has aluminum extrusions that run the length of the canister. These extrusions act as guide rails and provide lateral support for the reflector IV module during canister loading and storage. The aluminum extrusions are held in place and positioned by a series of stainless steel plates that are screwed into the extrusions. There is no separate lid for the reflector IV ISF basket. A load distribution base plate at the bottom of the canister distributes the weight of the reflector IV module to the canister lower impact plate.

The reflector V ISF basket, shown in Figure 4.2-22, has two stainless steel guide angles and one stainless steel guide plate that run the length of the canister. These stainless steel members act as guide rails and provide lateral support for the reflector V module during canister loading and storage. The three stainless steel guide rails are held in place and positioned by stainless steel end plates and two stainless steel intermediate plates screwed into the guide rails. In addition, three tie rods with tie rod support tubes installed between the end plates provide axial support and spacing for the intermediate plates. There is no separate lid for the reflector V ISF basket. A load distribution base plate at the bottom of the canister distributes the weight of the reflector V module to the canister lower impact plate.

The guide rail assembly for both the reflector IV and V modules is lowered into a 24-inch diameter canister on top of the canister lower impact plate. The guide rail assembly is held in place by welding the shield plug support ring into the canister shell. This assembly is performed as part of ISF canister fabrication and is not done at the ISF Facility.

The basket guide rails for both the reflector IV and V ISF baskets are configured to locate the reflector module nominally central within the canister vertical axis, although the eccentric shape of the module means that the loaded canister center of gravity is not on center. The canister center of gravity offset is within the limits in the DOE canister specification, and the actual offset is taken into consideration in the canister structural calculations.

Because of the low fissile content of the reflector IV and V modules, they do not require criticality control materials to satisfy future repository requirements; therefore, no gadolinium phosphate tubes are incorporated into their ISF baskets. Coatings are not used for corrosion protection.

Reflector IV Modules ISF Basket Materials

The reflector IV module ISF baskets are fabricated from the following materials:

- extruded aluminum guide rails – ASTM SB211 alloy 6061 T6
- spacer plates – ASME SA240 316L
- machine screws – ASME B18.6.3 type B8M
- load distribution base plate – ASME SA240 316L and ASME SA312 316L

Reflector V Module ISF Basket Materials

The reflector V module ISF baskets are fabricated from the following materials:

- guide rails – ASME SA240 316L
- end and intermediate plates – ASME SA240 316L
- tie rods – ASME SA479 316L
- tie rod support tubes – ASME SA213 316L
- machine screws – ASME B18.6.3 type B8M
- load distribution base plate – ASME SA240 316L and ASME SA312 316L

Reflector Rod ISF Basket

A total of 127 loose rods removed from Shippingport reflector modules will be transferred from the DOE for storage at the ISF Facility. A separate ISF basket structure is provided to handle and store these loose rods. This ISF basket is handled like the Peach Bottom and TRIGA ISF baskets. The ISF basket is removed from the canister for loading in the FPA. After the ISF basket is loaded, the lid is installed and the ISF basket is placed inside the ISF canister. The shield plug is placed inside the ISF canister and rests directly on the ISF basket. A shield plug support ring is not used for this basket and canister arrangement.

The reflector rod ISF basket is a tube-and-spacer-plate design, where the individual reflector rods are housed in a longitudinal support tube and the tubes are supported in a number of spacer plates. The outside diameters of the spacer plates of the ISF basket bear against the side of the canister to transmit ISF basket loads to the canister shell under accident conditions.

The reflector rod ISF basket holds 127 rods. The fuel tubes are 1.25-inch nominal outside diameter and run the length of the ISF basket. A total of six spacer plates along the length of the ISF basket provide lateral location and support for the fuel tubes. Because of the low fissile content of the reflector modules, gadolinium phosphate tubes are not required to meet future repository requirements.

Tie bars are used to set the spacing for the spacer plates. There are six tie bars around the periphery of the ISF basket to carry the ISF basket's axial loads, which are tensile when the ISF basket is being lifted in the FPA, and compressive when the shield plug weight bears onto the ISF basket. Each end of each tie bar segment is threaded or tapped so that each one can be screwed onto the next segment of tie bar and thereby clamp the spacer plates in position. The screwed-end connection of the tie bars permits the full diameter of the tie bar to carry the axial loads and provides a rigid connection at the spacer plates to withstand buckling loads.

A base plate is attached to the ends of the six tie bars by special screws, at the lower end of the ISF basket, directly below the bottom spacer plate. The reflector rods and the fuel support tubes rest on this plate. Vent holes are positioned approximately 2 inches above the base of the fuel tubes ensure that moisture is not trapped in the ISF basket during fuel drying and inerting operations.

A top plate is clamped above the end spacer plate to trap the fuel tubes within the spacer plates. A thermal expansion gap is left between the top of the fuel tubes and the underside of the top plate. The top plate is machined to provide chamfered lead-ins to each fuel tube, so SNF rods will not snag during loading operations. Six lid securing pins clamp the top plate to the ISF basket structure, with the securing pins threaded onto the six tie bars. The securing pins complete the tie bar lifting load path and are machined with a recess at the top to provide a feature that is used to attach the ISF basket lid in a manner similar to the Peach Bottom ISF basket lid.

The nominal outside diameter of the reflector rod ISF basket is 22.50 inches. The nominal inside diameter of the 24-inch diameter ISF canister is 23 inches, but when the combined tolerance effects of ISF canister diameter, thickness, ovality, and bow are taken into account, the effective envelope diameter to accommodate the ISF basket is approximately 22.6 inches, as shown in Table 4.2-5. The effect of bow along the length of the reflector rod ISF basket is taken into account and its outside diameter is sized to be a clearance fit within the ISF canister internal envelope diameter.

The reflector rod ISF basket is 117 inches long from the underside of the base plate to the top face of the lid locking plate. As this length does not fill the internal cavity length of a 15-foot-long ISF canister; a drum-shaped spacer is placed in the ISF canister to occupy the unfilled space. This spacer rests on the lower impact plate, and the reflector rod ISF basket rests on the spacer. The canister shield plug rests directly on top of the reflector rod ISF basket.

Reflector Rod ISF Basket Lid

The reflector rod ISF basket lid assembly is shown on Figure 4.2-23. The reflector rod ISF basket lid sub-assembly consists of the following components:

- lid
- lid locking plate
- lifting pintle
- lid locking bolt

The lid locking plate is captured by the lifting pintle and can rotate around the central boss on the lid plate. Six holes in the lid plate and lid locking plate align over the securing pins. The lid is attached to the securing pins by rotating the locking plate to engage the keyhole slot in the locking plate under the recess machined into the pins. The lid locking bolt is located close to the lifting pintle and controls the locking plate rotation. When the lid locking bolt is screwed home, the locking plate is locked in either open or locked position. When the lid locking bolt is unscrewed, the locking plate can rotate between the open and locked positions. When the locking bolt is unscrewed it protrudes above of the surface of the lid locking plate and prevents the ISF basket lifting device from engaging the lifting pintle. This mechanical interlock prevents attempting to lift the ISF basket unless the ISF basket lid is fully closed and locked. It also prevents the ISF basket lid from being removed unless the lid locking plate is fully opened and locked open.

The ISF basket lid is released from the top of the ISF basket by unscrewing the lid locking bolt to release the locking plate. The power manipulator system, attached to the FHM, is used to perform this operation, which then permits the locking plate to be rotated to its open position. After the lid locking bolt is screwed closed, the ISF basket lifting device can engage the lifting pintle and raise the lid clear of the ISF basket. Replacing the ISF basket lid is the reverse of the above sequence. Because the lifting features of the ISF basket lifting pintle and the canister shield plug lifting pintle are identical, both components are handled by the same lifting device in the FPA.

Reflector Rod ISF Basket Materials

Reflector rod ISF basket materials are stainless steel. Coatings are not used for corrosion protection. The reflector rod ISF baskets are fabricated from the following materials:

- lid, and locking plate – ASME SA240 316L
- lifting pintle – ASME SA479 316L
- tie bar, lid securing pin, and special screw – ASME SA564 type 630 (17-4 Ph)
- spacer plate, base plate, and top plate – ASME SA693 type 630 (17-4 Ph)
- fuel tubes – ASME SA213 316L

4.2.3.3 Design Bases and Safety Assurance

The design codes for the individual storage structures and components are provided in Section 4.2.1. The storage structures and components are designed for safe storage of SNF at ISF Facility for an interim period up to forty years. They are designed to survive normal, off-normal, and postulated accident conditions with no significant radiological consequences to workers or the public. The storage structures and components are designed and fabricated in accordance with recognized codes and standards that provide acceptable safety margins.

Design features incorporated into the ISF Facility to provide safe interim storage include:

- leak-tight welds on the canister and storage tube assembly
- redundant metallic seals on the storage tube assembly
- inert (helium) gas atmosphere prevents fuel and canister degradation
- thick shield plugs and walls to minimize radiation exposure to public and site personnel
- design of canister and canister internals to withstand normal, off-normal, and accident conditions during storage and handling operations
- design of storage vault and charge face to protect the canister and storage tube assembly from postulated environmental events

Methods used to minimize personnel radiation exposure during ISF operations are discussed in Chapter 7. Design features to maintain subcritical conditions for normal operations and credible accident scenarios are discussed in Section 4.2.3.3.7.

The ISF canisters and canister internals are classified ITS to ensure that criticality safety of the SNF is maintained during normal, off-normal, and accident conditions. The exceptions are the Shippingport Reflector IV basket and Reflector V basket that are classified NITS as the Reflector modules do not require criticality control features within the ISF canister. The design codes for the canister, ISF basket, and internal shield plug are described in Section 4.2.1. The design criteria for these components are specified in Chapter 3.

The analysis of the ISF canisters and canister internals addresses areas within the ISF Facility where ISF canisters are handled and stored. These areas are the Transfer Area, Transfer Tunnel, CHM, and storage tube assemblies.

4.2.3.3.1 ISF Canister Structural Evaluation

Design Loads

The following summarizes the loads and conditions used in the canister structural and thermal analysis. Further details of the design criteria for the canister assemblies are in Chapter 3.

Design Loadings. The design loadings (established in accordance with ASME Code Section NCA-2142.1) for the ISF canisters are as follows:

- The Design Pressure (as defined in NCA-2142.1) is the maximum difference in pressure between the inside and outside of the canister under the most severe loading for which the Level A Service Limits are applicable. For the ISF canisters the internal design pressure has conservatively been set to 50 psig, which envelopes the normal, off-normal, and accident internal pressure loadings by a large margin. The vacuum drying process subjects the canister to an external pressure. For the structural evaluation of the canisters, a full vacuum at 14.7 psi (at mean sea level) inside the canister has been assumed.
- The Design Temperature (as defined in NCA-2142.1) is the expected maximum mean temperature through the wall thickness of the canister for which Level A Service Limits are specified. Although the maximum Level A temperature during storage inside the storage tubes is not expected to exceed 129°F, the design temperature for the ISF canisters has been conservatively set to 650°F.
- The Design Mechanical Loading is the dead weight of the canister and its internals under 1g gravitational loading with the canister standing vertical.

Normal Service Temperatures. The minimum and maximum service temperatures for the ISF canisters have been determined from thermal analyses of a combined model of the canister and storage tube with appropriate SNF heat generation rate and the maximum and minimum temperatures of air entering through the storage vault inlet air vents. Although the minimum and maximum normal air temperatures are –26° F and 98° F, respectively, the off-normal minimum (-40° F) and maximum (101° F) have been used in the thermal calculation.

Normal Service Pressures. The canister internal pressure resulting from the initial volume of helium used as cover gas, the volume of fill gas in the fuel rods, out-gassing of fuel, the number of ruptured fuel rods, and temperature have been considered. NUREG-1536 (Ref. 4-13) requires that 1 percent of the fuel rods are assumed to have failed to calculate internal pressure. The initial fill pressure is nominally 6 to 7 psig. No significant increase in pressure results from the 1 percent failed fuel rods. For the structural evaluation for the normal condition, 50 psig internal pressure (design pressure) is conservatively used. The canister is subjected to external pressure during vacuum drying. As stated above, full vacuum has been conservatively assumed; this condition is treated under Design Loading. The ASME Code, Section III, Division 1, Subsection NB methodology is used to verify that the canister is capable of withstanding this external pressure.

Operating Loads. The canisters are designed to withstand the static loads due to their own self-weight and the weight of internal components (e.g., basket, spent fuel, shield plug, and impact plates). The weights of vacuum drying and seal welding equipment attached to the upper dome have also been considered. The weights considered are the maximum canister weights in Table 4.2-6. The center of gravity (CG), in all cases except Module IV and Module V canisters, lies on the canister centerline. The Module IV basket CG has a radial offset of 0.9-inch and Module V has a radial offset of 1.06-inch. Canisters are oriented vertically during interim storage.

Only the heaviest canisters have been evaluated for structural adequacy. Thus, the 18-inch diameter, long canister is evaluated for the Peach Bottom 1 fuel, 18-inch diameter, short canister for the TRIGA fuel, and 24-inch diameter, long canister for the Shippingport Module IV fuel.

Lifting Loads. For the vertical lifts of the fully loaded canisters, the dead weight loads have been increased by 15 percent to include dynamic effects from lifting operations, as recommended by CMAA 70. The ISF canister lifting rings and the impact absorbers meet the requirements of ANSI N14.6 as applicable to a critical load.

Thermal Loads. Structural analyses have been performed using the normal service temperatures calculated as discussed above. The canister and basket materials have identical coefficients of thermal expansion and the canister and its internals are free to expand; therefore, the thermal stresses resulting from the normal service temperatures are insignificant.

Off-Normal Service Temperature and Pressure. Thermal analyses have been performed to determine the off-normal canister temperatures and pressures due to a partial vent blockage and failure of 10 percent of the fuel rods. The 10 percent fuel failure is combined with off-normal temperatures. The difference between normal and off-normal conditions is not significant. Conservatively, 50 psig (design pressure) is used as off-normal pressure for the structural evaluation. Note that the normal service temperatures are calculated using off-normal environmental temperatures. Therefore, off-normal thermal loading considered is due to partial vent blockage only. The thermal stresses resulting from this off-normal event are also negligible for the reasons stated above.

Drop Accidents. The following drop scenarios are considered to determine the critical drop that must be evaluated:

- Spent-fuel loaded canister stays in a vertical position inside the canister cask on the canister trolley until the final closure weld is made and it is vacuum dried and filled with helium after the leak test and weld inspections are completed in the CCA. The jacks in the canister cask lift the canister approximately 3 feet to perform these operations. The jacks are designed to be single-failure-proof and to ANSI N14.6 requirements (Ref. 4-14). Therefore, a drop event is not considered credible.

- Upon completion of the final closure weld and the other operations in the CCA, the canister is brought into the Storage Area. The CHM, which has a single-failure-proof hoisting system, lifts the canister into the Storage Area, then positions it over a pre-selected storage module and lowers it into the storage tube. Because a single-failure-proof lifting device performs these operations, a drop event is not considered credible. The following non-mechanistic drops can be considered:

  a) The canister drops back into the canister cask on the canister trolley

  b) The canister drops onto the charge face in the storage area

  c) The canister drops into the storage tube

The last case is the critical case that has the maximum drop height; it has been considered as a non-mechanistic drop in the canister and storage tube structural analysis.

Seismic. Seismic analysis of the canister has been performed by the equivalent static method using the peak spectral accelerations and a conservative amplification factor that envelopes the peak accelerations at the charge face and the storage vault floors.

Accident Pressure and Temperature. The accident condition temperatures and pressures have been calculated using the following guidelines from NUREG-1536:

- 100 percent of the fuel rods are assumed to have failed.
- 100 percent of the initial rod fill gases and a release of 30 percent of the fission product gases into the canister are assumed for pressure calculation.
- The storage vault air inlet vents and the air outlet vents around the storage tubes are assumed to be 50 percent blocked.

No significant differences between normal, off-normal and accident conditions are found. The 50 psig design pressure envelops the identified conditions and has been used for structural evaluations.

Load Combinations

The canister pressure boundary is evaluated using the acceptance criteria of ASME Code, Section III, Subsection NB. The normal condition loadings are considered as those required to satisfy Level A service limits. The off-normal and accident condition loadings are evaluated against Level B and Level D service limits, respectively. Table 4.2-7 defines the loading combinations, for the pressure-retaining portions of the canister that have been used in the stress analyses, to ensure conformance with appropriate ASME code requirements. The thermal stresses resulting from the accident thermal condition are considered secondary stresses that have no limit prescribed by the ASME Code under Level D. As permitted by the ASME code and because there are no structural components in the canister assembly that can fail due to thermal loading, these stresses are not combined with the primary stresses.

Allowable Loads and Stresses

For design and service conditions the stresses within the canister pressure boundary must comply with ASME III, Division 1, Subsection NB stress limits. The allowable stress intensities for each of the Service Levels are calculated using the criteria listed in Table 4.2-8, and the material mechanical properties for each of the ISF canister materials are provided in Table 4.2-9.

The allowable stress limits for the canister materials are detailed in Table 4.2-10. In accordance with the Code Case N595-2 requirement, allowable stress intensities for the final closure weld are reduced by a factor of 0.70, although the weld examination will be performed by both ultrasonic and liquid penetrant methods.

Structural Analysis

The ISF canister pressure boundary is designed and built in accordance with ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB. The Code jurisdictional boundary includes the cylindrical shell, the top and bottom heads, and the weld at each end between the impact absorber and the head. In accordance with NB-1132, the canister internals such as retaining rings for impact plates and shield plug, impact plates, shield plug, and basket are considered non-pressure-retaining components. The structural characteristics of these attachments have been considered in the canister structural evaluation.

The lifting ring and impact absorbers have been analyzed to evaluate their compliance with ANSI N14.6 structural requirements. An ANSYS (Ref. 4-15) finite-element stress analysis was performed to demonstrate structural adequacy and code compliance for applicable loading conditions postulated to occur at the ISF Facility during interim storage of the spent fuel loaded canisters.

The ANSYS finite element model included the canister, the canister internals and the storage tube modeled with 3 dimensional solid elements. Figure 4.2-24 shows the finite element model of the canister assembly. The gap between the inside surface of the storage tube and the outside surface of the canister was represented by node to node contact elements to allow prediction of any canister tip-over during lateral seismic loading. The canister is free standing inside the storage tube and the contact elements between the top of the storage tube bottom plate and the canister bottom allow any uplift and tip-over of the canister but support it under vertically downward loading. The impact plates were modeled by solid elements with surface to surface contact elements representing the contact surfaces between the canister domed head and the impact plate. The baskets were modeled using radial and vertical beam elements and lumped masses. A small gap between the radial beam and the inner surface of the canister allowed the basket to slide under lateral loading. The shield plug was also modeled as a lumped mass positioned at the top of the basket, except for the Shippingport reflector IV and V module ISF canisters. For these canisters, both the shield plug and the support ring are also modeled using solid elements.

For the non-mechanistic drop of a canister into a storage tube, an elastic-plastic analysis of the canister was performed to assess the change in geometry and to obtain the stress/strain response. The drop analysis was performed using LS-DYNA (Ref. 4-16) with the previous ANSYS model modified to generate a quarter model sufficient to analyze this case. As a consequence of the drop, the lower impact absorber, lower dome, lower lifting ring and a portion of the storage tube undergo plastic deformation. The elastic-plastic analysis was based on the kinematic hardening material model and the bilinear stress-strain behavior of the component materials.

Summary of Results

The calculated stresses for the canister pressure boundary components and the design margins are detailed in Table 4.2-11. This shows each of the canister types with respect to the service level loadings. Design margin is defined as the ASME code allowable stress divided by the actual calculated stress, minus one. A net positive design margin is required to demonstrate compliance to the code stress allowables.

Canister Lifting Ring and Impact Absorber

The canister lifting ring and impact absorber have been designed as a single load path for lifting a critical load. A dynamic factor of 1.15 has been applied to the canister weight and the maximum tensile stress and combined shear stresses are limited to ANSI N14.6 acceptance criteria (one-sixth of yield strength or one-tenth of ultimate tensile stress, whichever is lower).

To analyze the canister lifting ring and impact absorber extensions, a 1/16 ANSYS finite element model was constructed because the grapples have eight lifting jaws. The vertical load was applied as a pressure load on the lifting ring over an area equal to half of a grapple jaw contact area because of the symmetry of the applied load. The allowable stress and the design margin for these components are provided in the Table 4.2-12.

4.2.3.3.2 ISF Canister Internals Structural Evaluation

Design Loads

The following summarizes the loads and conditions used in the ISF basket structural and thermal analysis. Further details of the design criteria for the ISF basket assemblies are in Chapter 3.

Design Loadings. The design loadings established in accordance with ASME Code, Section NCA-2142.1 for the ISF baskets are as follows:

- Design pressure = 0 psig. Although the basket is contained within a pressurized container (i.e., the canister) it is a vented structure so there are no pressure loads on any structural members.
- Design temperature range = -40°F to +650°F.
- Design mechanical loading = dead weight under 1g gravitational loading (with the basket resting on its base).

Normal Service Temperatures. The minimum and maximum service temperatures for the ISF basket assemblies have been determined from thermal analyses of a combined model of the canister and basket with appropriate SNF heat generation rate and the storage vault air inlet minimum and maximum normal temperatures. The structural analysis of the ISF baskets was performed using bounding maximum temperatures of 400°F and 260°F; the thermal analysis has shown that the actual basket temperatures are encompassed by these values.

Operating Loads. The baskets are designed to withstand the static loads due to the basket self weight, the fuel weight, and the shield plug weight. The baskets are oriented vertically during interim storage at the ISF Facility.

Lifting Loads. For the vertical lifts of the fully loaded baskets, the dead weight loads have been increased by 15 percent to include dynamic effects from lifting operations, as recommended by CMAA 70. The ISF basket lifting device has been designed in accordance with ANSI N14.6.

Thermal Loads. Thermal loads and stresses resulting from the temperature gradients derived from the vault thermal analysis have been calculated and used in the structural analysis.

Off-Normal Service Temperature. Thermal analyses have been performed to determine the off-normal ISF basket temperatures due to a partial vent blockage and failure of 10 percent of the fuel rods. These service temperatures are below the bounding temperature of 400°F used in the structural analysis.

Seismic Loads. As a bounding condition the seismic design and analysis of the ISF baskets have been evaluated using an equivalent-static design acceleration of ±10g. This acceleration has been applied equally in all three orthogonal directions and was selected to conservatively bound the seismic accelerations of the Storage Area vault floors and charge face structure. The actual peak accelerations on the canister and basket from the ISF storage tube seismic analysis are 4.13g horizontal and 0.32g vertical. The actual peak accelerations on the canister and basket from the CHM seismic analysis are 0.60g horizontal and 3.56g vertical.

In the specific case where the basket is suspended by a lifting device engaged with its lifting pintle (i.e., in the FPA), the basket is free to swing and, therefore, isolated from the horizontal components of the seismic excitation. The FHM design precludes slack rope conditions during a seismic event.

Load Combinations

Table 4.2-13 defines the loading combinations for the ISF baskets classified ITS that have been used in the stress analyses to ensure conformance with appropriate ASME Code requirements. The basket is normally vertically oriented during handling, loading, and storage operations.

The thermal accident condition could be assessed to Level D Service Limits, but because the thermal stresses are similar to the thermal off-normal case, the accident condition has been conservatively assessed against Level B limits.

Allowable Loads and Stresses

For design and service conditions, the stresses in basket components are less than ASME III Division 1, Subsection NG stress limits. In addition, for linear-type basket components where buckling is a possible mode of failure, the requirements of NUREG/CR-6322 are satisfied (Ref. 4-17).

The lifting path of the baskets has been designed as a single load path for lifting a critical load. A dynamic factor of 1.15 has been applied to the basket weight and the maximum tensile stress and combined shear stresses are limited to ANSI N14.6 acceptance criteria (one-sixth of yield strength or one-tenth of ultimate tensile stress, whichever is lower).

Table 4.2-14 provides the allowable material stresses for the primary components of the ISF basket assembly. These allowable material stresses are based on material properties obtained from the ASME Code and are provided in Table 4.2-15.

Structural Analysis

Because the spent fuel baskets are tube-and-spacer-plate design, the structural analysis is based on a common approach.

Description of Analyses. Structural analysis has been carried out by two methods:

- finite element analysis using ANSYS software
- hand calculation methods

The approach has been to decouple the mechanical loadings from the thermal loadings, with separate calculations prepared for each. The stresses are then combined as necessary as part of the ASME stress assessment. In practice the thermal stresses are low and are of secondary importance in the assessment. This has allowed the stress assessment process to be simplified.

The following sections summarize the main steps in the assessment and provide a basic description of the methods and analytical models used. Full details of the methods used in the structural assessment of the basket are given in the individual component calculations.

Analysis of Mechanical Loadings. The most severe mechanical loadings for the baskets, both in absolute terms and in relation to the allowable stresses, arise from the seismic cases where triaxial accelerations of 10g are assumed to apply. The remaining mechanical load cases involve only unidirectional loading effects (i.e., gravity). Therefore, analysis of the basket structure is primarily concerned with the seismic cases, and stresses for the dead weight cases are derived from simple factoring of the results determined for the 10g vertical component of seismic acceleration (with the basket resting on its base).

For the lifting case the load-path through the basket differs from that associated with the dead weight and the seismic loads. Therefore, a separate analysis has been performed to address this condition.

It has been possible to analyze the structure of the tube-and-spacer-plate design of baskets using a combination of several relatively small-scale finite element models and hand calculations. It has not been necessary to create a whole-basket structural analysis model, because each component (spacer plates, support tubes, and tie-bars) can be treated separately.

For the seismic analysis the equivalent-static method is used. This is a simple method that applies the specified accelerations of 10g as separate static loads in the north-south, east-west, and vertical directions and then combines the results from each direction. This is then added to the dead weight.

The usual method of combining the seismic directional results takes into account phasing of the earthquake directional excitations, typically by using the square root sum of the squares method (SRSS). These procedures recognize that the maximum north-south ground motion does not arise at the same time as the maximum east-west and vertical ground motions. Therefore, by assuming the peak acceleration applies in each direction concurrently, an additional conservatism has been built into the basket design to simplify processing of the seismic results. This approach was adopted with the prior knowledge that the basket structure is capable of withstanding far greater loads than those that arise during the design basis seismic event.

To understand the seismic assessment approach it is important to know that most of the total seismic stress for certain basket components arises from the horizontal seismic accelerations and for the others the vertical accelerations dominate. For instance, the horizontal loads constitute the principal loading for the spacer plates and the support tubes, whereas the principal loading for the tie bars and basket lid results from the vertical seismic acceleration.

This has allowed some simplification of the analysis by permitting decoupling of the load components despite the potentially non-linear nature of some of the analysis, which involves modeling of contact surfaces. However, where tie-bar buckling is addressed it has been necessary to consider loading in all directions concurrently when applying the requirements of NUREG/CR-6322.

Evaluation of the Basket Spacer Plates. To establish the loads imposed on the spacer plates by the support tubes, gadolinium tubes, and the tie bars during a horizontal seismic event, ANSYS beam element models of the individual components were used. Each beam model was supported by the appropriate number of spacer plates and subjected to an evenly distributed load multiplied by the resultant seismic acceleration.

The reaction loads at the spacer plate supports were input to an ANSYS finite element model of the spacer plate along with a 2-inch length section of the canister wall constructed from 2-dimensional structural solid elements.

Contact surfaces were defined between the spacer plate and the canister and between the canister and a rigid surface representing the surrounding structural boundary of the CHM turret inner bore or storage tube. The reaction forces from the beam element models were applied together with a resultant horizontal seismic inertia body loading to the spacer plate and canister model. The reaction loads were conservatively applied as point loads rather than distributed loads.

The baskets have some degree of symmetry. Therefore, repeat elastic static analyses with different contact angles between the spacer plate and canister, over a segment of the plate, were performed to obtain the worst basket orientation in terms of stress intensity developed within the spacer plate.

A calculation assessed in-plane buckling failure of the spacer plate ligament between the support tube positions. Elastic buckling stress was compared to the material yield strength and a margin was calculated against the onset of plastic buckling on the basis that plastic buckling could not occur at yield stress.

The stress generated in the spacer plates from the 11g vertical acceleration (i.e., 10g seismic plus 1g due to gravity) was calculated by modification of the ANSYS model that was used to assess the horizontal impact case. The spacer plate is supported at the tie bar positions, and the 11g acting on the self-weight of the plate generates the load. For the combined seismic loads, vertical, horizontal and gravity, superposition of the individual stresses was used to calculate the resultant stresses in the spacer plate.

Evaluation of the Base Plate and Lid. Comparing the base plate and lid to the basket spacer plate shows that the horizontal seismic loading on the spacer plate exceeds that on the lid and base plate due to the loads transferred from the support tubes, tie bars, etc. The base plate and lid have to support their own inertia loadings only, and having only small vent holes makes them inherently stronger. Therefore, the base plate and lid are not assessed for horizontal seismic loading.

A finite element model of the lid was generated to establish the stresses in the lid during the 11g vertical seismic event including inertia loads imposed by the shield plug supported above the basket. The lid is supported at the tie bar positions. The loads acting on the lid for a vertical acceleration produce a bending effect that is not evident in the base plate, which is in direct compression only. Hence the bending stresses calculated for the lid will bound those arising in the base plate.

Evaluation of Fuel Support Tubes and Gadolinium Phosphate Tubes. To establish the loads imposed on the tubes during the horizontal seismic loads both types were modeled as shell elements in an ANSYS finite element model. Rigid supports were defined to represent the interaction between the tubes and spacer plates. Contact surfaces were defined at each support location to allow accurate representation of the interaction between the tubes and the bores of the spacer plate through holes.

The contents of the tubes (i.e., the fuel or gadolinium phosphate) were assumed to have no structural stiffness of their own. Therefore, the tube is required to support the inertia of its contents, applied as a uniformly distributed load, as well as its own inertia resulting from the seismic inertia loading. This is a conservative assumption for the fuel support tube where the fuel will have a significant bending stiffness.

Elastic static analyses were conducted to determine maximum stress intensity values in the tubes for use in the stress assessment. In addition, the possibility of buckling as a result of compressive stresses developed in the thin shell of the tube was considered by the use of ANSYS elastic/plastic large-deflection analyses. In this analysis conservative bilinear material properties were specified for the tube material. This analysis established a margin on the critical buckling load. The buckling analysis did not consider the concurrent vertical seismic loading as this is expected to have only a minor influence on behavior of the tubes. This approach is further justified on the basis of the extremely high margin established against plastic buckling when subjected to the dominant horizontal seismic loading.

Calculations determined the compressive stress induced in the tubes generated by the 11g vertical acceleration acting on the tube mass. The fuel and gadolinium phosphate are assumed to impose loading through the base of the basket only. Because the calculated stresses were low it was possible to demonstrate an adequate design by use of a general design rule provided by ASME, Section III, Div. 1, sub-section NG-3133.6. This clause defines a method for determining the maximum allowable compressive stress to be used in the design of cylindrical shells and tubular products subjected to axial compression.

This is a conservative approach, as the stress generated from a Level D type loading has been compared with an allowable stress defined for a normal design loading. For the combined seismic loads (vertical, horizontal and gravity), superposition of the individual stresses was used to calculate the resultant stresses in the fuel support tubes and the gadolinium phosphate tubes.

Evaluation of the Tie Bar. The stresses developed in the tie-bars due to the horizontal seismic loading can be adequately determined from the beam element model that was used to calculate reaction loads imposed by the tie bars on the spacer plates. For the tie bars the stress and buckling analysis is performed in accordance with NUREG/CR-6322 under a combination of the vertical and horizontal seismic accelerations plus dead weight. The directional seismic loads are not decoupled for this assessment because the horizontal load has the potential to reduce the critical buckling load under axial compression.

Margin on the critical buckling load was demonstrated using the calculation methods in NUREG/CR-6322, which limits actual compressive load to less than two-thirds of the critical buckling load. Two buckling calculations were performed. The first considers the buckling of an individual tie bar between spacer plates. The allowable compressive load (with concurrent lateral loading) was based on the radius of gyration of the individual tie bar, an effective length factor of 1.2 (based on the end conditions factor provided in NUREG/CR-6322) and the material elastic modulus and yield strength.

The second buckling calculation (not a requirement of NUREG/CR-6322 but presented as additional supporting evidence) considers the basket as a composite structure. The unbraced length of the basket was taken as the full basket length. The allowable compressive load was based on the radius of gyration of the tie bars acting as a group, an effective length factor of 2.1 (based on the end conditions factor provided in NUREG/CR-6322) and the material elastic modulus and yield strength.

Note that the tie bars are assumed to take loads from the spacer plates, tie bars, lid, and shield plug. The tubes and fuel will apply load directly through the base (or lid) and not through the tie bars.

Evaluation of Lifting Load Path Items. The stresses in the lifting load path have been determined by a combination of hand calculation methods and ANSYS finite element analysis and are compared against the requirements of ANSI N14.6. The lifting load path extends down from the lifting pintle (onto which the basket lifting device engages) through the locking plate and lifting pins and into the tie bars. The tie bars connect with the base of the basket, through which the weight of the fuel assemblies, fuel support tubes, and gadolinium phosphate tubes are carried.

Summary of Results

Stresses caused by mechanical loads are treated as primary stresses and are therefore compared with the ASME primary stress limits where appropriate. As can be seen from the thermal stress results in Section 4.2.3.3.6 the secondary stresses are low and can be ignored in the ASME stress assessment.

Also note that the peak stress component of the total stress is not relevant in this assessment, as peak stress is only evaluated in a fatigue analysis. This is not necessary because during storage, the basket structure will not experience significant cyclic stresses other than during seismic events that are infrequent and are of short duration involving relatively few stress cycles.

The following tables identify the primary stress results for the four basket types:

- Peach Bottom 1 and 2
- Peach Bottom 1 ART
- TRIGA
- Shippingport reflector rod

Peach Bottom 1 and 2 Baskets

Component Structural Stress Results. The structural stress results for each basket component for the Peach Bottom 1 and 2 baskets are summarized in the following tables. The tables compare the calculated stresses against the code allowable stresses. The safety margin in the design is expressed as a Factor of

Safety (FOS) against ASME code requirements. FOS is defined as ASME code-allowable stress divided by calculated stress (or capacity divided by demand). Therefore, FOS values greater than 1.0 are required to demonstrate compliance to the code stress requirements.

Tie Bars. Refer to Table 4.2-16, Peach Bottom ISF Basket – Tie Bar Stress Results. In addition to the assessment of the individual tie bars, a buckling check has been carried out for the basket structure as a whole. For the most severe case, the seismic case, the FOS for the whole basket is calculated at 24.5 against overall buckling.

Spacer Plates. Refer to Table 4.2-17, Peach Bottom ISF Basket – Spacer Plate Stress Results.

Fuel Support Tubes. Refer to Table 4.2-18, Peach Bottom ISF Basket – Fuel Support Tube Stress Results.

Gadolinium Phosphate Storage Tube. Refer to Table 4.2-19, Peach Bottom ISF Basket – Gadolinium Phosphate Storage Tube Stress Results.

Basket Lid. Refer to Table 4.2-20, Peach Bottom ISF Basket – Basket Lid Stress Results.

Top Plate. No significant membrane or bending stresses are imposed on the top plate, as this plate is well supported by the lid and top spacer plate. Bearing stress at the contact area with the lid support pins and shear stress caused by the fuel tubes during vertical seismic accelerations are summarized below.

Bearing stress during normal storage is 26.53 ksi; comparing this with the allowable stress of 47.25 ksi provides a FOS of 1.78. Shear stress resulting from vertical seismic loads is 0.077 ksi; comparing this with an allowable of 26.02 ksi provides a FOS of 340.

Base Plate. The principal load case for the base plate is during lifting and the results from this analysis are included with the load path items below. During normal operation and the seismic load case the base plate stresses are bounded by the spacer plate results.

Other Lifting Load Path Items. Refer to Table 4.2-21, Peach Bottom ISF Basket – Load Path Items Stress Results. The lifting load path items are analyzed to the reduced stress limits of ANSI 14.6 with a dynamic factor of 1.15 applied to the masses.

Peach Bottom 1 ART Baskets

Component Structural Stress Results. The structural stress results for each basket component for the Peach Bottom 1 ART baskets are summarized in the following tables. The tables compare the calculated stresses against the code allowable stresses. The safety margin in the design is expressed as a FOS against ASME code requirements. FOS is defined as ASME code-allowable stress divided by calculated stress (or capacity divided by demand). Therefore, FOS greater than 1.0 are required to demonstrate compliance to code stress requirements.

Tie Bars. Refer to Table 4.2-22, Peach Bottom ART ISF Basket – Tie Bar Stress Results. In addition to the assessment of the individual tie-bars, a buckling check has been carried out for the basket structure as a whole. For the most severe case, the seismic case, the FOS is calculated at 19.4 against overall buckling.

Spacer Plates. Refer to Table 4.2-23, Peach Bottom ART ISF Basket – 316L Spacer Plate Stress Results, for the stresses in the end spacer plates and Table 4.2-24, Peach Bottom ART ISF Basket – 17-4 Ph Spacer Plate Stress Results, for the stresses in the central spacer plates.

Fuel Support Tubes. Refer to Table 4.2-25, Peach Bottom ART ISF Basket – Fuel Support Tube Stress Results.

Gadolinium Phosphate Storage Tube. Refer to Table 4.2-26, Peach Bottom ART ISF Basket – Gadolinium Phosphate Storage Tube Stress Results.

Basket Lid. Refer to Table 4.2-27, Peach Bottom ART ISF Basket – Basket Lid Stress Results.

Top Plate. No significant membrane or bending stresses are imposed on the top plate, as this plate is well supported by the lid and top spacer plate. Bearing stress at the contact area with the lid support pins and shear stress caused by the fuel tubes during vertical seismic accelerations are summarized below.

Bearing Stress during normal storage is 21.5 ksi; comparing this with the allowable stress of 47.25 ksi provides a FOS of 2.20. Shear Stress resulting from vertical seismic loads is 0.147 ksi; comparing this with an allowable of 26.02 ksi provides a FOS of 177.

Base Plate. The principal load case for the base plate is during lifting; results from this analysis are included with the load path items below. During normal operation and the seismic load case the base plate stresses are bounded by the spacer plate results.

Other Lifting Load Path Items. Refer to Table 4.2-28, Peach Bottom ART ISF Basket – Load Path Items Stress Results. The lifting load path items are analyzed to the reduced stress limits of ANSI 14.6 with a dynamic factor of 1.15 applied to the masses.

TRIGA Baskets

Component Structural Stress Results. The structural stress results for each basket component for the TRIGA ISF basket are summarized in the following tables. The tables compare the calculated stresses against the code allowable stresses. The safety margin in the design is expressed as a FOS against ASME code requirements. FOS is defined as ASME code-allowable stress divided by calculated stress (or capacity divided by demand). Therefore, FOS greater than 1.0 are required to demonstrate compliance to code stress requirements.

Tie Bars. Refer to Table 4.2-29, TRIGA ISF Basket – Tie Bar Stress Results.

Lid Support Pins. Refer to Table 4.2-30, TRIGA ISF Basket – Lid Support Pins Stress Results.

Spacer Plates. Refer to Table 4.2-31, TRIGA ISF Basket – Spacer Plate Stress Results.

Fuel Support Tubes. Refer to Table 4.2-32, TRIGA ISF Basket – Fuel Support Tube Stress Results.

Gadolinium Phosphate Storage Tube. See Table 4.2-33, TRIGA ISF Basket – Gadolinium Phosphate Storage Tube Stress Results.

Basket Lid. Refer to Table 4.2-34, TRIGA ISF Basket – Basket Lid Stress Results.

Top Plate. Refer to Table 4.2-35, TRIGA ISF Basket – Top Plate Stress Results.

Base Plate and Support. Refer to Table 4.2-36, TRIGA ISF Basket – Base Plate and Support Stress Results.

Other Lifting Load Path Items. Refer to Table 4.2-37, TRIGA ISF Basket – Load Path Items Stress Results. The lifting load path items are analyzed to the reduced stress limits of ANSI 14.6 with a dynamic factor of 1.15 applied to the masses.

Shippingport Reflector Rod Basket

Component Structural Stress Results. The structural stress results for each basket component for the Shippingport Reflector Rod basket are summarized in the following tables. The tables compare the calculated stresses against the code allowable stresses. The safety margin in the design is expressed as a Factor of Safety (FOS) against ASME code requirements. FOS is defined as ASME code-allowable stress divided by calculated stress (or capacity divided by demand). Therefore, FOS greater than 1.0 are required to demonstrate compliance to code stress requirements.

Tie Bars. Refer to Table 4.2-38, Shippingport Reflector Rod ISF Basket – Tie Bar Stress Results. In addition to the assessment of the individual tie bars a buckling check has been carried out for the basket structure as a whole. For the most severe case, the seismic case, the FOS is calculated at 23.5 against overall buckling.

Spacer Plates. Refer to Table 4.2-39, Shippingport Reflector Rod ISF Basket – Spacer Plate Stress Results.

Fuel Support Tubes. Refer to Table 4.2-40, Shippingport Reflector Rod ISF Basket – Fuel Support Tube Stress Results.

Basket Lid. Refer to Table 4.2-41, Shippingport Reflector Rod ISF Basket – Basket Lid Stress Results.

Top Plate. Based on the large FOS calculated in the top plate for the vertical seismic load case, the stresses resulting from the normal deadweight conditions are insignificant. The resultant stresses on the top plate from the vertical seismic load case are summarized below.

Primary membrane stress is 1.55 ksi; comparing this with the allowable stress of 91.84 ksi provides a FOS of 59.2. Primary membrane plus bending stress is 6.12 ksi; comparing this with the allowable stress of 137.8 ksi provides a FOS of 22.5. Shear stress is 0.27 ksi; comparing this with an allowable of 55.1 ksi provides a FOS of 204.

Base Plate. Refer to Table 4.2-42, Shippingport Reflector Rod ISF Basket – Base Plate Stress Results.

Other Lifting Load Path Items. Refer to Table 4.2-43, Shippingport Reflector Rod ISF Basket – Load Path Items Stress Results. The lifting load path items are analyzed to the reduced stress limits of ANSI 14.6 with a dynamic factor of 1.15 applied to the masses.

Shippingport Reflector IV and Reflector V Baskets

The baskets in the canisters containing the Shippingport Reflector IV and V Modules are classified NITS. They do not provide any structural function during movement or storage within the ISF facility and are used only as an aid for loading the canisters. The low fissile contents of the Reflector modules ensure there are no criticality constraints to be addressed within the canisters. The shield plugs are supported on retaining rings that are securely fastened to the canister (not by the basket), therefore there are no structural loads imposed on the basket by the shield plug. Fuel retrievability is concerned with retrieving the complete canister as a whole assembly; the fuel will not be removed from the canister once it is sealed. Hence, no structural stress limits need to be satisfied for the Reflector IV and Reflector V baskets.

4.2.3.3.3 Storage Tube Assembly Structural Evaluation

The pressure boundary components of the storage tube assembly are classified ITS as they provide the secondary confinement barrier for the SNF during normal, off-normal, and accident conditions. The pressure boundary components of the storage tube assembly are N-stamped as an ASME Code, Section III, Division 1, Subsection NC, Class 2 vessel. The pressure boundary consists of the tube body (with welded forged base plate and tube top) and the storage tube lid.

Design Loads

The following summarizes the loads and conditions used in the storage tube structural and thermal analysis.

Design Pressure. The initial fill pressure for the storage tube is nominally 8 psig. An increase or decrease in this pressure would result from a change in external temperature. When the storage area air vents are 50% blocked (accident condition), the storage tube temperature is not expected to exceed 125°F. For this condition, the internal pressure may be in the 9 to 11 psig range. The maximum design internal pressure, however, (NC–3112.1) is conservatively set to 50 psig (design pressure for the canisters). The storage tube assembly is also designed for an external pressure of 14.7 psi that occurs when the storage tube is evacuated prior to inert gas filling.

Design Temperature. Although the maximum temperature during normal storage conditions is not expected to exceed 125°F, the design temperature (NC-3112.2) is specified as 300°F.

Design Mechanical Load. The design mechanical loading is the dead weight of the storage tube, canister, and canister internals under 1g gravitational loading with the storage tube and the canister inside the storage tube standing vertical.

Normal Service Temperatures. The minimum and maximum service temperatures for the storage tube have been determined from thermal analyses of a combined model of the canister and storage tube with appropriate SNF heat generation rate and the maximum and minimum temperatures of air entering through the storage vault inlet air vents. Although the minimum and maximum normal air temperatures are –26°F and 98°F, respectively, the off-normal minimum (-40°F) and maximum (101°F) have been used.

Normal Pressure. The storage tube assembly internal pressure has been calculated using the initial volume and pressure of helium used as cover gas (nominally 8 psig) and the normal service temperatures of the canisters. For the structural evaluation for the normal condition, 50 psig internal pressure (design pressure) is conservatively used.

Operating Loads. The normal operating loads are the self-weight of the storage tube components and the ISF canister assemblies.

Thermal Loads. Thermal loads and stresses resulting from the normal service temperatures and temperature gradients derived from the thermal analyses have been calculated and used in the structural analysis. The storage tube components are fabricated from materials that have similar coefficients of thermal expansion, and the storage tube can expand vertically as well as horizontally because of gaps designed between the storage tube and its lateral supports. Therefore the thermal stresses resulting from normal service temperatures are insignificant.

Off-Normal Service Temperature. Off-normal storage tube temperatures result from the off-normal temperatures of air entering the storage area and partial blockage of the air vents. Because normal service temperatures are calculated using off-normal environmental temperatures, the only off-normal thermal loading considered is due to partial vent blockage. Thermal analyses have been performed to determine the off-normal storage tube temperatures due to this event. The resulting temperatures are near those for the normal events. Structural analyses are, however, performed for a conservative temperature of 300°F.

Off Normal Service Pressure. The off-normal pressure results from off-normal temperatures. No significant change in pressure is calculated; however, a 50 psig pressure (design pressure) is used as off-normal pressure.

Accident Pressure and Temperature. The accident condition temperatures and pressures within the storage tubes have been calculated in accordance with NUREG-1536. The storage vault air inlet vents and the air outlet vents around the storage tubes are assumed to be 50 percent blocked and normal service temperatures are used for the air inlet temperatures. No significant difference between normal, off-normal and accident conditions are found. For structural analyses, a conservative pressure of 50 psig and temperature of 300°F has been assumed. No separate thermal analysis is performed for this case as the same temperature is used as an off-normal temperature.

Seismic Loads. The storage tube module has been evaluated for loads resulting from a design earthquake. The structural evaluation for the earthquake loading uses the response spectra at the charge face level and the storage vault floor level. Seismic analysis of the storage tube has been performed by the equivalent static method using the peak spectral accelerations and a conservative amplification factor. The design of the storage tube module and its interfaces mitigate the possibility of failure of the storage tube assemblies or supporting structure.

Drop Accidents. Three components potentially could be dropped onto the storage tube assembly: the ISF canister, tube plug, and storage tube lid.

The ISF canister is handled by a single-failure-proof hoist and grapple system. Therefore, a drop of this type is not considered credible. However, as a non-mechanistic drop analysis, the fuel-loaded canister has been evaluated for a vertical drop from its maximum height from inside the CHM during placement in the storage tube. This event is covered by Section 4.2.3.3.1.

The tube plug is handled by the tube plug hoist and grapple system of the CHM. This is not a single-failure-proof hoisting system but is a single load path with large safety factors. A tube plug drop has been assessed against a maximum drop height of approximately 89 inches, with no unacceptable consequences.

The storage tube lid is handled by commercial-grade hoisting and rigging. A storage tube lid drop from a height of 84 inches onto the tube body does not cause a nuclear hazard. The storage tube lid drop event is not evaluated because it is bounded by the tube plug drop event by reason of the storage tube lid lower drop energy (e.g., lower drop height and mass).

Load Combinations

Table 4.2-44 defines the loading combinations for the storage tube assembly components that have been used in the stress analyses, to ensure conformance with appropriate ASME code requirements.

Allowable Loads and Stresses

The storage tube pressure boundary is evaluated using the acceptance criteria of the ASME Code, Section III, Subsection NC. The normal condition loadings are considered as those that are required to satisfy the Level A service limits. The off-normal and accident condition loadings are evaluated against Level B and Level D service limits, respectively.

The allowable stress intensities for each of the Service Levels are calculated using the criteria listed in Table 4.2-45, and the material mechanical properties provided in Table 4.2-46. The allowable stress limits for the storage tube materials are detailed in Table 4.2-47.

Structural Analysis

The structural evaluation of the storage tube assembly is performed using ANSYS/Mechanical Version 5.7 and ANSYS/LS-DYNA Version 5.7 finite element analysis software and hand calculations. Structural analyses are performed by elastic and plastic analysis methods to demonstrate the structural adequacy and code compliance for applicable loading conditions postulated at the ISF Facility.

The ANSYS model includes the lower tube, forged base plate, support stool plate and alignment tees, and a simplified canister as shown in Figure 4.2-25. For the simplified canister, the internal structures and their associated contact surfaces are not modeled to bring about a stable solution. The upper and lower domes are modeled as flat plates. The total canister weight, including that of the loaded spent fuel basket and impact plates, is included as an increase in the modeled density of the canister material property.

The storage tube and simplified canister are modeled using the 3D solid element, SOLID45. The gap between the inside surface of the storage tube and the outside surface of the canister is represented by the 3D node-to-node contact element, CONTAC52. The canister is freestanding inside the storage tube. The node-to-node contact between the canister bottom and the storage tube bottom plate allow the canister to uplift and tip, but support it under compressive loading.

Constraints for the storage tube include models of the charge face liner support pads and the support stool. The charge face liner support pads are modeled as constrained nodes. Node-to-node contact elements, CONTAC52, are modeled between these nodes and nodes on the outer radius of the upper storage tube annular forging. The storage tube is freestanding on the support stool.

The support stool, including the support plate and alignment tees, is also modeled as constrained nodes. The support plate constrained nodes are offset vertically from the nodes making up the bottom surface of the storage tube bottom forged plate. Node-to-node contact elements, also CONTAC52, between the storage tube bottom plate and the support stool plate, allow the storage tube and its contents to uplift and tip, but support it under compressive loading. Node-to-node CONTAC52 gap elements are provided between the bottom outer radius of the storage tube and the support stool alignment tees.

ANSYS Model – Plastic Analysis. The drop analysis is performed using LS-DYNA, a software package that contains ANSYS for pre- and post-processing and an explicit code, DYNA3D, developed by Livermore Software Technology Corporation. (LSTC). Because LS-DYNA solver provides a fast solution for large deformation, non-linear dynamic and contact problems, it is well suited to handle the drop analysis.

For the postulated vertical drop of the tube plug in the storage tube, a quarter-symmetry model is necessary. The ANSYS model described above is modified to function properly within LS-DYNA. The SOLID45 elements are changed to SOLID164 elements. The BEAM4 elements are not transferred because the lid is not modeled. The CONTAC52 gap elements are deleted and node sets are defined in the input file for the surfaces in contact. Contact elements are generated by LS-DYNA from these node sets.

Summary of Results

The stress intensities and the design margin for the design and service conditions for both 18-inch and 24-inch diameter storage tubes are listed in Table 4.2-48. Design margin is defined as the ASME code allowable stress divided by the actual calculated stress, minus one. A net positive design margin is required to demonstrate compliance to the code stress allowables.

4.2.3.3.4 Charge Face Cover Plate Structural Evaluation

The charge face cover plate is classified ITS because it protects the storage tube assembly from tornado-generated missiles. The charge face cover plate is not part of the pressure boundary of the storage tube and therefore, has been designed to the AISC *Manual of Steel Construction*, Ninth Edition. The charge face cover plate has been evaluated for static loads, live loads, seismic loads, tornado wind, differential pressure and tornado generated missile impact loads.

Charge Face Cover Plate Loading

Tornado-Generated Missiles. Tornado missiles in the form of a wooden plank, 6-inch schedule 40 pipe and 1-inch steel rod could penetrate the exterior building walls of the Storage Area building. The charge face cover plate has been designed to withstand an impact from these missiles without damage to the storage tube assembly.

Tornado Wind and Differential Pressure. The charge face cover plate has been designed to withstand the upward suction resulting from the tornado wind speed of 200 mph assuming the building sheeting has failed.

Live Loads. The charge face cover plate is designed to support a live load of 150 psf.

Seismic Loads. The charge face cover plate is designed to withstand the effects of the design basis earthquake and will remain in place to protect the storage tube assembly during and following a seismic event.

Lifted Loads. The charge face cover plate is removed from the charge face encast by using a portable hoist that is rolled over the charge face to the desired storage location. The hoist attaches to three eyebolts that are screwed into threaded holes in the cover plate. The lifting hoist and lifting arrangement is designed to ensure that the charge face cover plate is safely handled to prevent dropping it on the charge face.

4.2.3.3.5 Storage Vault Structural Evaluation

The structural evaluation of the storage vaults is provided in Section 4.7.3.3.3, *Storage Area*.

4.2.3.3.6 Heat Transfer and Thermal Evaluation

This section presents the heat transfer and thermal analysis during storage and SNF handling operations. The significant thermal design feature of the storage system is the passive thermosyphon airflow used to remove the decay heat of the stored SNF. The system has been evaluated for the removal of up to 12.9 kW of decay heat distributed between both storage vaults. The maximum individual storage tube heat output and vault configurations for this maximum decay heat are presented in Table 4.2-49. The naturally circulating air inside the storage vault ensures that concrete temperatures are maintained below the design limits. Although long-term fuel cladding temperatures are calculated to be maintained below temperature limits where degradation might occur, this SAR does not take credit for fuel cladding integrity.

Air is naturally drawn into the vault structure through the air inlet/vents by the buoyancy action of the warm storage air rising. As cooler air is drawn into the vault it warms up from the heat generated in the storage tube. This warmer air rises and flows through annular gaps around each storage tube and enters the Storage Area building where it is dissipated into the atmosphere through fixed louvers. The analysis provides the temperatures and temperature distributions in the fuel, basket, canister, storage tubes and concrete throughout the ISF facility for normal, off normal, and accident conditions.

Design Data

Ambient Temperature Boundary Conditions

The ambient temperature boundary conditions used in the heat transfer and thermal calculations are listed in Table 4.2-50.

Thermal Properties of Materials

The thermal conductivity properties of the steel materials used in the heat transfer and thermal analysis were derived from ASME Section II, Part D, *Material Properties*. The values of surface thermal emissivity used in the thermal and heat transfer calculations are listed in Table 4.2-51. The values for the canister and fuel packaging stations represent plain metal surfaces while the other values represent painted surfaces.

Fuel Heat Outputs

The fuel heat outputs used in the heat transfer and thermal analysis models of the ISF baskets are detailed in Table 4.2-52. These values are based on the decay heat output for the year 2004.

A bounding heat output scenario was also evaluated, using maximum heat outputs of 40 watts and 120 watts per canister. Canister heat sources of 40 watts and 120 watts were used to calculate the ISF canister and storage tube temperature distributions used in their structural analysis.

Allowable Temperature Limits

Table 4.2-53 provides the allowable fuel and component temperature limits during normal, short term off normal, and short term accident conditions within the storage system or during SNF handling operations.

Heat Transfer and Thermal Analysis Modeling

The following sections summarize the main steps in the heat transfer and thermal analysis and provide a basic description of the methods and analytical models used. Full details of the methods used in the analyses are given in the individual component calculations.

The thermal modeling of the fuel, ISF basket, ISF canister, storage tube and SNF handling components uses a combination of hand calculations and finite element analysis using the ANSYS computer code. The ANSYS data sets were produced such that they could be used first to produce the steady state temperatures and then as part of the structural analysis. The heat transfer and thermal analysis has been carried out with the ISF canister and/or basket located in the FPA, the canister trolley cask, the CHM and the storage tube assembly.

In each of these locations the temperature calculation has been carried out in two stages. In the first stage models were created of the standard canister with a heat source representative of the appropriate fuel elements. These models were then run to calculate the steady state temperature reached by the canister wall. In the second stage a 3-dimensional model of the canister with its basket and fuel was modeled with the canister wall temperature, calculated in the first stage, applied as a boundary condition. The results of the second stage determined the required maximum steady state temperatures of the canister basket components and the temperature distributions.

Fuel Elements

The heat transfer process within the baskets and ISF canisters is modeled as conduction only. The fuel elements and modules have been modeled as a region of the canister fill gas with the same dimensions as the fuel active length. The decay heat is then applied within this gas region as a uniform volumetric heat source. Because the thermal conductivity of the fill gas is lower than that of the fuel assemblies, the maximum temperatures obtained are conservative. The thermal conductivity is selected to represent either helium or air at a specified pressure.

ISF Basket Components

The ANSYS models of the ISF baskets were constructed from 20-noded thermal brick elements. As the baskets are symmetric in the axial direction, only a section of the basket was modeled, consisting of half the thickness of a spacer plate together with half the gap between the spacer plates. The full circle of the spacer plate was modeled to facilitate the thermal stress analysis of the spacer plate and other canister components. The resulting centrally located section gives a conservative result because the heat loss that occurs from the canister ends is neglected.

The basket voids are modeled as gas. Heat transfer through the gas is modeled by conduction. Heat transfer by radiation and convection has not been considered in this model, which provides a conservative analysis.

The fuel support tubes are located concentrically in the holes in the spacer plates. The clearance gaps between the support tubes and spacer plate and between the canister and spacer plate are filled with gas.

Canisters

The ANSYS model of the canister is the same as that used for the structural analysis in Section 4.2.3.3.1. The steady state canister temperatures have been calculated for representative and bounding heat sources of 40 watts and 120 watts. For the long canisters both heat sources have been applied uniformly over a canister length of 100 inches. For the short canisters the 40-watt heat source has been applied uniformly over two 15-inch canister lengths, representative of that for TRIGA fuel. There is no representation of any basket structure within the canister.

Fuel Packaging Area

Fuel Operations and Monitoring Station. The heat producing components within the various incoming DOE canisters are distributed uniformly within the cross section area of the canisters. The fuel and contents of each of the incoming DOE canisters have been modeled as a single cylindrical gaseous region with a uniform volumetric heat source over the height occupied by the active length of the fuel. Because the fuel components and the basket are metals (oxides or carbides) they have a greater thermal conductivity than does the canister fill gas. Initially the canisters have their original gas fill, but after opening, the medium will be air. Air has the lower value of thermal conductivity, and this has been used for the calculations. This modeling methodology results in a conservative prediction for the maximum fuel, basket and reflector component temperatures within the DOE canister.

The smaller diameter DOE canisters, containing Peach Bottom and TRIGA fuels, are located within an adapter that rests within the bench vessel at the fuel operations and monitoring station. This is an encast within a concrete shield region that is nominally 3 feet thick. The larger diameter DOE canisters, containing the Shippingport reflector modules and loose rods, rest directly within the bench vessel. The heat transfer from the DOE canister to the adapter and to the bench vessel is modeled by convection through the air annuli and by thermal radiation across the concentric surfaces. The heat is then conducted through the concrete and transferred off the outside of the concrete by natural convection to the confined air below the FPA workbench level. The confined air also receives heat from other fuel storage and handling stations. The confined air then transfers the heat to the workbench by natural convection, and the workbench top surface then transfers the heat by natural convection to the FPA HVAC system. The heat transfer route from the DOE canister to the HVAC air has been modeled by hand calculations as a 1-dimensional steady state system.

Fuel Bucket Operations Station. Only the individual TRIGA shipping buckets are removed from the DOE canister and loaded into the fuel bucket operations station. The heat transfer processes within this station have been modeled using the same approach as employed at the fuel operations and monitoring station. The model assumes a uniform volumetric heat source within the air-filled fuel bucket. Heat transfer occurs in the radial (horizontal) direction from the fuel bucket to the side plates, to the bench vessel and then to the confined air below. The radial heat transfer is by conduction in the air, except for the heat transfer off the outside of the bench vessel by natural convection. No vertical (axial) heat transfer direct to the ventilation system air has been included. The heat transfer route from the TRIGA fuel bucket to the HVAC air has been modeled by hand calculations as a 1-dimensional steady state system.

Fuel Loading Stations. The FPA has three fuel loading stations where the individual fuel elements are loaded into baskets. Fuel Loading Stations 1 and 2 have a large bench vessel and can accommodate 18-inch baskets using an adapter sleeve or 24-inch baskets without an adapter. Fuel Loading Station 3 has a smaller bench vessel and can accommodate the 18-inch baskets used for Peach Bottom 1 ART fuel. The heat transfer methodology used at the fuel loading stations is the same as that for the vault storage area, but with the canister replaced by the adapter sleeve, if used.

Fuel Decanning Station. The methodology employed in modeling the Peach Bottom fuel and its can at the decanning station is the same as that employed at the fuel bucket operations station. The radial barriers to heat transfer are the fuel liner, inner can, outer can, adapter sleeve, and bench vessel.

Canister Trolley Cask and Canister Closure Area

The maximum steady state temperatures within the canister trolley cask will occur while the cask is jacked up into the CCA. In this position a 3-foot-high section of the cask is within the concrete roof of the transfer tunnel. To ensure that the results are conservative, it has been assumed that there is no heat loss from any part of the cask above the level of the transfer tunnel roof. Canister heat that is passed radially into the cask from above the level of the transfer tunnel roof will be conducted down through the cask steel shielding into the transfer tunnel area, before being transferred to the HVAC air environment in the Transfer Tunnel.

The natural convection heat transfer that occurs across the air gap between the canister and the inside surface of the canister cask was modeled using surface effect elements. The thermal radiation that occurs across this air gap was modeled using a radiation matrix utility. Neither the canister cage nor the heater elements were represented explicitly in the model.

The natural convection heat transfer and thermal radiation from the outside surface of the canister trolley cask to the ambient transfer tunnel air environment was modeled using surface effect elements. The applied heat transfer coefficient was temperature dependent and based on a laminar natural convection correlation.

Canister Handling Machine

For the CHM model heat is transferred from the outside of the CHM to the Storage Area air by natural convection and radiation. The air passing through the annulus between the CHM wall and the neutron shield material (JABROC) was modeled as a pseudo pipe, with heat being convected to and from the pipe by both boundary walls. Radiation and conduction were also modeled across the gap between the JABROC and the CHM wall. Conduction, convection, and radiation were included in the model for the air gaps within the CHM. Conduction but no convection or radiation was assumed to take place in the helium gas contained within the canister, leading to a conservative analysis. Heat loss from the ends of the canister was also not considered, leading to a conservative result.

In the CHM an off-normal condition may occur as a consequence of the failure of the Storage Area building ventilation system, following which the Storage Area building air temperature increases to a maximum value of 154°F.

The ANSYS model of the CHM is constructed in 2 dimensions from 4-node axisymmetric thermal solid elements. The ISF canister is modeled as a 2-dimensional mesh.

The air gaps between the various components within the CHM are modeled as mesh elements; if the air gap varied with height it was split into a lower and upper region. The natural convection heat transfer that occurs across these air gaps was modeled using surface effect elements. The thermal radiation that occurs across these air gaps was modeled using a radiation matrix utility.

A thermosyphon air cooling flow travels vertically upwards in the gap between the outer CHM wall and the JABROC. This airflow is modeled using fluid pipe elements with the pipe inlet temperature set at 100°F or 154°F, the normal and off normal storage area temperatures. The heat transfer coefficient applied to both sides of the annulus is temperature dependent and based on fully developed laminar flow.

The convection that occurs from the outside of the JABROC to the ambient air in the Storage Area building was modeled using surface effect elements. The thermal radiation that occurs from the outside of the JABROC was also modeled using surface effect elements.

Vault Storage Tube

For the vault storage tube model heat is transferred from the outside of the storage tube to the vault air by natural convection. The calculation of the air-cooling flow rate through the vault and over individual storage tubes is not a part of the ANSYS model. Conduction but no convection or radiation is assumed to take place in the helium gas contained within the storage tube and ISF canister, providing a conservative analysis. For the thermal calculation in the vault storage tube, conditions for normal, off-normal with 25 percent duct blockage and accident with 50 percent duct blockage are addressed.

The ANSYS canister model is incorporated into a 2-dimensional axisymmetric model that features the vault storage tube and its base support plate. The storage tube is truncated to the same height as the top of the ISF canister. The ANSYS model of the storage tube is constructed in 2 dimensions from 4-node thermal solid elements.

Heat is transferred through the ISF canister wall and the storage tube wall by the metal thermal conductivity, which is input as a function of temperature. The volume between the outside of the ISF canister and the inside of the vault storage tube is modeled as helium gas with the heat transported by the gas thermal conductivity which is input as a function of temperature.

Heat is transferred radially from the outside of the vault storage tube to the vault air by natural convection. The heat transfer coefficient is based on a laminar, uniform, heat flux correlation. The vault cooling air is modeled as pseudo pipe flow using the mass flow rates presented in Table 4.2-54.

The model boundary temperature is the vault cooling air inlet temperature. These ambient air temperatures are selected to represent the maximum values within the specified ranges.

Summary of Results

The heat transfer and thermal stress analysis of the SNF handling components, storage tube, ISF canister, ISF basket, and fuel have been evaluated in the FPA, canister trolley cask, CHM, and the storage vault.

Heat Transfer and Thermal Stress Results – Peach Bottom Fuel

The Peach Bottom 1 fuel geometry is the same as the Peach Bottom 2 fuel geometry for heat transfer purposes, except that the bottom of the Peach Bottom 2 fuel is located 18 inches higher in the ISF canister. The heat output for the Peach Bottom 1 fuel is significantly less than that for the Peach Bottom 2 fuel. The temperatures calculated for the Peach Bottom 2 fuel bound the Peach Bottom 1 fuel.

The heat transfer model for the Peach Bottom 1 ART fuel assembly is the same as the intact Peach Bottom 1 fuel assembly for heat transfer purposes. The difference in the baskets is the storage capacity: the Peach Bottom 1 and 2 ISF basket contains 10 fuel elements, but the Peach Bottom 1 ART ISF basket contains only 7 fuel elements. The 7-position baskets will have lower temperatures and lower temperature gradients than the 10-position baskets. The temperatures calculated for the Peach Bottom 2 fuel bound the Peach Bottom 1 ART fuel.

The maximum calculated temperatures of the Peach Bottom 2 fuel during handling and storage are summarized in the following tables. These results are bounding for the three Peach Bottom fuel types:

- Table 4.2-55, Fuel and Component Temperatures in FPA, Canister Trolley Cask and CHM
- Table 4.2-56, Peach Bottom Fuel – Storage Vault

The results of the thermal analysis within the Peach Bottom 1 and 2 basket show there are sufficient clearances in and around the basket to accommodate the thermal expansions associated with the overall temperature increases and the modest temperature differences between components. Representative results for the thermal accident case are as follows:

- fuel support tubes to top plate clearance, 0.35 inch when cold reduces to 0.18 inch when hot
- fuel support tube diameter to spacer plate through hole clearance, 0.010 inch when cold reduces to 0.005 inch when hot
- basket to canister length clearance, 0.25 inch when cold increases to approximately 0.29 inch when hot

The maximum thermal stresses calculated for the Peach Bottom 1 and 2 baskets and Peach Bottom 1 ART baskets spacer plates and fuel support tubes are summarized in Table 4.2-57. The maximum stresses in the spacer plates are localized around the outside of the plate. Away from these points the thermal stresses are typically below 200 psi. The thermal stresses within the basket components are self-limiting and are classed as secondary stresses.

Heat Transfer and Thermal Stress Results – TRIGA

The maximum calculated temperatures of the TRIGA fuel during handling and storage are summarized in the following tables:

- Table 4.2-55, Fuel and Component Temperatures in FPA, Canister Trolley Cask and CHM
- Table 4.2-58, TRIGA Fuel – Storage Vault

The results of the thermal analysis within the TRIGA basket show there are sufficient clearances in and around the basket to accommodate the thermal expansions associated with the overall temperature increases and the modest temperature differences between components. Representative results for the thermal accident case are as follows:

- fuel support tubes to top plate clearance, 0.150 inch when cold reduces to 0.135 inch when hot
- fuel support tube diameter to spacer plate through hole clearance, 0.012 inch when cold reduces to 0.010 inch when hot
- basket to canister length clearance, 0.250 inch when cold increases to approximately 0.26 inch when hot

The maximum thermal stresses calculated for the TRIGA basket spacer plates and fuel support tubes are summarized in Table 4.2-59. The maximum stresses in the spacer plates are localized around the outside of the plate. Away from these points the thermal stresses are typically below 300 psi. The thermal stresses within the basket components are self-limiting and are classed as secondary stresses.

Heat Transfer and Thermal Stress Results – Shippingport reflector rods

The maximum calculated temperatures of the Shippingport reflector rods during handling and storage are summarized in the following tables:

- Table 4.2-55, Fuel and Component Temperatures in FPA, Canister Trolley Cask and CHM
- Table 4.2-60, Shippingport Reflector Rods – Storage Vault

The results of the thermal analysis within the Shippingport reflector rod basket show there are sufficient clearances in and around the basket to accommodate the thermal expansions associated with the overall temperature increases and the modest temperature differences between components. Representative results for the thermal accident case are as follows:

- fuel support tubes to top plate clearance, 0.30 inch when cold reduces to 0.047 inch when hot
- fuel support tube diameter to spacer plate through hole clearance, 0.014 inch when cold reduces to 0.006 inch when hot

- basket to canister length clearance will increase as the assembly becomes hotter

The maximum thermal stresses calculated for the Shippingport reflector rod basket spacer plates and fuel support tubes are summarized in Table 4.2-61. The maximum stresses in the spacer plates are localized around the outside of the plate. The thermal stresses within the basket components are self-limiting and are classed as secondary stresses.

Heat Transfer and Thermal Stress Results – Shippingport Reflector Modules

The maximum calculated temperatures of the Shippingport reflector module during handling and storage are summarized in the following tables:

- Table 4.2-55, Fuel and Component Temperatures in FPA, Canister Trolley Cask and CHM
- Table 4.2-62, Shippingport Reflector Modules – Storage Vault

Thermal stresses within the reflector module baskets have not been analyzed, as the baskets do not provide any structural function.

Maximum Fuel and Component Temperatures

Table 4.2-63 provides a summary of the highest fuel and component temperatures from the heat transfer analysis during storage and fuel handling operations and compares these temperatures to the allowable temperature limits provided in Table 4.2-53. During storage conditions the charge face concrete is conservatively assumed to reach the temperature of the storage tube.

All fuel and component temperatures are within the normal and short term temperature limits.

Heat Transfer Results - Bounding Canister Temperatures

Table 4.2-64 summarizes the steady-state temperatures within the canister, calculated for the representative and bounding heat sources of 40 watts and 120 watts. The analysis of the canisters in the storage vault is based on an air inlet temperature of 101°F (the maximum off-normal inlet temperature). These temperatures are used for the ASME structural evaluation of the ISF canister.

The maximum calculated temperature of 185 °F is significantly below the ISF canister design temperature of 650 °F.

4.2.3.3.7 Criticality Evaluation

The design criteria for nuclear criticality are provided in Section 3.3.4, *Nuclear Criticality Safety*. The basic requirements are 1) k_{eff} shall not exceed 0.95 for any in-process or fuel storage array under normal, off-normal, or accident conditions, and 2) spent fuel handling, packaging, transfer and storage systems must be designed to ensure that, before a nuclear criticality accident is possible, at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety.

The scope of this section is a description of 1) the criticality models, and 2) the criticality evaluations and results for storage and transfer operations within the Storage Area. Additional information on criticality evaluations and operational controls for the ISF Facility are provided in:

- Appendix 4A to the SAR, *Criticality Models*
- Appendix A to the SAR, *Safety Evaluation of DOE-provided Transfer* Cask
- SAR Section 4.7.3.4, *Criticality Evaluation for Spent Fuel Handling Operations*
- SAR Section 5.1.3.1, *Criticality Prevention*
- SAR Chapter 8, *Accident Analysis*

The criticality evaluations for the ISF Facility fall into one of three categories:

Evaluation of normal fuel handling sequences. Fuel configurations that are known to occur during routine storage operations are analyzed to ensure that the planned geometry, separation, and material inventories will be safe during normal facility conditions.

Evaluation of off-normal and accident scenarios. Postulated off-normal and accident scenarios are evaluated to ensure that two unlikely, independent, and concurrent or sequential changes in geometry, separation, or material inventory are required before k_{eff} exceeds 0.95.

Evaluation of bounding cases. Due to the nature of fuel handling and storage operations, it is difficult to postulate all potential combinations of geometry, separation, and material inventory. To ensure that the conditions that could lead to a criticality for ISF Facility operations are well understood, "bounding" cases have been developed to identify the combinations of geometry, material inventory, and reflection/moderation that are required to achieve k_{eff} = 0.95 at the ISF Facility. In some instances, these bounding cases are used to evaluate the consequences of accident or off-normal conditions.

Criticality models developed to examine each of the three fuel types under the above conditions are provided in Appendix 4A to the SAR. The MCNP4 computer code (Ref. 4-18) described in Section 3.3.4.3.2 was used for each of the analyses.

By a combination of their basic pellet design and their reactor operations exposure, the Shippingport reflector modules are not enriched, and the lack of appreciable amounts of fissile material means that criticality safety is ensured without further limitations on geometry. The handling, transfer, and storage of Shippingport modules and loose rods do not present any limitations with regard to criticality safety. The increase in reactivity of Shippingport reflector modules due to neutronic coupling with the other two types of fuels is bounded by other cases involving just the other two types of fuels. Therefore, no further criticality evaluations involving Shippingport fuel are provided.

Normal Storage Area Operations

When fuel arrives at the Storage Area port, the fuel has been repackaged into the appropriate ISF basket and canister configurations. The canister closure operations have taken place and the canister is ready to be placed into the storage tube. Sections 4.2.3.2.4, 4.2.3.2.3, and 4.2.3.2.2 describe the physical design of these baskets, canisters, and storage tubes, respectively.

The normal operational case in the Storage Area is to have the ISF canisters stored in the storage tubes. Several configurations of infinite arrays of TRIGA and Peach Bottom canisters were evaluated. The results of these analyses are summarized in Table 4.2-65. Each of these configurations has a k_{eff} less than the 0.95 design criteria limit.

A handling operation that can occur in the normal condition is an ISF canister in the CHM passing over an ISF canister in the storage tube. The results of the criticality evaluations for a TRIGA canister over a TRIGA, and a Peach Bottom canister over a Peach Bottom canister, are shown in Table 4.2-65. The various combinations of Shippingport, Peach Bottom, and TRIGA were not modeled since they are bounded by the more reactive TRIGA-over-TRIGA configurations.

Storage Area Criticality Control During Off-Normal and Accident Events

Shippingport and Peach Bottom fuels do not require the ISF baskets to maintain geometric control of the fuel during off-normal or accident conditions. The TRIGA fuel does require the ISF basket to maintain geometric control of the fuel during off-normal or accident conditions. Section 4.2.3.3.2 discusses the structural analyses of the ISF canister internals and summarizes the results.

The CHM is designed as a single-failure-proof crane and the associated lifting devices are designed to ANSI N14.6. Therefore, accident scenarios involving a loss of geometry control or fuel separation due to dropping an ISF Canister are not credible, as two unlikely, independent and concurrent or sequential events are required to drop the canister.

Storage Area Bounding Analyses

To envelope unforeseen off-normal or accident conditions within the storage area, a parametric study was performed that investigated the effects of fully flooding and fully moderating the array of fuel canisters in the Storage Vault. Although this scenario is not considered a credible event, it served to demonstrate the limits of criticality safety for the storage configuration. The results of this analysis are presented in Table 4.2-65. For an infinite array of Peach Bottom fuels, $k_{eff} = 0.50$ under this scenario. For a TRIGA fuel infinite array, $k_{eff} = 0.84$. A mixed fuel infinite array, fully flooded and moderated, yielded $k_{eff} = 0.84$. All of these results meet the design criteria of $k_{eff} < 0.95$.

4.2.3.3.8 Chemical and Galvanic Evaluation

Loss of Corrosion Resistance

ISF Canister Interior Conditions

The internal atmosphere of the ISF canister during storage is specifically designed to prevent degradation of the fuel and the ISF canister internal structure. Vacuum drying and inert gas filling processes are performed to ensure that the canister internal atmosphere contains less than 2500 ppm oxidizing gases and less than 1300 ppm water content. This meets the requirements of NUREG 1536, Section 8, Subsection 5. The ISF canisters are vacuumed down to a pressure of 1 Torr. The canister is held in vacuum for at least 2 hours. The fuel is deemed dry if the pressure rises at a rate of less than 10 Torr per hour. The canister is then filled with helium and the lid weld is leak tested. Upon passing the leak test, the canister is evacuated then backfilled for the second time to provide an inert atmosphere for the fuel. The canister vent plug is inserted and the seal welded and leak tested. The ISF canisters are filled with helium with a specification of 99.995 percent purity, having less than 5 ppm oxygen and less than 5 ppm water.

The dry and inert internal atmosphere in the ISF canister ensures that there is not enough moisture and oxygen to allow corrosion or galvanic reactions to take place between:

- the stainless steel components of the ISF canister and ISF basket
- the stainless steel components of the ISF canister and aluminum components of the Shippingport reflector guides
- the stainless steel components of the ISF basket and the graphite of the Peach Bottom fuel element
- the stainless steel components of the ISF basket and the stainless steel cladding of the TRIGA fuel element
- the stainless steel components of the ISF basket and the aluminum cladding of the TRIGA fuel element
- the aluminum components of the Shippingport guides and the zirconium alloy-4 shell of the Shippingport reflector modules
- the aluminum components of the Shippingport guides and the stainless steel clamps of the Shippingport reflector modules
- the stainless steel components of the ISF basket and the zirconium alloy-4 clad of the Shippingport reflector module pins

The oxide layer produced in anodizing the Shippingport aluminum guides and the natural chromate layer produced by the stainless steel will significantly reduce the electrolytic contact between the two materials. Any minor corrosion of the aluminum guides produced from the contact of these two materials, inside the dry inert environment of the ISF canister, will not be detrimental to the integrity of the ISF canister, fuel, or guides.

ISF Canister Exterior Conditions

Just as the internal atmosphere in the ISF canister is designed to prevent degradation of the canister contents, the ISF canister is placed in a storage tube whose internal atmosphere is designed to prevent degradation of the ISF canister exterior. The ISF canister shell is fabricated from 316L stainless steel; corrosion will be extremely slow under normal atmospheric conditions, and negligible under dry and inert conditions. The storage tubes are fabricated from carbon steel grade SA-333 and SA-350. The inside surfaces of the storage tubes are protected by a graphite-based etch primer paint, which primarily provides protection for the carbon steel surface before establishing the internal inert atmosphere.

After loading the ISF canister into a storage tube, the tube is sealed and tested. The internal atmosphere of the storage tube is changed from an air environment to an inert environment by twice applying a vacuum down to 1 Torr and backfilling the storage tube with helium gas to a positive pressure with respect to atmosphere. The storage tubes are filled with helium with a specification of 99.995 percent purity, having less than 5 ppm oxygen and less than 5 ppm water.

The ISF canister stands on its lower impact absorber, and rests on the carbon steel surface of the storage tube base, and it may also lean over so that the tip of the upper impact absorber rests against the wall of the storage tube. The dry and inert atmosphere inside the storage tube ensures that there is not enough moisture and oxygen to allow corrosion or galvanic reactions to take place between the carbon steel components of the storage tube and the stainless steel components of the ISF canister.

Material Selection

The selected materials and coatings ensure that the storage tube, ISF canister, ISF baskets, and stored fuel elements will not cause chemical or galvanic reactions that could adversely affect the safety of dry storage, as required by NRC ISG-15 (Ref. 4-19).

Galvanic reactions between components of the ISF canister and its basket are precluded by the stainless steel composition of ISF canister; the stainless steel or aluminum basket components ; and the dry inert canister atmosphere. Galvanic reactions occur when dissimilar metals are in close contact in an electrically conductive environment. This usually requires the presence of both oxygen and an electrolyte, such as water, between the two metals to facilitate the reaction. The galvanic reaction causes one metal to corrode the other because of the difference in electrochemical potential of the two metals. Aluminum and ferritic steel are the most notable common instance of galvanic-induced corrosion. Austenitic stainless steels have a much lower galvanic effect upon aluminum alloys because of the presence of nickel and chrome. Different alloys of stainless steel have little galvanic effect among themselves due to their similar compositions. Galvanic effects between zircaloy-clad SNF and the stainless steel basket tubes are minimal, and galvanic effects between aluminum-clad SNF and the stainless steel basket tubes are small due to the choice of stainless steel for the canister basket. In addition, the lack of water and oxygen in the ISF canister during storage conditions minimize galvanic effects.

Galvanic reactions between components of the ISF canister and components of the storage system are precluded by coatings and lack of water and/or oxygen wherever ferritic steels are employed, especially in the storage tube. Coatings are low halide and will not cause galvanic reactions or induce stress corrosion cracking. Contact between uncoated components of the storage system and the ISF canister during loading operations are of short duration and galvanic effects will not occur.

Chemical Reactions

Gadolinium phosphate was selected as a neutron absorber for repository disposal purposes due to its low solubility and long life in a repository environment. This material is inert and does not react with the stainless steel 316L tube that contains it.

Liquids used for dye penetrant examinations conform to the low-halide requirements of coatings and markers. No cutting fluids or organic lubricants are required for loading SNF into the ISF canister, and no chemical reactions with organic materials in the canisters are possible. Carbon/alcohol lubricants used in the assembly of the ISF basket will not contribute to chemical reactions with the stainless steel components of the ISF basket or canister.

Decontamination fluids conform to the low-halide requirements of coatings and markers. Acids and corrosive materials are not allowed to contact the SNF canister or basket during normal operations.

Oxidation reactions, initiated by contamination of stainless steel surfaces by uncoated ferritic steel components, are limited by the nature of handling operations. Storage system components that could cause abrasion of the ISF canister stainless steel surfaces are coated as described in the following section. Storage system components that contact portions of the ISF canister for lifting operations (e.g., the CHM ferritic steel lifting hardware collets and the ISF canister stainless steel lift pintle) may experience minor and localized contamination.

Contamination of the Outside of the ISF Canister

The ISF Facility design basis and operational procedures will ensure that the total halide content of coatings that will contact the ISF canister will not exceed 200 ppm. The total combined content of iron and low melting point elements such as sulfur, lead, copper, zinc, cadmium and mercury will not exceed 300 ppm. The total halide, iron, and low melting point element content of the electrolyte for electrochemical etching (if used) will also conform to the above limits. Control of the constituents of the coatings applied to surfaces such as the vault storage tube will ensure that the ISF canister will not be adversely affected by contact with the external coating materials. Markers used on components of the ISF canister must also satisfy the above limits.

Housekeeping procedures for ISF canister loading and storage will ensure that coatings prevent substantial contact between the ISF canister and ferritic steel components. Substantial contact is defined as rubbing, scraping, or abrasion of the stainless steel surfaces of the ISF canister by ferritic steel components. Such contact could embed ferritic steel material in the surface layer of a stainless steel component and provide an initiation site for pitting corrosion. Incidental contact with ferritic materials such as bumping, touching, or gripping (without visible denting of the gripped surface) will not embed significant ferritic material in the surface of the stainless steel ISF canister.

This approach implements a material "start clean, stay clean" policy similar to the approach used for the exterior of some large commercial storage cylinders. The ISF canisters are manufactured with process controls that exclude ferritic steel materials (such as steel wool) and halogens (in detergents and markers). The ISF canister exterior must then be maintained free of contaminants that could be introduced through contact with components of the storage system through handling, or by long-term contact in a storage vault tube.

The ISF canister design requires that coatings be low-halogen and also contain only small quantities of several other elements. This specification ensures that coatings used to protect ferritic steels (such as PA-21, a black etching primer used in nuclear applications as a protective coating) like the inside of the storage tube will not adversely affect the ISF canister if traces of the coating transfer to the outside of the ISF canister.

Furthermore, abrasion of the ISF canister surface by ferritic steel components will be avoided where necessary by using stainless or stainless-steel-clad components. Components that do not contact the ISF canister in an abrasive fashion, such as a cradle for movement of an unloaded canister in the facility may be coated with PA-21 or similar.

The means of preventing ISF canister exterior surface contamination are summarized below based upon the contact environment. Stainless steel components may be used in place of clad or coated ferritic steels for less demanding environments.

ISF Canister Exterior Surface Handling Environments

Contact Environment	Protection Requirements
General handling	Wrap canister in protective film; cover lifting chains with protective sleeves.
Gripping high risk/high wear	From either stainless steel or hard plate (chrome or nickel), make cask collet jaws to provide protective layer.
High risk/high wear areas	Make from stainless steel, cover surface with stainless steel, stainless steel rubbing strips or hard plate surfaces. CCA new canister port, CHM 18-inch diameter bore, load/unload port.
Low risk or low wear areas	Paint

Flammable Gas Generation

The ISF canister and baskets are designed to prevent the production of flammable gases by chemical or galvanic reactions by appropriate selection of materials, coatings and storage environment. The ISF canister, basket, and fuels are loaded dry in the FPA and are not subject to water immersion and resulting chemical reactions.

The fuel chemistry analysis of the TRIGA, Peach Bottom and Shippingport Type IV and Type V fuels evaluated the formation of flammable mixtures as a result of radiolysis. The results of the analysis are:

- While chemical reactions are identified that result in production of flammable gases (H_2, CO, and CH_4), rates of reaction are sufficiently slow to eliminate concerns for thermal stability or rapid generation of flammable gas mixtures during drying and handling for all three fuel types.

- Of the three fuel types, only Peach Bottom core 1 fuel has a combination of known fuel failure, potential container failure, and material type (graphite and dicarbide fuel) that some flammable gas (CH_4) may have accumulated while in storage at INEEL, but the amount present in a container cannot be flammable because it is physically limited by the concentration of water vapor that leads to its formation,

Neither radiolysis nor chemical reactions are expected to produce a flammable atmosphere in any of the canisters during the 40-year interim storage period. Good fuel condition and low moisture content serve to inhibit the formation of hydrogen, while low oxygen concentration precludes formation of a flammable environment.

- The decay power of Shippingport reflector modules is not sufficient to generate appreciable amounts of hydrogen. Over the 40-year interim storage period, hydrogen gas concentrations may build up to only 2.5% in the Shippingport canisters.

- Peach Bottom fuel lacks sufficient moisture to dissociate into a flammable mixture. Hydrogen gas concentration in Peach Bottom fuel canisters is estimated to be less than 1% after 40 years of interim storage.

- Free pore and chemisorbed water in TRIGA fuel can potentially be present in quantities sufficient to generate significant amounts of hydrogen. The chemisorbed water is present in corrosion oxides on the fuel cladding (i.e., $Al_2O_3 \cdot 3H_2O$). Free pore water will only be present in significant quantities if the TRIGA fuel cladding is breached. TRIGA fuels to be handled at the ISF facility are in good condition; therefore, breached or significantly corroded cladding is not anticipated.

Based on fuel conditions described in Contract No. DE-AC07-00ID13729 and the vacuum drying process used to prepare the canisters for storage, flammable hydrogen concentrations (greater than 4%) are not anticipated in the ISF canisters.

As summarized above, the physical and chemical nature of the ISF project fuels are such that they may generate low levels of flammable gases such as hydrogen and methane due to interactions with moisture and other effects. The quantity of gas produced will not lead to flammable mixtures developing in the ISF canister, either before or after the canister has been welded and inerted.

After the ISF canister has been welded closed, inerted and sealed, the internal atmosphere will be dry helium. Under these conditions the spent fuel assemblies are resident in a dry non-oxidizing atmosphere. The absence of moisture and of oxygen ensures that the fuel clad and/or fuel material (if it were to be exposed) will not react with either the internal canister atmosphere or the basket materials against which they rest. Therefore there are no chemistry conditions local to the stored SNF that will produce detectable levels of flammable gases.

However, even though flammable gas mixtures are not expected to be produced during the fuel loading and canister closing operations, design features are provided and operating precautions will be taken to ensure that there are no consequences if flammable gases are present. The canister loading operations prevent flammable gas incidents by removal and prevention of gas accumulation, and monitoring for presence of flammable gases.

Design Features to Preclude Formation and Build-up of Flammable Gases

The ISF canister and baskets are fabricated mainly from stainless steel (with some aluminum). No organic coatings, lubricants or jointing compounds are used in their construction. The ISF canisters are designed for dry loading in an air environment. Because the basket cannot get wet, and because of the mainly stainless steel structure, no chemical reactions that affect the ISF canister and basket materials during ISF canister loading occur that can generate flammable gases.

The canister loading and closing operations are carried out in areas where there is always forced ventilation that will positively change the air environment around the ISF canister. The ventilation system will ensure that no pockets of flammable gases can collect in the working areas.

The fabrication clearances of the shield plug in the ISF canister allow gases produced in the canister to vent away. The internal configuration of the basket structure is designed to ensure that moisture can be evacuated during vacuum drying; as a result there are vent paths in the basket to ensure that flammable gases cannot build up or be trapped in the basket structure.

Canister closure operations cause the greatest risk of igniting flammable gas, as canister welding produces an ignition source. Before starting the ISF canister welding process the atmosphere near the canister shield plug will be sampled with a hand-held atmosphere monitor to ensure that flammable gases are not present at a level that could lead to a deflagration.

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4.3 AUXILIARY SYSTEMS

4.3.1 Ventilation and Off-Gas Systems

The ventilation and off-gas system at the ISF Facility is the HVAC system, which consists of the following subsystems:

- Cask Receipt Area – refer to Figure 4.3-1
- Storage Area – refer to Figure 4.3-2
- Transfer Area – refer to Figure 4.3-3 and Figure 4.3-4
- Operations Area
- Miscellaneous Areas

HVAC systems are designed to meet the operational life expectancy of the ISF Facility. Components with a potentially shorter life are designed and installed to permit replacement with minimal affect on operations and maintain personnel exposure ALARA. Provisions are made for the routine maintenance of HVAC components in order to maximize their operational life. The confinement barrier established for the FPA and FHM Maintenance Area is shown in Figure 4.3-5. This confinement barrier, which is established during SNF handling operations, relies on HEPA filters to prevent the release of radioactivity to the environment during normal, off-normal, and accident conditions. This confinement barrier is further discussed in Section 4.3.1.1.1.

4.3.1.1 Major Components and Operating Characteristics

The HVAC system supply and exhaust fans are not required for removal of decay heat from the storage vault and not required to ensure the integrity of the SNF at any time during fuel handling operations. Decay heat is removed from the stored SNF by passive natural convection through the storage vaults. The inlet vents in the concrete storage vault walls and exhaust louvers in the Storage Area building are classified ITS. In addition, portions of the ventilation ductwork and HEPA filters that form part of the confinement barrier for the FPA and FHM Maintenance Area are classified ITS. The balance of the HVAC system is classified NITS. ITS classifications for the ISF Facility are described in Section 3.4.

The HVAC system is designed to minimize the spread of contamination by filtration, maintain differential pressures between contamination control zones, and ensure that air flows from areas of low potential contamination toward areas of higher potential contamination. HVAC components are designed to provide environmental control that enable SSCs to operate within normal designed temperature parameters and interior temperature control for personnel comfort. The HVAC supply room, HEPA filter room, and HVAC exhaust room on Figure 4.2-1. The filters, supply and exhaust fans are located in these rooms. The HVAC system is designed to:

- prevent the accidental release of radiological hazards to the environment
- keep personnel exposure to radiological hazards ALARA
- maintain environmental conditions for habitability and reliable equipment operation
- provide integrated systems that support safe operation of the facility

The HVAC system is designed based on the following criteria:

- Doors, walls, ceilings, and roofs in pressure controlled areas are sealed and well insulated to prevent pressure loss and condensation.
- Accurate temperature control is less important than accurate pressure control; therefore, room temperatures may fluctuate when a pressure upset occurs.
- There are no special humidity requirements, so there are no provisions for humidity control.

The codes and standards listed below provide the principal design and construction requirements for the HVAC system:

- ASHRAE DG-1, Heating, Ventilating, and Air-Conditioning Design Guide for Department of Energy Nuclear Facilities (Ref. 4-21)
- ASHRAE Handbook: Fundamentals (Ref. 4-22)
- ASME N509, Nuclear Power Plant Air-Cleaning Units and Components (Ref. 4-23)
- ASME N510, Testing of Nuclear Air Treatment Systems (Ref. 4-24)
- ERDA 76-21, Nuclear Air Cleaning Handbook (Ref. 4-25)
- ACGIH, American Conference of Governmental Industrial Hygienists: Industrial Ventilation – A Manual of Recommended Practice (Ref. 4-26)
- SMACNA, HVAC Duct Construction Specifications (Ref. 4-27)

4.3.1.1.1 Major Components

The HVAC system uses either electric resistance or electric radiant heating, chilled water or direct-expansion cooling, and direct ventilation with outside air to maintain the required inside design temperatures. An air-cooled chiller and water-to-water heat exchanger (outside the Operations Area southwest corner) provide chilled water to the HVAC air handling unit heat exchangers. The primary side of the heat exchanger contains a mixture of propylene glycol and water. The secondary side of the heat exchanger contains water. Use of the glycol mixture eliminates the need to drain the chiller and primary piping each winter. Chemicals are added to inhibit corrosion. The primary pump provides constant flow to meet chiller requirements. The secondary pump is equipped with a variable frequency drive and two-way coil valves to conserve energy and provide improved part-load performance.

The final Transfer Area exhaust HEPA filters, as shown in Figure 4.3-4, consist of two banks of multiple, modular air-cleaning units. Each filter bank contains four modular two-stage air-cleaning units, with a total capacity of 23,800 cfm. The design permits one air-cleaning unit to be isolated for filter replacement, and a clean unit to be brought on line without diminishing either the capacity or function of the entire system. HEPA filters are type B, nuclear grade and meet the requirements of ANSI N509 and ANSI N510. Filters are housed in metal enclosures with a series of pressure differential and flow instruments to monitor differential pressure and flow across the individual filter banks.

Intermediate HEPA filters on exhaust ducts serving primary and secondary airborne contamination control zones are provided with a spare HEPA filter to allow filter changes without shutting the system down. HEPA filters are installed inside the FPA on the inlet to the exhaust ductwork to remove radioactive particulate from the air leaving this area. These filters reduce the number of filter change-outs and the associated dose rate for the final filters in the HEPA filter room. These filters also serve as a passive confinement barrier during off-normal and accident conditions.

Transfer Area Exhaust Filtration System

FPA Filter Units. HEPA filters are installed on the exhaust ducts leaving the FPA. These filters are located inside the FPA and are designed to facilitate replacement using the manipulators. These filters will act as pre-filters to protect the downstream ductwork from contamination. Isolation dampers are provided to isolate these filters during filter changes. Filter changes will be performed remotely using a manipulator controlled from the operating gallery. The HEPA filters inside the FPA will not require filter efficiency testing since they are only being used as roughing filters. The FPA exhaust duct will be provided with an isokinetic sampler, external to the FPA, to assist in determining the condition and efficiency of FPA exhaust filters.

Intermediate Filter Units. Additional HEPA filters are provided in other areas to protect supply and exhaust ductwork from contamination and to restrict backflow through the supply ducts should the room ever be pressurized. Filter efficiency test ports are provided on the intermediate filter units.

Final Filter Units. A set of HEPA filters is located immediately upstream of the point where the exhaust air discharges to the stack. These filters are considered the final filtration point for removing radioactive particles from the exhaust air. Each filter unit consists of one stage of pre-filters followed in series by two stages of HEPA filters. HEPA filters will be type B, nuclear grade and shall meet the requirements of ASME N509 and ASME N510. Filters are housed in metal enclosures. Bag-in/bag-out techniques will be utilized as the means for filter replacement. Isolation dampers are located between parallel banks of HEPA filters to facilitate filter changes. Instrumentation is provided on the filter housing for monitoring temperatures, flow rates, and differential pressures (dust loading). Injection and sample ports are provided for performing in-place filter efficiency tests.

Filter Change-Outs. The exhaust fans are designed for HEPA changes when the particulate loading on the filters reach levels that generate a differential pressure of 4-inches-water. When the differential pressure across the filter reaches this level the filters will be changed. Exhaust HEPA filters in the FPA will be changed when the dose associated with the filter reaches 250 mrem/hr or 4-inches-water, whichever occurs first. The 250 mrem/hr limit on the filter will ensure that the 500 mrem/hr limit on the solid waste boxes is not exceeded. Dose rate measurements associated with the internal FPA filters are described in Section 7.3.4. Refer to Section 6.4.4 for a detailed discussion regarding the waste characteristics and volumes associated with the filters.

Ductwork

Supply ductwork serving airborne contamination control Zones 1 and 2 will be fabricated and installed in accordance with SMACNA high-pressure duct construction standards due to the pressures involved. Ductwork will be galvanized steel with duct liner for thermal insulation. Exhaust ductwork serving Zones 1 and 2 will be fabricated and installed in accordance ERDA 76-21, ASME N509, and SMACNA high-pressure duct construction standard. Exhaust ducts are sized to maintain sufficient transport velocities to prevent particulate contaminants from settling out of the air stream.

Ductwork design is based on high (Class 2) contamination levels in the ductwork between the fuel packaging area and the final HEPA filters, moderate (Class 3) contamination levels in other areas, and an operating mode in which the exhaust system is shutdown in case of an accident. Ductwork from the FPA to the final HEPA filters will be welded construction (Level 4) due to potential contamination. Ductwork from the final HEPA filters out through the stack will be welded construction due to the pressures involved. Ductwork in other areas will be non-welded construction (Level 2) unless welded construction is required due to pressures and routing. This ductwork will be fabricated and installed per SMACNA high-pressure duct construction standard.

Exhaust Stack

The exhaust stack is nominally 38 inches in diameter and approximately 80 feet high. The stack diameter was selected based on fan pressure and discharge velocity requirements. The exhaust height was calculated in accordance with the ASHRAE Handbook, *Fundamentals to Ensure that Exhaust Re-Entrainment in the HVAC System Intake Air Does Not Occur*. Plume dispersion modeling was performed based on these parameters to ensure that radiation levels at the ISF Facility controlled area boundary do not jeopardize public health and safety. The exhaust stack features an isokinetic sampler and sample ports. Sample ports are located 90 degrees apart, a minimum of eight stack diameters above the inlet to the stack and a minimum of two stack diameters below the outlet. The exhaust stack is classified NITS. However, it is designed to withstand the effects of a seismic event to ensure that it does not fail and adversely affect ITS SSCs in the vicinity.

Airborne Contamination Control Zones

Airborne contamination control zones throughout the ISF Facility ensure that radioactive contamination is minimized and controlled. The ISF Facility is divided into four airborne contamination control zones, as shown in Figure 4.3-6 and Figure 4.3-7, based on varying degrees of potential contamination. These zones consist of an inner (primary) airborne contamination control zone where highly radioactive materials are processed; surrounded by an intermediate (secondary) airborne contamination control zone where some potential for radioactive release may exist; surrounded by an outer (tertiary) airborne contamination control zone where there is little potential for radioactive release; surrounded by the radiologically clean ancillary areas. Decreasing pressures between airborne contamination control zones maintain the airflow inward towards the primary airborne contamination control zone.

Zone 1 (Confinement Barrier) includes the FPA and FHM Maintenance Area. Air pressures in this zone are maintained at the maximum negative values with respect to atmosphere so that air flows toward this confinement barrier.

Zone 2 includes the operating gallery, workshop, CCA, SWPA, Solid Waste Storage Area, Liquid Waste Storage Tank Area, HEPA filter room, Transfer Tunnel, and cask decontamination zone. Air pressures in this zone are positive with respect to Zone 1 and negative with respect to Zone 3 and ambient pressure. This ensures that air flows from this zone towards the primary confinement barrier.

Zone 3 includes the Storage Area, Cask Receipt Area, and the following rooms in the Transfer Area: Operators Office/Equipment Room, change room, corridor outside Operators Office, New Canister Receipt Area, electrical room, and HVAC exhaust room. Contamination is not expected in these areas.

These areas operate at atmospheric pressure (with the exception of the Operators Office, change room, and corridor, which operate at a pressure slightly higher than atmospheric pressure).

Zone 4 Radioactivity will not be present in ancillary areas such as the Operations Area. The offices in the Operations Area are maintained at a pressure slightly higher than atmospheric pressure due to their proximity to the Transfer Area. Other ancillary areas are maintained at atmospheric pressure.

Cask Receipt Area

The Cask Receipt Area is located in Zone 3. The HVAC system flow diagram for the Cask Receipt Area is shown in Figure 4.3-1. The Cask Receipt Area is a radiologically clean area that operates at atmospheric pressure and is normally occupied during cask receipt and cask shipping operations. This area is heated and ventilated to ensure that the temperature is maintained above 32°F (minimum operating temperature for the cask receipt crane) and to provide moderate comfort for operations personnel. Unit heaters, wall-mounted exhaust fans, and wall-mounted intake dampers maintain design temperatures inside the area. Cask handling operations are suspended if the temperature in the Cask Receipt Area is at or below 32°F.

The ventilation system also removes diesel fumes from the building when a truck is being loaded or unloaded. This is accomplished with a separate, dedicated fume collection system that captures diesel fumes at the exhaust pipe of the truck and directs these fumes to the outside of the Cask Receipt Area.

Storage Area

The Storage Area is located in Zone 3. The HVAC system flow diagram for the Storage Area is shown in Figure 4.3-2. The Storage Area exhaust fans are not required to ensure adequate decay heat removal from the stored SNF. The Storage Area fixed building ventilation includes the sixteen inlet vents in the concrete storage vault walls, the annular gaps between the storage tubes and the charge face encast, and the six fixed louvers in the Storage Area building walls that permit airflow to support natural convection through the storage vaults. Figure 4.3-8, Figure 4.3-9 and Figure 4.2-4 show the fixed inlet and exhaust vents and louvers in the storage vault walls and Storage Area building. Additional information on the cooling features of the storage vaults is in Section 4.2.3.2.

The Storage Area building is a steel-framed metal-panel building that covers the storage vaults. This area is radiologically clean and operates at atmospheric pressure. It is normally occupied during storage vault loading and monitoring operations. The area is heated and ventilated to ensure that the CHM is operated above the minimum operating temperature of 32°F and to provide moderate comfort for operations personnel. Canister handling operations are suspended if the temperature in the Storage Area building is at or below 32°F. Electric radiant heaters, wall-mounted exhaust fans and wall-mounted intake dampers maintain design temperatures in the area.

The storage vaults in the lower level of the Storage Area are radiologically clean, because of the double-confinement barrier features of the storage tubes and canisters. These vaults operate at atmospheric pressure and are not occupied. Due to the high radiation levels inside the storage vaults, there are no personnel access features (i.e., doors or access ports) to these areas. Supplemental heating in this area is not required. The ISF canisters, storage tubes, charge face, and vault structure have been designed for a minimum temperature of -40°F to account for off-normal winter temperatures.

The ventilation fans in the upper level of the Storage Area are for personnel comfort. The fans and heaters inside the Storage Area building are thermostatically controlled to start and stop to maintain temperature within operating limits.

Transfer Area

The Transfer Area is located in several zones. The Transfer Area HVAC system services the following areas (or rooms):

- FPA
- FHM Maintenance Area
- CCA
- operating gallery
- workshop
- HEPA filter room
- Transfer Tunnel
- Liquid Waste Storage Tank Area
- SWPA
- Solid Waste Storage Area
- cask decontamination zone

Transfer Area supply and exhaust air flow diagrams, nominal operating differential pressures, and flow quantities are shown in Figure 4.3-3 and Figure 4.3-4, respectively. The Transfer Area is served by a once-through system consisting of a central make-up air handling unit, final exhaust HEPA filters, and exhaust fans. One-hundred-percent redundant supply and exhaust fans facilitate maintenance and provide backup capability. The Transfer Tunnel including the cask decontamination zone also includes stand-alone recirculation air handling units in each of these two areas to augment heating, cooling, and air filtration. These units reduce the size of the central air-handling unit and the required exhaust air flow rate. The unit in the decontamination zone receives make-up air from the Cask Receipt Area. Both units are provided with individual HEPA filters and continuous air monitors (CAMs).

Outside supply air entering the air handling unit is filtered before being introduced into the Transfer Area. In certain areas, backdraft dampers and barometric dampers prevent flow reversal due to accidental room pressurization. Additionally, HEPA filters are installed in the supply air system to the FPA, FHM Maintenance Area, Solid Waste Storage Area, and SWPA to prevent the spread of contamination should a flow reversal occur in these areas. Fire dampers and tornado dampers are provided at ductwork penetrations into the FPA and FHM Maintenance Area. A fire damper is provided at the ductwork penetration to the CCA.

Exhaust air leaving the FPA passes though HEPA filters installed within the FPA, before merging with the common exhaust duct. The common exhaust air passes through two stages of HEPA filtration before being discharged to the atmosphere. A variable frequency drive on the exhaust fan increases fan speed to maintain a constant exhaust flow rate as particulate collects on the final HEPA filters. A variable frequency drive on the supply fan modulates fan speed as pressure control dampers open and close.

Operations Area

The Operations Area is located in Zone 4. The Operations Area is a radiologically clean area and operates at a pressure slightly higher than atmospheric pressure. It is cooled, heated, and ventilated to maintain a comfortable working environment and provided with enough fresh air for odor, moisture, and pressure control. Unit heaters, wall-mounted exhaust fans, and wall-mounted intake dampers are provided in the HVAC supply room, the storage room and the mechanical equipment room to maintain design temperatures inside these areas.

Miscellaneous Areas

The New Canister Receipt Area, electrical room, storage room, and HVAC exhaust room are served by individual heating and cooling units in each room. Room air is recirculated and outside air is not introduced directly into these areas. The units in the electrical room and the HVAC exhaust room are designed for year-round cooling due to the large amount of heat generated by motors and electrical equipment. Unit heaters offset the extra heat loss through open roll-up doors. The rooms are maintained at atmospheric pressure.

The battery room is ventilated to exhaust battery fumes. A packaged cooling/heating unit serves the battery room. Tempered outside air is introduced into the room to make up exhaust air. A separate fan exhausts to the outside to ensure a constant supply of fresh make-up air in this room.

The operators office, change room, and corridor are served by a separate heating and cooling unit. The central make-up air-handling unit furnishes ventilation and pressurization air. This area is maintained at a slightly positive pressure relative to atmosphere.

Equipment rooms are heated and ventilated to protect equipment and to provide moderate comfort for personnel. Unit heaters, wall-mounted exhaust fans, and wall-mounted intake dampers are provided in the HVAC supply room, the storage garage, and the mechanical equipment room to maintain design temperatures inside these areas.

4.3.1.1.2 Operating Characteristics

The HVAC system is designed to operate continuously throughout the year. System capacities meet or exceed the requirements for filtration, ventilation, heating, and cooling under normal operating conditions. The main supply and exhaust fans serving the Transfer Area include redundant backup fans to allow for periodic maintenance and duty cycling between fans and to ensure reliable performance of the HVAC system. Furthermore, a 10 percent design margin is applied in the HVAC load calculations to account for unforeseen conditions. Occupied areas in the secondary airborne contamination control zone are designed for a minimum of four air changes per hour. Room pressure controls are described in Section 4.3.1.2.

Normal Operating Conditions

Table 4.3-1 provides the indoor design parameters under normal operating conditions for the areas in the ISF Facility. The rationale and description of the normal ambient design conditions are provided in Section 3.2.5.1.6.

Off-Normal Conditions

Failure of the HVAC systems could result in temperature changes in various areas of the ISF Facility reaching levels shown in Table 4.3-2 due to heat gains from solar, conduction, and internal heat loads unique to each area. These off-normal temperatures are based on normal site ambient maximum and minimum temperature conditions, as provided in Section 3.2.5.1.6. These temperatures are conservative, as they are based on steady-state heat transfer assumptions and do not take into account transient effects due to changes in outside air temperature and sun position over time. They also do not account for diminishing magnitude of heat transfer as inside temperature approaches outside temperature. Within hours of a failure of the HVAC system (assuming that it was not the result of a loss of off-site power), personnel would take action to secure lights and motors, which contributes to undesirable heat loading.

Accident Conditions

The HVAC system is not required to operate during design basis accidents. Portions of the system passively ensure that the confinement barriers of the FPA and FHM Maintenance Area are maintained during off-normal and accident conditions. Figure 4.3-5 schematically depicts the ITS and seismic boundaries of the HVAC system that penetrate the confinement barrier of the FPA and FHM Maintenance Area. Specific ITS functions of the HVAC system under external natural events and a fire event are provided below.

Fire Event

Although they are located in a room that is equipped with both fire suppression and detection systems, the active components (i.e., fans) of the HVAC system are not credited in the mitigation of a fire event. HVAC ductwork that penetrates the confinement barrier of the FPA and FHM Maintenance Area provides a minimum 1-hour fire barrier to prevent fires outside the confinement barrier from spreading into the FPA or FHM Maintenance Area.

Smoke detectors in the FPA system exhaust duct and in the FPA and FHM Maintenance Area will shut down the Transfer Area supply and exhaust fans and close the electro-thermal link fire dampers in the supply and exhaust ductwork if smoke is detected from a fire inside the confinement barrier or the in-cell HEPA filters. This will minimize the spread of radioactive material outside the FPA. These dampers can also close due to high temperature if the fire event is in an area outside the FPA or FHM Maintenance Area, to prevent the fire from spreading into the confinement barrier. Low combustibility air filters will be utilized throughout the facility in accordance with UL 586 and UL 900 (Refs. 4-28 and 4-29). The final HEPA filters will have fire detectors and a deluge suppression system. Refer to Section 4.3.8 for a complete discussion of the fire protection and detection systems at the ISF Facility.

Tornado Event

The HVAC system is not required to mitigate the effects of a design basis tornado. However, portions of the HVAC system provide a confinement barrier for the FPA and FHM Maintenance Area, as shown in Figure 4.3-5. The tornado pressure boundary is the roof, walls, and floor of the FPA and FHM maintenance area. The HVAC ducts penetrating this boundary are provided with spring-actuated tornado dampers designed to activate at a negative pressure less than -1.5 psi per NRC Regulatory Guide 1.76 (Ref. 4-30). The FPA supply tornado damper meets ASME AG-1 gas-tight criteria (Ref. 4-31). The tornado dampers are provided with locking devices to keep them closed after the tornado passes. The locking device is manually disengaged to return the dampers to service. Tornado dampers are installed as close to the primary confinement shield wall as practical and are protected from tornado missiles.

Seismic Event

The HVAC system is not required to function during or after a seismic event. The seismic switch described in Section 4.3.2 will de-energize the ISF Facility electrical distribution system including the Transfer Area supply and exhaust fans and local ventilation fans in the Cask Receipt Area and Storage Area buildings. Portions of the HVAC system that perform confinement barrier functions are designed to withstand the effects of the design earthquake. Figure 4.3-5 shows the seismic boundary. Ductwork that is considered ITS is designed to survive the effect of a design basis accident and continue to perform its required ITS function. A "breakaway" joint is provided at the ITS/NITS ductwork interface to protect the ITS ductwork.

Flood Event

The HVAC system is not required to mitigate a design basis flood and will be manually shut down if a flood occurs. HVAC equipment on the lower elevations of the ISF Facility could be submerged by floodwaters. The exhaust HEPA filters housings and connecting ductwork on the first floor of the Transfer Area are designed for airtight operation at pressures in excess of negative 10 inches water. However, during a flood event, the lower door seals are approximately 31 inches below the maximum probable flood (MPF) elevation. Therefore, the exhaust HEPA filters may have water damage. Before restarting the HVAC system after a flood, the interior of the housings will be inspected, cleaned, repaired, and leak tested. The filter elements will be changed and aerosol tested. Portions of the HVAC system that form a confinement barrier are above the MPF elevation. Therefore, the FPA and FHM Maintenance Area are protected from a design basis flood by the supply HEPA filters and in-cell exhaust HEPA filters.

4.3.1.1.3 Maintenance

The main supply and exhaust fans serving the transfer area are considered high maintenance items and will be provided with 100-percent redundant backup fans to allow periodic maintenance and duty cycling. The final HEPA filters will consist of multiple, modular air-cleaning units stacked one on top of the other. The system will be designed so that one air-cleaning unit can be isolated for filter replacement, and a clean unit brought on line without diminishing either the capacity or function of the entire system. Intermediate HEPA filters located on exhaust ducts serving primary and secondary confinement zones, will be provided with a spare HEPA filter to allow filter changes without having to shut the system down.

Instrumentation will be provided to facilitate maintenance, surveillance testing, and troubleshooting. Filter efficiency test ports will be provided on HEPA filters outside the FPA to allow regularly scheduled testing of the filters. Systems will be designed to minimize radiation exposure to operating personnel during maintenance on potentially contaminated equipment.

Access will be provided for maintenance and replacement of structures and components with less than a 40-year life span. Operations manuals, instruction books, and as-built drawings will be provided to permit testing, maintenance, and repair of components. Operations and maintenance personnel will receive training on the HVAC system and major pieces of equipment, with additional training on HVAC control systems.

4.3.1.2 Safety Considerations and Controls

HVAC system ductwork and components that provide the confinement barrier for the FPA and FHM Maintenance Area are classified ITS. The ITS boundary for this barrier is depicted on Figure 4.3-5. The fixed inlet vents in the storage vault concrete walls and the exhaust louvers in the Storage Area are classified ITS because they support natural circulation through the storage vault. Items that provide the confinement barrier are designed to maintain their integrity during accident events. Tornado dampers provide pressure protection for the HEPA filters. The tornado dampers will be protected from missile impact.

The remainder of the HVAC system is classified NITS. However, the main supply and exhaust fans serving the Transfer Area must be reliable to ensure that SNF handling operations are not affected. Therefore, 100-percent redundant backup fans are provided to allow for periodic maintenance and duty cycling. The effects of loss of filter integrity are minimized through the use of local intermediate filters, roughing filters in the final HEPA housings, and dual HEPA filtration sections in series in the final HEPA housings.

The Transfer Area supply and exhaust fans and battery room HVAC are connected to the standby motor control center (MCC), which can be energized by the standby diesel to ensure ventilation to these areas following a loss of offsite power. The HVAC control system will restart these fans automatically once the MCC is re-energized by the standby diesel generator after a power failure to maintain differential room pressures and continue filtration. However, during a power failure the heating and cooling units shut down and room temperatures may eventually equalize with the ambient outdoor temperature until offsite power is restored.

The automated HVAC control system used at the ISF Facility is connected to the uninterruptable power supply (UPS) to provide pressure and temperature control during a power failure and to facilitate the orderly restart of the HVAC system once power is restored. The Transfer Area supply and exhaust fans are fed from the standby MCC, which is powered by the standby diesel generator during a power failure. During an off-site power failure, these fans will restart automatically and continue to run to maintain differential room pressures. The HVAC automatic control system is powered by a UPS to ensure orderly restart of the HVAC system once unit power is restored.

The ventilation system has smoke detectors and fire dampers to shut off fans and protect wall openings in the event of fire. Ductwork penetrations into the FPA have heat-activated fire dampers with electro-thermal links that close to confine a fire in the FPA and prevent the spread of contamination through the ductwork. Additional information relating to the fire protection system is provided in Section 4.3.8.

Room and area design pressures are maintained by keeping the volume of exhaust air constant while varying the volume of supply air. The total volume of supply air is less than the total volume of exhaust air, resulting in negative pressures relative to atmospheric pressure (except for occupied areas such as the Operations Area, which has positive pressures). Supply fans are interlocked with exhaust fans and will not run unless the exhaust fan is running. Redundant supply and exhaust fans are interlocked to prevent simultaneous operation. An automated HVAC control system monitors room pressure, initiates alarms, and automatically shuts down the supply fan if a positive pressure is detected in either a primary or secondary airborne contamination control zone. The make-up and exhaust systems maintain the design pressure differential between rooms. The automated HVAC control system maintains this differential regardless of transient effects caused by changes in atmospheric pressure, wind speed and direction (except tornadoes), doors opening and closing, and routine maintenance procedures.

During fuel transfer into and out of the FPA through the cask and canister port, confinement barriers and area pressures are maintained by inflatable seals. An inflatable seal integral to the port engages the casks and canisters before removal of the port plugs. During fuel transfer through the cask and canister ports the confinement barrier includes the DOE transfer cask and the ISF canister. Benefits of using inflatable seals at these ports during fuel transfer include:

- continuously maintaining the confinement barrier
- eliminating fluctuations in airflow
- eliminating fluctuations in area pressures
- contamination control

Before waste transfer out of the FPA through the canister waste port or the process waste port, the pressure inside the SWPA is lowered to minimize differential air pressure between the SWPA and the FPA. This will minimize the airflow through the waste port to ensure that the FPA pressure remains at the proper negative pressure relative to other airborne contamination control zones. If there is SNF in the FPA, the waste ports will not be opened unless the following conditions are met:

- cask port is closed with the cask port plug installed
- canister port is closed with the canister port plug installed
- SNF in the FPA is in a designated storage location
- HVAC system is operating
- If the HVAC system becomes inoperable, waste transfer operations are suspended and the waste ports are replaced. Both waste ports must be installed before commencing fuel-handling operations.

Refer to Section 4.7.2.3 for a detailed discussion of the confinement barrier.

4.3.2 Electrical Systems

The electrical systems include power distribution, and instrumentation and controls. This section describes the major components, key operating characteristics, and safety considerations of the electrical systems.

4.3.2.1 Major Components and Operating Characteristics

4.3.2.1.1 Power Distribution System

The electrical power distribution system, except for the seismic switch, is classified NITS and is not credited for mitigating any design basis accidents. The electrical distribution system is designed to de-energize during seismic events to ensure that the fuel handling equipment is in a known safe state. The sensors and circuits that perform this function are classified ITS.

The electrical power distribution system is shown on Figure 4.3-10. Electrical power to the ISF Facility is supplied from a utility source at 13.8 kV. A stepdown transformer converts the power to 480V, and the 480V switchgear distributes the power throughout the ISF Facility.

The ISF substation is within the security fence, northeast of the Transfer Area, as shown in Figure 4.1-1. The step-down transformer, standby diesel generator, and switchgear are at the substation. MCCs are in the electrical room on the first floor below the operating gallery. The UPS equipment is in the battery room adjacent to the electrical room. The ISF Facility standby diesel generator provides backup power to specified loads if the main utility source becomes unavailable.

A seismic switch, consisting of seismic sensors in conjunction with redundant load interrupter switches installed in the 13.8 kV feed to the stepdown transformer will automatically de-energize the normal and standby power supply and initiate a signal to prevent the standby diesel generator from starting. Local power sources will continue to provide power to essential instrumentation and equipment.

The power distribution system includes the following major components:

- **Unit Substation.** The unit substation consists of a main stepdown transformer, switchgear, and metering. The stepdown transformer is oil-filled, 13.8 kV, 480/277V delta/wye-grounded, with a rated capacity of 3750 kVA. The transformer meets Factory Mutual Standard FM Loss Prevention Data Sheet 5-4 (Ref. 4-32) requirements. The switchgear distributes the power to the MCCs in the facility electrical room. The unit substation is in the switchyard.
- **Standby Generator.** Standby power is provided by a 500-kW diesel generator with fuel tank and automatic transfer switch. The generator fuel tank is sized to provide a minimum of 24 hours of generator run time. Longer run times can be obtained by bringing in additional fuel from offsite. The automatic transfer switch will switch from line power to generator power automatically, and may be set to manual or automatic switchback upon return of line power. The generator complies with NFPA 70, National Electrical Code Article 702, *Optional Standby Systems* (Ref. 4-33). The standby generator is in the switchyard.
- **Motor Control Centers.** Six MCCs provide the primary power distribution in the ISF Facility. The Normal-1 through Normal-4 MCCs provide power to the major facility equipment. During a design basis seismic event or loss of line power, power to these MCCs is interrupted. The standby

MCC provides power to selected equipment and systems as shown in Figure 4.3-11. During loss of line power, the standby generator supplies power to the standby MCC, and during a design basis seismic event, power is interrupted. A spare MCC is provided for future use. The MCCs are in the electrical room.

- **Seismic Switch.** The seismic switch consists of sensors to detect a design basis seismic event and pad-mounted, load interrupter switchgear that interrupt power to the step-down transformer and prevents the standby diesel from starting. The sensors are tri-axial force balanced accelerometers calibrated to detect the ground response within an adjustable frequency (1 Hz to 15 Hz) and to trip at an adjustable magnitude (0.05g to 0.5g). Each set of accelerometers consists of three units arranged in an X-Y-Z axis configuration. There are three of these sets, and two-out-of-three voting logic is implemented to reduce the likelihood of spurious trips. The seismic switch is powered by a dedicated uninterruptable power supply (UPS). When a design earthquake event is detected, the redundant load interrupters open and interrupt power to the step-down transformer. A signal is sent to prevent the diesel generator from starting or to trip the diesel if it is already running. The switches remain open until manually reset in accordance with facility operating procedures. The seismic switches and the load interrupter switchgear are in the electrical switchyard.

- **Uninterruptable Power Supply.** The UPS conditions the electrical power and provides a "clean" source for those electrical components sensitive to power surges and system fluctuations. The UPS is an on-line battery-backed system that provides constant power under normal conditions and continues to provide power in loss-of-power events for a minimum of 90 minutes. The loads connected to the UPS, shown on Figure 4.3-12, include selected FPA lighting, canister closure controls, radiation monitoring, HVAC controls, CCTV and the integrated data collection system (IDCS). The UPS is rated at a minimum of 25 kVA capacity and is in the battery room.

The power distribution system is designed for normal, off-normal, and design basis event conditions. Under most conditions, the power distribution system is fully functional and systems that require electrical power are supplied. In certain off-normal or design basis event conditions, the power distribution system is allowed to experience controlled interruption, and facility electrical equipment and systems enter a passive, safe state. To implement this design, commercial power is received from a single feed from the INEEL power grid, and divided into three sources to power the facility, each with its own characteristics.

The normal source is supplied directly from the unit substation and distributed to the four normal MCCs. The normal source is interrupted upon loss of utility power or a design basis seismic event. If power is interrupted by the seismic load interrupters, it will stay off until manually reset. If power is lost for other reasons, the normal MCCs will be automatically re-energized when power is restored. Controls for individual equipment are designed to remain off until an operator restarts them. The loads connected to the normal source are designed to enter a safe state on loss of power and remain safe until power resumes.

The normal/standby source is supplied from the unit substation and routed through the standby generator automatic transfer switch before distribution to the standby MCC. Under normal conditions, the automatic transfer switch is aligned to the unit substation. Upon loss of power, the standby generator will automatically start and the automatic transfer switch will align to generator power. The generator will take a short time to come up to speed before being placed online; therefore, loads on the normal/standby source will experience a momentary loss of power.

The normal/UPS source is derived from the normal/standby source, and routed through the UPS before distribution via the UPS distribution panel. Under normal or loss of utility power conditions, the normal/UPS source receives power from the unit substation or the standby generator. Power is passed through the UPS, ensuring that the UPS batteries are fully charged and that power is conditioned to remove any incoming surges or spikes and distributed to selected loads.

There is no emergency power system in the ISF Facility, which implements a "fail safe when de-energized" philosophy. Equipment and systems are designed to enter a passive, safe state on loss of power and stay safe until normal conditions are restored. The systems or components that require emergency power have local battery packs.

4.3.2.1.2 Instrumentation and Controls

Key instrumentation and control systems include the radiation monitoring system, the HVAC control system, the IDCS, and the facility interlocks.

Radiation Monitoring System. The radiation monitoring system includes criticality monitoring, area radiation monitoring, continuous air monitoring, record sample air monitoring, and personnel contamination monitoring. The radiation monitoring system for the ISF Facility is described in Section 7.3.4.

Heating, Ventilation, and Air Conditioning Controls. The HVAC control system employs a direct digital controller to monitor operating parameters, adjust system performance, and issue status and alarm signals. The HVAC control system is powered from the normal/UPS source. Additional information on the HVAC control system is provided in Section 4.3.1.

Integrated Data Collection System. The IDCS provides centralized acquisition, processing, and storage of ISF Facility data. The IDCS receives data from the following sources:

- Major equipment provides system status signals such as power on, equipment fault, and operation fault. Equipment fault is an indication that one or more equipment faults have been triggered without identifying the exact fault condition. Operation fault is an indication that the equipment is outside its normal operating parameters, such as an end-of-travel limit switch tripped without identifying the exact operational condition. Specific information is available at the equipment operating consoles.
- Radiation monitors provide discrete signals indicating when a set point has been exceeded, and in selected cases, a continuous analog signal indicating the monitored radiation level.
- The fire alarm system provides an input indicating the occurrence of any off-normal fire detection/suppression condition.
- The HVAC control system provides status information on key HVAC system parameters. The interface to the IDCS is for status information only. The HVAC system is controlled from the dedicated HVAC digital control system.

- The liquid waste collection system provides a high-level indication for the collection tank.
- Operators enter data necessary for waste tracking and shipping reports, SNF accountability and inventory, and operational reports.

The IDCS is powered from the normal/UPS source. The IDCS is in the operations monitoring room.

Facility Interlocks. The ISF Facility interlock system coordinates control signals between systems and components. Each status or alarm signal produced by one SSC and required by the operating logic of a second SSC is defined and managed by the facility interlocks. It is a distributed system without central equipment or a primary location. Facility interlocks are described in Chapter 5, *Operation Systems*.

4.3.2.2 Safety Considerations and Controls

The ISF Facility's "fail safe when de-energized" philosophy ensures that fuel handling equipment enters a passive, safe state upon loss of power, by providing mechanical safety features independent of the electrical systems. This allows the power sources, the associated distribution equipment, and most of the electrical control systems to be classified NITS. However, the seismic switch and associated components are classified ITS to ensure equipment is de-energized during a seismic event. The seismic switch interrupts power from the normal and normal/standby sources at the onset of a design basis seismic event, thus forcing the fuel handling equipment into a passive, safe state. The seismic sensors are configured to provide a positive signal to the load interrupter switchgear. Upon actuation of the switch (two-out-of-three voting), the positive signal is interrupted, resulting in both load interrupter switches opening. (Redundant load interrupters are provided in the event one fails to open.) This configuration is independent of the power supply to the seismic sensors or seismic line switch, because a power failure will result in a spurious trip of the load interrupter switches instead of a failure to trip. The seismic sensors, the seismic load interrupters, and the connections to the power feeds are ITS.

4.3.3 Air Supply Systems

There are two types of air supply systems at the ISF Facility: (1) compressed air, and (2) breathing air. The compressed air and breathing air systems are not used to operate any of the fuel handling equipment and are not credited for accident mitigation. The compressed air system is classified NITS. The breathing air system is NITS with the exception of the penetration and associated piping into the FHM Maintenance Area, which is part of the confinement boundary. This portion of the breathing air system is classified ITS to ensure the confinement boundary continues to perform its intended functions during normal, off-normal, and accident conditions.

4.3.3.1 Compressed Air

Compressed air is required for building operations, maintenance activities, and operation of pneumatic tools inside the ISF Facility. An air compressor and associated equipment are in the mechanical equipment room. There are compressed air connections throughout the facility where operations and maintenance activities occur. These areas include:

- Cask Receipt Area
- mechanical equipment room

- workshop
- Operators Office and Equipment Area
- operating gallery
- HEPA filter and HVAC exhaust room
- New Canister Receipt Area
- Solid Waste Storage Area
- SWPA
- Liquid Waste Storage Tank Area
- Transfer Tunnel
- CCA

The compressed air system boundaries are limited to the ISF Facility. The system boundary extends from the upstream side of the air compressor inlet filters to the piping and the service air connections (i.e., shutoff valves or hose quick disconnects) throughout the facility.

Air pressure is indicated at various points throughout the system, with a "compressed air trouble" alarm in the control monitoring station. The compressed air system also incorporates check valves upstream of the air receiver to prevent blowdown of the receiver when the compressor unloads. The compressed air system relies on the HVAC system to provide adequate ventilation for compressor air intake in the mechanical equipment room. The compressed air system operates on 480 VAC electrical power for the compressor and 230 VAC for the air dryer.

The major components of the compressed air system are an air compressor, aftercooler, refrigerant dryer, air receiver, coalescing filter, and service header. The compressed air system is designed to supply dry compressed air. Nominal operating pressure is 100 psig. The compressor is a single-stage, reciprocating, commercially available compressor. It is complete with an air-cooled aftercooler and a relief valve to protect from over-pressurization. The compressor is designed in accordance with ASME B19.3, Safety Standard for Compressors for Process Industries (Ref. 4-34).

The compressor can be started or shut down either manually or automatically. Automatic compressor start-up and shutdown is by low- and high-pressure signals from the air receiver. The compressor controls also provide for compressor load/unload, based on air receiver pressure, with automatic shutdown after running unloaded for a period of time.

The compressor motor is a standard three-phase motor having a National Electrical Manufacturers Association (NEMA) T-frame. The motor starter includes thermal relays to protect the motor windings and has a NEMA-rated enclosure. The air receiver has a capacity of 400 to 600 gallons. The receiver is designed and fabricated to the requirements of ASME Boiler and Pressure Vessel Code, Section VIII, Division 1.

The compressed air system piping is designed in accordance with ASME B31.9, *Building Services Piping* (Ref. 4-35) and ASME B31.1, *Power Piping* (Ref. 4-36).

4.3.3.2 Breathing Air

Breathing air provides personnel protection for those areas inside the ISF Facility that may have the potential for airborne radioactive contaminants. A high-pressure air compressor, pressure reducing stations, air dryer, and self-contained breathing apparatus (SCBA) cylinder charging equipment are in the mechanical equipment room. Breathing air manifolds are in the following areas:

- Transfer Tunnel
- Transfer Tunnel Decontamination Zone
- Solid Waste Processing Area
- Solid Waste Storage Area
- Liquid Waste Storage Tank Area
- operating gallery
- FHM Maintenance Area
- Operators Office and Equipment Area
- CCA
- New Canister Receipt Area

The breathing air system boundaries are limited to the ISF Facility. The system boundary extends from the upstream side of the breathing air compressor inlet filters to the piping and breathing air hose quick-disconnect manifolds throughout the facility. The breathing air system relies on the HVAC system to provide adequate ventilation for compressor air intake in the mechanical equipment room. The breathing air compressor is powered from the 480 VAC electrical distribution system standby MCC, which can be energized by the standby diesel generator. A local trouble alarm is at the breathing air compressor and a remote alarm is in the control monitoring station.

The breathing air system supplies compressed air for human respiration. The breathing air system is charged by a high-pressure compressor capable of delivering a minimum 9 standard cubic feet per minute (scfm) of compressed air at 5000 psig. The compressor and related purification equipment are capable of processing air to a quality verification level of at least Grade D in accordance with Compressed Gas Association, Inc. (CGA) G-7-1990, Compressed Air for Human Respiration (Ref. 4-37) and produces air free of moisture, odor, and at acceptable carbon monoxide and hydrocarbon limits. The breathing air flow-rate at each breathing air manifold station can provide at least 24 scfm. The number of personnel per manifold may be restricted, so that the available flow rate is not exceeded.

High-pressure storage bottles provide continuous air in the event of a power failure or compressor failure while the breathing air system is in use. These bottles will provide approximately 60 minutes of air at a rate of 24 scfm. The breathing air system is also capable of charging SCBA cylinders. For personnel protection, the SCBA cylinders are inside a Class 2 containment enclosure during the filling process (personnel remain outside the enclosure). This enclosure is in the mechanical equipment room.

4.3.4 Steam Supply and Distribution System

The ISF Facility does not contain a steam supply and distribution system.

4.3.5 Water Supply System

The potable water system provides drinking water and other domestic needs at the ISF Facility site. Potable water is also used as a source of make-up to the chilled water loop in the HVAC system.

4.3.5.1 Major Components and Operating Characteristics

Potable water is provided by INTEC as described in Section 4.1.2.3.1. The potable water system boundary begins at the ISF/INTEC interface tie-in connection on the west side of the ISF Facility site, as shown on Figure 4.1-1 and terminates downstream at each plumbing fixture or equipment that potable water is supplied to. The potable water system is designed to meet the expected demand for service and support facilities of the ISF Facility, Administration Center, and Guard House.

4.3.5.2 Safety Considerations and Controls

The potable water system is not relied on to mitigate any accidents and does not support any functions that are ITS. The potable water system is classified NITS.

4.3.6 Sewage Treatment System

The ISF Facility does not have a sewage treatment system. The sanitary wastewater system at the ISF Facility begins at floor drain or a potable water end device drain (e.g., sink, toilet, etc.) and extends to the tie-in location on the west side of the ISF Facility site boundary, as shown in Figure 4.1-1.

4.3.6.1 Sanitary Sewage

The sanitary wastewater system at the ISF Facility is designed in accordance with the Uniform Plumbing Code and is classified NITS. Drainage and sewage are collected from the Operations Area, Administration Center, Guard House and Visitor Center, and gravity fed to the INTEC sanitary sewer line. The decontamination shower and floor and equipment drains in contaminated or potentially contaminated areas, do not drain into the sanitary wastewater system. Bathroom fixtures are outside of areas that could be contaminated. Therefore, contamination of the sanitary sewer system is not likely.

4.3.6.2 Chemical Sewage

The ISF Facility does not have a chemical handling or treatment system.

4.3.7 Communications and Alarm Systems

The communication and alarm systems at the ISF Facility consists of three functional groups:

- non-emergency communications (phone and voice paging) system
- fire detection, alarm and emergency communication system
- data communication (broadband LAN) system

4.3.7.1 Major Components and Operating Characteristics

Non-emergency communication system consists of a network of telephones, fax machines and voice paging devices in designated areas of the ISF Facility. The non-emergency communication system is linked to the INTEC telephone network, which is tied into the local telephone company network.

Fire detection, alarm and emergency communication system consists of fire detection devices (smoke detectors, manual pull stations, flow switches, heat detectors) throughout the ISF Facility; a central fire alarm panel in the Operations Monitoring Room of the ISF Facility; audible and visual alarms throughout the ISF Facility; and a fiber optic cable network and telephone network connecting the ISF Facility, INTEC Facility, and the INEEL Central Fire Alarm Station. This system also includes emergency fire phone sets at the main entry to the ISF Facility Operations Area.

Data communication system consists of a broadband LAN throughout the ISF Facility operational areas, connected to the INTEC network via a T-1 line.

4.3.7.2 Safety Considerations and Controls

ISF Facility communication systems are classified NITS. The fire detection, alarm, and emergency communication system is normally powered from the standby MCC, which is energized by the standby diesel generator in the event of a loss of offsite power. The fire detection, alarm and emergency communication system also has a dedicated UPS to ensure function during a loss of offsite power until either the standby diesel generator or normal power is aligned to the standby MCC. The dedicated UPS is sized for 24-hour standby and 15-minute full alarm capability. The non-emergency communication system is connected to the ISF Facility UPS, which also is powered by the standby MCC.

4.3.8 Fire Protection System

The fire protection system is designed in accordance with ANS 57.9, *Design Criteria for an Independent Spent Fuel Storage Installation (Dry Type)*, NFPA 801 (Ref. 4-38) and other applicable NFPA codes and standards; NUREG-1567, *Standard Review Plan for Spent Fuel Dry Storage Facilities*, and NUREG 0800 Branch Technical Position 9.5-1 (Ref. 4-39). When deviations from these documents are identified, they will be evaluated and approved by a qualified fire protection engineer as described in Section 4.3.8.5 prior to operation of the facility.

4.3.8.1 Design Bases

The design bases for the ISF Facility fire protection system are as follows:

- ITS SSCs are designed and located to minimize, consistent with other safety requirements, the fire hazard so that they can continue to perform their safety functions effectively under credible fire exposure conditions. Non-combustible and heat-resistant materials are used wherever practical throughout the facility, in accordance with 10 CFR 72.122(c), *Protection Against Fires and Explosions*.
- The fire protection system is designed to minimize the effects of fires on ITS SSCs in accordance with 10 CFR 72.122(c). The system is designed to provide capability to fight the fire hazard encountered throughout the ISF Facility.

- The fire protection system is designed so that pipe rupture or inadvertent operation of the fire suppression system does not cause loss of function of ITS SSCs, in accordance with 10 CFR 72.122(c).
- Procedural controls are established to limit the use of combustible materials and to prevent potentially hazardous situations.

The ISF Facility contains five buildings, a diesel generator area, and a switchyard that have been evaluated for worst-case postulated fires and the potential affect on ITS SSCs. Only one of these buildings (the ISF building) and the switchyard contain ITS SSCs. The remaining five buildings or areas (diesel generator area, Guard House, Administrative Center, Storage Warehouse, and Visitor Center) do not contain ITS SSCs. The ISF Building, where the SNF is received, packaged, and passively stored, and radioactive waste is processed/stored, does contain ITS SSCs. In addition, the switchyard area contains a seismic switch system that will isolate electrical power from the facility to ensure a safe configuration for the electrically operated ITS SSCs.

The ISF building and switchyard area have been evaluated to address both internal fire hazards and the potential affect on nearby ITS SSCs. The remaining four buildings were evaluated for possible exposure fire hazards to the ISF building and switchyard where the ITS SSCs are located. Personnel egress from each building has been addressed in the design for life safety.

The ISF building is a two-story, steel-frame Uniform Building Code (UBC) Type II non-combustible structure. Portions of the building that contain the SNF handling and storage processes are constructed of reinforced concrete for shielding and tornado missile protection, which are equivalent to a UBC Type I fire resistive facility. The building consists of three sub-buildings interconnected by a partially below-grade tunnel. Figure 4.3-13 and Figure 4.3-14 show the fire protection features of the first and second floors, respectively. The three sub-buildings include the Cask Receipt Area, Storage Area, and Transfer Area plus the connecting Transfer Tunnel. The type of combustible materials within the facility are typical Class A or B combustibles and do not involve dangerous or hazardous combustibles.

For fire hazards evaluation purposes the ISF Facility is divided into three fire areas:

- Fire Area 1: areas where SNF is removed from the DOE transfer cask, processed into the new storage canisters, and prepared for storage
- Fire Area 2: areas where the SNF is passively stored
- Fire Area 3: the remaining portions of the ISF building, support structures, and yard area

Overall, the scenarios for a fire in any location inside or outside of the ISF building considering the fire location, intensity, and duration have been analyzed and are discussed in Section 8.2.4.4. The analysis determined that the postulated fires would not compromise the ITS SSCs.

4.3.8.1.1 Fire Area 1 – Fuel Handling Areas

Fire Area 1 consists of the ISF building structures identified as the Transfer Tunnel, FPA, and CCA. The Transfer Tunnel is composed of two fire zones, the FPA consists of two fire zones, and the CCA is a single fire zone in this fire area. Each one of these rooms will be discussed in detail below. The purpose of this fire area boundary is to isolate ITS fuel handling and processing activities from all credible fires outside this area.

Transfer Tunnel Fire Zone

The Transfer Tunnel is a single-story, reinforced-concrete structure located partially below grade and connects the Cask Receipt Area, Storage Area, and Transfer Area. The structure has a fire resistive construction with a minimum 3-hour fire rating for the structural components. The doors, HVAC penetrations, electrical penetrations, and other non-structural components are constructed and maintained for a 1-hour fire rating. The Transfer Tunnel consists of two fire zones, the south end where decontamination activities occur, and the north end where transfer activity between the Storage Area, FPA, and CCA occurs.

The postulated fire loading in the south end of the Transfer Tunnel is associated with cask decontamination activities. Administrative controls on the quantity of materials in this area and the use of flammable storage cabinets limit the potential fire loading in this area. The postulated combustibles consist of Class A and B materials that constitute a low combustible loading. A low combustible loading is defined as an equivalent combustible loading of less than 30 minutes. The 1-hour fire-rated barrier between this and surrounding areas will ensure adequate fire protection from this fire loading. Fire detection is located in this area. Automatic fire suppression is not provided in this area due to the radiological considerations of potentially spreading contamination by spraying contaminated casks or trolleys operating in the area.

The postulated fire loading in the north end of the Transfer Tunnel is associated with operation of the cask trolley and canister trolley. The postulated combustibles consist of class A and B materials that constitute a low combustible loading. The 1-hour fire-rated barrier between this and surrounding areas will ensure adequate fire protection from this fire loading. Fire detection is located in this area. Automatic fire suppression is not provided due to the radiological considerations of potentially spreading contamination by spraying contaminated casks or trolleys operating in the area.

Fuel Packaging Area Fire Zone

The FPA is a tall, single-story, reinforced-concrete structure in the center of the Transfer Area north of the Storage Area. The structure has a UBC Type I fire resistive construction with a minimum 3-hour fire rating for the structural components. The doors, shield windows, HVAC penetrations, electrical penetrations, and other non-structural components are constructed and maintained for a 1-hour fire rating or an equivalency evaluation is performed if listed components are not available. The FPA consists of two fire zones, the west end where crane maintenance is performed and the east end where fuel packaging activity is performed.

The postulated fire loading in the west end of the FPA is associated with crane maintenance activities. Administrative controls on the quantity of materials in this area limit the potential fire loading. The postulated combustibles consist of Class A and B materials that constitute a low combustible loading. The 1-hour fire-rated barrier, including equivalency evaluated components, between this and surrounding areas will ensure adequate fire protection from this fire loading. Fire detection is located in this area. Automatic fire suppression is not provided due to the radiological considerations of potentially spreading contamination outside this area.

The postulated fire loading in the east end of the FPA is associated with fuel packaging activities. Administrative controls on the quantity of materials in this area will limit the potential fire loading. The postulated combustibles consist of class A and B materials that constitute a low combustible loading. The 1-hour fire-rated barrier, including equivalency evaluated components, between this and surrounding areas will ensure adequate fire protection from this fire loading. Fire detection is provided from outside the zone by pulling an air sample from within the zone due to the high postulated radiation dose potential in this area. Automatic fire suppression is not provided in this area due to the radiological and criticality considerations associated with this area.

Canister Closure Area Fire Zone

The CCA is a single-story, reinforced-concrete structure above the north end of the Transfer Tunnel near the center of the Transfer Area. The structure has a fire resistive construction with a minimum 3-hour fire rating for the structural components. The door, window, HVAC penetrations, electrical penetrations, and other non-structural components are constructed and maintained for a 1-hour fire rating. The CCA is a single fire zone in this fire area.

The postulated fire loading in the CCA is associated with electric arc welding of the fuel canister and weld inspection activities. Administrative controls on the quantity of materials in this area and the use of flammable storage cabinets limit the potential fire loading. The postulated combustibles consist of Class A and B materials that constitute a low combustible loading. The 1-hour fire-rated barrier between this and surrounding areas will ensure adequate fire protection from this fire loading. Fire detection is located in this area. Automatic fire suppression is not provided due to the radiological considerations associated with this area.

4.3.8.1.2 Fire Area 2 – Storage Vaults

Fire Area 2 consists of the ISF building structure identified as the storage vaults. The storage vaults are composed of two fire zones. This fire area boundary isolates the ITS passive SNF storage area from credible fires outside this area.

Storage Vaults Fire Zone

The storage vaults are a single-story, reinforced-concrete structure at grade level between the Cask Receipt Area and the Transfer Area with the Transfer Tunnel running along the west side. The structure has a fire resistive construction with a minimum 3-hour fire rating for the structural components. Penetrations into this area are constructed and maintained for a 1-hour fire rating except for the air inlets in the exterior walls and charge face annular gap around each storage tube. The storage vaults area consists of two fire zones, the west end (Storage Vault 1 area) and the east end (Storage Vault 2 area). From a fire protection standpoint the two vaults are essentially the same, with a reinforced-concrete barrier separating the two sides.

This area is a high radiation area that is not accessible once SNF is stored in the storage tubes. The 1-hour fire-rated barrier between this and surrounding areas will ensure adequate fire protection from exposure fire hazards outside this area. The exterior wall air inlets are located approximately 20 feet above ground level at the top of the storage vaults. For shielding purposes these openings are designed with a right-angle turn down into the storage vaults. The height above grade, indirect path of the opening, and lack of credible combustible material on either side of the opening will ensure adequate protection from fire propagation. The small annular gap (~1/4 inch) around each storage tube through the 2-1/2 foot thick charge face provides a circuitous path that mitigates the postulated fire hazard from the second floor storage area. A low combustible loading would occur in the storage vaults even if the single largest Class B fluid container inventory from the second floor storage area entered through the annular gaps. No credible ignition source exists in the storage vaults. As a result of the inaccessibility and lack of a credible fire hazard in the storage vaults, fire detection or fire sprinklers are not provided in this area.

4.3.8.1.3 Fire Area 3 – Remaining Areas

Fire Area 3 consists of the remaining ISF building structures, diesel generator area, Visitor Center, Guard House, Administrative Center, Storage Warehouse, switchyard area, and general yard area. The ISF building structures included in Fire Area 3 consists of 15 fire zones; each of the remaining structures/areas are included in a single fire zone for the yard area. This fire area boundary isolates Fire Areas 1 and 2 from exposure fire hazards, minimizes the potential for radiological releases, and separates low but significant fire loading zones from these areas.

Cask Receipt Area (Fire Zone 1)

The Cask Receipt Area is a tall, single-story, steel-frame structure on the south side of the Storage Area and is attached to the Transfer Tunnel. The structure has a non-combustible construction with no fire rating on the exterior walls. ITS SSCs in this area include the DOE transfer cask, cask trolley, and 155-ton hoist used to move the transfer cask to the cask trolley.

The postulated fire loading in the Cask Receipt Area is associated with transport vehicle receipt and hoist/crane handling of the DOE transfer cask for movement into the Transfer Tunnel (Fire Area 1). Administrative controls on the quantity of materials in this area limit the potential fire loading. The postulated combustibles consist of Class A and B materials that constitute a low combustible loading. The 1-hour fire-rated barrier between this area and the Transfer Tunnel south wall will ensure adequate fire protection from this fire loading. Fire detection is located in this area. Automatic dry pipe fire suppression is provided in this area.

Administrative controls will ensure that the transport vehicles or other flammable-fueled vehicles will be either excluded from the area or administratively limited in fuel capacity. The DOE transfer cask and cask trolley are inherently fire resistant and will not be adversely affected by a postulated diesel fuel or lube oil fire. The fire resistance of the DOE transfer cask is described in Appendix A.

The structural supports for the 155-ton hoist will be protected by 1-hour fire proofing at the floor level up to a height determined by the Fire Hazards Analysis (FHA) to ensure that direct flames will not overheat the ITS structural elements. The postulated diesel fuel spill will drain to the west side of the structure, because of floor slope, and collect in a trench provided to contain these fluids. The postulated fire could temporarily burn around the DOE transfer cask, cask trolley, or structural support members for the 155-ton hoist, but would quickly pool in the drainage trench. Postulated lube oil spills between the cask trolley rails would run along the rail slots and minimize the size of the spill by confinement to the narrow rail slots. The separation by drainage to the trench or within the rail slots will further minimize the heating affect of this postulated fire. In addition, the volume of the Cask Receipt Area will ensure that significant heating of structures above this floor-based fire will not occur, due to the relatively small size of the postulated worst-case fire.

Second Floor Storage Area (Fire Zone 2)

The second floor Storage Area is an upper-level, single-story, steel-frame structure between the Cask Receipt Area and the Transfer Area above the storage vaults. The structure has a fire-resistive construction for the first 9 feet of wall elevation. The remainder of the structure is steel-framed non-combustible construction with no fire-rated barriers except the floor, addressed in the Storage Vaults description. ITS SSCs in this area include the CHM and SNF canisters during transfer operations to the storage vaults.

The postulated fire loading in the second-floor Storage Area is associated with CHM operation. Administrative controls on the quantity of materials in this area limit the potential fire loading. The postulated combustibles consist of Class A and B materials that constitute a low combustible loading. The 1-hour fire-rated barrier between this area and the Transfer Tunnel (Fire Area 1) and storage vaults (Fire Area 2) will ensure adequate fire protection from this fire loading. Fire detection is located in this area. Automatic fire suppression is not provided due to the radiological considerations associated with this area.

The worst-case postulated fire in this area is from high flashpoint lubricants in various machinery. The CHM structural material heat capacity and seismic structural integrity ensure that this fire loading will not adversely affect the ITS function of the CHM. The spent fuel canister will be in the CHM during transport in this area, and therefore will not be exposed directly to a postulated fire.

Operating Gallery (Fire Zone 3)

The operating gallery is a second-floor, steel-frame structure in a two-story building that is U-shaped around the east end of the FPA (Fire Area 1). The structure has a non-combustible construction with no fire-rated exterior walls. The floor is a 1-hour fire-rated barrier over the electrical room, battery room, HEPA filter room, and HVAC exhaust room; and the walls separating this area from the FPA are rated as describe in the Fire Area 1 description. ITS SSCs in this zone are associated with the wall to the FPA and are described in the discussion for that area.

The postulated fire loading in the operating gallery is associated with operations activity from this area. Administrative controls on the quantity of materials in this area limit the potential fire loading. The postulated combustibles consist of Class A materials that constitute a low combustible loading. The 1-hour fire-rated walls separating this area from the FPA (Fire Area 1) will ensure adequate fire protection from this fire loading. Both fire detection and automatic fire suppression are provided in this area.

Workshop (Fire Zone 4)

The workshop area is a second-floor, steel-frame structure in a two-story building adjacent to the south wall of the FPA (Fire Area 1). The overall structure has a non-combustible construction protected with a 1-hour fire barrier rating in this fire zone. ITS SSCs in this zone are associated with the wall to the FHM maintenance area boundary, including the personnel shielded access door, which is included in Fire Area

1. Providing fire rating for the barriers surrounding this zone isolates this low fire-load zone from ITS components adjacent to this area and confines potential radiological hazards within the zone.

The postulated fire loading in the workshop is associated with welding, machining, and repair equipment and materials. Administrative controls on the quantity of materials in this area and the use of flammable storage cabinets limit the potential fire. The postulated combustibles consist of Class A and B materials that constitute a low combustible loading. The 1-hour fire-rated barrier between this and surrounding areas will ensure adequate fire protection from this fire loading. Both fire detection and automatic fire suppression are provided in this area.

Operator's Office and Change Area (Fire Zone 5)

The Operators Office and Change Area is an upper-level, single-story, steel-frame structure on the west side of the CCA (Fire Area 1) partially above the Solid Waste Storage Area. The structure has a non-combustible construction with no fire rating on the exterior walls. A hallway connects this area on the west side of the CCA to the operating gallery on the east side of the CCA. A 1-hour fire-rated barrier is provided at the hallway intersection to the operating gallery. No ITS SSCs are in this zone but the boundary is shared with the FPA and Transfer Tunnel. Providing fire rating for the barriers separating this zone from Fire Area 1 and the second floor of the operating gallery isolates this low fire-load zone from ITS components adjacent to this area.

The postulated fire loading in the Operators Office and Change Area is associated with adjacent canister closure operations and health physics activities. Administrative controls on the quantity of materials in this area limit the potential fire loading. The postulated combustibles consist of Class A materials that constitute a medium combustible loading. A medium combustible loading is defined as an equivalent combustible loading of 30 minutes to 45 minutes. The 1-hour fire-rated barrier between this hallway and the operating gallery will ensure adequate fire protection from this fire loading. Both fire detection and automatic fire suppression are provided in this area.

Electrical Room (Fire Zone 6)

The electrical room is a first-floor, steel-frame structure, in a two-story building adjacent to the north wall of the FPA (Fire Area 1). The overall structure has a non-combustible construction protected with a 1-hour fire barrier rating in this fire zone. No ITS SSCs are in this zone, but there is a shared boundary wall with the FPA. Providing fire rating for the barriers surrounding this zone isolates this medium fire-load zone from ITS components on the level above.

The postulated fire loading in the electrical room is associated with the MCCs and electrical cabling. Administrative controls on the quantity of materials in this area limit the potential fire loading. The postulated combustibles consist of Class A materials that constitute a medium combustible loading. The 1-hour fire-rated barrier between this and surrounding areas will ensure adequate fire protection from this fire loading. Both fire detection and automatic fire suppression are provided in this area.

Battery Room (Fire Zone 7)

The battery room is a first-floor, steel-frame structure in a two-story building adjacent to the north wall of the FPA (Fire Area 1). The overall structure has a non-combustible construction protected with a 1-hour fire barrier rating in this fire zone. No ITS SSCs are in this zone. The purpose of providing fire rating for the barriers surrounding this zone is to isolate this medium fire-load zone from ITS components on the level above.

The postulated fire loading in the battery room is associated with the batteries, UPS system, and electrical cabling. Administrative controls on the quantity of materials in this area limit the potential fire. The postulated combustibles consist of Class A materials that constitute a medium combustible loading. The 1-hour fire-rated barrier between this and surrounding areas will ensure adequate fire protection from this fire loading. Both fire detection and automatic fire suppression are provided in this area.

HEPA Filter Room (Fire Zone 8)

The HEPA filter room is a first-floor, steel-frame structure in a two-story building adjacent to the south wall of the FPA (Fire Area 1). The overall structure has a non-combustible construction protected with a 1-hour fire barrier rating in this fire zone. No ITS SSCs are within this zone, but there is a shared boundary with the FPA. Providing fire rating for the barriers surrounding this zone isolates this medium fire-load zone from ITS components on the level above.

The postulated fire loading in the HEPA filter room is associated with HVAC equipment and the non-combustible HEPA filters enclosed in the ducting. Administrative controls on the quantity of materials in this area limit the potential fire loading. The postulated combustibles consist of Class A materials that constitute a low combustible loading. The 1-hour fire-rated barrier between this and surrounding areas will ensure adequate fire protection from this fire loading. Both fire detection and automatic fire suppression are provided in this area. In addition, the HEPA filtration system is provided with an automatic deluge suppression system.

HVAC Exhaust Room (Fire Zone 9)

The HVAC exhaust room is a first-floor, steel frame structure, in a two-story building adjacent to the south and east wall of the FPA (Fire Area 1). The overall structure has a non-combustible construction protected with a 1-hour fire barrier rating on the ceiling and interior walls to the adjacent HEPA filter room and battery room. The exterior walls are also 1-hour fire-rated. No ITS SSCs are within this zone, but there is a shared boundary with the FPA. Providing fire rating for the barrier separating this zone from adjacent rooms and the FPA isolates this medium fire-load zone from ITS components on the level above.

The postulated fire loading in the HVAC exhaust room is associated with the HVAC equipment. Administrative controls on the quantity of materials in this area limit the potential fire loading. The postulated combustibles consist of Class A materials that constitute a medium combustible loading. The 1-hour fire-rated barrier between this and surrounding areas will ensure adequate fire protection from this fire loading. Both fire detection and automatic fire suppression are provided in this area.

New Canister Receipt Area (Fire Zone 10)

The new canister receipt area is a one-story, steel frame structure, located on the north end of the Transfer Tunnel/Canister Closure Area (Fire Area 1). The overall structure has a non-combustible construction protected with a 1-hour fire barrier rating on the ceiling to the CCA and south wall. The exterior walls are not fire-rated. No ITS SSCs are in this zone. Providing fire rating for the barrier separating this zone from adjacent rooms and the Transfer Tunnel/Canister Closure Area isolates this low fire-load zone from ITS components in Fire Area 1 and material located in the adjacent radiological storage area.

The postulated fire loading in the new canister receipt area is associated with canister receipt operations. Administrative controls on the quantity of materials in this area limit the potential fire loading. The postulated combustibles consist of Class A materials that constitute a low combustible loading. The 1-hour fire-rated barrier between this and surrounding areas will ensure adequate fire protection from this fire loading. Both fire detection and automatic fire suppression are provided in this area.

Liquid and Solid Waste Areas (Fire Zones 11, 12, and 13)

The liquid and solid waste areas include the Solid Waste Storage Area (Fire Zone 11), the SWPA (Fire Zone 12), and the Liquid Waste Storage Area (Fire Zone 13). The liquid and solid waste areas are a single-story, part steel-frame/part concrete structure at grade level on the west side of the Transfer Tunnel (Fire Area 1). The steel structure is non-combustible construction with 1-hour fire rating in this fire zone. The reinforced concrete structure is fire resistive construction with a minimum 3-hour fire rating for the structural components. No ITS SSCs are in this zone, but part of the walls and ceiling do frame boundary with the FPA and tunnel. The barriers surrounding the liquid and solid waste processing and storage areas are 1-hour fire-rated, based on the contents and the potential for radiological releases. The walls and doors between the three fire zones that make up this area are not fire rated.

The postulated fire loading in the liquid and solid waste area is associated with waste processing equipment and miscellaneous dry combustibles. Administrative controls on the quantity of materials in this area and the use of flammable storage cabinets limit the potential fire loading. The postulated combustibles consist of Class A and B materials that constitute a medium combustible loading in Fire Zones 11 and 12. Fire Zone 13 has a low combustible loading. The 1-hour fire-rated barrier between these zones and surrounding areas will ensure adequate fire protection from this fire loading. Both fire detection and automatic fire suppression are provided in these areas.

Operations Area (Fire Zones 14 and 15)

The Operations Area is a two-story, steel-frame structure on the west end of the FPA (Fire Area 1) and the liquid and solid waste areas. The structure has a non-combustible construction with no fire rating on the exterior walls. The walls separating this zone from the first and second floor of the Transfer Area are 1-hour fire-rated. No ITS SSCs are in this zone. Providing fire rating for the barriers separating these zones from Fire Area 1, liquid and solid waste areas, and the second floor of the operating gallery isolates this medium fire-load zone from adjacent ITS components.

The postulated fire loading in the operations area is associated with administrative and record keeping and health physics activities. Administrative controls on the allowable quantity of materials in this area and the use of flammable storage cabinets limit the potential fire loading. The postulated combustibles consist of Class A and B materials that constitute a medium combustible loading. The 1-hour fire-rated barrier between this area and the remainder of the facility will ensure adequate fire protection from this fire loading. Both fire detection and automatic fire suppression are provided in this area.

ISF Facility Yard Area (Fire Zone 16)

The general yard area surrounds the other structures and the switchyard area within the ISF Facility site boundary fence. The concern for this area is a wildfire from outside the facility creating a fire hazard for the ITS SSCs. The ISF Facility site features provided to mitigate the concern from a range fire are discussed in Section 8.2.4.4.

The general yard area includes several structures to be discussed separately: the diesel generator area, Guard House, Visitor Center, Administration Center, Storage Warehouse, and switchyard area.

The diesel generator area is in the switchyard area over 20 feet northeast of the ISF building. No building structure is associated with the diesel generator package. This area does not contain ITS SSCs. The fuel oil supply for the diesel engine driver is approximately 1000 gallons, and is directly under the diesel engine/generator set in a double-wall tank in accordance with NFPA 30 (Ref. 4-40). The distance separating this component from the ISF building and the fuel oil tank design standards ensure that an exposure fire hazard is not created.

The Guard House is over 200 feet west of the ISF building. This building does not contain ITS SSCs. The building has no fire-rated barriers. The building is a small office area and will contain various amounts of Class A combustibles. The distance separating this structure from the ISF building ensures that an exposure fire hazard is not created, in accordance with NFPA 80A (Ref. 4-41). Fire detection is provided for this structure.

The Visitor Center is over 200 feet west of the ISF building. This building does not contain ITS SSCs. The building has no fire-rated barriers. The building is generally open for display areas and will contain various amounts of Class A combustibles. The distance separating this structure from the ISF building ensures that an exposure fire hazard is not created, in accordance with NFPA 80A. Fire detection is provided for this structure.

The Administration Center is over 50 feet west of the ISF building. This building does not contain ITS SSCs. The building has no fire-rated barriers. The building will contain office spaces with a moderately high Class A combustible fire loading. The distance separating this structure from the ISF building ensures that an exposure fire hazard is not created, in accordance with NFPA 80A. Fire detection is provided for this structure.

The Storage Warehouse is over 50 feet northeast of the ISF building. This building does not contain ITS SSCs. The building has no fire-rated barriers. The distance separating this structure from the ISF building ensures that an exposure fire hazard is not created, in accordance with NFPA 80A. Fire detection is provided for this structure.

The switchyard area is an outside area where the ISF Facility power supply transformer and diesel generator area (addressed separately) are approximately 20 feet from the northeast corner of the operating gallery. This area contains a seismic switch system classified ITS.

The seismic switch system is ITS during an earthquake and does not provide a safety function during other postulated events. If an earthquake is postulated to occur that directly results in a fire in this area, the seismic switch system will have performed the safety function before it is exposed to the hazards of a subsequent fire. If a fire occurs first, a subsequent earthquake need not be postulated. Therefore, no fire protection is necessary to ensure that the seismic switch system can perform the intended safety function.

The worst-case postulated fire hazard in this area, excluding the diesel generator discussed separately, is the step-down transformer. The transformer converts the 13.8 kV supply power to 480-208/120 V power to the ISF Facility. The transformer contains approximately 600 gallons of oil. The distance separating this transformer from the ISF building ensures that an exposure fire hazard is not created, in accordance with Factory Mutual Data Sheet 5-4, *Transformers*.

4.3.8.1.4 Design Code Compliance

The following lists various fire water system components and their respective codes.

- sprinkler systems designed in accordance with NFPA 13 (Ref. 4-42)
- standpipe and hose connections designed in accordance with NFPA 14 (Ref. 4-43)
- INTEC fire pumps and water supply tanks provided in accordance with NFPA 20 (Ref. 4-44) and NFPA 22 (Ref. 4-45), respectively
- fire hydrants and water mains designed and installed in accordance with NFPA 24 (Ref. 4-46) and American Water Works Association specifications
- portable fire extinguishers provided in accordance with NFPA 10 (Ref. 4-47)
- fire protection equipment including the sprinkler systems, standpipe and hose connections in the ISF Building, yard hydrants, ISF Facility underground fire main loop, and all associated components maintained in accordance with NFPA 25 (Ref. 4-48)
- fire detection systems designed in accordance with NFPA 72 (Ref. 4-49)
- lightning protection designed and installed in accordance with NFPA 780 (Ref. 4-50)
- ISF building occupancy classification in accordance with the Uniform Building Code (International Conference of Building Officials) (Ref. 4-51)

4.3.8.2 System Description

The fire protection system consists of monitoring, detection, alarm, suppression, and extinguishing systems to protect the area or equipment from damage by fire. It includes the following major features:

- fire protection water supplies, yard mains, and hydrants
- automatic wet and dry sprinklers
- standpipes and hose connections
- fire and smoke monitoring, detection, and alarm systems
- fire barriers, seals, and penetrations
- smoke removal
- offsite fire department support

The fire protection system components provide comprehensive protection against fire hazards throughout the facility, with the greatest emphasis on the risk of fire in the component's immediate location.

The ISF Facility is designed so that ITS SSCs do not require electrical power to perform their safety functions. Therefore, no unique features are provided to protect the electrical power and control cabling from fire exposure, other than that normally provided by a non-combustible construction type and administrative controls to limit the potential fire loading in ITS areas of the facility.

4.3.8.2.1 Fire Protection Water Supply

The ISF Facility fire water supply system is provided by the existing INTEC main water distribution system, a raw water system independent of the potable water system. It consists of two deep well pumps, water storage tanks, fire pumps, make-up pumps, distribution piping, and isolation valves. The fire water system is classified NITS.

The INTEC fire water supply system is designed to be fully redundant. The storage tanks can be filled by either deep well pump, and each water storage tank and fire pump can support the maximum water demand rate. The fire water storage system consists of two 60-foot diameter by 40-foot high, seismically qualified water storage tanks. These tanks supply both the fire water distribution system and the raw water system storage tanks. When the water level drops in the raw water tanks, a signal is transmitted to the deep well pumps to start. The deep well pumps fill the fire water storage tanks to the point where the tanks overflow into a standpipe that supplies the raw water tanks. INTEC use of the raw water system continually circulates water through the fire water tanks, thereby maintaining the fire water temperature well above freezing during the winter. A minimum of 450,000 gallons is reserved in each of the fire water storage tanks for firefighting purposes. This minimum supply exceeds the postulated largest expected fire water flow rate in accordance with NFPA 13 for a period of 2 hours, including a 500 gpm allowance for manual hose streams at the ISF Facility.

Each INTEC fire water storage tank has an associated fire pump and pump house. The fire water storage tanks and pump systems are independent, but supply a common water distribution system. Each fire pump is rated for 2500 gpm at 125 psi and is powered by a diesel driver. Equipment associated with the fire water pump trains is UL listed and FM approved.

The INTEC fire water distribution system static pressure is maintained by two electric make-up pumps rated at 300 gpm at approximately 160 psi. These pumps are designed to minimize pressure fluctuations on the system and are not required to maintain system operability. These pumps prevent minor system pressure fluctuations from unnecessarily starting the larger fire pumps and causing premature wear on the main fire pumps. One make-up pump maintains the static pressure of the main water distribution system at approximately 135 psi when there is little demand on the system. If the water pressure in the main water distribution system drops to approximately 125 psi, the second make-up pump starts. If the pressure in the main water distribution system continues to drop and reaches approximately 120 psi, the fire pump sequential timers start.

There is a sequential timer in each of the fire pump control panels. The sequential timer starts when the pressure in the main water distribution system drops to approximately 120 psi. A pressure of approximately 140 psi must be developed to stop and reset the sequential timer. If the main water distribution system pressure has not recovered to greater than approximately 140 psi within 30 seconds, the primary fire pump starts. If the stop pressure of approximately 140 psi has not developed within 50 seconds, the secondary fire pump starts. The fire pumps must be manually shut off once they have started. At the annual fire pump testing, the pump start sequence, primary and secondary, is reversed.

The INTEC main water distribution system is a loop configuration with two dead-end legs. The main water distribution system piping varies from 8 inches to 12 inches in diameter. Several pipe materials are present in the underground supply system, including steel, cement-lined ductile iron, PVC, and bond strand fiberglass pipe. The two underground connections from the INTEC main water distribution system to the ISF Facility underground fire water loop are made from connections to the distribution piping.

The ISF Facility underground fire main loop is designed and installed in accordance with NFPA 24, *Standard for the Installation of Private Fire Service Mains and Their Appurtenances*, and AWWA specifications. Isolation valves throughout the ISF Facility underground fire main loop allow isolation of loop sections or of individual fire suppression systems. The isolation valves permit isolation of outside fire hydrants from the fire main for maintenance or repair without interrupting the water supply to automatic or manual fire suppression systems in the ISF Facility areas containing or presenting a fire hazard to ITS SSCs. Fire hydrants are installed approximately every 250 feet along the ISF Facility underground fire main loop. Threads compatible with those used by the INEEL fire department are provided on hydrants and standpipe risers in the ISF Facility.

4.3.8.2.2 Fire Suppression

The automatic fire suppression in the ISF building is a hydraulically designed (ordinary hazard) system that generally uses wet-pipe sprinklers in the climate-controlled portions of the building, and dry-pipe sprinklers in the remaining areas. The exceptions are Fire Area 1 (Transfer Tunnel, FPA, and CCA), Fire Area 2 (storage vaults), and a portion of Fire Area 3 (second floor Storage Area).

Fire Area 1 contains areas where SNF is packaged for interim storage; because of concerns with potential criticality and spread of contamination, the area does not have automatic water suppression. Fire Area 2 is inaccessible to personnel and does not normally contain combustible materials or credible ignition sources. A fire zone within Fire Area 3 for the second floor Storage Area contains equipment used to transport ISF canisters to the storage vaults (Fire Area 2). Because of concerns for potential spread of contamination combined with a low combustible loading, the area does not have automatic water suppression.

The areas of the facility used for operator monitoring and security monitoring are provided with automatic sprinkler protection. These areas are located in the second floor operations area (fire zone 15) and the operator's office (fire zone 5).

The primary HEPA filters in Fire Area 3 (HEPA filter room) are provided with an internal deluge system in accordance with NFPA 801.

4.3.8.2.3 Standpipes and Hose Connections

The ISF building is equipped with seismically supported standpipes and hose connections in the stair enclosures.

4.3.8.2.4 Fire Detection

Fire detection in the ISF building is provided in areas where significant fire loading is postulated, personnel may be present, and the room involves a floor area of at least 200 square feet.

The fire detection system consists of photoelectric/ionization smoke detectors, or equivalent, and air sampling smoke detectors in or drawing air samples from the ISF building areas, except the enclosed storage vault area and small closet or cable/duct chase areas. The storage vaults are inaccessible and do not normally contain combustible material or ignition sources. Areas that contain smoke detectors and/or personnel have manual pull systems. Fire suppression water flow alarms are also provided in the ISF building. The smoke detectors, manual pull stations, and water flow alarms in each area are interconnected to a central alarm panel in the ISF Facility operations monitoring room. The ISF Facility central alarm panel will report grouped alarms (alarm, supervisory, trouble) to the central fire alarm station at the continuously manned INEEL facility.

The smoke alarms will sound in the ISF building where personnel may be located, and at the continuously manned INEEL facility.

The fire detection and alarm system equipment is powered by a local battery system that is connected to the battery backup UPS system in the ISF building, which is connected to the utility grid and to the standby diesel generator.

Smoke detectors in the HEPA filter air streams and inside the ductwork will monitor air filtration equipment and exhausts. In addition, the smoke detection in Fire Area 1 (Transfer Tunnel, FPA, and CCA) will electrically activate the closure of fire dampers around this area and trip the supply and exhaust fans to prevent the potential spread of contamination.

In addition, photoelectric/ionization smoke detectors are installed in the Guard House, Visitor Center, Operations Center, and Storage Warehouse buildings. These outlying building smoke detectors are not required to protect SSCs ITS, and no credit was taken for these detectors when the evaluation for exposure fire hazards was made.

4.3.8.2.5 Fire Barriers

Passive fire protection includes fire barrier walls, fire doors, and fire barrier penetration seals. The stair enclosures are 1-hour fire rated enclosures for life safety purposes. The remaining fire-rated walls, described in Section 4.3.8.1, are 1-hour fire-rated throughout the ISF building. Penetrations in the fire-rated walls will be sealed in accordance with NFPA 221 (Ref. 4-52).

Fire doors in the 1-hour fire-rated walls are fire rated in accordance with NFPA 80. Certain specialty doors will have an equivalency evaluation performed when rated doors are not available.

Fire dampers in the ventilation ducts that penetrate into the FPA confinement barrier are fire-rated components installed in accordance with NFPA 90A (Ref. 4-53).

4.3.8.2.6 Smoke Removal

Smoke from a fire in the ISF building will be removed by the building's ventilation exhaust fans, except in the Fire Area 1 rooms. The rooms in Fire Area 1 will be isolated by fire dampers, with the ventilation fans tripped, until radiological concerns can be addressed. Fans will be manually operated to exhaust any remaining smoke from the area after the radiological concerns are addressed. Portable exhaust fans may be used by the INEEL fire department, as necessary.

4.3.8.2.7 Off Site Fire Department Support

The INEEL fire department provides off site fire response in accordance with the emergency plan. The protection provided by the INEEL fire department is similar to that provided to the nearby TMI-2 ISFSI.

4.3.8.3 System Evaluation

Potential fires affecting ITS SSCs are evaluated in Section 8.2.4.4. The analysis concludes that these postulated fires will not produce an unsafe condition or preclude the ability of the ITS SSCs to function. The sprinkler system in the ISF building further ensures that fires will be automatically extinguished within a short time. Backup manual fire suppression and early warning fire detection are also provided. These features support the defense-in-depth approach used for the overall fire protection program.

The FHA was performed in accordance with NRC guidance and NFPA-801. The FHA includes an assessment of the postulated fire loading in each area, used to establish the adequacy of the passive fire-rated barriers in the ISF building. Combustible materials in areas containing ITS SSCs are estimated at less than 10 pounds per square foot: a fire severity approximately equivalent to a standard fire curve 1-hour fire loading, as defined by the NFPA Fire Protection Handbook, 18th Edition, Section 7, Chapter 5 (Ref. 4-54). Therefore, a 1-hour fire-rated barrier will appropriately contain postulated fires in the ISF building and passively prevent fire spread outside the area of origin.

The fire water standpipes in the ISF building stair enclosures are seismically supported to ensure manual fire fighting capability throughout the structure after a postulated earthquake. A non-seismically designed sprinkler system may fail and create water exposure or flooding concerns. The ISF building electrical system, which may be affected by postulated water exposure, is not classified ITS; thus, its failure could not adversely affect safety functions. The ISF building drainage system has been sized to accommodate postulated pipe break flow and prevent flooding in each area. Potentially contaminated areas containing sprinkler piping will drain to the Transfer Tunnel. The Transfer Tunnel is designed to contain the credible water sources discharged from fire fighting activities for 30 minutes, in accordance with NFPA 801.

4.3.8.4 Inspection and Testing Requirements

The fire protection systems including the sprinkler systems, standpipe and hose connections in the ISF building, yard hydrants, ISF Facility underground fire main loop, and associated components will be maintained in accordance with NFPA 25. The fire detection and alarm system will be maintained, inspected, and tested in accordance with NFPA 72, *National Fire Alarm Code.*

Fire barriers, excluding penetration seals, fire dampers, and fire doors will be visually inspected at least once per 18 months. Penetration seals will be identified by type and at least 10 percent of each type will be visually inspected at least once per 18 months. If the penetration seal is determined to be inoperable, an additional 10 percent of the degraded type of seal will be visually inspected. This process will continue until a 10-percent sample with no visually apparent adverse degradation has been completed or until all required sealed penetrants of the degraded type have been inspected. Samples will be selected such that each penetration seal will be inspected at least once per 15 years.

4.3.8.5 Personnel Qualification and Training

The design and selection of equipment, inspection and testing of completed physical aspects of the fire protection systems, and development of the overall fire protection program will be performed with the assistance of a qualified fire protection engineer. A qualified fire protection engineer will be either a graduate of an accredited engineering curriculum and have completed not less than 4 years of engineering practice, 3 of which shall have been in responsible charge of diverse fire protection engineering work. If not such a graduate, a qualified fire protection engineer shall either (1) demonstrate a knowledge of the principles of engineering and have completed not less than 6 years engineering practice, 3 of which shall have been in responsible charge of diverse fire protection engineering projects; (2) be a registered professional engineer in fire protection; or (3) meet the requirements for Member Grade in the Society of Fire Protection Engineers.

The offsite fire department periodic training and fire drills will be handled under the DOE program for the INEEL site, which has previously been reviewed for the nearby TMI-2 ISFSI. The ISF Facility will coordinate training with the INEEL Fire Department to ensure that site-specific training is incorporated. Personnel at the ISF Facility will be provided training as part of the General Employee Training Program. Specialized training will be provided to emergency response personnel in accordance with the ISF Facility Emergency Plan.

Personnel responsible for maintaining and inspecting the fire protection equipment will be under control of ISF Facility personnel as specified in the fire protection program.

4.3.9 Maintenance Systems

This section describes the design bases, locations, and modes of operation related to the maintenance programs for the ISF Facility. Chapter 5, *Operation Systems*, describes the systems and operations necessary for maintaining the facility in a safe condition. As part of the maintenance program, routine tests and inspections are to be performed, at specific intervals, on selected equipment to verify that safety features built into the various systems are operating correctly and have not been damaged or their function otherwise compromised. Special tests and inspections will be performed following off-normal events in accordance with approved facility procedures. Non-standard operations are discussed in Section 5.1.1.6.

Generally, ISF Facility major equipment is designed for a 40-year life with replacement components having a typical service life of 1 to 5 years. The ISF Facility maintenance program consists of two general types of maintenance activities: (1) routine maintenance, and (2) overhaul maintenance. Routine maintenance ensures that moving parts are correctly lubricated and that wear is detected before the part fails. Equipment is inspected regularly, at intervals determined by the amount and type of work the equipment does and the frequency of use.

Overhaul maintenance includes replacement of specific components when routine maintenance indicates that replacement is required. The extent of dismantling is determined by the condition of the subassemblies. Some subassemblies may not require strip-down, but this decision is based on the results of inspection as dismantling proceeds. Maintenance activities are performed in accordance with operations and maintenance procedures in conjunction with approved facility drawings.

4.3.9.1 Major Components and Operating Characteristics

This section describes the major components and operating characteristics of the primary ISF Facility maintenance systems. These systems include the following:

- Storage Area maintenance hoist
- FHM and PMS
- FHM Maintenance Area
- CHM maintenance equipment
- Transfer Tunnel Trolley maintenance area
- Workshop Area

Maintenance features associated with the CHM are described in Section 4.7.3.

4.3.9.1.1 Storage Area Maintenance Hoist

The Storage Area maintenance hoist is a 10-ton capacity overhead electric wire-rope hoist system that runs along a monorail hoist beam built into the roof structure of the Storage Area. This hoist operates in the Storage Area along the centerline of the Transfer Tunnel. It handles parts for the CHM during maintenance operations and other equipment used during Storage Area maintenance activities. It also raises and lowers equipment through the CHM maintenance hatch. The Storage Area maintenance hoist consists of the following components:

- 10-ton capacity overhead electric wire rope hoist assembly and trolley
- monorail hoist beam
- power supply and control collectors, support brackets, and festooning

4.3.9.1.2 FHM and PMS

The FHM is mounted on rails in the FPA and FHM Maintenance Area. The PMS is mounted on the FHM trolley. It is used primarily to assist in latching and delatching lifting devices in the FPA. It can also assist with maintenance work in the FPA, such as removal and replacement of equipment and in-cell HEPA filters. Additional information regarding the FHM and PMS is provided in Section 4.7.3

4.3.9.1.3 FHM Maintenance Area

The FHM Maintenance Area is at the west end of the FPA, separated by a thick concrete wall. The FHM Maintenance Area is shown in Figure 4.3-15. The opening between the FPA and the FHM Maintenance Area is T-shaped to allow passage of the FHM and PMS through steel shield doors.

A 2-ton crane is installed in the overhead of the FHM Maintenance Area to provide for the removal, maintenance, or replacement of FHM parts. A hoist well is incorporated into the floor of the FHM Maintenance Area to allow access to the SWPA below to facilitate removal and replacement of components needed to maintain the FHM. A shielded personnel access door provides access into the FHM Maintenance Area from the workshop. Stairways and platforms inside the FHM Maintenance Area provide access up to the FHM level.

4.3.9.1.4 CHM Maintenance Equipment

Maintenance equipment is provided for routine maintenance of the CHM. The CHM is located in the storage area over the transfer tunnel for maintenance as this provides a clear working floor area and the use of the overhead 10 ton capacity maintenance hoist.

The major components and operating characteristics of the CHM are discussed in Section 4.7.3. Non-standard operations for this system are described in Section 5.2.2.1.1.

The main CHM maintenance equipment items are:

- maintenance trolley for removing the nose and turret base castings from the rotating turret
- setting jig for targeting the TV camera
- hydraulic stud tensioning kit
- turret jacking equipment

CHM Maintenance Trolley. The CHM maintenance trolley enables initial site assembly and subsequent removal for maintenance, if needed, of the following subassemblies:

- nose casting and shield skirt
- lower shield casting
- intermediate shield casting
- transition shield casting

The maintenance trolley assembly consists of a fabricated steel frame supported at each corner by a swivel wheel assembly. One side of the frame is removable to allow access for the trolley assembly around the CHM shield skirt. On the upper side of the frame are three screw jacks to raise and lower the assemblies into position.

Setting Jig for Targeting the TV Camera. This jig is used to target the cross wires of the TV camera image on the center of the CHM nose bore, at the level of the top of the tube plug lifting pintle. With the CHM over the maintenance pit, the jig is bolted to the underside of the nose and the camera cross wires targeted on to the bulls eye that is located in the center of the jig. This procedure can be repeated at regular intervals for confirmatory purposes or after alignment camera maintenance activities.

Hydraulic Stud Tensioning Kit. This is commercial equipment used for controlled tightening of the long studs in the turret cask shielding sections and preloading the slewing ring bearing studs. The equipment is used primarily for initial assembly of the CHM, but can be used for major dismantling and maintenance activities.

Turret Jacking Equipment. The turret jacking equipment is provided to enable removal of the 2 inch packers for raising or lowering the turret assembly in situ, without having to dismantle the turret assembly down to its smaller piece part assemblies. The packers are adjusted in thickness to set the running clearance between the CHM shield skirt over the charge face. Once the running clearance of the CHM has been set during initial installation, it is not expected to require further adjustment for the rest of the facility operation.

4.3.9.1.5 Cask and Canister Trolley Maintenance

Routine maintenance of the cask trolley and the canister trolley takes place in the transfer tunnel at either the cask decontamination zone or in the cask receipt area. The cask receipt crane auxiliary hoist, or the cask receipt crane main hoist used for lifting components off and on the trolleys when they are in the cask receipt area. Maintenance that does not require overhead lifting equipment is performed with the trolleys located in the decontamination zone.

4.3.9.1.6 Workshop Area

A workshop for routine maintenance and repair of both contaminated and non-contaminated equipment is on the second floor of the Transfer Area, outside of the FHM Maintenance Area, as shown in Figure 4.2-2.

4.3.9.2 Safety Considerations and Controls

The ISF Facility design simplifies access for maintenance of SNF handling equipment, and ensures adequate radiation protection and confinement of radioactive contamination, so that routine and corrective maintenance can be performed with minimal personnel radiation exposure.

- Storage Area Maintenance Hoist – The Storage Area maintenance hoist is classified NITS. The hoist beam incorporates end stops (bumpers) to prevent damage to equipment. Maintenance activities in the Storage Area are performed in a clean non-contaminated area. Workers are exposed to only minimal radiation, because of built-in shielding.
- FHM and PMS – This equipment allows recovery of the FHM hoist and transfer of the FHM and PMS to the maintenance area in the event of any single component failure. Off-normal event recovery operations for these systems are described in Section 5.1.1.6, and the safety considerations/controls associated with the FHM and the PMS are described in Section 4.7.3.2.

  Items of the FHM requiring maintenance can be broken down into easily detachable units that can be handled by the 2-ton maintenance crane in the FHM Maintenance Area. The units are also sized to fit through the door. The FHM design considers that operators wearing protective suits, rubber gloves, and respirators to carry out maintenance. Special tools required for maintenance are supplied with the FHM.
- FHM Maintenance Area – A thick concrete wall separates the FPA and the FHM Maintenance Area. Steel shield doors allow the FHM to move between the FPA and the FHM Maintenance Area. The shield doors provide the necessary radiation shielding protection if work must be done

on the FHM while there is SNF in the FPA. A control station adjacent to the shield window in the south operating gallery nearest the workshop opens and closes the shield doors. It contains controls, indications, and alarms to enable safe control of the shield doors. The control system provides operational and safety interlocks, and system status and alarms to the IDCS.

- Workshop Area – The workshop is designed in accordance with OSHA Standards in 10 CFR 1910 (Ref. 4-55) to ensure a safe working environment during maintenance activities. Appropriate contamination control methods will be used when performing maintenance and repair on contaminated items inside the workshop.

4.3.10 Cold Chemical Systems

The chilled-water system primary side loop will contain a 50-percent mixture of propylene glycol and water. The secondary side loop will contain potable water. A backflow preventer is installed to ensure no chemical contamination of the potable water system. Chemicals will be added to inhibit corrosion. Five-gallon chemical feed tanks are installed in the primary and secondary side of the system, in the mechanical equipment room. These chemicals are used in small quantities in the first floor of the Transfer Area and do not pose a hazard to personnel or to handling and storage of SNF.

4.3.11 Air Sampling Systems

Air sampling and monitoring systems are used for process controls, evaluation of environmental releases, and personnel protection. Workplace monitoring uses portable monitors and fixed location samplers. Portable monitors are used in work areas with the potential for a rapid or significant change in airborne radioactivity. An exhaust stack monitor continuously monitors environmental releases from the facility. CAMs and ARMs are in the Cask Receipt Area, Transfer Tunnel, Storage Area, and Transfer Area. CAM locations are described and shown in Chapter 7, *Radiation Protection*.

4.3.11.1 Major Components and Operating Characteristics

A fixed monitoring system is used to evaluate the ISF Facility exhaust stack releases. This air sampling system samples and monitors ventilation exhaust air for beta, gamma, ^3H, and particulate iodine. Multiple sampling probes in the stack draw a sample stream down to sampling and monitoring instruments. The beta-gamma monitoring units have local and remote alarm capability. A multi-point in-stack isokinetic sampling probe is designed based on the airflow profile of the stack. The sampling system is designed so that a variation in exhaust flow rate will result in a variation in monitoring system flow rate. A flow totalizer is used to determine the amount of stack effluent removed for the monitoring system.

HVAC exhaust flow from the FPA is sampled by a process fixed head sampler located downstream of the in-cell HEPA filters and upstream of the first-stage exhaust HEPA filters. The monitoring unit can initiate automatic actions such as tripping the intake and exhaust fan, changing HVAC valve or damper position, and other protective actions. In addition to the exhaust monitoring system, fixed and portable sampling systems are used in areas with the potential for a rapid or significant change in airborne radioactivity. Portable monitoring systems will also be used for personnel protection during maintenance and repair activities in areas with the potential for airborne radioactivity. Fixed location samplers are in the CCA, operating gallery, workshop, Transfer Tunnel, Liquid Waste Storage Tank Area, and the SWPA and Solid Waste Storage Area. Readouts from various CAMs will be routed to the central radiation control panel.

Local-alarming portable monitoring units (alpha or beta CAMS) are available to provide early warning of significant changes in airborne activity during facility activities, when necessary. Additional operating characteristics are described in Chapter 7, *Radiation Protection*.

4.3.11.2 Safety Considerations and Controls

The exhaust stack monitoring system provides local and remote alarms. These units have two radioactivity alarm levels (high and low) and system failure indication. The high-level set point is used to initiate an alarm; the low-level and system failure set points requires personnel to investigate and determine the cause for the alarm. The exhaust stack monitoring system is connected to a dedicated UPS. In case of a power failure the system will remain operating. The UPS is powered from the standby MCC, which is automatically energized from the standby diesel generator during a loss of offsite power.

Portable monitors would continue to operate during off-normal and accident conditions. CAMs are connected to the UPS and will remain in operation during power failure. Vacuum sources for the radiation monitoring equipment are portable and will also continue to operate during off-normal and accident conditions.

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4.4 DECONTAMINATION SYSTEMS

4.4.1 Equipment Decontamination

Equipment may require decontamination to reduce personnel radiation exposure. Equipment requiring radioactive decontamination may be decontaminated in place or by moving it to an area specifically designed for such decontamination processes. Major facility areas where equipment decontamination may be needed are equipped with necessary services. Decontamination processes will include methods such as wipedown with dry or dampened towels or rags, bottle water, or water spray. More aggressive methods may be employed on a case-by-case basis, depending on the value of the item (either monetary or for plant operation) and the desired endpoint.

4.4.1.1 Major Decontamination Systems

FWENC anticipates that four facility areas will require routine equipment decontamination services: (1) FHM Maintenance Area, (2) Transfer Tunnel, (3) CCA, and (4) SWPA. Non-routine decontamination activities may be required at any location (radiation areas) in the facility. A liquid collection sump is built into the FPA floor specifically for use during decontamination and dismantling of the total facility or the FPA. Blind flanges and removable spool pieces outside the area shielding walls will isolate the sump discharge lines from the liquid waste collection system.

FHM Maintenance Area

The FHM Maintenance Area is on the second floor of the FPA at the west end of the fuel handling area, as shown on Figure 4.2-2. This area is separated from the FPA by a shield wall and steel shield doors. The shield wall extends above the floor and includes a t-shaped slot to allow passage of the FHM into this area for maintenance. The shield door can be closed after the FHM is moved into this area, to allow personnel to access this area even if SNF is present in the FPA.

This area will also be used to maintain or repair other equipment from the FPA that can be brought into it by the FHM. A hoist well in the floor of the FHM Maintenance Area allows access to the SWPA below. Workers can remove smaller items to the adjacent workshop. Concrete surfaces and joints of this area are sealed to minimize the absorption of radioactive contamination and to aid in facility decontamination.

Cranes and other equipment will normally be decontaminated by manual wipedown using dampened towels and rags. Water or mild decontamination solution spray may be used to facilitate decontamination. Such waste will be disposed of as solid waste material. A limited quantity of free liquid (mainly water) will be allowed in this area. Liquids will be adsorbed and disposed of as solid waste, or transferred to the Liquid Waste Storage Tank Area.

Transfer Tunnel Cask Decontamination Zone

The Cask Decontamination Zone, shown in Figure 4.2-1, is in the south section of the Transfer Tunnel and is defined by the outer and inner doors of the Transfer Tunnel. The CHM maintenance hatch is in the ceiling of the Cask Decontamination Zone. The hatch is covered with a steel box that provides additional headroom above the tunnel ceiling to allow personnel access to the top of a cask on the cask trolley. The concrete surfaces and joints in this area are sealed to minimize the absorption of radioactive contamination and to aid in facility decontamination. The floor is sloped to a sump near the center of this area to support decontamination operations. This sump can be pumped to the liquid waste storage tank for processing.

The Cask Decontamination Zone is used to decontaminate external surfaces of the empty DOE transfer cask and the cask trolley before movement into the Cask Receipt Area, thus preventing the potential spread of contamination into the "clean" Cask Receipt Area. This cask is expected to be decontaminated by manual wipedown with dampened rags or towels.

The sump allows the use of a larger quantity of water and additional portable equipment for decontamination. This would be performed as a special process requiring special implementation approval.

Canister Closure Area

The CCA is on the second floor of the Transfer Area, as shown in Figure 4.2-2. This area is predominantly a "clean" area and is used for automatic welding of the canister lid to a loaded ISF canister, and for drying, purging, and inerting the ISF canister with helium.

The principal decontamination operation in this area is decontamination of the canister weld prep area before automatic welding. Dampened rags or towels will be used for wipedown. They may be dampened with either water or mild decontamination solution available in the area in small quantities.

Solid Waste Processing Area

The SWPA is on the first floor, west side of the Transfer Area, as shown in Figure 4.2-1. The floors and walls are sealed to minimize absorption of contamination and aid in cleanup and decontamination at the end of a waste processing campaign.

Radioactively contaminated material items such as towels, rags, and spray bottles from ISF Facility operations is received in this area for volume reduction, packaging and shipping. In addition, there is a sump pit, which can be used with a pump to send wastewater to the Liquid Waste Storage Tank Area.

4.4.1.2 Safety Considerations and Controls

As discussed above, the floors and walls of areas where decontamination activities are performed are sealed to minimize contamination retention. Engineered features to minimize exposure and contamination spread also include drainage control, curbing, and floors sloping to local sumps or drains. Using ALARA principles, radiation exposure to workers during decontamination activities will be minimized by both administrative and engineered controls. Before decontamination activities begin, the surrounding area and item to be cleaned will be evaluated to identify radiation levels, specific administrative controls, and needed personnel protective equipment.

4.4.2 Personnel Decontamination

Under normal operating conditions, personnel are not likely to be contaminated. However, if a worker becomes contaminated, a decontamination shower is provided on the second floor of the Operations Area.

Wastewater from the shower is collected and sent to the Liquid Waste Storage Tank Area.

Personnel with suspected radioactive contamination, but without an injury, will go or be escorted to a personnel decontamination station. The area of concern will be identified using portable survey instrument or other monitoring techniques. Special emphasis will be placed on locating "hot spots" on the individual.

Decontamination methods may include wiping of contaminated area with appropriate material, safety shower procedures, eye wash procedures, etc. Decontamination will avoid any method that could spread localized contamination or increase penetration of the contaminant into the body. The mildest methods of cleansing will be attempted first, and in most instances, mild cleansing should achieve personnel decontamination for the types of activities performed at the ISF Facility. Initial decontamination will include multiple soap-and-water washes and water rinses. If milder methods are not effective, more aggressive decontamination methods will be used, as appropriate. Depending on the extent and location of the person's contamination, and under the direction of medical personnel, these more aggressive methods could include soft or stiff scrub brushes, commercial decontamination solution, and chelating agents such as potassium permanganate-sodium thiosulfate or other similar chemicals.

For personnel who have been both contaminated and injured, medical care is the first priority to transport, treat, and decontaminate involved workers as needed. Foster Wheeler will be added as appropriate to DOE's existing memoranda of understanding (MOU) with local hospitals. The DOE and local area hospitals are well equipped to handle such incidents safely and efficiently.

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4.5 DOE TRANSFER CASK

The ISF Facility does not have cask repair or cask maintenance facilities. Two DOE-provided transfer casks will be used to deliver SNF from the adjacent INTEC area to the ISF Facility. These transfer casks are also used to transport the SNF from the Cask Receipt Area to the FPA. DOE is responsible for the repair and maintenance of these transfer casks.

During transfer of SNF to the ISF Facility, the DOE transfer casks will travel solely within the DOE-controlled area boundary, not on public roads or highways. Therefore, these casks do not require licensing or certification under 10 CFR 71 (Ref. 4-56). The ISF Facility is adjacent to and east of the INTEC area, as shown in Figure 2.1-5. The DOE casks will travel approximately 500 yards between facilities, across owner-controlled roads, on a horizontal transporter.

The DOE will use two similar transfer casks to transfer SNF to the ISF Facility. These casks will contain the baskets and liners designed specifically for each type and configuration of SNF. DOE is responsible for loading the casks with SNF, closing the casks, placing the casks on the transporter, securing the casks on the transporter, performing required inspections, and driving the transportation vehicle with the cask and transporter to the Cask Receipt Area. The sequences of receiving and handling the DOE transfer casks at the ISF Facility are detailed in Chapter 5. The transfer cask handling equipment including the cask receipt crane and the cask trolley are described in Section 4.7.

Appendix A to the Safety Analysis Report, "Safety Evaluation of DOE-Provided Transfer Cask", provides a detailed evaluation of these casks including the suitability of their use within the ISF Facility.

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4.6 CATHODIC PROTECTION

The ISF Facility does not have a cathodic protection system. Because the ISF Facility is a dry, aboveground facility, cathodic protection of ITS SSCs in the form of impressed current is not required. There are three pipelines within the ISF Facility that have the potential of requiring cathodic protection. The applications that have been considered are potable water, service water, and fire water supplies.

The potable water will be piped from the ISF Facility site vault on the boundary of the ISF Facility. The piping material is class polyvinyl chloride (PVC). This type of pipe does not require cathodic protection.

The service waste will be piped to the ISF Facility site vault on the boundary of the ISF Facility. The piping material is acrylonitrile – butadiene – styrene (ABS). This type of pipe does not require cathodic protection.

The fire water will be piped from the ISF Facility site vault on the boundary of the ISF Facility. The piping material selected is PVC pressure pipe. This type of pipe does not require cathodic protection.

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4.7 SPENT FUEL HANDLING OPERATION SYSTEMS

This section addresses the functions, design features, and design bases of structures, systems and components used during SNF handling operations at the ISF Facility, including the following handling activities:

- lifting DOE transfer cask from transporter and placement on cask trolley
- moving DOE transfer cask through the Transfer Tunnel to the FPA
- removing SNF from DOE transfer cask and placing it in the FPA
- SNF packaging operations inside the FPA
- ISF canister transfer to the CCA on the canister trolley
- ISF canister closure, welding, examinations, vacuum drying, and helium inerting
- ISF canister transfer to the storage vault

The spent nuclear fuel (SNF) handling systems are designed to ensure adequate safety and to withstand the effects of site environmental conditions, natural phenomena, and accidents in accordance with 10 CFR 72.122(b) and 10 CFR 72.128(a). The major SNF handling structures and systems used at the ISF Facility consist of the following:

- Cask Receipt Area
- cask receipt crane
- cask trolley
- Transfer Tunnel
- Fuel Packaging Area
- Fuel Handling Machine
- bench vessels
- worktable
- FHM lifting devices
- canister trolley
- Canister Handling Machine
- Canister Closure Area

This section provides a summary of the analysis and design methodology used for evaluating the SNF handling structures and systems for environmental conditions, natural phenomena, normal loading conditions, off-normal loading conditions, and accident conditions.

SSCs are discussed in this section in the sequence of SNF receipt to SNF storage. Other ancillary equipment involved in SNF packaging is also included in this section, such as:

- power manipulator system
- master slave manipulators
- decanning machine
- vacuum drying system
- helium backfill system
- welding equipment

The FPA shield doors are also included since they provide maintenance and recovery support for the FHM.

4.7.1 Structural Specifications

This section provides a summary of the codes and standards, materials of construction, fabrication and inspection, and features covered by the ISF Project Quality Assurance Program for ITS SSCs used for SNF handling operations.

4.7.1.1 Cask Receipt Area

The CRA, shown in Figure 4.2-9 and Figure 4.2-1, is a steel-framed building anchored to a concrete foundation. The CRA includes the structural steel tower that supports the Cask Receipt Crane (CRC).

Codes and Standards

Concrete

The concrete slab that supports the trolley rails, the concrete footings and foundation that support the CRC, and the footings and foundations that support the primary structural steel of the CRA are designed to the following principal codes and standards:

- ANSI/ANS 57.9, *Design Criteria for an Independent Spent Fuel Storage Installation –Dry Type*
- ACI 349, *Code Requirements for Nuclear Related Concrete Structures* (for ITS) (as modified by NUREG 1567 paragraph 5.4.3.2 when using ACI-318 for construction)
- ACI 318 for NITS concrete structures
- ANSI A58.1 – *Minimum Design Loads for Buildings and Other Structures*
- ASCE 7 *Minimum Design Loads for Buildings and Other Structures*

The design of the remaining concrete structures of the CRA complies with the following principal codes and standards:

- Uniform Building Code (UBC) (partially modified by DOE – ID Architectural/Engineering Standard for snow loads)
- ASCE 7 *Minimum Design Loads for Buildings and Other Structures*
- ACI 318, *Concrete Requirements for Reinforced Concrete Structures*.

Steel

The design of the primary CRA structural steel, including the structural steel that supports the CRC, complies with the following principal codes and standards:

- ANSI/ANS 57.9, *Design Criteria for an Independent Spent Fuel Storage Installation – Dry Type, Sections 5 and 6*
- American Institute of Steel Construction (AISC) *Manual of Steel Construction*, 9th Edition
- ANSI A58.1 – *Minimum Design Loads for Buildings and Other Structures*
- ASCE 7 *Minimum Design Loads for Buildings and Other Structures*
- UBC Uniform Building Code (partially modified by DOE – ID Architectural/Engineering Standard for snow loads)
- American Welding Society (AWS), *Structural Welding Code*, D1.1

The design of the secondary and non-structural structural steel complies with the following principal codes and standards:

- AISC *Manual of Steel Construction*, 9th Edition
- ASCE 7 *Minimum Design Loads for Buildings and Other Structures*
- UBC Uniform Building Code (partially modified by DOE – ID Architectural/Engineering Standard for snow loads)
- AWS D1.1 *Structural Welding Code*

Materials of Construction

Concrete Structures

- Cement
  ASTM C150 *Specification for Portland Cement*
- Aggregate
  ASTM C33 *Specification for Concrete Aggregate*
- Reinforcement Steel
  ASTM A615 *Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement*
  ASTM A706 *Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement*
- Embedments
  ASTM A36 *Standard Specification for Structural Steel*

Steel Structures

- Structural Steel
  ASTM A36 *Standard Specification for Structural Steel*
  ASTM A53 *Standard Specification for Pipe, Steel, Black and Hot Dipped, Zinc Coated, Welded*

and Seamless
ASTM A242 *Standard Specification for High-Strength Low-allow Structural Steel*
ASTM A572 *Standard Specification for High-Strength, Low Alloy Columbium-Vanadium Steels of Structural Quality*
ASTM A588 *Standard Specification for High-Strength Low Alloy Structural Steel with 50ksi Minimum Yield Point to 4 in. Thick*

- High Strength Bolts
  ASTM A325 *Standard Specification for High Strength Bolts for Structural Steel Joints*

Fabrication and Inspection

Fabrication and inspection of the primary steel and concrete of the CRA are in accordance with the following:

Concrete

- ACI 349 for ITS concrete structures (as modified NUREG 1567 Paragraph 5.4.3.2 when using ACI 318 for construction)
- ACI 318 for ITS concrete structures (as stated in NUREG 1567 Paragraph 5.4.3.3 when using ACI 318 for construction)
- ACI 318 for NITS concrete structures

Steel

- AISC Code of Standard Practice for Steel Buildings and Bridges
- AWS D1.1 *Structural Welding Code - Steel*

Secondary steel and architectural features of the CRA comply with the UBC

Features Covered by QA Program

The design, fabrication, inspection and testing of ITS structural concrete and steel shall be in accordance with the ISF Facility Quality Assurance Program.

4.7.1.2 Cask Receipt Crane

The CRC is a fixed single failure proof hoist mounted on a large structural steel tower inside the CRA. The design codes and standards for the steel tower are provided above with the CRA structural steel. Figure 4.7-1 and Figure 4.2-9 show the hoist and steel tower respectively. The CRC is used to lift the DOE transfer cask from the transporter on to the cask trolley. The CRC has a rated capacity of 155 tons and a working capacity of 150 tons. A loaded DOE transfer cask weighs approximately 35 tons.

Codes and Standards

The design of the CRC complies with following principal specifications:

- NUREG-0612, *Control of Heavy Loads at Nuclear Power Plants*

- NUREG-0554, *Single-Failure-Proof Cranes for Nuclear Power Plants*
- Crane Manufacturers Association of America, Inc. CMAA 70, *Specification for Electrical Overhead Traveling Cranes*
- ANSI N14.6- *American National Standard for Radioactive Materials – Special Lifting Devices for Shipping Containers Weighting 10,000 Pounds (4500kg) or More*
- AISC *Manual of Steel Construction*, 9th Edition
- NFPA 70 *National Electrical Code.*
- AWS D1.1, *Structural Welding Code-Steel*

Materials of Construction

Principal load carrying members of the CRC and other components that perform functions ITS are constructed of the materials in Table 4.7-1.

Fabrication and Inspection

CMAA 70 is the primary document used for fabrication, construction and testing criteria for the CRC with the following exceptions and supplemental requirements:

- welding is in accordance with AWS D1.1 rather than AWS D14.1
- anchor bolts are in accordance with AISC, *Manual of Steel Construction*, 9th Edition
- lifting devices are fabricated, tested and inspected per ANSI N14.6
- NUREG 0554 and NUREG 0612 have been invoked and take precedence over CMAA 70 where applicable

Features Covered by QA Program

Load bearing members and other components classified as ITS are designed, fabricated, inspected and tested in accordance with the ISF Facility Quality Assurance Program.

4.7.1.3 Cask Trolley

The cask trolley, shown in Figure 4.7-2, is a steel fabricated structure mounted on four rail wheels. The cask trolley is used to move the DOE transfer cask containing SNF from the CRA to the FPA. The cask trolley runs on steel rails from the CRA into the Transfer Tunnel. The cask trolley is designed to transport the DOE transfer casks described in Appendix A.

Codes and Standards

The cask trolley complies with the following principal specifications:

- NUREG-0612, *Control of Heavy Loads at Nuclear Power Plants*
- NUREG-0554, *Single-Failure-Proof Cranes for Nuclear Power Plants*

- Crane Manufacturers Association of America, Inc. CMAA 70, *Specification for Electrical Overhead Traveling Cranes*
- AISC *Manual of Steel Construction*, 9th Edition
- ANSI N14.6- *American National Standard for Radioactive Materials – Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500kg) or More*
- ASME B30.2 and Addenda B30.2a, *Overhead and Gantry Cranes (Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist)*
- AISC – Steel Construction Manual, 9th edition (Rails, rail support plates and cast-in-place anchor bolts only)

Materials of Construction

Principal load carrying members of the cask trolley and other components that perform functions ITS are constructed of the materials listed in Table 4.7-2.

Fabrication and Inspection

CMAA 70 is the primary document used for fabrication, construction and testing criteria for the cask trolley with the following exceptions and supplemental requirements:

- welding is in accordance with AWS D1.1 rather than AWS D14.1
- anchor bolts are in accordance with AISC, *Manual of Steel Construction*, 9th Edition
- lifting Devices are fabricated, tested and inspected per ANSI N14.6
- NUREG 0554 and NUREG 0612 have been invoked and take precedence over CMAA 70 where applicable

Features Covered by QA Program

Load bearing members and other components classified as ITS are designed, fabricated, inspected and tested in accordance with the ISF Facility Quality Assurance Program.

4.7.1.4 Transfer Area

The Transfer Area, shown in Figure 4.2-9, Figure 4.2-1 and Figure 4.2-2, includes the north section of the Transfer Tunnel, FPA, CCA, operating gallery, waste processing areas, Operations Area, and various equipment rooms.

Codes and Standards

The Transfer Area is comprised of a concrete structure containing the FPA, CCA, Solid Waste Processing Area and north section of the Transfer Tunnel, surrounded by a steel structure containing the Operating Gallery, Operations Area and equipment rooms.

Concrete Structure

The design of the foundations, walls, roof, and slabs related to the FPA, Transfer Tunnel, and CCA comply with the following principal codes and standards:

- ANSI/ANS 57.9, *Design Criteria for an Independent Spent Fuel Storage Installation –Dry Type*
- ACI 349, *Code Requirements for Nuclear Related Concrete Structures* (for ITS) (as modified by NUREG 1567 paragraph 5.4.3.2 when using ACI-318 for construction)
- ACI 318 for NITS concrete structures
- ANSI A58.1 – *Minimum Design Loads for Buildings and Other Structures*
- ASCE 7 *Minimum Design Loads for Buildings and Other Structures*

The design of the balance of the concrete complies with the following principal codes and standards:

- UBC (partially modified by DOE – ID Architectural/Engineering Standard for snow loads)
- ASCE 7, *Minimum Design Loads for Buildings and Other Structures*
- ACI318, *Code Requirements for Reinforced Concrete Structures*

Steel Structures

The design of the primary structural steel, crane rails and supports, and the FPA workbench and its associated supports and embedments comply with the following principal codes and standards:

- ANSI/ANS 57.9, *Design Criteria for an Independent Spent Fuel Storage Installation – Dry Type*, Sections 5 and 6
- AISC *Manual of Steel Construction*, 9th Edition
- ANSI A58.1 – *Minimum Design Loads for Buildings and Other Structures*
- ASCE 7 *Minimum Design Loads for Buildings and Other Structures*
- UBC (partially modified by DOE – ID Architectural/Engineering Standard for snow loads)
- AWS, *Structural Welding Code*, D1.1
- Steel Deck Institute, *Design Manual for Composite Decks, Form Decks, Roof Decks, and Cellular Deck Floor Systems with Electrical Distribution*

The design of the balance of the structural steel complies with the following principal codes and standards:

- AISC *Manual of Steel Construction*, 9th Edition
- ASCE 78 *Minimum Design Loads for Buildings and Other Structures*
- UBC (partially modified by DOE – ID Architectural/Engineering Standard for snow loads)
- AWS D1.1 *Structural Welding Code - Steel*

- Steel Deck Institute, *Design Manual for Composite Decks, Form Decks, Roof Decks, and Cellular Deck Floor Systems with Electrical Distribution*

Materials of Construction

Concrete Structures

- Cement
  ASTM C150 *Specification for Portland Cement*
- Aggregate
  ASTM C33 *Specification for Concrete Aggregate*
- Reinforcement Steel
  ASTM A615 *Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement*
  ASTM A706 *Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement*
- Embedments
  ASTM A36 *Standard Specification for Structural Steel*

Steel Structures

- Structural Steel
  ASTM A36 *Standard Specification for Structural Steel*
  ASTM A53 *Standard Specification for Pipe, Steel, Black and Hot Dipped, Zinc Coated, Welded and Seamless*
  ASTM A242 *Standard Specification for High-Strength Low-allow Structural Steel*
  ASTM A572 *Standard Specification for High-Strength, Low Alloy Columbium-Vanadium Steels of Structural Quality*
  ASTM A588 *Standard Specification for High-Strength Low Alloy Structural Steel with 50ksi Minimum Yield Point to 4 in. Thick*
- High Strength Bolts
  ASTM A325 *Standard Specification for High Strength Bolts for Structural Steel Joints*
- Trolley Rails
  ASTM A759 *Specification for Carbon Steel Crane Rails*
- Rail Hold Down Brackets
  ASTM A516 Grade 70, *Pressure Vessel Plates, Carbon Steel for Moderate and Lower Temperature Service*

Fabrication and Inspection

Fabrication and inspection of the primary steel and concrete of the Transfer Area are in accordance with the following:

Concrete

- ACI 349 for ITS (as modified NUREG 1567 Paragraph 5.4.3.2 when using ACI-318 for construction)
- ACI 318 for ITS (as stated in NUREG 1567 Paragraph 5.4.3.3 when using ACI-318 for construction)
- ACI 318 for NITS

Steel

- AISC Manual of Steel Construction, 1992
- AWS D1.1 *Structural Welding Code - Steel*

Secondary steel and architectural features of the Transfer Area comply with the UBC.

Features Covered by QA Program

Concrete and structural steel classified as ITS are designed, fabricated, inspected and tested in accordance with the ISF Facility Quality Assurance Program.

4.7.1.5 Fuel Handling Machine

The FHM is shown in Figure 4.7-3. The FHM is a 10,000-lb capacity bridge and trolley crane used for SNF handling operation inside the FPA. It is single failure-proof in accordance with NUREG-0554. The FHM lifting devices are part of the FHM system. The FHM lifting devices are designed to meet the applicable requirements of ANSI N14.6.

Codes and Standards

The FHM complies with the following principal specifications:

- NUREG-0612, *Control of Heavy Loads at Nuclear Power Plants*
- NUREG-0554, *Single Failure Proof Cranes for Nuclear Power Plants*
- CMAA 70, *Specification for Electrical Overhead Traveling Cranes*
- ANSI N14.6 - *American National Standard for Radioactive Materials – Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 kg) or More*
- AISC, *Manual of Steel Construction*, 9th Edition
- ASME B30.2 and Addenda B30.2a, *Overhead and Gantry Cranes (Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist.*
- NFPA 70, *National Electrical Code*
- AWS D1.1, *Structural Welding Code - Steel*

Materials of Construction

Principal load carrying members of the FHM are constructed of the materials listed in Table 4.7-3.

Fabrication and Inspection

CMAA 70 is the primary document used for fabrication, construction, and testing criteria for the FHM with the following exceptions and supplemental requirements:

- welding is in accordance with AWS D1.1 rather than AWS D14.1
- anchor bolts are in accordance with AISC, *Manual of Steel Construction*, 9th Edition
- lifting devices are fabricated, tested and inspected per ANSI N14.6

NUREG 0554 and NUREG 0612 have been invoked and take precedence over CMAA 70 where applicable.

Features Covered by QA Program

Load-bearing members and other components classified ITS are designed, fabricated, inspected and tested in accordance with the ISF Facility Quality Assurance Program.

4.7.1.6 Canister Trolley

The canister trolley, shown in Figure 4.7-4, is used to move loaded ISF canisters from the FPA to the CCA for closure lid welding, purging and inerting, and then from the CCA to the Storage Area load/unload port.

Codes and Standards

The canister trolley complies with the following principal specifications:

- NUREG-0612, *Control of Heavy Loads at Nuclear Power Plants*
- NUREG-0554, *Single-Failure-Proof Cranes for Nuclear Power Plants*
- Crane Manufacturers Association of America, Inc CMAA 70, *Specification for Electrical Overhead Traveling Cranes*
- ASME B30.2 and Addenda B30.2, *Overhead and Gantry Cranes (Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist)*
- ANSI N14.6- *American National Standard for Radioactive Materials – Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500kg) or More*
- NFPA 70 *National Electrical Code*
- AWS D1.1 2000, *Structural Welding Code-Steel*
- AISC – Steel Construction Manual, 9th edition (Rails, rail support plates and cast-in-place anchor bolts only)

Materials of Construction

Principal load carrying members of the canister trolley are constructed of the materials listed in Table 4.7-4.

Fabrication and Inspection

CMAA 70 is the primary document used for fabrication, construction, and testing criteria for the Canister Trolley with the following exceptions and supplemental requirements:

- welding is in accordance with AWS D1.1 rather than AWS D14.1
- rail anchor bolts are in accordance with AISC, *Manual of Steel Construction*, 9th Edition

NUREG 0554 and NUREG 0612 have been invoked and take precedence over CMAA 70 where applicable.

Features Covered by QA Program

Load bearing members and other components classified as ITS are designed, fabricated, inspected and tested in accordance with the ISF Facility Quality Assurance Program.

4.7.1.7 Canister Handling Machine

The CHM, shown in Figure 4.7-5 and Figure 4.7-6, is a shielded rotating turret assembly mounted on a bridge and trolley that runs on rails inside the Storage Area building. The CHM lifts loaded ISF canister assemblies from the Canister Trolley and places them in the storage tubes inside the storage vaults.

Codes and Standards

The CHM is designed in accordance with the following principal codes and specifications:

- NUREG-0554, *Single Failure-Proof Cranes for Nuclear Power Plants*
- NUREG-0612, *Control of Heavy Loads at Nuclear Power Plants*
- CMAA 70, *Specifications for Electrical Overhead Traveling Cranes*
- AISC, *Manual of Steel Construction Allowable Stress Design,* 9th Edition
- ANSI N14.6, *Special Lifting Devices for Shipping Containers Weighing 10,000 pounds (4500 Kg) or More*
- ANSI/IEEE C2, *National Electrical Safety Code*
- NFPA 70, *National Electrical Code*
- ANSI/AISC N690, *Specification for the Design, Fabrication and Erection of Steel Safety Related Structures for Nuclear Facilities*
- ASME B30.2, *Overhead and Gantry Cranes (Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist)*
- AWS D1.1, *Structural Welding Code - Steel*

Materials of Construction

Table 4.7-5 lists the material specifications of the main structural components of the CHM. The requirements of the materials selected for the CHM satisfy the requirements of CMAA-70 and the additional requirements of NUREG-0554. Components or sub-assemblies of the bridge, trolley, and canister hoist are designed as either "structural" or "mechanical" components in accordance with CMAA-70-3 and 70-4, respectively.

Fabrication and Inspection

CMAA 70 is the primary document used for fabrication, construction and testing criteria for the CHM with the following exceptions and supplemental requirements:

- welding is in accordance with AWS D1.1 rather than AWS D14.1
- anchor bolts are in accordance with AISC, *Manual of Steel Construction*, 9th Edition
- lifting devices are fabricated, tested and inspected per ANSI N14.6
- NUREG 0554 and NUREG 0612 have been invoked and take precedence over CMAA 70 where applicable

Features Covered by QA Program

Load bearing members and other components classified as ITS are designed, fabricated, inspected and tested in accordance with the ISF Facility Quality Assurance Program.

4.7.1.8 Storage Area Building (Excluding Storage Vaults)

The storage vault codes and standards, materials of construction, fabrication, and quality assurance features are provided in Section 4.2.1.1. This section addresses the steel framed building over the storage vaults.

The Storage Area building is a NITS structure; however the primary structural members of the building have been designed for applicable seismic and tornado loads.

The Storage Area building, shown in Figure 4.2- 9 and Figure 4.3-8, encloses the storage vaults and canister handling machine to provide protection from the environment. The primary structural steel of the Storage Area building is supported by the reinforced concrete walls of the storage vault.

Codes and Standards

The design of the structural steel of the Storage Area building complies with the following principal codes and standards:

- ANSI/ANS 57.9, *Design Criteria for an Independent Spent Fuel Storage Installation – Dry Type, Sections 5 and 6*
- AISC *Manual of Steel Construction*, 9th Edition;
- ANSI A58.1 – *Minimum Design Loads for Buildings and Other Structures*

- ASCE 7 *Minimum Design Loads for Buildings and Other Structures*
- UBC (partially modified by DOE – ID Architectural/Engineering Standard for snow loads)
- AWS, *Structural Welding Code,* D1.1
- Steel Deck Institute, *Design Manual for Composite Decks, Form Decks, Roof Decks, and Cellular Deck Floor Systems with Electrical Distribution*

Materials of Construction

- Structural Steel
  ASTM A36 *Standard Specification for Structural Steel*
  ASTM A53 *Standard Specification for Pipe, Steel, Black and Hot Dipped, Zinc Coated, Welded and Seamless*
  ASTM A242 *Standard Specification for High-Strength Low-allow Structural Steel*
  ASTM A572 *Standard Specification for High-Strength, Low Alloy Columbium-Vanadium Steels of Structural Quality*
  ASTM A588 *Standard Specification for High-Strength Low Alloy Structural Steel with 50ksi Minimum Yield Point to 4 in. Thick*
- High Strength Bolts
  ASTM A325 *Standard Specification for High Strength Bolts for Structural Steel Joints*

Fabrication and Inspection

Fabrication and inspection are in accordance with the following:

- AISC Code of Standard Practice for Steel Buildings and Bridges
- AWS D1.1, *Structural Welding Code - Steel*

Features Covered by QA Program

The Storage Area building is designed, fabricated, inspected and tested in accordance with applicable portions of the ISF Facility Quality Assurance Program.

4.7.2 Installation Layout

4.7.2.1 Building Plans

Figure 4.2-1 and Figure 4.2-2 provide a plan view of the first and second floor of the ISF Facility depicting the CRA, Storage Area, Transfer Area and interconnecting Transfer Tunnel as well as the Operations Area.

4.7.2.2 Building Sections

Building section and elevation views of the ISF Facility are provided in the following:

- Figure 4.2-9 Transfer Tunnel Section (looking east)
- Figure 4.3-15 Transfer Area Section (looking north)

- Figure 4.7-7 Storage Area Section (looking north)
- Figure 4.7-8 Cask Receipt Area Elevation (looking east)
- Figure 4.3-8 Storage Area Elevation (looking north)
- Figure 4.3-9 Storage Area Elevation (looking south)
- Figure 4.7-9 Transfer Area North Elevation (looking south)

4.7.2.3 Confinement Features

The confinement barrier during SNF storage is discussed in Section 4.2.2.3. This section addresses confinement features of the ISF Facility during SNF handling operations.

The confinement boundary associated with SNF handling operations at the ISF Facility is shown in Figure 4.7-10. Confinement of radioactive material at the ISF Facility during SNF handling operations is accomplished by physical barriers and supplemented by the ventilation system design features.

Physical barriers that comprise the FPA confinement boundary prevent the spread of radioactive materials. In addition, the ventilation system ensures that the flow of air is from areas of low potential contamination to areas of higher contamination and then through a series of exhaust HEPA filters before release to the environment. A constant volume ventilation exhaust coupled with a variable volume ventilation supply is used to accomplish this.

Supply air is filtered before being introduced into the Transfer Area. In certain areas the supply air is filtered through a HEPA filter to prevent the spread of contamination in the unlikely event that a flow reversal occurs. Exhaust air is filtered through a minimum of two stages of HEPA filtration before being discharged to the atmosphere via the exhaust stack. Refer to Section 4.3.1 for detailed information on the design features of the ventilation system.

Cask Receipt Area

The CRA does not perform a confinement barrier function. SNF is received at the ISF Facility in the DOE transfer cask. This cask and associated internal container performs the confinement barrier function during this phase of SNF handling operations.

Transfer Tunnel

The Transfer Tunnel is designed to ensure that the SNF is protected from damage due to natural phenomena during SNF handling operations. The Transfer Tunnel is seismically designed and also provides tornado wind and missile protection to the cask trolley and canister trolley. This is accomplished by the use of thick reinforced concrete walls, ceiling, and the outer door of the Transfer Tunnel. The cask trolley and canister trolley are also designed to prevent damage to the SNF during a seismic event. This is accomplished by the use of lock pins and rail brackets that prevent movement of these trolleys under seismic loading conditions.

The Transfer Tunnel is served by the Transfer Area Ventilation System, which is provides both controlled air flow and HEPA filtration of the exhaust from the Transfer Tunnel. The inner and outer Transfer

Tunnel doors also provide ventilation control and impede the spread of contamination from the Transfer Tunnel. The outer Transfer Tunnel door is designed to withstand design basis accidents.

SNF inside the Transfer Tunnel is located within the DOE transfer cask or the canister cask. These casks provide additional protection to the SNF

Fuel Packaging and FHM Maintenance Areas

The FPA and FHM Maintenance Area provide a confinement barrier during SNF transfer operations and are designed to maintain this function during normal, off-normal, and accident conditions. During SNF packaging operations, the confinement boundary is provided by physical barriers formed by:

- concrete floor, ceiling and walls
- shield windows
- sealed wall penetrations
- HEPA filters and duct work
- personnel shielded access door into the FHM maintenance area
- port plugs located in the floor of the FPA
- inflatable seals at the canister and cask port

Portions of the HVAC ductwork, dampers and filters form part of the confinement barrier as shown in Figure 4.3-5.

The personnel shielded access door provides access into the FHM Maintenance Area. This door remains closed during normal SNF transfer operations and is part of the confinement boundary. This door is designed to withstand tornado and seismic loads and to minimize leakage.

There are two ports in the floor of the FPA that open to the Transfer Tunnel, the Cask Port and the Canister Port. When SNF is not being transferred in or out of the FPA, these ports are kept closed by the installation of the cask port plug and canister port plug that serve a confinement barrier function.

During SNF transfer operations between the DOE transfer cask and the FPA, an inflatable seal on the underside of the cask port, shown in Figure 4.7-11, mates with the cask adapter plate mounted to the DOE transfer cask to provide a confinement barrier extension into the transfer cask. This inflatable seal ensures the integrity of the confinement barrier is maintained when the cask port plug is removed, and prevents a radiological release into the Transfer Tunnel in the event of a failure of the HVAC system. The inflatable seal is classified ITS and is designed to maintain a seal in the event of a loss of off-site power or seismic event. Before removing the cask port plug or the transfer cask lid, this seal will be inflated. Once inflated, the fail-safe position of the seal is to remain inflated.

Upon completion of SNF transfer operations from the DOE transfer cask to the FPA, the transfer cask lid is reinstalled, the cask port plug is replaced in the cask port, and the cask port seal is deflated. At this time the confinement boundary inside the FPA becomes the cask port plug.

A similar arrangement is used at the canister port. Once the canister trolley is positioned under the canister port, the trolley jacks the canister cask upward into the recess below the canister port. The canister port seal, shown in Figure 4.7-12, is inflated to form a seal with the canister cask body. With the canister port seal inflated, the canister port plug is removed allowing access to the ISF canister located inside the canister cask. A loaded SNF basket or reflector module can then be lowered into the ISF canister while maintaining the integrity of the FPA confinement boundary.

After SNF transfer operations into the ISF canister are completed, the canister shield plug is installed into the ISF canister and the canister port plug is replaced. At this time the confinement boundary inside the FPA becomes the canister port plug. The canister port seal is then deflated, and the canister trolley lowers the loaded ISF canister down to clear the recess below the canister port. The canister trolley is now moved to the CCA port for welding of the canister lid assembly.

The Transfer Tunnel, the canister cask, and the canister shield plug that covers the top of the canister basket protects the SNF located in the loaded ISF canister from damage. This configuration maintains the SNF in a stable and protected configuration while the loaded ISF canister is in the CCA port.

The cask port and canister port seals are inflated by the facility compressed air system. Seal deflation is avoided during transfer operations through the use of a pilot valve and check valves. Seal deflation is achieved by actuating a solenoid valve that applies air to the pilot to vent the inflated seal. The solenoid and pilot valve fail-safe position is to prevent seal deflation by blocking the vent path. A relief valve prevents over-inflation of the seals, and pressure switches monitor the minimum and maximum inflation pressure with indication in the operating gallery. The pilot valve, check valves and relief valve and associated connecting tubing to the seals are classified ITS and are seismically designed.

A camera system installed within the Transfer Tunnel provides a video display of the canister trolley and cask trolley to the operators in the operating gallery.

There are also two waste ports (canister waste port and process waste port) in the floor of the FPA that open to the Solid Waste Processing Area. These ports are normally closed by the canister waste port plug and process waste port plug when SNF handling operations are occurring inside the FPA. These plugs are part of the confinement boundary during normal operations when waste transfers out of the FPA are not occurring.

The waste ports will not be open during SNF handling operations. In addition, if SNF is present inside the FPA, it must be in a designated storage location before removal of either waste port. This will minimize the potential for a release of contamination while a waste port is open. As an added precaution, the HVAC system must also be operating before removing either waste port. This will ensure that air flow is directed into the FPA to prevent the release of any radioactive contamination to the solid waste processing area. Additional details of the HVAC system design during waste transfer operations are provided in Section 4.3.1, Ventilation and Off-gas Systems.

4.7.3 Individual Unit Description

SNF handling operations at the ISF Facility begin in the CRA, and ends when the SNF is stored in storage tubes within the Storage Vaults. The following areas are involved in SNF handling operations and are described in detail in this section:

- Cask Receipt Area
- Transfer Tunnel
- Fuel Packaging Area
- Canister Closure Area
- Storage Area

4.7.3.1 Functions of Fuel Handling Operational Areas

4.7.3.1.1 Cask Receipt Area

Cask Receipt Area Description

The CRA, shown in Figure 4.2- 9, Figure 4.2-1 and Figure 4.7-8 provides a weather-protected area to receive the DOE transfer cask, lift the cask from the transporter, and place it on the Cask Trolley. The cask adapter and cask lid lifting device are also installed inside the CRA.

The CRA is a steel-frame building approximately 86 feet by 63 feet. Because the CRA finished floor level is below grade elevation, a 5-foot retaining wall around most of the perimeter of the CRA is used. Portions of the west and north sides of the CRA do not have retaining walls to permit access to the building via a sloped driveway, and access into the Transfer Tunnel respectively. A trench and sump pit at the west entrance roll-up door prevents rainwater run-off from entering the CRA.

Reinforced-concrete footers and the retaining wall around the perimeter of the building provide support for structural steel columns. The exterior of the CRA is constructed from steel panels bolted to the steel superstructure. The roof of the CRA is a pitched standing seam metal roof over steel roof joists and purlins. There are isolated footers located in the center of the CRA, which provides bearing support for the columns of the 155-ton CRC.

The floor of the CRA is a reinforced concrete "floating" slab design with a finished floor elevation of 4913 feet, 2 inches, established to provide an elevation equal to the top of the cask trolley rails that enter the north end of the CRA from the Transfer Tunnel. The floor of the CRA is essentially level with minimal sloping for drainage to the floor drains. A recessed area on the west entrance to the CRA is designed to control run-on of precipitation, or run-off of any diesel fuel or oil that may drop on the floor from the transport vehicle during transfer cask delivery.

A pair of steel rails on 12-foot centers enters the CRA from the north end and traverses the building for a distance of approximately 42 feet. The rails are supported by a thicker reinforced-concrete slab that extends from the Transfer Tunnel into and under the CRC. The rails run in trenches such that the tops of the rails are flush with the finished floor of the CRA. The rails are attached to concrete embedments by mechanical means.

A steel roll-up door on the west end provides access for the DOE transfer cask transporter to the CRA from the adjacent road. The CRA is adjacent to the Transfer Tunnel to permit cask unloading and transfer in a climate-controlled condition. The CRA is structurally isolated from the adjacent Transfer Tunnel/Storage Area by a seismic isolation joint. Electric heaters inside the CRA maintain the temperature above 32°F. Cask handling operations are not performed if the temperature inside the CRA is less than 32°F, or more than 104°F.

An auxiliary overhead crane with a capacity of 10 tons runs along elevated rails, in the north-south direction. The auxiliary crane is used to remove shipping clamps and install lifting devices on the DOE transfer cask.

Cask Receipt Area Activities

The DOE transfer cask is delivered to the CRA on a horizontal transporter. The transporter is moved through the CRA external roll-up door and positioned below the CRC. The CRC is a 155-ton fixed hoist, supplemented by the cask receipt auxiliary (10-ton X-Y) crane.

Using a combination of the vertical hoist movements of the CRC, and horizontal motion of the transporter, the cask is rotated from the horizontal to the vertical position, pivoting on the lower trunnions of the transfer cask and trunnion saddles of the transporter. Once vertical, the cask is raised to clear the trunnion saddles of the transporter, allowing the transporter to move away from under the transfer cask.

The cask trolley is moved into position to its pre-determined location below the transfer cask. The hoist lowers the transfer cask into the cask trolley. The cask restraint is fitted to restrain the cask within the trolley. The CRC lifting device is disconnected from the transfer cask and raised to clear the path for the auxiliary crane.

The cask receipt auxiliary crane installs the cask adapter to the top of the cask. The cask adapter is a circular collar designed to rest on top of the upper trunnions of the transfer cask and around the outside of the cask body. The adapter has cutouts that mate with the upper trunnions of the cask. The cask adapter has hold down features and turnbuckles, which attach to the trolley base frame and firmly anchor the transfer cask to the cask trolley. At this time the transfer cask lid lifting device, which allows the transfer cask lid to be handled within the FPA, is secured to the cask lid, using the auxiliary crane. The cask receipt auxiliary crane is moved away from the cask trolley and the trolley is clear to approach the Transfer Tunnel outer door.

The CRA houses the controls for the CRC, the cask receipt auxiliary crane, cask trolley, and Transfer Tunnel inner and outer doors.

Cask Receipt Area Performance Objectives

The performance objectives for the CRA are:

- provide a structural load path and foundation for the CRC (ITS function)
- provide a structural load path and foundation for the cask trolley rails (ITS function)
- maintain structural integrity of the primary steel super-structure during postulated tornadoes, earthquakes and floods to prevent collapse
- provide a structural load path for receipt of the DOE cask transport vehicle
- provide a temperature-controlled environment to maintain the CRC above 32°F to facilitate cask handling operations

- provide a controlled environment free from the effects of rain and snow to allow safe handling of shipping casks during inclement weather
- provide a level of comfort to operations personnel by the use of ventilation and heating inside the area.
- provide adequate lighting to facilitate cask handling operations
- provide a staging area for equipment required for cask handling operations

4.7.3.1.2 Transfer Tunnel

Transfer Tunnel Description

The Transfer Tunnel, shown in Figures 4.2-1 and Figure 4.2-9, provides a shielded and protected route for the cask trolley to safely travel between the CRA and the FPA and the canister trolley to travel between the FPA, the CCA, and the Storage Area.

The Transfer Tunnel is structurally part of two separate areas. The south section is integral with the Storage Area vaults, and was designed and analyzed as part of that structure. The north section is integral with the Transfer Area structure, and was designed and analyzed as part of that structure. A seismic isolation joint between these two structures allows for differential movement during the design earthquake.

The Transfer Tunnel is made primarily of reinforced concrete that provides a shielded corridor between the CRA, Storage Area, FPA and CCA. Rails attached to the floor of the tunnel provide the load path for both the cask and canister trolley. Both trolleys run on common rails. Interlocks are provided to preclude collisions between the trolleys in the tunnel. The tunnel runs from the CRA on the south end, to the CCA on the north end, a distance of approximately 170 feet.

The Transfer Tunnel walls and ceiling are sufficiently thick to provide the necessary radiation shielding in the event that personnel need to access this area while SNF is in the FPA bench vessels or Storage Area vaults. Access ports in the ceiling of the Transfer Tunnel allow access to the second floor of the Storage Area building, FPA, and CCA. In addition, a maintenance hatch is built into the Transfer Tunnel ceiling, below the southwest corner of the Storage Area, to support CHM maintenance activities.

A camera system installed within the Transfer Tunnel allows the operators to view cask and canister trolley transfer operations. The Transfer Tunnel houses the positional switches that interact with the trolley instrumentation to allow the operators at the trolley control station to monitor the position of each trolley.

The Transfer Tunnel is separated from the CRA by a steel outer door that provides tornado protection to the cask and canister trolleys during SNF transfer operations taking place inside the Transfer Tunnel. This door also supports the HVAC system in controlling the air flow through the Transfer Tunnel. A second door is installed deeper into the Transfer Tunnel at the north end of the Cask Decontamination Zone. This inner door is closed when SNF transfers are occurring between the Transfer Tunnel and the FPA to aid in maintaining the required differential pressure and air flow between these areas. The HVAC system maintains the Transfer Tunnel at a pressure below the CRA to ensure the flow of air is from the CRA to the Transfer Tunnel when these doors are open.

Manned access into the north end of the Transfer Tunnel is permitted under strict radiological control to facilitate recovery of the trolleys and maintenance of the inflatable seals, should it be necessary. The exception is when "vertical" SNF transfers are taking place (i.e., SNF transferred into or out of the FPA or Storage Area).

Transfer Tunnel Activities

The south end of the Transfer Tunnel contains the Cask Decontamination Zone. The Outer Transfer Tunnel Door and the Inner Transfer Tunnel Door define this area. Arriving DOE transfer casks are monitored for flammable gas atmospheres and internal airborne contamination levels in this area prior to transferring the SNF into the FPA. This area is also used to remove the DOE transfer cask lid bolts. The cask adapter, installed inside the CRA, contains lid hold down features to securely hold the transfer cask lid in place with the lid bolts removed.

The Cask Decontamination Zone is also the area where empty DOE transfer casks are monitored after the SNF has been transferred into the FPA, before traveling back into the CRA to be returned to the DOE. If unacceptable levels of external contamination are discovered, the cask and cask trolley will be decontaminated.

In the ceiling of the Cask Decontamination Zone is an access hatch into the Storage Area building. This hatch provides a raised area to allow workers to access the top of the Cask Trolley to remove and install bolts on the transfer cask lid. This hatch is also used to transfer equipment and parts for the CHM located inside the Storage Area building to the CRA.

The north end of the Transfer Tunnel contains four ports. These ports have removable port plugs, which are normally installed unless transfer operations or ISF canister closure activities are occurring. A description of these ports follows:

Cask Port. The cask port, which has an internal diameter of 51 inches, provides a path between the Transfer Tunnel and the FPA. This port is used to allow the contents of the DOE transfer cask, which is positioned under this port by the cask trolley, to be removed and placed inside the FPA for further processing and repackaging. This port has an inflatable seal that is inflated before opening the port. The seal inflates downward and makes contact with the cask adapter as shown in Figure 4.7-11. The cask port plug weighs approximately 8354 pounds and is 62 inches at its largest diameter. The cask port plug is made from a fabricated steel exterior shell filled with concrete, and has stepped sides to provide shielding and positive positioning inside the port opening. The cask port plug is removed and installed by the FHM hoist, which has a capacity of 10,000 pounds.

Canister Port. The canister port provides a path between the Transfer Tunnel and the FPA to load SNF into an awaiting ISF Canister. An ISF canister is positioned under this port by the canister trolley. The canister trolley jacks the canister cask up into a 52-inch diameter cavity in the Transfer Tunnel ceiling, located immediately below the canister port opening. The canister port opening into the FPA is 26 inches, which permits loading 18 inch and 24 inch ISF baskets or Shippingport reflector modules into awaiting ISF canisters. The recess minimizes the direct radiation path into the Transfer Tunnel during SNF transfers into the ISF canister. This feature also improves viewing of the ISF canister within the FPA and improves the reach when loading the ISF canister. This port has an inflatable seal that is inflated before opening the port. The seal inflates radially inward to contact the cask of the canister trolley as shown in

Figure 4.7-12. The canister port plug weighs approximately 2568 pounds and is nominally 38.5 inches at its widest diameter. The canister port plug is made of steel and has stepped sides to provide shielding and positive positioning inside the port opening. The canister port plug is removed and installed by the FHM hoist, which has a capacity of 10,000 lbs.

CCA Port. This port provides a path between the Transfer Tunnel and the CCA. The Canister Trolley is positioned under this port with a loaded ISF canister after leaving the FPA. This port location is used to weld the ISF canister lid assembly to the ISF canister body assembly and to perform purging, vacuum drying, inerting, weld examinations and leak checks on the completed assembly. The port cover is made of carbon steel plate and has a diameter of approximately 54 inches and weighs approximately 1920 lbs. The CCA port cover is normally handled by the CCA crane, which has a capacity of 10 tons. The CCA cover is also placed on top of the canister cask after closure activities are completed on the ISF canister. Placing the port cover on top of the cask provides additional shielding prior to removing the collets. Once the collets are removed, the canister trolley lowers the cask into the Transfer Tunnel, leaving behind the CCA port cover in the port opening.

Storage Area Load/Unload Port. The storage area load/unload port provides a path between the Transfer Tunnel and the Storage Area Building. The canister trolley is positioned under this port after ISF canister closure operations have been completed at the CCA. This port is accessed by the CHM to lift the loaded ISF canister from the canister trolley and raise it up into the CHM turret. The CHM then travels over the charge face to deposit the ISF canister in the designated storage tube location. A thick steel cover plate protects the port plug from tornado missiles and damage that could occur during routine maintenance in this area. The cover plate weighs approximately 1025 pounds, and is removed and installed by the storage area maintenance hoist, which has a capacity of 10 tons.

Below the cover plate is the storage area load/unload port, which is designed with an inner and outer section that allows the port to be configured differently to accommodate 18-inch and 24-inch ISF canisters. The inner port plug is nominally 18 inches in diameter and is made from a steel external shell filled with concrete. The outer port liner is a steel ring that creates a 25-inch diameter port opening when removed. When an 18-inch canister is being handled, the inner port plug is removed by the CHM. This section weighs approximately 1000 lbs. When a 24-inch canister is being handled, the inner plug and outer port liner are connected together by a connecting ring and are removed as one piece by the CHM. This combined assembly weighs approximately 2500 lbs.

Transfer Tunnel Performance Objectives

The performance objectives for the Transfer Tunnel are:

- Provide a structural load path and foundation for the rails of the cask trolley and canister trolley (ITS function)
- Provide structural support and foundation for the FPA (ITS function)
- Provide structural support and foundation for the Storage Area (ITS function)
- Maintain structural integrity of the west wall of the Storage Area vault (ITS function)
- Prevent missiles generated by the design basis tornado from impacting SNF stored in the Storage Area vault (ITS function)

- Prevent missiles generated by the design basis tornado from impacting the cask trolley and canister trolley during SNF transfer operations (ITS function)
- Prevent damage to SNF during a design earthquake (ITS function)
- Prevent damage to the SNF by maintaining the structural integrity of the load path of the cask trolley and canister trolley during the design basis flood (ITS function)
- Prevent damage to SNF by mitigating and containing the effects of a fire at the ISF Facility
- Provide radiological protection to workers in the Transfer Tunnel by shielding the direct radiation from ISF canisters stored in the adjacent storage vaults or SNF within the FPA
- Provide a physical personnel barrier to prevent unauthorized or inadvertent entry during transport activities to prevent radiation exposure to workers
- Provide a temperature and weather-controlled environment to permit safe SNF transfer operations during inclement weather

4.7.3.1.3 Fuel Packaging Area

Fuel Packaging Area Description

The FPA, shown in Figure 4.3-15 and Figure 4.7-13, is a shielded, tornado protected, seismically designed confinement barrier to safely and remotely handle SNF. SNF is removed from the DOE transfer cask, unpackaged, inspected, placed in new ISF baskets and into new ISF canisters inside the FPA.

The FPA is located inside the Transfer Area and is constructed with thick reinforced concrete walls, floor and ceiling. The FPA long axis runs perpendicular over the top of the Transfer Tunnel as shown in Figure 4.2-2.

On the east end of the FPA the concrete floor has two cavities that extend down to the first floor at elevation 4919 feet, 6 inches. A steel "workbench" bridges across these cavities at elevation 4938 ft-6 inches, and is used to support a number of cylindrical bench vessels used to temporarily hold the SNF baskets, waste containers and monitoring equipment during the various repackaging campaigns. The workbench also contains the decanning machine and designated laydown areas for the various lifting devices and equipment within the FPA. The east cavity is provided to allow future activities not included in the scope of this SAR. The workbench and associated structural steel spans across the FPA and is supported by corbels on the north and south walls.

On the west end of the FPA is an area designated for maintenance of the FHM. The FHM enters this area by passing through a concrete shield wall that has a T-shaped slot. Two steel shield doors normally close off the slot. The elevated ceiling above the FHM maintenance area allows workers access to the top of the FHM and provides a cavity to retract the upper shield door. Power screw jacks are mounted on the roof of the FHM Maintenance Area to raise the larger upper door. A smaller door covers the lower slot in the wall. The slot provides clearance for the PMS mast. The lower door travels horizontally on rails. Both doors are on the FHM Maintenance Area side of the dividing wall. The steel shield doors between the FPA and the FHM Maintenance Area allows workers to perform maintenance on the FHM even with SNF located inside the FPA. The personnel shielded access door provides the only personnel access into the FHM Maintenance Area. There is no direct personnel access into the FPA. The FPA shield doors are described in greater detail later in this chapter.

Most of the handling operations within the FPA are performed by the FHM. The FHM comprises an overhead electric crane, fitted with a top running bridge and cross travel trolley. The FHM is equipped with a 10,000-lb hoist unit and a PMS. The FHM range of motion is from the east wall of the FPA to the west wall of the FHM Maintenance Area. A range of lifting devices are used to suit various lifting applications.

The cask trolley and canister trolley can be accessed via designated ports in the floor of the FPA. These ports allow SNF to be moved in and out of the FPA using the FHM under the remote control of operators located in the operating gallery. Shielded plugs are provided for each of the ports. These plugs provide radiation protection and define part of the confinement barrier between the FPA and the Transfer Tunnel. These plugs also help to ensure a negative pressure is maintained in the FPA relative to the surrounding areas.

The FPA is designed with the capability to monitor and handle solid waste generated during SNF handling and packaging operations. Waste is routed to the Solid Waste Processing Area through either the process waste port or the canister waste port located on the west side of the FPA. These waste ports are normally closed during SNF handling operations. When SNF handling operations are not occurring, the waste ports also provide a route for bringing new equipment into the FPA.

Four shield windows on the south wall and three shield windows on the north wall provide visual observation stations for operators during SNF handling operations. Master-slave manipulators (MSM) are positioned at the shield window locations to perform manual operations inside FPA. The shield window assembly has a sealed-glass plate fixed to the window liner on the inside of the FPA that prevents the spread of radioactive contamination if the shield window is removed from the window liner for maintenance. The shield windows have been evaluated to demonstrate that they can withstand accident events. The shield window set is also designed for the temperature differentials that could occur between the inside of the FPA and the operating galley during normal, off-normal, and accident conditions.

A camera system in conjunction with the shield windows provides the ability to visually identify SNF cans or elements, and provides a documented inventory record of the SNF that is handled and packaged. Cameras are mounted in the FPA and also on the FHM. The weight of each unloaded and loaded ISF basket is documented using information from a load cell on the FHM allowing for a record of the weight of SNF stored in each ISF canister. Through-wall penetrations in the walls of the FPA are designed to minimize radiation dose rates to operators in the Operating Gallery.

Fuel Packaging Area Activities

The following SNF handling activities occur in the FPA:

- Removing the lid from the DOE transfer cask
- Unloading the DOE canister from the DOE transfer cask
- Removing the lid from the DOE canister
- Removing SNF elements from the DOE canister

- Performing decanning operations (PB 1 fuel only)
- Transferring SNF elements to the ISF basket
- Installing the basket lid (except Shippingport reflector modules)
- Placing the loaded basket inside the ISF canister (except Shippingport reflector modules which are loaded directly into baskets pre-installed in the ISF canister)
- Placing the shield plug inside the ISF canister

In addition to the above, to recover from potential problems that may occur during SNF repackaging campaigns, a worktable system, as shown in Figure 4.7-14, is available inside the FPA. This is a multi-purpose station bolted to the FPA workbench that incorporates various machines and equipment for handling and decontaminating empty waste containers used in the transfer of the SNF. The worktable system can also be used in recovery and packaging of damaged SNF elements, recovery of stuck or broken SNF elements in a fuel can, or cutting and sectioning empty SNF containers.

Details on specific SNF handling operations inside the FPA are provided in Chapter 5.

Fuel Packaging Area Performance Objectives

The performance objectives for the FPA are:

- Prevent the release of radioactive materials to the environment during normal, off-normal, and accident conditions (ITS function)
- Provide a confinement barrier to permit safe handling of SNF during normal, off-normal, and accident conditions (ITS function)
- Prevent damage to SNF during normal, off-normal, and accident conditions (ITS function)
- Ensure SNF remains in a subcritical configuration during normal, off-normal, and accident conditions (ITS function)
- Provide the capability to maintain SNF temperatures within allowable material limits (ITS function)
- Provide a structural load path and foundation for the rails of the FHM (ITS function)
- Provide structural support and foundation for the bench vessels that contain SNF (ITS function)
- Provide visual capability through shielded windows and CCTV to allow observation, inspection, and documentation of SNF packaging operations
- Prevent missiles generated by the design basis tornado from impacting SNF being handled in the FPA (ITS function)
- Prevent damage to SNF during the design earthquake (ITS function)
- Prevent damage to the SNF by maintaining the structural integrity of the confinement barrier during the design basis flood (ITS function)
- Prevent damage to SNF by mitigating the effects of a fire at the ISF Facility

- Provide temporary storage capability for SNF arriving at the ISF Facility before packaging into ISF canisters
- Provide shielding to workers in the operating gallery and surrounding office and maintenance areas due to direct radiation from the SNF being handled in the FPA
- Provide a physical personnel barrier to prevent unauthorized or inadvertent entry to prevent worker exposure to very high radiation dose rates
- Provide an area to perform remote SNF handling operations
- Provide a shielded area to permit maintenance and repair activities on the FHM

4.7.3.1.4 Canister Closure Area

Canister Closure Area Description

The CCA, shown in Figure 4.7-15 and Figure 4.7-16 provide a controlled area to perform canister closure activities, which include welding, purging, vacuum drying, inerting, inspections, and testing.

The CCA is a reinforced-concrete room approximately 22 feet wide by 40 feet long and 27 feet high, located immediately north of the FPA. The Transfer Tunnel runs below a portion of the CCA to allow the canister trolley to be positioned under the floor for access to the CCA port. The CCA building is structurally part of the FPA and is located within the Transfer Area of the ISF Facility.

Adjacent to the CCA is an operations office and equipment room where operators monitor canister closure operations, and where the vacuum drying and helium fill equipment is located. A large observation window between the operators office and the CCA allows operators to view the automatic welding, vacuum drying, helium fill, and leak detection sequences while remaining outside of the immediate CCA working area. Use of remotely operated equipment reduces the dose burden to the operators.

The CCA contains the following major components:

- canister vertical storage rack containing new ISF canister body assemblies and a canister lifting cage
- new canister lifting rig
- canister handling equipment
- lifting cage table
- canister welding system
- vacuum dry, helium fill and leak detection system
- new ISF canister lid assembly storage racks
- CCA port and cover plate
- new canister port and cover plate

Canister Closure Area Activities

The following activities are performed in the CCA:

- receiving and staging new empty ISF canister and ISF basket assemblies
- installing new empty ISF canisters into the canister trolley via the CCA port
- removing ovality from the ISF canister lower subassembly before welding the ISF canister upper subassembly
- welding the ISF canister upper subassembly to the lower subassembly after SNF is loaded into the ISF canister
- performing non-destructive examination on the closure weld
- vacuum drying the loaded canister
- inerting the canister with helium gas
- fitting screwed vent plug into canister vent port
- seal welding the canister vent plug
- performing non-destructive examination on the vent plug seal weld
- performing helium leak testing on the canister closure weld and vent plug seal weld

New Canister Operations

New ISF canisters are delivered to the ISF Facility from the fabricators in a new canister crate and placed into storage at the ISF Facility warehouse. The empty ISF canisters and baskets are moved horizontally from the warehouse to the CCA using the new canister cart. When the new canister cart is positioned under the CCA new canister port and the loading bay outer doors are closed, the new canister port can be opened. Specifically designed lifting equipment and the CCA crane are used to raise the canister and basket from the horizontal to vertical position and up into the CCA. The ISF canister shield plug and lid assembly are lifted into the CCA separately from the canister body assembly. The ISF canister body assemblies are stored in vertical racks inside the CCA.

After the canister trolley has transported a loaded canister to the Storage Area, it returns to the CCA to collect an empty canister. The new ISF canisters are placed into the canister lifting cage to facilitate transfer of the canister into the canister cask. The canister cask is prepared to receive the new canister by removing the cask and canister funnels, and the collet system (described below). This exposes the lifting cage that had been used to place the previous canister into the canister cask. This cage is removed and the canister cask inspected before lowering in the new ISF canister. A spacer stool is used in the canister cask to convert it to accommodate the short ISF canister.

After placing the new ISF canister into the canister cask, the upper lifting equipment is detached from the lifting cage and the canister cask collets are fitted. The internal diameter of the new ISF canister body assembly adjacent to the lid weld is trued up using the collets. This removes ovality from the bore of the canister body to ensure that the lid assembly fits correctly. The anti-contamination seals are fitted to the protruding portion of the canister and the cask shield ring and basket funnel are fitted.

The ISF basket is lifted out and then replaced to check that it fits freely in the ISF canister. The ISF canister shield plug is placed into the ISF canister and similarly cycled using the CCA crane. After the shield plug has been demonstrated to fit freely in the canister, its lifting pintle is fitted with a screwed plug that prevents further handling of the shield plug inside the CCA. This is to mitigate any inadvertent attempt to remove the shield plug from the canister after it has been loaded with SNF. The canister trolley is now ready to be transferred to the FPA for SNF loading operations.

Canister Closure Operations

After the ISF basket and ISF canister have been loaded at the FPA and the ISF canister shield plug reinserted, the canister trolley is then moved along the Transfer Tunnel into position under the CCA port. The canister trolley jacks the canister cask (with the loaded ISF canister and basket assembly) partially into the CCA floor opening. The CCA port cover plate is removed from the floor of the CCA. The canister trolley is jacked-up further to permit access to the ISF canister for welding, inspection, vacuum drying, and inert filling operations.

After the cask shield ring and basket funnel have been removed from the top of the canister cask, the protruding end of the ISF canister is inspected to ensure that no damage has occurred during the basket loading operations. The exposed surfaces of the ISF canister are cleaned and swabbed to check that no contamination is present on the canister outside surfaces.

The upper ISF canister subassembly is then installed and welded to the lower ISF canister subassembly using the automated canister welding system, followed by NDE inspections. The canister is then vacuum dried and filled with helium gas. A helium leak test is performed on the circumferential weld between the upper and lower subassemblies. Finally, the vent port plug is fitted and the port seal welded closed and inspected. The vent port weld is inspected by dye penetrant inspections, and helium leak test.

The canister cask shield ring and the canister funnel are fitted to the top of the cask, and before the cask collets are released the CCA port cover plate is placed over the top of the cask shield ring. The CCA port cover plate is 2 inches thick and by placing it over the top of the cask, it reduces the streaming dose from the ISF canister that occurs when the collets are released. With the cover plate in place, the cask collets are released and the canister cask is lowered into the Transfer Tunnel by the canister trolley jacking system. As the cask passes down through the CCA port, the cover plate is automatically left behind to close the port, and maintain control of the ventilation differential pressure between the CCA and Transfer Tunnel. The canister trolley then moves the sealed canister down the Transfer Tunnel to the Storage Area load/unload port for the canister to be removed from the canister cask and placed into the storage vault.

Canister Closure Area Performance Objectives

The performance objectives of the CCA are:

- Control the release of radioactive materials to the environment during normal, off-normal, and accident conditions (ITS function)
- Prevent damage to SNF during normal, off-normal and accident conditions (ITS function)
- Provide the capability to maintain SNF temperatures within allowable material limits (ITS function)

- Provide a temperature-controlled environment to facilitate canister closure welding and vacuum drying
- Provide an area to stage, handle, and install new canisters into the canister trolley
- Provide visual capability through an observation window to monitor canister welding, inerting, inspecting, and testing activities
- Provide a boundary to ensure proper ventilation flow path during normal operating conditions
- Prevent damage to the SNF during the design earthquake (ITS function)
- Prevent damage to the SNF by mitigating the effects of a fire at the ISF Facility
- Provide shielding to workers in the operating gallery and surrounding office and maintenance areas due to direct radiation from the SNF inside loaded canisters in the CCA

4.7.3.1.5 Storage Area Building

Storage Area Building Description

The Storage Area building, shown in Figure 4.2-4, provides a weather-protected area that covers the Storage Area vaults and portions of the Transfer Tunnel. A detailed description of the Storage Area vaults are provided in Section 4.2. This section addresses the building above the vaults and charge face.

The Storage Area building is a steel-framed structure mounted on top of the walls of the Storage Area vaults. The steel-frame superstructure is covered with metal panels and a standing seam pitched metal roof over steel joists and purlins.

Fixed louvers located in the walls of the building provide airflow to support natural circulation cooling of the Storage Area vaults. The building also has exhaust fans and intake air louvers to provide forced air flow for personnel comfort. This forced ventilation is not required to maintain temperature limits for the SNF stored in the vaults below. Electric heaters are used to maintain the general area inside the Storage Area building and the CHM above 32°F in the winter to permit canister handling operations to continue in cold weather. Section 4.3.1 provides additional details on the HVAC system design.

The CHM runs along rails mounted to the walls of the Storage Area vaults. The steel superstructure of the Storage Area building is independent of the CHM. The Storage Area building also covers the south end of the Transfer Tunnel, which allows the CHM to access the Storage Area load/unload port inside a climate-controlled area.

Normally, CHM maintenance occurs at the west end of the storage building, over the Transfer Tunnel. A 10-ton monorail hoist is mounted on structural steelwork in the roof of the Storage Area building to facilitate CHM maintenance. The 10-ton hoist can travel the full width of the vault above the Transfer Tunnel and is used for removal and replacement of components on the CHM during maintenance. However, the maintenance hoist cannot travel over the storage vault area and therefore cannot drop dismantled CHM components onto the vault. The hoist is also used to bring maintenance equipment, spare parts, and operating consumables into the Storage Area building through the CHM maintenance hatch that is located over the Transfer Tunnel.

Storage Area Building Activities

The following activities are performed inside the Storage Area building:

- Transfer loaded canisters from the Transfer Tunnel via the load/unload port to the Storage Area vault using the CHM
- Transfer loaded canisters from one storage tube into another storage tube using the CHM
- Transfer loaded canisters from a storage tube to the load/unload port using the CHM
- Prepare storage tubes or the load/unload port for CHM operations
- Closure of storage tubes or load/unload port after CHM operations
- Leak testing a storage tube
- Evacuating and helium filling a storage tube
- Installing a tamper indicating device on the loaded storage tube for SNF accountability purposes
- Monitoring storage tube conditions during storage
- Maintenance of the CHM

After the ISF canister closure is completed at the CCA, the canister trolley travels south along the Transfer Tunnel to the Storage Area load/unload port. Once the trolley is positioned under the Storage Area load/unload port, a locking pin is deployed to prevent inadvertent movement of the canister trolley during transfer of the ISF canister to the CHM in the Storage Area. The canister trolley jacks the canister cask up to prepare for removal of the canister. Jacking the canister cask positions the shielded cask close to the ceiling of the Transfer Tunnel, thereby minimizing direct radiation inside the tunnel when the canister is lifted into the CHM.

The CHM located in the Storage Area is used to remove the Storage Area load/unload port plug allowing access to the canister cask that is positioned below the Storage Area charge face floor. The CHM lowers the canister grapple onto the ISF canister until the grapple is seated on the canister. The grapple jaws are closed and the ISF canister is hoisted out of the canister cask and into the CHM turret cask. Because there is no shielding in the area above the storage vault, the CHM provides the required shielding and protection of the canister until it is placed into the concrete shielded vault area below the charge face of the Storage Area.

The CHM travels to the designated storage tube location using its on-board TV camera navigation system. The CHM removes the shield plug from the storage tube and lowers the ISF canister down into a storage tube. The CHM re-installs the storage tube plug into the storage tube. The shield plug lifting pintle is removed and the storage tube lid is installed, bolted down. The storage tube is evacuated and filled with helium. Leak checks are performed to ensure the storage tube vent port dual metal seal rings have sealed properly. Finally, the charge face cover plate is installed and bolted down to protect the storage tube assembly from potential tornado damage.

The CHM is also used to remove an ISF canister from a storage tube. ISF canisters will be removed at the end of the storage campaign for offsite shipment. ISF canisters may also need to be removed from a storage tube for operational reasons (e.g., if a problem were to develop with a storage tube lid seal).

Removal of an ISF canister from a storage tube is the reverse operation to loading the tube. Before the CHM can remove the ISF canister, the storage tube will be vented to reduce the internal helium pressure to atmospheric pressure, the lid bolts undone, and the storage tube lid removed. The lifting pintle is fitted to the storage tube plug. The CHM can now position itself over the storage tube by lining up with the shield plug lifting pintle target. The storage tube shield plug is removed and the canister grapple lowered to engage the ISF canister in the tube. The CHM hoists the ISF canister out of the storage tube and takes it to its next location.

Storage Area Building Performance Objectives

The performance objectives of the Storage Area building are:

- provide a weather-protected area over the storage vaults to prevent rain or snow from entering and to minimize the effect of wind during canister handling operations
- maintain structural integrity of the primary steel structure during postulated tornadoes and earthquakes to prevent collapse
- provide a flow path to support natural circulation flow from the storage vaults to the outside through the fixed louvers in the walls of the storage area building
- provide a temperature-controlled environment that will maintain the CHM temperature above 32°F to permit continued SNF handling operations
- minimize outside debris from blocking the cooling air ventilation ports in the charge face of the storage vaults
- provide a level of comfort to operations personnel by the use of ventilation and heating inside the area
- provide adequate lighting to facilitate canister handling operations
- provide an area for performing maintenance on the CHM
- provide an area for storage of equipment and systems that are required to support SNF storage operations
- provide a physical boundary to ensure personnel safety during canister handling operations

4.7.3.2 Components for Fuel Handling Operations

Components for SNF handling operation are discussed in relative order from SNF receipt to storage. In addition, this section addresses other major components that are used to support SNF packaging activities.

4.7.3.2.1 Cask Receipt Crane

The CRC, shown in Figure 4.7-1, is used to lift the 35-ton DOE transfer cask from the transportation vehicle and lower it onto the cask trolley. The CRC is rated at 155 tons. The CRC is a fixed, single-failure-proof hoist in accordance with of NUREG-0554. A special lifting device, shown in Figure 4.7-17, is used to lift the DOE transfer cask from the transport vehicle and place it on the cask trolley. The lifting device is designed in accordance with ANSI N14.6. The CRC is operated by a pendent from the floor of the CRA.

The CRC is supported by a structural steel tower, integral with and housed inside, the CRA. A load cell is provided in the CRC load path to initiate an alarm if the CRC attempts to lifts more than the maximum critical load. The load cell will also trip the drives and engage the brakes on detection of an overload condition. The CRC has a dual braking system that fails safe on loss of power. A detailed description of cask loading and off-loading sequences is provided in Chapter 5. The CRC and associated lifting devices are classified ITS.

The CRC is assisted by a 10 ton X – Y auxiliary crane. The cask receipt auxiliary crane is used to remove and replace transfer cask hold down devices on the horizontal transporter, install the cask adapter, and other supplementary rigging operations. The cask receipt auxiliary crane is classified NITS.

4.7.3.2.2 Cask Trolley

The cask trolley, shown in Figure 4.7-2, is used to transport a loaded DOE transfer cask between the CRA and the cask port below the FPA in the Transfer Tunnel, and to return the empty transfer cask back to the CRA. The cask trolley is single-failure-proof in accordance with NUREG-0554. The maximum weight the cask trolley will transport is a DOE transfer cask, cask adapter and cask lid lifting device for a total design load of approximately 35 tons. The trolley rails are designed for a maximum load that includes the trolley, cask, and lifting devices.

The cask trolley is made of a carbon steel fabricated framework mounted on four wheels to form a base platform. The DOE transfer cask is supported in an elevated position on the cask trolley in order to present it at the correct height at the cask port beneath the FPA. One side of the framework has a vertical opening to allow side loading of the cask onto the cask trolley. This feature minimizes the height the transfer cask must be raised to position it on the cask trolley. After the transfer cask is placed onto the trolley, a restraint device is used to close this opening and ensure the cask remains in an upright position while the cask adapter is being installed.

The trolley runs on a pair of steel rails set 12 ft apart and approximately 215 feet long. The rails are attached to rail support plates mounted to the concrete floor of the CRA and Transfer Tunnel. Cask trolley wheels are protected from jamming by track debris deflector plates mounted close to the rail in front of and behind each wheel module. The cask trolley design prevents the trolley from being derailed during normal operations, a seismic event, or an impact event. In the event of a wheel or axle failure, the trolley fall is limited to 1 inch. Jacking points are incorporated adjacent to each wheel. The jacking points allow the replacement of a wheel/axle module while a loaded cask is in place on the cask trolley within the confines of the Transfer Tunnel. The wheel modules can be replaced at any position within the Transfer Tunnel.

The cask trolley has two speeds; creep at 1 foot per minute, and normal at 10 feet per minute. Slow zones have been established on either side of the cask trolley activity positions. The cask trolley can only move at creep speed while in these zones and creep or normal speed while outside of these zones. The cask trolley is controlled by plant operators at the control console inside the CRA. The cask trolley moves along the Transfer Tunnel by driving a pair of wheels using an onboard electric motor and gear unit, which incorporates an electromagnetic brake and clutch. Upon loss of electrical power, the brake fails safe to stop cask trolley motion. The brake release coils are connected directly across the motor starter terminals. The brake incorporates emergency release features that allow the brake to be released for recovery of the cask trolley following power failure.

Video cameras located in the Transfer Tunnel display images of activities on a monitor mounted adjacent to the operator console. The control console contains the controls, indicators and alarms required to control cask trolley functions. System operational interlocks are carried out by a programmable logic controller (PLC), which provides system status via remote signal to the integrated data collection system (IDCS). Proximity-type sensors placed within the Transfer Tunnel provide position indication, control, and operational interlocks to the PLC for the cask trolley. Over travel of the cask trolley is prevented by "end of travel" limit switches that are hard-wired into the drive contactor control circuit.

The cask trolley has designated stopping positions below the CRC, inside the cask decontamination zone of the Transfer Tunnel, and the cask port beneath the FPA. The cask trolley uses a locking pin that extends from the base platform and fits into an engineered cavity in the floor to lock the cask trolley in position at the cask port beneath the FPA. This feature locks the cask trolley in position before unloading the transfer cask through the cask port and into the FPA. The locking pin is design to fail as-is during a loss of power. This design ensures that the cask trolley will remain locked in position if a seismic event should occur while loading the transfer cask onto the trolley or during SNF transfer from the transfer cask into the FPA. The design incorporates manual recovery features to allow extension or retraction in the event of a locking pin failure.

Power for the electric motor is provided by the normal electrical distribution system. An electrical power and control cable reeling system is mounted on the cask trolley with the fixed position of the cable located in the CRA. The cable reeling system is a motorized payout and retrieval drum. A cable guide is attached to guide brackets fixed to the concrete floor of the Transfer Tunnel. During cask trolley motion away from the CRC, the cable reeling system pays out the electric and controls cable at a constant tension and lays it in the cable guide. During cask trolley motion towards the CRC, the cable reeling system drive rewinds the cable back onto the reel. A cable reel motion detector is used to ensure that the cable reel system is properly paying out and retrieving cable during trolley travel.

A cask adapter, made from a stainless steel fabricated ring is installed over the top of the DOE transfer cask. The cask adapter is installed inside the CRA after the transfer cask is situated inside the cask trolley. The cask adapter rests on the upper trunnions of the transfer cask and is positioned on the outside of the cask body and lid to allow the lid to be removed once inside the transfer tunnel. The cask adapter uses a series of turnbuckles around the perimeter that attach to the cask trolley and are used to anchor the cask to the trolley. The cask adapter incorporates remote lid release clamps to hold the cask lid closed after the cask lid bolts have been removed inside the Transfer Tunnel Cask Decontamination Zone. These remote release lid clamps are released by the power manipulator system when the cask is positioned under the cask port in the floor of the FPA.

When the cask trolley is positioned below the cask port, the relationship between the cask adapter and the cask port generates an engineered gap. An inflatable seal, mounted on the underside of the cask port is deployed using compressed air. This inflatable seal contacts the machined surface of the cask adapter and seals the interface between the FPA and the Transfer Tunnel. This seal provides a continuous confinement barrier between the FPA and the DOE transfer cask before opening the cask port. This feature also minimizes the disruption to the HVAC system flow balance and the potential for the spread of contamination.

The cask trolley, cask adapter, and inflatable seal are classified ITS.

4.7.3.2.3 Canister Trolley

The canister trolley, shown in Figure 4.7-4, incorporates two major components. The canister cask is attached permanently to the canister trolley and is not removed during SNF handling operations. The canister cask can be raised and lowered within the trolley using a jacking system and can accommodate the three sizes of ISF canisters (18-inch short, 18-inch long, and 24-inch long).

Canister Trolley. Includes the trolley frame, wheel base platform, wheels, seismic restraints, actuated locking pin system, and canister jacking system. The canister trolley performs the following functions:

- transfers new ISF canisters containing empty SNF baskets and shield plug from the CCA to the FPA
- transfers ISF canisters containing SNF, SNF baskets, and shield plug from the FPA to the CCA
- raises the canister cask to the required working level at the canister port, CCA port, and Storage Area load/unload port
- transfers sealed ISF canisters containing SNF from the CCA to the Storage Area load/unload port

Canister Cask. Includes the shielded housing for the ISF canister, the canister heating system, and the canister 'rounding' equipment. The canister cask performs the following functions:

- provides means to remove the ovality of the weld preparation area of the ISF canister assemblies before transferring the new ISF canister to the ISF canister port
- supports the ISF canister assembly during the final closure weld process (including vacuum drying, weld inspection, and pressure/leak test)
- provides radiation shielding during the transfer and final closure weld operations
- provides heating of the canisters to facilitate canister welding and vacuum drying
- provides a suitable mating surface for the inflatable seal at the ISF canister port, below the FPA

When discussed throughout the SAR, the term canister trolley is meant to imply the entire assembly (trolley and cask) unless otherwise stated.

The canister trolley is fabricated from a carbon steel framework mounted on four wheels to form a base platform. Mounted on the base platform is a carbon steel fabricated framework to support a jacking system and guide for the canister cask. The canister trolley runs on the same steel rails as the cask trolley inside the Transfer Tunnel. The canister trolley wheels are protected from jamming by track debris deflector plates mounted close to the rail in front and behind of each wheel module. The canister trolley design prevents the trolley from being derailed during normal operations, a seismic event, or an impact event. In the event of a wheel or axle failure, the trolley fall is limited to 1 inch. The jacking points enable the replacement of a wheel/axle module with a fully loaded canister in place on the canister trolley within the Transfer Tunnel. The wheel modules are capable of being replaced at any position within the Transfer Tunnel.

The normal travel sequence of the canister trolley is from the CCA to the FPA, back to the CCA and finally to the Storage Area. During maintenance, the canister trolley can also be moved into the Transfer

Tunnel Cask Decontamination Zone. At the designated loading and unloading positions, the canister trolley is locked in position using a locking pin system to prevent movement during a seismic event. The locking pin extends from the base platform of the trolley and fits into an engineered cavity in the floor to lock the canister trolley in position. The locking pin is design to fail as-is during a loss of power. This design ensures that the canister trolley will remain locked in position if a seismic event should occur while SNF transfer operations or canister closure operations are occurring. The design incorporates manual recovery features to allow extension or retraction in the event of a failure.

The control console for the canister trolley is located in the CCA operations room. A camera system installed within the Transfer Tunnel provides video pictures of the canister trolley to the operator during operations. The canister trolley has two operating speeds, creep, and normal. The creep speed is one foot per minute and the normal operating speed is 10 feet per minute. The canister trolley moves along the Transfer Tunnel by driving a pair of wheels using an onboard electric motor gear unit. The motor gear unit has an electromagnetic brake and clutch. Upon loss of electrical power, the brake fails in a safe state to stop canister trolley motion. The brake incorporates an emergency release feature that allows the brake to be released for recovery of the canister trolley following power failure.

Electrical power is derived from the normal electrical distribution system. An electrical power and control cable reeling system is mounted on the canister trolley with the fixed position of the cable beneath the CCA. The cable reeling system is a motorized payout and retrieval drum. As the canister trolley moves away from the CCA, cable pays out at a constant tension and is laid in a tray. As the canister trolley moves toward the CCA, the cable reeling system drive automatically re-winds the cable back onto the reel with a cable diverter ensuring even layering of the cable on the reel. A cable reel motion detection system is used to ensure that the reel is properly paying out or retrieving cable as the canister trolley moves.

Proximity sensors located within the Transfer Tunnel provide accurate position indication and positioning for the canister trolley. The sensors are also used to provide operational interlock functions to the PLC. Over travel of the canister trolley is prevented by end of travel shunt limit switches that are hardwired into the drive contactor control circuit. The limit switch is hard wired in series with the supply to the drive on the canister trolley and is capable of breaking the full load current of the motor. Refer to Chapter 5 for additional details on controls and interlocks.

In the event of a canister trolley overrun beyond the interlocks, motion is stopped by bumpers mounted to the extreme ends of the canister trolley, which react against rail mounted end stops at one end and against the cask trolley at the other end.

A cask jacking system comprised of multiple, inverted translating screw actuators are mounted on the canister trolley framework. A braked motor gear unit drives the screw actuators. Suspended from the screw actuators is the canister cask. The canister cask provides shielding along the length of the canister. The shielding along the length of the canister is in two parts with the top of the shielding sufficiently below the canister/lid interface to allow for lid welding and canister ovality removal. The interface between the two parts is stepped in order to prevent any radiation shine paths at the joint, and bolted together. The bottom part of the shielding is designed to house the canister lifting cage assembly. The top part of the shielding is designed to accept the rounding equipment. The function of the rounding equipment is to remove any ovality from the canister while it is in the cask. To facilitate handling the short ISF canister an internal stool is positioned in the bottom of the cask to present the top of the short canister at the same height as the long canister.

The multiple inverted screw actuators are designed to perform the following functions:

- raise, lower, and hold the cask and ISF canister in position at each required location under normal, off-normal, and accident conditions
- accurately position the ISF canister at each transfer point in the vertical direction
- provide redundant features so that the failure of a single system will not result in the loss of capability to retain the ISF canister in position
- incorporate manual recovery features to allow the cask and ISF canister to be safely lowered onto the canister trolley in the event of jacking system failure

The ISF canister heating system maintains the canister temperature between 80°F and 100°F to assist vacuum drying of the SNF during the canister closure process.

When the canister trolley is in position at the canister port below the FPA, the canister cask is jacked up into a recess in the Transfer Tunnel ceiling. An inflatable seal is inflated using compressed air to close the radial gap between the canister cask and the transfer tunnel recess. This seal extends the FPA confinement barrier into the cask when the canister port plug is removed. This seal also minimize the disruption to the HVAC system flow balance and the potential for the spread of contamination.

The canister trolley and control system must function to prevent damage to the SNF during handling, and provide reasonable assurance that SNF can be received, handled, packaged, stored, and retrieved without undue risk to the health and safety of the public. The canister trolley (canister trolley and the canister cask assemblies) provides capabilities for lifting, handling, and transfer of SNF. Therefore, the canister trolley is classified as ITS.

4.7.3.2.4 Fuel Packaging Area Shield Doors

This section describes both the FPA shield doors and the Personnel Shielded Access (PSA) door. The shield doors are located between the FHM Maintenance Area and the FPA. The PSA door is located in the workshop and provides personnel access into the FHM Maintenance Area.

Fuel Packaging Area Shield Doors

The FPA shield doors, shown in Figure 4.7-18, and Figure 4.7-19, consist of one vertical door and one horizontal sliding door that will be opened to allow the FHM to pass through and then closed to enable maintenance of the FHM in the FHM Maintenance Area. The FPA shield doors are constructed from carbon steel plates and provide radiological shielding to personnel in the FHM Maintenance Area during maintenance of the FHM.

The vertical door is suspended from two screw jacks. Rollers and guides are mounted on the door, and guide the door movements vertically and horizontally. The rollers and guides are mounted on the walls of the FHM Maintenance Area. The rollers and guides are designed so that they can be maintained/replaced from the FHM Maintenance Area. This ensures that the door guide and restraint systems can be repaired or maintained even when there is SNF present within the FPA (when the door is closed). The rollers and guides provide support to keep the door in place during and following a seismic event.

The screw jacks are mounted on the roof of the FHM Maintenance Area. The screw jacks are driven by a single-braked motor through a twin output reduction gearbox and drive shafts that are mounted on the roof of the FHM Maintenance Area. The brake is electromagnetic and fails safe on a loss of electrical power (energize to release and de-energize to brake via a spring). The brake also has a hand release feature.

Two lock assemblies mounted on the roof of the FHM Maintenance Area lock the door in its fully raised position. Each lock assembly comprises a manually operated twist lock that mates with a feature on the top of the door. Each lock assembly is capable of maintaining its function if the other lock fails. These two lock assemblies are used when necessary to perform maintenance on the screw jacks or other door features so that the vertical shield door cannot be inadvertently dropped.

The horizontal door runs on wheel modules on a rail mounted to the wall inside the FHM Maintenance Area. The top of the door runs in guide rollers mounted on the vertical sliding door and on the wall of the FHM Maintenance Area. The wheel modules are designed so that they can be maintained or replaced from the FHM Maintenance Area, thereby allowing maintenance access to these components with minimum radiological exposure to the maintenance operator. Attached to the base of the door is a seismic restraint that acts to keep the door on its rail during and following a seismic event. In the top face of the door is a recess for the guide rollers to run in. The rollers act to keep the door in place during and following a seismic event. The horizontal door moves by a rack mounted on the door and a pinion that is driven by a braked motor gear unit through an electromagnetic clutch. The motor gear unit is mounted on the wall of the FHM Maintenance Area.

The speed of the vertical sliding shield door is approximately 16 inches per minute, resulting in a time for the door to open or close of approximately 8 minutes. The speed of the horizontal sliding shield door is approximately 39 inches per minute, resulting in a time for the door to open or close of approximately 2 minutes. The shield doors are powered from the normal electrical distribution system.

The shield doors are operated by manual push buttons on a control station. The control station, which includes an emergency stop button, is located next to the shield window in the operating gallery nearest the workshop to allow operators to see the shield door area.

The FPA shield doors are classified as NITS, however, the FPA shield doors are seismically designed to withstand the design earthquake when they are closed.

PSA Door

The PSA door, shown in Figure 4.7-20, is constructed from carbon steel plate mounted on two hinge assemblies to a steel door frame. The latch mechanism locks the door from the workshop side while allowing for emergency egress from the FHM Maintenance Area. The PSA door is approximately 4 feet wide by 7 feet high.

The PSA door is sealed when closed and is manually opened and closed to allow personnel access into and out of the FHM Maintenance Area to perform maintenance on the FHM. The PSA door is classified ITS, because it forms part of the FPA confinement barrier.

4.7.3.2.5 Fuel Handling Machine and Power Manipulator System

The FHM, shown in Figure 4.7-3, is a 10,000-lb bridge/trolley crane designed to operate in the FPA. It has a single failure-proof hoist designed in accordance with NUREG-0554. The PMS is an electrically powered robotic arm mounted on a telescopic mast, which in turn is mounted on the bridge of the FHM. The PMS does not routinely handle SNF and is not designed to be single failure-proof.

The FHM system is operated remotely by operators viewing SNF handling operations from the Operating Gallery through shield windows in the FPA wall and CCTV cameras mounted on the FHM and in the FPA. Operators use the FHM to perform remote handling operations of SNF in the FPA where the levels of radiation are too high for hands-on operation. The PMS, mounted on the trolley of the FHM, is used to assist in the latching and de-latching of lifting devices and to assist with packaging and maintenance work within the FPA.

The FHM consists of an overhead electric crane with a top running bridge and cross travel trolley. The FHM is mounted on rails that run in the east-west direction through the FPA and into the FHM Maintenance Area. The FHM is equipped with a hoist unit. A range of lifting devices designed for attachment to the FHM hoist provides capability for the various lifting applications associated with handling the different SNF types, DOE containers, and ISF baskets in the FPA. The lifting devices for the FHM are discussed further in Section 4.7.3.2.10.

The FHM has a load cell designed to accommodate a minimum of 125 percent of the maximum critical load (MCL) for the static load test. The load cell is used to prevent the hoist overloading by an interlock that trips the hoist if the MCL is exceeded, and to weigh the SNF assembly or SNF and ISF canister basket. The load cell has an accuracy of ±150 pounds at 10,000 pounds.

The FHM hoist has a power control braking system and two holding brakes. The brakes act directly on the rope drum flanges and fail safe to lock the hoist on loss of electrical power or the loss of a single phase. The hold brakes are energized to be 'off' and de-energized 'on', by dual springs, for redundancy. Each of the holding brakes has the capability to fully arrest more than the maximum critical load from maximum speed.

The FHM hoist has two independently powered hoist motors. The motors are powered by variable speed controllers where the maximum and minimum speeds allow maximum speed hoisting and "soft landing" and "soft start" hoisting. The variable speed controllers allow the operator to select the optimum speed to perform accurate maneuvering. The minimum and maximum hoist speed is 0.5 feet/min and 14 feet/min respectively.

The PMS consists of an electrically powered telescopic mast, manipulator arm and tools, and associated instrumentation and controls. The telescopic mast is a multi-part telescopic tube set that can retract to 8 feet and extend to 22 feet. The manipulator arm and remotely detachable jaw and associated tools are used to remotely latch and de-latch the special lifting devices on the FHM hoist hook. The PMS is fitted with a load cell that is used to prevent the PMS from overloading by tripping an interlock if the design load rating is exceeded. A detailed description of operational sequences using the FHM and PMS and the instrumentation, controls, and interlocks on the FHM and PMS are provided in Chapter 5.

A video camera with light source is mounted on the manipulator arm to assist in viewing PMS operations or viewing other areas within the FPA. The camera provides the capability to record operations and document information such as SNF assembly markings. The monochrome video camera attached to the PMS has pan, tilt, zoom, and focus capabilities controlled remotely by operators, and is capable of viewing and recording numbers and letters stamped on SNF assemblies. A second monochrome video camera with remote pan, tilt, zoom, and focus is mounted on the FHM trolley and provides general viewing capability of the FPA.

Operational and load carrying components of the FHM are classified as ITS. The PMS is classified NITS.

4.7.3.2.6 Master Slave Manipulator

A typical MSM is shown in Figure 4.7-21. A series of through-wall MSMs are mounted adjacent to the through wall shield windows in the walls of the FPA as shown in Figure 4.2-2. The MSMs are used to assist in the steadying and alignment of components suspended from the FHM hoist, and to provide support to the PMS by positioning tools and fittings that may be required.

The MSMs extend the dexterous manipulative capabilities of a human operator into a hazardous environment. They provide safe and efficient handling of materials where the human operator cannot have direct contact with the material. The MSMs reproduce the natural movements and forces of the human hand. The manipulator jaw will move as the operator moves the manipulator handle, except for slight amounts of deflection and lost motion. The forces at the jaw are equal to those applied at the handle, except for slight amounts of friction and unbalance

The master arm is located in the operating gallery and the slave arm inside the FPA. The MSM uses include the following:

- assisting the FHM
- removing and replacing the canister and waste package lids
- latching and detaching unpowered grapples
- sorting and packaging waste
- equipment operation and maintenance

Two through-wall encasts are provided adjacent to each shield window. Each of these positions will not be occupied by MSMs. Any encast position that is not occupied by a MSM will have a shield plug installed with the shielding capability of the shield wall that can be removed to allow for the installation of a MSM should the need arise. Encast liners anchor the through-wall tube during operation of the MSMs and provide seals to prevent the spread of radioactive contamination from the FPA. They also allow the through-wall tubes to be removed easily from the shield walls surrounding the FPA for maintenance and repairs.

The MSM through wall tubes and encasts are classified ITS since they form part of the FPA confinement barrier. The balance of the MSM is NITS.

4.7.3.2.7 Bench Vessels

The FPA bench vessels are flanged tube assemblies positioned in openings in the steel 'workbench', or an encast inside a concrete cavity in the FPA. With the exception of the fuel basket operations and monitoring station, the bench vessels are supported from the concrete floor of the FPA as shown in Figure 4.7-22, which shows a typical bench vessel arrangement for the Shippingport Fuel campaign.

The primary function of the bench vessels is to provide stability and support to the DOE canisters and ISF baskets while individual SNF elements are removed or loaded within the FPA. There is also a range of adapters designed for specific applications for each of the SNF types that will be assembled into the relevant bench vessel at the start of a particular SNF campaign.

With the exception of the fuel basket operations and monitoring station, the bench vessels are held in position by bolted top flanges and a doweled pin located on a base plate at the bottom. The fuel basket operations monitoring station is an encast located within a concrete cavity that provides shielding to permit radiation monitoring of empty waste containers to occur inside this station. The bench vessels are not removed during SNF handling operations and are not required to be changed to handle different SNF types. A removable bucket is located at the bottom of each bench vessel to allow the recovery of items that may fall into the vessels. Unused vessels are blanked off if not required for a particular SNF campaign.

There are eight main bench vessels in the FPA. Five are used to support the packaging and processing of the various SNF types and the other three are used to provide temporary storage for empty SNF cans and canisters to support solid waste processing activities.

The bench vessels that support SNF packaging are:

- fuel basket operations and monitoring station
- decanning station
- fuel loading station 1
- fuel loading station 2
- fuel loading station 3

With the exception of the fuel basket operations and monitoring station , the bench vessels are constructed from steel pipe with flanges welded to the top and a steel pipe support 'stool' welded to the bottom. Depending upon the location and application, the bench vessel is either stainless steel, or coated carbon steel. The bench vessels do not hang from the FPA bench. They are supported by a base plate from the concrete floor. The base plate incorporates a dowel pin to provide lower lateral restraint for the vessel. The dowel pin will allow the bench vessel to be removed and replaced by remote means should it become necessary. Bolting the top flange to the steel workbench provides lateral support and vertical constraint for the vessels. The bolting arrangement includes a disc spring stack to allow for differential thermal expansion between the bench vessel and the first and second floors of the FPA. The bench vessels are sized with sufficient clearance to ensure smooth loading/unloading of the various canisters, baskets, adapters, and liners buckets.

The bench vessels function to support and provide temporary storage of SNF and are classified ITS.

4.7.3.2.8 Decanning Machine

The decanning machine, shown in Figure 4.7-23, is used to remove a small upper section of the can or salvage can that contains the Peach Bottom 1 fuel elements to allow removal and storage in the ISF baskets. The can will be received, at the decanning station, in the vertical orientation and restrained, in this position, while a small upper section is cut away, to enable removal of the SNF element from the can.

The decanning machine is required to process three types of cans:

- Peach Bottom 1 fuel element can
- Peach Bottom 1 fuel element salvage can
- Peach Bottom 1 fuel element can, with attached removal tool (ART)

The cans with or without ART are decanned in the same manner. However, the salvage can contains another can within it. Therefore, to remove a SNF element from these cans two cutting operations are required. The Peach Bottom 1 fuel element can and salvage can along with the cut locations for each can are shown in Figure 4.7-24.

The decanning machine is situated in a bench vessel inside the FPA directly in front of a shield window. A video camera system is used for additional viewing. The orientation of the decanning machine allows the can identification number, which is marked near the top of the can to be identified, recorded and verified before the cutting process commences. The decanning machine uses an adjustable four-blade cutting head to minimize waste and accommodate cutting of both standard and salvage cans, which differ in diameter and length. The cans are cut at a predetermined cut zone location near the top of the can, thereby removing a small portion of the can to gain access for removal of the SNF element.

The decanning machine is secured to a bench vessel using alignment dowels installed in the workbench. These studs align the tool during installation and secure the tool against seismic forces. The decanning machine's lower base plate & spool assembly also interface with the lower section of the bench vessel to provide seismic restraint for the full-length or the SNF element.

Based on the physical design features described above, the decanning machine is not capable of damaging the SNF. Therefore, the decanning machine is classified NITS.

4.7.3.2.9 Worktable

The worktable, shown in Figure 4.7-14, is a multipurpose table bolted to the FPA workbench incorporating various machines and equipment. It is designed for safe handling and decontamination of empty waste containers (canisters, cans, buckets etc.) used in the transfer of SNF. The worktable also has the capability to allow recovery from anticipated problems that may occur during SNF processing activities, including the handling and recovery of broken or stuck SNF elements.

The worktable is a large rectangular base plate with welded pads that have bolted connections to accommodate various machines and equipment subsystems. The worktable is made up of 3 sections approximately 6 feet long and 4 feet, 6 inches wide for a total length of 18 feet. Each section has location features to ensure proper alignment of attached components and has bolted fasteners for attachment to the FPA workbench. Construction of the worktable in this modular manner assists in the installation, removal, or replacement during the operational life and ultimately with decommissioning. A retaining feature around the perimeter of the worktable is provided to contain any loose material within the table area. The primary components of the worktable are:

Tipping Machine – The tipping machine is used to rotate a fuel can complete with SNF element (Peach Bottom 1) from the vertical position to a horizontal axis position on the worktable.

Can Cutting Machine – The can cutting machine is used to cut off the bottom of the Peach Bottom 1 fuel cans and TRIGA fuel cans.

Down-ender and Rotate Machine – The down-ender and rotate machine is used in conjunction with the FHM to lower a DOE canister or Shippingport liner from the vertical position down to a horizontal position on the worktable.

Canister Slitting Saw – The canister slitting saw is mounted on a dovetail slide assembly that is fixed to the worktable. The traverse of the saw, which will be adjusted by an MSM, will enable the cutting of DOE canisters or Shippingport liners. The operation of the canister slitting saw is similar to that of the can cutting machine, but the size of the component to be cut has increased.

Canister Support Rollers – Sets of rollers are fixed to the worktable to support the canister when it is lowered down on the down-ender and rotate machine by the FHM. Each set of rollers are mounted on a fabricated bracket to support the canister at the correct height. The fabricated brackets are bolted to the worktable at the correct spacing to support the canister along its length. Alternative sets of rollers are provided to accommodate the difference in diameters of the various canisters.

Jacking Attachment – The jacking attachment is a screw jack mounted on a bracket, assembled onto the back of the can cutting machine with the PMS. It is attached with a single pin that can be installed or removed using the MSM.

Rodding Attachment – The rodding attachment assembles to the back of the can cutting machine as an alternative to the jacking attachment. It is designed to push broken SNF element parts out of the fuel can and into a new broken fuel element container as shown in Figure 4.7-25. The rodding attachment is also utilized in the decontamination of empty fuel cans.

The worktable and tipping machine are classified as ITS because they may support SNF. The balance of the worktable attachments are classified NITS.

4.7.3.2.10 Lifting Devices for the Fuel Handling Machine

A range of dedicated special lifting devices work in conjunction with the FHM to lift and move various loads inside the FPA. These loads include, but are not limited to the DOE transfer cask lid, FPA shield plugs, ISF baskets, DOE fuel containers and individual SNF elements.

The function of each special lifting devices is to provide a safe load path between the FHM hook and the item being lifted. There are no electrical, hydraulic, or pneumatic services required to operate the special lifting devices. Latching is performed by mechanical means operated by the PMS or MSM.

The FHM lifting devices are suspended from the FHM hoist hook. Each FHM lifting device has a common lifting bail that standardizes the latching and delatching to the FHM hook. The FHM hook includes a safety latch, which is actuated by the PMS or MSM to ensure that the special lifting device stays secured to the hook.

Only the required special lifting devices needed for a specific SNF packaging campaign will be in the FPA during that campaign. Each of the special lifting devices for a specific SNF campaign has a park station in the FPA where it is stored when not in use.

Lifting devices that provide a load path to support SNF or handle the transfer cask lid are classified ITS. Table 4.7-6 provides a list of ITS lifting device for the FHM including a description of the item lifted. These ITS lifting devices utilize a single load path requiring increased stress design factors in accordance with ANSI N14.6, Section 7, "Special Lifting Devices For Critical Loads".

Each of the ITS lifting devices for the FHM have been categorized into six general types as identified in Table 4.7-6. One of each type of lifting device is described below.

Type 1 Lifting Device

Description: A type 1 lifting device is a lever actuated device with three positive engagement cams that rotate outward as shown in Figure 4.7-26. Lifting device 1 and 14 are type 1 lifting devices. Lifting device 1 is described below.

Items lifted with this type of device have a 26-inch inside diameter cavity covered by a 1 inch thick lifting flange. The lifting flange has a 22 inch diameter opening in the center. The type 1 lifting device is inserted into the lifting cavity and engages the item to be lifted by rotating three cams outward and below the lifting flange.

Three vertical guides center the lifting device as it is lowered into the lifting flange cavity. The bottom portion of the vertical guides are tapered so that the lifting device is centered before the cams reach the flange. The vertical guides also set the vertical position of the lifting device within the cavity. When the device is inserted into the cavity of the item to be lifted, the cams are 1 inch below the lifting flange to provide adequate clearance and ensure engagement.

The three cams of the lifting device are rotated outward 90 degrees to engage the top flange of the lifted item. Each cam is supported by a shaft that protrudes above the cavity. A driven gear is bolted and pinned to the top of each shaft. Each of the three cams with associated shaft and driven gear are supported from the base plate. The base plate is welded to a vertical shaft that is connected by a nut to the upper plate. The lifting bail is welded to the upper plate and a nut is pinned to the shaft to ensure it cannot rotate free.

Around the main shaft is a tube that has a drive gear welded to the lower portion above the base plate. The drive gear engages the three driven gears that are attached to the shaft of the three cams.

Just below the upper plate is an operating arm that is used by the PMS to rotate the tube with attached drive gear. The drive gear rotates the three driven gears, which in turn rotates the three cams 90 degree to engage or disengage the item to be lifted.

Attached to the upper plate is a lock plate that rotates down to lock the operating arm in the engaged position to prevent accidental release of the lifted load in the event the operating arm is contacted. The lock plate has a protruding latch handle to facilitate engagement by the PMS. An extension spring holds the latch in the open or closed position. A stop pin limits the motion of the latch. The latch provides visual indication that the lifting device is engaged.

Operation. To engage the lifting device, the PMS first contacts the latch handle from above, and pushes down to move the spring past the over center point. The weight and the spring forces the latch down to the engaged position resting against the stop pin.

The lifting device is then lowered into the cavity of the item to be lifted until the vertical guides contact the bottom of the cavity. The PMS then rotates the operating arm to the engaged position which rotates the cams outward. The lock plate moves up as the operating arm contacts it, and then down as the operating arm engages the notch in the lock plate. The notch in the lock plate engages the operating arm and prevents the device from opening.

To disengage the device, the weight of the lifted item must be off the lifting device to relieve the friction on the cams. The PMS first moves the latch handle to the unlocked position, and then moves the operating arm to the disengaged position. Latching in the disengaged position is not necessary as the friction of the system will hold the cams in the disengaged position.

Type 2 Lifting Device

Description: A type 2 lifting device uses a slip clutch actuator which drives an engagement screw that threads into the item to be lifted as shown in Figure 4.7-27. Lifting devices 2a, 2b, and 13 are type 2 lifting devices. Lifting device 2b is described below.

A vertical shaft with the engagement thread is supported by the base plate of the lifting bail and is secured to this base plate by a locating collar that allows the shaft to turn. A miter gear is mounted on the upper end of this shaft. The mating drive gear is connected to a horizontal paddle.

The slip clutch is installed between the drive gear and paddle to prevent over-torque of the engagement thread. The clutch utilizes a spring-loaded pawl that engages a notch on a flange. When tightening the engagement screw, the angular side of the pawl contacts the end of the notch and is held in position by the spring. As the torque increase the spring deflects allowing the pawl to ride up out of the notch and the clutch slips. In the loosening direction, the end of the pawl contacts the end of the slot and prevents the flange from rotating relative to the pawl. The clutch is then locked in that direction to ensure that it can be removed without slipping.

Around the shaft is a position indication tube with a slot and pin that prevent the tube from sliding off the shaft. This position indication tube provides a visual indication that the engagement screw is fully engaged in the item to be lifted. The shaft has two colored indentations at appropriate heights. As the screw enters the item, the bottom of the tube contacts the item to be lifted and begins to move up. When the colored indentation is covered, the device is fully seated.

Operation. The lifting device is positioned over the threaded hole of the item to be lifted and is slowly lowered so that the tapered end of the screw engages the hole. The PMS grips and turns the paddle until the colored indentation is covered. The slip clutch prevents over-tightening. To disengage the device, the paddle is turned in the opposite direction.

Type 3 Lifting Device

Description. A type 3 lifting device uses a hook that engages a lifting bail on the items to be lifted. A safety latch ensures the lifting bail is captured by the hook. A type 3 lifting device is shown in Figure 4.7-28, and is used on lifting devices 3, 12 and 16. Lifting device 3 is described below.

The type 3 lifting device consists of a hook welded to a vertical shaft that is welded to the lifting bail. A lock bar slides through guides attached to the shaft. When the lock bar is down, the lifted load is captured by the hook and lock bar. The lever raises the lock bar until the lock release catches the hook on the top of the lock bar to hold the lock bar up. This allows the hook to be disengaged from the lifted load.

The lock bar provides assurance that the bail of the lifted load will not become disengaged from the hook. Accidental operation of the lever will not cause the lid to disengage, therefore locking the bar in the engaged position is not considered necessary. The position of the lever provides the visual indication of engagement.

Operation. To engage the lifting device, the FHM hoist is used to position the hook in the lifting bail of the item to be lifted. The PMS then strikes the lock release, which lowers the lock bar. To release the lifting device, the PMS raises the lever until the lock release engages the notch on the top of the lock bar.

Type 4 Lifting Device

Description. A type 4 lifting device uses a sliding tube which actuates multiple gripper fingers to provide positive engagement of a lifting pintle as shown in Figure 4.7-29. Lifting devices 4, 5, 8, 11, and 18 are type 4 lifting devices. Lifting device 8 is described below.

This lifting device uses three gripper fingers to engage a lifting pintle on the item to be lifted. A sliding tube actuates the gripper fingers and locks them in place after engaging the lifting pintle.

A locator guide block with a tapered leading edge is used to align the lifting device with the lifting pintle on the item to be lifted. The locator guide block also supports the gripper fingers and is part of the load path. The three gripper fingers pivot on pins. The sliding tube moves down over the lower portion of the gripper fingers holding them in engagement with the pintle. The upper portions of the gripper fingers have arms that protrude through slots in the sliding tube when the gripper fingers are engaged. When the sliding tube is raised, the bottom portion of the slots push the arms of the gripper fingers inward toward the shaft to release the gripper fingers from the lifting pintle.

The shaft is attached to the locator guide block at the bottom end and a lifting bail at the top to form the load path. The sliding tube moves vertically up and down the shaft. Vertical travel of the sliding tube is controlled by the lifting bail at the top of the shaft and the lower stop at the bottom of the shaft. Mounted towards the top of the slide tube is a latch block which supports a spring-loaded latch that engages in grooves in the shaft. This latch is used to hold the sliding tube in the engaged and disengaged positions. Releasing this latch allow the sliding tube to lower to engage the gripper fingers around the lifting pintle of the item to be lifted. The latch block plates are used by the PMS to raise and lower the sliding tube.

Operation. The sliding tube is raised to the disengaged position by the PMS until the spring latch engages the groove in the upper shaft. The lifting device is lowered down over the lifting pintle of the item to be lifted. The PMS is used to press the spring latch to release it from the groove in the shaft and then to push the latch block plates down until the gripper fingers are engaged around the lifting pintle. The weight of the sliding tube assembly ensures the gripper fingers remain engaged; therefore accidental operation of the spring latch will not disengage the lifting device.

To disengage the lifting device, the PMS raises the latch block plates to raise the sliding tube until the spring latch engages the groove in the shaft. As the sliding tube moves up, the gripper fingers open to release the lifting pintle.

Type 5 Lifting Device

Description. A type 5 lifting device uses a sliding tube actuator with collet friction gripping as shown in Figure 4.7-30. Lifting devices 15a, 15b, and 17a are type 5 lifting devices. Lifting device 15a is described below.

This device uses a collet to grip the item to be lifted. A conical tube is slid over the collet by a spring to provide the gripping action. The outside of the collet is tapered to allow it to be forced inward by the outer sliding tube. The collet is threaded to the shaft and pinned to prevent unscrewing. The upper end of the shaft is attached to the lifting bail. The collet, shaft and lifting bail form the load path.

The sliding tube is spring loaded to squeeze the collet together to engage the item to be lifted and provides the gripping force and compensation for wear. At the top of the sliding tube is the latch block that supports a spring latch. The spring latch engages grooves in the shaft to hold the sliding tube in the engaged and disengaged positions. The latch block plates on the top and bottom of the latch block are used by the PMS to raise and lower the sliding tube to disengage and engage the collet around the item to be lifted. Raising the latch block plates forces the spring to be extended. When the upper latch block plate hits the bottom of the lifting bail, the spring latch can engage the groove in the shaft to hold the sliding tube up in the disengaged position.

Operation. With the sliding tube raised to the disengaged position, the lifting device is lowered over the item to be lifted. The PMS inserts the fingers of its gripper between the two latch block plates and closes the gripper until it contacts and releases the spring latch. This releases the sliding tube to move vertically relative to the shaft. The PMS then moves the latch block plates down until the sliding tube is forced over the collet and the spring in the tube compresses. When the slide tube reaches its down limit of travel, the PMS opens its gripper fingers allowing the spring latch to engage the lower shaft groove. To release the load, the process is reversed. The position of the tube and latch provide visual indication the device is engaged.

Type 6 Lifting Device

Description. A type 6 lifting device uses a screw driven actuator assembly with a hinged jaw friction gripper as shown in Figure 4.7-31. This is used for lifting device 6. Lifting device 6 is described below.

Lifting device 6 grips the Peach Bottom 2 fuel assembly by friction since the upper end fitting of these SNF elements had been previously removed. The screw actuator assembly compresses springs which force the fixed and movable jaws together to provide the gripping force on to the SNF element.

A vertical locator block on the fixed jaw sets the vertical position of the lifting device on the SNF element. The fixed jaw is attached to a lifting bail by a square shaft. The movable jaw pivots about a shoulder bolt on the fixed jaw. A fixed jaw is used to align the SNF element with the lifting bail so that the SNF element hangs vertically when lifted.

The PMS turns the paddles to rotate the screws of the spring actuator assembly. The screws of the spring actuator assembly force the upper portion of the movable jaw away from the upper portion of the fixed jaw causing the lower portion of the jaws to close and grip the SNF element. The springs on each screw force the jaws to compress to ensure that sufficient grip force is applied.

Around each screw is a housing attached to the screw. When the housing contacts the crossbar sufficient force has been generated. Only the cross bar on the movable jaw side is threaded.

Since the PMS can operate only one screw at a time, each screw has sufficient free play to allow one to be fully engaged while the other is full disengaged. This feature prevents using the screw to provide the opening force, therefore two extension springs are used to open the jaws.

Operation. With the jaws in the open position, the lifting device is lowered over the SNF element until the vertical locator block rests on it. The PMS grips one of the paddles to turn one screw until its housing contact the cross bar. It then turns the other paddle until its housing contacts the cross bar. The procedure is reversed for disengaging the device.

4.7.3.2.11 Canister Welding System

The canister welding system is located inside the CCA and performs the following functions:

- Perform the circumferential weld between the ISF canister lid assembly and body assembly after the SNF has been loaded
- Perform the seal weld on the vent plug after completing the vacuum drying and helium back fill process

The welding system consists of two remote controlled, automated welding machines and a common control/supply unit. The welding heads are connected to the control/supply unit by a bundle of hoses and cables. One of the welding heads is configured to perform the circumferential canister lid assembly to body assembly weld, the other is configured to seal weld the canister vent plug. The circumferential welding head is re-configured to weld both 18 and 24-inch canisters. The seal welding head does not need to be re-configured since the same vent plug and socket arrangement is used on both the 18 and 24-inch canisters. The lid assembly to body assembly welding head is fitted with a CCTV system that allows the operators to remotely view the weld formation. Both welding heads are remotely operated and supplied power, gas, and water from the control/supply unit.

The welding system control unit is connected to the operators' computer and provides a real time display of the weld parameters and enables the welding heads to be remotely controlled. There is an observation window in the CCA wall to allow the operators to observe the welding heads from the operating console.

The welding heads are lifted onto the canister using the CCA crane. The circumferential welding head is secured to the canister lid assembly and the vent plug seal welding head is secured to the canister vent socket. To minimize the time that the operators are exposed to the loaded ISF canister, the welding heads are designed for ease of use and to minimize the set up and removal time. To aid the attachment and alignment of the welding heads to the ISF canister, a jig is used to align the welding head to the lid assembly in advance of fitting the lid assembly to the body assembly.

The welding system is capable of completing the lid assembly to body assembly weld in accordance to the requirements of the ASME Code, Section III, Division 1, Subsection NB and Code Case N-595.

The welding process is a multipass, full penetration single sided Category B butt weld, per ASME NB3351.2. The vent plug seal weld is a single pass seal weld.

The closure welds are inspected and tested in accordance to the requirements of the ASME Code subsection NB5000.

Circumferential Weld	Ultrasonic examination, acceptance criteria per NB5331 and NB5332 Liquid penetrant, acceptance criteria per NB5352
Seal Weld	Liquid penetrant, acceptance criteria per NB5352

After the lid assembly to body assembly weld has been completed the closed canister is subjected to a vacuum test where the pressure within the canister is reduced to less than one Torr and over a period of 2 hours must rise less than 10 Torr per hour. After seal welding the vent plug the dried, back filled, and sealed canister is examined for helium leakage. The rate at which helium escapes must not exceed $1x10^{-4}$ std cm^3/sec.

A welding system qualification program will determine the final welding parameters. The welding system must perform a number of trial welds in order to determine:

- The weld parameters that must be controlled in order to consistently achieve an acceptable weld.
- The optimum value for each of the controlled weld parameters.
- The appropriate control method and permissible variation limits for each of the weld control parameters.
- The maximum gap that can be tolerated between the opposing lands of the circumferential weld preparations.
- The maximum clearance that can be tolerated between the vent plug and vent socket.
- Demonstrate the welding system is capable of consistently and reliably producing high quality circumferential and seal welds, with no unacceptable weld defects, that fully comply with the requirements of the ASME code.

4.7.3.2.12 Vacuum Drying and Helium Fill System

The canister vacuum dry, helium fill, and leak detection system is required to:

- Vacuum dry the canister and SNF to acceptable levels of dryness.
- Provide a suitably inert canister environment, thus preventing degradation of SNF and ISF canister internals, by means of introducing helium cover gas.
- Allow for placement of the canister vent plug while maintaining the required helium environment within the canister.
- Leak test the canister lid assembly to body assembly circumferential weld and vent plug seal weld to the required acceptance standards.

The majority of the vacuum, helium fill, and leak detection system is located within the equipment room as shown in Figure 4.7-16. The connection tool and HEPA filter are located within the CCA. The individual assemblies of the canister vacuum dry, helium fill, and leak detection system and their detailed individual functional requirements are as follows:

Canister Connection Tool

The canister connection tool provides a leak tight connection between the ISF canister and the vacuum dry and helium fill systems.

The canister connection tool is used to:

- remove the canister vent plug for vacuum drying and helium filling
- re-insert the canister vent plug while maintaining the required overpressure of the helium back-fill in the canister

The canister connection tool is designed to provide a leak tight connection between the canister and the vacuum dry and helium fill systems. The canister connection tool is designed so that after helium filling the canister vent plug and seal can be re-inserted while maintaining the required overpressure of the helium back-fill in the canister. The vent plug incorporates a seal that allows the back-fill pressure to be maintained before vent plug seal welding.

The canister connection tool has a minimum design pressure of less than 1 Torr absolute and a maximum design pressure of 50 psig. The canister connection tool is designed to the requirements of ASME B31.1, and is fabricated from stainless steel. The canister connection tool incorporates a lifting feature so that the CCA crane can lift it on and off the canister.

Two pressure transducers and a thermocouple within the canister connection tool measure the absolute pressure and temperature during vacuum drying. The signals are wired back to an operator's computer within the equipment room that records pressure-temperature-time data to prove conformance to the vacuum drying criteria. The pressure and temperature instruments are checked before and after each vacuum dry/helium fill operation.

Before each vacuum dry/helium fill operation the canister connection tool is leak tested. The face of the connection tool that seals onto the top of the canister incorporate two O-ring seals and an O-ring interspace and test port, to facilitate leak testing the O-ring interspace.

Vacuum Drying System

The vacuum drying system is required to evacuate and remove any oxidizing gases that may degrade the SNF or ISF canister internals during long-term storage, and to dry the SNF to acceptable levels of moisture. The ISF canister is then back filled with helium cover gas. The system incorporates a HEPA filter that utilizes bagging techniques for filter replacement.

The canister vacuum drying system connects to the canister connection tool and is designed to provide a vacuum of 1 Torr or less. The canister is held in vacuum for a period of at least 2 hours with a pressure rise of less than 10 Torr per hour. The ISF canisters undergo two cycles of vacuum drying and helium filling. To aid the drying and welding processes the canister is heated as required to a temperature range of 80°F to 100°F.

A HEPA filter is located between the canister connection tool and the vacuum pump. The filters are housed in metal enclosures, utilizing bag in and out techniques as means of filter replacement. Instrumentation is provided for monitoring differential pressure of the HEPA filter. The canister vacuum drying system is also designed for an internal pressure of 50 psig to mitigate against the possibility of the helium fill system pressurizing the vacuum dry system. The vacuum pump discharges, via a diffuser, into the CCA. An oil mist filter and water trap is provided on the exhaust side of the vacuum pump.

The canister vacuum drying system piping is designed to the requirements of ASME B31.1. The piping is fabricated from stainless steel. Flexible tubing is used to connect the canister connection tool to a manifold mounted on the south wall of the CCA. Rigid tubing runs from the manifold to the remainder of the system. The HEPA filter is located in the CCA and the balance of the equipment on the exhaust side of the filter is located in the equipment room.

Helium Fill System

The helium fill system is required to provide the ISF canister with a helium atmosphere that is inert and sufficiently free from oxidizing gases that may degrade the SNF during long-term storage.

The canister helium fill system connects to the canister connection tool and is designed to provide an inert helium atmosphere to the canister at 20 psia ± 1psia (at 90°F ± 10°F). The canister helium fill system includes a pressure relief device set to 40 psig to protect the canister from over-pressurization resulting from off-normal events such as failure of cylinder pressure regulators. The helium fill system is designed to withstand a vacuum of less than 1 Torr. This low design pressure mitigates against the effect of the helium fill system experiencing the vacuum of the vacuum fill system. The canister helium fill system piping is designed to ASME B31.1.

The helium gas is of sufficient purity to ensure that the ISF canister atmosphere contains sufficiently small concentrations of impurities to prevent oxidation and degradation of the SNF, the canister and its internal structures.

Leak Check System

The leak check system is required to demonstrate that the lid assembly to body assembly closure weld and the vent plug seal weld have acceptably low leak rates. This is carried out using a portable, hand held helium sniffer. The helium sniffer is source-checked before and after leak testing.

Both the canister lid assembly to body assembly closure weld and vent plug seal weld are helium leak tested in accordance with the requirements of the *ASME Boiler and Pressure Vessel Code*, Section V, Article 10, Appendix IV to verify that no leakage can be detected that exceeds the rate of $1x10^{-4}$ std cm^3/sec. The leak testing is performed in accordance with ANSI N14.5.

4.7.3.2.13 Canister Handling Machine

The CHM is located in the Storage Area building as shown in Figure 4.7-5 and Figure 4.7-6. The CHM is a crane with a rigidly attached shielded cask used to transfer loaded ISF canisters from the canister trolley, located in the Transfer Tunnel, to the vault storage tubes. The CHM will also be used in the future to remove ISF canisters from the storage vault and transfer them to a transport cask for offsite shipment. The CHM rails are set at a span of 73 feet to ensure access to all the storage tubes, the CHM maintenance hatch and the Storage Area load/unload port.

The storage tubes are accessed from a charge face above the vaults. Storage tubes and the vault storage system are discussed in detail in Section 4.2. The CHM consists of a bridge and trolley that carries a shielded cask/turret assembly. The CHM runs on rails mounted on a parapet wall that runs in the east-west direction above the charge face floor of the Storage Area. A single failure proof wire rope hoist and grapple system is mounted at the top of the turret assembly. The hoist and grapple assembly handles the loaded ISF canisters. The total weight of the CHM assembly is approximately 380 tons, and the working capacity of the canister hoist is 10,000 lb. The hoist load capacity is 13,500 lb. and this includes the weight of the lifted load, plus the ISF canister grapple and load block.

The maximum loaded weight of a 24-inch canister containing a Shippingport Reflector module is approximately 10,000 lb. The maximum loaded weight of an 18-inch ISF canister containing Peach Bottom fuel is approximately 4100 lb.

The CHM is powered from the normal electrical distribution system. A single operator uses the trolley-mounted control desk to operate the CHM. Operations for positioning the CHM and handling the ISF canisters are performed at the control desk. Drive control interlocks prevent the possibility of an ISF canister being trapped inside the nose cavity of the CHM by inadvertent activation of any of the travel drives or turret rotate drive when the ISF canister is being raised or lowered.

The CHM is held locked in position during canister raise/lower operations. This avoids the potential for trapping and damaging a canister if uncontrolled movement of the CHM occurred with the canister partially inserted into a storage tube and the CHM. A seismic event could lead to such an occurrence, so the CHM locking system is designed primarily to withstand seismic forces. To ensure that uncontrolled motion of the CHM does not occur, substantial clamps lock the bridge to the long travel rail system, the trolley to the bridge, and the rotating parts of the turret to the trolley and the non-rotating base casting.

The turret is fully shielded and provides protection from gamma and neutron radiation emitted by the SNF in the ISF canisters during transfer operations.

The 24-inch diameter long, 18-inch diameter long, and 18-inch diameter short ISF canisters are all handled by the CHM. The internal bore of the turret cask is sized for handling 24-inch ISF canisters. An internal sleeve is fitted to the bore of the turret cask and nose unit cavities when the CHM handles 18-inch diameter ISF canisters to create an acceptable radial clearance between the canister and cask body.

The major subassemblies of the CHM are:

- A bridge assembly including girders, cross travel rails, end trucks, long travel drive, wheels, seismic locks, and the power supply collecting system.
- A trolley assembly with structural steel frame, cross travel drive unit, wheels, seismic locks, power supply collecting system, operator control desk, instrumentation and control cubicles, and a turret rotate festoon system used to convey power and control between the trolley and the rotating turret.
- A turret assembly, shown in Figure 4.7-32 and Figure 4.7-33, that incorporates three operational cavities:
    - A canister cavity inside the main cask body together with a dedicated single failure proof canister hoist and grapple for raising and lowering the ISF canisters containing SNF.
    - A storage tube plug cavity with its dedicated plug hoist and grapple system that is used for handling tube plugs.
    - A navigation cavity with its CCTV system that is used to accurately position the CHM over the storage tubes or other stations and for viewing the canister identification numbers.

The turret and cask assembly consists of several subassemblies:

- A cast steel cask body is used to form the canister cavity and tube plug hoist cavity. The steel is used to provide gamma shielding and is surrounded by a fabricated Jabroc jacket, which provides neutron shielding. Jabroc is a boron impregnated densified wood product.
- A single failure-proof canister hoist subassembly complete with load block, guide sheaves, drum and drive system, gearboxes, brakes, and electrical and mechanical safety systems.
- Pneumatically operated, canister grapple that is suspended from the canister hoist load block to safely transfer canisters between the various locations.
- A support turntable and rotate drive system for the turret assembly.
- A retractable shield skirt subassembly, which is lowered to close the gap between the bottom of the CHM and the charge face to maintain radiation shielding when a canister is raised or lowered across the interface.
- A tube plug hoist and grapple sub-assembly, which removes and re-inserts the tube plugs at the storage tubes and other charge face penetrations. This permits the insertion and removal of canisters while maintaining shielding throughout the operating cycle.

- A turret locking pin assembly to seismically lock the rotating turret/cask assembly to the trolley.
- A base locking pin assembly to seismically lock the non-rotating nose part of the cask to the rotating body section of the cask during canister raising or lowering operations.
- Base torsion link that provides the torque reaction for the fixed nose unit and prevents it from rotating when the turret is indexed between operational positions.
- A CCTV subassembly that is used to align the CHM nose over its selected destination and also permits reading of canister identification numbers.
- Pneumatic system that provides compressed air for the canister grapple operation and for cooling the CCTV lights.

Detail descriptions of the CHM subassemblies are provided below.

Bridge and Drive

The CHM crane bridge girders are plate box sections, utilizing welded construction with diaphragms at suitable intervals. The bridge drive consists of two variable speed motors located on the trucks. Fast travel speed of 40 feet/min and creep of one foot/min are achieved by a variable speed system drive which also provides the control required to position the trolley to within the 3/16 inch target location. Rail clamps are used to provide the required 'Y' direction seismic clamping force. A hydraulic power pack provides the releasing force. In the 'X' and 'Z' directions, passive systems are used that do not require deployment. The 'X' direction seismic restraints are formed by the wheel flanges and the 'Z' direction seismic restraints are formed by shaped hooks that reach under the rail head to prevent vertical uplift. The bridge 'X and 'Z' restraints are passive and are in place during CHM transfer operations.

Trolley and Drive

The CHM trolley supports the rotating CHM turret assembly and nose, and enables the CHM to be traversed in the east - west direction. The trolley frame is built up from structural shapes and plate, welded into a rigid unit. Cross traverse buffers are installed to arrest the trolley in the event of a failure of the end of travel, and ultimate end of travel limit switches. The trolley cross-traverse drive consists of a motor, brake, reduction gearbox driving two of the four trolley wheels. Fast travel speed of 40 feet/min and creep of one feet/min are achieved by a variable speed system drive which also provides the control required to position the trolley.

Rail clamps are used to provide trolley 'X' direction seismic clamping force. A second rail is mounted to the top face of the girders for use by the seismic restraint system. A hydraulic power pack, provides the releasing force. In the trolley 'Y' and 'Z' directions, passive seismic restraints are used. The trolley "Y" restraints are formed by the wheel flanges and the trolley "Z" restraints are formed by shaped hooks that reach under the rail head to prevent vertical uplift.

Turret Body

The shielded cask provides safe transfer of ISF canisters within the Storage Area building. The cask is designed into the structure of the CHM turret assembly. Gamma shielding consists of steel castings made from carbon steel, while neutron shielding is provided by Jabroc (boron impregnated densified wood) above and below the turntable fabrication. At the turntable fabrication and around the nose, the neutron shielding is provided by cast concrete.

The cask assembly is bolted to the turntable fabrication with a segmented packer at the interface. This segmented packer, in conjunction with the annular gap between the Jabroc and the cask gamma shielding provides a natural convection air passage.

When the CHM is in traveling mode, the turret is rotated so that the TV camera is positioned above the hole in the nose assembly – this is called the 'navigation position. The lower ends of the canister and tube plug cavities are automatically closed off whenever the upper turret/cask is rotated to the navigation position, thereby completing the shielding requirements. This closure prohibits accidental dropping of a canister onto the charge face while in transit and the closure also provides axial gamma shielding.

To provide operational and seismic restraint against uncontrolled oscillation, especially during canister raising and lowering operation, a powered turret locking pin locks the upper turret/cask to the trolley, and a powered base locking pin locks the upper turret/cask to the base assembly at each turret index position.

The completion of the radiation shielding at the interface between the charge face and the nose of the CHM is achieved by lowering the shield skirt when the CHM is connected to a storage tube. The shield skirt annular cast slab is raised and lowered by three motor driven screw jacks and, when in the lowered condition, sits on three pads which protrude from the underside of the assembly. In the raised condition, the assembly is suspended from the screw jack lead screws.

Charge face height variation is accommodated in the stroke of the screw jacks while an over-travel system in the jack suspension point allows the charge face construction tolerances to be accommodated. This system is also used to prevent the CHM body weight from being supported by the charge face after the skirt has been lowered to touch the charge face. The over-travel system is also sufficient to ensure that the vertical seismic motion of the turret does not cause the turret body to impact the charge face.

ISF Canister Hoist and Enclosure

The CHM canister hoist system provides variable lifting and lowering speeds of zero to 5 feet per minute. The motor drive system incorporates a brake for controlled lowering of the load with a capacity to stop and hold the rated load independently of the load holding brake. The hook is capable of a 40 foot travel up and down to ensure that the grapple can access the bottom of a storage tube and be lowered out of the CHM into the Transfer Tunnel for maintenance.

The hoist design is based on a dual rope system with a twin-grooved drum. The hoist drum is driven by a variable speed motor and primary drive train external to the hoist structure with a secondary drive train connected to the opposite end of the drum. An electric shoe brake positioned before the motor provides the main load holding brake function. The secondary drive ensures that no single failure will result in the loss of the ability to stop and hold a load. The secondary drive incorporates a second shoe brake, a depth resolver, and a hand-wind connection.

Connected behind the motor through a bevel gearbox are a hand-wind connection, a depth resolver, and a depth indicator. The handwind provides a means of raising and lowering a load in the event of a motor failure. An interlock switch ensures that the power to the motor is isolated before engagement of the handwind handle. The shoe brake is provided with a manual release mechanism to aid manual handwind operations.

The position of the grapple is shown on the visual indicator while the depth resolver provides an accurate reading of grapple height for use with the control system.

The balancing beam is positioned at the top of the hoist structure and each rope, attached via duplicate load cells, is positioned equi-spaced about the beams central pivot. Two damping cylinders are also connected to the balancing beam and provide protection against rope overload in the event of a single rope failure.

In the unlikely event that one of the hoist ropes should fail, the load on the remaining rope will overbalance the beam. The damping cylinders ensure that this overbalance motion occurs in a smooth and controlled manner, limiting any impact or shock loading to the mechanism, rope, and structure to within allowable values. A mechanical stop above the beam limits the amount of beam movement during this type of event. Twin limit switches positioned on the balancing beam pivot mounting indicate when excessive rope length discrepancy movement has occurred and stops the hoisting sequence.

The load sensing system for the ISF canister hoist consists of four in line load cells, two per rope. With four falls of rope supporting a lifted load of 13,500 pounds, the load cells will see a load of 3,375 pounds. The load cells are used to provide signals that feed into interlocks to control the hoist under overload or underload conditions.

With both drives external to the hoist enclosure, operation of the handwinds and access to the drive components for inspection is achieved without having to open the hoist enclosure. Gloveports, windows, and internal lighting within the hoist structure facilitate inspection of the internal components. Removable sealed panels allow access to the hoisting system for maintenance or repair work. Maintenance platforms and access ladders allow in situ servicing.

ISF Canister Grapple

The CHM ISF canister grapple, shown in Figure 4.7-34, is a self-centering eight-jaw grapple, designed to engage, lift, lower and release ISF canisters. A pneumatic cylinder controls the jaws operation once the grapple is positioned and a mechanical lock ensures the jaws cannot be opened when the grapple is carrying a load. The grapple configuration is designed to ensure that all the jaws can achieve the fully closed position without being constrained by the ISF canister lifting ring. Sequence control and indication of the grapple state is facilitated through limit switches mounted on the grapple. A manual release mechanism is incorporated in the unlikely event of the jaws failing to open with the primary release system.

Tube Plug Exchange. If a faulty storage tube plug occurs, then it can be replaced by using the ISF canister grapple to handle a new tube plug to exchange it with the faulty tube plug. Due to the different lifting features of the ISF canister and the tube plug, the ISF canister grapple is not capable of lifting a tube plug by its regular lifting pintle, therefore, a tube plug adapter is fitted to the new tube plug, which provides an ISF canister style lifting feature. The adapter consists of a feature that is manually bolted into the tube plug, in place of the lifting pintle. Its profile matches the ISF canister lifting feature. Control system interlocks ensure that when handling a replacement tube plug the ISF canister grapple only raises part way up the ISF canister cask.

Turret Rotate Drive and Locking System

Rotation of the CHM turret and the support turntable is achieved by a drive comprising a pinion driven by an epicyclic reduction gearbox via a variable frequency driven AC motor with brake, hand release lever and tacho generator. A separate input shaft to the gearbox permits manual hand drive; a key interlock on the access cover to the hand drive shaft inhibits the motor while the hand drive is engaged. End of travel rubber buffers stop the travel if the electrical travel limit switches fail.

Angular position indication of the turret assembly is provided by a resolver driven from the reduction gearbox. The turret is driven to one of the three nominal positions on the resolver and, at the tube plug hoist, ISF canister hoist and TV camera positions, the final location is achieved by a turret locking pin, which also provides the rotational seismic lock. Pockets fitted to the turntable accept the locking pin at these three positions. Similarly, the nose locking pin prevents relative rotation between the rotating turret base and the non-rotating nose casting during a seismic event.

Retractable Shield Skirt

A retractable shield skirt around the lower end of the base assembly is lowered onto the charge face to provide continuous shielding whenever a canister or tube plug is being handled. This facility is required when the CHM operates at the load/unload port or a storage tube. The shield skirt is designed to provide radial shielding at the interface. Vertically floating plate segments provide flexibility to accommodate unevenness of the operating floor over the diameter of the skirt. Raising and lowering the shield skirt is accomplished by three motor driven screw jacks. When the shield skirt is resting on the charge face, it is suspended such that vertical seismic displacements are accommodated such that the shielded cask/turret system does not impact the charge face and the vertical movement of the turret does not cause the shield skirt to impact the charge face.

The retractable shield skirt assembly consists of a concrete and steel annular shield ring fitted around the protruding nose of the CHM base. The cast steel ring forms the bulk of the gamma shielding. Additional gamma and neutron shielding is provided by a top slab and annular ring of concrete.

The screw jacks used to raise and lower the skirt are driven via a braked geared motor reduction unit. A manual hand drive feature is incorporated on the motor unit utilizing a key interlock. Removal of the access key from the CHM operator's station inhibits the skirt drive.

In order to provide access for the hand drive handle at the motor the interlock key must be inserted and turned, this action retains the key at the motor and allows hand drive operations to commence. The motor brake is fitted with a spring return manual release lever for use during hand drive operations.

Tube Plug Hoist and Grapple

The CHM tube plug hoist and grapple, shown in Figure 4.7-32, is designed to engage and lift, and lower and release tube plugs from the storage tubes. The tube plug hoist is mounted on top of the tube plug cask cavity of the CHM and consists of a 20-ton screw jack driven by an electric motor. The motor drives the jack through a bevel gearbox and a mechanical torque limiter that is used to prevent any overloading of the hoist and grapple assembly.

A pair of detectors fitted in the tube plug cavity wall indicates when the grapple is holding a tube plug. These detectors are to prevent the CHM being uncoupled from a storage tube without first replacing the tube plug. The exception is when the CHM is in the tube plug exchange mode. If a tube plug is found to be faulty, then the plug is raised and held in the tube plug cask while a replacement tube plug fitted with an adapter is inserted using the ISF canister grapple.

Turret Locking Pin

The turret locking pin prevents rotation of the turret during a seismic event while the CHM is coupled to an operating position or while traveling between locations. The locking pin is necessary because the center of gravity of the large mass of the turret is eccentric to the center of rotation.

The locking pin assembly is extended and retracted inside a housing that is bolted to the CHM trolley. The pin can engage with any one of three identical pockets bolted to the turret support turntable. These pockets align with the pin when one of the three positions is aligned with the CHM nose (i.e., ISF canister cask, tube plug cavity, or TV camera cavity).

The pin is extended and withdrawn by a mechanical screw jack system that is driven by an electric motor. A hand wind facility permits manual operation of the pin. Engagement of the hand wind is interlocked to prevent electric motor operation. Electrical switches are provided in the engaged and disengaged positions to provide the interlock and control signal requirements.

Base-Locking Pin

The base-locking pin is similar in principle and features to the turret locking pin and prevents relative rotational movement between the machine nose and the interface with the bottom face of the rotating turret assembly. The base locking pin assembly is attached to the turret base plate and extends into pockets machined into the machine base nose block.

Base Torsion Link

The turret assembly and nose unit are connected by the lower ball bearing slewing ring. An anti rotation restraint feature is provided to prevent rotation of the nose when the turret assembly rotates during handling operations and to maintain the orientation of the nose relative to the bridge and storage tube positions.

The base torsion link and support bracket restraint system comprises a link attached at one end to the nose casting and at the other to the torsion link support frame. The torsion link support frame is mounted from the underside of the trolley fabrication. An adjustable clevis arrangement is used as the attachment method at each end of the link.

The base torsion link is not subject to seismic loadings as the loads are transferred through to the base locking pin.

TV Camera System Cavity

The CHM camera system cavity, shown in Figure 4.7-32, consists of a shield box, bolted to the top face of the support slab on the CHM turret assembly. The cavity houses the cameras and lighting equipment necessary to achieve accurate positioning of the CHM and enable viewing inside the storage tubes.

The functional requirements of the system are to:

- enable the operator to align the CHM over any storage tube position
- provide the operator with a means to read the identifier number on the top face of each tube plug
- provide the operator with the facility to view down to the bottom, inner face of the storage tube
- provide the facilities for identification of an ISF canister within a storage tube

Alignment and viewing functions are performed by a camera, fitted with a motorized zoom, focus, and auto iris lens. A standby camera, fitted with a fixed lens, is also installed into the cavity to allow course alignment with the maintenance pit in the event of main camera failure. The main camera and zoom lens are mounted centrally within the TV camera cavity with the standby camera offset and angled to provide a maximum viewing target.

To achieve the required accuracy the main camera is optically aligned with the machine axis to ensure that the machine movements are correctly represented on the monitor screen. The target is a recess machined into the top of each tube plug lifting pintle. The recess provides suitable scene contrast for the camera.

The video signals from the cameras are fed into a commercial electronic X-wire generator whose output is connected to a video monitor. The resulting monitor picture is a composite of tube plug or ISF canister identifier and cross wire, the latter formed by the electronically generated X-wire. The presence of the X-wire anywhere on the target will confirm alignment of the machine and the video picture allows confirmation of the object identifier.

Tungsten halogen lamps, mounted concentrically around the main camera and lens assembly inside the cavity, provide target and storage tube illumination. Lighting level output from the lamps is adjustable due to the range of the object distance from the camera, 5 to 30 feet (i.e., to more than cover the range of top to bottom of storage tube), this allows the operator to minimize and control any glare.

To maximize equipment life and minimize any rise in camera temperature due to heat generated by the lamps, an air supply is connected to the TV camera cavity. The air supply is taken from the CHM compressed air supply, and is automatically energized and de-energized, via a solenoid operated valve, when the lamps are operated. The cooling air enters the cavity above the camera and flows down through cutouts around each lamp.

Pneumatic System

The CHM has an on board air compressor that provides compressed air for operation of the ISF canister grapple and to provide a cooling flow of air to the ISF canister TV camera and lighting equipment.

The CHM pneumatic system consists of a compressor, pneumatic panel, and an air receiver situated on the top plate of the hoist structure. The CHM pneumatic system is divided into three main subsystems:

The Grapple Open System. The ISF canister grapple jaws are closed by the self weight of a central sleeve within the grapple. The central sleeve is raised, to open the jaws, by energizing the pneumatic cylinder. Compressed air is fed into the cylinder to retract the rod and raise the sleeve. When the air supply is removed the spring return in the cylinder extends the rod and allows the sleeve to lower down to close the jaws. A solenoid actuated spool valve is used to direct the compressed air to, or to relieve pressure from, the grapple actuation cylinder. The solenoid actuated spool valve is spring fail to relieve the pressure within the grapple actuation cylinder on loss of electricity; this ensures the grapple air supply fails safe, i.e., with the jaws closed.

The Grapple Manual Open System (Manual Release). The ISF canister grapple manual release is used to open the jaws in the event that the sleeve cannot be raised by the main jaw opening cylinder. If the manual release cylinder is retracted, it raises the jaw operating sleeve to open the jaws.

An air receiver is mounted on the top of the hoist enclosure and holds sufficient air to allow the grapple emergency release to function should there be a loss of electrical supply that prevents the compressor from operating.

A check valve fitted between the main line system and the receiver prevents loss of pressure in the receiver and the grapple cylinder in the event of a loss of supply. A fortress interlock valve unit is used to direct the compressed air to the manual release cylinder when required; releasing the pressure allows the cylinder to retract. The air supply is connected to the grapple by a quick release coupling at the grapple load block. This coupling is disconnected during normal operation and is only connected, via the hoist enclosure glove port, when required.

TV Camera Cooling System. Cooling air is fed down to the camera cavity to minimize the rise in camera temperature due to the heat generated by the lamps. A solenoid valve controls the flow of compressed air to the camera cavity; it opens when the lights are switched on and closes when the lights are switched off. The solenoid actuated spool valve is spring fail to close on loss of electricity.

4.7.3.3 Design Bases and Safety Assurance

The design bases for each of the three main ITS structures within the ISF Facility and each major ITS component involved with SNF receipt, packaging and storage are discussed in this section. This section also provides the design loads, load combinations, structural analysis methodology and summary of analysis results for each of these ITS structures and components.

The design bases of the ISF canister assembly, ISF basket assembly, and the storage tube assembly are discussed in Section 4.2.3.3.

4.7.3.3.1 Cask Receipt Area

Design Bases

The CRA consists of a central structural steel tower that supports the CRC and a steel framed building that surrounds, and is connected to, the central tower structure. The central tower is a welded, moment-resisting frame and is designated as ITS. The remainder of the steel building is a braced frame and is NITS. In the discussion that follows, primary structural members include columns, beams, and braces that constitute the main load path for building loads. Roof purlins, floor joists, and wall girts are considered secondary steel members. The CRA has been evaluated and designed to include the following:

- **Tornado** – Primary structural steel of the CRA including the CRC tower is designed to withstand tornado wind loads using the assumption that the wall and roof panels remain in place to transfer the wind loads to these members, even though they are not designed to stay in place under tornado wind conditions.

  Wall and roof panels are not designed to withstand tornado missiles or tornado differential pressure. Therefore, the structure is considered vented and the primary steel is not subjected to the design differential pressure.

  Primary structural support members of the CRA including the steel tower that supports the CRC are designed to withstand tornado missiles. Secondary members such as purlins and girts are not designed to withstand tornados.

- **Earthquake** – Primary structural steel members of the CRA are designed to resist the design earthquake. Since the worst case load on the tower occurs when the CRC lifts its maximum load, the vertical lifted mass was included in the seismic analysis of the CRA. The NITS primary structural steel members of the CRA are also designed to withstand the design earthquake loads. Secondary members such as purlins and girts, as well as roof and wall panels, are not designed for the design earthquake.

- **Fire or Explosion** – A fire hazards analysis was performed to evaluate potential fires that could affect the CRA to ensure that ITS SSC's of the CRA can continue to perform without loss of safety function during credible fires. Fire detection and suppression systems are installed in the CRA. Refer to Section 4.3.8 for additional details on the fire protection system inside the CRA and potential fire hazards.

- **Flood** – The design flood is based on failure of the Mckay Dam under conditions of maximum probable precipitation. The CRA is assumed to be fully flooded for the design flood. The elevation of the floor of the CRA is 4,913 feet 2 inches and the level of the floodwater is at 4,921 feet. The floodwater is expected to reach a depth of eight feet within the CRA. Because the CRA is fully flooded, the buoyancy forces on the center tower ITS structure are negligible. The hydrodynamic forces on the structure are also negligible because of the low velocity of the flood. The floodwater takes 13.5 hours to reach the ISF site and fuel handling operations will be secured and the facility placed in a safe configuration when the flood warning is received. Refer to Section 3.2.2 for additional details on the PMF.

- **Lightning** – The CRA incorporates a lightning arrestor system designed in accordance with NFPA 780, *Lightning Protection Code.*

- **Shielding Considerations** – The CRA building does not provide a shielding function. SNF is confined within shielded DOE transfer casks when being handled inside the CRA. Workers in the CRA are shielded from radiation during SNF transfer operations inside the Transfer Tunnel by the canister trolley and the DOE transfer casks.

- **Temperature Effects** – The HVAC system is designed to maintain the temperature inside the CRA between 40°F and 105°F with an outside minimum and maximum normal site ambient temperature range of -26°F and 98°F. Since the CRA is a steel structure, enclosed in insulated roof and wall panels, the thermal stresses associated with off normal temperature conditions are considered negligible and self-limiting, and therefore not specifically included in the design of the CRA.
- **Retrieval Considerations** – Spent fuel handling in the CRA consists of lifting the DOE transfer cask from the transporter to the cask trolley. The CRC is a single failure proof design, which considers credible loading conditions. In the event of a breakdown of the CRC, normal repair activities could be performed in the CRA since radiation levels would be minimal. The hoist brake hand release feature allows a fully loaded CRC to be lowered by hand safely and in a controlled manner in accordance with the requirements of NUREG-0554.
- **Decontamination Considerations** – The CRA is considered a clean area and is not expected to become contaminated during transfer cask handling operations. Empty transfer casks leaving the Transfer Tunnel are monitored in the cask decontamination zone before being released to the CRA.

Design Loads

The following loads were included in the design of the CRA. They are based on the loads presented in Table 3-1 of NUREG 1536.

- Dead Loads (D) – This includes the self-weight of the structure and permanently attached equipment and utilities including the weight of the CRC.
- Live Loads (L) – The CRA floor is designed for a live load of 200 psf. Loads associated with the DOE transfer cask trolley are treated as concentrated live loads in addition to the area floor loads. The CRA roof live load is defined as 20 psf and the roof snow load is 30 psf.
- Soil Pressure (H) – These are defined as lateral soil pressure due soil weight, ground water, and loads imparted through the soil from adjacent structures. These loads are considered negligible for analysis of the ITS structures of the CRA.
- Wind Loads (W) -Wind loads are based on a 90 mph three-second gust in accordance with ASCE 7 and are applied to both ITS and NITS structural members of the CRA. Refer to Section 3.2.1.1 for design basis wind load parameters.
- Temperature Loads (T) – Considered negligible for the CRA
- Earthquake Loads (E) – Loads attributable to the direct and secondary effects of the design earthquake are applied to the base of the CRA. The response spectra method is used to evaluate structural demand on CRA structures. Refer to Section 3.2.3 for seismic design criteria applied to the CRA.
- Tornado Loads (Wt) – Tornado loads include tornado wind, tornado differential pressure, and tornado missiles. Specific tornado loads applied to individual components of the CRA are discussed above. Refer to Section 3.2.1 for tornado load design criteria and parameters applied to the ISF Facility.

- Accident Loads (A) – There are no accident loads, other than those described above, included in the design of the CRA

Material Properties

Properties of concrete used in the analysis of the CRA include:

- Concrete Units Weight, γ_{conc} = 145 pcf
- Concrete Compressive Strength, f'_c = 4,000 psi
- Concrete Young's Modulus, E_{conc} = 3,604,000 psi
- Concrete Poisson's ratio, v = 0.2
- Reinforcing Steel Yield Strength, f_y = 60,000 psi
- Reinforcing Steel Modulus, E_{steel} = 29,000,000 psi
- Coefficient of Thermal Expansion = 5.5 x 10^{-6} in./in./°F

Properties of steel used in the analysis of the CRA:

- Modulus of Elasticity = E_{steel} = 29,000,000 psi
- Poisson's Ratio, v = 0.3
- Density γ = 490 pcf

Soil properties used in the analysis of the CRA are:

- In-place unit weight of soil = 135 pcf
- Mohr-Coulomb Soil friction angle (ϕ) = 41°
- Lateral soil coefficient for at-rest conditions = 0.34
- Lateral soil coefficient for passive conditions= 4.81
- Lateral soil pressure for active conditions = 0.21
- Soil/Concrete Coefficient of Friction (μ) = 0.55

Load Combinations

The loads listed in Table 4.7-7 were included in the structural analysis of the CRA. Specific load combinations are discussed in Section 3.2.5.2.

Structural Analysis

The major structural components are the four columns that support CRC. The steel structure analysis of the CRA was limited to the primary structural members. The secondary structural members included in the analysis were used to collect loads for transfer to primary members. The four center tower columns are supported by a four foot thick mat foundation which also supports the cask and canister trolley rails. The rest of the CRA building is supported by spread footings isolated from the mat foundation.

Computer Model and Program. The CRA structural steel was analyzed by using a frame element model in the finite element program STAADPRO (Ref. 4-57). The steel structure was designed and analyzed as a bolted braced-frame except for the central tower. The center tower supporting the CRC was modeled with the end moments restrained to represent the moment resisting connections. The end moment restraints (local My and Mz) were released for the rest of the CRA surrounding the center tower to model the bolted braced-frame connections. A yield strength of 50 ksi was specified for all steel W-shapes. The four center tower columns in the direct load path of the CRC were modeled with moment-resisting connections at the base. The rest of the column bases for the CRA were pinned (Figure 4.7-35 through Figure 4.7-38).

The ratio, K, effective column length to actual unbraced length was determined from inspection of the shape of the deflected column and a comparison with the AISC Manual. The unbraced length of beams and columns was specified such that the value chosen enveloped the actual lengths for the group.

Modeling of Mass and Stiffness. STAADPRO includes a structural section library for rolled steel sections contained in the AISC Manual. This provides an accurate call out of the steel section properties used in the model. Non-prismatic section structural properties and additional masses were externally calculated, documented, and included in the input stream. The program internally assigns nodes so that the dynamic degrees of freedom match the system degrees of freedom. The frame elements have 6 degrees of freedom for both static and dynamic response. Self-weight of the structure is automatically lumped to the nodes and additional external dead loads are accounted for by manually lumping mass at appropriate nodes.

The CRA model contains rigid elements and nodal constraints to simulate eccentricities, member offsets at multi-member connections, and nodal coupling.

Dynamic Coupling. Mass and stiffness characteristics of the CRC support beams and girders were explicitly modeled in the CRA analysis in order to correctly account for coupling between the CRC and the rest of the building. The lifted load of 155 tons was included as a vertical accelerated mass in the analysis. Significant masses of other equipment were applied at appropriate locations and positioned to automatically capture the worst dynamic effects on the supporting main structure.

Consideration of Adjacent Structures. The Storage Area is adjacent to the CRA and is structurally isolated from it by a seismic gap.

Static Analysis

The static analysis of the CRA included the effects of self-weight, dead loads, live loads and wind loads. Some primary loads were applied to secondary structural members. Forces and in some cases moments were then transferred to the primary members.

The tornado wind loads were applied in a manner consistent with ASCE 7. A comparison of the roof pressure coefficient values between ANSI 58.1 and ACSE 7 revealed that the ASCE 7 values are approximately 13% greater than the ANSI 58.1. Wall pressure coefficients were the same in both references. Both normal and tornado wind loads were included in the finite element model.

Thermal loads were not included in the computer analysis since only normal temperatures need be considered and the gradient between normal temperatures did not result in a significant change in length of the steel. Steel is a ductile material at normal temperatures and the forces are considered to be self-limiting.

Dynamic Analysis

Dynamic Soil-Structure Interaction. The effects of structure-soil-structure interaction were captured in the CRA analysis by using an input response spectra generated from the SSI analysis (discussed in section 3.2.3.1.8). No additional amplifications are performed in this analysis. The results of the SSI analysis showed that the SSI effects are not pronounced in the response of the CRA and the fixed-base analysis methods adequately capture the response of the structure.

Modal Analysis. Modal response characteristics were evaluated and the fundamental frequencies in three global directions were noted. Mode shapes and level of mass participation were evaluated to check the dynamic model. More than 90% of the building mass was accounted for, meeting the requirements of ASCE 4 (Ref. 4-58) and NRC Regulatory Guide 1.92 (Ref. 4-59).

Linear Elastic Dynamic Response Spectra Analysis. The seismic response of the CRA was analyzed by the response spectra method. The input response spectra used were calculated from the SSI analysis of the CRA as discussed in section 3.2.3.2. The 4% spectra were used for the CRA because the ITS tower structure is a welded moment-resisting frame. Modal combinations were performed by the ten percent method to account for closely spaced nodes. The analysis was run for 500 modes in order to dynamically capture sufficient mass in the three directions. Spatial combination of the modal responses in the three orthogonal directions was performed by the square root of the sum of the squares (SRSS) method.

Structural Steel Design

Structural steel was designed in accordance with the AISC Manual allowable stress method as modified by the requirements of NUREG 1536. The load combinations were calculated in accordance with the criteria presented in section 3.2.5.2. Capacity/demand ratios were computed for selected members to show compliance with the design criteria.

Local effects of applicable tornado missiles were evaluated for tower column sections in accordance with the methodologies in Topical Report BC-TOP-9-A, "Design of Structures for Missile Impact" Revision 2, (Ref. 4-60). Tornadoes with the ability to generate "heavy" missiles (e.g., utility pole, 12" schedule 40 pipe, automobile) have an occurrence probability of less than 1.0×10^{-7} yr^{-1} at the ISF Project site, and therefore were not included in the analysis. A more detailed discussion of the tornado event is provided in Section 8.2.5.4.

Reinforced Concrete Design

The 4 foot thick mat foundation for the CRA tower structure was analyzed in a separate finite element calculation using the computer program SAP2000 (Ref. 4-61). The analysis is based on the theory of flat-plate bending with the mat supported by the soil. The mat was modeled as a mesh of shell elements interconnected at node points. Only bending moments and transverse forces are supported with plate elements. The soil is modeled using springs with the spring constants based on the modulus of subgrade reaction for the soil. Enveloped tower column reactions (forces and moments) from the STAAD-Pro finite element analysis and rail loads from the analysis of the cask/canister trolleys were used as input for the design of the mat foundation. The mat foundation model is shown in Figure 4.7-39.

The modulus of subgrade reaction, k_s, is equal to q/δ where q is the bearing pressure and δ is the settlement or deflection. An initial modulus of subgrade reaction was estimated based on allowable bearing pressure. The modulus of subgrade reaction was converted to a nodal spring constant by multiplying K_s by the tributary area of the nodes.

The use of a uniform modulus of subgrade reaction to analyze and design mat foundations can result in a simplified soil response. Therefore, k_s was modified based on the subgrade response. The nodal (spring) reactions and deflections were obtained from the initial finite element run. The estimated settlement due to the subgrade response (springs reactions) was calculated and compared with the mat deflections from the finite element run. New modulus of subgrade reaction values were calculated for each node based on the subgrade response and the estimated settlement. The finite element analysis was performed again with the new modulus of subgrade reaction and this process was repeated until comparable deflections were achieved.

The out-of plane forces and moments from the finite element analysis were used to size the thickness and the reinforcement of the mat foundation. This was in accordance with the requirements of ACI 349.

Overturning and Sliding

The capacity/demand ratio for sliding is defined as F_S/V_S, where F_S is the resisting force (capacity) and V_S is the sliding force (demand). The sliding force V_S depends on the load or load combination considered. The resisting force F_S is determined from the following equation:

$$F_S = N_T * \mu,$$

where N_T is the total normal force and μ is the soil-concrete friction coefficient.

The capacity/demand ratio for overturning is defined as M_R/M_O, where M_R is the resisting moment (capacity) and M_O is the overturning moment (demand). The overturning moment is obtained by multiplying the lateral load V_S by the appropriate lever arm. The moment is taken about the toe of the mat foundation. The resisting moment M_R is obtained by multiplying resisting normal forces with their appropriate lever arm.

Since there are no lateral soil loads on the CRA under normal loads, overturning and sliding is considered only for tornado wind pressure loads and earthquake combinations as defined below. The minimum allowable capacity/demand ratio for overturning and sliding is 1.1.

Earthquake loads were determined using a "Static Analysis" method. Inertial forces resulting from the steel structure were calculated using the total mass of the steel structure and applying the floor acceleration values at the crane rail level of the CRA (close to the center of mass of the steel structure). The inertial forces resulting from the mat foundation were calculated using the floor accelerations at the base of the CRA (input spectra). The in-structure floor accelerations were taken from the SSI analysis.

For conservatism, the normal forces used to resist overturning and sliding are obtained by taking the total dead weight of the structure minus the vertical inertial force.

Tornado wind loads for four different directions were considered and the maximum enveloped loads were used. The tornado wind load was estimated by summing up the base reactions resulting from the load from the analysis of the CRA. This lateral load is assumed to act at the center of mass. Tornado differential pressures are not considered since the panels around the steel framed structure would be blown off and overall effects would be dissipated.

Summary of Results

Modal Frequencies and Mass Participation

The significant modes of vibration and mass participation are summarized in the Table 4.7-8.

- Mode 1 is the fundamental mode for the east-west direction and it occurs at approximately 2.4 Hz. About 64% of the mass of the structure participates in this mode.
- The fundamental north-south mode occurs at approximately 3.9 Hz (mode 6). About 49% of the mass of the structure participates in this mode. Part of the secondary building steel is excited in the north-south direction at mode 4 at approximately 2.8 Hz. This secondary mode accounts for about 22% of the mass.
- The fundamental vertical modes are a combination of modes 27, 28 and 29. These are closely spaced between 11.3 to 11.7 Hz and account for about 43% of the mass. This mode is primarily due to the local modes of vibration of the CRC.

The CRA model was run for 354 modes and over 99% of the mass was captured in the horizontal direction while over 94% of the vertical mass participated.

Steel Design Stress Summary

Steel section stresses calculated from the analysis were less than the allowable stresses for the loads and combinations considered. Table 4.7-9 presents representative ITS members from the center tower structure and their capacity to demand ratios to factored AISC Manual allowable stresses. Only gross member response is shown in the table.

Mat Foundation Design Results Summary

Steel requirements vary throughout the mat in order to reinforce for localized loads. The capacity of the mat for bending and out-of-plane shear is shown in Table 4.7-10 below based on the minimum required area of steel. The demand is based on an envelope of the load combinations and is compared to the capacity.

Overturning and Sliding Results Summary

The minimum capacity/demand ratio for sliding in the east-west direction was 1.13 based on seismic loading. The minimum ratio of 1.11 for overturning in the east-west direction was based on the tornado wind loads. In the north-south direction the seismic load controlled for sliding with a capacity/demand ratio of 1.15. The tornado loads controlled for overturning in the north-south direction with a ratio of 1.70. These results are documented in Table 4.7-11. These ratios are greater than the minimum allowable ratio of 1.1. The structure has additional margin because the calculations are based on just the mat foundation profile, neglecting the perimeter foundation. They also neglect the contribution of soil lateral pressures to resist sliding.

4.7.3.3.2 Transfer Area

Design Bases

The Transfer Area includes ITS concrete structures that form the FPA, CCA, FHM Maintenance Area, and Transfer Tunnel. The steel braced framed building housing the operating spaces, operations offices, HVAC, electrical, and waste processing areas is NITS. In the discussion that follows, primary structural steel members include columns, beams, and braces that constitute the main load path for building loads. Roof purlins, floor joists, and wall girts are considered secondary steel members. The Transfer Area has been evaluated and designed to include the following:

- **Tornado** – The concrete walls of the FPA and FHM Maintenance Area, Transfer Tunnel, and CCA are designed to withstand the effects of the design basis tornado wind, tornado missiles and tornado differential pressure. To protect the SNF during transfer operations inside the Transfer Tunnel and the FPA, the outer door of the Transfer Tunnel and personnel shielded access door into the FHM Maintenance Area are also designed to withstand these tornado effects.

  The FPA shield windows have been designed to withstand the differential pressure associated with the design basis tornado and wind. The shield windows of the FPA are over 23 inches thick. An evaluation was performed that determined these windows would withstand credible tornado missiles. The observation window in the CCA is not designed to withstand tornado effects, however, it is not required for missile protection. When ISF canister closure operation are being conducted inside the CCA the SNF inside the ISF canister is protected by the 11 inch thick shielding cask on the canister trolley, the canister shield plug which sits above the ISF basket, and the collets that surround the upper region of the canister.

  Primary structural steel of the Transfer Area is designed to withstand tornado wind loads using the conservative assumption that the wall and roof panels remain in place to transfer the wind loads on these members.

  Wall and roof panels are not designed to withstand tornado wind, tornado missiles or tornado differential pressure. Therefore, the structure is considered vented and the primary steel is not subjected to the design differential pressure

  Primary structural support members of the Transfer Area are designed to withstand tornado missiles. Secondary members such as purlins and girts are not designed to withstand tornadoes.

- **Earthquake** – The ITS reinforced concrete FPA, FHM Maintenance Area, Transfer Tunnel, and CCA are designed to withstand the design earthquake. The NITS primary structural steel members of the Transfer Area are also designed to withstand the design earthquake loads. Secondary members such as purlins and girts, as well as roof and wall panels, are not designed for the design earthquake.

- **Fire or Explosion** – A fire hazards analysis has been performed to ensure that the Transfer Area maintains structural integrity without loss of safety function during all credible fires. A fire detection system is installed in the FPA, FHM Maintenance Area, Transfer Tunnel, and CCA. The structural steel areas within the Transfer Area have fire sprinklers and smoke detectors. The HVAC system ducts serving the FPA are provided with dampers to prevent the spread of fire and smoke from within this area. The dampers receive a close signal from the fire alarm control panel upon actuation of area smoke detectors and also have fusible links. Refer to Section 4.3.8 for details on the fire protection system for the Transfer Area and an evaluation of fire hazards in this area.

- **Flood** – The lower elevations of the Transfer Area may be subjected to flood water since the doors into the Transfer Tunnel and Solid Waste Processing Areas are not watertight. The PMF elevation is nominally 4,921 feet, which corresponds to approximately 8 and one half feet of water above the finished floor of the Transfer Tunnel (elevation 4,912 feet, 6 inches) and approximately 3 feet of water inside the Solid Waste Processing Area (elevation 4917 feet, 6 inches).

  The FPA work bench and FHM Maintenance Area floor are located at elevation 4,938 feet, 6 inches, which is approximately 18 feet above the PMF elevation level. Penetrations and construction joints in the lower elevation of the FPA below the PMF elevation are sealed or have water stops to resist leakage into the FPA.

  The mass of the Transfer Area counteracts any buoyancy forces; therefore these forces are considered negligible and are not explicitly included in the structural loads. The hydrodynamic forces on the structure are also negligible because of the low velocity of the flood. The floodwater takes 13.5 hours to reach the ISF site and fuel handling operations will be secured and the facility placed in a safe configuration when the flood warning is received. Refer to Section 3.2.2 for design criteria on the PMF.

- **Lightning** – The Transfer Area has a lightning arrestor system designed in accordance with NFPA 780, *Lightning Protection Code.*

- **Shielding Considerations** – The FPA and FHM Maintenance Area are designed to ensure that radiation exposure to operations and maintenance personnel are minimized. The walls of the FPA are 4 feet thick to provide protection from gamma and neutron radiation. Refer to Chapter 7 for an evaluation of the dose rates around the FPA and radiation protection features of the ISF Facility.

- **Temperature Effects** – The FPA, FHM Maintenance Area and Transfer Area were analyzed for a range of normal and off normal temperature conditions. Section 3.2.5.1.10 provides off-normal temperature cases used to analyze these concrete structures. The temperature effects on the steel structures surrounding the Transfer Area are considered negligible and self-limiting, and therefore not included in the design.

- **Retrieval Considerations** – Fuel handling inside the Transfer Area is performed primarily by the FHM and canister trolley. These components provide retrieval capability of the SNF in the event of a credible failure. These features are discussed in the associated section that describes each SNF handling component.

- **Decontamination Considerations** – The design of structural concrete incorporates features to facilitate decontamination. This is primarily accomplished through the use of decontaminatable coatings on concrete surfaces.

Design Loads

The following loads were included in the design of the Transfer Area.

- Dead Loads (D) – This includes the weight of the structure and permanently attached equipment and utilities including the weight of the FHM and FPA shield doors.
- Live Loads (L) – The area live loads for the Transfer Area are defined as follows:
  - The first floor and second floor of the Operations Area on the west side of the Transfer Area were designed for area live loads of 150 psf and 80 psf respectively.
  - The area live loads applied to the first and second floor inside the FPA are 250 psf and 150 psf respectively.
  - The Transfer Tunnel area live load is 200 psf.
  - The area live loads for the first and second floor of the operating gallery are 200 psf and 150 psf respectively.
  - A roof live load of 60 psf and a snow load of 30 psf were applied to the concrete roof over the FPA.
  - The panel roof over the Operations Area and the Operating Gallery was designed for a live load of 20 psf and snow load of 30 psf.
- Soil Pressure (H) - These are defined as lateral soil pressure due to soil weight, ground water, and loads imparted through the soil from adjacent structures. These loads are considered negligible for analysis of the ITS structures of the Transfer Area since the depth of the structure below grade is minimal.
- Wind Loads (W) - Wind loads are based on a 90 mph three-second gust in accordance with ASCE 7 and are applied to both ITS and NITS structural members of the Transfer Area. Refer to Section 3.2.1.1 for design basis wind load parameters.
- Temperature Loads (T) – Thermal loads associated with temperature distribution and thermal gradients and effects of expansion and contraction of concrete elements. Refer to Sections 3.2.5.1.6 and 3.2.5.1.10 for the temperature cases used in the analysis of the concrete structures of the Transfer Area.
- Earthquake Loads (E) - Loads attributable to the direct and secondary effects of the design earthquake are applied to the base of the Transfer Area. The response spectra method is used to evaluate structural demand on Transfer Area structures. The input response spectra are based on the results of the SSI analysis. Refer to Section 3.2.3 for seismic design criteria applied to the Transfer Area.
- Tornado Loads (Wt) – This includes tornado wind, tornado differential pressure, and tornado missiles. Specific tornado loads applied to individual components of the Transfer Area are

discussed above. Refer to Section 3.2.1 for tornado load design criteria and parameters applied to the ISF Facility.

- Accident Loads (A) – There are no accident loads included in the design of the Transfer Area c.

Material Properties

Properties of Concrete Used in the Transfer Area are:

- Concrete Units Weight, γ_{conc} = 145 pcf
- Concrete Compressive Strength, f'_c = 4,000 psi
- Concrete Young's Modulus, E_{conc} = 3,604,000 psi
- Concrete Poisson's ratio, v = 0.2
- Reinforcing Steel Yield Strength, f_y = 60,000 psi
- Reinforcing Steel Modulus, E_{steel} = 29,000,000 psi
- Coefficient of Thermal Expansion = 5.5 x 10^{-6} in./in./°F

Properties of Steels Used in the Transfer Area are:

- Modulus of Elasticity = E_{steel} = 29,000,000 psi
- Poisson's Ratio, V = 0.3
- Density γ = 490 pcf

Soil properties used in the analysis of the Transfer Area are:

- In-place unit weight of soil = 135 psf
- Mohr-Coulomb Soil friction angle (ϕ) = 41°
- Lateral soil coefficient for at-rest conditions = 0.34
- Lateral soil coefficient for passive conditions = 4.81
- Lateral soil pressure for active conditions = 0.21
- Soil/Concrete Coefficient of Friction (μ) = 0.55

Load Combinations

Specific load combinations are provided in Section 3.2.5.2. The load cases and combinations listed in Table 4.7-7 were included in the structural analysis of the Transfer Area.

Structural Analysis

The structural analysis of the Transfer Area was performed to demonstrate the structural adequacy of the concrete ITS structures under the design loads and combinations. The structural analysis methodology included static and response spectra methods. The multipurpose finite element (FE) analysis program, SAP2000, was used to model and analyze the Transfer Area.

The purpose of the analysis was to show that the ITS portions of the Transfer Area (the concrete structure) were structurally adequate for the defined design loads. The steel NITS structure that surrounds the FPA was included in the finite element model of the Transfer Area specifically for its effect on the concrete structure. Similar design bases loads were applied to the NITS primary steel structure as to the ITS concrete structure, including seismic and tornado wind.

Computer Model and Program

Transfer Area Building Structure. The main reinforced concrete structure enclosing the FPA and CCA is ITS and consists of 2 foot to 4 foot thick concrete walls and slabs supported on a 5 foot thick mat foundation. The ITS concrete structure is shown in Figure 4.7-40 through Figure 4.7-43. The surrounding steel building is attached to the concrete walls and is supported at the base on spread footings. The steel framed superstructure, shown in Figure 4.7-44 and Figure 4.7-45 is classified as NITS.

Computer Model. The mathematical model developed for the Transfer Area building structures was generated in accordance with requirements addressed in ASCE 4 and applicable NRC Regulatory Guide 1.92. Modeling requirements to account for parameters such as degrees of freedom, stiffness, and mass are discussed further in the following sections. Figure 4.7-46 through Figure 4.7-49 show additional views of the Transfer Area finite element model, including cut-away views of the FPA.

Shell and Beam Elements. The reinforced concrete walls, slabs, and foundation mats were simulated by the SAP2000 shell element. This element is either a three-node triangular or four-node quadrilateral element with an isoparametric formulation that combines separate membrane and plate-bending behavior. When used in a dynamic analysis it is capable of six (6) degrees of freedom excitation, and nodal data input and output. Other linear elements use the SAP2000 frame element. This element represents beams and truss type members in the model, with either prismatic or non-prismatic sections. It uses a three-dimensional, beam to column formulation that includes the effects of biaxial bending, torsion, axial deformation, and biaxial shear deformations. Nodes were located to capture true geometric properties and configurations, attain regular shell mesh shapes and aspect ratios, and locate dominant point masses.

Required Dynamic Degrees of Freedom. The Eigenvector analysis option for modal extraction and combination in SAP2000 was utilized. The program internally assigns nodes so that the dynamic degrees of freedom match the system degrees of freedom. This option approaches the theoretical exact solution. If a higher total number of eigenvectors are sought such that the total accounts for 90 percent or more of the total mass, the eigenvector option approaches the true dynamic response of a structure. This is due to the fact that it considers each mode in the range requested for extraction, expansion and combination.

Modeling of Stiffness and Mass. The SAP2000 program includes a structural section library for rolled steel sections contained in the AISC Manual. This provides an accurate call out of the steel section properties used in the model. Non-prismatic section structural properties and additional masses were externally calculated, documented, and included in the input stream.

Stiffness of reinforced concrete elements was modeled using concrete material properties and the gross thickness of the element. Structural analysis results are reported as nodal and/or element forces and moments, which were then used for member structural design.

The Transfer Area model contains rigid elements and nodal constraint to simulate eccentricities, member offsets at multi-member connections, and nodal coupling. Rigid elements are SAP2000 frame or shell elements with relatively large stiffness with respect to adjacent elements. Nodal constraints and coupling are pre programmed formulations available in SAP2000.

Dynamic Coupling. Major equipment including the FHM crane in the FPA was explicitly modeled with the building structure. Main girders, vertical members, and appropriate end conditions were modeled. Significant masses of other equipment were applied at designated locations and positioned to capture the most critical dynamic effects on the supporting structure.

Consideration of Adjacent Structures. The Storage Area is located immediately to the south of the Transfer Area. These structures are isolated from one another by a seismic gap that was sized based on the relative seismic deflections calculated from the SSI analysis. The effects of the structure-soil-structure interaction were captured into the response spectra generated by the SSI analysis.

Static Analysis

Static structural analysis refers to the methodology used to analyze the structure under static loads such as dead and live loads. This relates to a single structural solution in calculating forces and moments. The static load cases for the Transfer Area structure include dead, live, wind, and pressure loads. They are combined linearly with the multi-solution response spectra seismic case.

A separate finite element analysis was performed to evaluate thermal response of the Transfer Area because different boundary conditions were required. Boundary conditions for the thermal structural model allowed free thermal expansion at the base, while a fixed base support was used for the other static design loads and dynamic seismic loads. Figure 4.7-50 shows boundary conditions for static force load cases including seismic, and Figure 4.7-51 reflects a single node base support used for the thermal load case. Thermal effects due to changes in material temperature from the reference temperature (assumed stress free) to a final steady state temperature were captured in this analysis. The effect of the temperature gradient across the shell thickness was also included in the thermal analysis.

Dynamic Seismic Analysis

Dynamic Soil-Structure-Interaction Analysis. The time history SSI analysis described in section 3.2.3.1.8 was performed to investigate SSI effects and to develop in-structure response spectra for the Transfer Area. The input response spectra used for the fixed-base response spectra analysis were calculated by enveloping the SSI in-structure response spectra across the base of the Transfer Area. The intent was to capture SSI effects in the input spectra for the building analysis. In order to evaluate the ability of the fixed-base model to properly incorporate the SSI effects, peak in-structure accelerations from the fixed-base model were compared to the in-structure peak accelerations calculated in the SSI analysis for various locations in the Transfer Area. The results indicated that the overall accelerations were comparable.

Modal Analysis (Eigen Method Modal Extraction). Modal response characteristics were evaluated and the fundamental frequencies in three global directions were noted. Mode shapes and level of mass participation were evaluated to check the dynamic model, and to estimate the degree of missing mass.

More than 90% of the building mass was accounted for in the horizontal direction and 89% in the vertical direction, which meets the requirements of ASCE 4 and NRC Regulatory Guide 1.92.

Linear Elastic Dynamic Response Spectra Analysis. Structural analyses of the combined steel and reinforced concrete structures under seismic loads were performed using the response spectra method. The method of combining modal responses and spatial (X, Y, Z) components as well as the requirements for total mass participation are in accordance with the guidelines of NRC Regulatory Guide 1.92. The value for structural damping was taken from NRC Regulatory Guide 1.61.

Response spectra analysis parameters. The following input parameters were used in the dynamic seismic analysis:

- Input Response Spectra Curves at 7% Structural Damping
  (refer to Figures 3.2-11 through 3.2-52)
- Structural Damping = 7% - from NRC Reg. Guide 1.61
- Modal Damping = 7%, - from NRC Reg. Guide 1.61
- Modal Combination Method = GMC - Reg.Guide 1.92, ASCE 4
- Target Total Percent Mass Participation = 90% - Reg.Guide 1.92, ASCE 4
- Spatial Combination = SRSS - Reg.Guide 1.92, ASCE 4

Both static and dynamic structural analyses use the same finite element model and boundary conditions. Static analysis methods were used for load cases involving static dead and live loads, wind, and pressure. These static load cases do not involve time dependent functions. Crane trolleys and bridges were placed in locations that were expected to produce the most critical response in the structure.

Reinforced Concrete Structural Design

Load Combinations. Since there are many load cases and combinations defined in the Transfer Area structural analyses, enveloping load cases were formulated to evaluate the structural demands on the reinforced concrete components. This provides a simplified method to evaluate the component based on maximum design conditions. Portions of the structure are evaluated more rigorously by evaluating individual load cases. Preliminary member sizing was based on the enveloping load cases defined below.

- RCCOMBO is the envelope of the maximum and minimum forces and moments of static and dynamic load cases and load combinations, except thermal loads.
- Thermal load cases were defined for Normal and Off-Normal/Accident conditions. Each of these has a case for winter and summer.
  - Normal Temperatures – Normal outside temperature range with normal operating conditions.
  - Off-Normal Case 1– Normal outside temperature range with failure of the HVAC system.
  - Off-Normal Case 2 – Extreme outside temperature range and normal operation of the HVAC system.

Walls and Slabs. Walls and slabs were designed based on flexural and shear loads. The input forces and moments for each wall were taken from the contour plots of the shell element forces and moments from the envelope load case (RCCOMBO). Contour plots of the shell element forces and moments were also plotted for each of the thermal load cases defined above. Forces and moments representing the demand on the section were taken from the contour plots. The extracted values represent the dominant flexure and shear behavior in each section. The reinforcement used in determining the concrete capacity was calculated based on the requirements of ACI 349. This was done for the enveloped case (RCCOMBO) and also for the addition of temperature loads.

Structure Foundation Analysis and Design

An enveloping load case was formulated based on the static and dynamic load combinations of NUREG 1536, Table 3-1 to evaluate the structural demands on the reinforced concrete foundation. This load case enveloped the unfactored load combinations applicable to foundation design.

Mat Foundation

The 5 foot thick mat foundation for the Transfer Area was analyzed in a separate finite element calculation using the computer program SAP2000. The analysis was based on the theory of flat-plate bending with the mat supported by the soil. The mat was modeled as a mesh of shell elements interconnected at node points. Bending moments and transverse forces were modeled with the shell elements. The supporting soil was modeled using springs with the initial spring constants based on the modulus of subgrade reaction for the soil. Enveloped reactions (forces and moments) from the finite element analysis of the Transfer Area were directly used as input for the analysis of the mat foundation. The mat foundation finite element model is shown in Figure 4.7-52.

The modulus of subgrade reaction, k_s, is equal to q/δ where q is the bearing pressure and δ is the settlement or deflection. An initial modulus of subgrade reaction was estimated based on allowable bearing pressure. The modulus of subgrade reaction was converted to a nodal spring constant by multiplying K_s by the tributary area of the nodes.

The use of a uniform modulus of subgrade reaction to analyze and design mat foundations can result in a simplified soil response. Therefore, k_s was modified based on the subgrade response. The nodal (spring) reactions and deflections were obtained from the initial finite element run. The estimated settlement due to the subgrade response (springs reactions) was calculated and compared with the mat deflections from the finite element run. New modulus of subgrade reaction values were calculated for each node based on the subgrade response and the estimated settlement. The finite element analysis was performed again with the new modulus of subgrade reaction and this process was repeated until comparable deflections were achieved.

Contour plots of the forces and moments from the foundation finite element analysis were plotted. Contour plots of the forces and moments from the thermal analysis of the Transfer Area were also plotted showing the foundation response. The design forces and moments used for flexure and shear design of the mat were taken from these plots. Demand and capacity of the mat were calculated in accordance with the requirements of ACI 349.

Overturning and Sliding

The capacity/demand ratio for sliding is defined as F_S/V_S, where F_S is the resisting force (capacity) and V_S is the sliding force (demand). The sliding force V_S depends on the load or load combination considered. The resisting force F_S is determined from the following equation,

$F_S = N_T*\mu$,

where N_T is the total normal force and μ is the soil-concrete friction coefficient.

The capacity/demand ratio for overturning is defined as M_R/M_O, where M_R is the resisting moment (capacity) and M_O is the overturning moment (demand). The overturning moment is obtained by multiplying the lateral load V_S by the appropriate lever arm. The moment is taken about the toe of the mat foundation. The resisting moment M_R is obtained by multiplying resisting normal forces with their appropriate lever arm.

Since there are no lateral soil loads on the Transfer Area under normal loads, overturning and sliding is considered only for tornado wind pressure loads and earthquake combinations as defined below. The minimum allowable capacity/demand ratio for overturning and sliding is 1.1.

Earthquake forces for overturning and sliding were determined using two different methods. The first "Static Analysis" estimated the inertial forces by using the total mass of the structure and applying the acceleration values at the second floor of the Transfer Area building (close to the center of mass of the structure). These acceleration values were the peak floor accelerations obtained from the SSI analysis. The inertial forces were assumed to act at the center of mass. The normal force, N_T, was calculated by taking the total weight of the structure minus the vertical inertial force.

The second method used to determine earthquake force was the "Seismic Analysis Method." In this method, the forces were obtained by summing the enveloped base reactions from the Transfer Area finite element analysis (using the SRSS of "XYZ" seismic loads). The vertical and horizontal forces were then applied at the calculated center of gravity of the Transfer Area.

Tornado loads from the four directions were considered. The tornado forces were obtained by summing the base reactions from the Transfer Area finite element analysis. Tornado wind loads for four different directions were considered and the maximum enveloped. The vertical and horizontal forces were then applied at the calculated center of gravity of the Transfer Area.

Steel Structural Design

The steel structure is classified as NITS. The structural steel is modeled in this calculation for its affects on the reinforced concrete structure.

Summary of Results

Modal Frequencies and Mass Participation

The significant modes of vibration and mass participation are summarized in Table 4.7-12.

- The fundamental mode for the North-South direction occurs at about 8.1 Hz and is due to a combination of modes 20 and 21 (closely spaced modes). About 29% of the mass of the structure participates in the fundamental mode. The second mode of vibration for the North-South direction occurs at mode 27 (9.14 Hz). It represents an overall north-south motion of the Transfer Area out-of-phase with gallery floor slabs. About 12.6% of the structure mass participates in this secondary mode.
- The fundamental east-west mode is a combination of modes 70 and 71 (closely spaced) occurring at about 14 Hz. About 67% of the mass of the structure participates in this mode.
- The vertical modes are scattered throughout the high frequency range with the fundamental mode occurring at about 28.9 Hz (mode 179). About 23% of the mass participates in this mode which means that the balance of the vertical mass is primarily excited by the zero period acceleration (ZPA) of the response spectra.

The Transfer Area model was run for 675 modes and over 90% of the mass was captured in the horizontal direction while over 87% of the vertical mass participated.

Plots of modes of vibration for Transfer Area are shown in Figure 4.7-53 through Figure 4.7-58.

Mat Foundation Design Results Summary

The Transfer Area concrete building is supported on a mat foundation. The mat in the Tunnel Tunnel and at grade are 4 feet and 5 feet thick respectively. The Transfer Tunnel mat extends 4 feet beyond the outside face of the Tunnel wall (and under the 5-foot thick mat), resulting in a section with a total thickness of 9 feet. To satisfy ACI 349 code requirements, a minimum area of steel of 1.04 in^2/ft is required for the 4-foot thick section, 1.30 in^2/ft is required for the 5-foot section of mat, and 2.33 in^2/ft is required for the 9-foot section. Actual steel requirements vary throughout the mat, depending on the magnitude of the bending and shear forces and moments in the mat.

The capacity of the mat for bending and out-of-plane shear is shown in Table 4.7-13 based on the minimum required area of steel. The demand is based on an envelope of the load combinations and is compared to the capacity.

Overturning and Sliding Results Summary

The minimum capacity/demand ratio for sliding in the east-west direction was 1.26 based on seismic loading. The minimum ratio of 5.5 for overturning in the east-west direction was also based on the seismic loads. In the north-south direction the seismic load controlled for sliding and overturning with capacity/demand ratios of 1.87 and 4.2, respectively. These results are shown in Table 4.7-14. These ratios are greater than the minimum allowable ratio of 1.1. The structure has additional margin because the calculations are based on the mat foundation profile, neglecting the perimeter foundation. They also neglect the contribution of soil lateral pressures to resist sliding.

Transfer Area Reinforced Concrete Wall Summary

The reinforced concrete walls were designed based on overall demands for flexure and shear for each main section of wall. The thickness of the walls is governed by radiological shielding requirements and so there is sufficient space to locally reinforce the concrete as needed. Table 4.7-15 provides a summary of the demand and capacity for the various wall thicknesses in the Transfer Area under static, dynamic and thermal load combinations.

In-plane shear forces were derived from the most critical load cases and load combinations from the analysis of the Transfer Area. Results obtained from this shear wall structural analysis demonstrated that the Transfer Area shear wall section capacities exceed shear force demands. The area of reinforcement provided to adequately resist the shear demands was calculated based on ACI 349 guidelines. The capacity/demand ratios for shear wall behavior are presented in Table 4.7-16.

Transfer Area Reinforced Concrete Slabs Summary

The reinforced concrete slabs were designed based on overall demands for flexure and shear for each main section of wall. The thickness of the slabs is governed by radiological shielding concerns. Table 4.7-17 provides a summary of the demand and the capacity for the various slabs in the Transfer Area under static, dynamic and thermal load combinations.

Transfer Area Temperature Effects

The results in Table 4.7-15 through Table 4.7-17 demonstrate that the facility has sufficient capacity to withstand off-normal/accident thermal loads. Additional capacity will be present, since the structural analysis does not include the following load-limiting effects:

- Construction joints and other stress-relieving effects.
- Discontinuities in shell element-to-element application of the loads.
- Time-dependent variations in extreme temperatures.

4.7.3.3.3 Storage Area

Design Bases

The Storage Area is comprised of the concrete storage vault structure, the adjoining south section of the Transfer Tunnel, and steel framed structure that covers the storage vaults and provides weather protection for the CHM. The reinforced concrete storage vaults and transfer tunnel structure are classified ITS. The steel building is classified NITS.

- **Tornado** – The concrete storage vault walls, storage vault charge face, storage tube covers, and Transfer Tunnel are designed to withstand the effects of the design basis tornado, including tornado wind, tornado missiles, and differential pressure.

  Primary structural steel of the Storage Area is designed to withstand tornado wind loads using the conservative assumption that the wall and roof panels remain in place to transfer the wind loads to these members.

  Wall and roof panels are not designed to withstand tornado wind, tornado missiles or tornado differential pressure. Therefore, the structure is considered vented and the primary steel is not subjected to the design differential pressure.

Primary structural support members of the Storage Area are designed to withstand tornado missiles. Secondary members such as purlins and girts are not designed to withstand tornadoes.

- **Earthquake** – The ITS reinforced concrete Storage Area is designed to withstand the effects of the design earthquake. This includes the concrete vault walls, floor slab, foundation, charge face, and Transfer Tunnel. The NITS primary structural steel members of the Storage Area are also designed to withstand the design earthquake loads. Secondary members such as purlins and girts, as well as roof and wall panels, are not designed for the design earthquake.

- **Fire or Explosion** – A fire hazards analysis was performed to evaluate potential fires that could affect the Storage Area and to ensure that ITS features of the Storage Area vault continue to perform without loss of safety function during credible fires. Fire detection systems are installed in the Storage Area building but not the Storage Area vaults. Fire sprinklers are not installed inside the Storage Area building to ensure that an inadvertent actuation will not result in water entering the vault through the air vents in the charge face. Refer to Section 4.3.8 for additional discussion on the fire detection system and fire hazards inside the Storage Area.

- **Flood** –The Storage Area charge face is located at elevation 4938 feet, 6 inches approximately 18 feet above the PMF level. The bottom of the inlet air vents are also located above the PMF level; therefore, floodwater cannot enter the air vents in the storage vaults. The storage vaults do not have through-wall penetrations below the PMF level, and construction joints have water stops to ensure leak tightness.

  The south portion of the Transfer Tunnel may be subjected to flood water through the outer door, which is not watertight. Approximately 8 and one half feet of water could flood the inside the Transfer Tunnel.

- **Lightning** – The Storage Area building has a lightning arrestor system designed in accordance with NFPA 780, *Lightning Protection Code.*

- **Shielding Considerations** – One of the primary functions of the Storage Area vaults is to provide radiation shielding from the SNF stored within this structure. The vault walls and charge face were designed with thick concrete sections and design features to minimize the radiation dose rates in adjacent areas that can be occupied by personnel at the ISF Facility. Chapter 7 provides an evaluation of the expected dose rates in the areas around the Storage Area.

- **Temperature Effects** - The storage vaults, charge face structure and Transfer Tunnel were analyzed for a range of normal and off normal temperature conditions. Section 3.2.5.1.6 and Section 3.2.5.1.10 provides off-normal temperature cases used to analyze these concrete structures. The temperature effects on the steel Storage Area building are considered negligible and self-limiting, and therefore not included in the design.

- **Retrieval Considerations** – Spent fuel handling in the Storage Area consists of lifting ISF canisters from the canister trolley and inserting them into storage tubes in the charge face of the storage vault. The CHM is a single failure proof design, which considers normal and off-normal loading conditions. In the event of a breakdown of the CHM, normal repair activities could be performed in the Storage Area because radiation levels would be minimal due to the shielding of the CHM turret. The CHM includes features to manually lower a canister in the event of a power failure.

- **Decontamination Considerations** – The Storage Area is considered a "clean" area and is not expected to become contaminated during canister transfer operations. The south section of the Transfer Tunnel is designed to permit decontamination of the cask trolley and canister trolley should the need arise. The design of structural concrete incorporates features to facilitate decontamination. This is primarily accomplished through the use of decontaminatable coatings on concrete surfaces in the Transfer Tunnel.

Design Loads

The following loads were included in the design of the Storage Area.

- Dead Loads (D) -Includes the weight of the structure and permanently attached equipment and utilities including the weight of the CHM.
- Live Loads (L) – The area live loads for the Storage Area are defined as follows:
    - The charge face and the area over the Transfer Tunnel were designed for a live load of 150 psf in addition to the concentrated loads associated with CHM maintenance equipment.
    - The Transfer Tunnel was designed for a live load of 200 psf in addition to the loads associated with the cask and canister trolley.
    - The panel roof of the Storage Area building was designed for a live load of 20 psf and snow load of 30 psf.
- Soil Pressure (H) - These are defined as lateral soil pressure due soil weight, ground water, and loads imparted through the soil from adjacent structures. These loads are considered negligible for analysis of the ITS structures of the Storage Area since the depth of the structure below grade is minimal.
- Wind Loads (W) - Wind loads are based on a 90 mph three-second gust in accordance with ASCE 7 and are applied to both ITS and NITS structural members of the Storage Area. Refer to Section 3.2.1.1 for design basis wind load parameters.
- Temperature Loads (T) – Thermal loads associated with temperature distribution and thermal gradients and effects of expansion and contraction of concrete elements. Refer to Section 3.2.5.1.6 and Section 3.2.5.1.10 for the off-normal temperature cases used in the analysis of the concrete structures of the storage vault, charge face structure and Transfer Tunnel.
- Earthquake Loads (E) - Loads attributable to the direct and secondary effects of the design earthquake are applied to the base of the Storage Area. The response spectra method is used to evaluate structural demand on Storage Area structures. The input response spectra are based on the results of the SSI analysis. Refer to Section 3.2.3 for seismic design criteria applied to the Storage Area.
- Tornado Loads (Wt) – This includes tornado wind, tornado differential pressure, and tornado missiles. Specific tornado loads applied to the Storage Vault, Transfer Tunnel and Storage Area building are discussed above. Refer to Section 3.2.1 for tornado load design criteria and parameters applied to the ISF Facility.

- Accident Loads (A) – There are no accident loads included in the design of the Storage Area in addition to those described above.

Material Properties

Properties of concrete used in the Storage Area are:

- Concrete Units Weight, γ_{conc} =145 pcf
- Concrete Compressive Strength, f'_c = 4,000 psi
- Concrete Young's Modulus, E_{conc} = 3,604,000 psi
- Concrete Poisson's ratio, v = 0.2
- Reinforcing Steel Yield Strength, f_y = 60,000 psi
- Reinforcing Steel Modulus, E_{steel} = 29,000,000 psi
- Coefficient of Thermal Expansion = 5.5 x 10^{-6} in./in./°F

Properties of Steels Used in the Storage Area are:

- Modulus of Elasticity = E_{steel} = 29,000,000 psi
- Poisson's Ratio, v = 0.3
- Density γ = 490 pcf

Soil properties used in the analysis of the Storage Area are:

- In-place unit weight of soil = 135 pcf
- Mohr-Coulomb Soil friction angle (ϕ) = 41°
- Lateral soil coefficient for at-rest conditions = 0.34
- Lateral soil coefficient for passive conditions = 4.81
- Lateral soil pressure for active conditions = 0.21
- Soil/Concrete Coefficient of Friction (μ) = 0.55

Load Combinations

Specific load combinations are provided in Section 3.2.5.2. The load cases and combinations listed in Table 4.7-7 were included in the structural analysis of the Storage Area.

Structural Analysis

The structural analysis of the Storage Area was performed to demonstrate the structural adequacy of the concrete ITS structures under the design loads and combinations. The structural analysis methodology included static and response spectra methods. The multipurpose finite element (FE) analysis program, SAP2000, was used to model and analyze the Storage Area.

The purpose of the analysis was to show that the ITS portions of the Storage Area (the concrete structure) were structurally adequate for defined design loads. The steel NITS structure that covers the Storage Area charge hall was included in the finite element model of the Storage Area specifically for its effect on the concrete structure. Similar design bases loads were applied to the NITS steel structure as to the ITS concrete structure, including seismic and tornado wind.

Computer Model and Program

Storage Area Building Structure. The main reinforced concrete structure consisting of the Transfer Tunnel and storage vaults 1 and 2 is classified as ITS. The ITS concrete structure is shown in Figure 4.7-59 through Figure 4.7-62. The steel framed superstructure, shown in Figure 4.7-63 and Figure 4.7-64 is classified as NITS. It is supported atop the concrete shield walls of the storage area. The steel is included in the finite element model to capture its effects on the concrete.

The walls of the Storage Area are 36 inches thick and are supported on a mat foundation that varies in thickness from 4 feet to 3 feet. The floor over the transfer tunnel is 36 inches thick. The charge face structure over the storage vaults is 30 inches thick. The charge face is penetrated with an array of transfer ports that provide access to the storage tubes. The storage tubes are both vertically and horizontally supported at the base of the vault, but are only laterally supported by the charge face structure.

The charge face of the storage vaults was modeled as reinforced concrete beams that run in both directions supporting the steel storage tube penetration encasts. A series of interconnected 3-dimensional frame elements were used to model this structure and are referred to as "grid beams". These grid beams were modeled to provide only lateral support to the storage tubes and not allow transfer of vertical loads. The storage tubes were modeled for effect on the vault structure using frame elements. The storage tubes are modeled with a pinned connection to the vault floor. The center to center distance and the cross section of the beams is based on the narrowest effective cross section of the concrete section between two adjacent canister storage tubes.

Computer Model. The mathematical model developed for the Storage Area structures was generated in accordance with requirements addressed in the ASCE 4 and NRC Regulatory Guide 1.92. Modeling requirements to account for parameters such as degrees of freedom, stiffness, and mass are discussed further in the following sections. Figure 4.7-65 through Figure 4.7-67 show additional views of the Storage Area, including cut-away views of the storage vaults and transfer tunnel.

Shell and Beam Elements. The reinforced concrete walls, slabs, and foundation mats were simulated by the SAP2000 shell element. This element is a three-node triangular or four-node quadrilateral element with an isoparametric formulation that combines separate membrane and plate-bending behavior. When used in a dynamic analysis it is capable of six (6) degrees of freedom excitation, and nodal data input and output. Other linear elements use the SAP2000 frame element. This element represents beams and truss type members in the model, with either prismatic or non-prismatic sections. It uses a three-dimensional, beam to column formulation that includes the effects of biaxial bending, torsion, axial deformation, and biaxial shear deformations. Nodes were located to capture true geometric properties and configurations, attain regular shell mesh shapes and aspect ratios, and locate dominant point masses.

Required Dynamic Degrees of Freedom. The Eigenvector analysis option for modal extraction and combination in SAP2000 was utilized. The program internally assigns nodes so that the dynamic degrees of freedom match the system degrees of freedom. This option approaches the theoretical exact solution. If a higher total number of eigenvectors are sought such that the total accounts for more than 90 percent or more of the total mass, the eigenvector option approaches the true dynamic response of a structure. This is due to the fact that it considers each mode in the range requested for extraction, expansion and combination.

Modeling of Stiffness and Mass. The SAP2000 program includes a structural section library for rolled steel sections contained in the AISC Manual. This provides an accurate call out of the steel section properties used in the model. Non-prismatic section structural properties and additional masses were externally calculated, documented, and included in the input stream.

Stiffness of reinforced concrete elements (SAP2000 shell elements) were modeled using concrete material properties and the gross thickness of the element. Structural analysis results are reported as nodal and/or element forces and moments, which were then used for member structural design.

The Storage Area model contains rigid elements and nodal constraints to simulate eccentricities, member offsets at multi-member connections, and nodal coupling. Rigid elements are SAP2000 Frame or Shell elements with relatively large stiffness with respect to adjacent elements. Nodal constraints and coupling are pre programmed formulations available in SAP2000.

Dynamic Coupling. The CHM was explicitly modeled with the building structure. The model of the CHM included main girders, vertical members, appropriate member releases, and lumped masses to capture its static and dynamic characteristics. The CHM crane girders and turret were positioned to produce the most critical loads in the Storage Area walls. Significant masses of other equipment were applied at designated locations and positioned to capture the most critical dynamic effects on the supporting structure.

Consideration of Adjacent Structures. The Storage Area is located between the Transfer Area and Cask Receipt Area. These structures are isolated from one another by a seismic gap that was sized based on the relative seismic deflections calculated from the SSI analysis. The effects of the structure-soil-structure interaction were captured into the response spectra generated by the SSI analysis.

Static Analysis

Static structural analysis refers to the methodology used to analyze the structure under static loads such as dead and live loads. This relates to a single structural solution in calculating forces and moments. The static load cases for the Storage Area structure include dead, live, wind, and pressure loads. They are combined linearly with the multi-solution response spectra seismic case.

A separate finite element analysis was performed to evaluate thermal response of the Storage Area because different boundary conditions were required. Boundary conditions for the thermal structural model allowed free thermal expansion at the base, while a fixed base support was used for all other static design loads and dynamic seismic loads. Figure 4.7-68 shows boundary conditions for all static force load cases including seismic, and Figure 4.7-69 reflects a single node base support used for the thermal load case. Thermal effects due to changes in material temperature from the reference temperature (assumed stress free) to a final steady state temperature were captured in this analysis. The effect of the temperature gradient across the shell thickness was also included in the thermal analysis.

Dynamic Seismic Analysis

Dynamic Soil-Structure-Interaction Analysis. The time history SSI analysis described in Section 3.2.3.1.8 was performed to investigate SSI effects and to develop in-structure response spectra for the Storage Area. The input response spectra used for the fixed-base response spectra analysis were calculated by enveloping the SSI in-structure response spectra across the base of the Storage Area. The intent was to capture SSI effects in the input spectra for the building analysis. In order to evaluate the ability of the fixed-base model to properly incorporate the SSI effects, peak in-structure accelerations from the fixed-base model were compared to the in-structure peak accelerations calculated in the SSI analysis for various locations in the Storage Area. The results of the comparison indicated overall accelerations were comparable.

Modal Analysis (Eigen Method Modal Extraction). Modal response characteristics were evaluated and the fundamental frequencies in three global directions were noted. Mode shapes and level of mass participation were evaluated to check the dynamic model, and to estimate the degree of missing mass. More than 90% of the building mass was accounted for, meeting the requirements of ASCE 4 and NRC Regulatory Guidelines.

Linear Elastic Dynamic Response Spectra Analysis. Structural analyses of the combined steel and reinforced concrete structures under seismic loads were performed using the response spectra method. The method of combining modal responses and spatial (X, Y, Z) components as well as the requirements for total mass participation are in accordance with the guidelines of NRC Regulatory Guide 1.92. The value for, meeting NRC Regulatory Guide 1.92.

Response spectra analysis parameters. The following input parameters were used in the dynamic seismic analysis:

- Input Response Spectra Curves at 7% Structural Damping (refer to Figures 3.2-11 through 3.2-52)
- Structural Damping = 7% - from NRC Reg. Guide 1.61
- Modal Damping = 7%, - from NRC Reg. Guide 1.61
- Modal Combination Method = GMC - Reg.Guide 1.92, ASCE 4
- Minimum Total Percent Mass participation = 90% - Reg.Guide 1.92, ASCE 4
- Spatial Combination = SRSS - Reg.Guide 1.92, ASCE 4

Both static and dynamic structural analyses use the same finite element model and boundary conditions. Static analysis methods were used for load cases involving static dead and live loads, wind, and pressure. These static load cases do not involve time dependent functions. Crane trolleys and bridges were placed in locations that were expected to produce the most critical response in the structure.

Reinforced Concrete Structural Design

Load Combinations. Since there are many load cases and combinations defined in the Storage Area structural analyses, enveloping load cases were formulated to evaluate the structural demands on the reinforced concrete components. This provides a simplified method to evaluate the component based on maximum design conditions. Portions of the structure may be evaluated more rigorously by evaluating individual load cases. Preliminary member sizing was based on the enveloping load case defined below.

- RCCOMBO is the envelope of the maximum and minimum forces and moments of all static and dynamic load cases and load combinations, except thermal loads.
- Thermal load cases were defined for Normal and Off-Normal/Accident conditions. Each of these has a case for winter and summer.
    - Normal Temperatures – Normal outside temperature range with normal operating conditions.
    - Off-Normal Case 1 – Normal outside temperature range with failure of the HVAC system and partial blockage of vault vents.
    - Off-Normal Case 2 – Extreme outside temperature range and normal operation of the HVAC system.

Walls and Slabs. Walls and slabs were designed based on flexural and shear loads. The input forces and moments for each wall were taken from the contour plots of the shell element forces and moments from the envelope load case (RCCOMBO). Contour plots of the shell element forces and moments were also plotted for each of the thermal load cases defined above. Forces and moments representing the demand on the section were taken from the contour plots. The extracted values represent the dominant flexure and shear behavior in each section. The reinforcement used to determine the concrete capacity was calculated based on the requirements of ACI 349. This was done for the enveloped case (RCCOMBO) and also for the addition of temperature loads.

Structure Foundation Analysis and Design

An enveloping load case was formulated based on the static and dynamic load combinations of NUREG 1536, Table 3-1 to evaluate the structural demands on the reinforced concrete foundation. This load case enveloped the unfactored load combinations applicable to foundation design.

Mat Foundation

The 3 foot and 4 foot thick mat foundation for the Storage Area were analyzed in a separate finite element calculation using the computer program SAP2000. The analysis was based on the theory of flat-plate bending with the mat supported by the soil. The mat was modeled as a mesh of shell elements interconnected at node points. Bending moments and transverse forces were modeled with plate elements. The supporting soil was modeled using springs with the initial spring constants based on the modulus of subgrade reaction for the soil. Enveloped reactions (forces and moments) from the finite element analysis of the Storage Area were directly used as input for the analysis of the mat foundation. The mat foundation finite element model is shown in Figure 4.7-70.

The modulus of subgrade reaction, k_s, is equal to q/δ where q is the bearing pressure and δ is the settlement or deflection. An initial modulus of subgrade reaction was estimated based on allowable bearing pressure. The modulus of subgrade reaction was converted to a nodal spring constant by multiplying K_s by the tributary area of the nodes.

The use of a uniform modulus of subgrade reaction to analyze and design mat foundations can result in a simplified soil response. Therefore, k_s was modified based on the subgrade response. The nodal (spring) reactions and deflections were obtained from the initial finite element run. The estimated settlement due to the subgrade response (springs reactions) was calculated and compared with the mat deflections from the finite element run. New modulus of subgrade reaction values were calculated for each node based on the subgrade response and the estimated settlement. The finite element analysis was performed again with the new modulus of subgrade reaction and this process was repeated until comparable deflections were achieved.

Contour plots of the forces and moments from the foundation finite element analysis were plotted. Contour plots of the forces and moments from the thermal analysis of the Storage Area were also plotted showing the foundation response. The design forces and moments used for flexure and shear design of the mat were taken from these plots. Demand and capacity of the mat were calculated in accordance with the requirements of ACI 349.

Overturning and Sliding

The capacity/demand ratio for sliding is defined as F_S/V_S, where F_S is the resisting force (capacity) and V_S is the sliding force (demand). The sliding force V_S depends on the load or load combination considered. The resisting force F_S due to soil friction is determined from the following equation,

$F_S = N_T * \mu$,

where N_T is the total normal force and μ is the soil-concrete friction coefficient. Passive soil pressures were also used to resist the sliding forces.

The capacity/demand ratio for overturning is defined as M_R/M_O, where M_R is the resisting moment (capacity) and M_O is the overturning moment (demand). The overturning moment is obtained by multiplying the lateral load V_S by the appropriate lever arm. The moment is taken about the toe of the mat foundation. The resisting moment M_R is obtained by multiplying resisting normal forces with their appropriate lever arm.

Since there are no lateral soil loads on the Storage Area under normal loads, overturning and sliding is considered only for tornado wind pressure loads and earthquake combinations as defined below. The minimum allowable capacity/demand ratio for overturning and sliding is 1.1.

Earthquake forces for overturning and sliding were determined using two different methods. The first, "Static Analysis" estimated the inertial forces by using the total mass of the structure and applying the acceleration values at the second floor of the Storage Area (close to the center of mass of the structure). These acceleration values were the peak floor accelerations obtained from the SSI analysis. The inertial forces were assumed to act at the center of mass. The normal force, N_T, was calculated by taking the total weight of the structure minus the vertical inertial force.

The second method used to determine earthquake force was the "Seismic Analysis Method." In this method, the forces were obtained by summing the enveloped base reactions from the Storage Area finite element analysis (using the SRSS of "XYZ" seismic loads). The vertical and horizontal forces were then applied at the calculated center of gravity of the Storage Area.

Tornado loads from the four directions were considered. The tornado forces were obtained by summing the base reactions from the Storage Area finite element analysis. Tornado wind loads for four different directions were considered and the maximum enveloped. The vertical and horizontal forces were then applied at the calculated center of gravity of the Storage Area.

Steel Structural Design

The steel structure provides an enclosure over the Storage Area vaults. This steel structure is classified as NITS. The structural steel is modeled in this calculation for its affects on the reinforced concrete structure.

Summary of Results

Modal Frequencies and Mass Participation

The significant modes of vibration and mass participation are summarized in Table 4.7-18.

- Due to the high vertical stiffness of the Storage Area, the vertical mass is distributed throughout the frequency range without a clear single fundamental mode. Modes 31, 45 and 112 (10.6 Hz, 12.9 Hz, and 28.3 Hz) demonstrate the response of the three main sections of floor slab in the Charge Hall. These modes, along with the CHM vertical mode (mode 57) and other secondary modes, account for about 26% of the vertical mass below 28.3 Hz. The remaining mass is excited throughout the high frequency range of response.
- Mode 47 reflects the Storage Area east-west fundamental frequency of 14.8 Hz. This mode accounts for about 53% of the total east-west mass of the structure.
- The fundamental mode of vibration of the Storage Area structure in the north-south direction occurs at Mode 75 (22.2 Hz) and accounts for almost 31% of the north-south mass.

The global dynamic response of the structure was captured by inclusion of 650 modal responses in the modal combination (or summation). The total percent of accumulated mass from the 650 modes is approximately 93% for the north-south direction, 92% for the east-west direction and 89% for the vertical direction. This satisfies the requirements for a response spectra analysis addressed in the ASCE 4 guidelines.

Plots of modes of vibration for Transfer Area are shown in Figure 4.7-71 through Figure 4.7-73.

Relative Displacements

The relative displacements due to seismic loads were calculated from the SSI analysis and are presented in Table 4.7-19. There is very little relative movement between the Storage Area and the Transfer Area or the CRA. The maximum relative displacement is less than 0.20 inches.

The relative vertical displacement between the charge face and the vault base is of interest to ensure control the gaps between the storage tube and the charge face penetration liners. The maximum vertical relative displacement is less than 0.10 inches.

Mat Foundation Design Results Summary

The Storage Area concrete building is supported on a mat foundation. The mat in the tunnel is 4 feet thick and the mat is 3 feet thick under the storage vault. To satisfy ACI 349 code requirements, a minimum area of steel of 0.78 in^2/ft is required for the 3-foot thick section and 1.04 in^2/ft is required for the 4-foot thick section of mat. Actual steel requirements vary throughout the mat, depending on the magnitude of the bending and shear forces and moments in the mat.

The capacity of the mat for bending and out-of-plane shear is shown in Table 4.7-20 based on the minimum required area of steel. The demand is based on an envelope of the load combinations and is compared to the capacity.

Overturning and Sliding Results Summary

The minimum capacity/demand ratio for sliding in the east-west direction was 1.23 based on seismic loading. The minimum ratio of 3.4 for overturning in the east-west direction was also based on the seismic loads. In the north-south direction the seismic load controlled for sliding and overturning with capacity/demand ratios of 1.56 and 4.3, respectively. These results are shown in Table 4.7-21.These ratios are greater than the minimum allowed ratio of 1.1.

Storage Area Reinforced Concrete Wall Summary

The reinforced concrete walls were designed based on overall demands for flexure and shear for each main section of wall. The thickness of the walls is governed by the radiological shielding requirements so there is sufficient space to locally reinforce as needed for highly loaded area. Table 4.7-22 provides a summary of the demand and capacity for the various wall thicknesses in the Storage Area under static, dynamic and thermal load combinations.

In-plane shear forces were derived from the most critical load cases and load combinations from the analysis of the Storage Area. Results obtained from this shear wall structural analysis demonstrated that the Storage Area shear wall section capacities exceed shear force demands. The capacity/demand ratios for shear wall behavior are presented in Table 4.7-23. The area of reinforcement provided to adequately resist the shear demands was calculated based on ACI 349 guidelines.

Storage Area Reinforced Concrete Slabs Summary

The reinforced concrete slabs were designed based on overall demands for flexure and shear for each main section of wall. The thickness of the slabs is governed by radiological shielding concerns. Table 4.7-24 provides a summary of the demand and capacity for the various slabs in the Storage Area under static, dynamic and thermal load combinations.

Storage Area Temperature Effects

The results in Table 4.7-22 and Table 4.7-24 demonstrate that the facility has sufficient capacity to withstand off-normal/accident thermal loads. Additional capacity will be present, since the structural analysis does not include the following load-limiting effects:

- Construction joints and other stress-relieving effects.

- Discontinuities in shell element-to-element application of the loads.
- Time-dependent variations in extreme temperatures.

4.7.3.3.4 Cask Receipt Crane

Design Bases

The design of the CRC considered the following conditions:

- **Tornado** – Tornado effects are not included in the design of the CRC. The probability that the CRC will be handling a transfer cask containing a SNF shipment concurrently with a tornado event is extremely low (< 10^{-7} events/year) and is therefore not considered a credible event at the ISF Facility. Chapter 8 presents additional information regarding tornado events at the ISF Facility.
- **Earthquake** – The CRC is designed for seismic loads using the response spectra method. The CRC will remain in position and continue to support the maximum design load during and after a seismic event, but may not remain operational. The crane control system is de-energized during and following a seismic event, and fail safe on loss of electrical supply. The CRC was analyzed loaded and unloaded in the "hook-up" and "hook-down" positions.
- **Fire or Explosion** – The CRC meets the requirements NFPA-70, *National Electric Code* to minimize the likelihood and effect of any fires that might occur from faulty electrical equipment. Credible fires or explosions in the CRA that may have an adverse effect on the CRC are discussed in Section 4.3.8.
- **Flood** – The CRC hoist is located well above PMF elevation, and therefore would not be subjected to flood loads. Structural support members of the CRC would be submerged, however, there would be no significant differential pressure or hydraulic loads acting on this structure. Wave action during the PMF is expected to be minimal, and a water velocity of 1 to 3 feet/sec would produce negligible dynamic loads on the steel framing that supports the CRC.
- **Lightning** – The CRC is located inside of the CRA building, which is provided with a lightning arrestor system designed in accordance with NFPA 780, *Lightning Protection Code*. The CRC is also grounded in accordance with electrical design requirements. The CRC will not be subjected to direct lightning strikes.
- **Shielding Considerations** – The CRC handles shielded shipping casks and does not require additional shielding.
- **Temperature** – The CRC operates inside the CRA. Normal temperatures in the CRA building are controlled by the HVAC system within a range of 40°F to 105°F. The minimum and maximum anticipated off-normal temperature in the CRA building are -26°F and 149°F respectively. The minimum off-normal temperature may occur if the heating system in the building fails during the winter months when the outside ambient temperature is extremely low. Under these conditions, load handling operations are terminated, and the CRC will remain unloaded at temperatures below 32°F or above 105°F.
- **Retrieval Considerations** – SNF handling operations consist of lifting a shipping cask from a transporter and lowering it into the cask trolley. The CRC is a single failure proof design, which

considers credible loading conditions. In the event of a breakdown of the CRC, normal repair activities could be performed in the CRA because radiation levels would be within acceptable levels. The hoist brake hand release feature allows a fully loaded CRC to be lowered by hand safely and in a controlled manner in accordance with the requirements of NUREG-0554.

- **Decontamination Considerations** – The CRC operates in a "clean" area and not subjected to airborne contamination.
- **Protective Coatings** – The CRC is protected from the external environment by the floor, roof, and walls of the CRA building. Protective coatings consist of two finish coats of paint over a single coat of rust-inhibiting metal primer.
- **Off normal design considerations** – The CRC has been designed with features in accordance with NUREG-0554 to prevent two-blocking and load hang-up.

Design Loads

The following loads were included in the design of the CRC:

Loads	Term	Description of Load
Dead Loads	DL	Includes the weight of effective fixed parts of the crane and support base.
Lifted Load	LL	Working load and the weight of the lifting devices used for handling and holding the working load such as the load block, lifting beam, and other supplemental devices. The DOE transfer cask and contents weighs approximately 35 tons. The CRC was designed and analyzed to handle a future transportation cask weighing 300,000 lbs and a 10,000 lb lifting device.
Inertia Force from Drives	IFD	not applicable to fixed hoist CRC
Hoist Load Factor	HLF	0.15
Test Load	--	125 percent of rated load
Seismic Load	DE	

Load Combinations

The following load combinations were used in the design of the CRC:

Load Case	Description	Terms
1	Crane in regular use under principal loading	(DL) + 1.15 (LL) + IFD
2	Crane in regular use under principal and additional loading	Not applicable to the CRC
3	Extraordinary loads	See Below
3.1	Loaded crane with design earthquake	DL + LL + DE + IFD
3.2	Static test load	DL + 1.25 (LL)

Structural Analysis

This section addresses the structural analysis of the CRC hoist, equalizer beam, equalizer support beam and main girder. The structural analysis of the steel tower that supports the CRC is included in the analysis of the CRA in Section 4.7.3.3.1.

The static and dynamic analyses of the CRC were performed with STAADPRO, a general-purpose finite element program.

Seismic Model

The cask receipt crane is represented by a generalized three dimensional lumped mass system interconnected by weightless elastic members. The model reflects the overall size, length, connectivity, and stiffness of various structural members. The primary members include main girders, equalizer support beams, equalizer beam, drums, and hoist ropes. The rope and the lower block with lifted weight behave as a pendulum at about 0.26 Hz during a seismic event. The horizontal seismic response due to this pendulum effect is negligibly small.

Dynamic degrees of freedoms are assigned to a sufficient number of lumped mass points in locations that simulate the actual mass distribution. Structural members subjected to concentrated loads are provided with additional nodes at points where concentrated loads or their equivalent masses are positioned. The mathematical model for the cask receipt crane is shown in Figure 4.7-74 for the hook up condition. The hook down position is 50 feet below the center of the equalizer beam.

Seismic Analysis

A linear elastic response spectrum method was employed for the seismic analysis. Modal participation factors and response spectrum values corresponding to the modal frequencies were used to select the significant modes. Modes were divided into flexible or rigid range. Modes in the flexible range were combined by the SRSS method while the modes in the rigid range, which accounts for the missing masses, were combined by the algebraic sum method. The flexible range response and the rigid range response were combined again by the SRSS method. This method is equivalent to considering all modes and is consistent with Appendix A to SRP Section 3.7.2 of NUREG-0800. The responses obtained from the three direction analyses were combined in accordance with the NRC Regulatory Guide 1.92. In lieu of a 7% damping applicable to the cask receipt crane analysis for design earthquake, a conservative 5% modal damping value was applied in the analysis.

The CRC was analyzed for three conditions: lifting a future 150 ton transportation cask and 10,000 pound lifting device on the hook; lifting the 35 ton DOE transfer cask and lifting device on the hook, and no load on the hook. Both hook up and hook down positions were analyzed. The vertical frequency of the fixed trolley with the proposed transportation cask and lifting device on hook is close to the frequency region of the 5% damped response spectrum peak acceleration. Thus, the hook up and hook down positions with the proposed repository transportation cask and lifting device on hook are the controlling design conditions.

Slack Rope Condition

Slack rope conditions were examined by comparing the static deflection with the dynamic upward displacement at the hook location as shown in the following:

Hook Position	Static Deflection (in)	Seismic Upward Displacement (in)
Hook Up	0.33	0.20

Hook Down	0.91	0.38

Since the seismic displacements are less than the static deflection, there is no slack rope condition under seismic events in either the hook up or hook down position.

Member Design

Member design was based on CMAA 70. Load case 1 was conservatively increased to 1.15(DL+LL) to simplify the analysis. The acceptance criteria for this load case per CMAA 70 is Stress Level 1. Load case 3.2 was conservatively increased 1.25(DL+LL) to simplify the analysis, and Stress Level 1 instead of Stress Level 3 was conservatively applied to this load case. The acceptance criteria for the load case 3.1 (DL+LL+DE) was 1.5 times the CMAA 70 Stress Level 1.

Summary of Results

A summary of results is presented in Table 4.7-25, in the form of stress ratios for shear and interaction ratios for combined axial force and bending for the primary members in the load path under the governing load cases. The design is shown to be in compliance with CMAA 70 for all load combinations as defined above under bounding loading conditions. Since this SAR is only licensing the CRC for lifting the DOE transfer cask, which is lighter by a factor of approximately 5, significant additional margins are available for all members.

4.7.3.3.5 Cask Trolley

Design Bases

The design of the cask trolley considered the following conditions:

- **Tornado** – While the cask trolley is inside the CRA, the SNF is protected by the DOE transfer cask. When the cask trolley is inside the Transfer Tunnel, the cask lid bolts and lid will be removed. The outer door of the Transfer Tunnel will be closed during this evolution, thereby protecting the cask trolley and transfer cask from the effects of the design basis tornado. The outer Transfer Tunnel door is designed to withstand tornado missiles, wind, and differential pressure. Therefore, the cask trolley was not specifically designed for tornado wind or missiles.
- **Earthquake** – The cask trolley was designed for seismic loads using an equivalent static method as described in Section 3.2.3.2.1. The cask trolley and supporting rails are designed to resist the design earthquake. The acceptance criteria for the cask trolley is to remain locked in position during and following a seismic event while the cask trolley is parked at the cask port below the FPA inside the Transfer Tunnel. The cask trolley is also designed to remain on its rails during and following a seismic event at any intermediate position during travel between transfer locations. The cask trolley control system is de-energized during and following a seismic event by activation of the seismic switch and fail safe on loss of electrical supply.
- **Fire or Explosion** – The cask trolley meets the requirements of NFPA-70, *National Electric Code* to minimize the likelihood and effect of fires, which might occur from faulty electrical cabling and equipment. Credible fires or explosions in the CRA or Transfer Tunnel that may have an adverse effect on the cask trolley are discussed in Section 4.3.8.

- **Flood** – The lower section of the cask trolley may be subject to flooding. However, the cask trolley supports the bottom of the DOE transfer cask approximately 8 feet above the floor of the Transfer Tunnel. Because the maximum flood elevation is also approximately 8 feet above the Transfer Tunnel floor, only the very bottom of the DOE transfer cask would be submerged. The top of the cask would be significantly above the flood elevation, precluding water from entering the cask even if the lid of the cask were removed. Submerging the lower portion of the cask trolley could result in failure of the drive motor, however, the load would be securely supported. Based on the nature of the design basis flood and the site location, dynamic forces due to wave action or moving water were not included in the design of the cask trolley.
- **Lightning** – The cask trolley is located inside the CRA or transfer tunnel and therefore is not subjected to direct lightning strikes. These structures are designed with lightning arrestors.
- **Shielding Considerations** – The cask trolley transports shielded DOE transfer casks and does not have additional shielding. The stainless steel cask adapter that is installed on top of the transfer cask provides supplemental shielding during SNF removal from the cask.
- **Temperature Effects** – The cask trolley is designed to operate within a temperature range of 32°F to 105°F. The cask trolley will not be used to transfer SNF if the temperature is outside this range. The minimum and maximum off-normal temperature conditions could occur when the cask trolley is in the CRA. The minimum and maximum off-normal temperature in the CRA is -26°F, and 149°F. The minimum temperature of -26°F may occur if the heating system in the cask receipt building fails to operate when the outside ambient temperature is extremely low. The higher off-normal maximum temperature is due to the heat contributions of the lighting and equipment inside the CRA assuming the ventilation system failed. In the unlikely event that these conditions occur, lighting and equipment would be secured and cask-handling operations would be stopped well before these limits are approached.
- **Retrieval Considerations** – The cask trolley is designed to house the self-shielded DOE transfer cask. The shielding on this cask permits entrance into the Transfer Tunnel for recovery/repair of the cask trolley during normal retrieval situations when the cask lid is still in place on the cask. Off-normal retrieval situations occur when SNF is being transferred into the FPA and a trolley failure occurs (wheel, axle or motor failure). In this condition, the SNF must be moved into the FPA or lowered back into the cask and the cask lid replaced. With the SNF in the FPA or cask, the cask trolley can be manually recovered.
- **Decontamination Considerations** – Paint on the cask trolley meets the requirements of ASTM D 4082, *Standard Test Method for Effects of Gamma Radiation on Coatings for Use in Light Water Nuclear Power Plants* for radiation resistance and is decontaminable.
- **Protective Coatings** – The cask trolley coating is Service Level II in accordance with ASTM D5144-00, *Standard Guide for Use of Protective Coating Standards in Nuclear Power Plants* At a minimum, the coating consists of two finish coats of epoxy paint over a single coat of primer.

Design Loads

The following loads were included in the design of the cask trolley:

Loads	Term	Description of Load
Trolley Loads	TL	Includes cask trolley weight and fixed equipment supported by the trolley. TL = 42 Kips
Lifted Load	LL	Working load includes weight of cask assembly and internals. LL = 68 Kips
Inertia Force from Drives	IFD	0.025(TL+LL)
Dead Load Factor	DLF	1.1
Hoist Load Factor	HLF	0.15
Force due to skewing	SK	0.05(TL+LL)
Collision Force	CF	Per CMAA70 3.3.2.1.3.2
Test Load	--	Static not to exceed 125 percent of the cask load on cask trolley in a fixed position. Dynamic 100 percent of cask load on cask trolley moving at speeds and motions that the system is designed for.
Axle or Wheel Break	AWB	Maximum 1" drop
Seismic Load	DE	See Below
Flood Load	FL	Uplift of the cask due to hydrostatic loading

Additional off-normal loading conditions were evaluated as follows:

- 1 inch drop due to an axle break will not cause the cask and cask trolley to tip over
- cask trolley breakdown due to bearing seizure, drive failure, overload, distortion, and/or corrosion
- cask trolley stoppage due to overload, corrosion, misalignment, or structural failure of the rails
- the CRC lowers a cask onto the cask trolley at maximum main hoisting speed
- suspended cask impacted laterally by the cask trolley as it is traveling at creep speed under the CRC
- cask trolley, with a full cask in position, impacts an adjacent structure while traveling at the maximum travel speed

For analysis, the cask trolley is considered equivalent to a service Class D (Heavy), load Class L4 device as defined by CMAA-70.

Cask Trolley Load Combinations

The following load combinations were included in the design of the cask trolley:

Load Case	Description	Terms
1	Trolley in regular use under principal loading	1.1 (TL) + 1.15 (LL) + IFD
2	Trolley in regular use under principal and additional loading	1.1 (TL) + 1.15 (LL) + IFD + SK
3	Extraordinary loads	See 3.1 to 3.6 below
3.1	Trolley in collision	TL + LL + CF
3.2	Loaded trolley in locked position and subjected to Flood Load	TL+ LL + FL
3.3	Loaded trolley with axle or wheel break	TL+ LL+AWB
3.4	Loaded trolley with design earthquake	TL + LL + IFD + SK + DE
3.5	Static test load, 125 percent of the cask load on cask trolley in a fixed position	TL + 1.25 (LL)
3.6	Dynamic test load, 100 percent of the cask load on cask trolley moving at speeds and motions for which the system is designed	1.1(TL) + LL + IFD + SK

Structural Analysis

The cask trolley is design as a metal frame on top of trolley trucks mounted on four rail wheels. The structure consists of continuous vertical members, horizontal framing members forming three platform levels, and bracing members in vertical and horizontal planes. The mathematical model used in the static analysis is shown in Figure 4.7-75.

Boundary conditions at the base of the trolley consist of the following:

- Hold-downs resist vertical uplift (tension) loads, and lateral loads in the longitudinal direction (parallel to the rails). Hold-downs can resist lateral loads only when they are engaged in tension.
- Wheels resist vertical downward (compression) loads, and lateral loads as listed below. Wheels can only resist lateral loads when they are in contact (compression) with the rails.
- The locking pin, when engaged, can only resist loads in the longitudinal direction (parallel to the rails).
- If the design earthquake event occurs when the trolley is not locked into position, the trolley will potentially slide longitudinally (parallel to the rails) before the maximum seismic force is otherwise obtained. The seismic load for this case, in the longitudinal direction, is limited to the inertia force caused by friction between the trolley wheels and the rails. Restraint conditions are summarized below:

Restraint Condition

Translation				Rotation		
Node	X (across rail)	Y (along rail)	Z (vertical)	Theta X	Theta Y	Theta Z
A (front right wheel)	Fixed	Fixed	Fixed	All nodes are considered free to rotate		
B (back right wheel)	Fixed	Free	Fixed			
C (front left wheel)	Free	Fixed	Fixed			
D (back right wheel)	Free	Free	Fixed			

Trolley vertical and lateral loads are represented by 12 node loads, one at each corner of each platform level. The cask weight is applied as a concentrated load at the cask support floor level. The vertical cask seismic load is an equivalent concentrated load applied at either the top or bottom of the cask depending upon the direction of seismic motion. Lateral cask seismic loads are modeled as two concentrated loads applied at the top and bottom of the cask. Load cases are analyzed using RISA3D.

A linear elastic, equivalent static method is used for seismic analysis. Equivalent static seismic forces are calculated by multiplying the weight of the trolley and lifted loads by a factor of 1.5 and by using the design response spectra acceleration maxima for 4 percent critical damping. Results obtained by this method are conservative, compared to the dynamic response spectra method, for which each acceleration peak is reached at a different frequency. The equivalent static method is based on the simplification that the trolley behaves as a rigid unit and that its peak acceleration is the maxima of the input spectra. With such simplification 100 percent of the mass is subject to the peak spectral acceleration. Loading conditions are summarized below:

Cask Trolley Loading Conditions

Loading Conditions	Structural Response
Static Load Cases	
Cask Load and Trolley Load	SR1
Dynamic Load Cases	
Horizontal direction earthquake	
Traverse to rails	SR3
Longitudinal to rails	SR4
Vertical direction earthquake	
Cask Load on Cask Trolley	SR6

Structural responses are analyzed for each direction of the seismic force:

- Perpendicular (transverse) to rails: SR3+ and SR3-
- Parallel (longitudinal) to rails: SR4+ and SR4-
- Vertical: SR6+(up) and SR6-(down)

Maximum values of structural response of the three- directional components of earthquake motion added with the static load response are given by:

- $SR22 = SR_1 + (SR_3^2 + SR_4^2 + SR_6^2)^{1/2}$

Structural response combinations SR22+ and SR22- are calculated for restraint reactions, member forces and nodal displacements (at the top level only).

- Two combinations (SR22+ and SR22-) are used to combine only the structural responses that create internal forces/displacements with the same sign/direction.
- After the internal forces are computed, the maxima of the absolute values are used to calculate member stresses, except that SR22- for axial forces is used for the design tension force, and SR22+ is used for the design compression force for a particular member. Taking the maximum of the absolute values of bending and shear for SR22+ and SR22- generates an envelope of member forces.

The trolley model is analyzed for two cases:

- When the locking pin is engaged
- When the trolley is free to move along the length of the rail (this case does not control the design of the trolley members)

Summary of Results

Member stresses and unity checks for shear, bending, axial tension and axial compression were calculated. An envelope of member forces was generated by taking the maximum of the absolute values of the design parameters for the load combinations for a particular case. The Load Case 3.4 stresses (loaded trolley with design earthquake) control for the design of the members.

Members subject to combined axial compression and bending are proportioned to satisfy the interaction requirements in the form of unity checks given in CMAA 70, Section 3.4.6.3. Direct comparison of individual stresses with allowable stresses is not applicable under the combined stress condition. To maintain uniformity of the summary of results, only the final unity check results (ratios) are provided for all stress conditions.

Table 4.7-26 provides a summary of the analysis results of the cask trolley including unity checks for representative trolley members in the load path under the governing load case. The design is found to be compliant with code requirements.

4.7.3.3.6 Canister Trolley

Design Bases

The design of the canister trolley considered the following conditions:

- **Tornado** – The canister trolley operates within the Transfer Tunnel. The Transfer Tunnel and outer door of the Transfer Tunnel are designed to withstand tornado missiles, wind, and differential pressure. Therefore, the canister trolley will not be subjected to tornado related loads.

- **Earthquake** – The canister trolley is designed for seismic loads using an equivalent static method as described in Section 3.2.3.2.1. The canister trolley is designed to withstand the design earthquake and to prevent uncontrolled movement or tip-over of the canister and canister cask. Seismic restraints are provided on the trolley to prevent derailment. The canister trolley is designed to remain locked in position during and following a seismic event when the canister trolley is parked at each SNF transfer location (e.g., canister port and Storage Area load/unload port) as well as the CCA port to preclude potential damage to the SNF of the ISF canister. The canister trolley control system is de-energized during and following a seismic event, and will fail safe on loss of electrical supply.

- **Fire or Explosion** – The canister trolley meets the requirements of NFPA-70, *National Electric Code* to protect it from the likelihood and effect of fires that might occur from faulty electrical equipment. The canister trolley operates inside the Transfer Tunnel. A fire hazards analysis was performed to evaluate potential fires that could affect SNF handling operations using the canister trolley. Credible fires or explosions in the Transfer Tunnel that may have an adverse effect on the canister trolley are discussed in Section 4.3.8.

- **Flood** – The lower section of the canister trolley may be subject to flooding. However, the canister trolley supports the bottom of the canister cask approximately 8 feet above the floor of the Transfer Tunnel. Because the maximum flood elevation is also approximately 8 feet above the Transfer Tunnel floor, only the very bottom of the canister cask would be submerged. Since the lower portion of the canister cask is water tight and the top of the canister cask is significantly above flood elevation, the SNF is protected from flood water entering the open ISF canister. Submerging the lower portion of the canister trolley could result in failure of the drive motor; however, the ISF canister would be securely supported. Based on the nature of the design basis flood and the site location, dynamic forces due to wave action or moving water were not considered in the design of the canister trolley.

- **Lightning** – The canister trolley operates inside the Transfer Tunnel and will not be subject to direct lightning strikes.

- **Shielding Considerations** – The shielding cask of the canister trolley is provided to minimize operator exposure during canister closure operations and canister trolley recovery and maintenance activities inside the Transfer Tunnel. The canister trolley has three primary operating positions; CCA port, ISF canister port (below the FPA), and Storage Area load/unload port. At each of these positions the on-board jacking system will jack the nose of the shielded cask into a recess below the floor of each of the operational area. This alleviates the radiation streaming that would occur if the SNF transfers were done in an unshielded position. The wall thickness of the canister cask is approximately 11 inches of steel. The trolley shielding is designed to reduce maximum exterior exposure rates to less than 25 mR/hr for recovery/repair operations. ITS components located on the canister trolley or which may come into close proximity to the cask are either radiation tolerant or provided with suitable shielding to ensure adequate reliability of the canister trolley and the control system.

- **Retrieval Considerations** – The canister trolley is an assembly of two major subassemblies, the trolley and the shielded cask (cask) (see section 4.7.3.2.2 for a more detailed description). The cask provides a shielded housing for the ISF canisters. The shielding is designed to allow operator access to the canister trolley when a SNF loaded canister is inside the cask, therefore allowing manual recovery during normal retrieval operations. The off-normal situation postulated is a trolley failure (wheel, axle, or motor failure) during SNF transfer. The design intent for this off normal retrieval condition is manual intervention to repair the failed component. This is viable because the potential drop of the canister trolley is limited by pads at the wheels and by the seismic rail restraints. These features will ensure that the 'nose' of the canister will remain within the shielding provided by the recess in the floor of each of the operational areas.

- **Decontamination Considerations** – Paint meets the requirements of ASTM D 4082, *Standard Test Method for Effects of Gamma Radiation on Coatings for Use in Light Water Nuclear Power Plants* for radiation resistance and is decontaminable.
- **Protective Coatings** – The canister trolley coating is Service Level II in accordance with ASTM D5144-00, *Standard Guide for Use of Protective Coating Standards in Nuclear Power Plants.* At a minimum, the coating consists of two finish coats of epoxy paint over a single coat of primer.

Design Loads

The following loads were included in the design of the canister trolley:

Canister Trolley Design Loads

Loads	Term	Description of Load
Trolley Loads	TL	Includes canister trolley weight and fixed equipment supported by the trolley. TL = 62 Kips
Lifted Load	LL	Working load includes weight of canister assembly and internals. LL = 86 Kips
Inertia Force from Drives	IFD	0.025(TL+LL)
Dead Load Factor	DLF	1.1
Hoist Load Factor	HLF	0.15
Force due to skewing	SK	0.05(TL+LL)
Collision Force	CF	Per CMAA70 3.3.2.1.3.2
Test Load	----	CMAA test load – 3.3.2.4.3.3 Static not to exceed 125 percent of the cask load on cask trolley in a fixed position. Dynamic 100 percent of cask load on cask trolley moving at speeds and motions that the system is designed for.
Axle or Wheel Break	AWB	Maximum 1" drop per CMAA 70 3.9.2
Seismic Load	DE	See below
Flood Load	FL	The design will prevent the uplift of the cask due to hydrostatic loading

- **Normal Loading Conditions** – The maximum total canister weight (canister plus contents) the canister trolley will carry is 10,000 lb. The FHM will lower a fully loaded fuel basket at normal hoist operating speed into the canister. The canister trolley is considered equivalent to the trolley for a Class D (Heavy Service) Crane in accordance with CMAA 70, Section 70-2 based on anticipated loadings and operational cycles.

- **Off-Normal Loading Conditions –** The canister trolley is designed to ensure that the failure of a single component will not result in the loss of capability of the canister jacking system to maintain the canister and canister cask in position. Manual recovery features are included in the design to ensure that a failed jacking system can safely lower a canister into the transfer position for recovery and replacement of the failed component. The canister trolley is designed with appropriate restraints to prevent movement or tip over of the canister cask and canister while on the canister trolley. Off-normal conditions considered in the design include:
  - canister trolley breakdown due to bearing seizure, drive failure, overload, distortion, and/or corrosion
  - canister trolley stoppage due to overload, corrosion, misalignment, or structural failure of the rails
  - potential damage to canister cask
  - FHM lowers a fully loaded fuel basket into the canister at maximum hoist speed from the fully raised condition
  - canister trolley, with a fully loaded canister in position, travels with the maximum travel speed and impacts an adjacent structure or equipment
  - axle or wheel break

Load Combinations

The following load combinations were used in the design of the canister trolley:

Canister Trolley Load Combinations

Load Case	Description	Terms
1	Trolley in regular use under principal loading	1.1 (TL) + 1.15 (LL) + IFD
2	Trolley in regular use under principal and additional loading	1.1 (TL) + 1.15 (LL) + IFD + SK
3	Extraordinary loads	See 3.1 to 3.6 below
3.1	Trolley in collision	TL + LL + CF
3.2	Loaded trolley in locked position and subjected to Flood Load	TL+ LL + FL
3.3	Loaded trolley with axle or wheel break	TL+LL+AWB
3.4	Loaded trolley with design earthquake	TL +LL + IFD + SK + DE
3.5	Static test load, 125 percent of the canister load on canister trolley in a fixed position	TL + 1.25 (LL)
3.6	Dynamic test load, 100 percent of the canister load on canister trolley moving at speeds and motions for which the system is designed	1.1(TL) + LL + IFD + SK

Structural Analysis

The canister trolley is a metal frame on top of trolley trucks mounted on four wheels. The structure consists of continuous vertical members, horizontal framing members forming three platform levels, and bracing members in vertical and horizontal planes. The mathematical model used in the static analysis is shown in Figure 4.7-76.

Boundary conditions at the base of the trolley consist of the following:

- Hold-downs resist vertical uplift (tension) loads, and lateral loads in the longitudinal direction (parallel to the rails). Hold-downs can resist lateral loads only when they are engaged in tension.
- Wheels resist vertical downward (compression) loads, and lateral loads as listed below. Wheels can only resist lateral loads when they are in contact (compression) with the rails.
- The locking pin, when engaged, can only resist loads in the longitudinal direction (parallel to the rails).
- If the design earthquake event occurs when the trolley is not locked into position, the trolley will potentially slide longitudinally (parallel to the rails) before the maximum seismic force is otherwise obtained. The seismic load for this case, in the longitudinal direction, is limited to the inertia force caused by friction between the trolley wheels and the rails.

The restraint conditions used for the canister trolley analysis are summarized below.

Restraint Condition

Translation				Rotation		
Node	X (across rail)	Y (along rail)	Z (vertical)	Theta X	Theta Y	Theta Z
A (front right wheel)	Fixed	Fixed	Fixed	All nodes are considered free to rotate		
B (back right wheel)	Fixed	Free	Fixed			
C (front left wheel)	Free	Fixed	Fixed			
D (back right wheel)	Free	Free	Fixed			

Trolley vertical and lateral loads are applied to the model as concentrated loads at the joints. Load cases are analyzed using RISA3D, a three-dimensional analysis program.

A linear elastic, equivalent static method was used for seismic analysis. Equivalent static seismic forces are calculated by multiplying the weight of the trolley and lifted loads by a factor of 1.5 and by using the design response spectra acceleration maxima for 4 percent critical damping. Results obtained by this method are conservative, compared to the dynamic response spectra method, for which each acceleration peak is reached at a different frequency. The equivalent static method is based on the simplification that the trolley behaves as a rigid unit and that its peak acceleration is the maxima of the input spectra. With such simplification 100 percent of the mass is subject to the peak spectral acceleration. Loading conditions are summarized below:

Canister Trolley Loading Conditions for Seismic Analysis

Loading Conditions	Structural Response
Static Load Cases	
Cask load and trolley load	SR_1
Dynamic Load Cases	
Horizontal direction earthquake	
Traverse to rails	SR_3
Longitudinal to rails	SR_4
Vertical direction earthquake	
Cask load on cask trolley	SR_6

Structural responses are analyzed for each direction of the seismic force:

- Perpendicular (transverse) to rails: SR_3+ and SR_3-
- Parallel (longitudinal) to rails: SR_4+ and SR_4-
- Vertical: SR_6+(up) and SR_6-(down)

Maximum values of structural response of the three- directional components of earthquake motion added with the static load response are given by:

- $SR_{22} = SR_1 + (SR3^2 + SR4^2 + SR6^2)^{1/2}$

Structural response combinations SR_{22}+ and SR_{22}- are calculated for restraint reactions, member forces and nodal displacements (at the top level only).

- Two combinations (SR_{22}+ and SR_{22}-) are used to combine only the structural responses that create internal forces/displacements with the same sign/direction.
- After the internal forces are computed, the maxima of the absolute values are used to calculate member stresses, except that SR_{22}- for axial forces is used for the design tension force, and SR_{22}+ is used for the design compression force for a particular member. Taking the maximum of the absolute values of bending and shear for SR_{22}+ and SR_{22}- generates an envelope of member forces.

The trolley model is analyzed for two cases:

- When the locking pin is engaged
- When the trolley is free to move along the length of the rail (this case does not control the design of the trolley members)

Summary of Results

Member stresses and unity checks for shear, bending, axial tension and axial compression were calculated. An envelope of member forces was generated by taking the maximum of the absolute values of the design parameters for the load combinations for a particular case. The Load Case 3.4 stresses loaded trolley with design earthquake) control for the design of all members.

Members subject to combined axial compression and bending are proportioned to satisfy the interaction requirements in the form of unity checks given in CMAA 70, Section 3.4.6.3. Direct comparison of individual stresses with allowable stresses is not applicable under the combined stress condition. To maintain uniformity of the summary of results, only the final unity check results (ratios) are provided for all stress conditions.

Table 4.7-27 provides a summary of the analysis results for the canister trolley, including unity checks for representative trolley members in the load path under the governing load case. The design is found to be compliant with code requirements.

4.7.3.3.7 Fuel Handling Machine

Design Bases

The design of the FHM considered the following conditions:

- **Tornado** – The FHM operates within the FPA, which has thick reinforced concrete walls and roof designed to withstand design basis tornado winds, differential pressure and missiles. The FPA shield windows have also been designed to withstand tornado wind and differential pressure, and have been evaluated to withstand tornado missile impact. Therefore, FHM was not designed for tornado loadings.
- **Earthquake** – The FHM and associated support structure and rails are designed to withstand seismic loads in both the unloaded and loaded conditions. The FHM bridge and trolley are fitted with seismic restraints, which capture the rails to resist vertical motion associated with uplift and horizontal motion associated with cross rail horizontal sliding and to prevent the bridge and trolley from leaving their respective rails. Brakes inhibit movement of the bridge and trolley along their respective rails. The FHM bridge, trolley, hoist, and lifting devices will remain in position and continue to support the critical load during and after a seismic event. The FHM control system will be de-energized by the seismic switch during and following a seismic event and will fail safe on loss of electrical supply.
- **Fire or Explosion** – The FHM system is designed to meet the requirements of the National Fire Protection Association NFPA-70, *National Electric Code* to minimize the likelihood and effect of any fires which might occur from faulty electrical equipment. The FHM operates inside the FPA and the FHM Maintenance Area. These areas have smoke detectors and limited quantities of combustible materials. A fire hazards analysis was performed to evaluate fires that could occur inside the FPA due to lubricants associated with the FHM. Credible fires or explosions in the FPA that may have an adverse effect on the FHM or SNF handling operations are discussed in Section 4.3.8.
- **Flood** – This event would not affect the FHM since it operates on rails well above the PMF. Therefore, the FHM design does not consider flood loading or submergence.
- **Lightning** – The FHM is located inside of the FPA, which is provided with a lightning arrestor system designed in accordance with NFPA 780, *Lightning Protection Code.* In addition the FHM is also grounded in accordance with electrical design requirements. The FHM is not subjected to direct lightning strikes.

- **Shielding Considerations** – The FHM does not provide a shielding function. The FHM operates in an extremely high radiation field and was designed to withstand these levels of radiation over the life of the facility.
- **Temperature Effects** – Normal temperature conditions in the FPA are between 50°F and 90°F. The minimum and maximum off-normal temperature inside the FPA is -26°F and 156°F respectively. The crane will not be operated when FPA temperatures are below 32°F or above 156°F.
- **Retrieval Considerations** – The FHM is designed to be retrievable. Individual motors and reducers power each of the four bridge wheels. For bridge retrieval it is assumed that one of the wheels is locked and skidding against the runway rail. The remaining three motors are capable of moving the FHM and this activity does not exceed CMAA 70 allowable stress levels.
- **Decontamination Considerations** – The paint on the FHM meets the requirements of ASTM D 4082, *Standard Test Method for Effects of Gamma Radiation on Coatings for Use in Light Water Nuclear Power Plants* for radiation resistance.
- **Protective Coatings** – The FHM coatings are Service Level II in accordance with ASTM D5144-00, *Standard Guide for Use of Protective Coating Standards in Nuclear Power Plants.* At a minimum, the coating consists of two finish coats of epoxy paint over a single coat of primer.

Design Loads

The following loads were included in the design of the FHM.

FHM Design Loads

Loads	Term	Description of Load
Dead Loads	DL	Includes the weight of effective parts of the bridge structure, the machinery parts, and the fixed equipment supported by the structure.
Trolley Loads	TL	Includes trolley weight and equipment attached to the trolley
Lifted Load	LL	Lifted Load (LL): Working load and the weight of the lifting devices used for handling and holding the working load such as the load block, lifting beam, and other supplemental devices. This is also the maximum critical load (MCL) and the design rated load (DRL).
Inertia Force from Drives	IFD	0.025(TL+LL); 2.5% of the vertical load applied to the lateral load. These loads are applied to the FHM in both longitudinal and transverse directions based on the mass distribution of the bridge and trolley.
Dead Load Factor	DLF	1.1
Hoist Load Factor	HLF	0.15
Skewing Loads	SK	0.05(TL+LL); Taken from the CMAA chart, 5% of the vertical load is applied to wheels on one end truck of both the bridge and trolley as the skewing force.
Collision Force	CF	The force generated during impact with an end stop at 40% of the rated speed.

FHM Design Loads

Loads	Term	Description of Load
Recovery Load	LAR	Loads associated with the recovery of the bridge upon failure of one motor. This load is defined as the skidding of one wheel while driving with only three wheels.
Test Load	----	125 percent of rated load
Axle or Wheel Break	AWB	Loads associated with the impact of the bridge or trolley on the rails after the failure of a wheel or axle.
Seismic Load	DE	Loads associated with the design earthquake.

- **Normal Loading Conditions** – The FHM hoist is used to lift and move the various SNF types and a variety of other components within the FPA. The Maximum Critical Load (MCL) rating is established at 10,000 pounds.
- **Off-Normal Loading Conditions** – The FHM is designed to ensure that off-normal conditions associated with maximum or minimum analyzed ambient temperature excursions will not result in a loss of function.
- **Special Loading Conditions** – A load cell is provided on the FHM hoist. The load cell is designed to accommodate a minimum of 125 percent of the MCL static load test. The load cell is used to prevent the hoist overloading by an interlock that trips the hoist if the MCL is exceeded and is also used to weigh a ISF canister basket assemblies loaded with SNF before it is set into the ISF canister.

Load Combinations

The following load combinations were used in the design of the FHM.

FHM Load Combinations

Load Case	Description	Terms
1	Crane in normal service under principal loading	1.1(DL) + 1.1(TL) + 1.15(LL) + IFD
2	Crane in regular use under principal and additional loading	1.1(DL) + 1.1(TL) + 1.15(LL) + IFD + SK
3	Extraordinary loads	See 3.1 to 3.6 below
3.1	Crane in collision	DL + TL + LL + CF
3.2	Loaded crane with axle or wheel break	DL + TL+ LL + AWB
3.3	Loaded crane with design earthquake	DL + TL + LL + IFD + SK + DE
3.4	Static load test 125% of live load with FHM in fixed position	DL + TL + 1.25(LL)
3.5	Dynamic test load	1.1(DL) + 1.1(TL) + LL + IFD + SK
3.6	Loaded crane subjected to loads associated with recovery	DL + TL + LL + LAR

Structural Analysis

A finite element model was used for the static load conditions and the modal seismic analysis. The finite element analysis provides forces and moments at the various connections in addition to member loads and stresses. Stresses are calculated on each member and each end connection.

Analysis was performed with the trolley at the mid-span and end of travel positions. The highest bridge beam stress will occur with the trolley at mid-span and the highest wheel and end truck loading will occur with the trolley at end of travel. The trolley located at the ¼ span location is enveloped by the mid and end trolley positions.

The live load includes the PMS and main hoist maximum capacities, treated as point loads at their respective positions. The main hoist frame was treated as a distributed load across the trolley. The PMS mast was treated as a lumped mass on the carriage. The bridge beams and end trucks were distributed loads. The trolley drive, trolley wheels, bridge drives and other components were lumped masses at their center of gravity locations.

The 2.5 percent acceleration was applied to the centers of gravity except the main hoist live load as a lateral load. The 2.5 percent acceleration factor is applied to the PMS carriage and arm in two directions to simulate bridge and trolley accelerations.

Lateral guide rollers are used to limit skewing on the bridge end trucks. Forces will act through these rollers rather than through the wheels. An additional 5 percent of the live and dead trolley loads including the main hoist load were applied to both bridge guide rollers on one end truck in opposite directions to simulate skewing. An additional 5 percent of the live and dead trolley loads including the main hoist load were applied to both trolley guide rollers.

The finite element model provides beam stresses and loading at the major connections. The stresses in brackets, connections, bolts, wheel axles etc, were manually calculated from the connection loads. The main hoist components were manually analyzed. Connections in the load path are classified ITS.

The manipulator arm, mast and hoist were modeled only to input their weights and centers of gravity. The manipulator hoist supports the load by a wire rope and the mast provides only lateral guidance. In this case the hoist, hoist mounting and wire rope were manually analyzed for the vertical loading. The 2.5 percent lateral load on the mast is manually analyzed. The mast connection to the trolley loading was included in the finite element model to apply reaction loads on the trolley.

Finite Element Model

A detailed finite element model of the FHM included major components of the bridge and trolley structures. The steel tubes used for the main beams and end trunks were modeled with plate elements. Non-structural portions were modeled with stiff elements and concentrated masses. Details of the model are discussed in the following paragraphs.

Finite Element Program. The finite element program used for the analysis of the FHM was COSMOS/M. The program was written for linear and non-linear analysis of complex structures.

COSMOS/M has comprehensive modeling tools, graphics for pre and post-processing information. Numerical results can be combined for each load case and output for further post-processing and comparison to allowable design stresses.

Bridge Model. The bridge portion of the FHM, presented in Figure 4.7-77, was composed of approximately 3700 elements. The steel tube sections for the main beams and end trucks were modeled using thick-shell elements (SHELL4T). Each element was approximately 4"x 4" and used the thickness of the tube or plate for that portion of the structure. The SHELL4T element was a 4-node quadrilateral thick shell element with membrane and bending capabilities. Six degrees of freedom for each node (three translation and three rotation) were considered in the analysis. The model also included endplates on the beams, plates in the wheel assemblies and the bridge rails.

The connections between the beams, end trucks and wheel assemblies included some beam elements (BEAM3D) to aid in the design of the connection details. The BEAM3D elements were three dimensional beam elements with six degrees of freedom at each end. Motors, gearboxes wheels and axles were modeled with stiff beam elements and lumped masses to account for weights and geometry of these components. The lumped masses were modeled with MASS elements that allow concentrated mass and rotational inertia to be applied to a node.

Trolley Model. The trolley structure, presented in Figure 4.7-78, was modeled in the same way as the bridge. Approximately 2300 elements were used in the trolley. Thick shell elements were used for the steel tube sections and plates in the trolley structure. The plates in the wheel assemblies and connections were modeled with shell and beam elements.

Some of the components of the trolley were modeled in less detail than the main structural components. The 5-ton hoist was modeled with stiff 3-D beam elements to approximate the center of gravity of the hoist drums, shafts, hoist drives and brakes. The weights of each of these components were represented by mass components at the nodes. The hoist cable was modeled with a beam element that has the axial stiffness of the cable. The hook block and main hoist load were modeled as lumped mass elements.

The PMS mast and arm were included as 3-D beam elements. The section properties of the beam elements vary for each section of the telescoping mast. Lumped mass elements were included to account for the PMS load and the weights of some components. The connection of the PMS mast to the trolley structure was represented by stiff beam elements and the hoist weight is concentrated at a node using a mass element.

Boundary Conditions. Boundary conditions varied as required for the load conditions being considered. The finite element model had restraints at the contact surface of the wheels and cam followers as necessary to represent the supports of the structure. Member shear and rotational releases were located as required so that the model is not over constrained. Reaction forces at the boundary conditions were checked for each load condition and compared to the applied loads.

Static Analysis. The finite element model was analyzed for each of the static load cases using the static analysis features of COSMOS/M. The analysis results in displacements at each node and stresses in each element for the individual load conditions. Combined stresses for each load combination were analyzed and individual elements were checked against the allowable stresses for that condition.

Earthquake Analysis. The earthquake analysis of the FHM was completed by first solving the finite element model for frequencies and mode shapes. 40 modes were extracted. For the case with the trolley at midspan and the hoist under full loaded, frequencies ranged from 2.38 Hz to 60.15 Hz. The appropriate response spectrum curves were then applied and the resulting stresses were compared to the allowable stresses for each element.

Stress Evaluation. The principal stresses and maximum shear stress were computed along with the maximum stress by the CMAA method described in section 3.3.4.1 for the top and bottom fiber of each plate element. The maximum stress levels were then obtained for plate element in each plate element group by finding the maximum absolute stress value of the principal stresses, CMAA 3.3.4.1 or the sigma x-x or sigma y-y. Each element was also checked for shear.

Summary of Results

The maximum stress in the FHM is experienced in Case 3.6A, Bridge Recovery, Plate Shear Stresses with the trolley at end span. Allowable stresses in this condition are per CMAA 70 paragraph 3.4.3 Stress Level 3. Plate stress ratios for the FHM are below 1.0 and thus are acceptable. The summary of the calculated stresses for Case 3.6, Bridge Recovery, Plate Shear Stresses with the trolley at end span, are listed in Table 4.7-28. Additionally, the summary of the calculated stresses for Case 3.3, Loaded Crane with design earthquake, Plate Shear Stresses with the trolley at end span, are listed in Table 4.7-29. The maximum stress on the FHM is experienced in case 3.6A, and Case 3.3 is shown for comparison. The design is found to be compliant with code requirements.

4.7.3.3.8 Canister Handling Machine

Design Bases

The design of the CHM, and the Storage Area interfaces incorporate engineered features and safety provisions that address the following conditions:

- **Tornado** – The CHM is design to withstand the effects of tornado winds and differential pressure. The tornado wind and differential pressure is evaluated in combination with other loads. Credit is taken for the seismic restraints for holding the CHM in position on the rails. The connections holding the CHM shielding have been evaluated to ensure that there is no significant loss of shielding due to tornado wind loads. Loss of the supplemental Jabroc shielding is considered permissible under accident tornado wind conditions, as the radiation dose rate from neutron radiation does not significantly contribute to the overall dose rate.

  Although it is likely that the CHM would withstand the effects of tornado missiles, tornado missile loads have not been explicitly incorporated into the design of the CHM hoist and control systems. The combined probability of a tornado occurring of sufficient strength to generate tornado missiles at the same time the CHM is handling an ISF canister is estimated to be $< 10^{-7}$ events/year and is therefore not considered credible at the ISF Facility. Chapter 8 provides additional information regarding tornado events at the ISF Facility.

- **Earthquake** – The CHM is designed to withstand the effects of the design earthquake. The seismic design of the CHM provides the bounding structural design basis for the CHM. The CHM is seismically designed to prevent failure during the design earthquake, and to prevent damage to an ISF canister should the earthquake occur during handling operations. The CHM is also designed to ensure that deflections that may occur during an earthquake will not result in impact to the charge face of the storage vault.

The girders, trolley and turret are designed to limit the horizontal seismic deflections of the turret nose unit so that the turret nose unit cannot trap an ISF canister when it is being inserted into the storage tube or the load/unload port. The vertical seismic displacement of the nose of the CHM relative to the charge face is designed to limit deflections to prevent the CHM turret/cask assembly from imparting a load on the charge face during the seismic event. While the shield skirt rests on the charge face during canister transfer, the suspension is designed to prevent transmitting CHM loads to the charge face, and to prevent the skirt from hammering the charge face during the seismic event.

The seismic switch will de-energize the CHM during an earthquake. De-energizing the CHM will ensure that it remains in a known safe state during and after a design earthquake. The seismic switch does not automatically reset. Interlocks and safety features on the CHM do not require electrical power to maintain the CHM in a safe state. De-energizing the CHM either during normal operation or as a result of a seismic trip results in seismic clamps engaging and clamping the rails to prevent bridge and trolley movement. The rail clamps are used to react to "along the rail" loads while wheel flanges and claws are used to react to "across the rail" and vertical loads, respectively.

- **Fire or Explosion** – Noncombustible and heat resistant materials are used wherever practical throughout the CHM design. The Jabroc neutron shielding that surrounds the CHM is highly fire retardant and therefore poses a low fire risk. The CHM meets the requirements of NFPA-70, *National Electric Code*, to minimize the likelihood and effect of fires which might occur from faulty electrical equipment. De-energizing the CHM in the event of a fire incident will result in the seismic clamps engaging and clamping the rails to prevent bridge and trolley movement, the canister hoist brakes will engage and hold the canister. Interlocks and safety features on the CHM do not require electrical power to maintain the CHM in a safe state. Credible fires or explosions in the Storage Area that may have an adverse effect on the CHM or SNF transfer operations are discussed in Section 4.3.8.

- **Flood** – The CHM is mounted on rails in the Storage Area building, above the charge face of the storage vault. Charge face elevation is significantly higher than the PMF elevation, therefore the CHM could not be flooded and flood loads or submergence is not considered in the design of the CHM.

- **Lightning** – The CHM is located inside of the Storage Area Building, which is provided with a lightning arrestor system designed in accordance with NFPA 780, *Lightning Protection Code.* The CHM will not be subject to direct lightning strikes.

- **Shielding Considerations** – Because the CHM is controlled by an operator located on the trolley, the CHM is designed to ensure dose rates to the operator remain ALARA during canister handling operational phases. The main cask body contains the cavity for the ISF canister and provides radiation protection using carbon steel gamma shielding, clad with a layer of Jabroc to provide neutron shielding. The shield skirt and storage tube shield plug ensure streaming effects are minimized during cask/trolley orientations over the open fuel tube. The gamma shielding components are designed to remain intact during normal, off-normal and accident conditions, including seismic and tornado wind. Loss of the supplemental Jabroc shielding is considered permissible under accident tornado wind conditions, as the radiation dose rate from neutron radiation does not significantly contribute to the overall dose rate.

- **Temperature Effects** – The CHM is designed to operate in the normal and off-normal temperature range that occurs in the Storage Area building. Structural materials are selected for their ability to operate under normal, off-normal and accident conditions. Failure of the storage area heating system can result in temperatures below 32°F and possibly as low as the external temperature of -26°F in the Storage Area. This will be considered an accident condition. The CHM will not operated if the temperature in the Storage Area building is less than 32°F. The Storage Area building temperature would only reach this temperature if there is a failure of the heating system. Under low temperature conditions, i.e. less than 32°F, the CHM is placed in a dedicated parking position at the load/unload port until the temperature condition is corrected. Failure of the storage area ventilation system can result in ambient temperatures up to 154°F. The CHM shall not be operated at temperatures greater than 104°F.
- **Retrieval Considerations** – CHM retrieval design features are discussed in Section 4.7.3.2.13
- **Decontamination Considerations** – The CHM operates in a clean area and handles clean ISF canisters. It is not expected to become contaminated during normal operating conditions.

Design Loads

The following loads were included in the design of the CHM:

Loads	Term	Description of Load
Dead Loads	DL	Includes the weight of effective parts of the bridge structure, the machinery parts, and the fixed equipment supported by the structure.
Trolley Loads	TL	Includes trolley weight and the equipment attached to the trolley, including the total turret weight but excluding the ISF Canister Grapple weight and the ISF Canister weight.
Lifted Load	LL	Working load and the weight of the lifting devices used for handling and holding the working load, i.e. the weights of the ISF Canister Grapple and the ISF Canister
Inertia Force from Drives	IFD	0.025(TL+LL)
Dead Load Factor	DLF	1.1
Hoist Load Factor	HLF	0.15
Force due to skewing	SK	0.05(TL+LL)
Operating Wind Load	WLO	Specified as zero for the ISF Facility since CHM is inside the Storage Area Building
Stored Wind Load	WLS	Specified as zero for the ISF Facility since CHM is inside the Storage Area Building
Collision Force	CF	Per CMAA70 3.3.2.1.3.2
Test Load	----	CMAA test load not to exceed 125 percent of the rated load
Axle or Wheel Break	AWB	Maximum 1" drop per CMAA
Seismic Load	DBE	Load due to Design Earthquake

Loads	Term	Description of Load
Tornado Wind	TW	Load due to wind from the Design Basis Tornado
Tornado Differential Pressure	DP	Load due to differential pressure from wind of the Design Basis Tornado
Flood Load	FL	Zero for the CHM since it is above the flood plan elevation

Off-Normal Loading Conditions

The CHM was designed to include the following off-normal conditions:

CHM breakdown due to mechanical or electrical failure. The CHM is designed to permit manual operation of the drive systems to be able to recover from mechanical or electrical failures. In the event of loss of electrical supply, it is possible to hand-wind the canister hoist to lower the ISF canister into a storage tube to put the system into an overall safe condition.

CHM stoppage due to overload, corrosion, misalignment or structural failure of the rails. The CHM design incorporates features that prevent overloads from causing damage to drive systems. Motors are designed with overload fuses and thermal cut-outs.

Axle break. An axle break associated with the bridge or the trolley is considered in the structural evaluation of the CHM. Based on a 1 inch drop of the bridge or trolley, there is no damage caused to the ISF canister, and no excessive stresses in the CHM or rail system.

ISF canister drop. The CHM is designed with appropriate structures, mechanisms, restraints, and interlocks to prevent dropping or trapping the ISF canister during handling. The following design bases ensure high integrity lifting of the ISF canister:

- The ISF canister hoist is designed as a single failure proof hoist to CMAA 70 and NUREG 0554.
- The ISF canister grapple is designed as a high integrity grapple to ANSI N14.6 (using the higher factors of safety)
- The ISF canister grapple incorporates mechanical interlocks that prevent the grapple jaws from releasing its load, unless the weight of the load is supported. If the grapple jaw open actuator is inadvertently energized while carrying an ISF canister, the canister will not be released from the grapple.
- Guide features are designed into the canister handling route to ensure that there are no ledges or snag points that could cause the ISF canister to bind as it is being lowered into a storage tube. This design principle is also backed up by load cells on the canister hoist system that will detect an underload condition and stop the hoist from continuing to lower if the canister were to bind.

ISF canister shear. The CHM incorporates design features and control system interlocks that prevent a canister from being inadvertently sheared. A canister could be trapped or sheared if:

- The Turret was to try to rotate when the canister is lowered so that it is part way between the turret body and the fixed nose unit.

- The crane or trolley drives try to move the CHM when the canister is lowered so that it is part way between the nose unit and a storage tube or load/unload port.
- Lateral seismic deflections of the nose unit exceed the clearance around the canister while it is lowered so that it is part way between the nose unit and a storage tube or load/unload port.

Control system interlocks are used to prevent drives from operating unless the ISF canister is in a defined position where trapping cannot occur. This requires a control signal from the hoist to confirm that the grapple is fully raised before the turret rotate or crane drives can be permitted to operate.

One of the seismic design bases of the CHM is to limit the nose unit lateral deflection during a seismic event so that a partially inserted canister cannot be trapped. This drives the design of the main girders and is the reason why the girders are nearly as wide as they are deep. The lateral loads across the girders are very similar to the vertical loads due to the lateral seismic forces emanating from the turret mass.

Collision between the CHM and objects in its travel path on the charge face. An operator located on the trolley drives the CHM around the storage area charge face. In addition, a second operator located on the charge hall provides guidance and assistance with positioning the machine and ensuring that the CHM does not collide with any item that may have been left on the charge face. Good housekeeping is used to minimize the number of items that are left out on the charge face, but during storage tube preparation operations there will be occasions when equipment has to be moved onto charge face.

Collision between the bridge, trolley, or turntable and their end-of-travel bumpers. The CHM crane long travel, trolley cross travel, and turret rotate travel utilize end of travel bumpers that are designed to absorb the energy of the CHM if it were to run into the bumpers. These bumpers are not expected to be used, as limit switches are provided to stop the CHM from reaching the bumper position. However, in the event that the limit switch fails to provide the stop signal, then the bumpers will stop the CHM.

Load Combinations

The following load combinations were included in the design of the CHM:

Load Case	Description	Terms
1	Crane in regular use under principal loading	1.1 (DL) + 1.1 (TL) + 1.15 (LL) + IFD
2	Crane in regular use under principal and additional loading	1.1 (DL) +1.1 (TL) + 1.15 (LL) + IFD + WLO + SK
3	Extraordinary loads	See 3.1 to 3.8 below
3.1	Crane subjected to out of service wind load	DL + TL + WLS – Not required for CHM
3.2	Crane in collision	DL + TL + LL + CF
3.3	Loaded Crane with axle or wheel break	DL + TL + LL + AWB
3.4	Loaded Crane with Tornado Wind Load	DL + TL + LL + IFD + SK + TW
3.5	Loaded Crane with Differential Pressure from Tornado Wind	DL + TL + LL + IFD + SK + DP
3.6	Loaded Crane with Tornado Wind plus One-half Differential Pressure from Tornado Wind	DL + TL + LL + IFD + SK + TW + 0.5 (DP)
3.7	Static Test Load, 125 percent of the ISF Canister weight of 10000 lbs. Over the full	DL + TL + 1.25 (LL)

Load Case	Description	Terms
	range of hoist, bridge, trolley and turret positions	
3.8	Dynamic Test Load, 100 percent of the ISF Canister weight of 10000 lbs. Over the full range of hoist, bridge, trolley and turret positions moving at speeds and motions for which the system is designed	1.1 (DL) + 1.1 (TL) + LL + IFD + SK
4	Extreme Environmental Loads	See Below
4.1	Loaded Crane with Design Earthquake	DL + TL + LL + IFD + SK + DBE

Structural Analysis

The structural analysis of the CHM was performed to demonstrate compliance with the load and stress limit requirements of CMAA-70 and the additional requirements of NUREG-0554, NUREG-0612, ANSI N14.6 and NOG-1, as applicable to individual sub-assemblies and load cases.

The analysis can be categorized into four basic groupings dictated by the four different stress levels applicable to the different types of applied loading. These are as follows:

- Normal operating loads and stresses where the stress limits are dictated by the code permissible fatigue stress limits or other low stress limits in components not subject to fatigue. Stresses result from Load Case 1.
- Normal plus additional loads and stresses; the additional loads resulting from wheel flange friction from skewing of the bridge and trolley on their rails. Permissible stresses for these load cases are typically 10 percent higher than those for normal operating. Stresses result from Load Case 2.
- Extraordinary loads and stresses resulting from normal plus additional events such as collision with the trolley or bridge "end of travel" buffers, axle break or tornado wind effects. Permissible stresses for these load cases are typically 75% of the material tensile yield strength. Stresses result from Load Case 3.1 to 3.8.
- Seismic loads resulting from the design earthquake where permissible stresses are typically 90% of the material tensile yield strength. Stresses result from Load Case 4.1.

As both the applied loads and the permissible stress levels for each of the above four load cases vary, a governing "worst loading" case scenario is not evident and therefore a detailed analysis of each load case was performed and evaluated against its relevant permissible stresses.

Finite Element Model

An overall view of the CHM model with the trolley at mid-span is provided Figure 4.7-79. The quarter, mid and end of span models used in the analysis are identical structurally except for the relative trolley position. The finite element model is a beam/shell element representation of the machine.

Turret Assembly. Most of the rotating portion of the turret has been modeled as a beam along the central axis of the canister cavity using ANSYS BEAM4 elements. The mass of JABROC shielding, non-structural components and equipment have been included using the ADDMAS option on the real constant and using ANSYS MASS21 lumped mass elements.

Radial arms of rigid massless beams were used to connect the turret to the turntable. Nodes were included along the length of the turret beam model at positions corresponding to the bolted interfaces. The offset mass of the turret nose and lower castings have been modeled as single point masses using ANSYS MASS21 elements located at their centers of gravity and connected back to the beam representing the turret with a rigid massless link.

A connection between the rotating turret and to the non-rotating nose unit was made at the end of radial arms extending out to the radius of the base slewing ring. The nodes at the ends of both sets of radial arms are coincident and coupled together and are rotated into a cylindrical co-ordinate system, with Z vertical. This allows coupling in the radial and vertical directions at all nodes and tangentially at four equally spaced nodes to prevent rotation of the nose casting relative to the turret.

Point masses representing the various pieces of equipment mounted on the turret base were modeled at their estimated centers of gravity on the ends of rigid massless beams. The hoist drum and drive box was modeled using a 3-D shell representation as part of the hoist fabrication.

The retractable shield skirt assembly around the turret nose unit has been modeled as a lumped mass on the nose unit at its center of gravity. During operation it is lowered onto and raised from the charge face, hence, it has a relatively flexible attachment to the nose unit. When the canister is being transferred from the load/unload port or to a storage tube the skirt is in contact with the charge face. The seismic analyses have been performed with the skirt in this position. During the seismic event, the horizontal flexibility between the skirt and nose unit will allow horizontal movement of the turret, but the skirt will remain decoupled vertically. Hence, only the horizontal mass of the skirt is included in the seismic analysis.

The skirt suspension system provides vertical clearance so that the skirt does not hammer the charge face during an earthquake.

Turntable. Inner and outer rings of the turntable slew bearing and the radial arms connecting the two rings were modeled in ANSYS BEAM44 elements. The real constant ADDMAS option has been used to include the distributed mass of the floor plates. Connections between the outer ring and the trolley were made with short massless rigid arms constructed from BEAM4 elements and spaced uniformly around the ring. These arms represented the slewing ring connection between turntable and trolley. The two halves of each arm were coupled through coincident nodes at the bearing diameter. These nodes were rotated towards the turntable center of rotation, hence, the coupling in the vertical and radial directions. Four of the nodes were also coupled in a tangential direction to resist the rotational moment between turntable and trolley, which in practice would be resisted by a single location pin.

Trolley. The trolley has been modeled with ANSYS BEAM44, SHELL63 and MASS21 elements. The BEAM44 elements with offsets to bring the node line on a plane level with the top surface of the trolley. The SHELL63 elements have been used to model the trolley, deck and walkways. The MASS21 elements have been used to model more significant lump masses.

The real constant ADDMAS option has been used to include additional distributed loads due to floor plates, cubicles and other miscellaneous features not already modeled as part of the structure. More significant masses carried on the trolley such as the seismic restraints, wheels etc, were individually modeled as lumped masses.

The electrical panels on the trolley have been modeled as lumped masses at their center-of-gravity (CG) linked by rigid beam elements to the trolley. This is to allow the extraction of the acceleration of the CG to enable the design of the hold down bolts. It is assumed that the internals of the electrical cubicles will be designed and fabricated such that the components mounted inside these cubicles will be dynamically rigid, i.e., have resonant frequencies above the ZPA frequency.

The operator control console has been modeled with a single lumped mass at its CG and is attached back to the trolley deck by BEAM44 elements to four hold down bolt positions. The turret rotate festoon has been modeled with BEAM44 elements with the mass of the hangers and cables added as a non-structural mass using the real constant ADDMAS option.

Note that the seismic load path for base torsion is via the base locking pin assembly. The torsion links extending down from the trolley to prevent the turret base rotating, were not modeled as structural elements but their mass was included as single point masses attached to the trolley.

Pairs of coincident nodes were located at points where the trolley wheels and seismic restraints contact the trolley rails / brake rails and bridge beams. The trolley model was connected to one of each coincident node pair through constraint equations and short rigid beams to the nodal axis of the bridge beams. By including short rigid beams in the trolley half of the connections, their resulting element forces gave direct values of trolley wheel and seismic restraint loads.

Connections between coincident nodes were made in the X, Y or Z direction as appropriate with no rotational restraint applied. Note that in the analyses vertical Z connections between trolley and bridge were made through the trolley wheels and seismic rail claws.

Main Bridge Beams and End Carriages. Fabricated sections of the main bridge beams and end carriages were modeled in ANSYS BEAM44 and MASS21 elements. The node line for the main bridge beams was set at a height of approximately 15 feet from the bridge rails, with a rigid offset to the bolted joint with the end carriages. The properties of the bridge beams are offset from the modeled location, using the appropriate ANSYS input, to the correct neutral axis position of the cross section. The rigid offset to the end carriages allows the extraction of the force and moments acting on the bolted joints between bridge beams and end carriages.

Items such as trolley festoon, rails, rail bearers and stiffening diaphragms which added very little to the overall bending stiffness of the bridge beams, were included only for their mass contribution and were accounted for by using the ADDMAS option on the real constant.

The node line of the end carriages horizontal member has been set at the neutral axis of the section. The end carriages horizontal member is modeled offset by rigid links from the main bridge beams. The offset to the wheel assemblies is by beams representing the vertical leg of the end carriage and rigid links.

Connections to ground were made with vertical massless beams extending down from the top of the wheel assemblies. For the vertical Z connection the rigid beams were connected to the carriage nodal lines at positions corresponding to the 4 bridge wheel assemblies. No attempt has been made to model the wheel assembly, a single link was used to connect the nodal line down to a point where the bridge wheels made contact with the runway rails. The loads developed at the end of this single point termination will therefore represent the load acting on the bogie assembly pivot pin and not the load on each individual wheel. Single point MASS21 element have been attached to the vertical links to model the masses of the bridge wheel assemblies.

For the horizontal Y ground connection, rigid links were extended from the node line of each end carriage horizontal beams to pairs of Y-seismic restraints. The links were extended down to a level equivalent to the position of the runway rails. MASS21 elements were added to simulate the mass of each Y-seismic engagement mechanism.

Horizontal X ground connections were made through the same rigid links as the Z ground connection but at one end only. Connections to ground at the end carriages were made in the translational degrees of freedom; no rotational restraint has been applied.

Canister, Grapple and Hoist Ropes. The canister and grapple have been modeled as single point MASS21 elements. They are connected by rigid massless BEAM4 elements such that the center of gravity of the canister is at its fully raised height. These are suspended from an ANSYS COMBIN14 Spring element to represent the rope.

The spring stiffness of the rope element has been input for (a) fully raised position and (b) fully lowered position. The length of the spring element was set at approximately 79 inches for modeling convenience.

Two distinct analyses were performed, for each trolley position. The only difference between the two analyses is the spring stiffness of the rope element and the coupling of the grapple/canister mass to the turret. In the first analysis the spring stiffness is that of the hoist rope stiffness for the fully raised height. Each mass has been laterally coupled to the turret in the X and Y direction but free in the Z. In the second analysis the spring stiffness is that of the hoist rope stiffness for the fully lowered height, i.e., where the grapple is about to release the canister in the storage tube. In the fully lowered position, the coupling of the canister/grapple mass is effectively removed by setting the added mass in the X and Y directions to zero.

Total Mass. The total mass of the structure as modeled is 387.5 tons. However, the "effective total mass" varies for X, Y and Z directions as shown below:

Rope Position	Direction	Effective Mass (tons)	Comments
Raised	X	387.5	Actual total mass
	Y	387.5	
	Z	373.1	Shield skirt rests on charge face
Lowered	X	381.4	Payload, grapple and load block not effective horizontally
	Y	381.4	
	Z	373.1	Shield skirt rest on charge face

Analysis Methods

Load Case 1 - Normal Operating

- The static weight loads during regular use operation were enhanced in the vertical direction by the dynamic factors of CMAA-70, Section 3.3.2.1.1.4.
- The additional horizontal inertia loads induced by the trolley and bridge drive accelerations were obtained by applying horizontal accelerations to the ANSYS model used for the seismic analysis.
- Hand calculations were used as appropriate to calculate the fatigue stresses for the number of stress cycles corresponding to CMAA-70, Service Class 'D', and L4 Load Class.
- Calculated stresses were compared with permissible stresses from CMAA-70, Section 3.4.2 or CMAA-70, Section 4.11, as appropriate.
- The canister grapple was analyzed against the conservative stress limits of ANSI N14.6.

Load Case 2 - Normal Operating plus Skew Loads

- Skew loads were calculated in accordance with CMAA-70, Section 3.3.2.1.2.2 and added to the normal operating loads. Calculated stresses were then compared with the permissible values from CMAA-70, Section 3.4.2.

Load Case 3 - Extraordinary Loadings

The extraordinary loadings listed below were evaluated and the stresses were calculated for the greatest of these loadings and compared with the permissible values from CMAA-70, Section 3.4.3. The rules of 3.4.3 were also applied to mechanical components designed to CMAA-70, Section 70-4 under extraordinary loadings.

- Crane in collision with the "end of travel" bumpers. The deceleration rates from CMAA-70, Sections 4.14.1.2 and 4.14.5.2, were used as input for calculating the collision loads.
- The effects of a 1 inch drop following an axle break were analyzed and were applied as a dynamic multiplier to the normal vertical static loads.
- Static and dynamic test loads were considered but these were less than the generally governing axle break condition.
- Tornado wind loads were evaluated from the maximum wind speeds, air density and the drag coefficients of shapes in the wind path.
- Differential pressure from tornado wind was not included for the turret as the machine is open ended and the main body of the machine is greater than 12 inches thickness of steel.

Load Case 4.1 - Loaded Crane with Design Earthquake

A dynamic seismic modal analysis to ASME NOG-1-1998, Section NOG-4150, using the response spectrum method, was performed to establish the response of the CHM to the design earthquake. The analysis used as input the response spectra for x, y and z directions at the long travel rails level of the CHM bridge.

The primary sub-assemblies of the CHM comprise a turret assembly, a trolley assembly and a bridge assembly. The turret assembly is 38 feet tall and is comprised of bolted sub-assemblies around a payload suspended from a rope system. The turret is in turn bolted to a welded turntable that is fastened to the trolley via a large bolted slewing ring bearing. The trolley is a welded structure with bolted wheel assemblies and bolted seismic restraints, electric cubicles, an operator control desk and cable festoons.

The bridge is a welded box girder structure with bolted end trucks, wheel assemblies and seismic restraints. The magnitude of the design earthquake is such that additional sliding and frictional damping will be present at the clearances between the bridge rails and wheel flanges and between the trolley rails and wheel flanges. Therefore the damping values appropriate to a bolted structure from Regulatory Guide 1.61 are considered applicable to the overall assembly and a Response Spectrum of 7 percent of critical damping has been used in the seismic analysis. This is consistent with the damping value guidelines from NOG-4153-8.

The analysis was performed using 3-D finite element beam and shell models. The Grouping Method of mode combination was used in the analysis in accordance with NOG-4153-10(b)(1). The general-purpose finite-element program ANSYS was used for the analysis.

For the design earthquake, the permissible stresses are to be within the requirements of ASME NOG-1-1998, for Extreme Environmental Loading. The model loading conditions and the method of mode combination in the analyses conform to the requirements of NOG-4153. Stresses have been assessed to the requirement of NOG-4321, 4322 and 4324. Forces and moments at the joints and other interfaces were also tabulated to allow subsequent assessment of detailed mechanisms and bolted joints using hand calculations. Nose deflections were also tabulated to confirm that these were not large enough to trap a canister during its transit through the vault/machine interface.

Active seismic restraints are incorporated in the CHM that are engaged when the machine is in position over a vault storage tube or load/unload port. These are provided to ensure that in a seismic event there will be no significant movement between the machine and storage channel which could result in trapping or damage to a partially inserted canister or tube plug. The analyses were carried out with the seismic restraints engaged, representing the machine "locked" over a storage tube or load/unload port, i.e. bridge locked to its rails, trolley locked to its rails, turret rotationally locked to trolley and turret rotationally locked to the nose casing. If an earthquake occurs when the machine is not locked in position, the seismic trip accelerometers will cut the electrical supply to the machine and the long and cross travel seismic restraints will automatically engage and clamp to the rails.

Three trolley locations were considered in the analysis, in accordance with NOG-1, Table NOG-4153.7-1. These positions were interpreted so as to place the node center-line of the CHM over the nearest vault storage tube to the nominal location. The analysis considered the loaded grapple in both the fully raised and fully lowered positions. It was considered that the "no load on hook" case would give no additional information towards the overall assessment, for a machine where the lifted load is only 1.7% of the total mass of the machine, and was therefore not analyzed.

The objectives of the CHM seismic analysis were to:

- Calculate the maximum seismic stresses in the bridge, trolley, turntable and turret and show that they are below the allowable stresses;

- Calculate the maximum nose unit displacements, due to translation and rotation of the CHM, in order to be able to demonstrate that the canister will not lock-up between the turret and storage tube during transfer. Also to ensure that the clearance between the nose and charge face precludes the nose hammering the charge face during an earthquake;
- Calculate the reaction forces on the trolley and bridge wheels and seismic restraints for use in the design;
- Calculate the forces and moments on the nose unit and turntable bearings for use in the design of the base locking pin and turret locking pin mechanisms;
- Calculate the forces and moments in the cask body and plug hoist shielding bolted joints for use in the detail design;
- Calculate the forces and moments in the main bridge beam and end carriage bolted joints for use in the detail design;
- Calculate the forces and moments in the main bridge beam under the trolley; used to determine the local stresses in the main bridge beams top flange due to the trolley wheel loads;
- Calculate the maximum seismic stresses in the turret rotate festoon support structure.

The analysis produced separate lists of static loadings due to the 1g vertical static weights of the components for the three trolley positions. This was used as input for the normal operating load cases. Additional runs with 1g horizontal loadings were applied and scaled to produce the forces and moments induced by the bridge and trolley acceleration inertias and the buffer collision deceleration loads.

The plus/minus dynamic seismic loads were calculated separately and added or subtracted to the static loads to give the worst case loading, e.g. maximum bridge and trolley wheel loads were obtained by adding static plus seismic and maximum uplift at the wheels by subtracting static minus seismic. Calculated stresses were compared with the NOG-1 allowable stress limits and were less than the code permissible values.

The response spectrum analysis indicated a slack rope condition for the canister hoist. In accordance with the requirements of NOG-4154, a non-linear time history analysis of the rope system was performed. This yielded a peak rope load that was less than the bounding value of 4g (1g static + 3g seismic) which was used for the structural calculations.

Summary of Results

Table 4.7-30 provides a summary of the lowest factors of safety that are derived from the structural calculations for the main structural components. It is the seismic loading (Load Case 4.1) that generates the highest loads and stresses in the main structural components of the CHM.

Factor of safety is defined as the ratio of allowable stress extracted from the applicable code to the calculated stress. A value of 1.0 or above signifies that the component meets the structural code requirement. The design is found to be compliant with code requirements.

4.7.3.4 Criticality Evaluation for Spent Fuel Handling Operations

The general approach to evaluating the criticality safety of the SNF within the ISF Facility is to follow the fuel through the facility during each major operation.

The design criteria for nuclear criticality are provided in Section 3.3.4, *Nuclear Criticality Safety*. The basic requirements are 1) k_{eff} shall not exceed 0.95 for any in-process or storage fuel array under normal, off-normal, or accident conditions, and 2) spent fuel handling, packaging, transfer and storage systems must be designed to ensure that, before a nuclear criticality accident is possible, at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety.

The scope of this section is a description of 1) the criticality models, and 2) the criticality evaluations and results for fuel handling and packaging operations outside of the Storage Area. Additional information on criticality evaluations and operational controls for the ISF Facility are provided in:

- Appendix 4A to the SAR, *Criticality Models*
- Appendix A to the SAR, *Safety Evaluation of DOE-provided Transfer* Cask
- SAR Section 4.2.3.3.7, *Criticality Evaluation* [for storage operations]
- SAR Section 5.1.3.1, *Criticality Prevention*
- SAR Chapter 8, *Accident Analysis*

The criticality evaluations for the ISF Facility fall into one of three categories:

Evaluation of normal fuel handling sequences. Fuel configurations that are known to occur during routine fuel handling and packaging operations are analyzed to ensure that the planned geometry, separation, and material inventories will be safe during normal facility conditions.

Evaluation of off-normal and accident scenarios. Postulated off-normal and accident scenarios are evaluated to ensure that two unlikely, independent, and concurrent or sequential changes in geometry, separation, or material inventory are required before k_{eff} exceeds 0.95.

Evaluation of bounding cases. Due to the nature of fuel handling and packaging operations, it is impossible to postulate all potential combinations of geometry, separation, and material inventory. To ensure that the conditions that could lead to a criticality for ISF Facility operations are well understood, "bounding" cases have been developed to identify the combinations of geometry, material inventory, and reflection/moderation that are required to achieve $k_{eff} = 0.95$ at the ISF Facility. In some instances, these bounding cases are used to evaluate the consequences of accident or off-normal conditions.

As an example, two scenarios have been analyzed to understand the bounding conditions for loose material: "crushing" intact fuel elements into a uniformly homogenized mass, and the potential separation of U-235 from the fuel matrix.

- The first scenario (described in Section 3.2 of Appendix 4A to the SAR) is an attempt to bound the postulated accident event of the drop of a full DOE-transfer cask loaded with Peach Bottom fuel. Under the scenario described, the material from 14 Peach Bottom fuel elements homogenized, packed into a sphere, and reflected by graphite is required before k_{eff} approaches 0.95. These conditions cannot be achieved in the ISF Facility. A maximum of 18 Peach Bottom core 1 elements will be shipped to the ISF Facility in the DOE transfer cask; however, these elements are individually canned, and are overpacked in a transfer basket. If the cask (or transfer basket) is dropped during transfer, the basket and individual fuel element cans would provide the separation and geometry control necessary to prevent criticality. Peach Bottom core 2 fuel elements are not individually canned; however, a maximum of 12 Peach Bottom core 2 fuel elements will be shipped to the ISF Facility in any single cask. Therefore, there is insufficient material to achieve $k_{eff} > 0.95$. Nevertheless, this bounding case has been used to demonstrate that under unforeseen off-normal or accident conditions involving the DOE transfer cask, nuclear criticality safety controls are adequate to ensure that a criticality does not occur.

- For the second scenario (described in Section 3.1 of Appendix 4A to the SAR), "microspheres" of uranium carbide from a Peach Bottom fuel element are assumed to accumulate separately from the fuel element matrix, and become packed in a sphere that is fully reflected and moderated by water. Under these conditions, the maximum safe mass of uranium that can accumulate is 680 grams before k_{eff} reaches 0.95. As with the scenario described above, these conditions cannot be achieved in the ISF Facility. Uranium can only be separated from the fuel element matrix through a deliberate process. No such process exists within the ISF Facility.

Criticality models developed to examine each of the three fuel types under normal, off-normal, accident, and bounding conditions are provided in Appendix 4A to the SAR. The MCNP4 computer code (Ref. 4-18) described in Section 3.3.4.3.2 was used for each of the analyses.

By a combination of their basic pellet design and their reactor operations exposure, the Shippingport reflector modules are not enriched, and the lack of appreciable amounts of fissile material means that criticality safety is ensured without further limitations on geometry. The handling and packaging of Shippingport modules and loose rods do not present any limitations with regard to criticality safety. The increase in reactivity of Shippingport reflector modules due to neutronic coupling with the other two types of fuels is bounded by other cases involving just the other two types of fuels. Therefore, no further criticality evaluations involving Shippingport fuel are discussed.

4.7.3.4.1 Cask Handling Operations

This section discusses normal, off-normal/accident, and bounding criticality evaluations performed by Foster Wheeler to support the use of the DOE transfer cask. Additional information regarding this government-furnished equipment is provided in Appendix A to the SAR, *Safety Evaluation of DOE-provided Transfer Cask*. The results of these analyses are summarized in Table 4.7-31.

Normal Cask Handling Operations

Cask handling operations begin with the receipt of the DOE transfer cask at the ISF Facility. The cask transport configuration and relevant analyses are described in Appendix A to the SAR.

Once it is received, the loaded DOE Transfer Cask is removed from the transport trailer using the cask receipt crane, and placed on the cask trolley. The fuel remains within the cask, with the cask lid bolted in place during this entire process.

Once the transfer cask is placed on the cask trolley, it is moved to the Cask Decontamination Zone within the Transfer Tunnel. There, the cask lid bolts are removed, and a cask adapter holds the cask lid in place during subsequent operations. The cask trolley then moves the transfer cask down the Transfer Tunnel to the FPA for unloading.

Throughout this operating sequence, the normal cask transport geometry is maintained, and criticality calculations performed for the transport configuration remain valid. For the maximum fuel inventory case (18 canned Peach Bottom core 1 fuel elements), k_{eff} is calculated to be 0.33. For 90 TRIGA elements (the maximum number of TRIGA elements to be shipped in the DOE Transfer Cask, as specified in Section C, Attachment C-A-D of Contract No. DE-AC07-00ID13729), k_{eff} is calculated to be approximately 0.38.

Although the Shippingport fuel does not require the DOE container to maintain geometric control of the fuel during normal handling operations, the Peach Bottom and TRIGA fuels are anticipated to require the DOE container to remain intact to maintain geometric control. This is discussed further under *Cask Handling Bounding Criticality Analyses* below.

Cask Handling Criticality Control During Off-Normal and Accident Events

As noted above, the Shippingport fuel does not require the DOE container to maintain geometric control of the fuel during normal, off-normal, or accident events; however, the Peach Bottom and TRIGA fuels do require the container to remain intact to maintain geometric control and separation.

The cask receipt crane is designed as a single-failure-proof crane, and the associated lifting devices are designed to ANSI N14.6. Section 4.7.3.3.4 provides the structural analyses and summaries of results for the cask receipt crane. The DOE transfer cask trunnions meet ANSI N14.6 criteria (see Appendix A of the SAR). Therefore, accident scenarios involving a loss of geometry control or fuel separation due to dropping the DOE transfer cask in the Cask Receipt Area are not credible, as they require two unlikely, independent and concurrent or sequential events to occur.

The cask trolley is designed to the applicable single-failure-proof criteria of NUREG-0554 and NUREG-0612. The requirements of these design criteria serve to prevent the cask from being dropped or overturned during handling in the Transfer Tunnel. The structural analyses for the cask trolley are presented in Section 4.7.3.3.5. Transport accident conditions analyzed for the DOE transfer cask are anticipated to bound normal, off-normal, and accident loads imparted to the DOE transfer cask and fuel by accidents involving the cask trolley. Therefore, accident scenarios involving a loss of geometry or fuel separation due to dropping the DOE transfer cask within the Transfer Tunnel are not credible, as they require two unlikely, independent and concurrent or sequential events to occur.

Cask Handling Bounding Criticality Analyses

To envelope unforeseen off-normal or accident conditions during cask handling operations, parametric studies were performed to simulate loss of geometry control under accident conditions. These studies investigated the effects of: 1) crushing Peach Bottom fuel elements into a homogeneous, graphite moderated sphere; 2) close-packing Peach Bottom fuel elements; and 3) close-packing TRIGA fuel elements. Although none of these scenarios are considered credible events, they serve to demonstrate the limits of criticality safety for cask handling operations.

The results of these analyses are presented in Table 4.7-31. A k_{eff} of 0.95 is approached with 14 Peach Bottom elements under the "crushed fuel" scenario. This is two elements more than the amount of fuel to be shipped in any single cask load of Peach Bottom core 2 fuel. Under the close-packed scenario, a k_{eff} of 0.55 is achieved with 37 Peach Bottom elements – over twice the amount of Peach Bottom core 1 fuel received in any single cask shipment. For TRIGA fuel, a k_{eff} approaching 0.95 was achieved with 48 elements, assuming the elements were close-packed and reflected.

4.7.3.4.2 Fuel Packaging Area Operations

This section discusses normal, off-normal/accident, and bounding criticality evalutions relevant to fuel handling operations conducted within the FPA. The results of these analyses are summarized in Table 4.7-32. As noted above, Shippingport fuel handling operations are bounded by the conditions described for Peach Bottom and TRIGA fuels. Therefore, Shippingport fuel handling activities are not described.

Normal Fuel Packaging Area Operations

Fuel packaging operations begin with unloading the fuel from the DOE transfer cask and placing the inner DOE fuel containers into temporary storage locations within the FPA. The DOE fuel containers and their related safety analyses are described in Appendix A of the ISF Facility SAR.

Once in the FPA, DOE fuel containers containing Peach Bottom and TRIGA fuels are opened, and the fuel elements removed and packaged into the ISF baskets. During this process, no more than one fuel element is transferred at any given time. Once the ISF basket is filled, a lid is placed onto the basket and locked into place. The basket is then lifted and placed into an ISF Canister. Worktable operations may involve the handling of fuel fragments, single intact elements, or multiple intact elements. These fuel configurations are bounded by the "crushed" element and close-packed scenarios summarized in Table 4.7-32. Handling operations within the FPA are limited to a single fuel type at any given time.

The handling operations described above involve a number of different geometries, including close-packed groupings of fuel elements (symbolizing baskets of fuel, or single elements in close proximity to a basket of fuel), and arrays of fuel element groupings (symbolizing baskets of fuel in close proximity to each other). The cases analyzed to represent these normal fuel packaging operations and their results are summarized in Table 4.7-32. In all cases, k_{eff} remains below 0.95.

Fuel Packaging Area Criticality Control During Off-Normal and Accident Events

The design of the FPA, and operations conducted within the FPA, incorporate numerous features that serve to provide geometry control and separation. These features are described in detail in Section 5.1.3.1.

In most instances, fuel handling operations within the FPA are carried out using the FHM hoist, a single-failure-proof hoist that meets the requirements of NUREG-0554 and NUREG-0612, using single-failure-proof lifting devices that meet the requirements of ANSI N14.6. Some of the DOE fuel containers have not been demonstrated to meet the requirements of single-failure-proof lifting devices and some fuel elements (e.g., Peach Bottom core 2 elements) do not have a lifting feature that allows for positive engagement with a single-failure-proof device. Dropping a fuel container is discussed in Section 8.2.2.1, and dropping of a single fuel element is discussed in Section 8.1.2.4.

Although fuel elements are to be placed into designated, controlled locations, it is possible to place fuel elements in close proximity to each other outside of these locations by violating administrative controls.

To investigate the consequences of these events, several scenarios were analyzed for both the Peach Bottom and TRIGA fuels. These include:

- Two closely-packed groupings of 18 Peach Bottom elements side-by-side. This analysis simulates two DOE inner fuel containers placed near each other outside of a controlled location. In this scenario, k_{eff} was calculated to be 0.54.
- Two closely-packed groupings of 54 TRIGA elements side-by-side. This analysis simulates two ISF TRIGA baskets placed near each other outside of a controlled location, and bounds dropping a single TRIGA element in close proximity to or on top of baskets of TRIGA fuel. In this scenario, k_{eff} was calculated to be 0.79.
- A closely-packed grouping of 19 Peach Bottom fuel elements. This analysis simulates dropping a Peach Bottom element onto or alongside a DOE inner fuel container full of Peach Bottom fuel. In this scenario, k_{eff} was calculated to be 0.34.
- Twelve "crushed" Peach Bottom fuel elements, homogenized into a uniform mass, packed into a sphere, and reflected by graphite. This analysis bounds dropping a Peach Bottom core 2 element back into the DOE inner fuel container during unloading operations, crushing the remaining 11 elements within the container. In this scenario, k_{eff} was calculated to be 0.90.

Fuel Packaging Area Bounding Criticality Analyses

The bounding scenarios evaluated for the FPA are the same as those described above for Cask Handling: 1) crushing Peach Bottom fuel elements into a homogeneous, graphite moderated sphere; 2) close-packing Peach Bottom fuel elements; and 3) close-packing TRIGA fuel elements. These evaluations are discussed above under *Cask Handling Bounding Criticality Analyses*, and their results summarized in Table 4.7-32.

4.7.3.4.3 Canister Handling and Closure Operations

This section discusses normal, off-normal/accident, and bounding criticality evaluations relevant to canister handling and closure operations conducted within the Transfer Tunnel and CCA at the ISF Facility. The results of these analyses are summarized in Table 4.7-33. Canister Handling operations within the CHM are addressed by the analyses described in Section 4.2.3.3.7.

Normal Canister Handling and Closure Operations

Canister handling operations involve the transfer of a single ISF Canister within the canister trolley from the FPA to the CCA, the welding of the canister in the CCA, and transfer of the sealed canister to the Storage Area. These activities are bounded by the analyses for a single ISF Canister. The results of these analyses are summarized in Table 4.7-33. In no case does k_{eff} approach 0.95.

Canister Handling Criticality Control During Off-Normal and Accident Events

The design of the ISF Canister, and operations conducted within the Transfer Tunnel and the CCA, incorporate numerous features that serve to provide geometry control and separation. These features are described in detail in Section 5.1.3.1.

The canister trolley is designed to the applicable single-failure-proof criteria of NUREG-0554 and NUREG-0612. The device used to jack the ISF Canister into the CCA meets ANSI N14.6. The requirements of these design criteria serve to prevent the ISF Canister from being dropped or overturned during handling in the Transfer Tunnel. The structural analyses for the canister trolley are presented in Section 4.7.3.3.6. Therefore, accident scenarios involving a loss of geometry or fuel separation due to handling events within the Transfer Tunnel are not credible, as they require two unlikely, independent and concurrent or sequential events to occur.

Canister Handling Bounding Criticality Analyses

The bounding analyses for Canister Handling are the same as those described for Storage Area operations: fully flooded and fully moderated infinite arrays of canisters. These bounding analyses are described in Section 4.2.3.3.7, and the results summarized in Table 4.7-33. The results of these analyses demonstrate that k_{eff} remains below 0.95.

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Table 4.2-1
Vault Module Storage Tube Locations

Vault Module	Storage Tube Array Configuration	Total Tube Positions	Number of Storage Tube Locations	
			18" Tubes	24" Tubes
Vault 1	17 x 6	102	72	30
Vault 2	18 x 8	144	144	-
Vault 1 + 2	-	246	216	30

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Table 4.2-2
DOE Canister Specification Requirements

Design Feature	Rationale
Large Canister	
610 mm (24") outside diameter	Design basis diameter for large standardized canister for storage and transport of fuel. Can be accommodated in repository instead of HLW canister.
12.7 mm (0.5") wall thickness	Structural requirements
CG to be radially within 203 mm (8") of canister centerline. CG to be vertically within 609.6 mm (24") of canister centroid.	Avoids lop-sided loading, to limit ANSI N14.6 stresses on lifting ring and skirt
4,570 mm (180") long canister length Max loaded weight 10,000 lbf	
3,000 mm (118") short canister length Max loaded weight 8,996 lbf	
Small Canister	
457 mm (18") outside diameter	Design basis diameter for small standardized canister for storage and transport of fuel. Can be accommodated in the center hole of 5 pack waste package.
9.53 mm (0.375") thick	Structural requirements
CG to be radially within 127 mm (5") of canister centerline. CG to be vertically within 609.6 mm (24") of canister centroid.	Avoids lop-sided loading, to limit ANSI N14.6 stresses on lifting ring and skirt
4,570 mm (180") long canister length Max loaded weight 6,000 lbf	
3,000 mm (118") short canister length Max loaded weight 5,005 lbf	
All Canisters	
Helium leak check to <1x10-4 std cm^3/sec	ASME III, section V, article 10, appendix IV.
Closure weld is horizontal circumferential weld, vee groove with backing ring	ASME III configuration
Shielding is not required	Shielding provided by external facilities
Lift using 12.7 mm (0.5") thick lifting ring, 610 mm (24") dia. or 457 mm (18") dia.	ANSI N14.6 code
Pick up from either end	Allows pick up after accidental drop or tip-over
Engraved label, visible from top	Records
Seal before transport	Transport regulations
Fill with helium gas	Inert atmosphere to prevent fuel degradation

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Table 4.2-3
Types of ISF Canister Assemblies

Fuel Type	ISF Canister Assembly
Peach Bottom 1	18 inch outside diameter, long, 15 feet long
Peach Bottom 1 (ART)	18 inch outside diameter, long, 15 feet long
Peach Bottom 2	18 inch outside diameter, long, 15 feet long
TRIGA	18 inch outside diameter, short, 10 feet long
Shippingport Reflector Module Type IV	24 inch outside diameter, long, 15 feet long
Shippingport Reflector Module Type V	24 inch outside diameter, long, 15 feet long
Shippingport Reflector Module Rods	24 inch outside diameter, long, 15 feet long

T9033

Table 4.2-4
SA-530 Specification for Alloy Steel Pipe

Nominal pipe size	18" OD	Nominal diameter tolerance: Ovality = Max OD – Min OD: Straightness: Weight tolerance:	+ 0.093", -0.031" 1.5% x nom OD 1:960 (welded pipe) +10%, -5%
Wall thickness	0.375"	Tolerance on wall thickness:	+ 0%, -12.5%
Nominal pipe size	24" OD	Nominal diameter tolerance: Ovality = Max OD – Min OD: Straightness: Weight tolerance:	+ 0.125", -0.031" 1.5% x nom OD 1:960 (welded pipe) +10%, -5%
Wall thickness	0.50"	Tolerance:	+ 0%, -12.5%

T9034

Table 4.2-5
Maximum/Minimum Pipe Internal Envelope Diameters

Nominal pipe size: 18" outside diameter		
Min OD	18.00" – 0.031"	= 17.969"
Max wall thick.	0.375" (assumes no weight tolerance effect)	
Max ovality	1.5% x 18"	= 0.27" ± .135"
Min pipe ID (with ovality)	18.00" (nom.) – 0.031"(dia. tol.) – 2x0.375"(max wall) –0.135"(ovality)	= 17.084"
Max bow over 144" canister length	144" x 1/960	= 0.15"
Min internal envelope diameter in 144" canister length	17.084" (min ID with ovality) – 0.15" (canister bow)	= 16.934"
Nominal pipe size: 24" outside diameter		
Min OD	24.00" – 0.031"	= 23.969"
Max wall thick.	0.50" (assumes no weight tolerance effect)	
Max ovality	1.5% x 24"	= 0.36", ± 0.18"
Min pipe ID (with ovality)	24.00" (nom.) – 0.031" (dia. tol.) –2x0.50" (max wall) – 0.18" (ovality)	= 22.789"
Max bow over 144" canister length	144" x 1/960	= 0.15"
Min internal envelope diameter in 144" canister length	23.789" (min ID with ovality) – 0.15" (canister bow)	= 22.639"

T9035

Table 4.2-6
ISF Canister Weights (in pounds)

Item	Peach Bottom 1	Peach Bottom 2	Peach Bottom ART Fuel	TRIGA	Clamped Module IV	Clamped Module V	Loose Reflector Rods
Basket (full)	2,102	2,102	2,029	2,010	6,217	5,139	4,354
Shield Plug, spacer, basket base plate, etc.	600	600	391	624	888	888	1,356
Canister (empty)	1,165	1,165	1,165	792	2,124	2,124	2,110
Canister Lid	222	222	222	222	461	461	460
Canister (full)	4,090	4,090	3,807	3,648	9,690	8,612	8,280

9128

Table 4.2-7
ISF Canister Assembly Load Combinations

Comb. No.	Deadweight	Pressure	Handling	Thermal	Seismic	Drop	Acceptance Criteria
Design Conditions							
DC1	D_v	P_D					NB-3221
DC2		P_{EXT}					NB-3133
Service Level A							
A1				T_{SV1}			NB-3222
A2				T_{SV2}			
A3	D_v	P_D		T_{SV1}			
A4	D_v	P_D		T_{SV2}			
Service Level B							
B1	D_v	P_D	H_N				NB-3223
B2				T_{VB}			
B3	D_v	P_D		T_{VB}			
Postulated Accident Conditions (Service Level D)							
D1	D_v	P_D			E		NB-3225 and Appendix F, F-1341.2
D2						A_{ST}	

Notes:

Loadings are defined as follows:

D_v Loading due to deadweight – canister oriented vertically

P_D Loading due to canister internal design pressure (conservatively, Design pressure is used in all load combinations).

P_{EXT} External Pressure during vacuum drying

H_N Loading due to normal ISF handling – canister oriented vertically

T_{SV1} Loading doe to thermal conditions when the Storage Vault inlet air temperature is 98°F.

T_{SV2} Loading due to thermal conditions when the Storage Vault inlet air temperature is –26°F.

T_{VB} Temperature when the vents are fully blocked. Assume 300°F.

E Seismic loading due to earthquake

A_{ST} Loading due to non-mechanistic vertical canister drop in the storage tube

Handling loads do not include deadweight.

T9036

Table 4.2-8
ISF Canister Assembly Allowable Stress Intensities–ASME Code Criteria

Service Level	Code Paragraph	Stress Type and Allowable				
		General Membrane Pm	Local Membrane PL	Primary Membrane + Bending (Pm or PL) + Pb	Secondary Q	Primary + Secondary (Pm or PL) + Pb + Q
Design Loading	NB-3221	Sm	1.5 Sm	1.5 Sm	NR	NR
A	NB-3222	NR	NR	NR	3 Sm	3 Sm
B	NB-3223	1.1 Sm	1.65 Sm	1.65 Sm	3 Sm	3 Sm
C	NB-3224	Greater of 1.2 Sm or Sy	Greater of 1.8 Sm or 1.5 Sy	Greater of 1.8 Sm or 1.5 Sy	NR	NR
D (elastic basis)	F-1331	Lesser of 2.4 Sm or 0.7 Su	Lesser of 3.6 Sm or Su	Lesser of 3.6 Sm or Su	NR	NR

Notes:

NR Evaluation not required by the ASME Code

Sm Basic Stress Intensity

Sy Yield Strength

Su Tensile Strength

T9123

Table 4.2-9
ISF Canister Assembly Material Properties

Material Property	Unit	Temperature, °F							
		70	100	200	300	400	500	600	650
Canister Upper and Lower Heads, Lifting Rings, Impact Plate Retaining Rings, Impact plates and Shield Plug SA-240, Type 316L									
Elastic Modulus, E	Ksi	28,300	28,100	27,600	27,000	26,500	25,800	25,300	25,100
Thermal Expansion Coeff., α	10^{-6} in/in/F	8.50	8.60	8.90	9.20	9.50	9.70	9.80	9.90
Yield Strength, S_y	Ksi	25	25	21.3	19	17.5	16.4	15.6	15.3
Ultimate Strength, S_u	Ksi	70	70	68.1	64	62.2	61.8	61.7	61.6
Stress Intensity, S_m	Ksi	16.7	16.7	16.7	16.7	15.8	14.8	14	13.8
Canister Shell and Upper and Lower Impact Absorbers: SA-312, Grade TP316L									
Elastic Modulus, E	Ksi	28,300	28,100	27,600	27,000	26,500	25,800	25,300	25,100
Thermal Expansion Coeff., α	10^{-6} in/in/F	8.50	8.60	8.90	9.20	9.50	9.70	9.80	9.90
Yield Strength, S_y	Ksi	25	25	21.3	19	17.5	16.4	15.6	15.3
Ultimate Strength, S_u	Ksi	70	70	68.1	64	62.2	61.8	61.7	61.6
Stress Intensity, S_m	Ksi	16.7	16.7	16.7	16.7	15.8	14.8	14	13.8

T9171

Table 4.2-10
ISF Canister Material Stress Limits,
SA-312 Type 316L and SA-240 Type 316L

Service Level	Stress Category	Allowable Stress Intensity (SI) ksi
Design Load	P_m	13.8$^{(2)}$
	P_m or $P_L + P_b$	20.7$^{(2)}$
A	Q	50.1
	P_m or $P_L + P_b + Q$	50.1
B	P_m	18.37
	P_m or $P_L + P_b$	27.55
	Q	50.1
	P_m or $P_L + P_b + Q$	50.1
D (Elastic Basis)	P_m	40.08
	P_m or $P_L + P_b$	60.12
D (Inelastic Basis)	P_m	58.4 (true stress)
	P_m or $P_L + P_b$	82.12 (true stress)
Testing	P_m	17.04
	$P_m + P_b$	28.75

Notes:

(1) The allowable stress intensities for Service Level D (inelastic analysis) for the austenitic steel are based on the following primary stress limits from F-1341.2 of Section III, Appendix F:

The general primary membrane stress intensity P_m shall not exceed the greater of $0.7S_u$ and S_y + $1/3(S_u - S_y)$.

The maximum primary stress intensity at any location shall not exceed $0.9S_u$.

As the Code allowable stresses are the nominal stresses and the elastic-plastic finite-element analyses provide true values of stresses and strains, the nominal allowable stresses are converted to true values as permitted by the Code.

(2) Based on a temperature of 650°F. All others except testing is at 300°F. Test condition allowable stresses are conservatively based on 200°F.

T9124

Table 4.2-11
ISF Canister Stress Results and Design Margins

Service Level	Loading/ Load Combination	Stress Category	Allowable Stress Intensity (SI) ksi	Peach Bottom Canister		TRIGA Canister		Shippingport Canister	
				Calculated SI ksi	Design Margin	Calculated SI ksi	Design Margin	Calculated SI ksi	Design Margin
Design Load	$D_V + P_D$	P_m	13.80	1.30	9.6	1.34	9.3	1.34	9.3
		P_m or $P_L + P_b$	20.70	1.86	10.1	1.84	10.3	2.3	8.0
	External Pressure	-	-	-	6.9	-	6.9	-	7.0
A	$D_V + P_D + T_1$ or T_2	P_m or $P_L + P_b + Q$	50.10	1.87	25.8	1.89	25.5	2.36	20.2
B	$D_V + P_D + H_n$	P_m	18.37	1.30	13.1	1.34	12.7	1.34	12.7
		P_m or $P_L + P_b + Q$	27.55	1.89	13.6	1.87	13.7	2.38	10.5
	$D_V + P_D + T_3$	P_m or $P_L + P_b + Q$	50.10	1.86	25.9	1.84	26.2	2.31	20.6
D	$D_V + P_D + E$	P_m	40.08	10.97	2.6	6.09	5.6	4.43	8.0
		P_m or $P_L + P_b + Q$	60.12	14.10	3.3	7.60	6.9	7.46	7.0
	Drop	P_m	58.40 (true)	42.36	0.38	46.40	0.26	35.29	0.65
		P_m or $P_L + P_b$	82.12 (true)	59.93	0.37	65.94	0.24	59.35	0.38
Testing	$D_V + 1.1\ P_D$	P_m	17.04	1.43	10.9	1.47	10.6	1.47	10.5
		$P_m + P_b$	28.75	2.05	13.0	2.07	12.9	2.53	10.3

Notes:
Design Margin = (Allowable Stress ÷ Actual Stress) – 1
Loadings are defined as follows:

D_v Dead weight of the canister assembly
P_D Canister internal pressure
T_1 Thermal loadings when the Storage Vault inlet air temperature is 101°F
T_2 Thermal loading when the Storage Vault inlet air temperature is –40°F
T_3 Thermal loading from temperature when the vents are blocked (300F assumed)
H_n Normal handling load (1.15 D_V)
E Earthquake loading
Drop Loading from non-mechanistic vertical canister drop in the storage tube. The results reported above are for the pressure boundary only

T9125

Table 4.2-12
Lifting Ring and Impact Absorber Allowable Stress and Design Margin

Member	Yield Strength (ksi)	Ultimate Strength (ksi)	Allowable Stress (ksi)	Maximum Principal Tensile stress (ksi)	Maximum Shear Stress (ksi)	Design Margin[1]	
						Tension	Shear
18" Canisters							
Lifting Ring	23.15	69.05	3.86	1.41	0.798	1.74	3.84
Impact Absorber	23.15	69.05	3.86	2.75	1.44	0.40	1.68
24" Canisters							
Lifting Ring	23.15	69.05	3.86	2.61	1.44	0.48	1.68
Impact Absorber	23.15	69.05	3.86	3.68	1.94	0.05	0.99

Note:
(1) Design Margin = (Allowable Stress ÷ Actual Stress) – 1
9129

Table 4.2-13
ISF Basket Load Combinations

Comb. No.	Deadweight	Handling	Thermal	Seismic	Acceptance Criteria
Design Conditions – (Service Level A)					
A1	D		T_D		NG-3222
Normal/Off Normal Operating Conditions – (Service Level B)					
B1	D		T_N		NG-3223 N14.6
B2	D	H_N	T_N		
B3	D		T_O		
B4	D		T_A		
Accident Conditions – (Service Level D)					
D1	D		T_N	E	NG-3225 Appendix F, F-1331

Notes:
Loadings are defined as follows:

D Loading due to deadweight
T_D Loading due to design temperature
T_N Loading due to normal temperature
T_O Loading due to off normal temperature
T_A Loading due to accident temperature
H_N Loading due to normal basket handling
E Loading due to seismic events

T9037

Table 4.2-14
ASME III Division 1 Subsection NG Stress Limits – ISF Canister Internals Materials

Stress Type	Design Loadings 650°F	Normal/Off Normal Conditions (Level A/B)		Accident Conditions (Level D)	
		400°F	260°F	400°F	260°F
ASME SA-693 Type 630 (17/4 Plate)					
P_m	41.9	43.8	45.0	91.8	94.5
P_L	-	-	-	137.8	141.7
$P_m + P_b$ or $P_L + P_b$	62.8	65.7	67.5	137.8	141.7
$P_m + P_b + Q$	-	131.4	135.0	-	-
Bearing	-	89.7	94.5	-	-
ASME SA-564 Type 630 (17/4 Bar)					
P_m	For Threaded Structural Fasteners – No Limits for Design Load Case	43.8	45.0	87.6	90.0
P_L		-	-	131.4	135.0
$P_m + P_b$ or $P_L + P_b$		-	-	131.4	135.0
$P_m + Q_m$		80.7	-	-	-
$P_m + P_b + Q$		107.4		-	-
Bearing		242.2	255.2	-	-
ASME SA-213 (316L Tube)					
P_m	13.8	15.8	16.7	37.9	40.1
P_L	-	-	-	56.9	60.1
$P_m + P_b$ or $P_L + P_b$	-	23.7	25.0	56.9	60.1
$P_m + P_b + Q$	-	47.4	50.1	-	-
Bearing	15.3	17.5	19.9	-	-
ASME SA240 (316L Plate)					
P_m	13.8	15.8	16.7	37.9	40.1
P_L	-	-	-	56.9	60.1
$P_m + P_b$ or $P_L + P_b$	20.7	23.7	25.0	56.9	60.1
$P_m + P_b + Q$	-	47.4	-	-	-
Bearing	15.3	17.5	19.9	-	-
ASME SA 312 (316L Pipe)					
P_m	13.8	15.8	16.7		40.1
$P_m + P_b$	20.7	23.7	25.0		

T9038

Table 4.2-15
ISF Canister Internals Material Properties

Temperature °F	Stress Intensity, S_m ksi	Yield Stress, S_y ksi	Tensile Stress, S_u ksi	Youngs Modulus psi	Thermal Expansion in/in/°F
SA693 Type 630 / SA564 Type 630					
Ambient	45.0	105.0	135.0	28.5e6	5.9e-6
260°F	45.0	94.5	135.0	27.4e6	5.9e-6
400°F	43.8	89.7	131.2	26.6e6	5.9e-6
650°F	41.9	83.6	125.5	25.2e6	5.9e-6
SA213 Type 316L / SA240 Type 316L / SA479 Type 316L / SA312 Type 316L					
Ambient	16.7	25.0	70.0	28.3e6	8.5e-6
260°F	16.7	19.88	65.6	27.2e6	9.1e-6
400°F	15.8	17.5	62.2	26.5e6	9.5e-6
650°F	13.8	15.3	61.6	25.0e6	9.8e-6

T9172

Table 4.2-16
Peach Bottom ISF Basket – Tie Bar Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety[3]
Design Loadings	Dead-weight (at 650°F)	Buckling; Axial Stress	0.239	33.74	141.7
Normal Storage	Dead-weight	P_m (main section)	0.239	43.8	183
		P_m (threaded end)	57.72	80.73	1.40[2]
		Shear (threaded end)	8.64	53.82	6.23
		Bearing	26.53	242.2	9.13[2]
		Buckling Axial Stress	0.239	36.07	151
Normal Lifting	Dead-weight and dynamic lifting effects	Direct (threaded end)	2.109	13.5	6.40
		Shear (in threads)	0.533	7.794	14.63
Seismic	10g tri-axial seismic acceleration plus gravity	$P_m + P_b$ (main section)	3.21	131.4	41.0
		P_m (threaded end)	17.19	87.6	5.10
		Buckling: Axial stress	2.625	(1)	16.7
		Bending stress	0.251		

Notes:

(1) The acceptance criteria for buckling with an axial load and a bending moment is based on the procedures in NUREG/CR-6322 section 6.32.

(2) Stresses in threaded ends and bearing stresses include effect of tensile preload achieved by torque tightening to 120 lbf-ft (to produce a preload of 16320 lbf). The preload (which is a self limiting loading) dominates the calculated stresses.

(3) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9039

Table 4.2-17
Peach Bottom ISF Basket – Spacer Plate Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety[5]
Design Loadings	Dead-weight (at 650°F)	$P_m + P_b$	0.056	62.85	1113
Normal Storage	Dead-weight	$P_m + P_b$	0.056	65.7	1164
		Bearing	26.53[1]	242.2	9.13
Seismic	10g tri-axial seismic acceleration plus gravity	P_m	9.93[3]	91.84	9.25
		$P_m + P_b$	28.73[3]	137.8	4.79
		$P_m + P_b$ (worst tolerance)	29.24[4]	137.8	4.71
		Ligament Buckling	28.73	89.7[2]	>3.12

Notes:

(1) The bearing stress result is taken from the Tie-Bar calculation. Bearing stresses are for the imposed load and Tie-Bar pre-load due to torque tightening.

(2) The allowable stress quoted is yield stress rather than a true buckling stress limit. This is because hand calculations established that the spacer plate ligaments could not buckle elastically. As the calculated ligament stresses were well below yield no further analysis was carried out to establish the true FOS against plastic buckling. The quoted FOS is conservative and is adequate to demonstrate that the design is satisfactory. In practice the FOS is expected to be well in excess of this value.

(3) Conservative as the stress quoted includes peak stress component.

(4) Allows for the 0.020" tolerance on fuel tube hole pitch. Other results are based on nominal pitch with maximum hole diameter.

(5) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9040

Table 4.2-18
Peach Bottom ISF Basket – Fuel Support Tube Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety(4)
Design Loadings	Dead-weight (at 650°F)	P_m	0.042	13.8	332
		Bearing	0.042	15.3	368
Normal Storage	Dead-weight	P_m	0.042	15.8	380
		Bearing	0.042	17.5	421
Seismic	10g tri-axial seismic acceleration plus gravity	P_m	1.622	37.92	23.3
		$P_L + P_b$	13.46(1)	56.88	4.22
		Buckling	-	-	>3.33(2)
		Axial Load	0.457	11.50(3)	25.2

Notes:

(1) Conservative as P_L stress quoted includes peak stress component.

(2) The Factor of Safety against buckling was established by elastic-plastic analysis. It was established that no buckling arises for the simultaneous application of 5 times the 10g seismic load. In order to determine a conservative critical load ASME III requires a factor of 2/3 to be applied. The quoted Factor of Safety is obtained from 5 * 2/3= 3.3.

(3) Based on ASME III Div 1 NG-3133.6 general design rule. Its use as an allowable for accident loading is therefore conservative.

(4) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9041

Table 4.2-19
Peach Bottom ISF Basket – Gadolinium Phosphate Storage Tube Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety(4)
Design Loadings	Dead-weight (at 650°F)	P_m	0.042	13.8	331
		Bearing	0.042	15.3	367
Normal Storage	Dead-weight	P_m	0.042	15.8	379
		Bearing	0.042	17.5	420
Seismic	10g tri-axial seismic acceleration plus gravity	P_m	0.425	37.92	83.9
		$P_L + P_b$	2.465(1)	56.88	23.1
		Buckling	-	-	>3.33(2)
		Axial Load	0.458	13.5(3)	29.5

Notes:

(1) Conservative as P_L stress quoted includes peak stress component.

(2) Factor of Safety against buckling was established by elastic-plastic analysis. No buckling arises for the simultaneous application of 5 times the 10g seismic load. In order to determine a conservative critical load ASME III requires a factor of 2/3 to be applied. The quoted Factor of Safety is obtained from 5 * 2/3 = 3.3.

(3) Based on ASME III div 1 NG-3133.6 general design rule. Its use as an allowable for accident loading is therefore conservative.

(4) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9042

Table 4.2-20
Peach Bottom ISF Basket – Basket Lid Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety[2]
Design Loadings	Dead-weight (at 650°F)	P_m	0.168	13.8	81.9
		$P_m + P_b$	0.216	20.7	95.9
Normal Storage	Dead-weight	P_m	0.168	15.8	93.7
		$P_m + P_b$	0.216	23.7	110
Normal Lifting	Dead-weight and dynamic lifting effects	Combined Stress	1.137	3.317	2.92
Seismic	10g vertical seismic acceleration plus gravity[1]	P_m	1.854	37.92	20.4
		$P_m + P_b$	2.374	56.88	24.0

Notes:

(1) The effect of the horizontal seismic acceleration on the lid is negligible.

(2) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9043

Table 4.2-21
Peach Bottom ISF Basket – Load Path Items Stress Results

Component	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety[3]
Lifting Pintle	Direct (Thread/Shank)	1.415	3.317	2.34
	Shear (Thread)	0.394	1.915	4.87
	Bending (Head)	0.807	3.317	4.11
	Shear (Head)	0.256	1.915	7.47
	Combined Stress (Head)	0.922	3.317	3.60
Lid Securing Pins	Direct+Bending (Shank)	2.56	13.50	5.27
	Shear (Head)	1.026	7.794	7.59
	Combined (Head/Shank)	2.517	13.50	5.36
	Direct+Bending (Body)	1.534	13.50	8.80
	Shear (Body)	2.311	7.794	3.37
Lid Locking Plate	Shear	0.452	1.915	4.23
	Combined Stress	1.713	3.317	1.93
Special Screws	Direct (Threaded end)	2.109	13.50	6.40[1]
	Shear (Threaded end)	0.533	7.794	14.6[1]
	Shear (Head)	(2)	7.794	-
	Combined (Head/Shank)	(2)	13.50	-
Base Plate	Combined Stress	1.123	13.50	12.0
	Shear (At special screw)	0.228	7.794	34.1

Notes:

(1) Results are identical to the Tie Bar results

(2) Results for Special Screw head and shank are bounded by the results for the lid securing pin head and shank.

(3) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9045

Table 4.2-22
Peach Bottom ART ISF Basket – Tie Bar Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety[3]
Design Loadings	Dead-weight (at 650°F)	Buckling: Axial Stress	0.195	17.14	87.7
Normal Storage	Dead-weight	P_m (main section)	0.195	43.80	224
		P_m (threaded end)	65.96	80.73	1.22[2]
		Shear	9.87	53.82	5.45
		Buckling Axial Stress	0.195	18.09	92.6[2]
		Bearing	30.35	242.2	7.98
Normal Lifting	Dead-weight and dynamic lifting effects	Direct (threaded end)	2.748	13.50	4.91
		Shear (threaded end)	0.69	7.794	11.30
Seismic	10g tri-axial seismic acceleration plus gravity	$P_m + P_b$ (main section)	3.62	131.4	36.3
		P_m (threaded end)	15.53	87.6	5.64
		Buckling: Axial stress	2.149	[1]	10.2
		Bending stress	0.671		

Notes:

(1) The acceptance criteria for buckling with an axial load and a bending moment is based on the procedures in NUREG/CR-6322 section 6.32.

(2) Stresses in threaded ends and bearing stresses include effect of tensile preload achieved by torque tightening to 120 lbf-ft (to produce a preload of 16320 lbf). The preload (which is a self limiting loading) dominates the calculated stresses.

(3) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9126

Table 4.2-23
Peach Bottom ART ISF Basket – 316L Spacer Plate Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety[4]
Design Loadings	Dead-weight (at 650°F)	Pm +Pb	-	-	[2]
Normal Storage	Dead-weight	Pm +Pb	-	-	[2]
		Bearing	30.35	47.25	1.56 [3]
Seismic	10g tri-axial seismic acceleration plus gravity	Pm	4.55 [1]	37.92	8.33
		Pm +Pb	10.45 [1]	56.88	5.45

Notes:

(1) Conservative as the stress quoted includes peak stress component.

(2) Not calculated as 17-4 Ph spacer plate results show this to be trivial.

(3) Results taken from Top Plate stress analysis.

(4) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9127

Table 4.2-24
Peach Bottom ART ISF Basket – 17-4 Ph Spacer Plate Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety[4]
Design Loadings	Dead-weight (at 650°F)	$P_m + P_b$	1.123[3]	62.85	56.0
Normal Storage	Dead-weight	$P_m + P_b$	1.123[3]	65.7	58.5
		Bearing	30.35[1]	242.2	7.98
Seismic	10g tri-axial seismic acceleration plus gravity	P_m	15.44[2,3]	91.84	5.95
		$P_m + P_b$	31.32[2,3]	137.8	4.40

Notes:

(1) The bearing stress result is taken from the tie-bar calculation. Bearing stresses are for the imposed load and tie-bar pre-load due to torque tightening.

(2) Conservative as the stress quoted includes peak stress component.

(3) Vertical loads conservatively include fuel and gadolinium phosphate tube masses. Results bound adapter plate.

(4) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9130

Table 4.2-25
Peach Bottom ART ISF Basket – Fuel Support Tube Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety [(3)]
Design Loadings	Dead-weight (at 650°F)	P_m	0.041	13.8	338
		Bearing	0.041	15.3	375
Normal Storage	Dead-weight	P_m	0.041	15.8	387
		Bearing	0.041	17.5	429
Seismic	10g tri-axial seismic acceleration plus gravity	P_m	1.657	37.92	22.9
		$P_L + P_b$	17.61[(1)]	56.88	3.23
		Buckling	-	-	>3.33[(2)]

Notes:

(1) Conservative as P_L stress quoted includes peak stress component.

(2) The Factor of Safety against buckling was established by elastic-plastic analysis. It was established that no buckling arises for the simultaneous application of 5 times the 10g seismic load. In order to determine a conservative critical load ASME III requires a factor of 2/3 to be applied. The quoted Factor of Safety is obtained from 5 * 2/3= 3.3.

(3) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9131

Table 4.2-26
Peach Bottom ART ISF Basket – Gadolinium Phosphate Storage Tube Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety (3)
Design Loadings	Dead-weight (at 650°F)	P_m	0.043	13.8	323
		Bearing	0.043	15.3	358
Normal Storage	Dead-weight	P_m	0.043	15.8	370
		Bearing	0.043	17.5	410
Seismic	10g tri-axial seismic acceleration plus gravity	P_m	1.38	37.92	27.4
		$P_L + P_b$	5.62 (1)	56.88	10.1
		Buckling	-	-	>3.33(2)

Notes:

(1) Conservative as P_L stress quoted includes peak stress component.

(2) Factor of Safety against buckling was established by elastic-plastic analysis. No buckling arises for the simultaneous application of 5 times the 10g seismic load. In order to determine a conservative critical load ASME III requires a factor of 2/3 to be applied. The quoted Factor of Safety is obtained from 5 * 2/3 = 3.3.

(3) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9132

Table 4.2-27
Peach Bottom ART ISF Basket – Basket Lid Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety (2)
Design Loadings	Dead-weight (at 650°F)	P_m	0.127	13.8	108
		$P_m + P_b$	0.175	20.7	118
Normal Storage	Dead-weight	P_m	0.127	15.8	123
		$P_m + P_b$	0.175	23.7	135
Normal Lifting	Dead-weight and dynamic lifting effects	Combined Stress	1.17	3.317	2.83
Seismic	10g vertical seismic acceleration plus gravity (1)	P_m	1.40	37.92	27.0
		$P_m + P_b$	1.93	56.88	29.5

Notes:

(1) The effect of the horizontal seismic acceleration on the Lid is negligible.

(2) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9133

Table 4.2-28
Peach Bottom ART ISF Basket – Load Path Items Stress Results

Component	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety [4]
Lifting Pintle	Direct (Thread/Shank)	1.373	3.317	2.41
	Shear (Thread)	0.382	1.915	5.01
	Bending (Head)	0.783	3.317	4.23
	Shear (Head)	0.249	1.915	7.69
	Combined Stress (Head)	0.895	3.317	3.71
Lid Securing Pins	Direct+Bending (Shank)	3.232	13.50	4.18
	Shear (Head)	1.328	7.794	5.87
	Combined (Head/Shank)	3.231	13.50	4.03
	Direct+Bending (Body)	1.956	13.50	6.90
	Shear (Body)	2.939 [3]	7.794	2.65
Lid Locking Plate	Shear	0.772	1.915	2.48
	Combined Stress	2.126	3.317	1.56
Special Screws	Direct (Threaded end)	2.73	13.50	4.95 [1]
	Shear (Threaded end)	0.69	7.794	11.3 [1]
	Shear (Head)	[2]	7.794	-
	Combined (Head/Shank)	[2]	13.50	-
Adapter Plate	Combined Stress	1.291	13.50	10.4
Base Plate	Combined Stress	1.071	3.317	3.10
	Shear (At special screw)	0.295	1.915	6.49

Notes:

(1) Results are identical to the Tie Bar results

(2) Stresses and FOS for the Special Screw head and shank will be bounded by those calculated for the Lid Securing Pin head and shank (as this is less substantial and is loaded non-uniformly around its periphery).

(3) Shear area used to calculate this stress is conservative.

(4) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9134

Table 4.2-29
TRIGA ISF Basket – Tie Bar Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety (4)
Design Loadings	Dead-weight (at 650°F)	Buckling: Axial Stress	0.389	23.77	61.1
Normal Storage	Dead-weight	P_m (main section)	0.389	45.0	116
		P_m (threaded end)	60.15	85.07	1.41(2)
		Buckling: Axial Stress	0.389	26.01	66.8
		Bearing	20.12	255.2	12.7(2)
Seismic	10g tri-axial seismic acceleration plus gravity	P_m +P_b (main section)	5.243	90.0(3)	17.2
		P_m +P_b (threaded end)	28.26	90.0(3)	3.19
		Buckling: Axial stress	4.282	(1)	7.58
		Bending stress	0.48		

Notes:

1. The acceptance criteria for buckling with an axial load and a bending moment are based on the procedures in NUREG/CR-6322 Section 6.3.2.
2. Stresses in threaded ends include the effect of pre-load. The preload dominates the calculated stresses.
3. Conservatively using the P_m stress limit to assess P_m+P_b stresses.
4. Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9135

Table 4.2-30
TRIGA ISF Basket – Lid Support Pins Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety (2)
Design Loadings	Dead-weight (at 650°F)	Buckling: Axial Stress	0.537	45.57	84.9
Normal Storage	Dead-weight	P_m	0.537	45.0	83.8
		Buckling: Axial Stress	0.537	51.39	95.7
		Bearing	26.08	255.2	9.79
Seismic	10g tri-axial seismic acceleration plus gravity	P_m +P_b (main section)	6.033	90.0	14.92
		Buckling: Axial stress	5.905	(1)	9.52
		Bending stress	0.128		

Notes:

(1) The acceptance criteria for buckling with an axial load and a bending moment is based on the procedures in NUREG/CR-6322 section 6.3.2.

(2) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9136

Table 4.2-31
TRIGA ISF Basket – Spacer Plates Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety (4)
Design Loadings	Dead-weight (at 650°F)	$P_m + P_b$	0.079	41.9(3)	531
Normal Storage	Dead-weight	$P_m + P_b$	0.079	45.0(3)	570
		Bearing	20.12(1)	255.2	12.7
Seismic	10g tri-axial seismic acceleration plus gravity	P_m	9.84	94.5	9.60
		$P_m + P_b$	30.72	141.75	4.61
		Buckling check	30.72	94.52(2)	>3.08

Notes:

(1) The bearing stress result is taken from the Tie-Bar calculation. Bearing stresses are for the imposed load and include Tie-Bar connection pre-load due to torque tightening.

(2) The allowable stress quoted is yield stress at 260°F rather than a true buckling stress limit. This is because hand calculations established that the disc ligaments could not buckle elastically. As the calculated ligament stresses were well below yield no further analysis was carried out to establish the true FOS against plastic buckling. The quoted FOS is conservative and is adequate to demonstrate that the design is satisfactory. In practice the FOS is expected to be well in excess of this value.

(3) Conservatively using the membrane allowable for the $P_m + P_b$ stress check rather than separate checks for P_m and P_b (note high FOS).

(4) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9137

Table 4.2-32
TRIGA ISF Basket – Fuel Support Tube Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety (4)
Design Loadings	Dead-weight (at 650°F)	P_m	0.007	13.8	1890
		Compression	0.007	11.4	1562
		Bearing	0.007	15.3	2096
Normal Storage	Dead-weight	P_m	0.007	16.7	2288
		Bearing	0.007	19.9	2723
Seismic	10g tri-axial seismic acceleration plus gravity	P_m	3.1	40.1(1)	12.9
		P_L	25.7(3)	60.1	2.34
		Buckling			>3.33(2)

Notes:

(1) Conservatively using the membrane allowable for the Pm +Pb stress check rather than separate checks for Pm and Pb.

(2) The Factor of Safety against buckling was established by elastic-plastic analysis. It was established that no buckling arises for the simultaneous application of 5 times the 10g seismic load In order to determine a conservative critical load ASME III requires a factor of 2/3 to be applied. The quoted Factor of Safety is obtained from 5 * 2/3 = 3.33.

(3) PL stress quoted conservatively includes peak stress component.

(4) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9138

Table 4.2-33
TRIGA ISF Basket – Gadolinium Phosphate Storage Tube Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety (4)
Design Loadings	Dead-weight (at 650°F)	P_m	0.007	13.8	1890
		Compression	0.007	11.4	1562
		Bearing	0.007	15.3	2096
Normal Storage	Dead-weight	P_m	0.007	16.7	2288
		Bearing	0.007	19.9	2723
Seismic	10g tri-axial seismic acceleration plus gravity	$P_m + P_b$	2.70	40.1(1)	14.9
		P_L	24.9(3)	60.1	2.41
		Buckling			>3.33(2)

Notes:

(1) Conservatively using the membrane allowable for the $P_m + P_b$ stress check rather than separate checks for P_m and P_b.

(2) Factor of Safety against buckling was established by elastic-plastic analysis. It was established that no buckling arises for the simultaneous application of 5 times the 10g seismic load In order to determine a conservative critical load ASME III requires a factor of 2/3 to be applied. The quoted Factor of Safety is obtained from 5 * 2/3 = 3.33.

(3) P_L stress quoted conservatively includes peak stress component.

(4) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9139.

Table 4.2-34
TRIGA ISF Basket – Basket Lid Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety (1)
Design Loadings	Dead-weight (at 650°F)	P_m	0.336	13.8	41.1
		$P_m + P_b$	0.597	20.7	34.7
		Bearing	0.479	15.3	31.9
		Shear	0.083	8.28	99.8
Normal Storage	Dead-weight	P_m	0.336	16.7	49.7
		$P_m + P_b$	0.597	25.1	42.0
		Bearing	0.479	19.9	41.5
		Shear	0.083	10.0	121
Normal Lifting	Dead-weight and dynamic lifting effects	Combined Stress	0.782	3.317	4.24
Seismic	10g vertical seismic acceleration plus gravity	P_m	3.69	40.1	10.9
		$P_m + P_b$	6.56	60.1	9.16
		Shear	0.94	27.6	29.4

(1) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9140

Table 4.2-35
TRIGA ISF Basket – Top Plate Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety [(1)]
Design Loadings	Dead-weight (at 650°F)	P_m	0.033	41.9	1270
		$P_m + P_b$	0.101	62.85	622
		Shear	0.003	25.14	8380
Normal Storage	Dead-weight	P_m	0.033	45.0	1364
		$P_m + P_b$	0.101	67.5	668
		Shear	0.003	27.0	9000
Seismic	10g vertical seismic acceleration plus gravity	P_m	2.53	94.5	37.4
		$P_m + P_b$	8.03	141.75	17.7
		Shear	0.17	56.7	334

(1) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9141

Table 4.2-36
TRIGA ISF Basket – Base Plate and Support Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety [3]
Design Loadings	Dead-weight (at 650°F)	Pm in Base	0.415	41.9	101
		Pm + Pb in Base	0.659	62.85	95.4
		Shear in Base	0.358	25.14	69.8
		Pm in Support	0.343	13.8	40.2
		Pm+Pb in Support	0.460	20.7	45.0
		Axial Compression in Support	0.343	11.4	33.2
Normal Storage	Dead-weight	Pm in Base	0.415	45.0	108
		Pm + Pb in Base	0.659	67.5	102
		Shear in Base	0.358	27.0	75.4
		Bearing in Base	20.12[1]	255.2	12.68
		Pm in Support	0.343	16.7	48.7
		Pm+Pb in Support	0.460	25.05	54.5
Normal Lifting	Dead-weight and dynamic lifting effects	Combined Stress			
		Support	0.885	3.317	3.75
		Base	1.162	13.5	11.6
		Tension (Screws)	0.665	16.14	24.3
Seismic	10g seismic accelerations plus gravity	Pm in Base	4.56	94.5	20.7
		Pm + Pb in Base	7.24	141.8	19.6
		Shear in Base	3.94	56.7	14.4
		Pm in Support	5.0	40.1	8.02
		Pm+Pb in Support	7.35	60.1	8.18
		Buckling in Support	-	-	>3.33[2]
		Pm+Pb in Clamps	4.15	94.5	22.8
		Combined Stress (Screws)	20.13	119.6	5.94

Notes:

(1) Bearing stresses in the base plate under the head of the special screw includes the effect of pre-load.

(2) The Factor of Safety against buckling was established by elastic-plastic analysis. It was established that no buckling arises for the simultaneous application of 5 times the 10g seismic load. In order to determine a conservative critical load ASME III requires a factor of 2/3 to be applied. The quoted Factor of Safety is obtained from 5 * 2/3 = 3.33.

(3) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9142

Table 4.2-37
TRIGA ISF Basket – Load Path Items Stress Results

Component	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety [(1)]
Lifting Pintle	Direct (Thread / Shank)	0.676	3.317	4.90
	Shear (Thread)	0.188	1.915	10.18
	Bending (Head)	0.386	3.317	8.59
	Shear (Head)	0.123	1.915	15.62
	Combined Stress (Head)	0.441	3.317	7.53
Lid Securing Pins	Direct+Bending (Shank)	2.051	3.317	1.62
	Shear (Head)	0.785	1.915	2.44
	Combined (Head / Shank)	1.904	3.317	1.74
Lid Locking Plate	Shear	0.454	1.915	4.22
	Combined Stress	1.568	3.317	2.12

Note:
(1) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)
T9143

Table 4.2-38
Shippingport Reflector Rod ISF Basket – Tie Bar Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety (3)
Design Loadings	Dead-weight (at 650°F)	Buckling: Axial Stress	0.458	27.36	59.7
Normal Storage	Dead-weight	P_m (main section)	0.244	43.8	179
		$P_m + Q_m$ (threaded end)	59.25	80.73	1.36 (2)
		Shear (threaded end)	8.866	53.82	6.07
		Buckling Axial Stress	0.458	29.16	63.7
		Bearing	29.04	242.2	8.33 (2)
Normal Lifting	Dead-weight and dynamic lifting effects	Direct (threaded end)	2.913	13.5	4.63
		Shear (threaded end)	0.442	7.794	17.65
Seismic	10g tri-axial seismic acceleration plus gravity	P_m (main section)	2.469	87.6	32.5
		$P_m + P_b$ (main section)	3.591	131.4	36.6
		P_m (threaded end)	37.81	87.6	2.31
		Buckling: Axial stress	5.040	(1)	7.19
		Bending stress	0.393		

Notes:

(1) The acceptance criteria for buckling with an axial load and a bending moment is based on the procedures in NUREG/CR-6322 section 6.32.

(2) Stresses in threaded ends and bearing stresses include effect of tensile preload achieved by torque tightening to 120 lbf-ft (to produce a preload of 16320 lbf). The preload (which is a self limiting loading) dominates the calculated stresses.

(3) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9144

Table 4.2-39
Shippingport Reflector Rod ISF Basket – Spacer Plate Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety [4]
Design Loadings	Dead-weight (at 650°F)	$P_m + P_b$	0.087	41.9 [3]	482
Normal Storage	Dead-weight	$P_m + P_b$	0.087	43.8 [3]	504
		Bearing	29.04[1]	242.2	8.33
Seismic	10g tri-axial seismic acceleration plus gravity	P_m	14.46	91.84	6.35
		$P_m + P_b$	19.51	137.8	7.06
		Ligament Buckling	19.51	89.7[2]	>4.8

Notes:

(1) The bearing stress result is taken from the Tie-Bar calculation. Bearing stresses are for the imposed load and Tie-Bar pre-load due to torque tightening.

(2) The allowable stress quoted is yield stress rather than a true buckling stress limit. This is because hand calculations established that the spacer plate ligaments could not buckle elastically. As the calculated ligament stresses were well below yield no further analysis was carried out to establish the true FOS against plastic buckling. The quoted FOS is conservative and is adequate to demonstrate that the design is satisfactory. In practice the FOS is expected to be well in excess of this value.

(3) Conservative as the membrane allowable stress used for the $P_m + P_b$ stress check rather than separate checks for P_m and P_b.

(4) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9145

Table 4.2-40
Shippingport Reflector Rod ISF Basket – Fuel Support Tube Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety (3)
Design Loadings	Dead-weight (at 650°F)	P_m	0.032	13.8	434
		Bearing	0.032	15.3	481
Normal Storage	Dead-weight	P_m	0.032	15.8	498
		Bearing	0.032	17.5	552
Seismic	10g tri-axial seismic acceleration plus gravity	P_m	1.94	37.92	19.5
		P_L	14.0 (1)	56.88	4.06
		Buckling	-	-	>3.33(2)

Notes:

(1) Conservative as P_L stress quoted includes peak stress component.

(2) The Factor of Safety against buckling was established by elastic-plastic analysis. It was established that no buckling arises for the simultaneous application of 5 times the 10g seismic load. In order to determine a conservative critical load ASME III requires a factor of 2/3 to be applied. The quoted Factor of Safety is obtained from 5 * 2/3= 3.3.

(3) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9146

Table 4.2-41
Shippingport Reflector Rod ISF Basket – Basket Lid Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety (2)
Design Loadings	Dead-weight (at 650°F)	P_m	0.209	13.8	66.0
		$P_m + P_b$	0.749	20.7	27.7
Normal Storage	Dead-weight	P_m	0.209	15.8	75.5
		$P_m + P_b$	0.749	23.7	31.6
Normal Lifting	Dead-weight and dynamic lifting effects	Combined Stress	2.614	3.317	1.27
Seismic	10g vertical seismic acceleration plus gravity (1)	P_m	2.30	37.92	16.49
		$P_m + P_b$	8.24	56.88	6.91

Notes:

(1) The effect of the horizontal seismic acceleration on the Lid is negligible.

(2) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9147

Table 4.2-42
Shippingport Reflector Rod ISF Basket – Base Plate Stress Results

Load Case	Loads (mechanical component)	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety (2)
Design Loadings	Dead-weight (at 650°F)	$P_m + P_b$	1.40	62.8	44.9
Normal Storage	Dead-weight	$P_m + P_b$	1.40	65.7	47.0
		Bearing (at special screw)	29.04	242.2	8.33 (1)
Normal Lifting	Dead-weight and dynamic lifting effects	Combined Stress	2.34	13.50	5.77
Seismic	10g vertical seismic acceleration plus gravity	$P_m + P_b$	15.38	137.8	8.96

Notes:

(1) The bearing stress in the base plate under the head of the special screw includes the effect of preload.

(2) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9148

Table 4.2-43
Shippingport Reflector Rod ISF Basket – Load Path Items Stress Results

Component	Stress/Load Category	Calculated Stress (ksi)	Allowable Stresses (ksi)	Factor of Safety [(1)]
Lifting Pintle	Direct (Thread / Shank)	2.93	3.317	1.13
	Shear (Thread)	0.815	1.915	2.35
	Bending (Head)	1.673	3.317	1.98
	Shear (Head)	0.531	1.915	3.60
	Combined Stress (Head)	1.909	3.317	1.74
Lid Securing Pins	Direct+Bending (Shank)	4.795	13.50	2.81
	Shear (Head)	1.417	7.794	5.50
	Combined (Head / Shank)	4.07	13.50	3.31
Lid Locking Plate	Shear	0.833	1.915	2.30
	Combined Stress	2.994	3.317	1.11

Note:
(1) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9149

Table 4.2-44
Storage Tube Load Combinations

Comb. No.	Dead-weight	Pressure	Thermal	Earthquake	Drop	Acceptance Criteria
Design Conditions						
DC1	D_V	P_D				NC-3217, Appendix XIII
DC2		P_{EXT}				NC-3133
Normal Operating Conditions (Service Level A)						
A1			T_{SV1}			NC-3217, Appendix XIII
A2			T_{SV2}			
A3	D_V	P_D	T_{SV1}			
A4	D_V	P_D	T_{SV2}			
Off-Normal Operating Conditions (Service Level B)						
B1			T_{VB1}			NC-3217, Appendix XIII
B2	D_V	P_D	T_{VB1}			
Postulated Accident Conditions (Service Level D)						
D1	D_V	P_D		E		NC-3217, Appendix XIII, F-1341.2
D2	D_V	P_D	T_{SV1}	E		
D3			T_{VB2}			
D4	D_V	P_D	T_{VB2}			
D5					A_{D1}	
D6					A_{D2}	
D7					A_{D3}	

Notes: The thermal accident condition can be assessed to Level D Service Limits, but as the thermal stresses are similar to the thermal off-normal case the accident condition has been conservatively assessed against Level B Service Limits.

Loadings are defined as follows:

D_V Loading due to deadweight of components

P_D Loading due to storage tube internal design pressure

P_{EXT} External pressure

T_{SV1} Loading due to thermal condition when the storage vault temperature is 98°F

T_{SV2} Loading due to thermal condition when the storage vault temperature is –26°F

T_{VB1} Loading due to thermal condition when 25% of the storage vault vents are blocked

T_{VB2} Loading due to thermal condition when 50% of the storage vault vents are blocked

E Seismic loading due to earthquake

A_{D1} Loading due to tube plug drop onto Storage Tube

A_{D2} Loading due to tube lid drop onto Storage Tube

A_{D3} Loading due to canister drop onto Storage Tube

In both T_{VB1} and T_{VB2} cases, the storage tube temperature is assumed to be 300 °F.

Load combinations D2, D3 and D4 are only for calculating design load for the storage tube lid bolts.

Only one of the D5 and D6 load combinations needs to be analyzed based on the kinetic energy of the tube plug and tube lid.

T9046

Table 4.2-45
Storage Tube Allowable Stress Intensity Limits – ASME Code Criteria

Service Level (NC-3217)	Stress Type and Allowable			
	General Membrane	**Local Membrane**	**Primary Membrane + Bending**	**Primary Plus Secondary Membrane + Bending**
Symbol[1]	P_m	P_L	$(P_m$ or $P_L) + P_b$	$(P_m$ or $P_L) + P_b + Q$
Code Para.	XIII-1142	XIII-1143	XIII-1144	XIII-1145
Design Loading	S_m	1.5 S_m	1.5 S_m	Evaluation not req'd.
A	S_m	1.5 S_m	1.5 S_m	3 S_m [2]
B	1.1 S_m	1.65 S_m	1.65 S_m	3 S_m [2]
C	1.2 S_m	1.8 S_m	1.8 S_m [3]	Evaluation not required
D[4]	0.7S_u	S_u	S_u	Evaluation not required

Notes:

(1) The symbols P_m, P_L, P_b and Q do not represent single quantities but rather sets of six quantities representing the six stress components. σ_t, σ_l, σ_r, τ_{lt}, τ_{lr}, and τ_{rt}.

(2) When the secondary stress is due to a temperature excursion at the point at which the stresses are being analyzed, the value of S_m shall be taken as the average of the values tabulated in Section II, Part D, Subpart 1, Tables 2A and 2B for the highest and the lowest temperature of the metal during the transient.

(3) Values shown are applicable when $P_L \leq 0.67 S_y$. When $P_L > 0.67 S_y$, use $[2.5\text{-}1.5(P_L/S_y)]\ (kS_m)$. This relationship only applies to Service Level C. However for this analysis there are no load combinations that implement Service Level C.

(4) For a complete analysis performed in accordance with NC-3211.1, the stress limits of Appendix F are applied. For elastic analysis methods, the Service Level D acceptance criteria of F-1331.1 are used. The allowables listed above are applied to elastic analysis.

T9150

Table 4.2-46
Storage Tube Assembly Material Properties

Material Property	Unit	Temperature, °F							
		70	100	200	300	400	500	600	650
Storage Tube Body: SA-333, Grade 6									
Elastic Modulus, E	Ksi	29,500	29,300	28,800	28,300	27,700	27,300	26,700	26,100
Ther. Expansion Coeff., α	10^{-6} in/in/F	6.40	6.50	6.70	6.90	7.10	7.30	7.40	7.50
Yield Strength, S_y	Ksi	35.0	35.0	32.1	31.0	29.9	28.5	26.8	25.9
Ultimate Strength, S_u	Ksi	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Stress Intensity, S_m	Ksi	20.0	20.0	20.0	20.0	20.0	18.9	17.3	16.9
Storage Tube Top and Bottom Forging: SA-350, Grade LF2									
Elastic Modulus, E	Ksi	29,500	29,300	28,800	28,300	27,700	27,300	26,700	26,100
Ther. Expansion Coeff., α	10^{-6} in/in/F	6.40	6.50	6.70	6.90	7.10	7.30	7.40	7.50
Yield Strength, S_y	Ksi	36.0	36.0	33.0	31.8	30.8	29.3	27.6	26.7
Ultimate Strength, S_u	Ksi	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Stress Intensity, S_m	Ksi	23.3	23.3	21.9	21.3	20.6	19.4	17.8	17.4
Storage Tube Lid and Lid Cover Plate: SA-516, Grade 55									
Elastic Modulus, E	Ksi	29,500	29,300	28,800	28,300	27,700	27,300	26,700	26,100
Ther. Expansion Coeff., α	10^{-6} in/in/F	6.4	6.5	6.7	6.9	7.1	7.3	7.4	7.5
Yield Strength, S_y	Ksi	30.0	30.0	27.5	26.5	25.6	24.4	23.0	22.2
Ultimate Strength, S_u	Ksi	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0
Stress Intensity, S_m	Ksi	18.3	18.3	18.3	17.7	17.2	16.2	14.8	14.5
Storage Tube Lid Bolts and Lid Cover Bolts: SA-193, Grade B7									
Elastic Modulus, E	Ksi	29,700	29,500	29,000	28,500	27,900	27,500	26,900	26,600
Ther. Expansion Coeff., α	10^{-6} in/in/F	6.4	6.5	6.7	6.9	7.1	7.3	7.4	7.5
Stress Intensity, S_m	Ksi	35.0	35.0	32.6	31.4	30.5	29.5	28.4	27.6

T9170

Table 4.2-47
Storage Tube Allowable Stress Intensities

Service Level	Temp.(1)	Design Stress Intensity Sm	Ultimate Strength Su	General Membrane Pm	Local Membrane PL	Primary Membrane + Bending (Pm or PL) + Pb	Secondary Membrane + Bending (Pm or PL) + Pb + Q
	°F	ksi	ksi	ksi	ksi	ksi	ksi
Tube Body, SA-333 Grade 6							
Design Loading	300	20.0	60.0	20.0	30.0	30.0	n/a
A	-40	20.0	60.0	20.0	30.0	30.0	60.0
	200	20.0	60.0	20.0	30.0	30.0	60.0
B	-40	20.0	60.0	22.0	33.0	33.0	60.0
	200	20.0	60.0	22.0	33.0	33.0	60.0
	300	20.0	60.0	22.0	33.0	33.0	60.0
D (elastic)	200	20.0	60.0	42.0	60.0	60.0	n/a
D (plastic)(2)	200	n/a	60.0	42.0	54.0	54.0	n/a
Testing3	200	20.0	Sy=32.1	25.6	25.6	43.3	n/a
Tube Top and Base Plate Forgings, SA-350 Grade LF2							
Design Loading	300	21.3	70.0	21.3	31.9	31.9	n/a
A	-40	23.3	70.0	23.3	34.9	34.9	69.9
	200	21.9	70.0	21.9	32.8	32.8	65.7
B	-40	23.3	70.0	25.6	38.4	38.4	69.9
	200	21.9	70.0	24.0	36.1	36.1	65.7
	300	21.3	70.0	23.4	35.1	35.1	63.9
D (elastic)	200	21.9	70.0	49.0	70.0	70.0	n/a
D (plastic)(2)	200	n/a	70.0	49.0	63.0	63.0	n/a
Testing3	200	21.9	Sy=33.0	26.4	26.4	44.5	n/a
Storage Tube and Lid Cover Plate, SA-516 Grade 55							
Design Loading	300	17.7	55.0	17.7	26.5	26.5	n/a
A	-40	18.3	55.0	18.3	27.4	27.4	54.9
	200	18.3	55.0	18.3	27.4	27.4	54.9
B	-40	18.3	55.0	20.1	30.2	30.2	54.9
	200	18.3	55.0	20.1	30.2	30.2	54.9
	300	17.7	55.0	19.4	29.2	29.2	53.1
D (elastic)	200	18.3	55.0	38.5	55.0	55.0	n/a
D (plastic)(2)	200	n/a	55.0	38.5	49.5	49.5	n/a
Testing(3)	200	18.3	Sy=27.5	22.0	22.0	37.1	n/a

Notes:

(1) Material property values tabulated in Section II, Part D, Subpart 1, Tables 2A and 2B have a minimum temperature listed of –20 °F. This value is also used for –40 °F.

(2) The allowable stress intensities of this table are nominal values determined from the Code. The Level D plastic nominal stress intensity values listed above are converted to true stress intensity allowables to compare to the calculated stresses.

(3) Membrane plus bending allowables listed for testing are for Pm ≤ 0.67 Sy. For 0.67 Sy < Pm ≤ 0.8 Sy, the allowable for membrane plus bending is (2.15 –y – 1.2 Pm).

T9047

Table 4.2-48
Storage Tube Stress Results and Design Margins

Service Condition	Load Comb.	Stress Category	Allowable Stress Intensity (ksi)	18-inch Storage Tube			24-inch Storage Tube		
				Calc. SI (ksi)	Component	Design Margin	Calc. SI (ksi)	Component	Design Margin
Design	DC1	Pm	20.0	1.31	Tube Body	14.2	2.06	Tube Body	8.7
	DC1	Pm + Pb	26.5	2.01	Storage Tube Lid	12.1	3.22	Storage Tube Lid	7.2
	External Pressure					9.0			1.8
A	A3, A4	Pm + Pb + Q	54.9	2.01	Storage Tube Lid	26.3	3.23	Storage Tube Lid	16.0
B	B2	Pm + Pb + Q	53.1	2.01	Storage Tube Lid	25.4	3.22	Storage Tube Lid	15.4
D (elastic)	D1	Pm	42.0	5.95	Tube Body	6.0	12.17	Tube Body	2.4
	D1	Pm + Pb	60.0	8.63	Tube Body	5.9	15.40	Tube Body	2.9
D (plastic)[1]	D7	Pm	46.50 (true)	41.28	Tube Body	0.12	37.68	Tube Body	0.23
	D7	Pm + Pb	66.72 (true)	42.08	Tube Body	0.58	42.67	Tube Body	0.56
Testing		Pm	25.6	1.44	Tube Body	16.7	2.27	Tube Body	10.2
		Pm + Pb	37.1	2.21	Storage Tube Lid	15.7	3.54	Storage Tube Lid	9.4

Notes:
1. The Code stress intensity limits are in terms of nominal stresses. The limits for Level D plastic analysis are the true values of stresses that are used to compare with the calculated true stresses as permitted by the Code.

2. Design Margin = (Allowable Stress ÷ Actual Stress) – 1

T9152

Table 4.2-49
Vault Bounding Heat Loads and Mixes

Canister Heat Loads	Storage Positions	
	Storage Vault 1	**Storage Vault 2**
18 inch Canisters with 40W	60	132
18 inch Canisters with 120W	12	12
24 inch Canisters with 40W	16	-
24 inch Canisters with 120W	14	-
Number of vault Storage Tubes	102	144
Total Heat Load		
Vault Heat Load	6160 Watt	6720 Watt
Total System Heat Load	12880 Watt	

T9048

Table 4.2-50
Ambient Temperature Boundary Conditions

Location	Temperature Range
External Environment – Normal	-26°F to +98°F
External Environment – Off Normal / Accident	-40°F to +101°F
Fuel Packaging Area – Normal	+50°F to +90°F
Fuel Packaging Area – Off Normal / Accident	-26°F to +156°F
Transfer Tunnel – Normal	+50°F to +90°F
Transfer Tunnel – Off Normal / Accident	-26°F to +163°F
CCA – Normal	+70°F to +80°F
CCA – Off Normal	-26°F to +138°F
Upper Storage Area – Normal	+40°F to +100°F
Upper Storage Area – Off Normal / Accident	-26°F to +154°F
CHM fuel loading/unloading operations	+32°F to +104°F

T9049

Table 4.2-51
Surface Thermal Emissivity

Surface/Material	Thermal Emissivity
Fuel Bucket Operation Station	E = 0.25
Decanning Station	E = 0.25
ISF Canister	E = 0.25
ISF Canister Cask – internal	E = 0.80
ISF Canister Cask – external	E = 0.80
CHM Guide Sleeve	E = 0.82
CHM Steel Shielding – internal	E = 0.82
CHM Steel Shielding – external	E = 0.80
CHM JABROC (painted)	E = 0.80

T9052

Table 4.2-52
Fuel Decay Heat Outputs

Fuel Type	Maximum Heat Output (Watts)	
	Per Element	Per Canister
Peach Bottom Core 1	0.053	0.53
Peach Bottom Core 2	3.28	32.8
Peach Bottom Core 1 ART	0.053	0.37
TRIGA (Aluminum & Stainless Steel)	0.33	35.3
Shippingport Reflector Rod	0.043	5.5
Shippingport Reflector IV Module	9.8	9.8
Shippingport Reflector V Module	7.1	7.1
Bounding Heat Output	-	40
Bounding High Heat Output	-	120

T9053

Table 4.2-53
Allowable Temperature Limits

Component	Temperature Limits	
	Normal	Short Term
Peach Bottom Fuel (1, 2 & ART) [(1)]	572°F	572°F
TRIGA (Aluminum Clad) [(2)]	400°F	400°F
TRIGA (Stainless Steel Clad) [(3)]	800°F	800°F
Shippingport Reflector Rods (loose) [(4)]	612°F	1058°F
Shippingport Reflector Modules [(4)]	612°F	1058°F
ISF Basket [(5)]	650°F	650°F
ISF Canister [(6)]	650°F	650°F
Storage Tube [(7)]	300°F	300°F
Concrete [(8)]	150°F / 200°F	350°F

Notes:

(1) Limit is based on pyrolytic carbon in an oxygen environment. Limit in a dry inert helium environment is significantly higher (Ref. 4-20).

(2) Limit is based on Perry's Chemical Engineer's Handbook, 6th Edition.

(3) Limit is based on ASME B&PV code, Section II, Part D, Material Limits.

(4) Limit is based on NUREG 1567 for zirconium alloy cladding.

(5) Limit is based on design temperature for ISF baskets.

(6) Limit is based on design temperature for ISF canister assembly.

(7) Limit is based on design temperature for storage tube assembly.

(8) Limits are based on ACI 349, Section A.4.

T9054

Table 4.2-54
Cooling Air Flow Rates

Storage Tube	Fuel Heat (Watts)	Normal Zero Blockage	Off-Normal 25% Blockage	Accident 50% Blockage
		Air Flow Rate per Storage Tube (lb/h)		
Peach Bottom –18"	32.8W	29.1	27.1	23.4
TRIGA – 18"	35.3W	29.1	27.1	23.4
Bounding Heat – 18"	40W	29.1	27.1	23.4
Bounding High Heat – 18"	120W	47.8	46.1	42.8
Shippingport Reflector rods – 24"	5.5W	33.9	31.7	27.5
Shippingport Reflector modules – 24"	9.8W	33.9	31.7	27.5
Bounding Heat – 24"	40W	33.9	31.7	27.5
Bounding High Heat – 24"	120W	55.4	53.6	49.9

T9055

Table 4.2-55
Fuel and Component Temperatures in FPA, Canister Trolley Cask and CHM

Component	Component Maximum Temperatures					
	FPA		Canister Trolley Cask		CHM	
	Normal	Off Normal	Normal	Off Normal	Normal	Off Normal
Peach Bottom						
Fuel	198.5°F	263.9°F	105.8°F	177.1°F	118.8°F	170.1°F
ISF Basket	128.7°F	201.5°F	104.6°F	176.0°F	117.7°F	169.1°F
ISF Canister	-	-	98.8°F	170.5°F	112.0°F	163.6°F
Concrete(1)	96.7°F	171.9°F	-	-	-	-
TRIGA						
Fuel	242.9°F	304.5°F	116.6°F	187.2°F	130.2°F	181.0°F
ISF Basket	148.1°F	218.4°F	115.9°F	186.5°F	129.5°F	180.3°F
ISF Canister	-	-	105.0°F	176.2°F	118.7°F	170.0°F
Concrete(1)	95.5°F	171.0°F	-	-	-	-
Shippingport Reflector Rods						
Fuel	103.6°F	177.4°F	92.2°F	164.9°F	102.3°F	155.1°F
ISF Basket	94.2°F	169.2°F	92.1°F	164.9°F	102.3°F	155.1°F
ISF Canister	-	-	91.2°F	164.0°F	101.4°F	154.2°F
Concrete(1)	90.9°F	166.1°F	-	-	-	-
Shippingport Reflector Module						
Fuel	113.7°F	186.3°F	95.7°F	168.1°F	107.4°F	159.9°F
ISF Canister	-	-	91.2°F	164.8°F	102.2°F	155.0°F
Concrete(1)	91.5°F	166.5°F	-	-	-	-

Note:
(1) Concrete around fuel basket operations and monitoring station inside FPA.

Table 4.2-56
Peach Bottom Fuel – Storage Vault

Component	Component Maximum Temperatures		
	Normal Condition	Off Normal Condition	Accident Condition
Storage Tube	116.4°F	119.5°F	120.3°F
ISF Canister	117.9°F	121.0°F	121.8°F
ISF Basket	123.6°F	126.7°F	127.5°F
Fuel Element	124.7°F	127.8°F	128.6°F

T9157

Table 4.2-57
Thermal Stress Results – Peach Bottom 1&2 and Peach Bottom ART ISF Baskets

Load Case	Maximum Thermal Stress for Basket Components	
	Spacer Plates	**Fuel Support Tubes**
Storage Vault: (Bounding for all conditions)	343 psi	26 psi
CHM: Normal	345 psi	27 psi
CHM: Off-Normal	329 psi	26 psi
FPA: Normal	492 psi	37 psi
FPA: Off-Normal	464 psi	36 psi
Canister Trolley Cask: Normal	367 psi	26 psi
Canister Trolley Cask: Off-Normal	347 psi	26 psi

T9058

Table 4.2-58
TRIGA Fuel – Storage Vault

Component	Component Maximum Temperatures		
	Normal Condition	Off Normal Condition	Accident Condition
Storage Tube	119.2°F	122.3°F	123.4°F
ISF Canister	123.1°F	126.2°F	127.3°F
ISF Basket	133.7°F	136.8°F	137.9°F
Fuel Element	134.4°F	137.5°F	138.6°F

T9162

Table 4.2-59
Thermal Stress Results – TRIGA ISF Basket

Load Case	Maximum Thermal Stress for Basket Components	
	Spacer Plates	Fuel Support Tubes
Storage Vault: (Bounding for all conditions)	311 psi	9 psi
CHM: Normal	315 psi	9 psi
CHM: Off-Normal	300 psi	9 psi
FPA: Normal	923 psi	17 psi
FPA: Off-Normal	862 psi	17 psi
Canister Trolley Cask: Normal	318 psi	9 psi
Canister Trolley Cask: Off-Normal	299 psi	9 psi

T9060

Table 4.2-60
Shippingport Reflector Rods – Storage Vault

Component	Component Maximum Temperatures		
	Normal Condition	**Off Normal Condition**	**Accident Condition**
Storage Tube	100.6°F	103.6°F	101.1°F
ISF Canister	100.8°F	103.8°F	101.3°F
ISF Basket	101.7°F	104.7°F	102.2°F
Fuel Element	101.7°F	104.7°F	102.2°F

T9166

Table 4.2-61
Thermal Stress Results – Shippingport Reflector Rod Basket

Load Case	Maximum Thermal Stress for Basket Components	
	Spacer Plates	**Fuel Support Tubes**
Storage Vault: (Bounding for all conditions)	68 psi	1 psi
CHM: Normal	68 psi	1 psi
CHM: Off-Normal	65 psi	1 psi
FPA: Normal	134 psi	1 psi
FPA: Off-Normal	125 psi	1 psi
Canister Trolley Cask: Normal	68 psi	1 psi
Canister Trolley Cask: Off-Normal	64 psi	1 psi

T9062

Table 4.2-62
Shippingport Reflector Modules – Storage Vault

Component	Component Maximum Temperatures		
	Normal Condition	**Off Normal Condition**	**Accident Condition**
Storage Tube	102.6°F	105.7°F	103.6°F
ISF Canister	102.9°F	106.0°F	103.9°F
Reflector Module	108.5°F	111.6°F	109.5°F

T9169

Table 4.2-63
Maximum Fuel and Component Temperatures

Component	Normal Storage Condition		Off-Normal or Accident Condition	
	Maximum Temperature	Temperature Limit	Maximum Temperature	Temperature Limit
Peach Bottom Fuel	125°F	572°F	264°F	572°F
TRIGA Fuel	135°F	400°F (1)	305°F	400°F (1)
Shippingport Reflector Rods	102°F	612°F	178°F	1058°F
Shippingport Reflector Modules	109°F	612°F	187°F	1058°F
ISF Basket	134°F	650°F	219°F	650°F
ISF Canister	124°F	650°F	177°F	650°F
Storage Tube	120°F	300°F	124°F	300°F
Concrete	120°F (2)	150°F	172°F (3)	200°F

(1)TRIGA temperature limits are based on an aluminum clad fuel

(2)Used storage tube temperature for conservatism

(3)Concrete around fuel basket operations and monitoring station inside FPA.

Table 4.2-64
ISF Canister Steady State Bounding Temperatures

Load Condition	Maximum Canister Temperature				
	18" Short 40W	18" Long 40W	18" Long 120W	24" Long 40W	24" Long 120W
Canister Trolley Cask					
Normal Operation	106.8°F	99.6°F	113.6°F	97.4°F	109.9°F
Off Normal Operation 163°F	177.8°F	171.2°F	183.4°F	169.3°F	180.2°F
Off Normal Operation -26°F	-20.0°F	-24.4°F	19.4°F	-23.8°F	-20.5°F
Canister Handling Machine					
Normal Operation (100°F)	121.0°F	113.3°F	135.2°F	108.8°F	123.5°F
Off Normal Operation (104°F)	125.0°F	117.3°F	139.2°F	112.8°F	127.5°F
Off Normal Operation (-26°F)	-17.9°F	-21.7°F	-15.3°F	-22.1°F	-15.8°F
Off Normal Operation (153°F)	172.1°F	164.9°F	185.0°F	161.1°F	174.9°F
Storage Vault					
Normal Operation (98°F)	126.4°F	121.8°F	151.4°F	117.5°F	142.5°F
Off Normal Operation (101°F)	129.5°F	124.9°F	154.7°F	120.7°F	145.1°F
Off Normal Operation (-40°F)	-32°F	-38.3°F	-28.6°F	-37.6°F	-34.3°F
Accident Condition (50% Duct Blockage)	131.2°F	126.6°F	155.6°F	121.4°F	145.3°F

T9064

Table 4.2-65
Value of k_{eff} for Various Storage Area Configurations[3]

Fuel Type	Normal			Bounding Analysis[1]		
	Desc.	Ref. #[2]	keff	Desc.	Ref. #[2]	keff
Peach Bottom	1 ISF canister with 10 elements	3.3	0.22	Infinite array flooded	3.4	0.50
	2 ISF canisters end to end	3.3	0.22			
	Infinite array of ISF canisters	3.4	0.46			
TRIGA	1 ISF canister with 2 baskets of 54 elements each	2.4	0.57	Infinite array flooded	2.3	0.84
	2 ISF canisters end to end	2.4	0.58			
	Infinite array of ISF canisters	2.3	0.75			
Mixed Vault	ISF canisters of TRIGA and Peach Bottom fuel in the storage array	3.5	0.53	Canisters of TRIGA and Peach Bottom fuel in the storage array, flooded	3.5	0.84

(1) Off-normal and accident conditions are addressed by the Bounding data.

(2) The reference number corresponds to the Section number of Appendix 4A to the SAR, *Criticality Models*.

(3) The Shippingport fuel does not represent a criticality hazard as described in Appendix 4A to the SAR, *Criticality Models* Section 4.1.

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Table 4.3-1
Normal Operating Indoor Design Parameters

Building Area	Cooling Temp °F (max)	Heating Temp °F (min)	Room Pressure Inch-wg (1)
Fuel Packaging Area	90	50	(-) 1.50
FHM Maintenance Area (2)	90	50	(-) 1.40
Canister Closure Area	80	70	(-) 0.20
Solid Waste Processing Area (2)	80	70	(-) 1.20
Solid Waste Storage Area	80	70	(-) 0.20
Operating Gallery	80	70	(-) 0.20
Workshop	80	70	(-) 0.20
Operators Office	76	72	(+) 0.05
Change Room	76	72	(+) 0.05
Corridor	76	72	(+) 0.05
Transfer Tunnel	90	50	(-) 0.50
Cask Decontamination Area	90	50	(-) 0.10
HEPA Filter Room	90	50	(-) 0.10
Liquid Waste Storage Tank Area	90	50	(-) 0.10
HVAC Exhaust Room	90	50	0.0
Electrical Room	90	50	0.0
Battery Room	86	74	0.0
New Canister Receipt Area	80	60	0.0
Operations Area			
Office Areas	76	72	(+) 0.05
Storage Garage	90	50	0.0
HVAC Supply Room	90	50	0.0
Storage Area			
Upper Level	100	40	0.0
Cask Receipt Area			
All Areas	105	40	0.0

(1) Room pressures are relative to atmosphere, and are nominal values.

(2) When these areas are occupied, room pressure will be reset to –0.4 inch wg

General Note Ambient design temperatures are provided in Chapter 3, *Principal Design Criteria*.

T9082

Table 4.3-2
Off-Normal Conditions

Room	Summer (Outside Air Temperature = 98°F)		Winter (Outside Air Temperature = -26°F)	
	Lights & Motors On	Lights & Motors Off	Lights & Motors On	Lights & Motors Off
Fuel Packaging Area	156°F	131°F	17°F	-26°F
Operating Gallery	138°F	125°F	-6°F	-26°F
Transfer Tunnel	163°F	137°F	-3°F	-26°F
Storage Area	154°F	128°F	-1°F	-26°F
Cask Receipt Area	149°F	109°F	35°F	-26°F

T9084

Table 4.7-1
Principle Load Carrying Members of the Cask Receipt Crane

Item / Component	Material Spec	Type/Grade	Notes
Structural and load carrying members	ASTM A 36	--	< 5/8"
	ASTM A 516	70	> 5/8" < 2 ½"
Equalizer Beam	ASTM A 572	--	--
Equalizer Support Beam	ASTM A 572	--	--
Main Girder	ASTM A 572	--	--
Bolting	ASTM A 325	--	--
Cables	IWRC 6 x 37	Improved Plow Steel	--
Drum	ASTM A 572	50	--

T9100

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Table 4.7-2
Principle Load Carrying Members of the Cask Trolley

Item/Component	Material Spec	Type/Grade	Notes
Structural and load carrying members	ASTM A 36	--	< 5/8"
	ASTM A 516	70	> 5/8" < 2 ½"
Bolting	ASTM A325 & A490	--	--
Rails	ASTM A 759	--	171 Bethlehem
Axles	ASTM A 322	4140 or 4340	--
Wheels	ASTM A 322	4140 or 4340	--
Seismic Lock Pin	ASTM A 322	4140 or 4340	--
Seismic Uplift Restraint	ASTM A 572	50	--

T9101

Table 4.7-3
Principal Load Carrying Members of the FHM and PMS

Item / Component	Material Spec	Type/Grade	Notes
Structural and load carrying members	ASME SA 36	--	< 5/8"
	ASME SA 537 or SA 516	Class 1 Grade 70	> 5/8" < 2 ½"
Bolting	SAE	Grade 5	--
Cables	IWRC 6 x 37	Improved Plow Steel	--
Axles	ASTM A 311	Class B, Grade 1144	--
Wheels	ASTM A 331	Grade 4140	--
Hook	ASTM A 331	Grade 4140	--
Rails	ASTM A 108	Grade 1044	--

T9103

Table 4.7-4
Principle Load Carrying Members of the Canister Trolley

Item / Component	Material Spec	Type/Grade	Notes
Structural and load carrying members	ASTM A 36	--	< 5/8"
	ASTM A 516	70	> 5/8" < 2½"
Bolting	ASTM A 325 and A 490	--	--
Axles	ASTM A 322	4140 or 4340	--
Wheels	ASTM A 322	4140 or 4340	--
Seismic Lock Pin	ASTM A 322	4140 or 4340	--
Seismic Uplift Restraints	ASTM A 572	Grade 50	--

T9104

Table 4.7-5
Canister Handling Machine Materials

Item / Component	Material Spec, Type/Grade
Bridge Components	
Bridge Girders	ASTM A36 (< 5/8") or ASTM A516 Grade 70 (> 5/8" < 2 ½")
Bridge End Tie Frame	
Bridge End Tie Cross Beam	
Trolley Frame	
Turret Components	
Turntable	ASTM A572 Grade 42/50 Type 1 or BS7191 Grade 355 EM
Turntable bolts	ASTM A490M Type 1 or BS970 817M40 'W'
Turret Body	ASTM A27 Grade U60-30 Class 2 or BS3100 Grade A1 Norm.
Turret body bolts	ASTM A490M Type 1 or BS970 826M40 'W'
Nose shield body	ASTM A27 GR. U60-30 Class 2 or BS3100 Grade A1 Norm.
Shield skirt	ASTM A27 Grade U60-30 Class 2 or BS3100 Grade A1 Norm.
Turret Rotate seismic lock pin	ASTM 108 Grade 1040 BS970 080M40N Heat Treat to 40,500 lb/in^2 Yield
Base locking pin	ASTM A434 Grade 4340 Class BD or BS970 817M40 'T'
Enclosure Structure	ASTM A572 GR. 50 Type 1 or BS7191 Grade 355 EM
Hoist Drum	ASTM A333 Grade 10 or BS HFS TUBE DIN 2448/1629 ST52.0
Wire Rope	Bridon Ropes 5/8in Diameter - 6 x 36 IWRC Grade 1960 with a min. breaking force of 40,200 lbs
Hoist Load Block	ASTM A508 Class 4a or BS4670 Grade 826M40
Grapple body	ASTM A434 Grade 4340 Class BC or BS970 709M40'T'
Grapple head	ASME SA516-60 or BS EN 10025 S355J2G3
Grapple jaws	ASTM A434 Grade 4340 Class BC or BS970 709M40'T'

T9105

Table 4.7-6
Fuel Handling Machine ITS Lifting Devices

Lifting Device No.	Device Type	Max. Load (lbs)	Function
1	1	8300	Provides a load path between the FHM hook and the Cask Lid, Cask Port Plug, Canister Port Plug, Process Waste Port Plug, Canister Waste Port and Monitor Shielding Cover.
2a	2	5150	Provides a load path between the FHM hook and the DOE Baskets that are lifted from the top of the basket. The baskets contain Peach Bottom 1 fuel.
2b	2	5150	Provides a load path between the FHM hook and the DOE Baskets that are lifted from the bottom of the basket. The baskets contain Peach Bottom 1 fuel.
3	3	1755	Provides a load path between the FHM hook and the DOE Canister containing Peach Bottom 2 and TRIGA fuel elements.
4	4	150	Provides a load path between the FHM hook and the Peach Bottom 1 Fuel Cans.
5	4	90	Provides a load path between the FHM hook and the individual Peach Bottom 1 Fuel Elements.
6	6	84	Provides a load path between the FHM hook and the individual Peach Bottom 2 Fuel Elements.
8	4	4354	Provides a load path between the FHM hook and the ISF Fuel Baskets.
11	4	90	Provides a load path between the FHM hook and the broken fuel element with fuel can from the de-caning station to the worktable.
12	3	2165	Provides a load path between the FHM hook and the ISF Peach Bottom Basket Handling Sleeve.
13	2	2165	Provides a load path between the FHM hook and the Shippingport Storage Liner.
14	1	5200	Provides a load path between the FHM hook and the Shippingport Fuel Module.
15a	5	16	Provides a load path between the FHM hook and the Shippingport Reflector Fuel Rods (external gripper)
15b	5	16	Provides a load path between the FHM hook and the Shippingport Reflector Fuel Rods (internal gripper)
16	3	200	Provides a load path between the FHM hook and the TRIGA Fuel Bucket.
17a	5	7.5	Provides a load path between the FHM hook and the instrumented TRIGA Fuel Element.
17b	4	7.5	Provides a load path between the FHM hook and the non-instrumented TRIGA Fuel Element.
18	4	955	Provides a load path between the FHM hook and the ISF TRIGA Fuel Rod Basket.

T9108

Table 4.7-7
Area Load Combinations

Primary Load Case	Load Combination					
	Normal	Off Normal	Accident Conditions			
			Earthquake	Tornado	Temperature	Flood
Dead Load	X	X	X	X	X	X
Live Load	X	X	X	X	X	X
Soil Pressure	X	X	X	X	X	X
Wind Load		X				
Normal Thermal		X	X	X		X
Seismic Load(1)			X			
Tornado Wind(1)				X		
Tornado Pressure(1)				X		
Tornado Missile(1)				X		
Accident Thermal (2)					X	
Flood Load						X

(1) Not evaluated for roof and wall panels and secondary steel (e.g., girts and purlins)

(2) Not evaluated for steel structures

T9110

Table 4.7-8
CRA Fundamental Frequencies and Mass Participation

Mode No.	Frequency (Hz.)	Mass Participation (% of mass)			Description
		N-S	E-W	Vertical	
1	2.441	0.05	63.59	0	Fundamental EW mode
4	2.798	22.37	0.06	0	Secondary steel NS mode
6	3.869	48.67	0.01	0.01	Overall Structure NS mode
27	11.319	1.64	0.47	5.70	Secondary steel Vertical mode
28	11.636	0.11	1.38	10.91	Fundamental Vertical mode
29	11.71	0.12	0.33	26.39	Fundamental Vertical mode

Total Participating Mass

Mode	Frequency (Hz)	Period (s)	Individual Mode			Cumulative Sum		
			N-S	E-W	Vertical	N-S	E-W	Vertical
354	107.95	0.009263	0.0	0.0	0.0	99.918	99.796	94.381

T9191

Table 4.7-9
CRA Structural Steel AISC Code Check

Member/Description	Load Combination	Local Member Forces/Moments			Critical ASIC Code Condition	C/D Ratio
		FX (kips)	MY (ft/kips)	MZ (ft/kips)		
76 - Southwest column above horizontal brace	64: SEISMIC	188.63	117.65	572.62	AISC – H1-3	1.97
876 – Battered column southeast corner tower	62: D+L+T+E	230.74	58.42	170.22	AISC – H1-1	1.49
269 – Horizontal brace at west side of tower	64: SEISMIC	20.68	0.53	11.44	AISC – H1-1	2.39
266 – Horizontal brace between battered columns	64: SEISMIC	40.26	27.68	195.8	AISC – H1-1	2.00

T9192

Table 4.7-10
CRA Mat Foundation Capacity/Demand Summary

Description	Envelope of Load Combinations			
	Area of Steel (in^2)	Capacity	Demand	C/D Ratio
4-Foot Thick Mat				
Boundary Moment (ft-kips/ft)	1.08	200	65.3	3.06
Out-of-Plane Shear (kips/ft)	n/a	54.2	20.8	2.61

T9193

Table 4.7-11
CRA Overturning and Sliding Results

Load Combination	Capacity/Demand Ratio (Sliding)	Capacity/Demand Ratio (Overturning)
East-West Direction		
Earthquake	1.13	1.70
Tornado Wind (East-West Wind)	1.14	1.11
North-South Direction		
Earthquake	1.15	2.11
Tornado Wind (North-South Wind)	1.28	1.70

T9194

Table 4.7-12
Transfer Area Fundamental Frequencies and Mass Participation

Mode No.	Frequency (Hz.)	Mass Participation (% of mass)			Description
		N-S	E-W	Vertical	
20	8.0997	20.4543	0.0002	0.0257	Fundamental mode (NS-direction)
21	8.12638	8.2367	0.0000	0.2010	Fundamental mode (NS-direction)
27	9.1419	12.6467	0.0082	0.0000	2nd fundamental mode (NS-direction)
70	13.9390	0.0022	19.1078	0.0269	Fundamental mode (EW-direction)
71	14.0015	0.0019	47.7259	0.0001	Fundamental mode (EW-direction)
179	28.86336	0.0039	0.6175	22.8683	Fundamental mode (Vert-direction)

Total Participating Mass

Mode	Frequency (Hz)	Period (s)	Individual Mode (%)			Cumulative Sum (%)		
			N-S	E-W	Vertical	N-S	E-W	Vertical
675	121.8	0.008207	0.0026	0.0022	0.0001	90.6578	93.4955	87.3304

T9195

Table 4.7-13
Transfer Area Mat Foundation Capacity/Demand Summary

Description	Envelope of Load Combinations Without Thermal				Envelope of Load Combinations With Thermal		
	Area of Steel (in^2/ft)	Capacity	Demand	C/D Ratio	Capacity	Demand	C/D Ratio
4-Foot Thick Mat							
Moment (ft-kips/ft)	1.08	200	122	1.64	200	193	1.04
Shear (kips/ft)	-	54.2	21.6	3.5	54.2	22.9	2.37
5-Foot Thick Mat							
Moment (ft-kips/ft)	1.30	600	400	1.5	600	516	1.16
Shear (kips/ft)	-	69.7	58.7	1.19	69.7	63.4	1.10
9-Foot Thick Mat							
Moment (ft-kips/ft)	2.33	1200	405	29.6	1200	542	2.21
Shear (kips/ft)	-	132	75.5	1.75	132	88.0	1.5

T9196

Table 4.7-14
Transfer Area Overturning and Sliding Results

Load Combination	Capacity/Demand Ratio (Sliding)	Capacity/Demand Ratio (Overturning)
East-West Direction		
Earthquake – Static Analysis Method	1.59	6.9
Earthquake – Seismic Analysis Method	1.26	5.5
Tornado Differential Pressure	121.8	529.1
Tornado Wind (East-West Wind)	17.3	75.2
Tornado Wind + 0.5 Differential Pressure	15.8	68.8
North-South Direction		
Earthquake – Static Analysis Method	1.87	4.2
Earthquake – Seismic Analysis Method	1.97	4.4
Tornado Differential Pressure	147.6	333.8
Tornado Wind (North-South Wind)	9.4	21.2
Tornado Wind + 0.5 Differential Pressure	8.9	20.1

T9197

Table 4.7-15
Transfer Area Reinforced Concrete Walls - Bending and Shear Capacity/Demand Summary

Wall Description	Area of Steel (in^2/ft)	Envelope of Load Combinations Without Thermal			Envelope of Load Combinations With Thermal		
		Demand	Capacity	C/D Ratio	Demand	Capacity	C/D Ratio
48 INCH WALL							
BENDING IN AXIS 1-1 (ft-kips/ft)	1.485	51.21	289.615	5.66	231.213	289.615	1.25
BENDING IN AXIS 2-2 (ft-kips/ft)	1.485	60.00	289.615	4.83	219.000	289.615	1.32
SHEAR (kips/ft)	-	24.00	50.17	2.09	36.000	67.400	1.87
36 INCH WALL							
BENDING IN AXIS 1-1 (ft-kips/ft)	1.988	22.99	278.752	12.12	227.057	278.752	1.23
BENDING IN AXIS 2-2 (ft-kips/ft)	1.988	44.00	278.752	6.34	169.000	278.752	1.65
SHEAR (kips/ft)	-	28.40	42.00	1.47	32.000	42.000	1.31
33 INCH WALL							
BENDING IN AXIS 1-1 (ft-kips/ft)	1.988	22.02	253.591	11.52	192.552	253.591	1.32
BENDING IN AXIS 2-2 (ft-kips/ft)	1.988	20.00	253.591	12.68	188.000	253.591	1.35
SHEAR (kips/ft)	-	24.00	38.464	1.60	34.000	38.464	1.13

T9198

Table 4.7-16
Transfer Area Shear Wall Capacity/Demand Summary

Wall Description	Concrete Section Shear Capacity Vc (kips/ft)	Rebar Capacity Vs (kips/ft)	Total Section Capacity ϕ(Vc+Vs) (kips/ft)	Shear Force Demand Vu (kips/ft)	Capacity/ Demand Ratio
North Wall EL: 3' - 0"	58.29	20.00	66.55	62.92	1.06
South Wall EL 3' - 0"	58.29	16.00	63.15	57.75	1.093
West Wall EL: 3' - 0"	43.72	12.00	47.36	35.98	1.316
East Wall EL: 3' - 0"	58.29	16.00	63.15	38.43	1.643
Tunnel East Wall EL: 3' - 0"	43.72	12.00	47.36	30.23	1.567
Tunnel West Wall EL: 3' - 0"	43.72	12.00	47.36	40.56	1.168

T9199

Table 4.7-17
Transfer Area Reinforced Concrete Slabs - Bending and Shear Capacity/Demand Summary

Slab Description	Area of Steel (in^2/ft)	Envelope of Load Combinations Without Thermal			Envelope of Load Combinations With Thermal		
		Demand	Capacity	C/D Ratio	Demand	Capacity	C/D Ratio
HIGH BAY AREA ROOF SLAB (24" Thick)							
BENDING (AXIS 1-1) (ft-kips/ft)	1.193	22.00	106.99	4.86	103.00	106.99	1.04
BENDING (AXIS 2-2) (ft-kips/ft)	1.193	22.00	106.99	4.86	103.00	106.99	1.04
SHEAR (kips/ft)	-	8.00	22.19	2.77	14.00	26.85	1.92
FPA ROOF SLAB (36" Thick)							
BENDING (AXIS 1-1) (ft-kips/ft)	1.841	66.00	259.00	3.92	246.00	259.00	1.05
BENDING (AXIS 2-2) (ft-kips/ft)	1.841	20.00	259.00	12.95	214.00	259.00	1.21
SHEAR (kips/ft)	-	8.00	35.10	4.39	14.00	42.10	3.01
CCA AREA ROOF SLAB (36" Thick)							
BENDING (AXIS 1-1) (ft-kips/ft)	2.227	50.00	308.66	6.17	263.00	308.66	1.17
BENDING (AXIS 2-2) (ft-kips/ft)	2.227	40.00	308.66	7.72	228.00	308.66	1.35
SHEAR (kips/ft)	-	12.00	31.58	2.63	25.00	41.85	1.67
CCA FLOOR SLAB (36" Thick)							
BENDING (AXIS 1-1) (ft-kips/ft)	1.988	66.00	171.41	2.60	131.00	171.41	1.31
BENDING (AXIS 2-2) (ft-kips/ft))	1.193	40.00	171.41	4.29	108.00	171.41	1.59
SHEAR (kips/ft)	1.193	19.00	42.34	2.23	26.00	42.33	1.63

T9200

Table 4.7-18
Storage Area Fundamental Frequencies and Mass Participation

Mode No.	Frequency (Hz)	Mass Participation (% of mass)			Description
		N-S	E-W	Vertical	
16	6.9	0.00	6.83	0.00	CHM in East-West Direction
21	7.9	6.87	0.00	0.05	CHM in North-South Direction
31	10.6	0.00	0.00	3.47	East Vault in Vertical Direction
45	12.9	0.00	0.44	6.04	West Vault in Vertical Direction
47	14.8	0.00	53.19	0.23	Building in East-West Direction
57	17.1	0.46	0.00	4.74	CHM in Vertical Direction
75	22.2	30.49	0.00	0.00	Building in North-South Direction
112	28.3	0.04	0.77	5.19	Tunnel Roof in Vertical Direction

Total Participating Mass

Mode	Frequency (Hz)	Period (s)	Individual Mode (%)			Cumulative Sum (%)		
			N-S	E-W	Vertical	N-S	E-W	Vertical
650	121.8	0.007505	0.0264	0.0017	0.0175	93.3284	92.1359	89.2892

T9201

Table 4.7-19
Relative Seismic Displacements for ISF Structures

Description Structure Interface	Relative Displacement (in)		
	N-S	E-W	Vertical
Between Storage Area and Transfer Area at Transfer Tunnel			
Top	0.16	0.073	-
Bottom	0.067	0.054	0.092
Between Storage Area and CRA			
Top	0.18	0.082	-
Bottom	0.041	0.044	0.025
Between Charge Face and Vault Base			
Storage Transfer Port and Vault Base	0.0058	0.0126	0.0126
Middle of West Storage Vault and Vault Base	0.0052	0.0163	0.0456
Middle of East Storage Vault and Vault Base	0.0031	0.0164	0.0942

T9202

Table 4.7-20
Storage Area Mat Foundation Capacity/Demand Summary

Description	Envelope of Load Combinations Without Thermal				Envelope of Load Combinations With Thermal		
	Area of Steel (in^2)	Capacity	Demand	C/D Ratio	Capacity	Demand	C/D Ratio
3-Foot Thick Mat							
Moment (ft-kips/ft)	1.53	200	105	1.90	200	174	1.15
Shear (kips/ft)	-	38.7	24.2	1.60	38.7	34.6	1.12
4-Foot Thick Mat							
Moment (ft-kips/ft)	1.64	300	155	1.94	300	224	1.34
Shear (kips/ft)	-	54.2	30.5	1.78	54.7	40.9	1.34

T9203

Table 4.7-21
Storage Area Overturning and Sliding Results

Load Combination	Capacity/Demand Ratio (Sliding)	Capacity/Demand Ratio (Overturning)'
East-West Direction		
Earthquake – Static Analysis Method	1.23*	3.4
Earthquake – Seismic Analysis Method	1.45	4.5
Tornado Wind (East-West Wind)	7.97	24.9
Tornado Wind + 0.5 Differential Pressure	7.27	22.7
North-South Direction		
Earthquake – Static Analysis Method	1.56	4.3
Earthquake – Seismic Analysis Method	2.41	5.1
Tornado Wind (North-South Wind)	7.58	20.7
Tornado Wind + 0.5 Differential Pressure	6.91	18.9

Notes:
(1) Includes contribution from passive earth pressure.

T9204

Table 4.7-22
Storage Area Reinforced Concrete Walls - Bending and Shear Capacity/Demand Summary

Wall Description	Area of Steel (in^2/ft)	Envelope of Load Combinations Without Thermal			Envelope of Load Combinations With Thermal		
		Demand	Capacity	C/D Ratio	Demand	Capacity	C/D Ratio
36 INCH WALL							
BENDING IN AXIS 1-1 (ft-kips/ft)	2.97	35.65	404.23	11.34	352.10	404.23	1.15
BENDING IN AXIS 2-2 (ft-kips/ft)	2.454	40.00	340.34	8.51	278.00	340.34	1.22
SHEAR (kips/ft)	-	12.50	41.85	3.34	36.00	41.85	1.16

T9205

Table 4.7-23
Storage Area Shear Wall Capacity/Demand Summary

Wall Description	Concrete Section Shear Capacity Vc (kips/ft)	Rebar Capacity Vs (kips/ft)	Total Section Capacity ϕ(Vc+Vs) (kips/ft)	Shear Force Demand Vu (kips/ft)	Capacity/ Demand Ratio
North Wall EL: 3'-0"	43.72	8.00	43.96	39.02	1.13
South Wall EL: 3'-0"	43.72	8.00	43.96	30.98	1.42
West Wall EL: 3'-0"	43.72	8.00	43.96	16.04	2.74
East Wall EL: 3'-0"	43.72	8.00	43.96	16.40	2.68
Intermd. Wall @ Y= 128.5' EL: 3'-0"	43.72	8.00	43.96	17.21	2.55
Intermd. Wall @ Y= 103.25 EL: 3'-0"	43.72	8.00	43.96	15.67	2.81

T9206

Table 4.7-24
Storage Area Reinforced Concrete Slabs - Bending and Shear Capacity/Demand Summary

Slab Description	Area of Steel (in^2/ft)	Envelope of Load Combinations Without Thermal			Envelope of Load Combinations With Thermal		
		Demand	Capacity	C/D Ratio	Demand)	Capacity)	C/D Ratio
SLAB OVER THE TRANSFER TUNNEL (36" Thick)							
BENDING (AXIS 1-1) (ft-kips/ft)	1.988	70.00	280.43	4.01	215.00	280.43	1.30
BENDING (AXIS 2-2) (ft-kips/ft)	1.988	92.00	280.43	3.05	267.00	280.43	1.05
SHEAR (kips/ft)		19.00	42.33	2.23	39.00	42.33	1.09
GRID BEAMS OVER VAULTS (30" Thick)							
BENDING (AXIS 1-1) (ft-kips/ft)	4.909	192.56	483.96	2.51	-	-	-
BENDING (AXIS 2-2) (ft-kips/ft)	2.454	110.29	267.32	2.42	-	-	-
SHEAR (kips/ft)	0.22	16.13	57.35	3.56	-	-	-

T9207

Table 4.7-25
Cask Receipt Crane Summary of Analysis Results

Component	Shear Stress Ratio(1)		Combined Axial and Bending Stress Ratio(2)	
	Load Case	Stress Ratio	Load Case	Stress Ratio
Equalizer Beam	Test Case 3.2	0.72	Test Case 3.2	0.32
Equalizer Support Beam	Test Case 3.2	0.33	Seismic Case 3.1	0.53
Main Girder	Test Case 3.2	0.24	Seismic Case 3.1	0.29

Notes:

(1) Shear Stress Ratio = $f_v/F_v \leq 1.0$

(2) Combined Axial and Bending Stress Ratio ≤ 1.0 (in accordance with CMAA 70, Section 3.4.6.3)

T9117

Table 4.7-26
Cask Trolley Summary of Analysis Results
(Design Earthquake - Load Case 3.4)

Component	Shear Stress Ratio[1]		Combined Axial and Bending Stress Ratio[2]	
	f_{vy}/F_v	f_{vz}/F_v	Compression	Tension
Trucks and Girts	0.558	0.303	0.570	0.564
Horizontal Framing Members	0.246	0.631	0.641	0.613
Vertical Framing Members	0.276	0.927	0.744	0.782
Horizontal Braces	---	---	0.556	0.470
Vertical Braces	---	---	0.496	0.206
Cask Adapter Restraints	---	---	---	0.506

(1) Shear Stress Ratio
f_{vy}/F_v = Y-direction
f_{vz}/F_v = Z-direction

(2) Combined Axial and Bending Stress Ratio ≤1.0 (in accordance with CMAA 70, Section 3.4.6.3)

T9189

Table 4.7-27
Canister Trolley Summary of Analysis Results
(Design Earthquake Load Case 3.4)

Component	Shear Stress Ratio(1)		Combined Axial and Bending Stress Ratio(2)	
	f_{vy}/F_v	f_{vz}/F_v	Compression	Tension
Trucks and Girts	0.547	0.692	0.896	0.896
Horizontal Framing Members	0.869	0.122	0.905	0.840
Vertical Framing Members	0.102	0.013	0.793	0.710
Horizontal Braces	---	---	0.543	0.386
Vertical Braces	---	---	0.603	0.361

(1) Shear Stress Ratio
f_{vy}/F_v = Y-direction
f_{vz}/F_v = Z-direction

(2) Combined Axial and Bending Stress Ratio ≤1.0 (in accordance with CMAA 70, Section 3.4.6.3)

T9190

Table 4.7-28
FHM Bounding Case Stress Summary

Summary of Plate Shear Stresses – Trolley at End Span
Case 3.6A – Loaded Crane Subject to Loads Associated With Bridge Recovery

Description	Stress (psi)	Allowable (psi)	Stress Ratio
Bridge – End Beam	7733	19,780	0.391
Bridge – Main Beam	11,690	19,780	0.591
Trolley – End Beam	2815	19,780	0.142
Trolley – Main Beam	2513	19,780	0.127
Trolley – End Plate	1950	21,500	0.091
Wheel Assembly – PL	3328	21,500	0.155
Bridge – End PL	11,481	21,500	0.534
Wheel Assembly - PL	6092	21,500	0.283
Wheel Assembly - PL	7766	21,500	0.361
Rail	754	15,480	0.049

Note:

$$\text{Stress Ratio} = \frac{\text{Actual Stress}}{\text{Allowable Stress}}$$

T9173

Table 4.7-29
FHM Stress Summary, Loaded Crane with Design Earthquake

Summary of Plate Shear Stresses – Trolley at End Span
Case 3.3, Loaded Crane with Design Earthquake

Description	Stress (psi)	Allowable (psi)	Stress Ratio
Bridge – End Beam	7911	23000	0.344
Bridge – Main Beam	11066	23000	0.481
Trolley – End Beam	4402	23000	0.191
Trolley – Main Beam	3689	23000	0.160
Trolley – End Plate	5873	25000	0.235
Wheel Assembly – PL	6022	25000	0.241
Bridge – End PL	13,350	25000	0.534
Wheel Assembly - PL	12450	25000	0.498
Wheel Assembly - PL	15818	25000	0.633
Rail	2615	18000	0.145

Note:

$$\text{Stress Ratio} = \frac{\text{Actual Stress}}{\text{Allowable Stress}}$$

T9174

Table 4.7-30
Canister Handling Machine Structural Components Factors of Safety

CHM Component	Lowest Factor of Safety (1) Seismic Loadings (Load Case 4.1)
Bridge Girders	2.50
Bridge End Tie	1.08
Trolley Frame	1.41
Turntable	2.65
Canister Hoist Drum and Drive System	1.45
Hoist Ropes	1.19
Canister Grapple	1.30

(1) Factor of Safety = (Allowable Stress ÷ Actual Calculated Stress)

T9175

Table 4.7-33
Value of k_{eff} for Various ISF Storage Canisters

Fuel Type	Normal			Bounding Analysis[1]		
	Desc.	Ref. #[2]	keff	Desc.	Ref. #[2]	keff
Peach Bottom	1 canister with 10 elements	3.3	0.22	Infinite canister array flooded	3.4	0.50
TRIGA	1 canister with 2 baskets of 54 elements each	2.4	0.57	Infinite canister array flooded	2.3	0.84
Shippingport	1 canister with 1 assembly	4.1	0.19	Infinite rod array flooded	4.1	0.65

(1) Off-normal and accident conditions are addressed by the bounding data

(2) The reference number corresponds to the Section number of Appendix 4A to the SAR, *Criticality Models*

Table 4.7-31
Value of k_{eff} for Fuel in DOE-provided Transfer Cask

Fuel Type	Normal			Bounding Analysis[2]		
	Desc.	Ref. #[1]	keff	Desc.	Ref. #[1]	keff
Peach Bottom	1 DOE canister with 18 canned PB-1 elements	3.3	0.33	14 Crushed elements	3.2	0.92
				37 Close-packed elements	3.3	0.55
TRIGA	1 DOE canister with 90 elements in 3 levels of 30 each	2.1	0.38	48 closed-packed elements in a corner	2.5	0.93

(1) The reference number corresponds to the Section number of Appendix 4A to the SAR, *Criticality Models*

(2) Appendix A, Safety Evaluation of DOE-Provided Transfer Cask, describes the analyses to be performed for transfer cask off-normal and accident conditions

Table 4.7-32
Value of k_{eff} for Fuel in FPA[2]

Fuel Type	Normal			Off Normal			Accident			Bounding Analysis		
	Desc.	Ref. #[1]	keff	Desc.	Ref. #[1]	keff	Desc.	Ref. #[1]	keff	Desc.	Ref. #[1]	keff
Peach Bottom	2 baskets with 18 elements each end to end	3.3	0.33	2 baskets with 18 elements each placed side by side	3.3	0.54	12 Crushed	3.2	0.90	14 Crushed	3.2	0.92
	1 DOE canister with 18 elements	3.3	0.33	18 elements with 1 additional element added to 1 side	3.3	0.34				37 Close Pack	3.3	0.55
	1 ISF canister with 10 elements	3.3	0.22									
TRIGA	1 basket with 54 elements	2.4	0.57	2 baskets of 54 elements each placed side by side	2.2	0.79	See Bounding	–	–	48 in a corner	2.5	0.93
	1 canister with 2 baskets containing 54 elements each	2.4	0.57									

(1) The reference number corresponds to the Section number of Appendix 4A to the SAR, *Criticality Models*

(2) The Shippingport fuel does not represent a criticality hazard as described in Appendix A, Section 4.1.

FIGURE 4.1-1
ISF Facility Site Plan

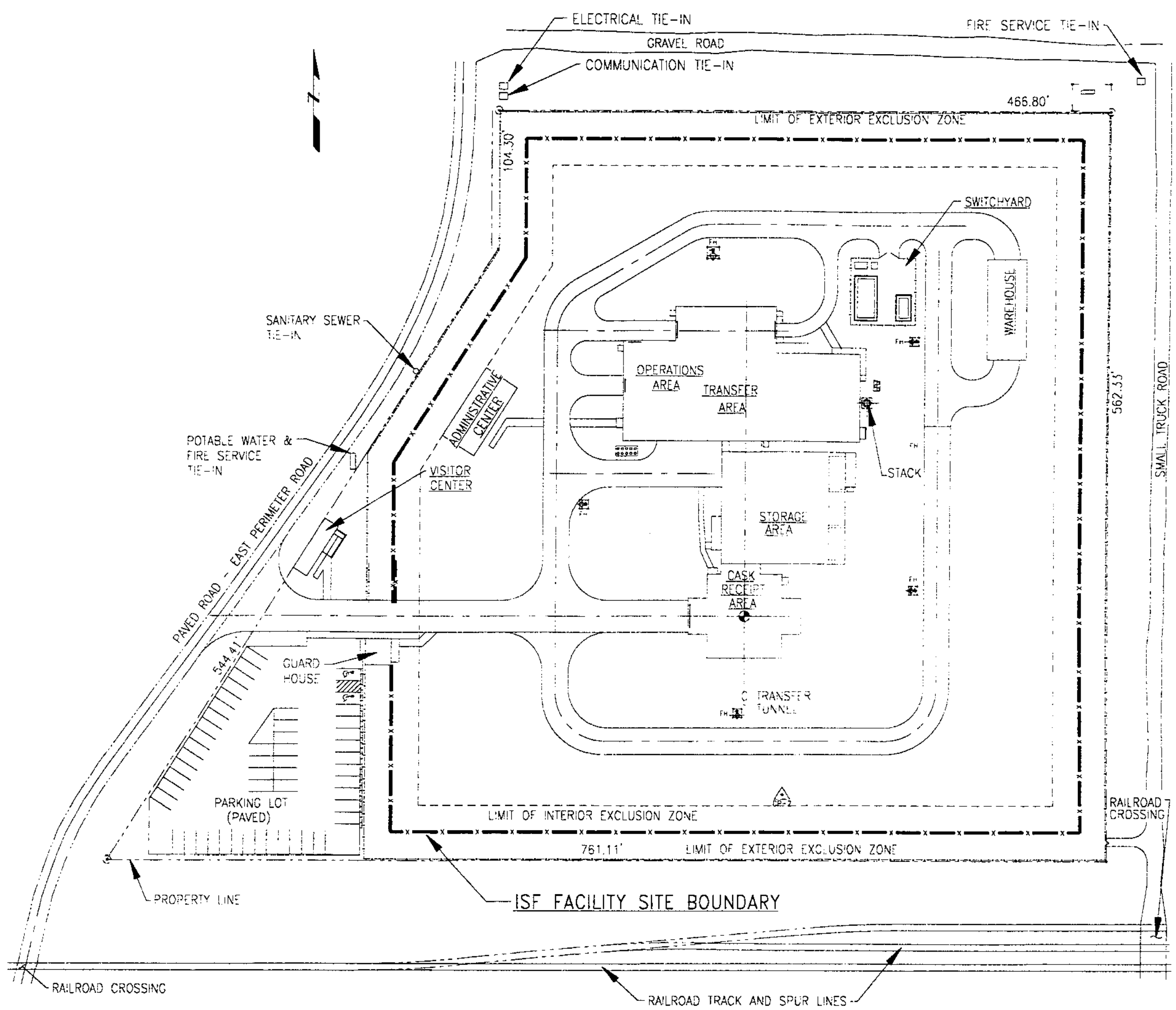


Figure 4.2-1
General Arrangement, First Floor

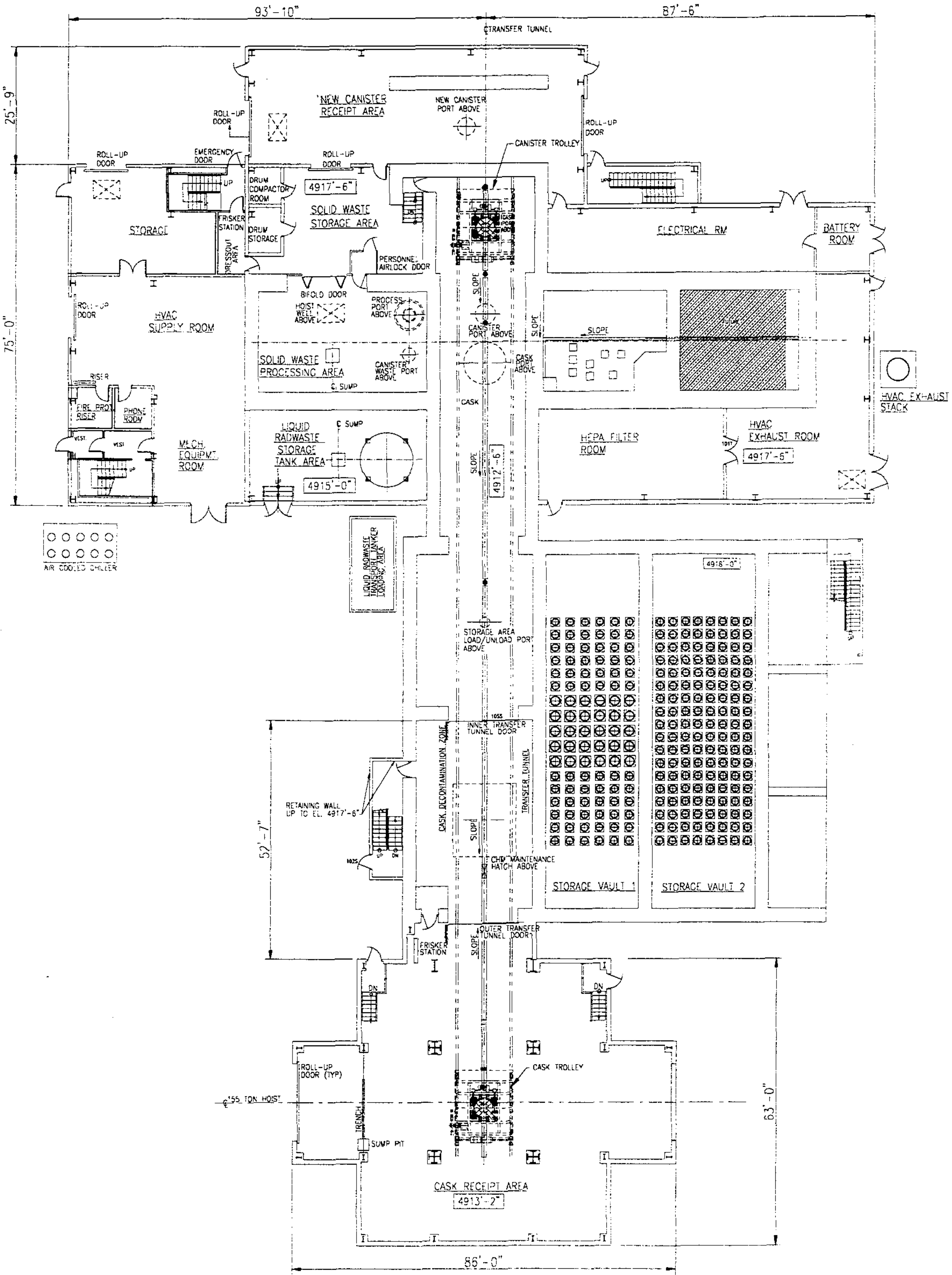


Figure 4.2-2
General Arrangement, Second Floor

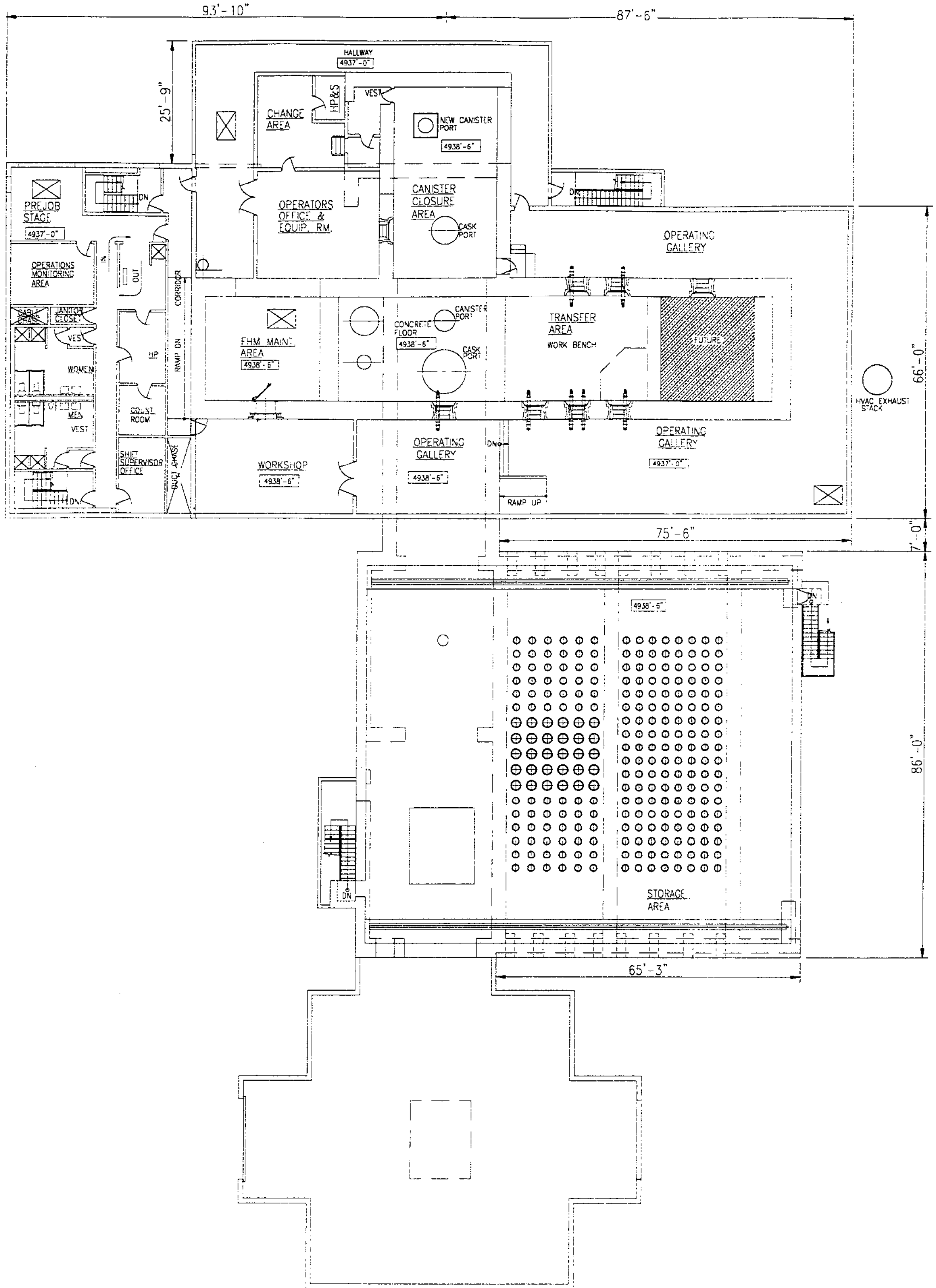


Figure 4.2-3
Storage Vault Plan View

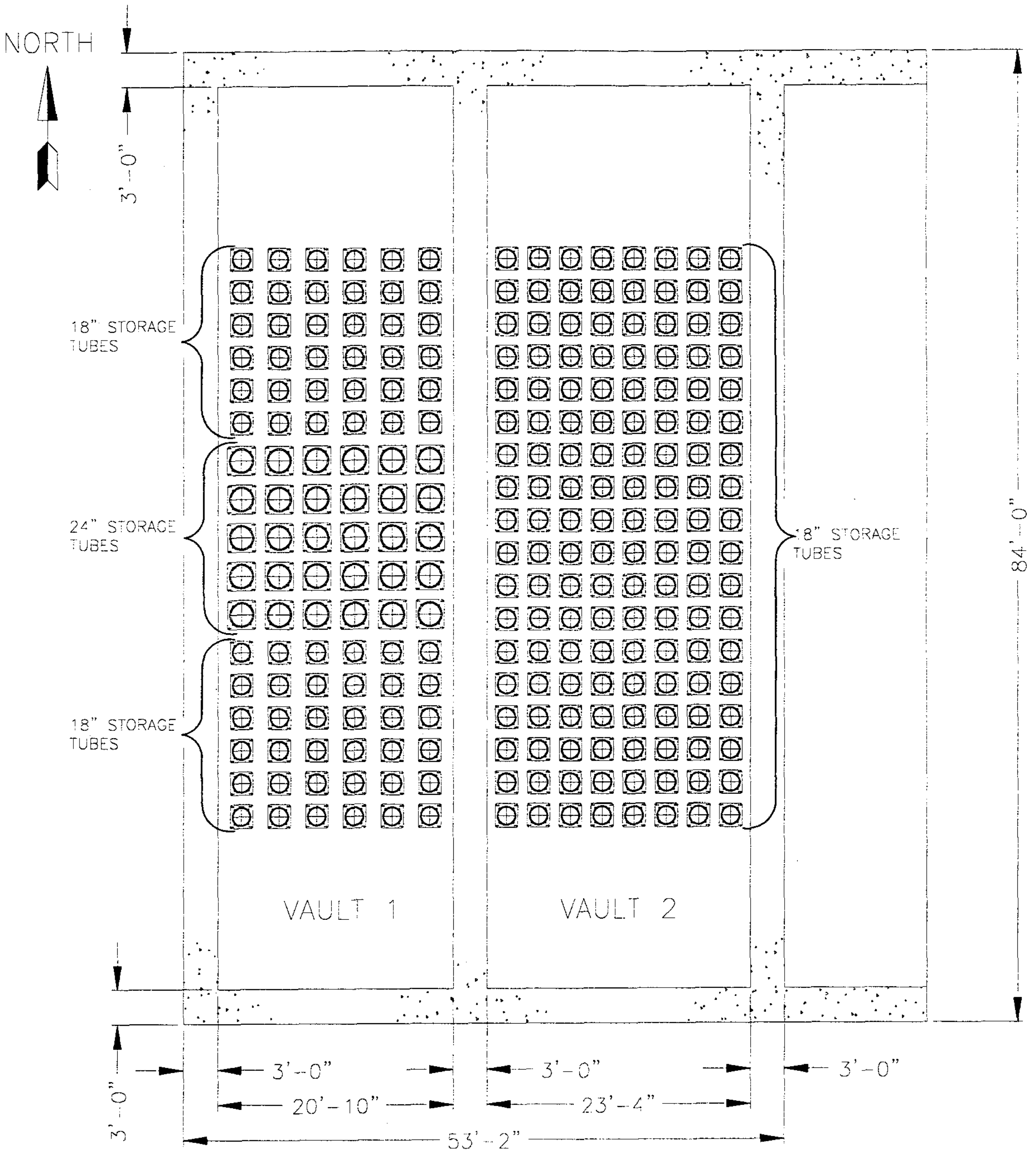


Figure 4.2-4
Storage Area Looking West

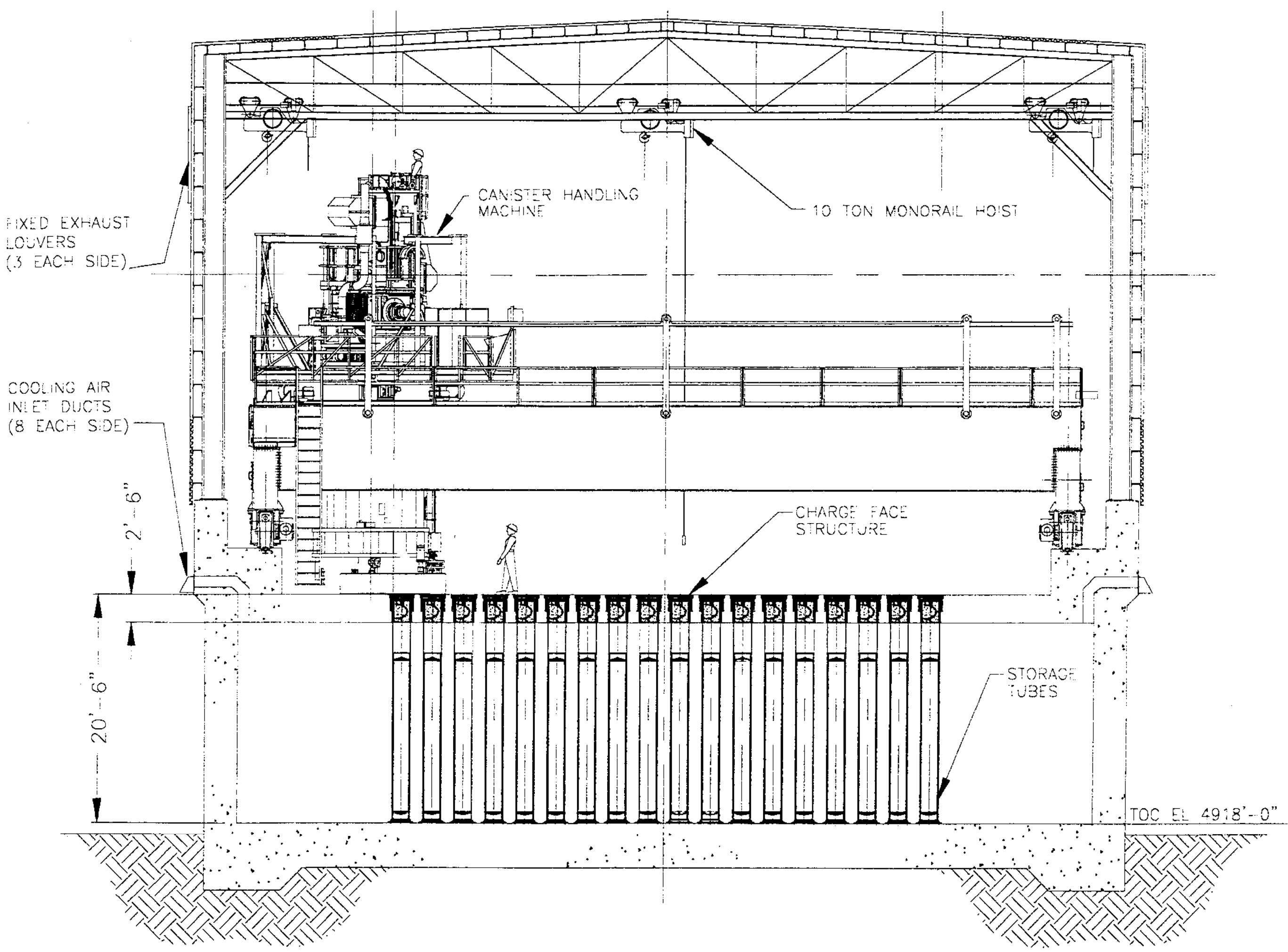


FIGURE 4.2-5
Storage Vault Section Looking North

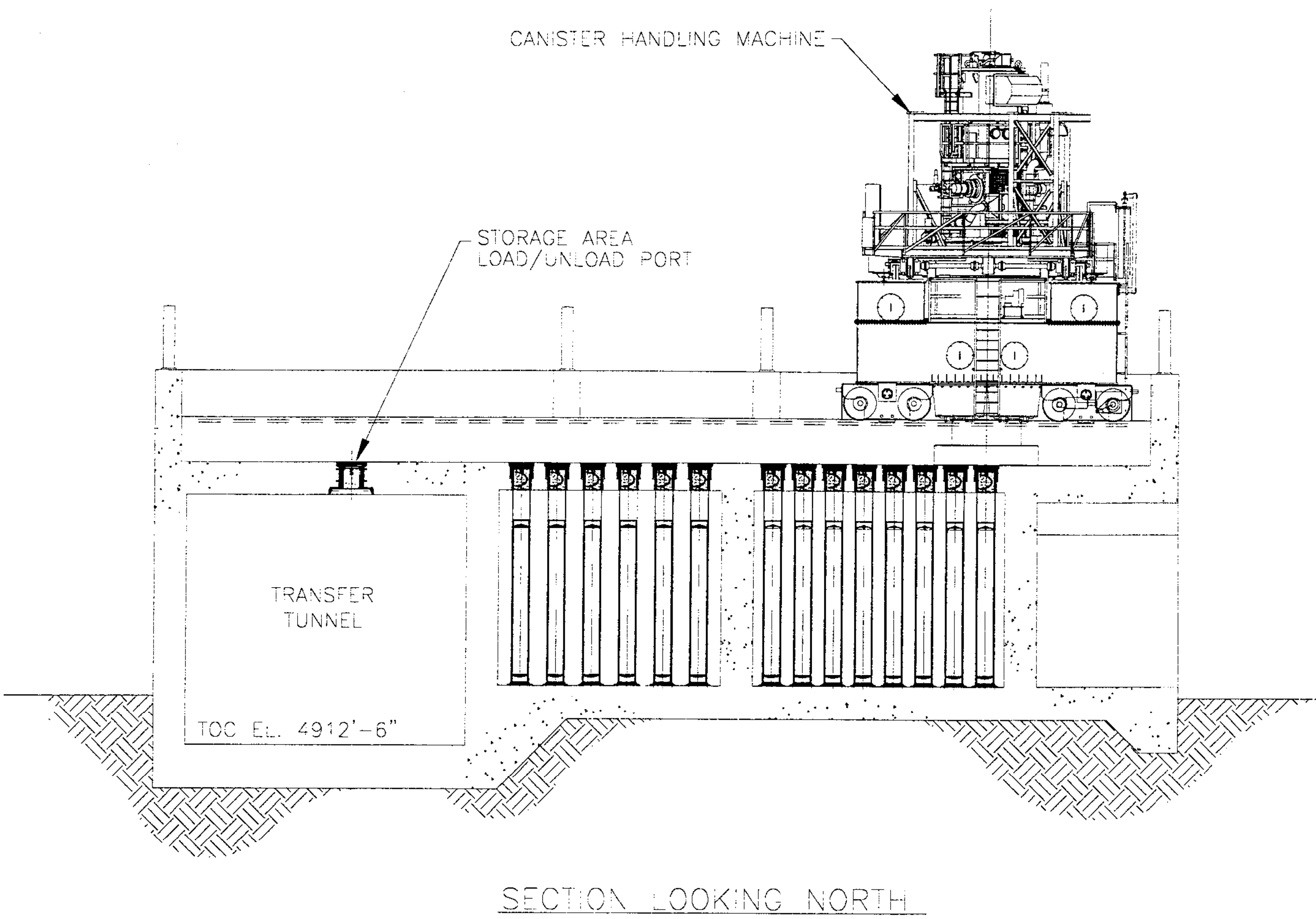


Figure 4.2-6
Storage Tube Assembly

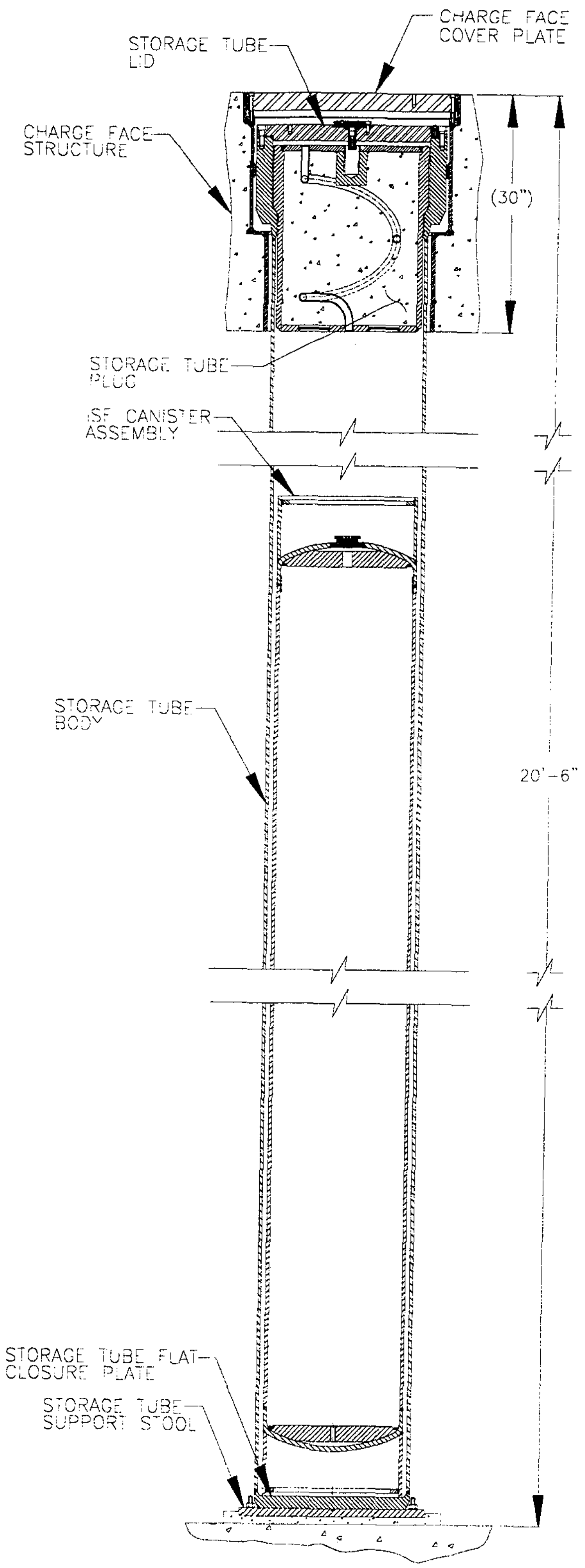


Figure 4.2-7
ISF Canister and Basket Assemblies

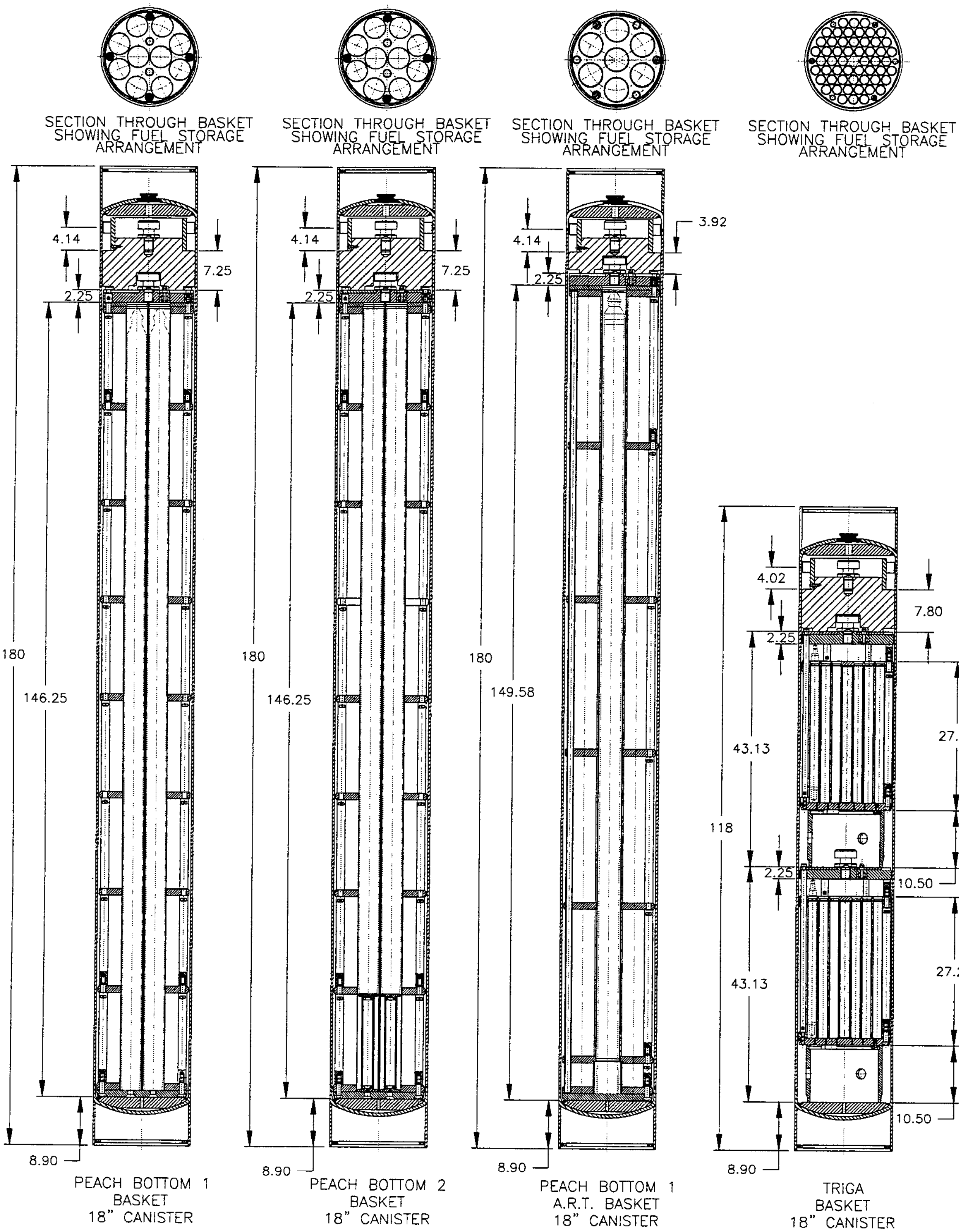


Figure 4.2-8
ISF Canister and Basket Assemblies

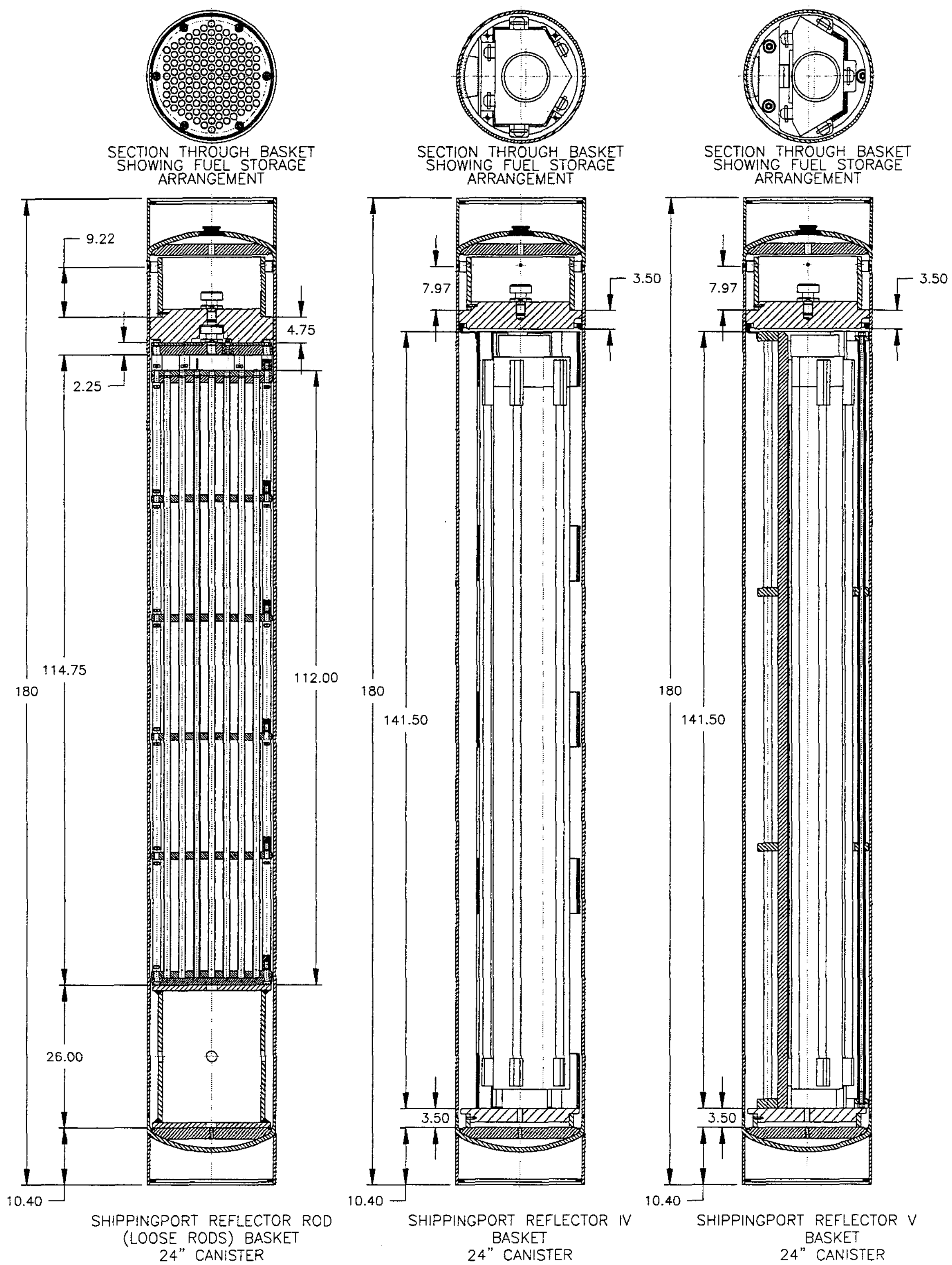


Figure 4.2-9
Location of Storage Area Relative to Transfer Area

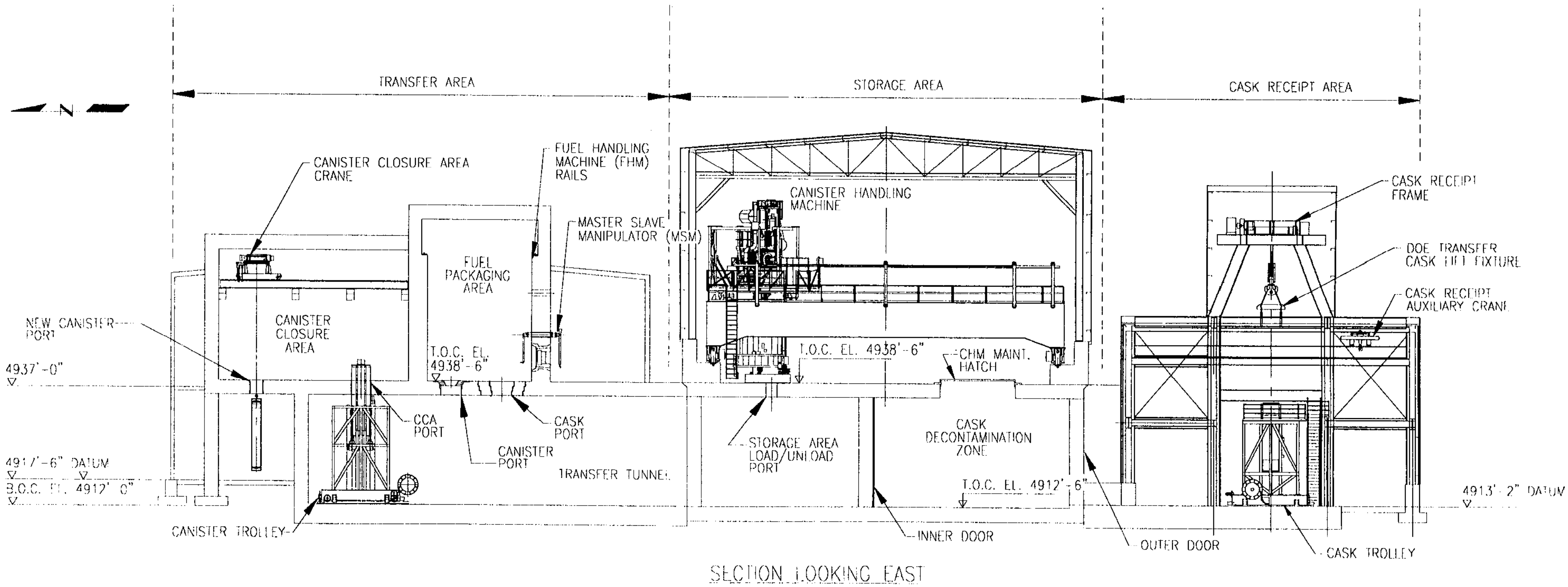


FIGURE 4.2-10
Storage Tube Air Flow

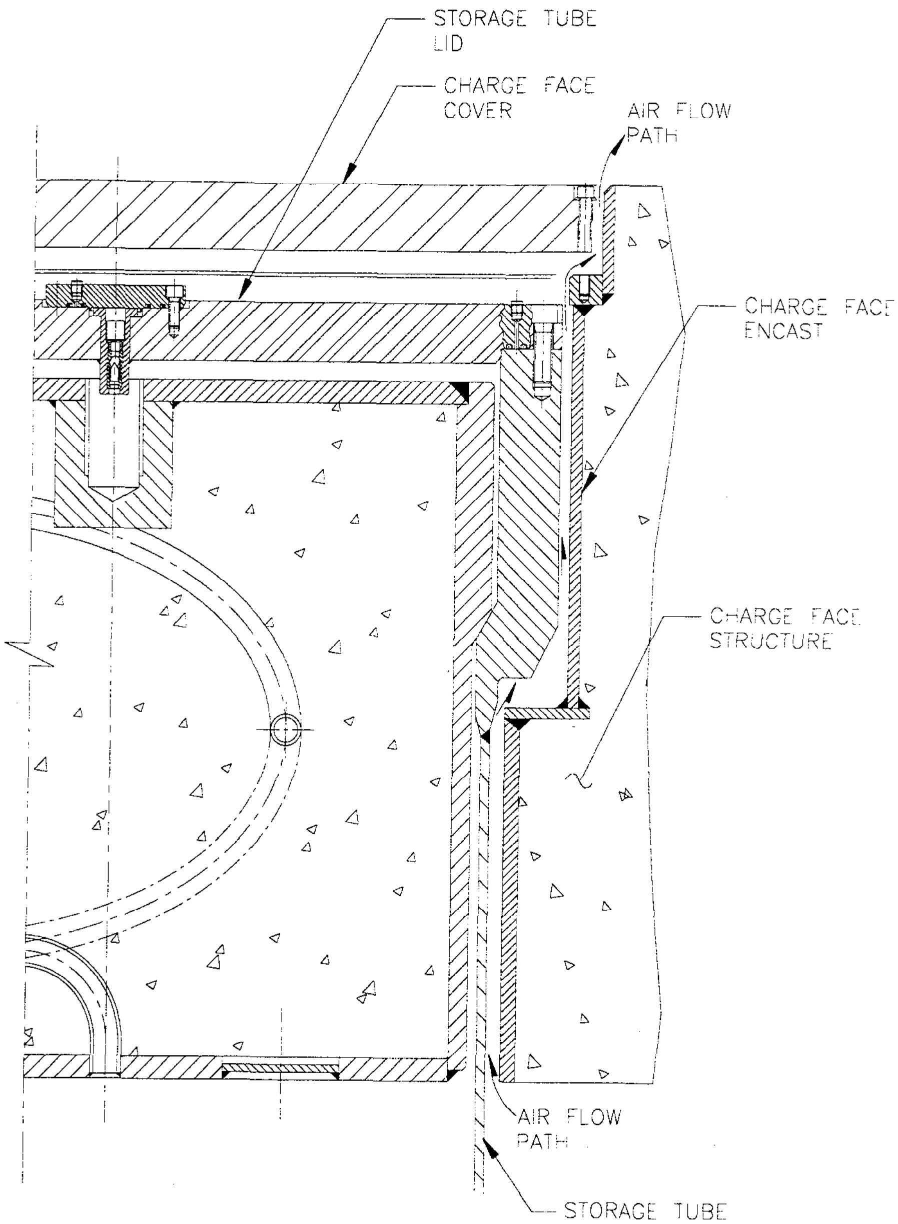


Figure 4.2-11
Storage Tube Closure Assembly

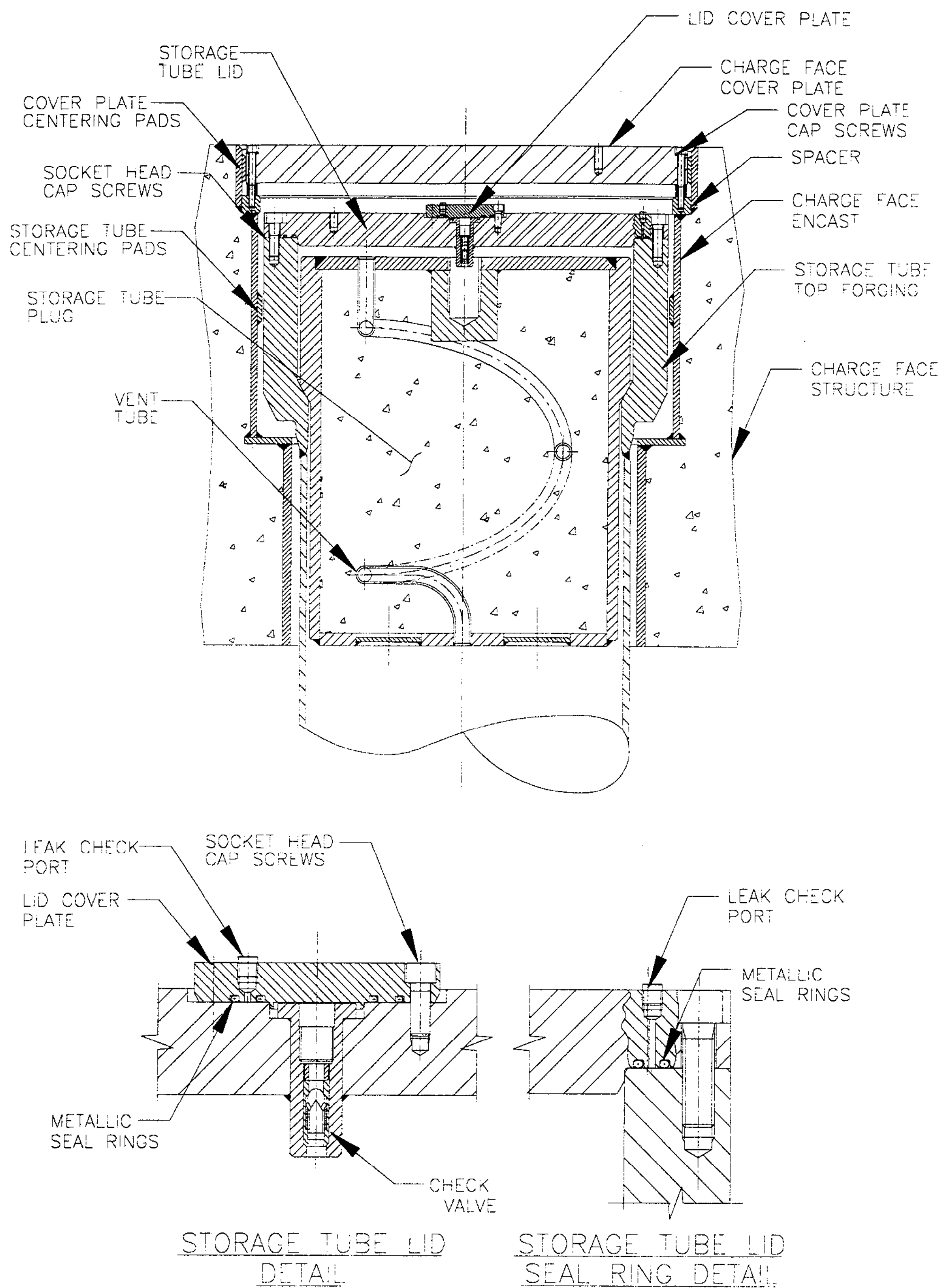


Figure 4.2-12
Tube Plug Lifting Pintle and Guide Ring

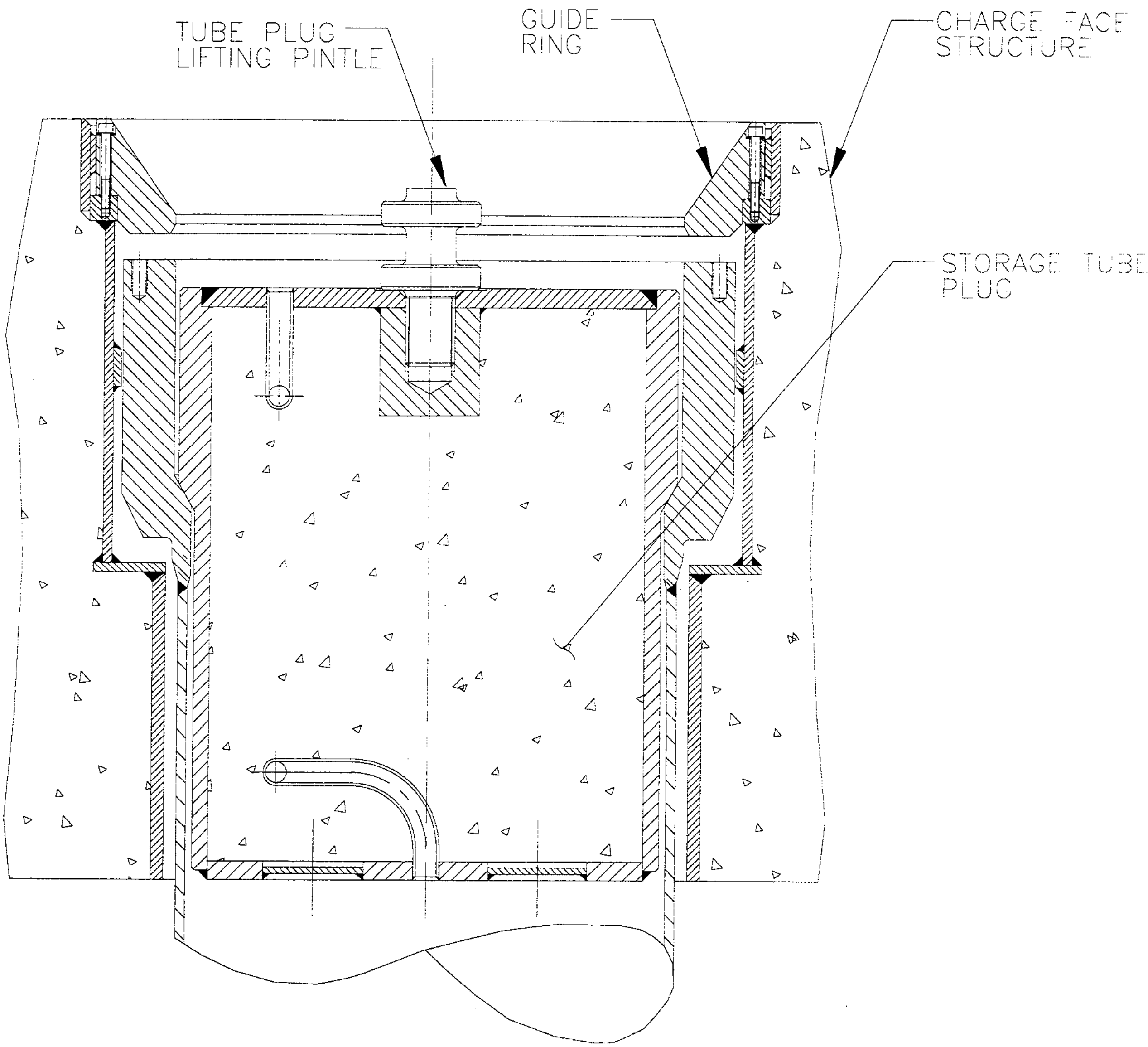


Figure 4.2-13
Support Stool Assembly

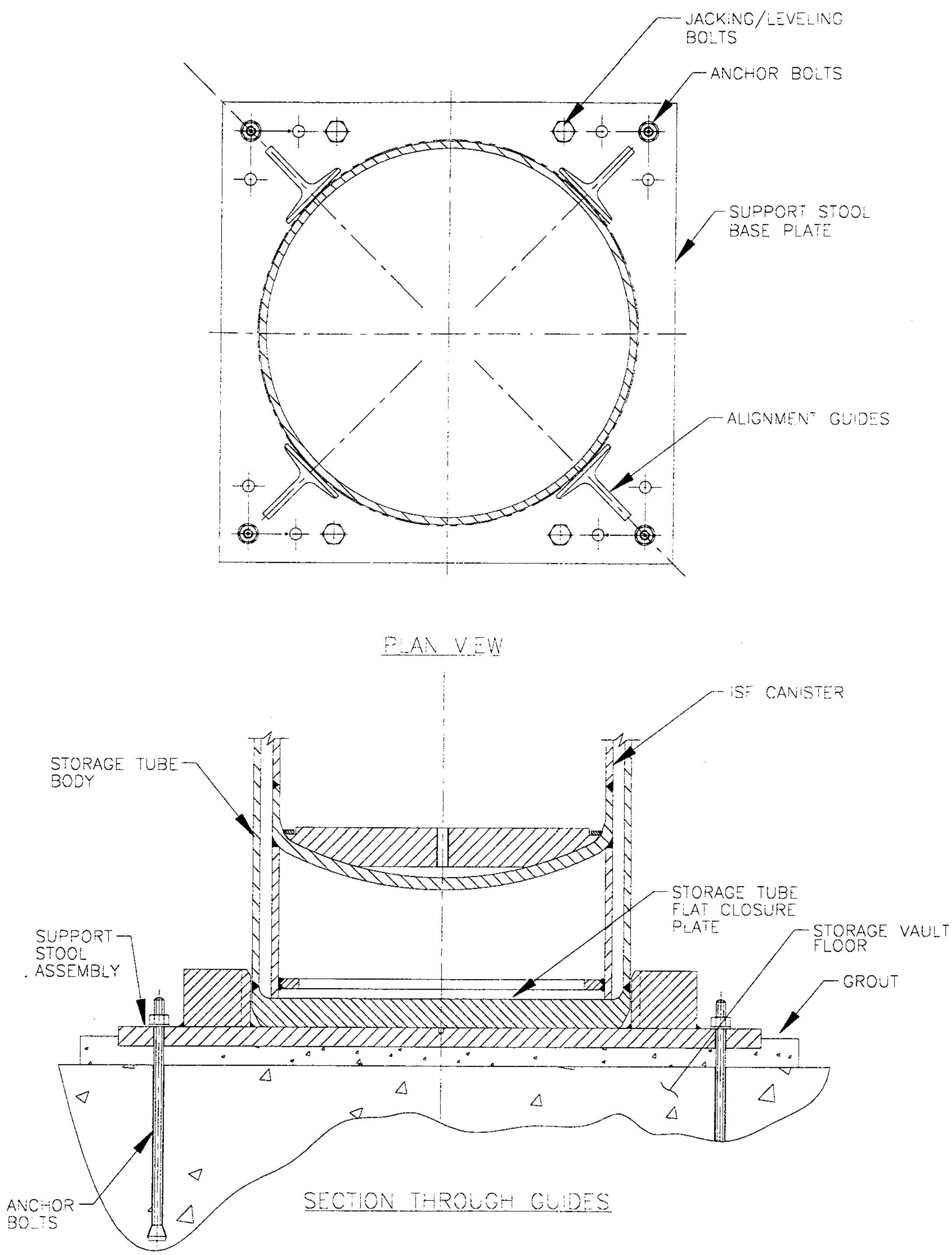


Figure 4.2-14
Storage Tube Plug Lifting Adapter

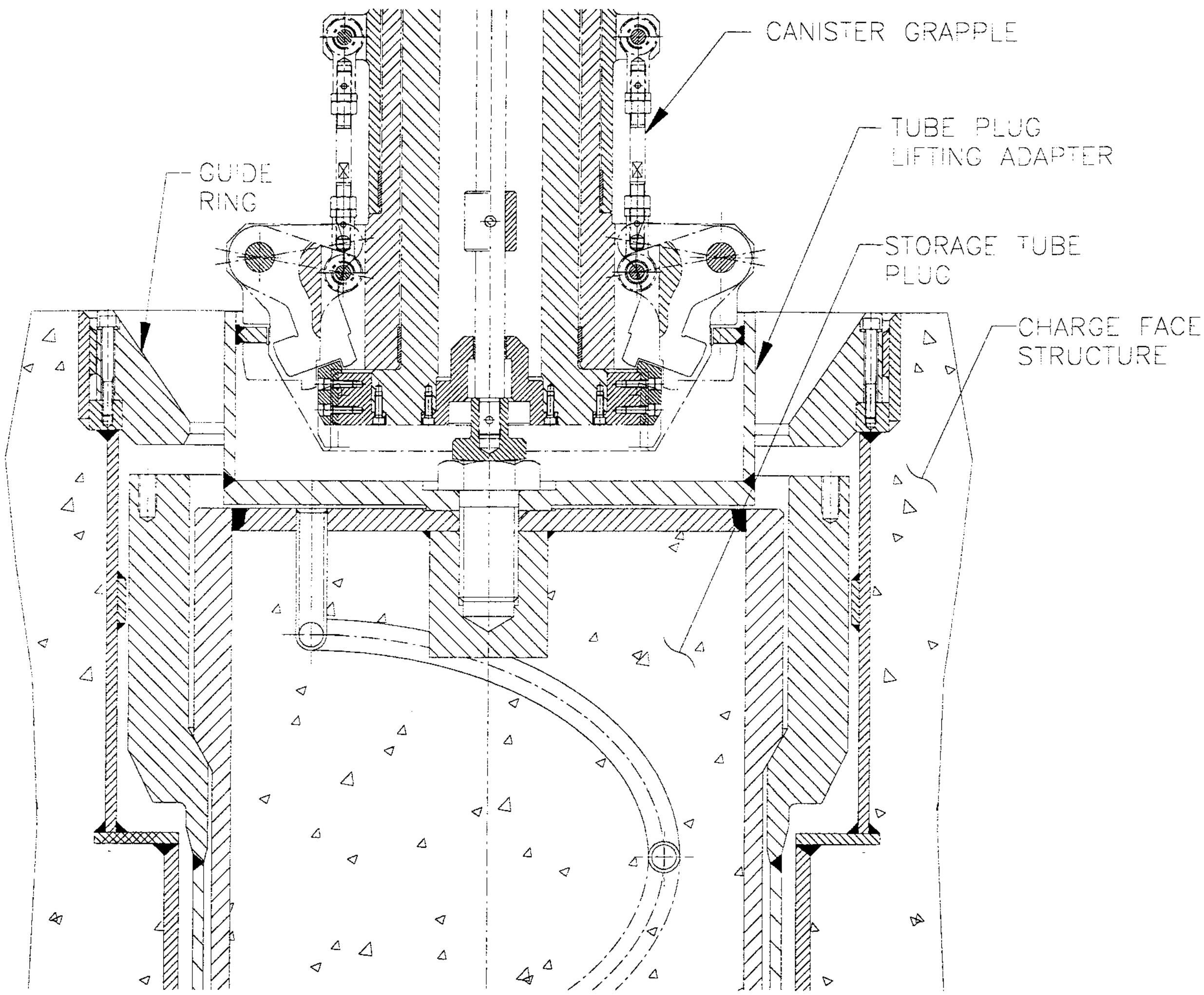


FIGURE 4.2-15
ISF Canister

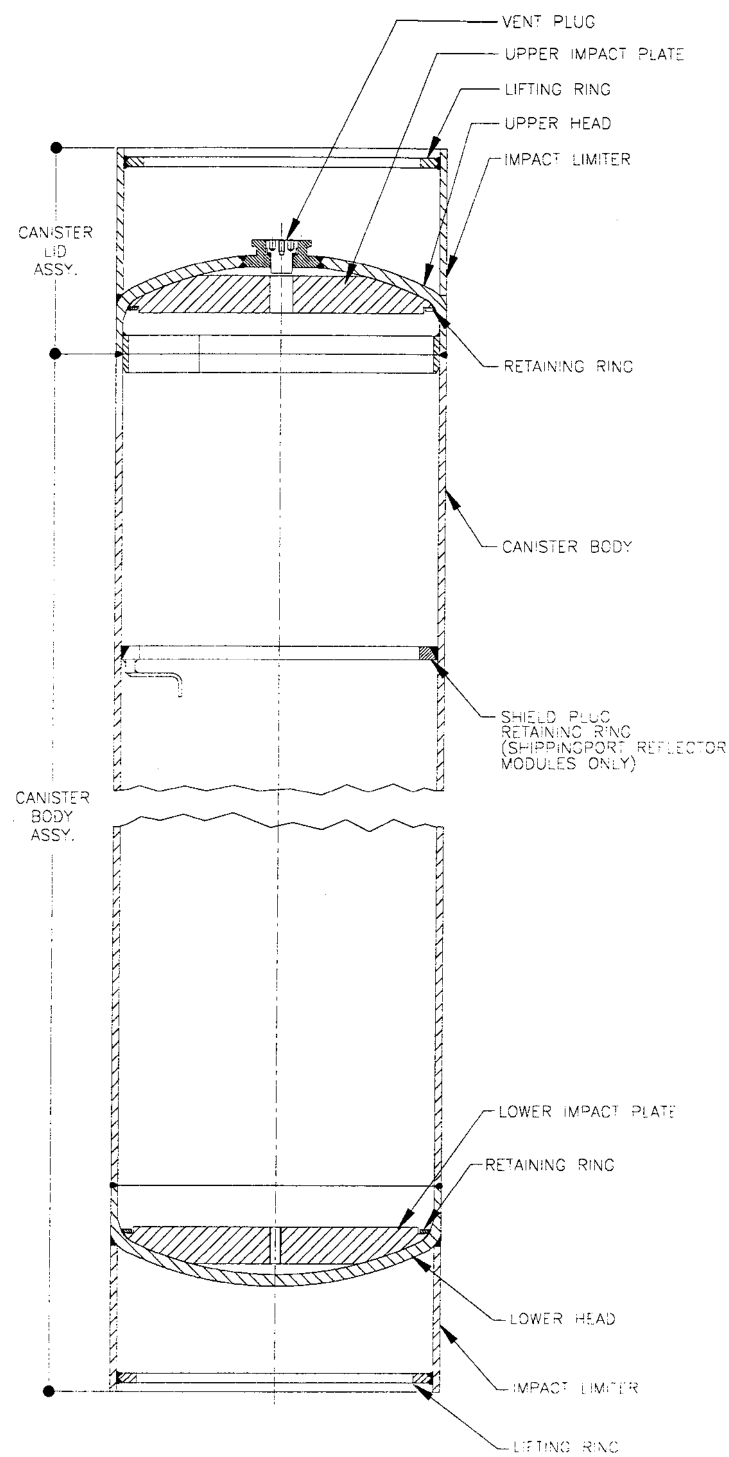


Figure 4.2-16
Canister Shield Plug

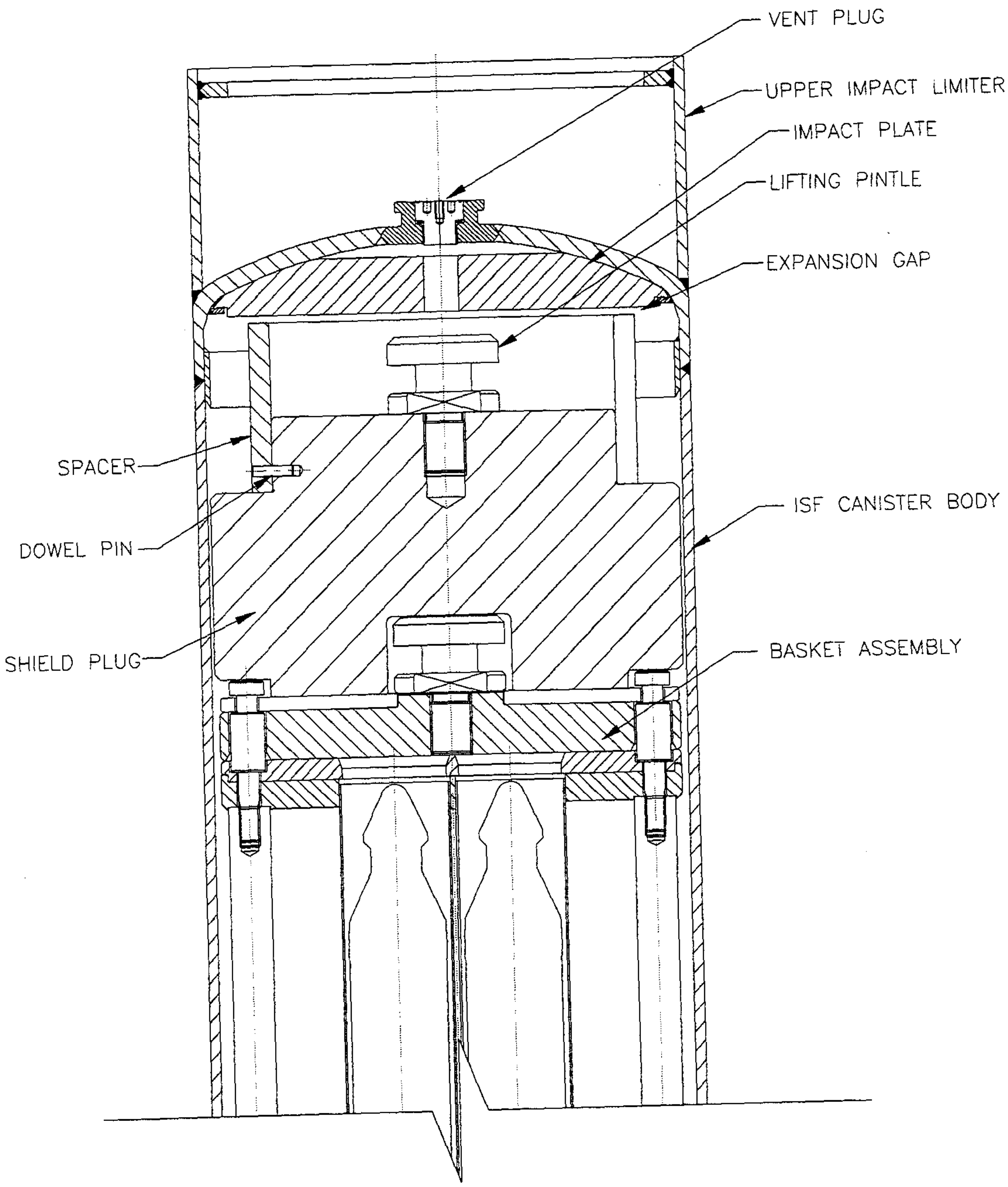


Figure 4.2-17
Lifting Tool for Empty Basket and Canister Shield Plug
For Use Inside the Canister Closure Area

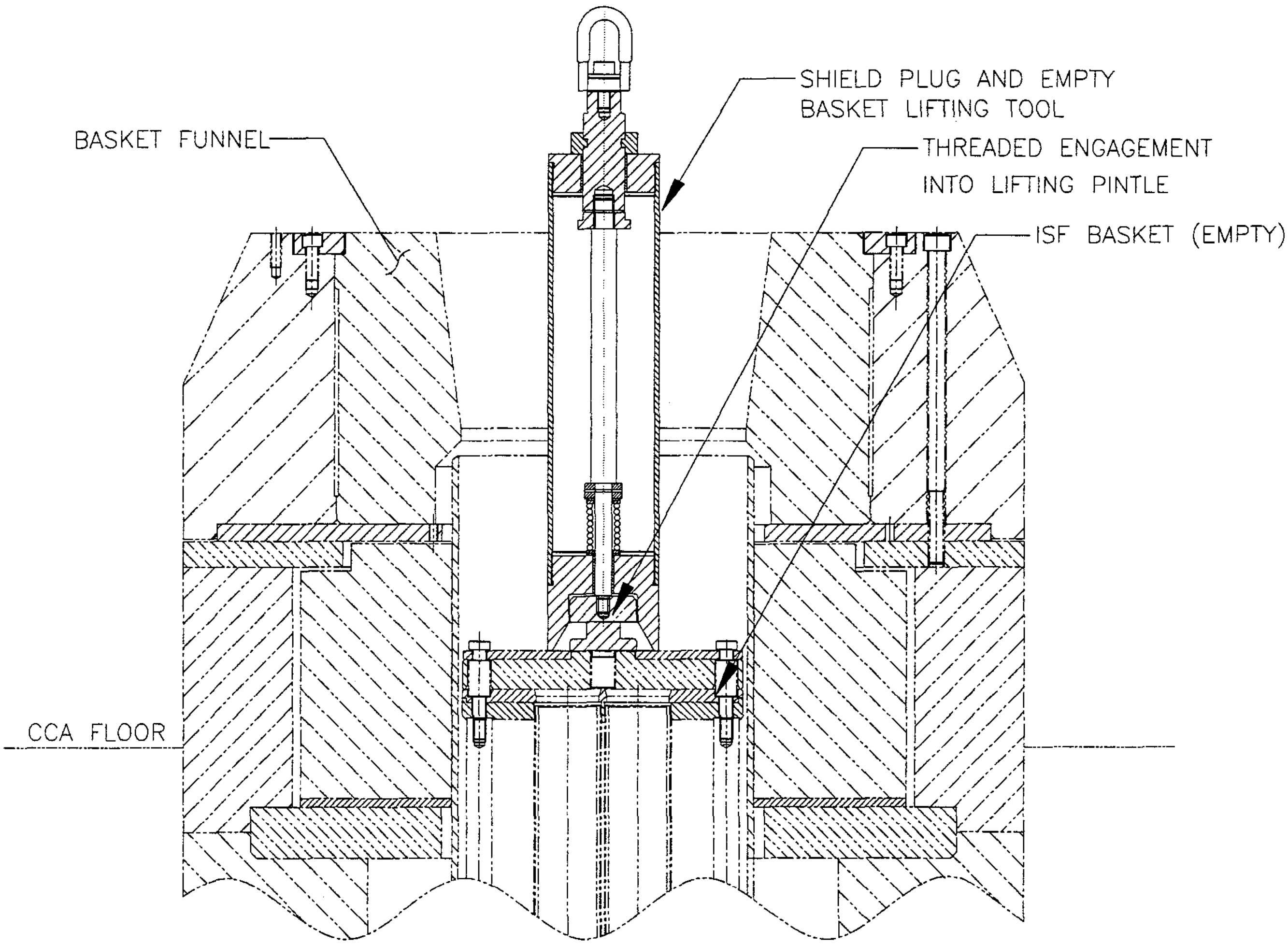
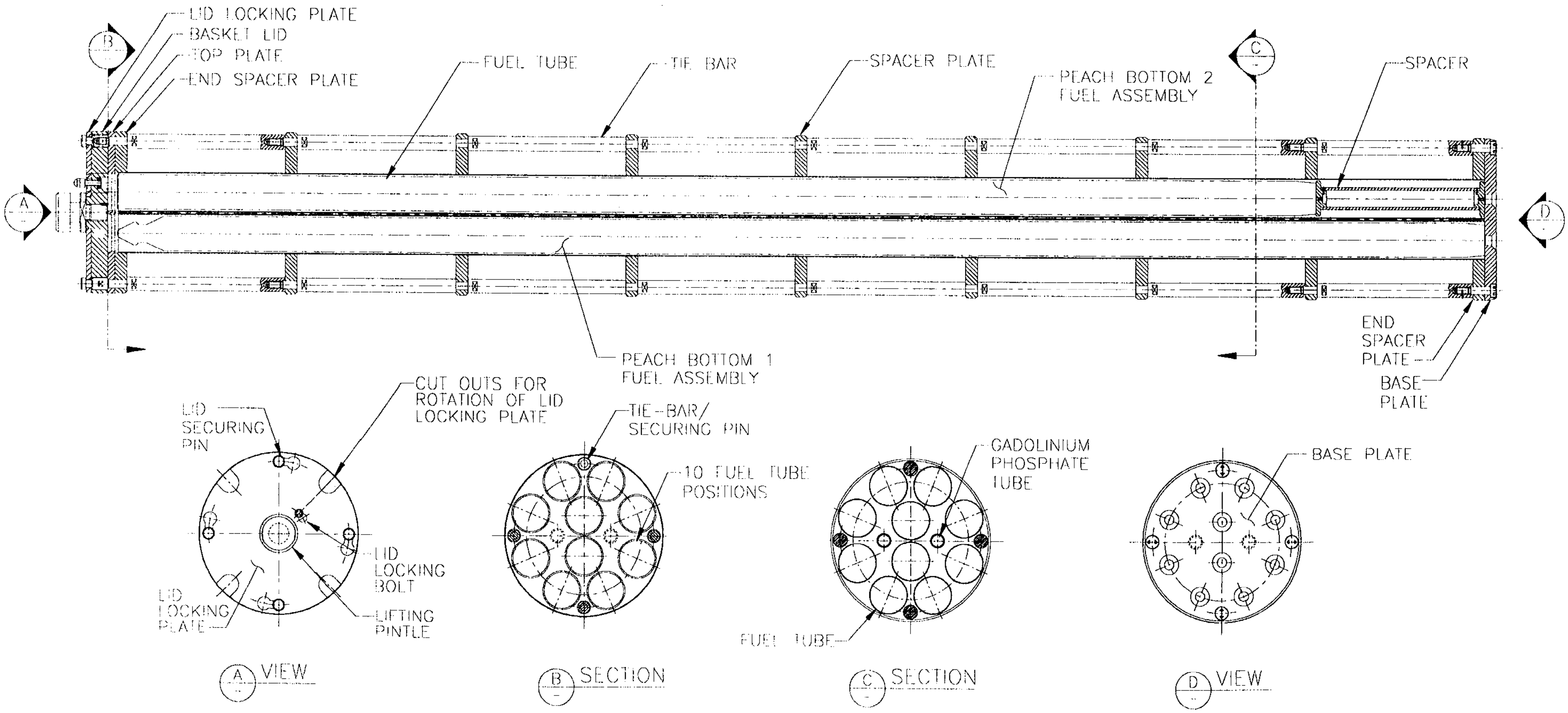


FIGURE 4.2-18
Peach Bottom 1 and 2 Basket



Note: Peach Bottom 1 and 2 fuel elements are not co-located in the same basket. They are depicted together on this figure only to show their relative configuration.

Figure 4.2-19
Peach Bottom 1 A.R.T. Basket Layout

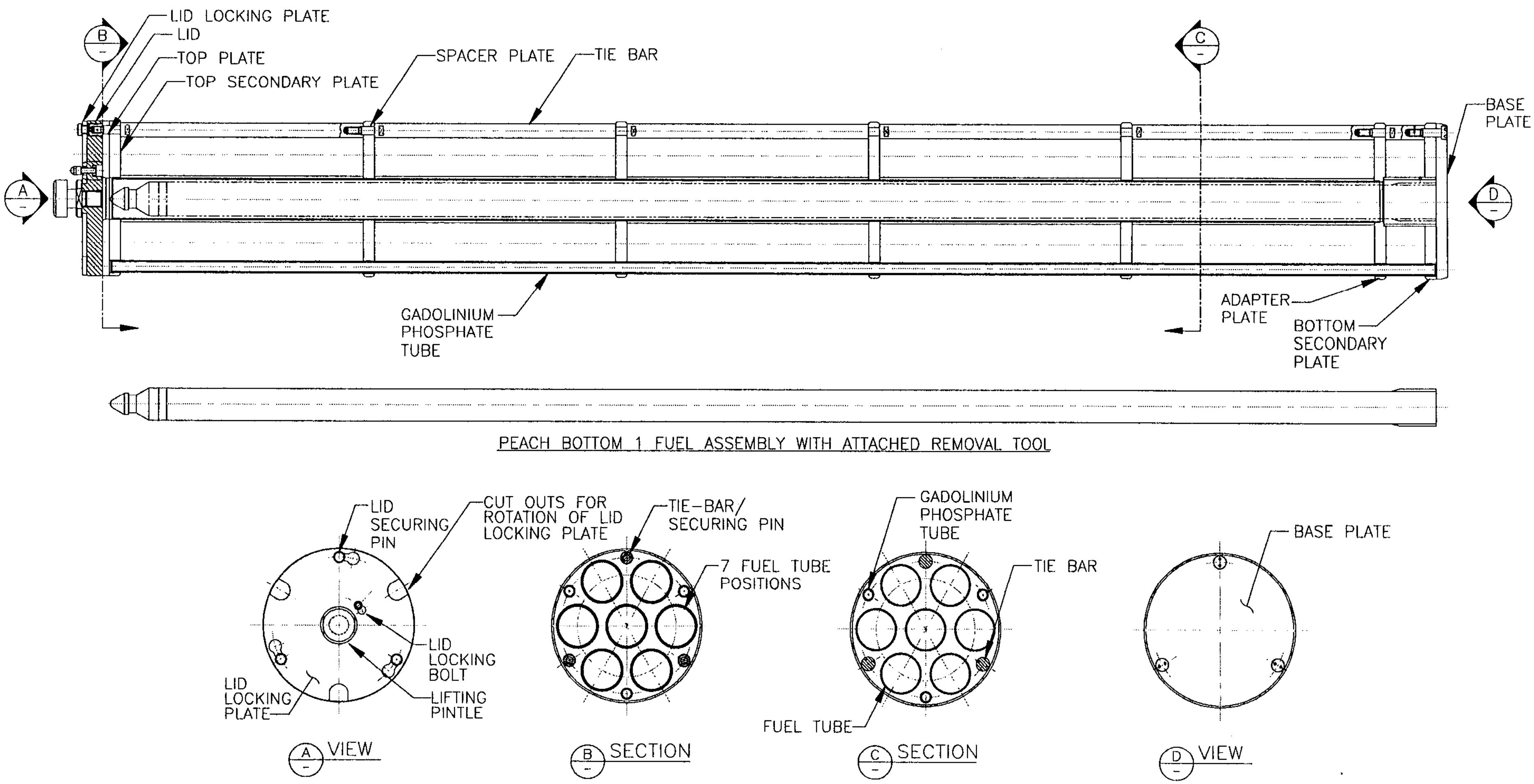


Figure 4.2-20
TRIGA Fuel Rod Basket Assembly

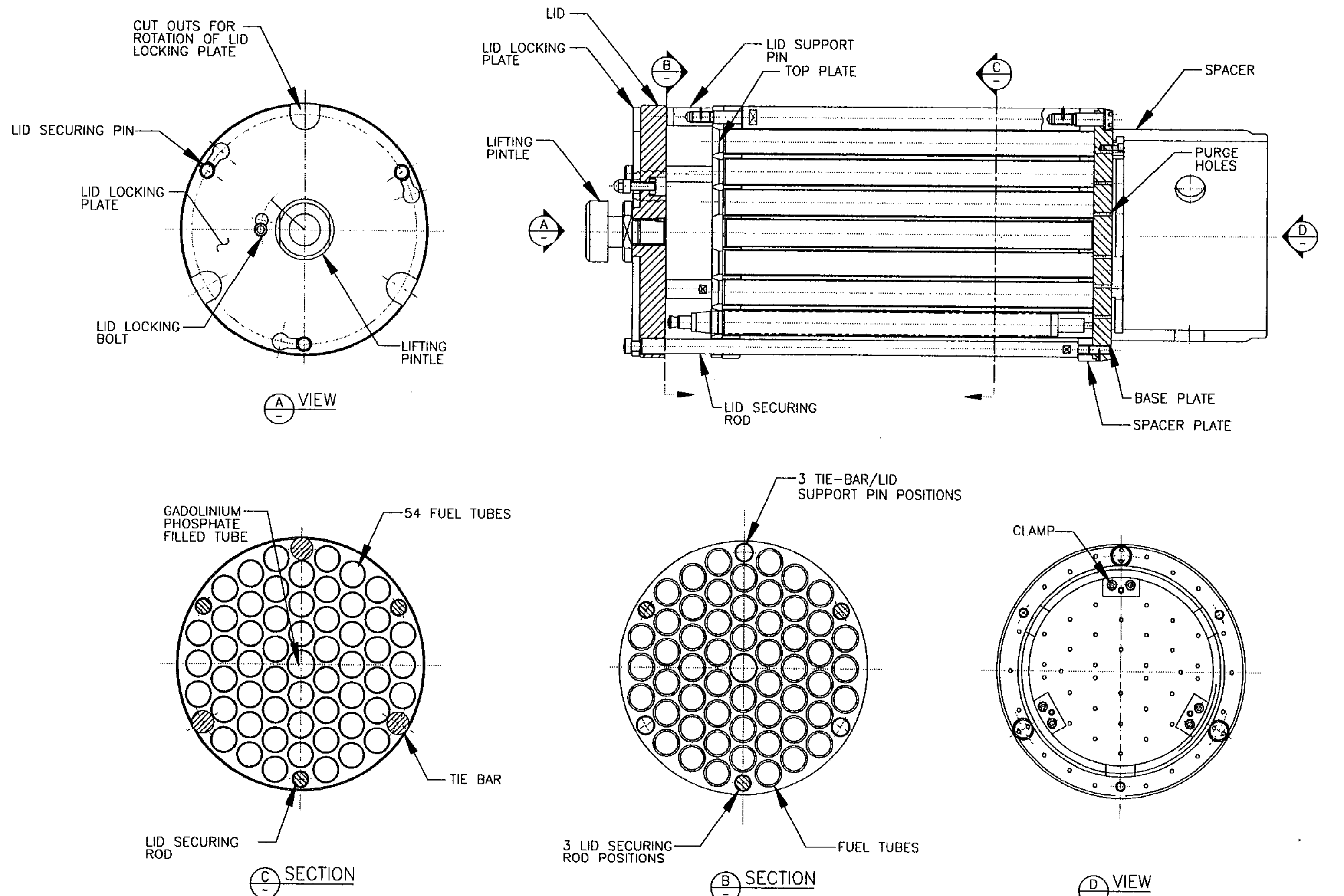


Figure 4.2-21
Shippingport Reflector IV Module Basket Layout

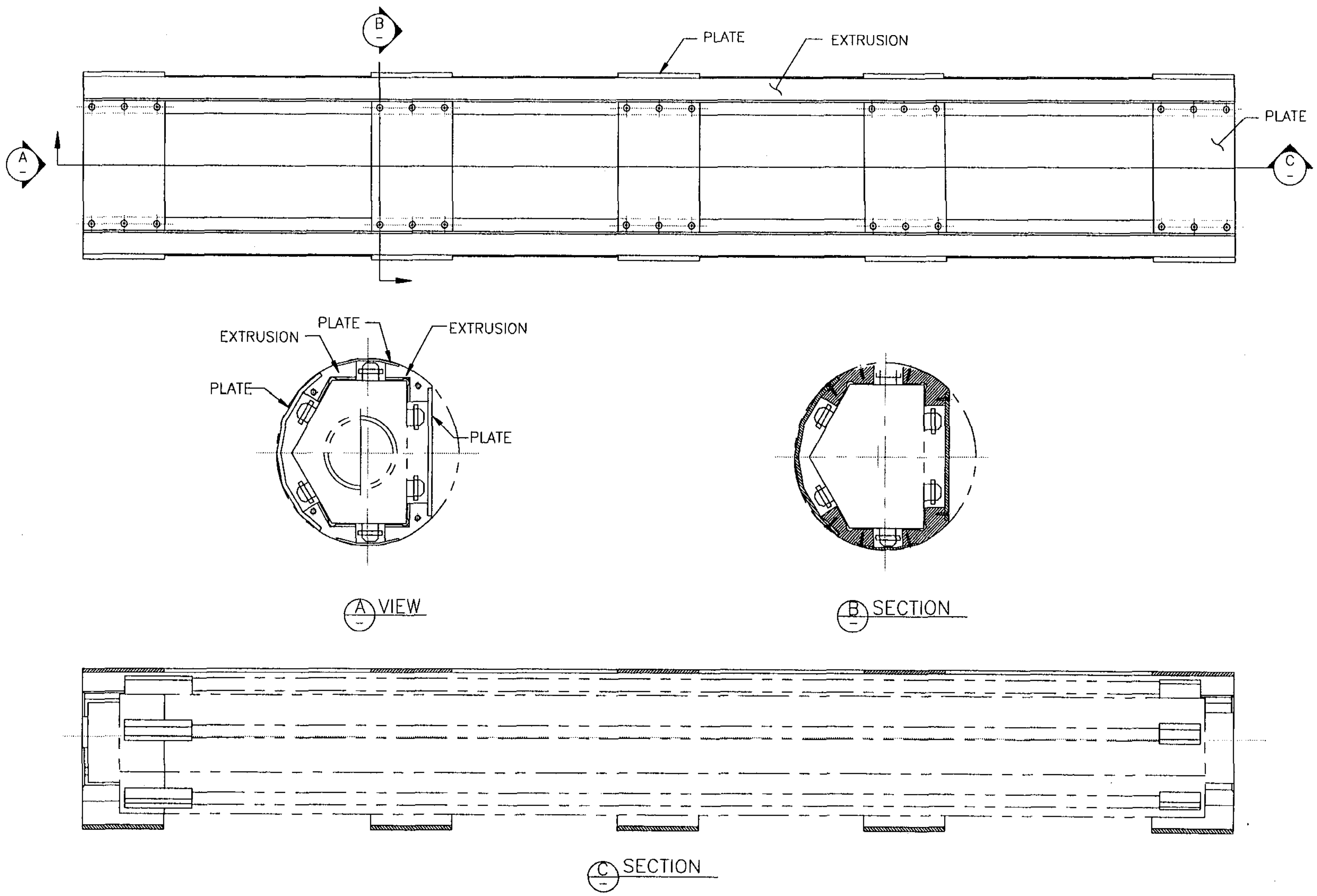


Figure 4.2-22
Shippingport Reflector V Module Basket Layout

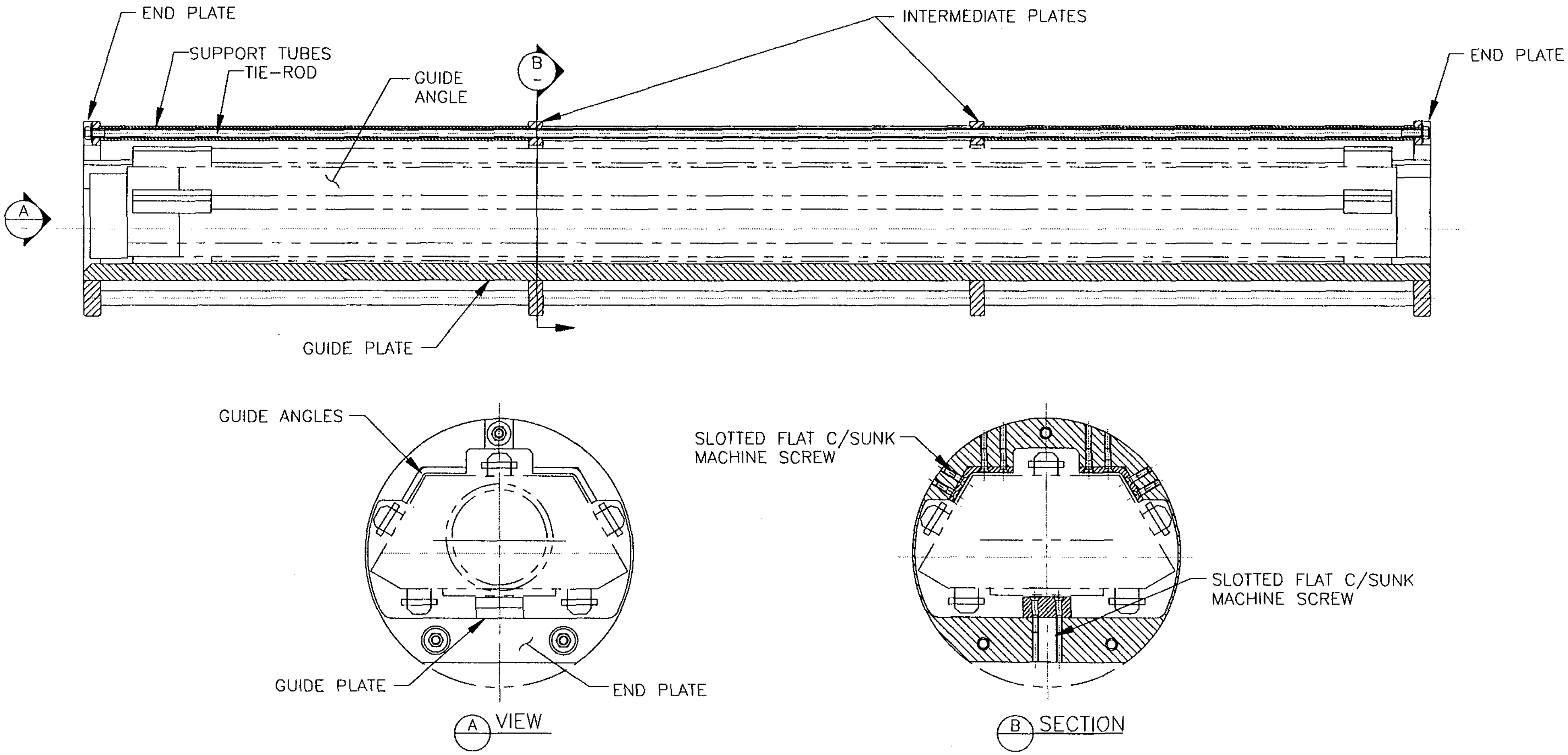


Figure 4.2-23
Shippingport Reflector Module Loose Rod Basket Layout

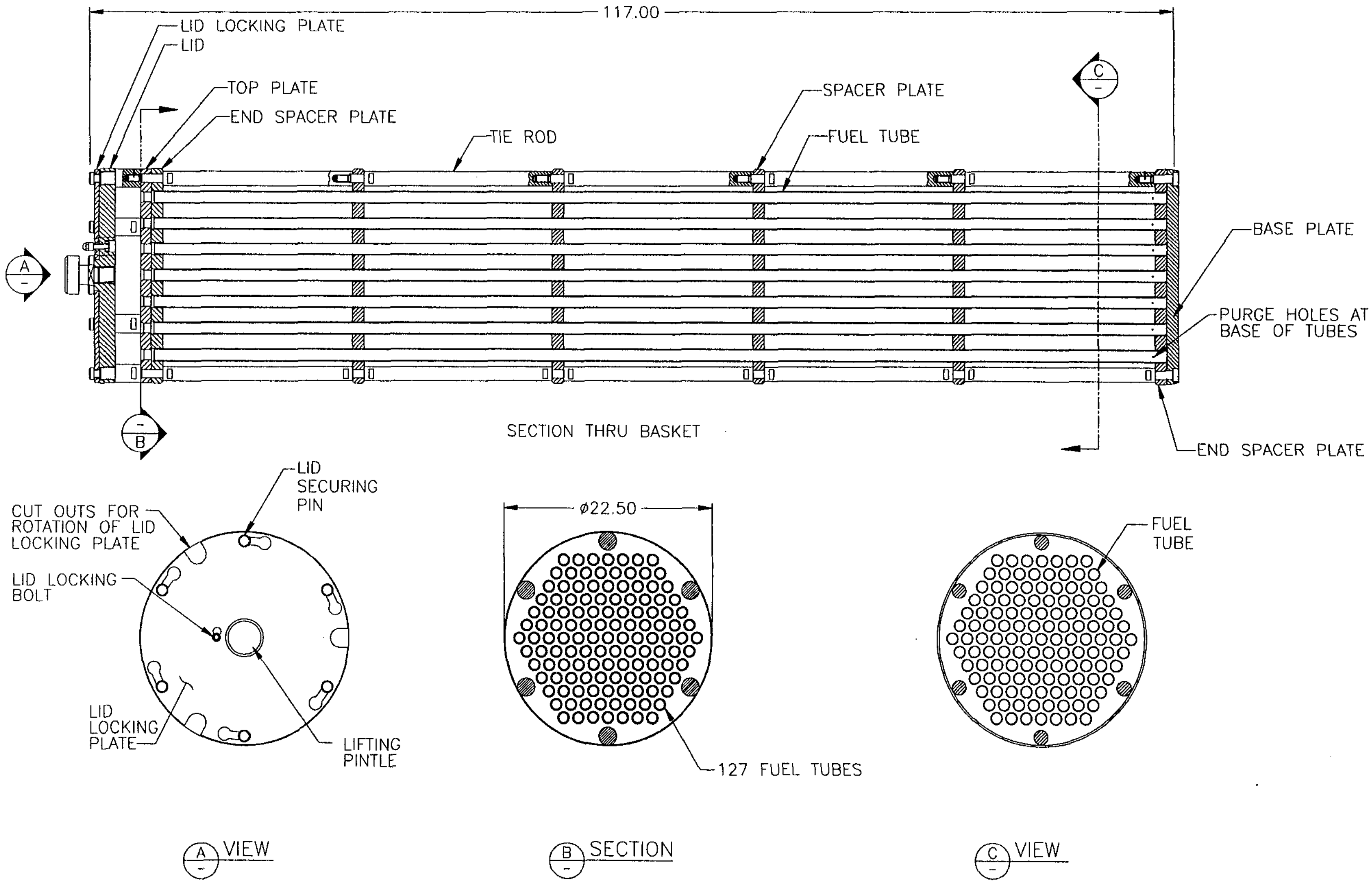


Figure 4.2-24
ISF Canister Assembly Finite Element Model

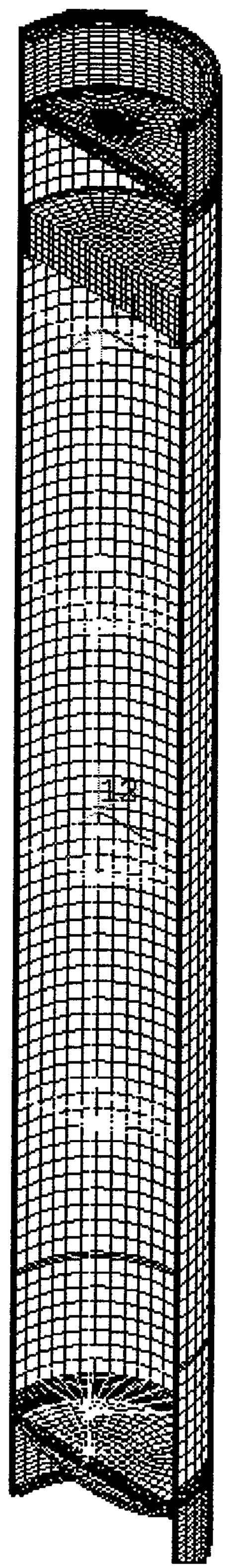


Figure 4.2-25
Storage Tube Assembly Finite Element Model

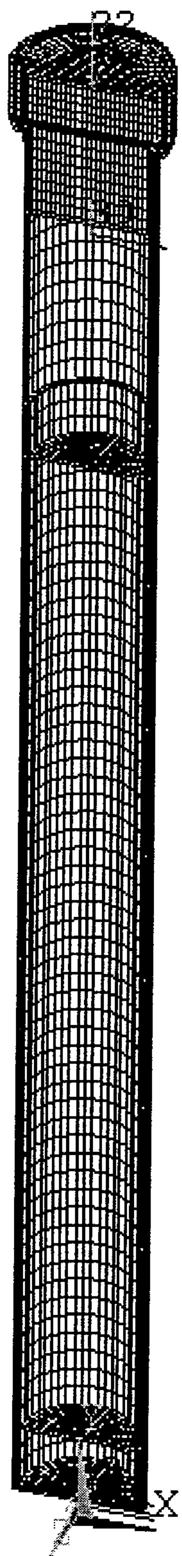


Figure 4.3-1
Cask Receipt Area HVAC Diagram

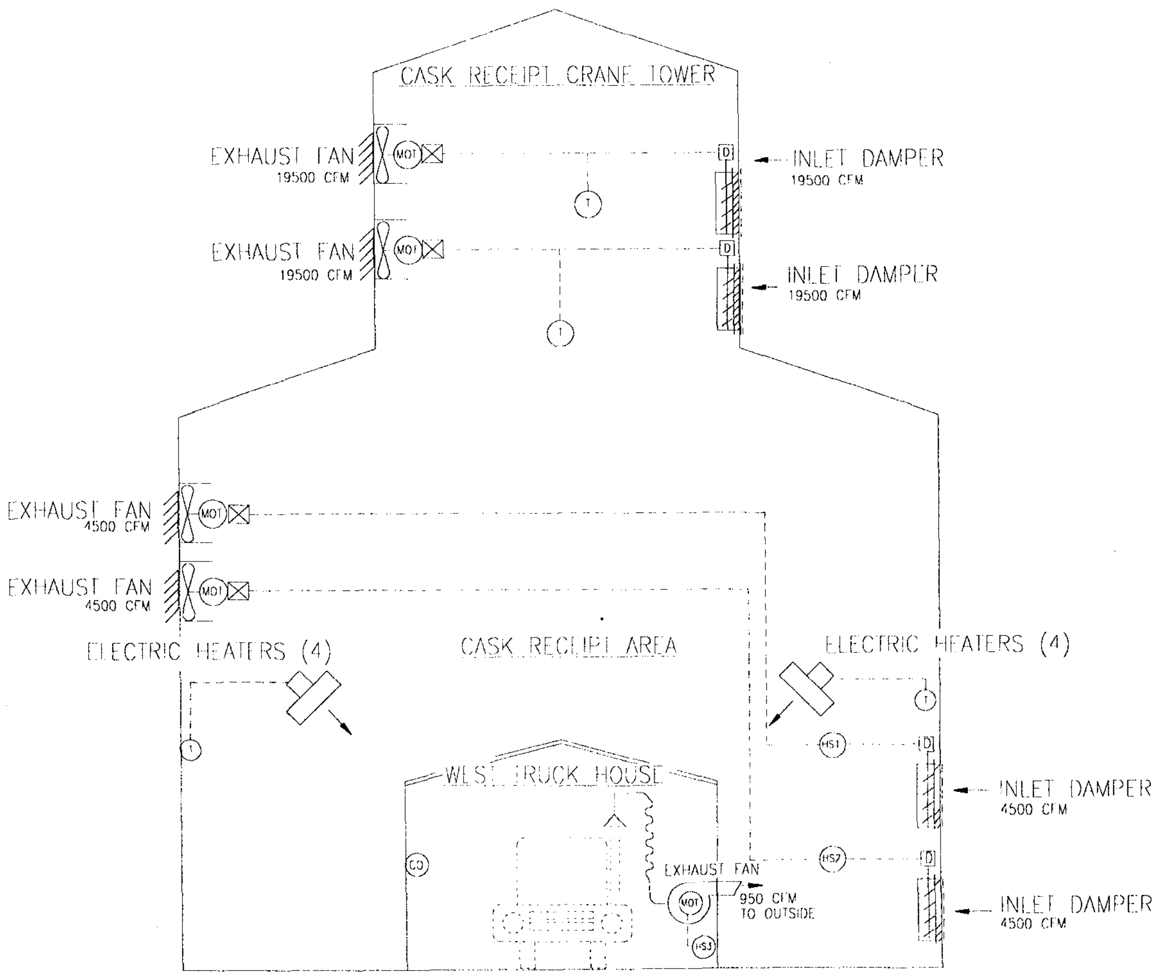


Figure 4.3-2
Storage Area HVAC Diagram

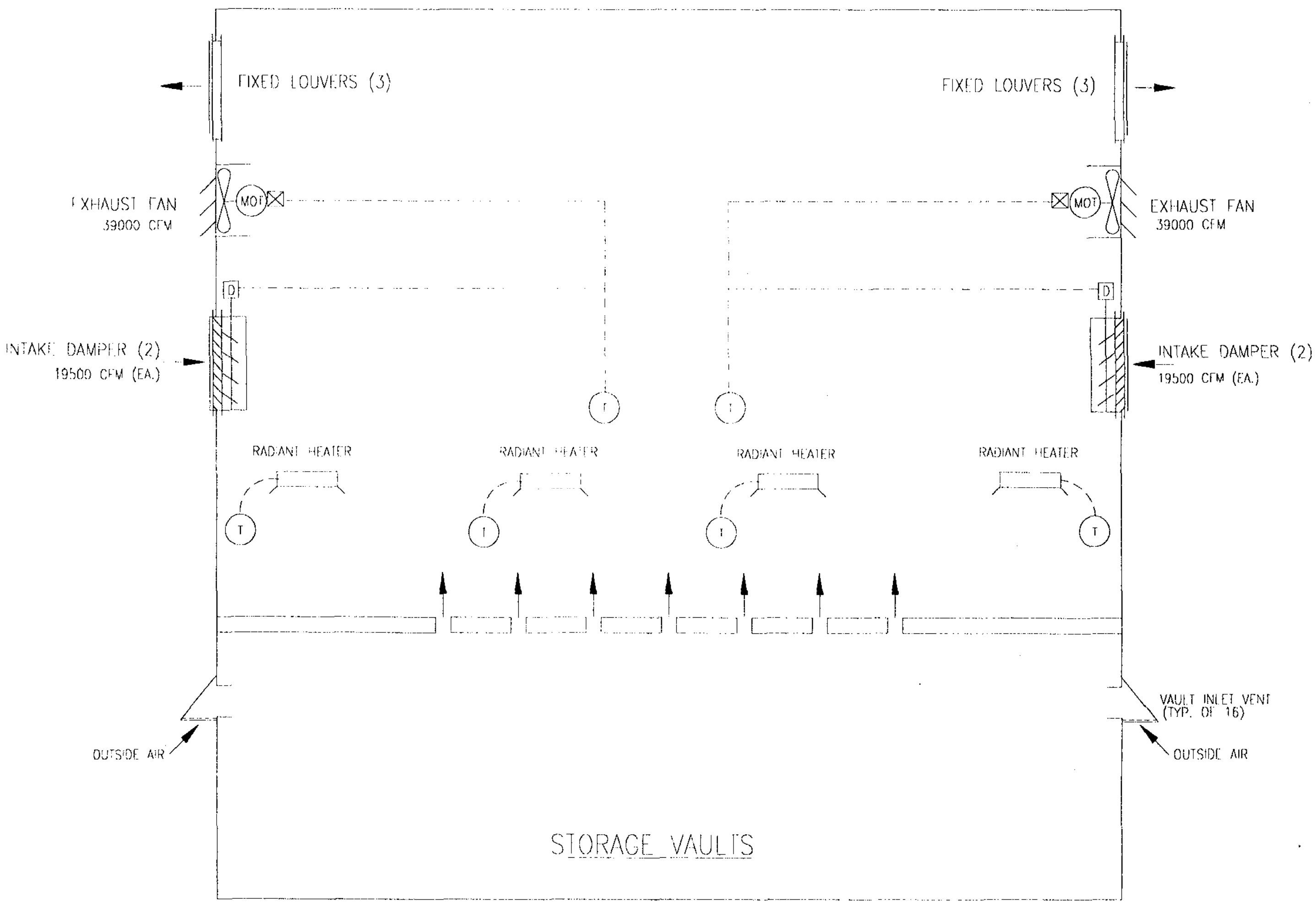
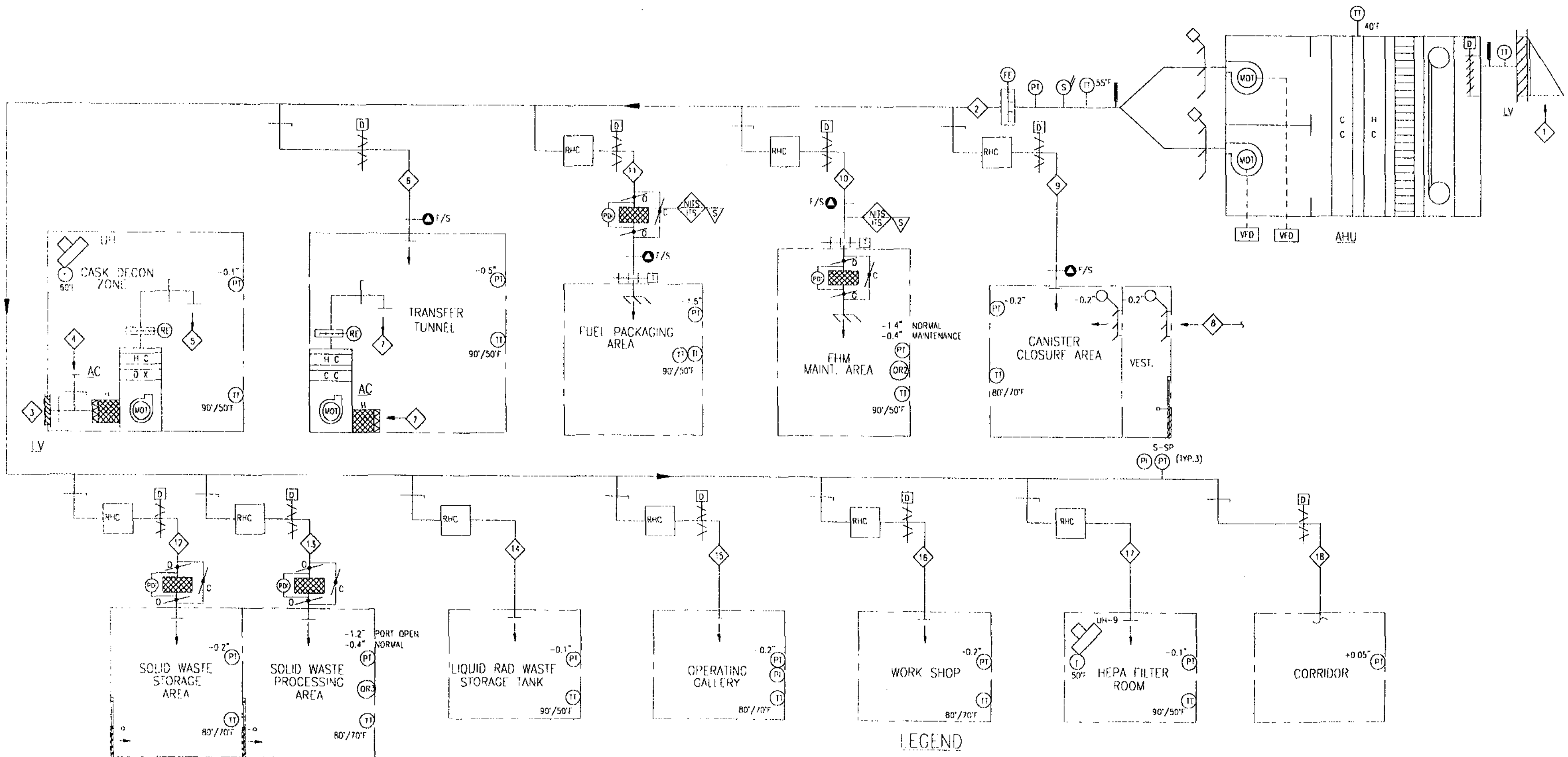


Figure 4.3-3
Transfer Area Supply System



ITEM	ITEM	CFM
1	OUTSIDE AIR	16500
2	TOTAL MAKE-UP AIR	16500
3	CASK DECON ZONE MAKE-UP AIR FR. CASK REC. AREA	550
4	CASK DECON ZONE RETURN AIR	1380
5	CASK DECON ZONE SUPPLY AIR	1930
6	TRANSFER TUNNEL MAKE-UP AIR	770
7	TRANSFER TUNNEL RECIRC. AIR	2390
8	CCA TRANSFER AIR (FROM AIR-LOCK)	100
9	CCA MAKE-UP AIR	2010

ITEM	ITEM	CFM
10	FHM MAINTENANCE AREA MAKE-UP AIR	1130
11	FUEL PACKAGING AREA MAKE-UP AIR	3290
12	SOLID WASTE STORAGE AREA MAKE-UP AIR	690
13	SOLID WASTE PROCESSING AREA MAKE-UP AIR	1420
14	LIQUID RAD. WASTE STOR. TANK AREA MAKE-UP AIR	220
15	OPERATING GALLERY MAKE-UP AIR	5150
16	WORKSHOP MAKE-UP AIR	1040
17	HEPA FILTER ROOM MAKE-UP AIR	200
18	AC PRESSURIZATION AIR	250

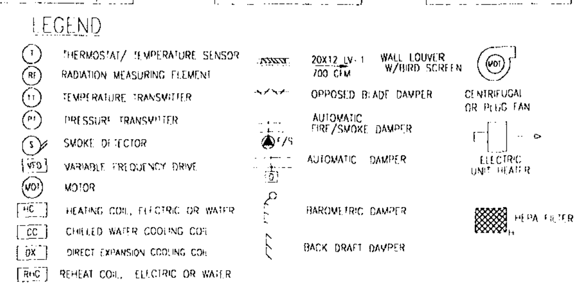
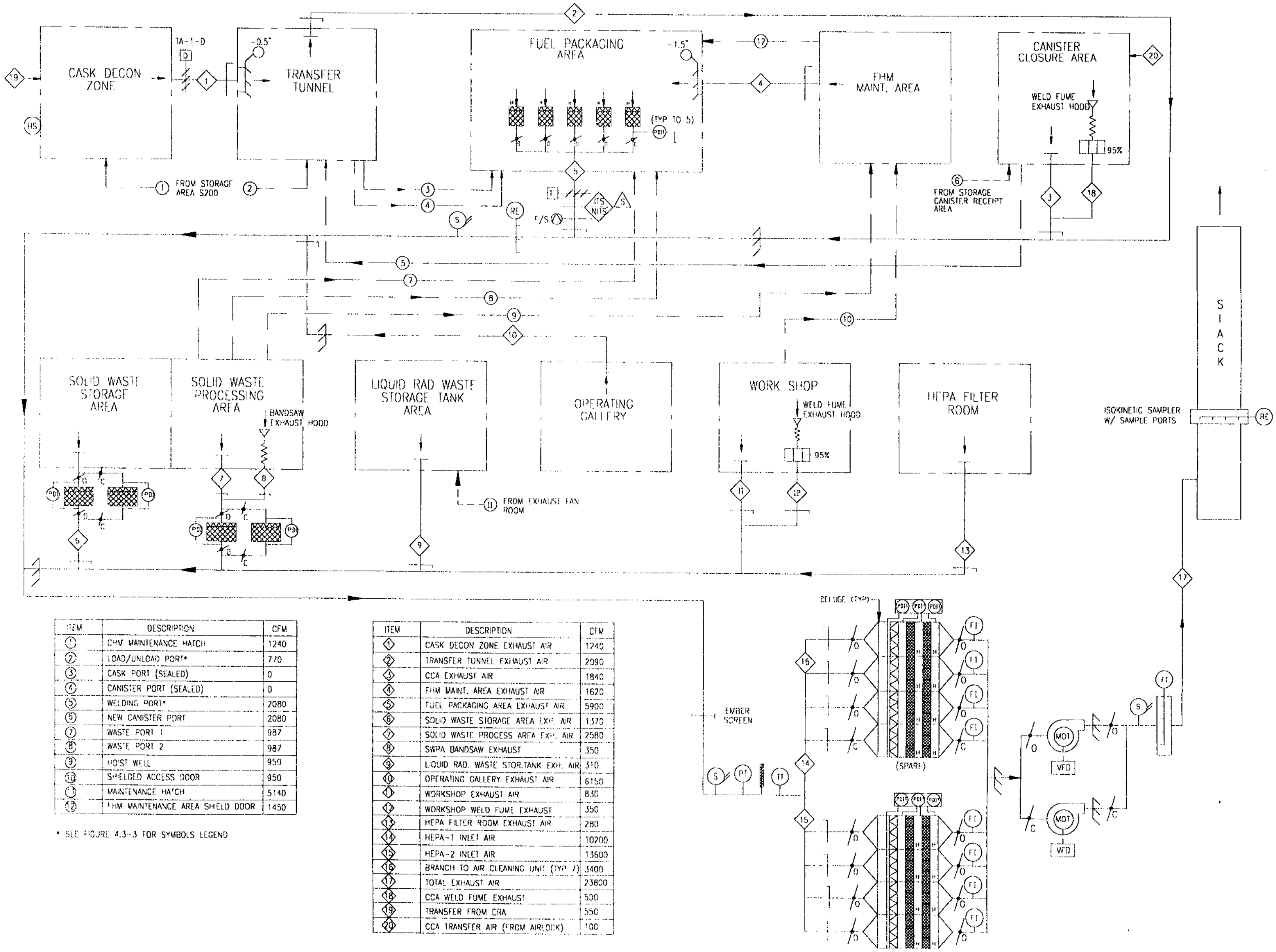


Figure 4.3-4
Transfer Area Exhaust System



ITEM	DESCRIPTION	CFM
①	CHM MAINTENANCE HATCH	1240
②	LOAD/UNLOAD PORT*	770
③	CASK PORT (SEALED)	0
④	CANISTER PORT (SEALED)	0
⑤	WELDING PORT*	2080
⑥	NEW CANISTER PORT	2080
⑦	WASTE PORT 1	987
⑧	WASTE PORT 2	987
⑨	HOIST WELL	950
⑩	SHIELDED ACCESS DOOR	950
⑪	MAINTENANCE HATCH	5140
⑫	FHM MAINTENANCE AREA SHIELD DOOR	1450

* SEE FIGURE 4.3-3 FOR SYMBOLS LEGEND

ITEM	DESCRIPTION	CFM
◇1	CASK DECON ZONE EXHAUST AIR	1240
◇2	TRANSFER TUNNEL EXHAUST AIR	2090
◇3	CCA EXHAUST AIR	1840
◇4	FHM MAINT. AREA EXHAUST AIR	1620
◇5	FUEL PACKAGING AREA EXHAUST AIR	5900
◇6	SOLID WASTE STORAGE AREA EXH. AIR	1370
◇7	SOLID WASTE PROCESS AREA EXH. AIR	2580
◇8	SWPA BANDSAW EXHAUST	350
◇9	LIQUID RAD. WASTE STOR.TANK EXH. AIR	310
◇10	OPERATING GALLERY EXHAUST AIR	6150
◇11	WORKSHOP EXHAUST AIR	830
◇12	WORKSHOP WELD FUME EXHAUST	350
◇13	HEPA FILTER ROOM EXHAUST AIR	280
◇14	HEPA-1 INLET AIR	10200
◇15	HEPA-2 INLET AIR	13600
◇16	BRANCH TO AIR CLEANING UNIT (TYP 7)	3400
◇17	TOTAL EXHAUST AIR	23800
◇18	CCA WELD FUME EXHAUST	500
◇19	TRANSFER FROM CRA	550
◇20	CCA TRANSFER AIR (FROM AIRLOCK)	100

Figure 4.3-5
HVAC Confinement Barrier Schematic For Fuel Packaging Area

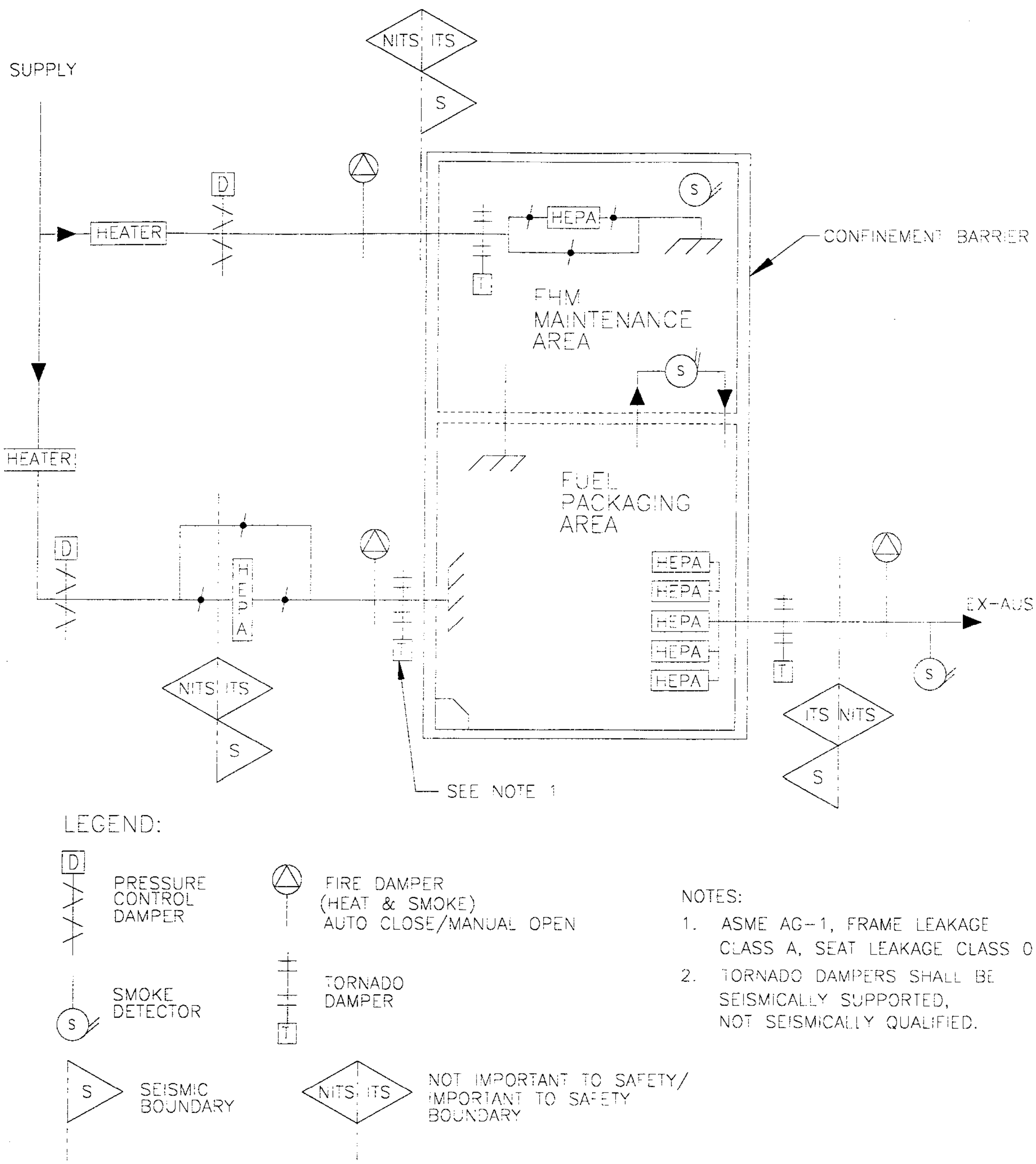


Figure 4.3-6
First Floor Airborne Contamination Control Zones

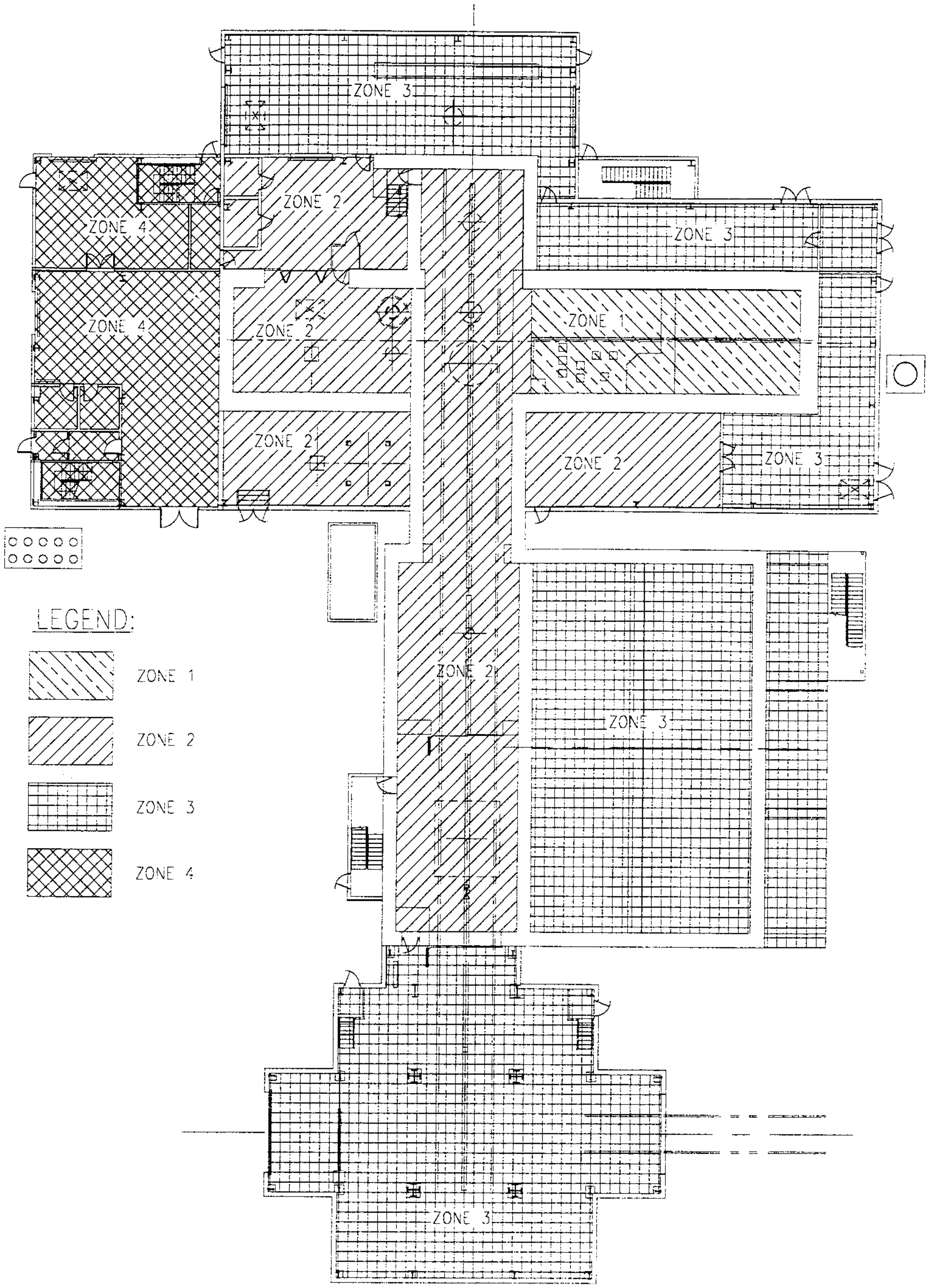


Figure 4.3-7
Second Floor Airborne Contamination Control Zones

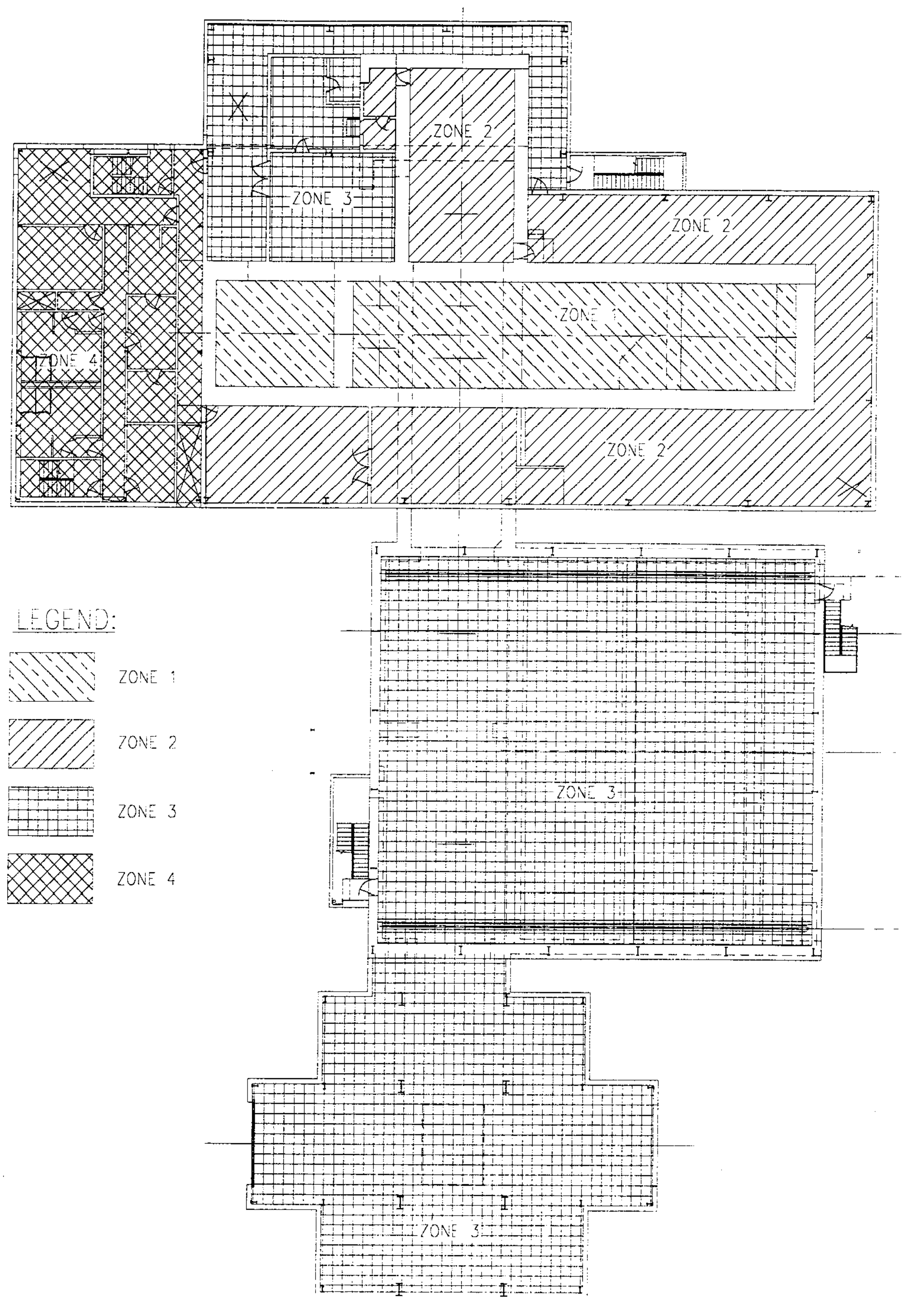


Figure 4.3-8
Storage Area Elevation (Looking North)

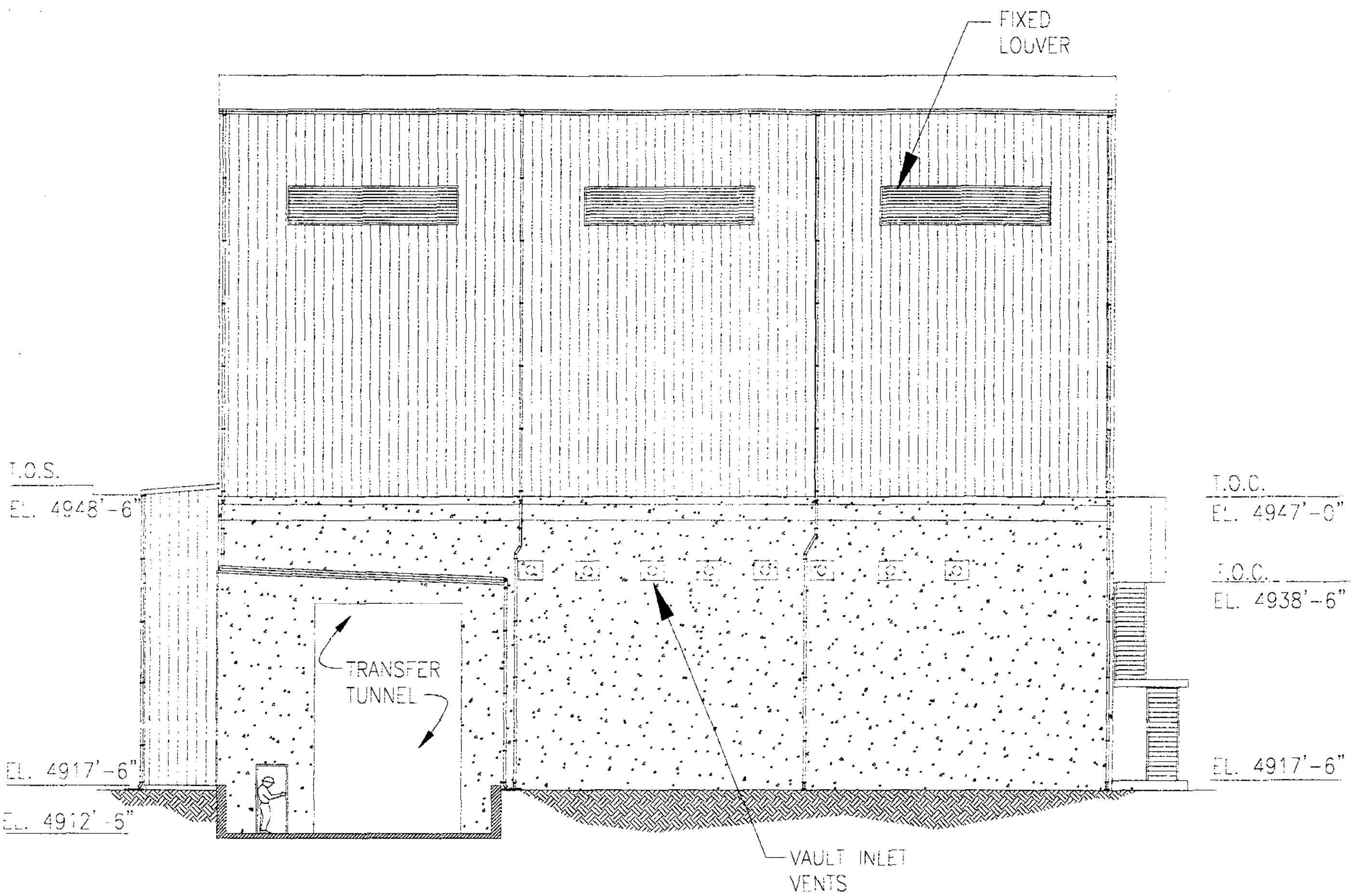


Figure 4.3-9
Storage Area Elevation (Looking South)

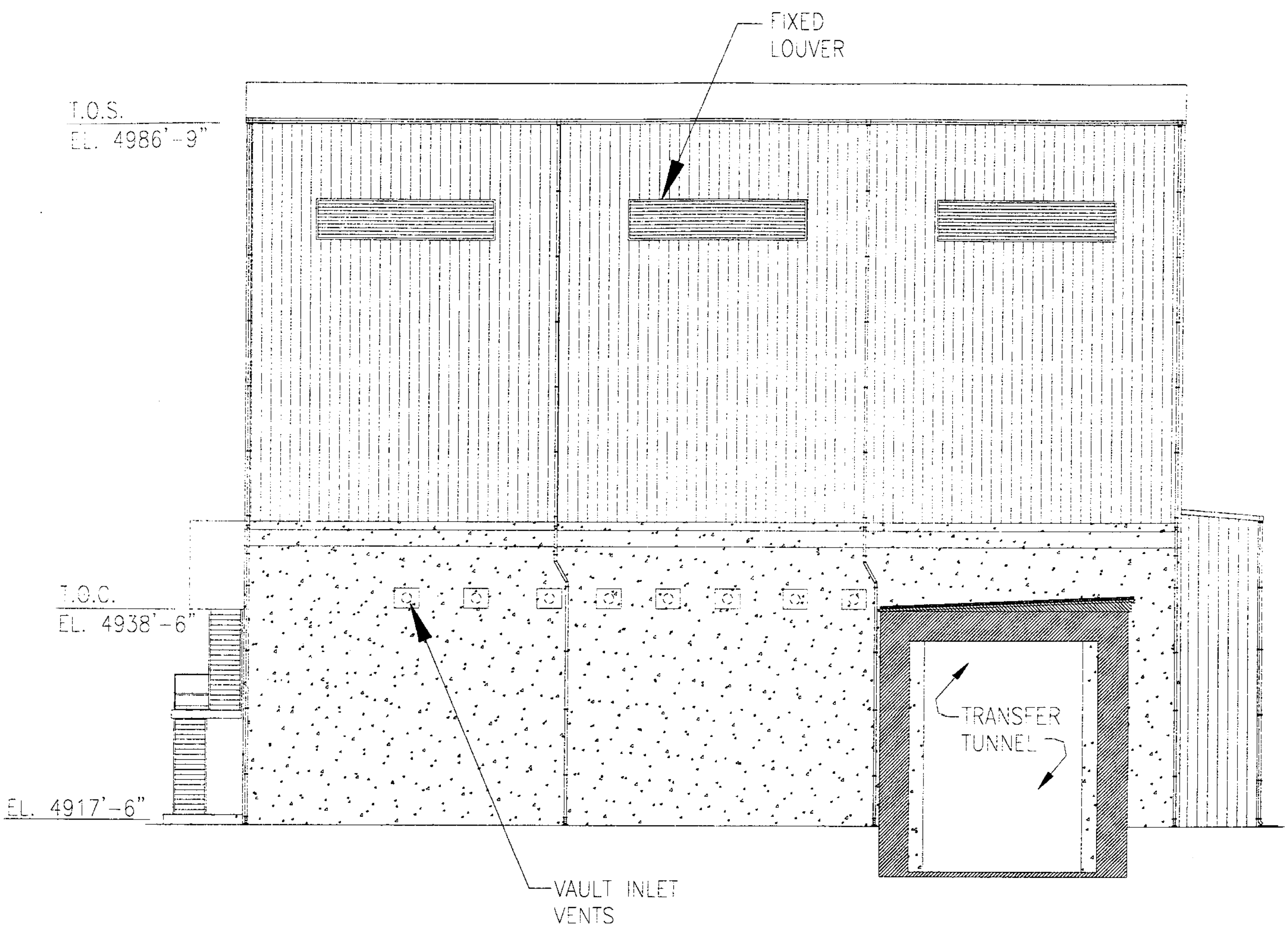


Figure 4.3-10
ISF Facility One Line Diagram

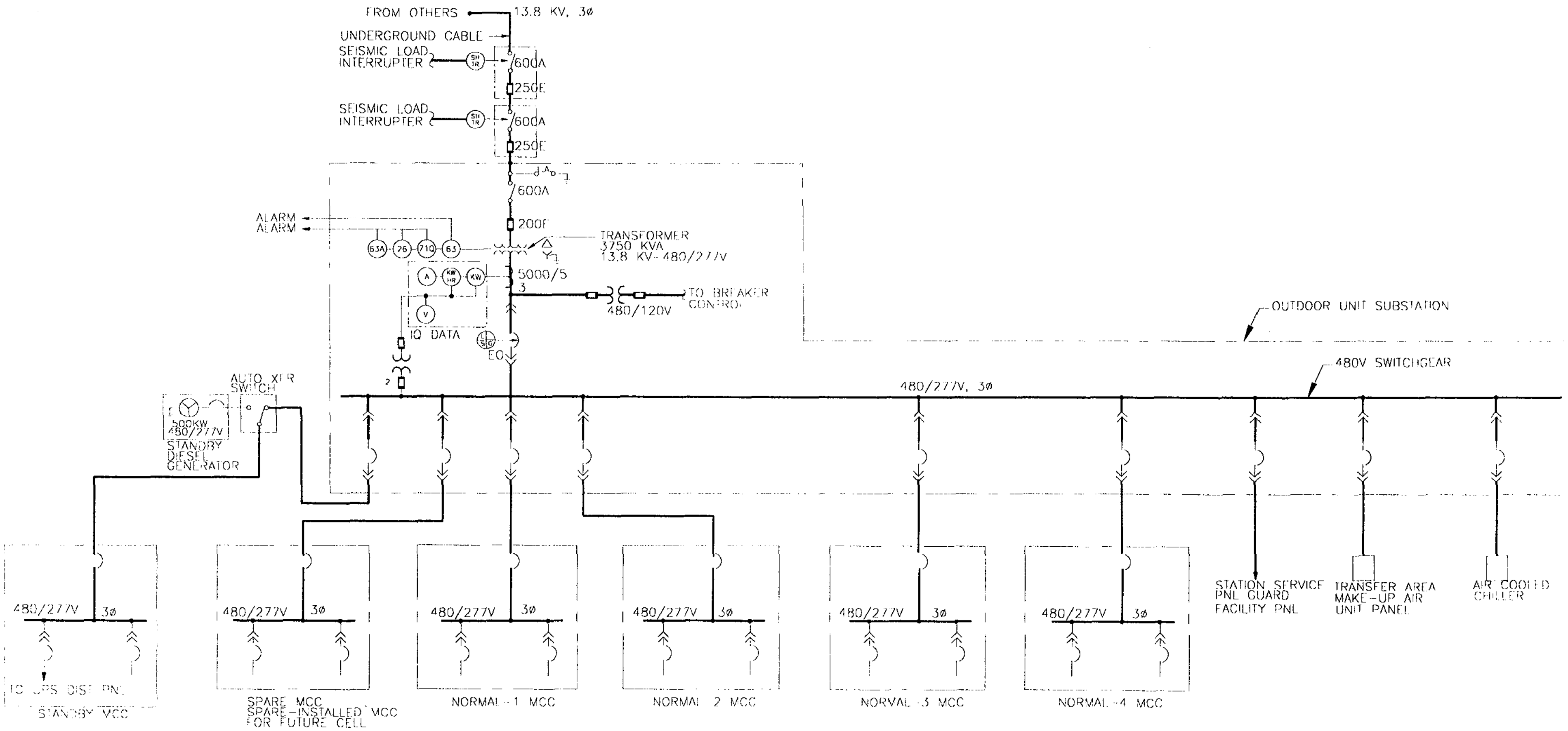


Figure 4.3-11
ISF Facility Standby MCC One-Line Diagram

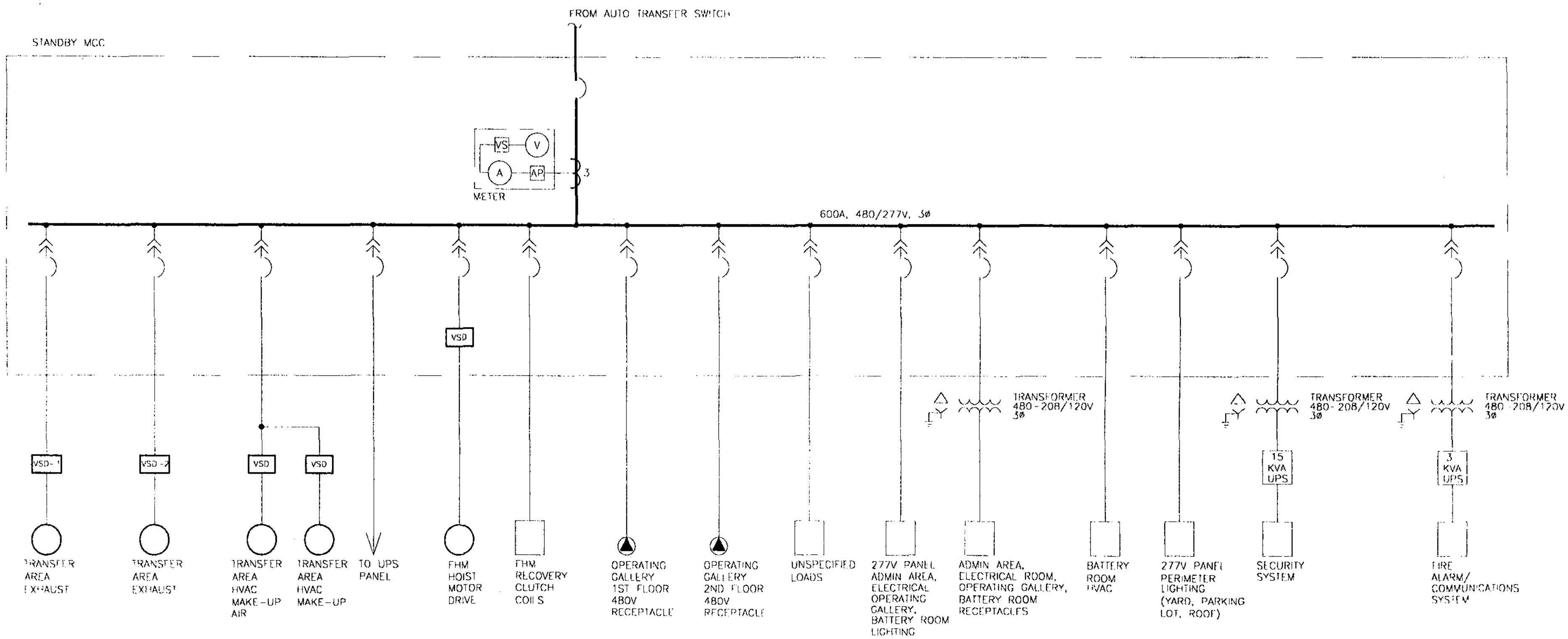


Figure 4.3-12
ISF Facility UPS Distribution One-Line Diagram

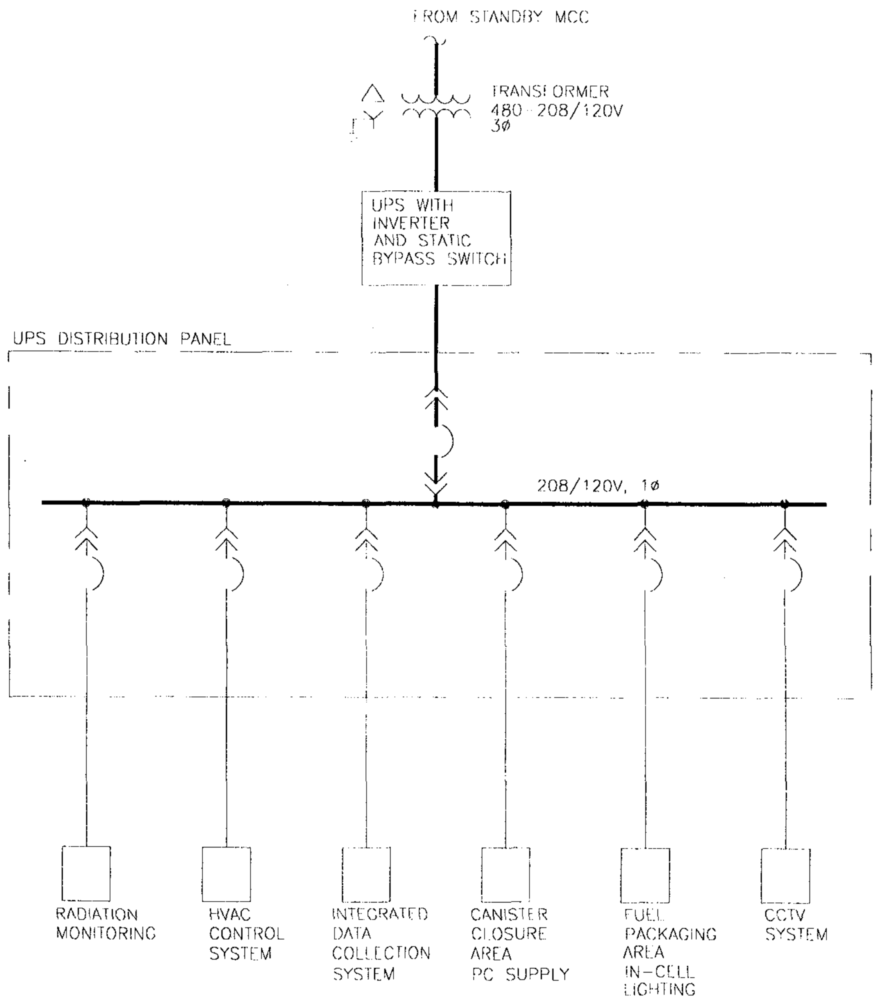


Figure 4.3-13
Fire Protection – First Floor

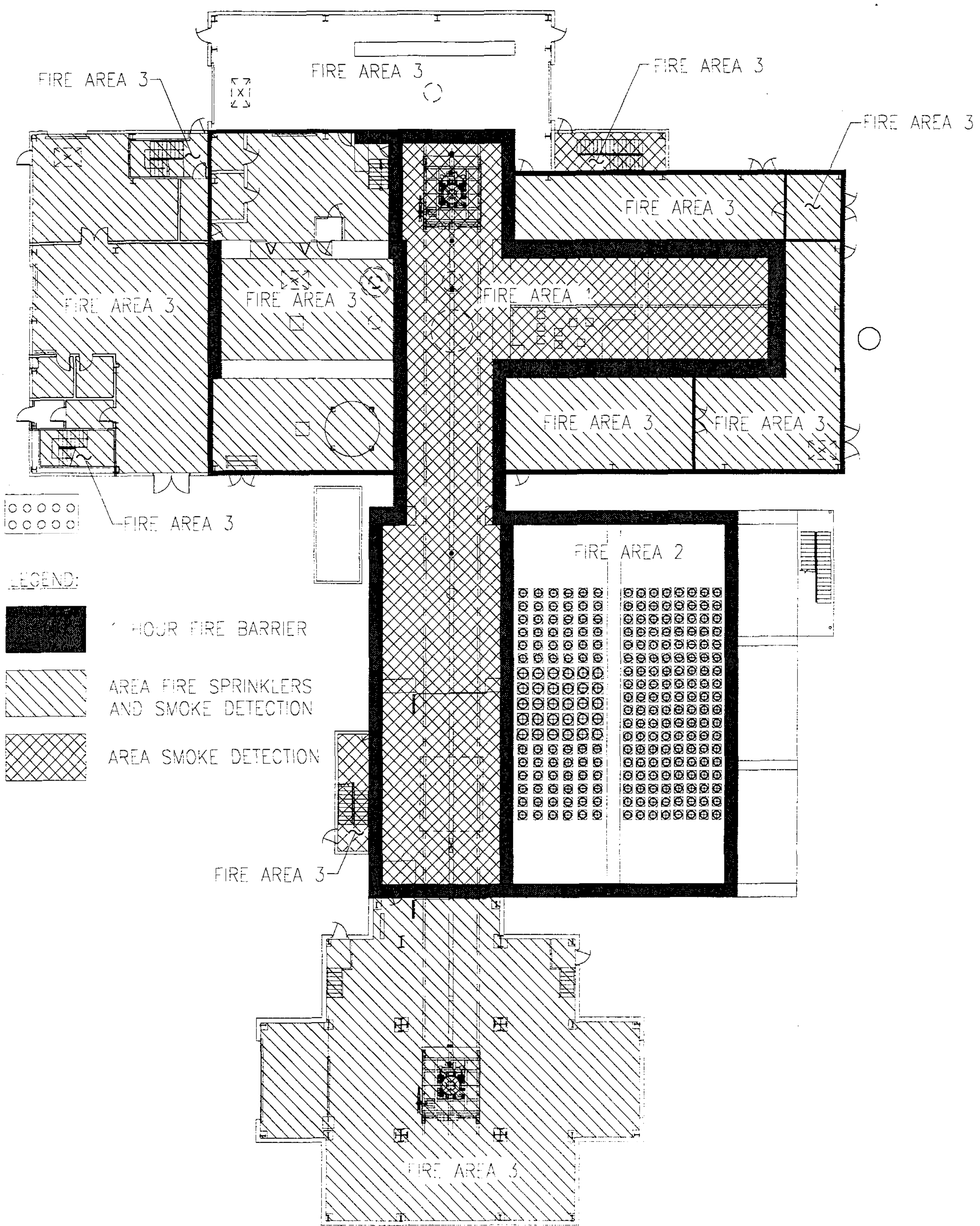


Figure 4.3-14
Fire Protection – Second Floor

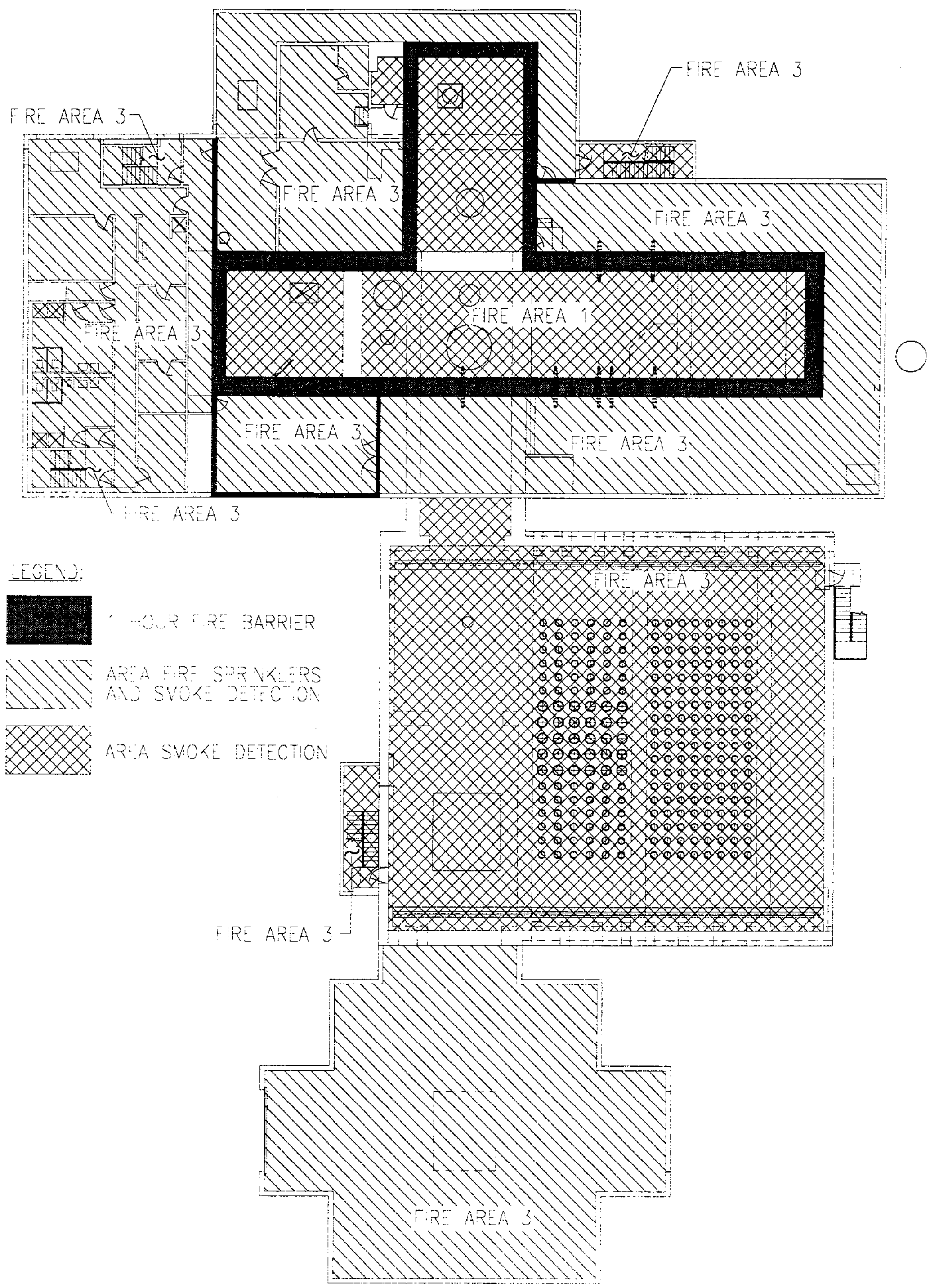
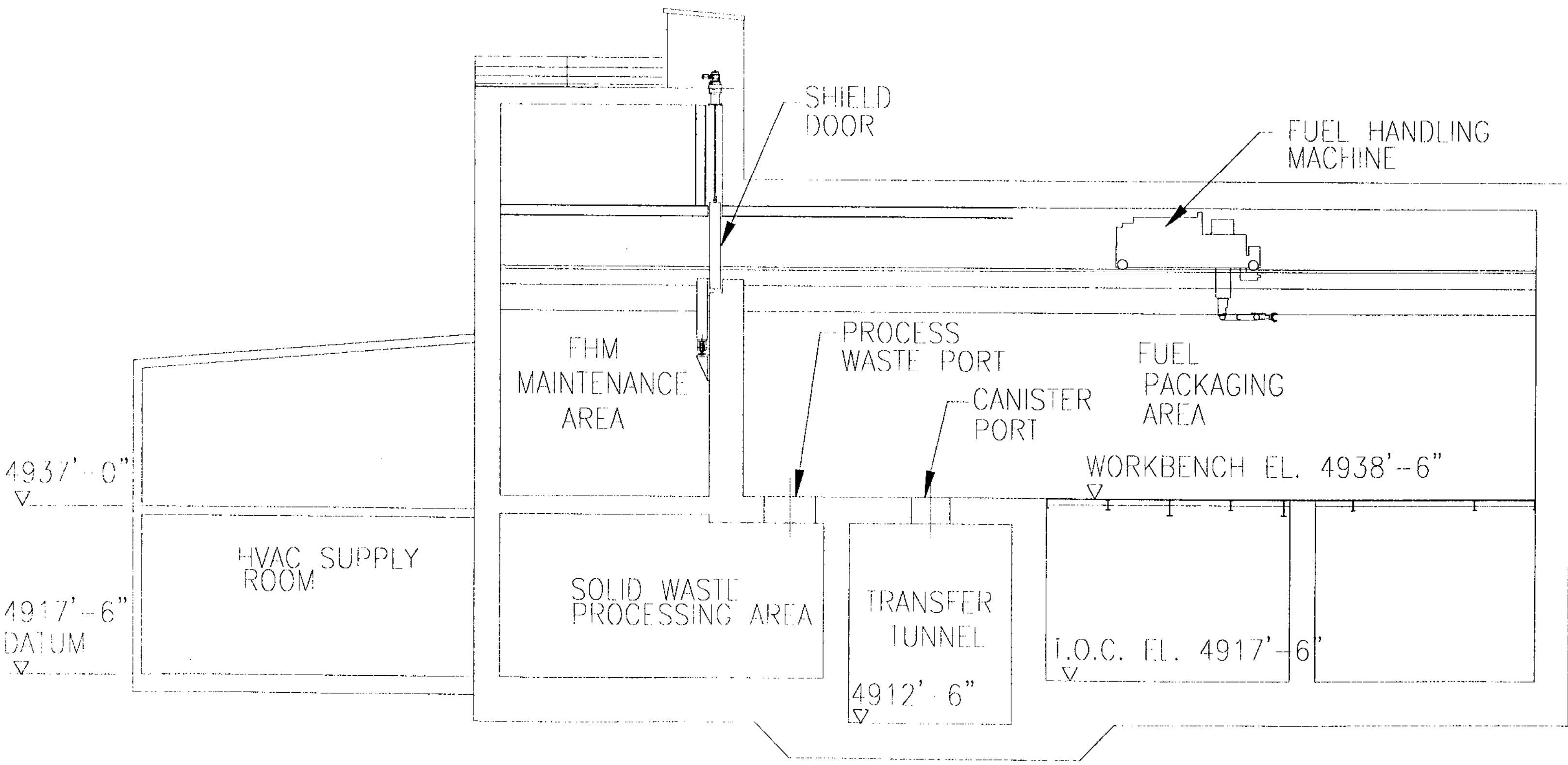


Figure 4.3-15
Transfer Area Section



SECTION LOOKING NORTH FROM ℄ FUEL PACKAGING AREA

Figure 4.7-1
Cask Receipt Crane

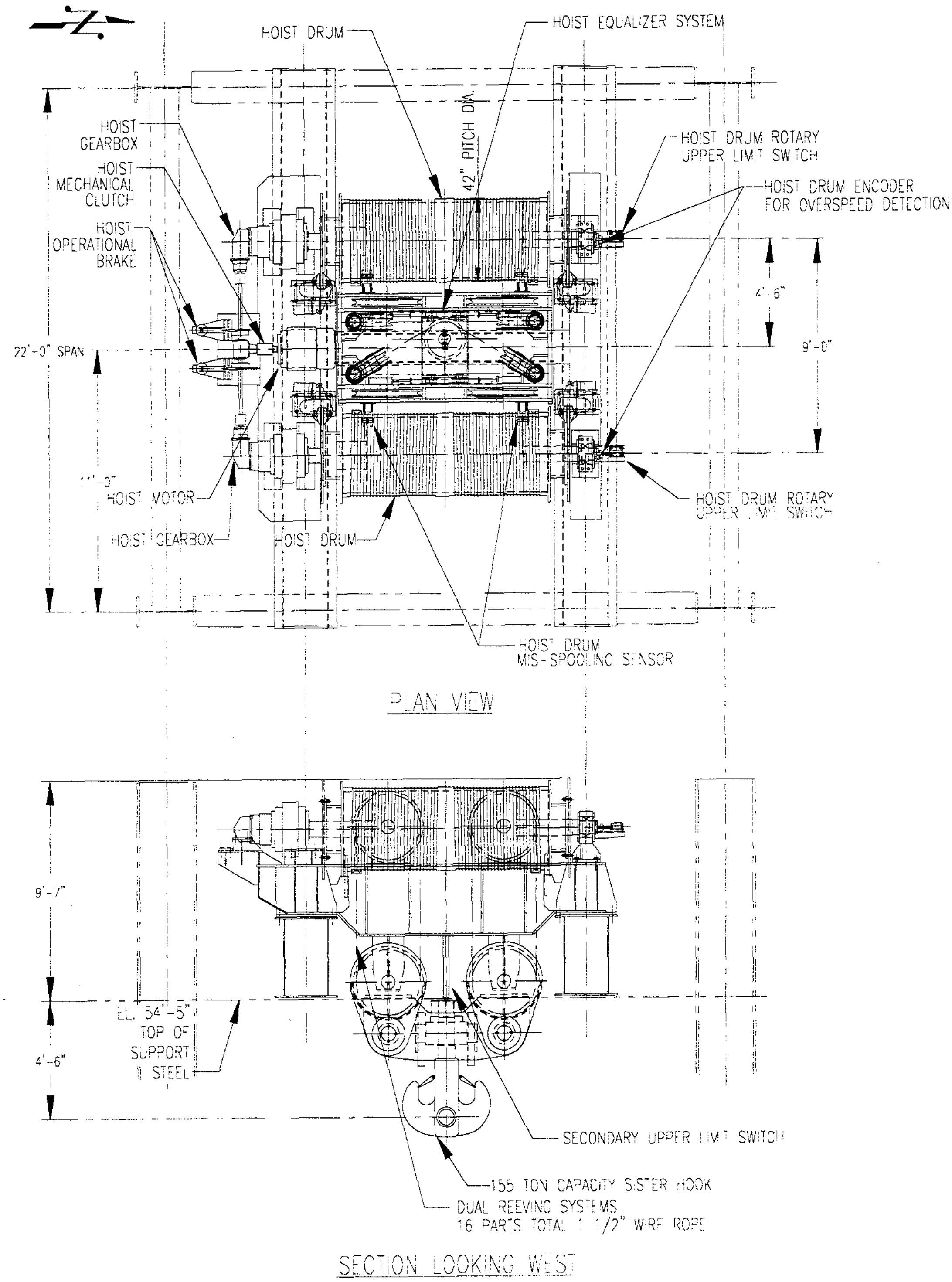


Figure 4.7-2
Cask Trolley

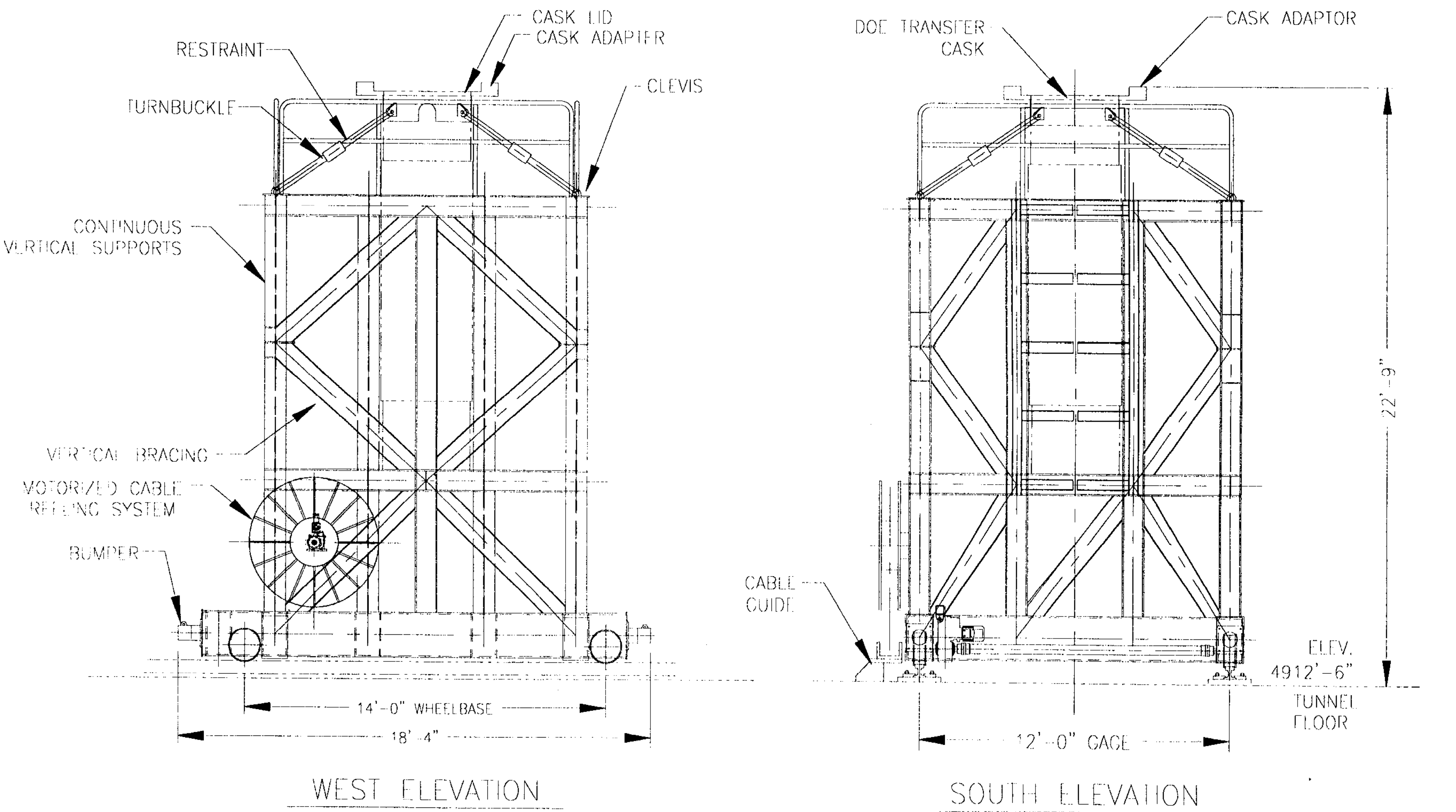


Figure 4.7-3
Fuel Handling Machine and Power Manipulator System

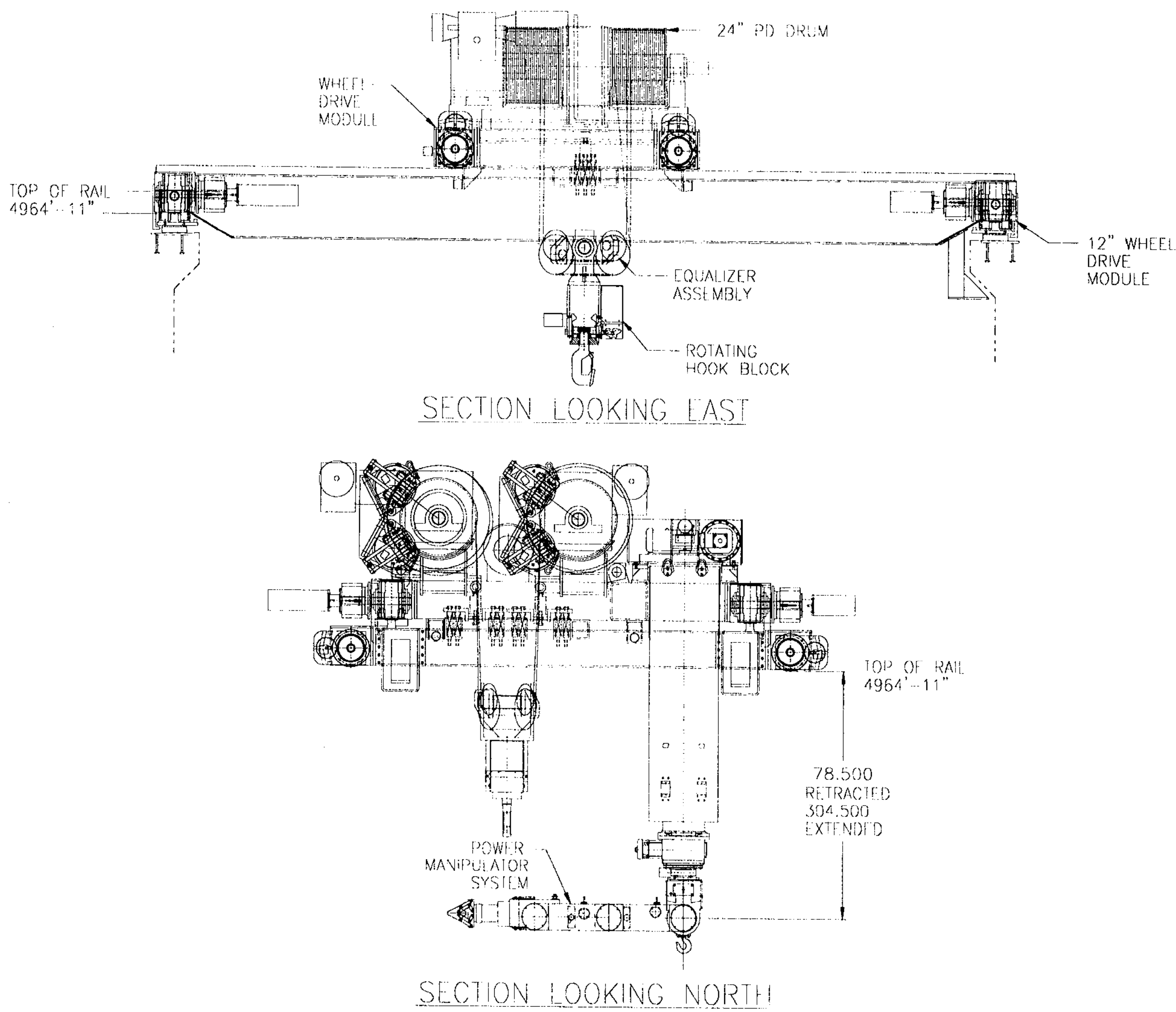


Figure 4.7-4
Canister Trolley

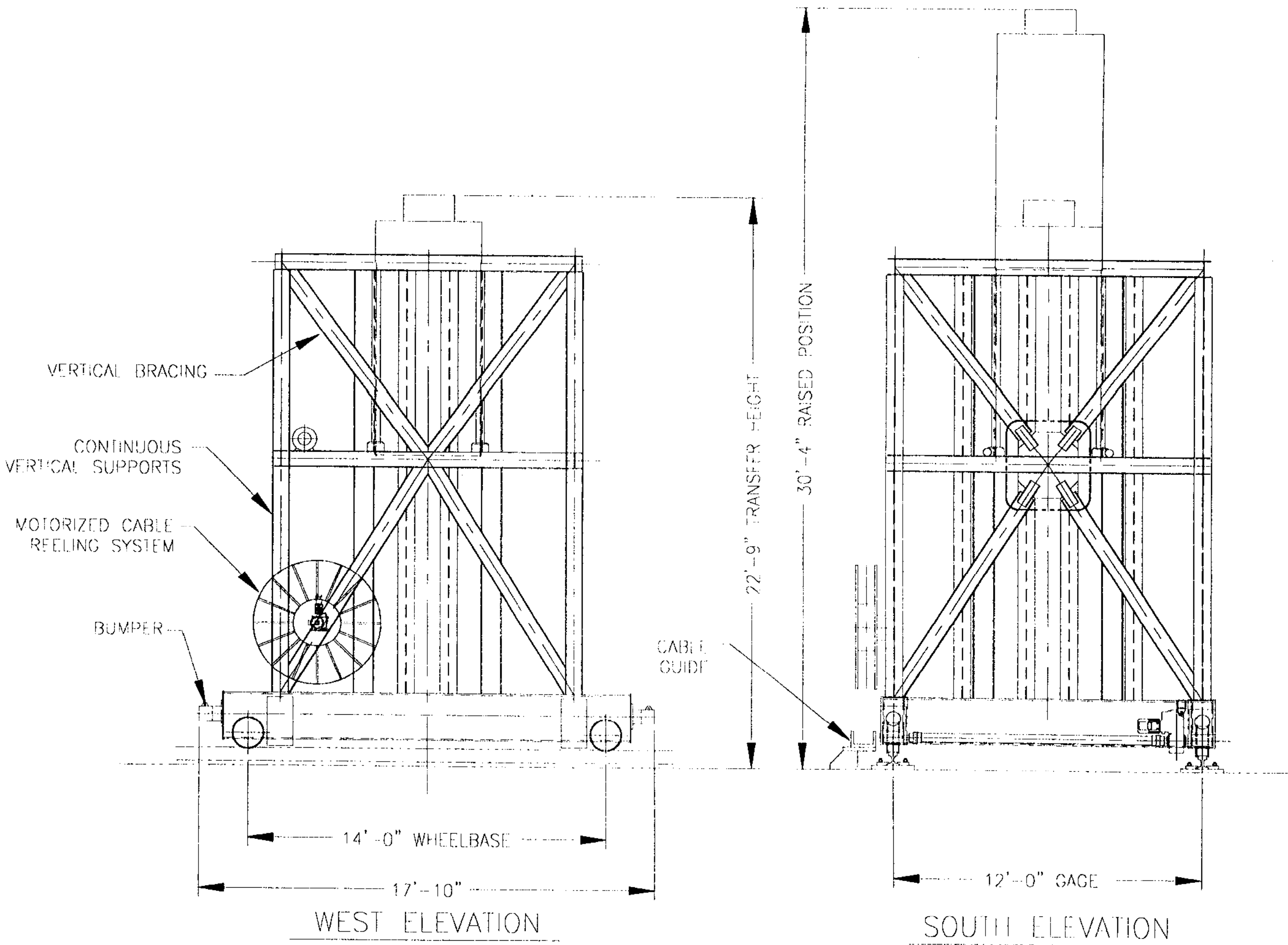


FIGURE 4.7-5
Canister Handling Machine Layout

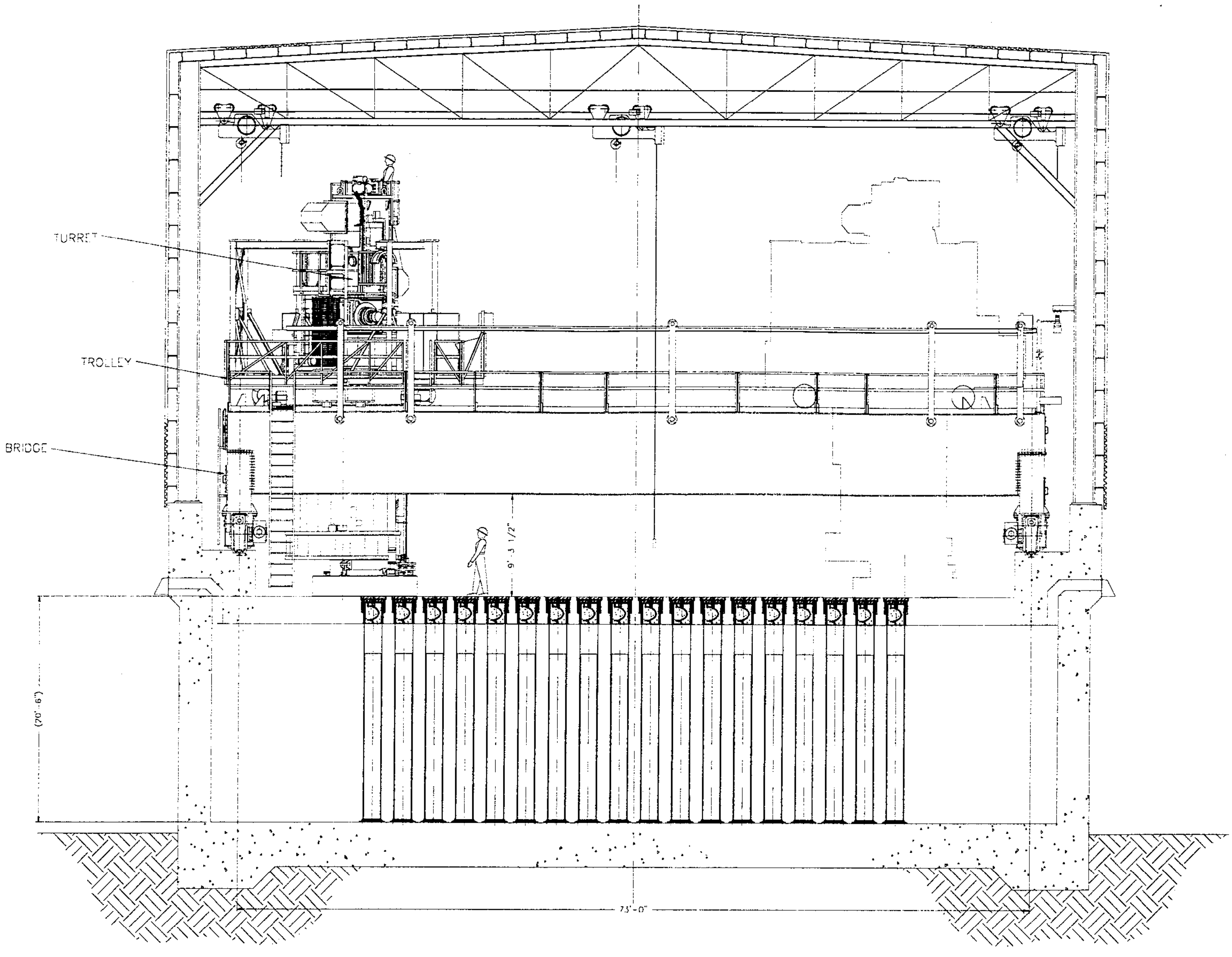


FIGURE 4.7-6
Canister Handling Machine Plan View

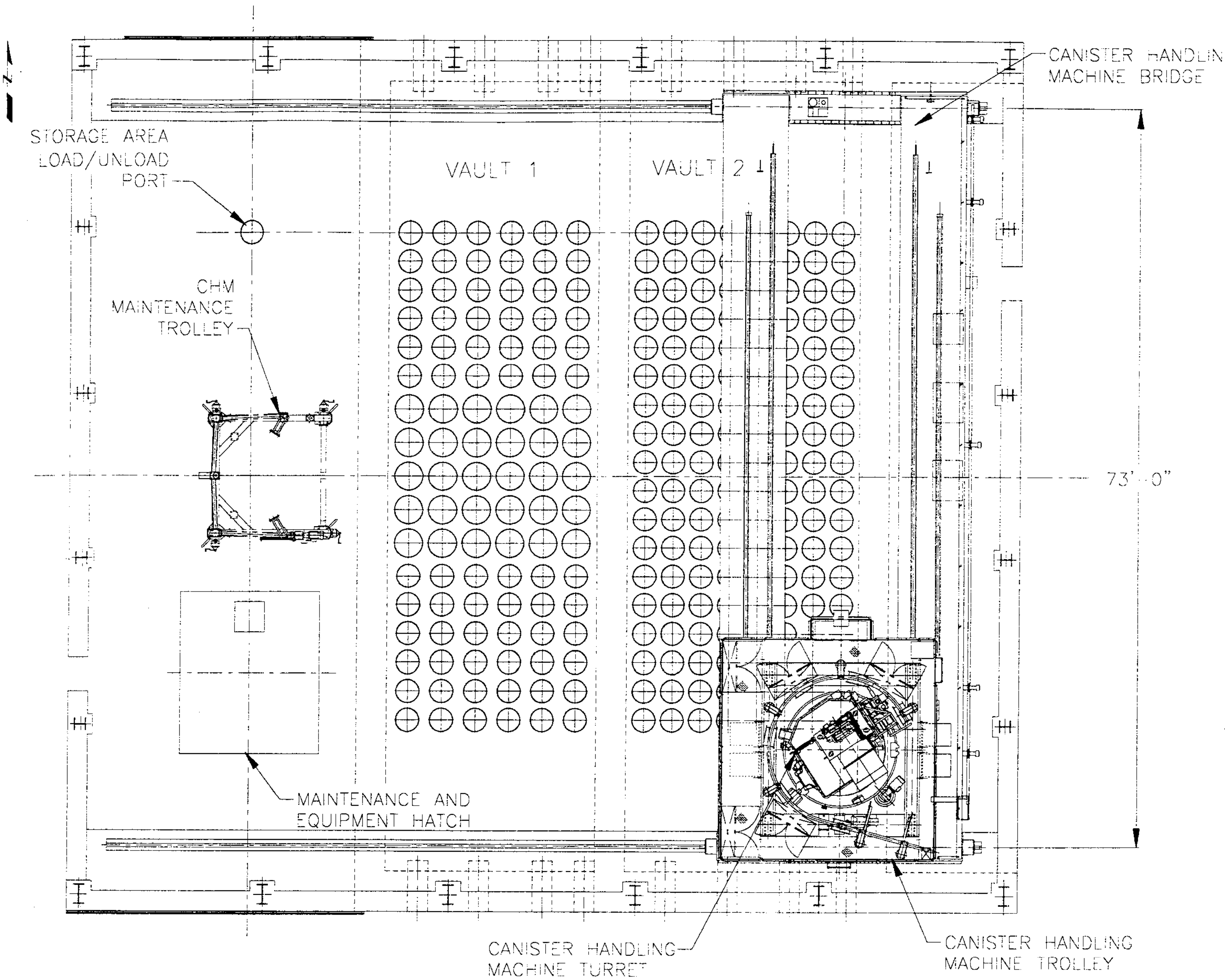


FIGURE 4.7-7
Storage Area Looking North

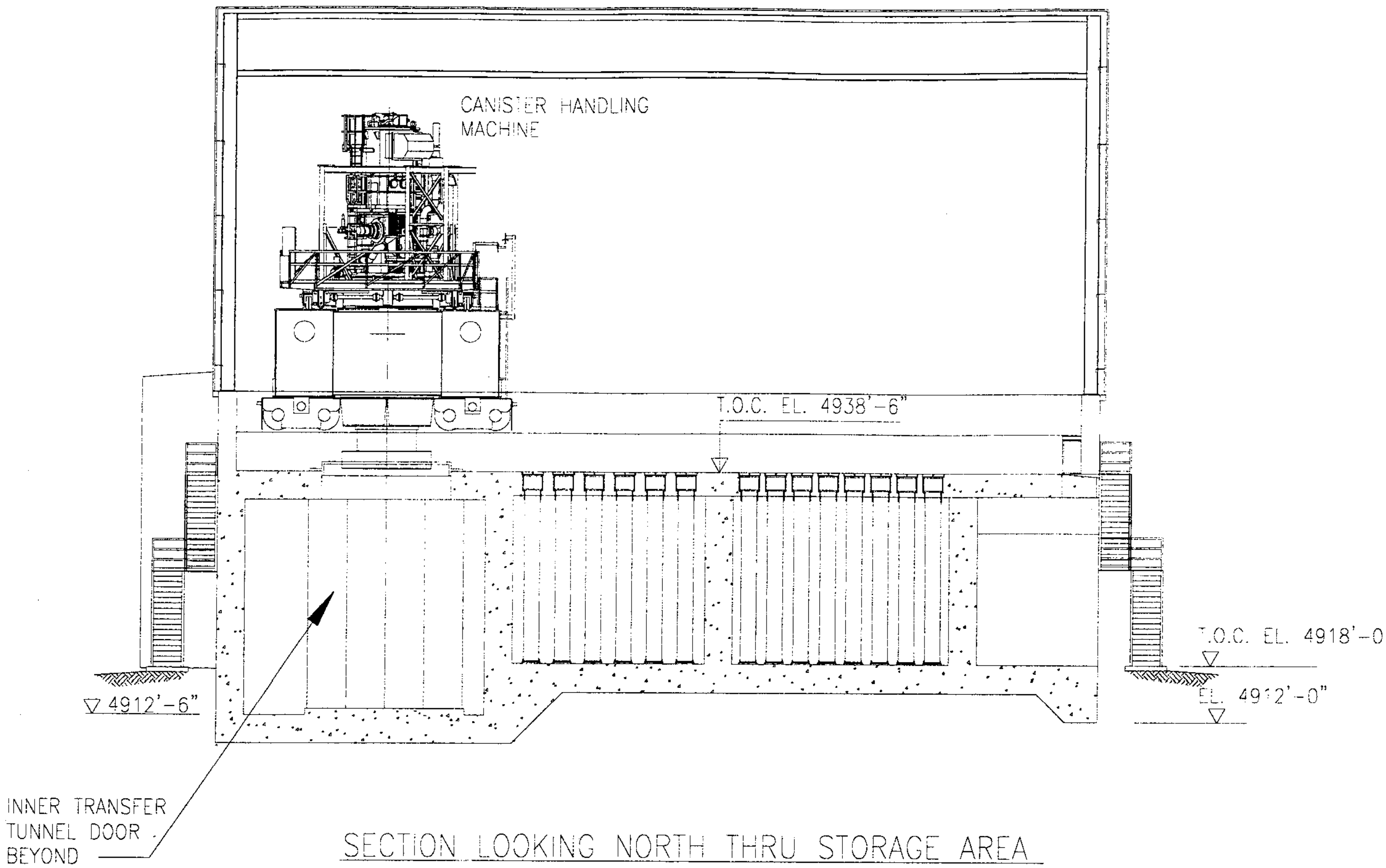


FIGURE 4.7-8
Cask Receipt Area Elevation (Looking East)

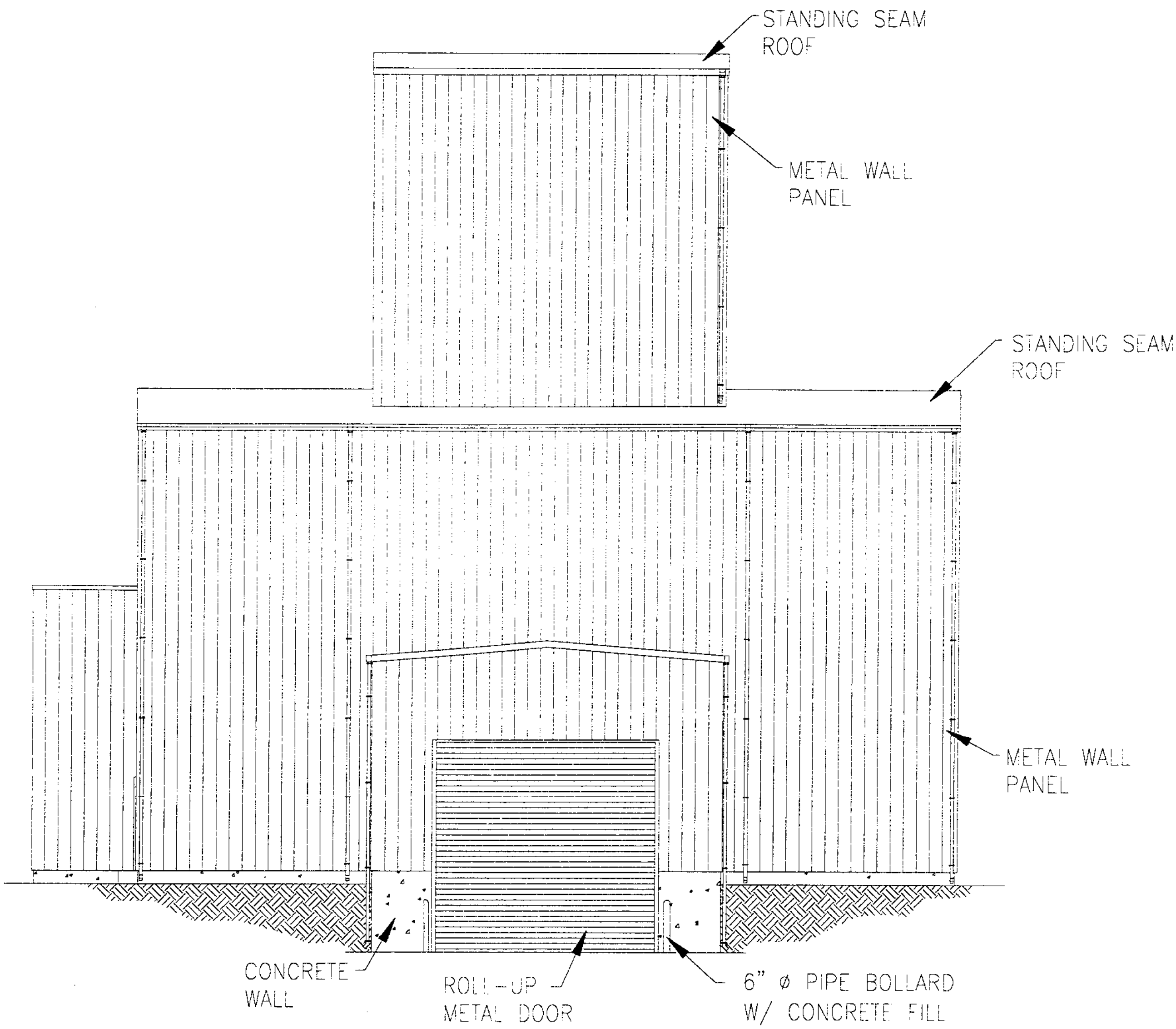


FIGURE 4.7-9
Transfer Area Elevation (Looking South)

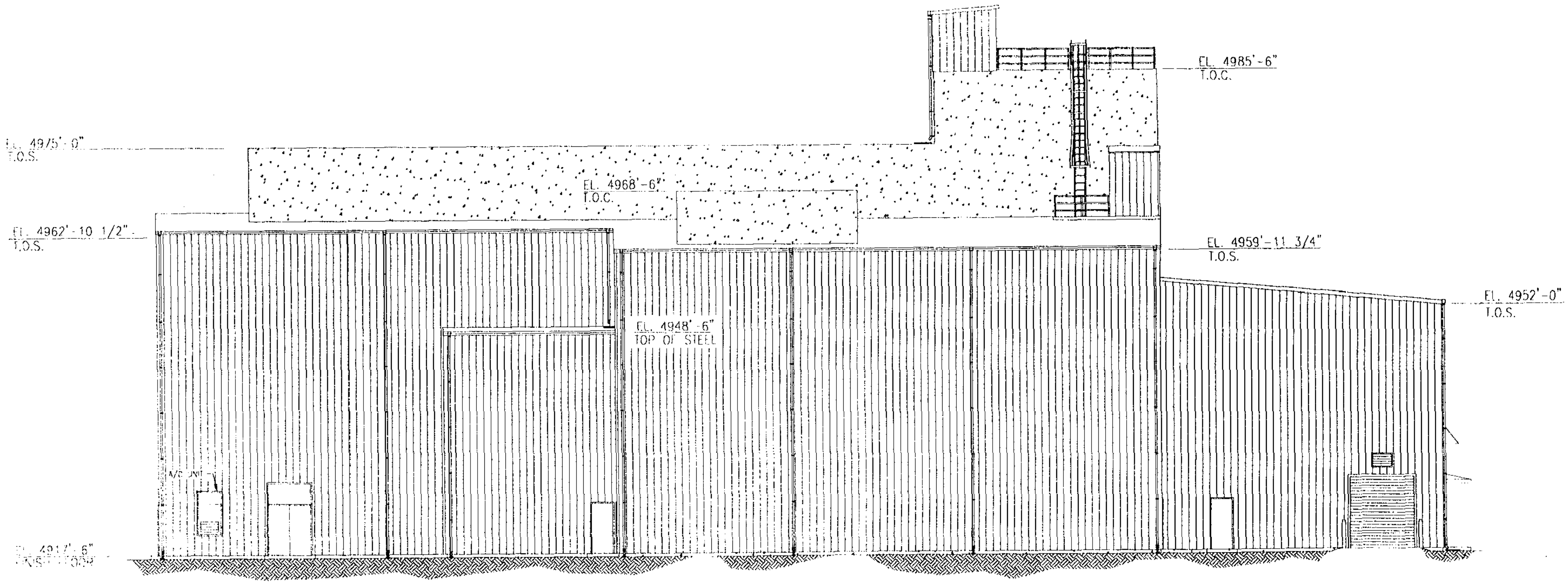
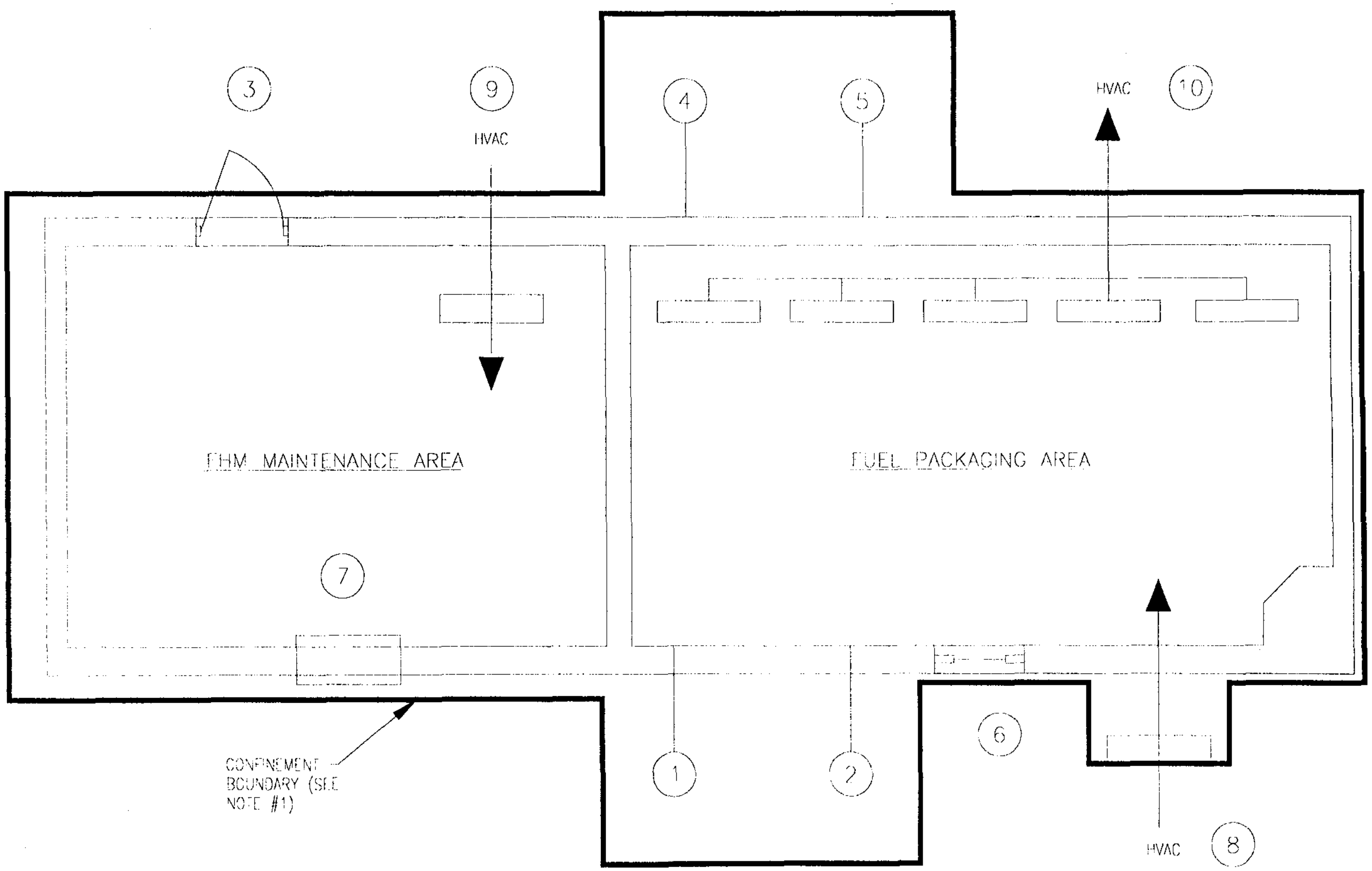


FIGURE 4.7-10
Confinement Boundary Schematic



NOTES:
1) CONFINEMENT BOUNDARY INCLUDES PORT PLUGS.

LEGEND:
1) CANISTER WASTE PORT
2) PROCESS WASTE PORT
3) PERSONNEL SHIELDED ACCESS DOOR
4) TRANFER TUNNEL CASK PORT
5) ISF TRANSFER TUNNEL CANISTER PORT
6) SHIELD WINDOWS
7) HOIST WELL
8) HVAC SUPPLY TO FUEL PACKAGING AREA (W/ HEPA FILTERS)
9) HVAC SUPPLY TO FHM MAINTENANCE AREA (W/ HEPA FILTERS)
10) HVAC EXHAUST FROM FUEL PACKAGING AREA (W/ HEPA FILTERS)

FIGURE 4.7-11
Cask Port Seal

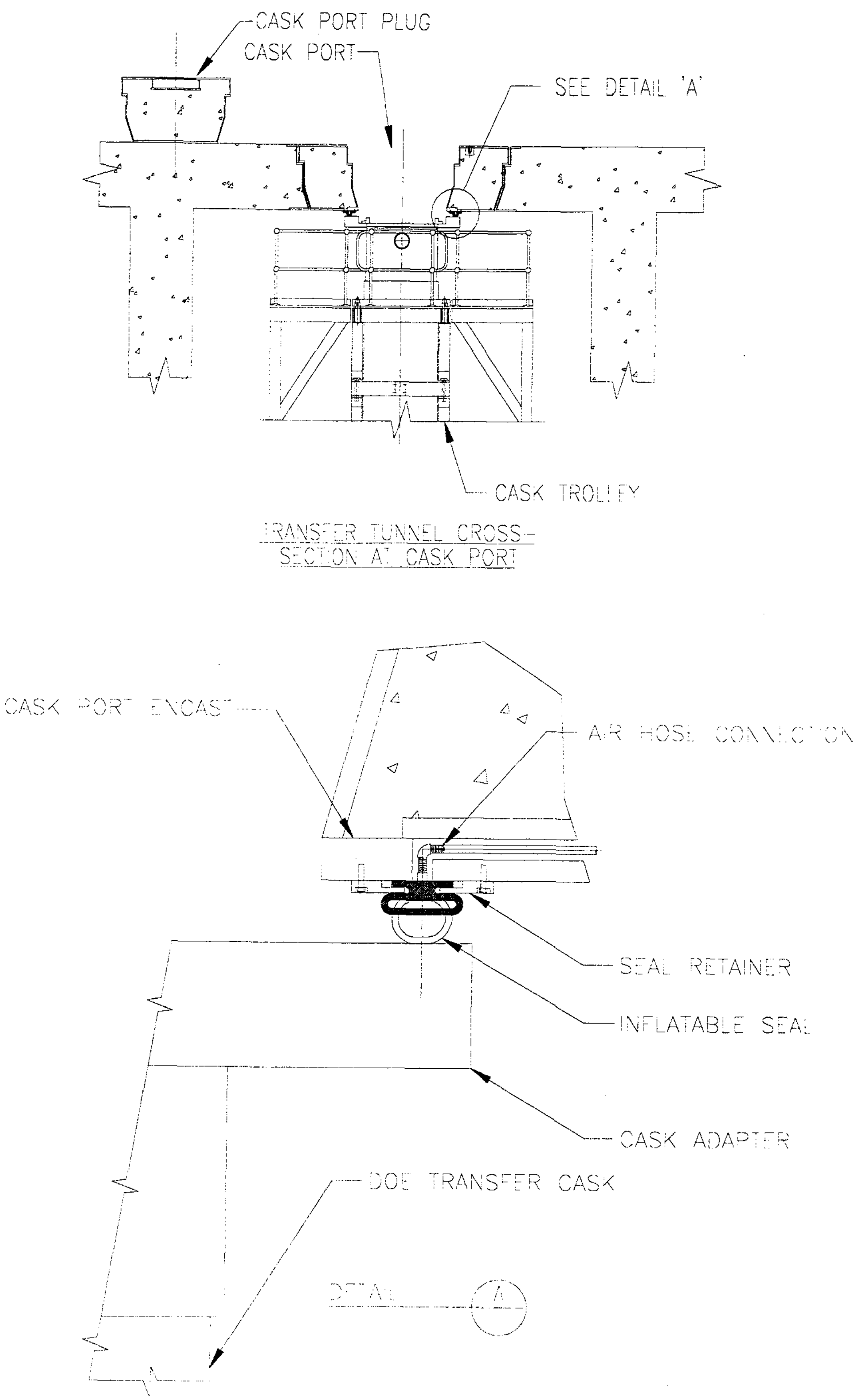
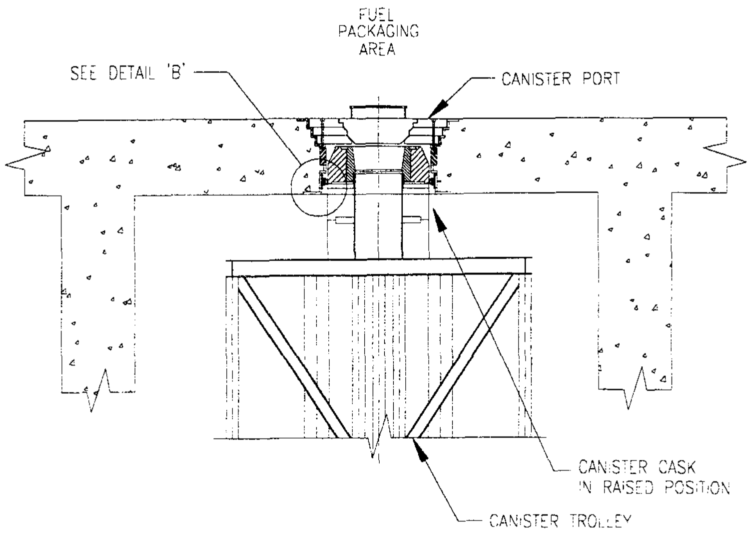
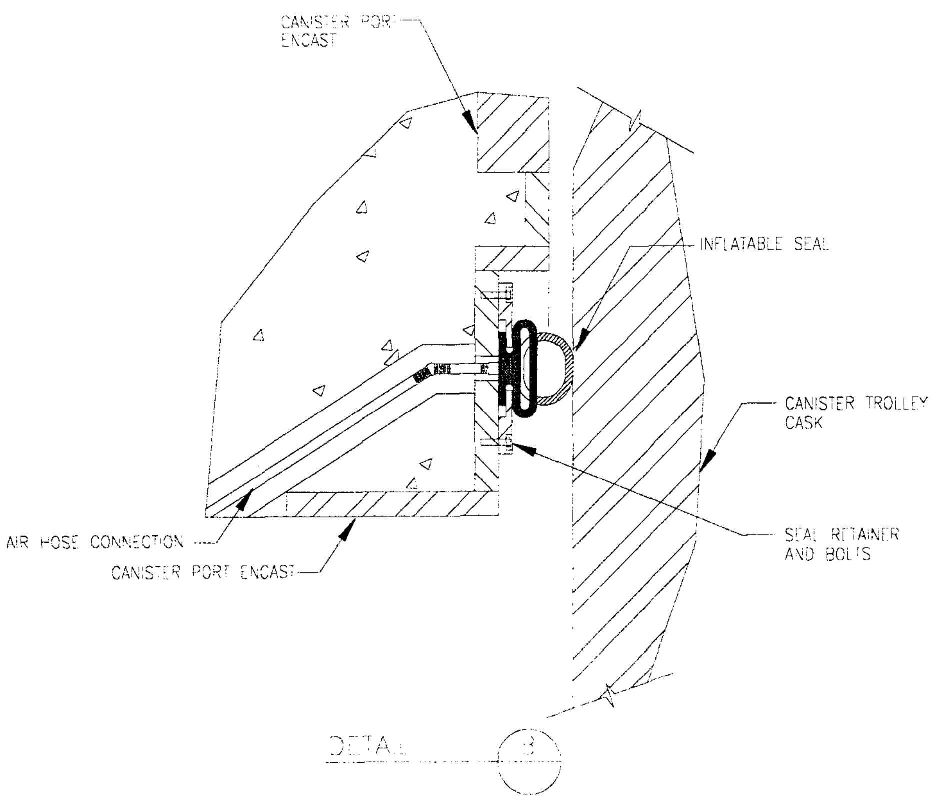


FIGURE 4.7-12
Canister Port Seal



TRANSFER TUNNEL CROSS-SECTION AT CANISTER PORT



DETAIL B

FIGURE 4.7-13
Fuel Packaging Area Workbench Configuration
Peach Bottom 1 Fuel Campaign

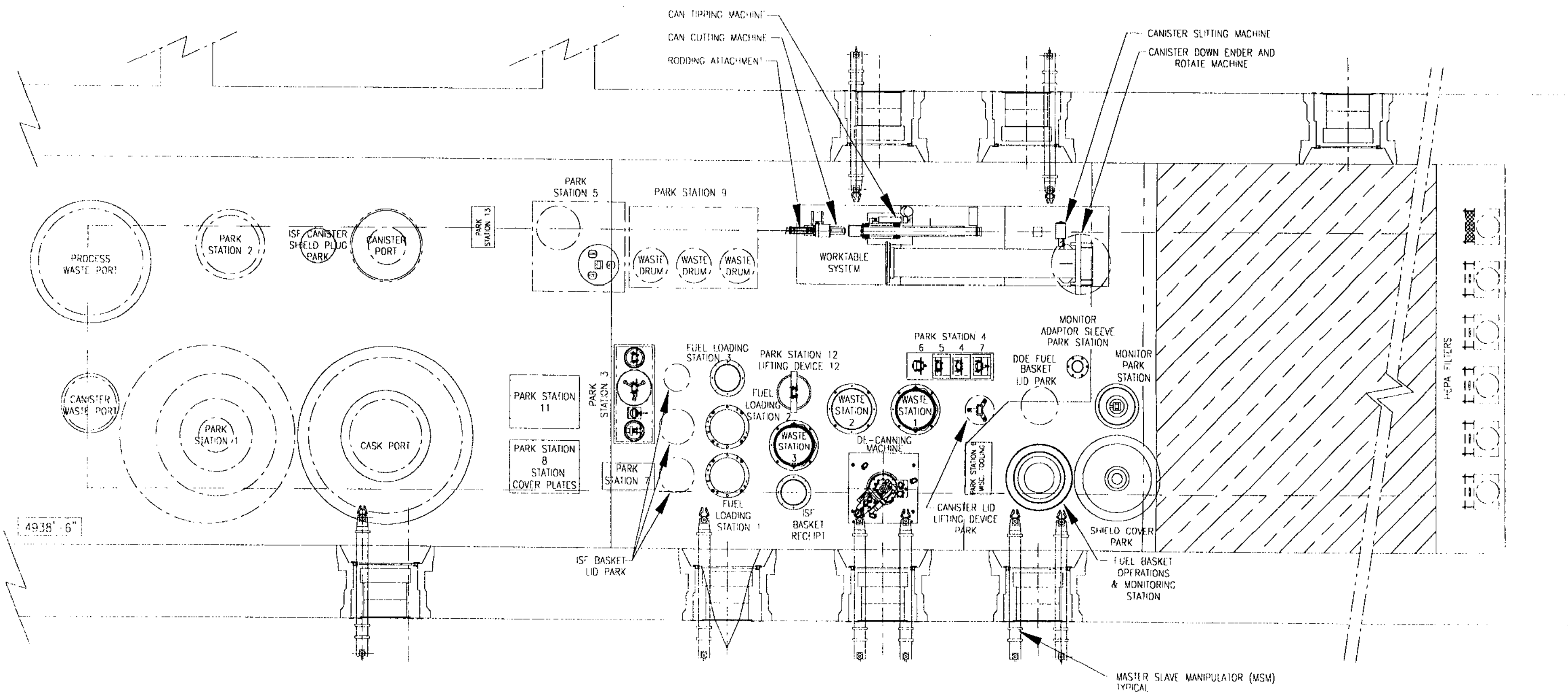


Figure 4.7-14
Worktable Arrangement

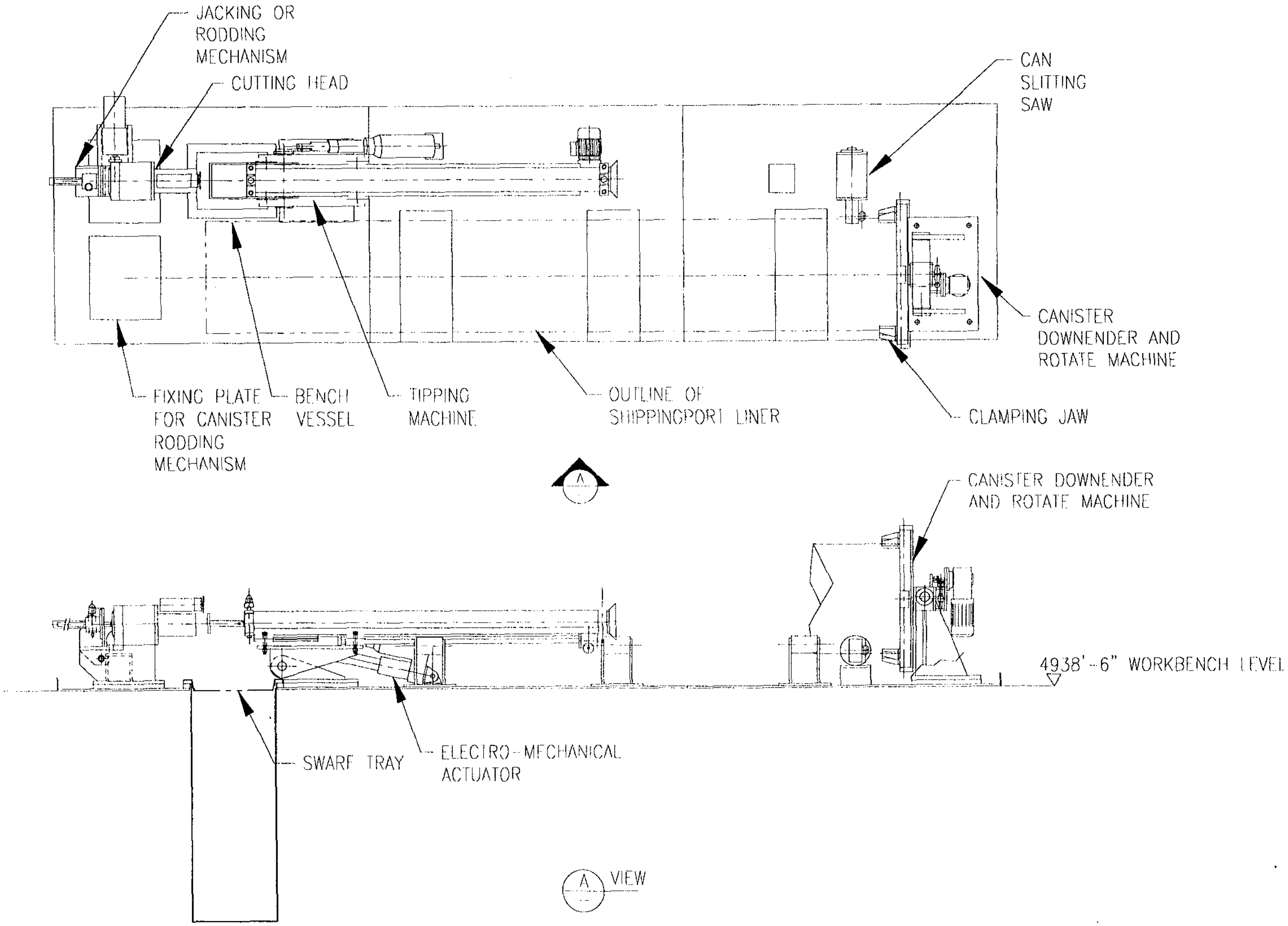


FIGURE 4.7-15
Canister Closure Area

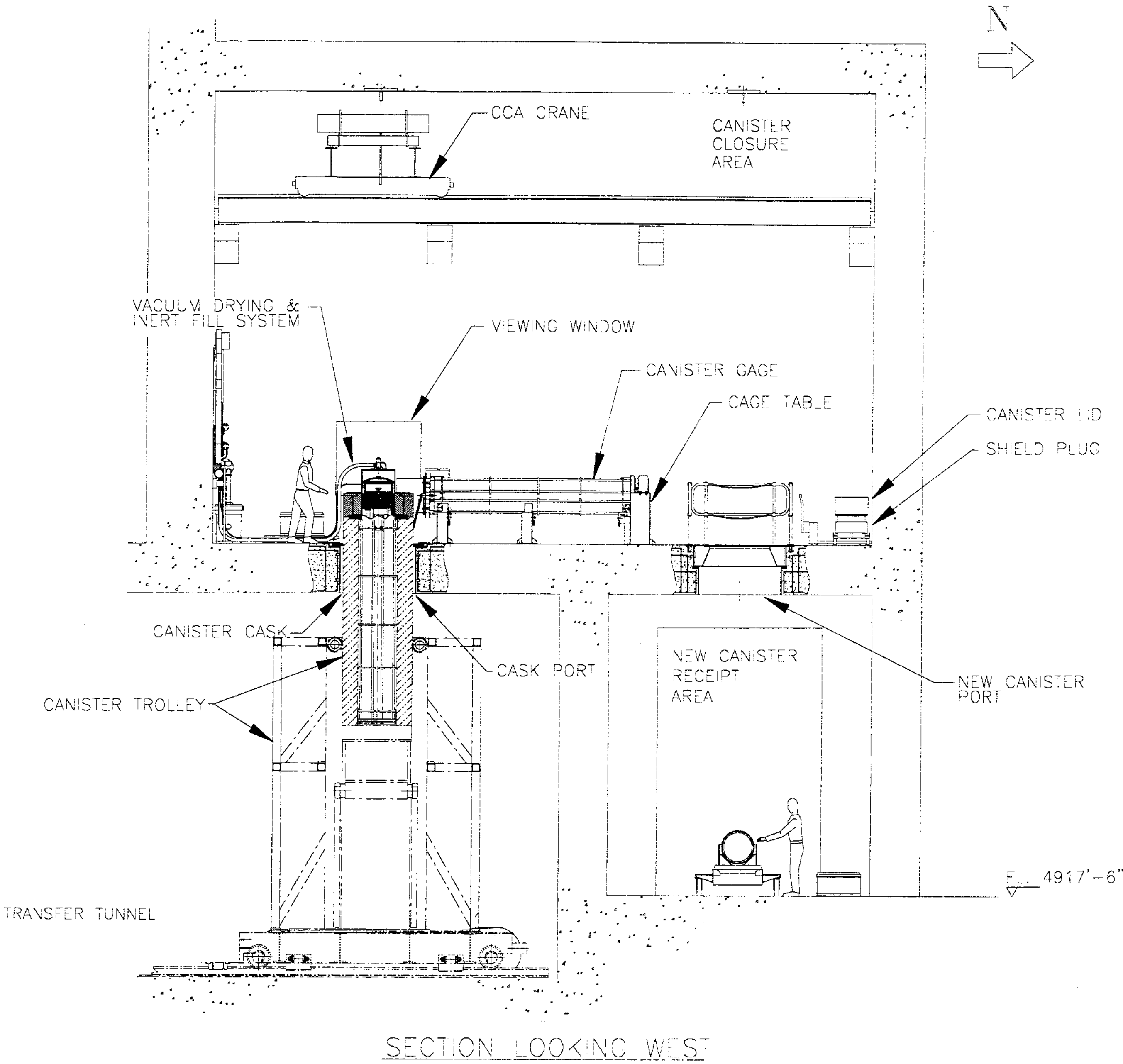


FIGURE 4.7-16
Canister Closure Area Operational Layout

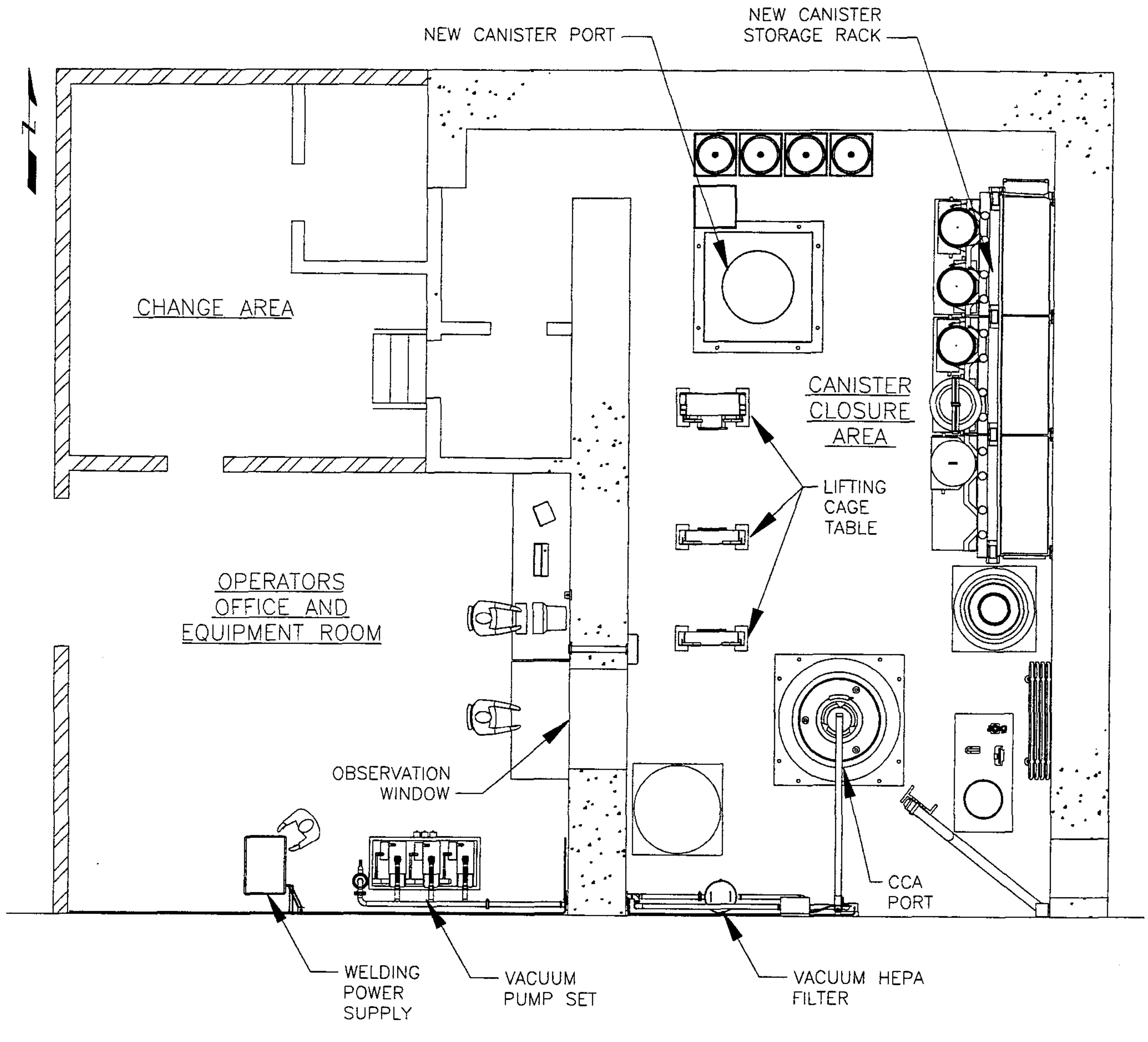


Figure 4.7-17
DOE Transfer Cask Lifting Device

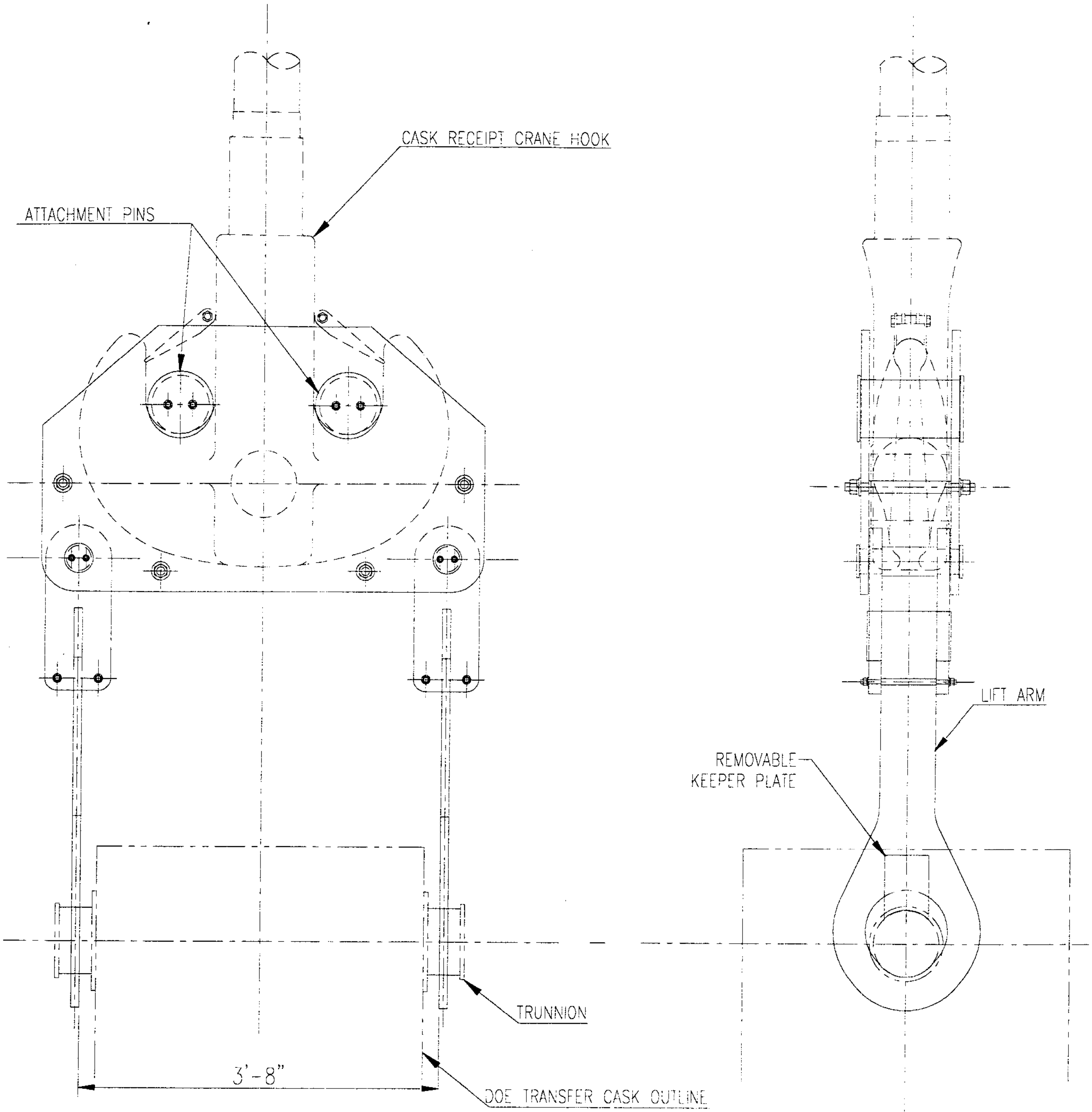
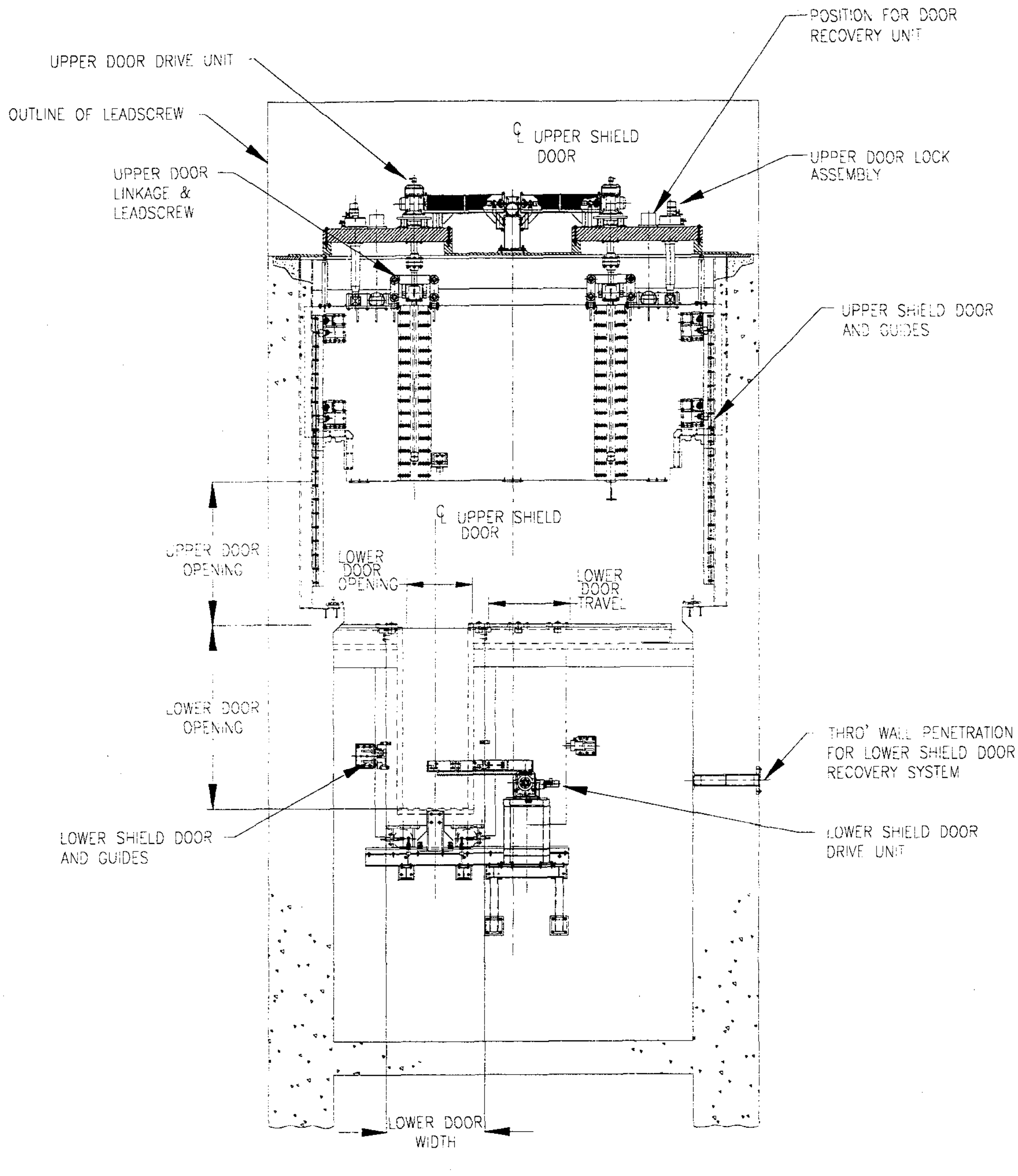


FIGURE 4.7-18
Fuel Packaging Area Shield Doors Arrangement



VIEW LOOKING EAST
(INSIDE FHM MAINTENANCE AREA WITH UPPER DOOR OPEN)

FIGURE 4.7-19
Fuel Packaging Area Shield Doors Arrangement Section

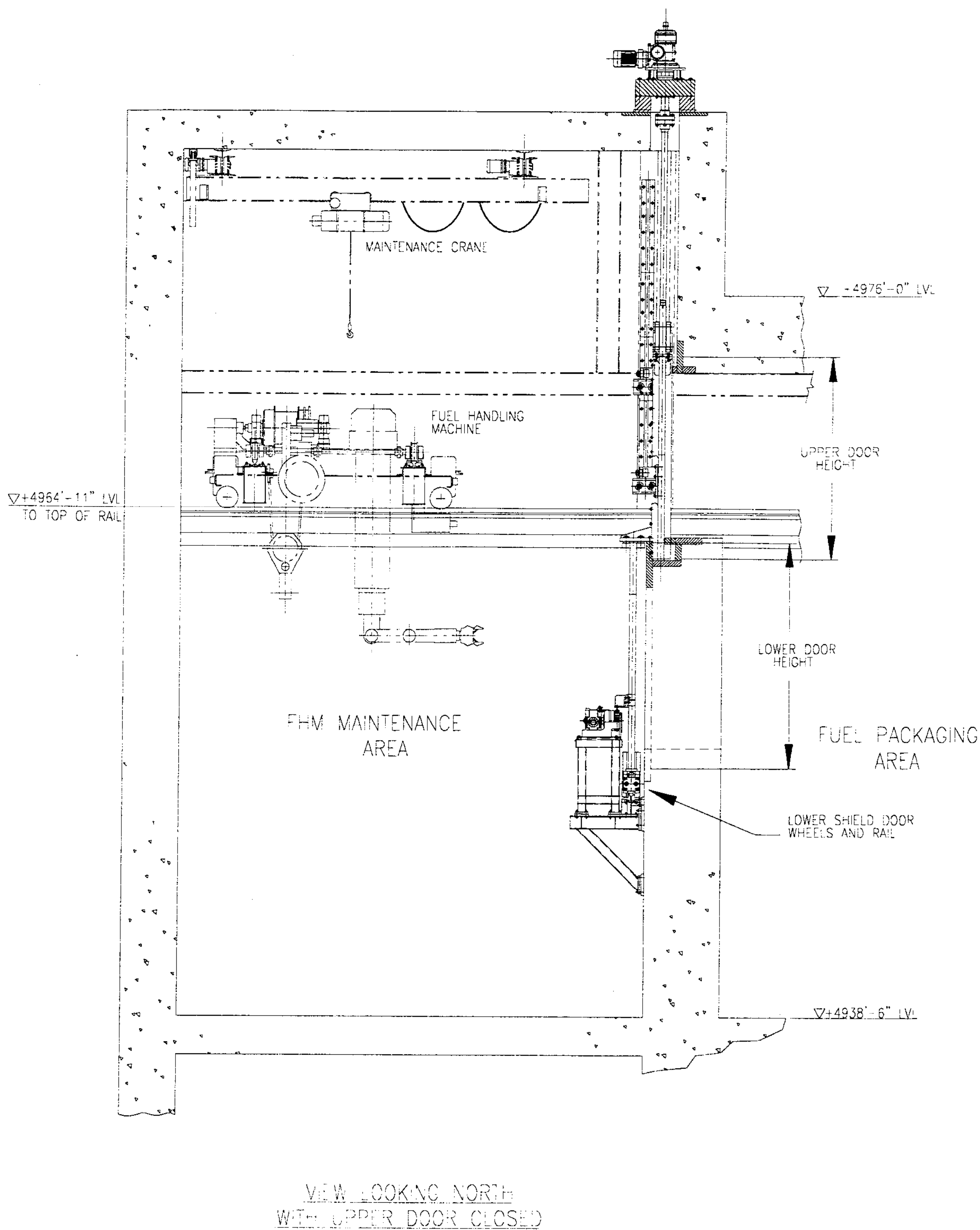


FIGURE 4.7-20
Personnel Shielded Access Door

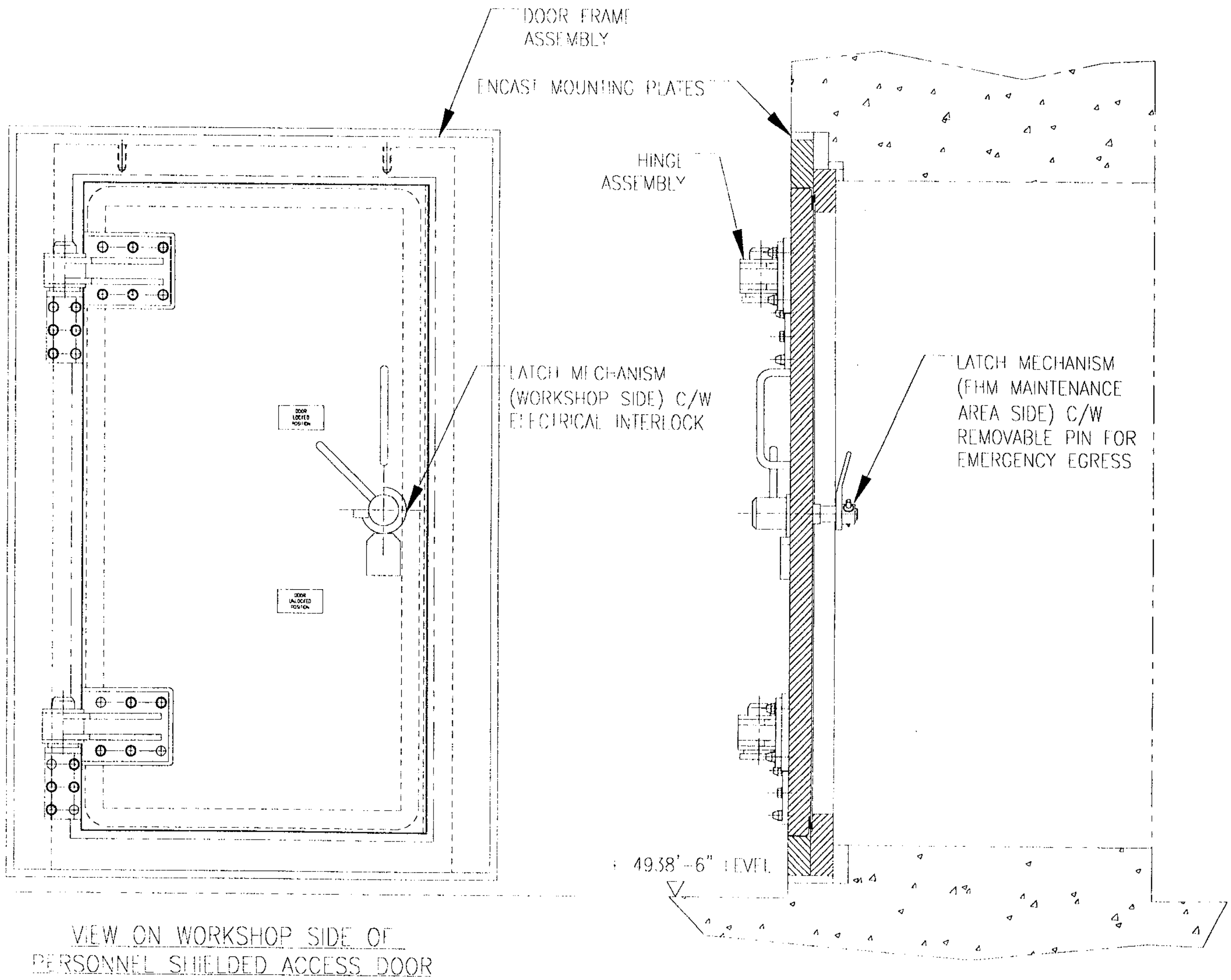


FIGURE 4.7-21
Typical Master Slave Manipulator Configuration

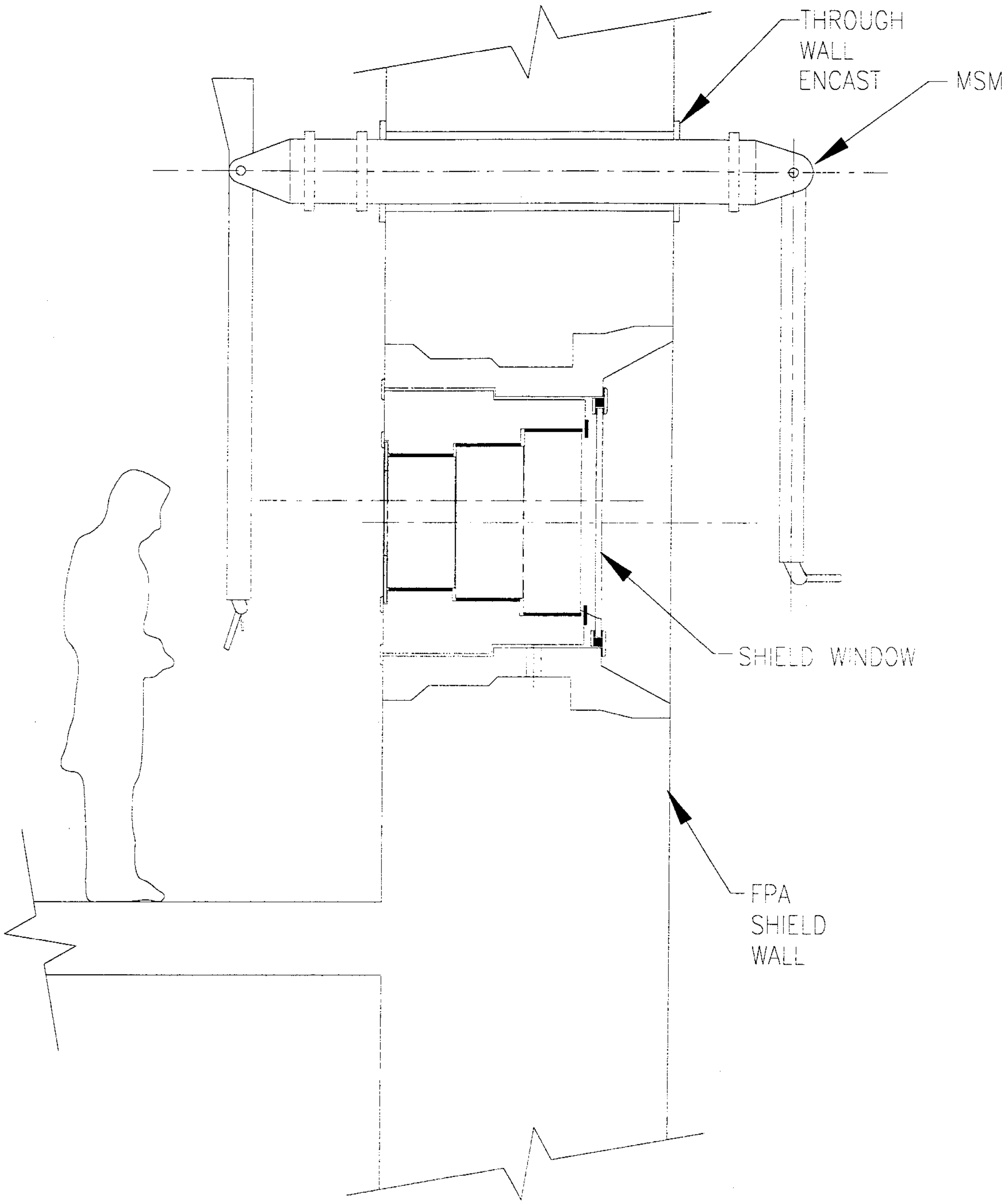
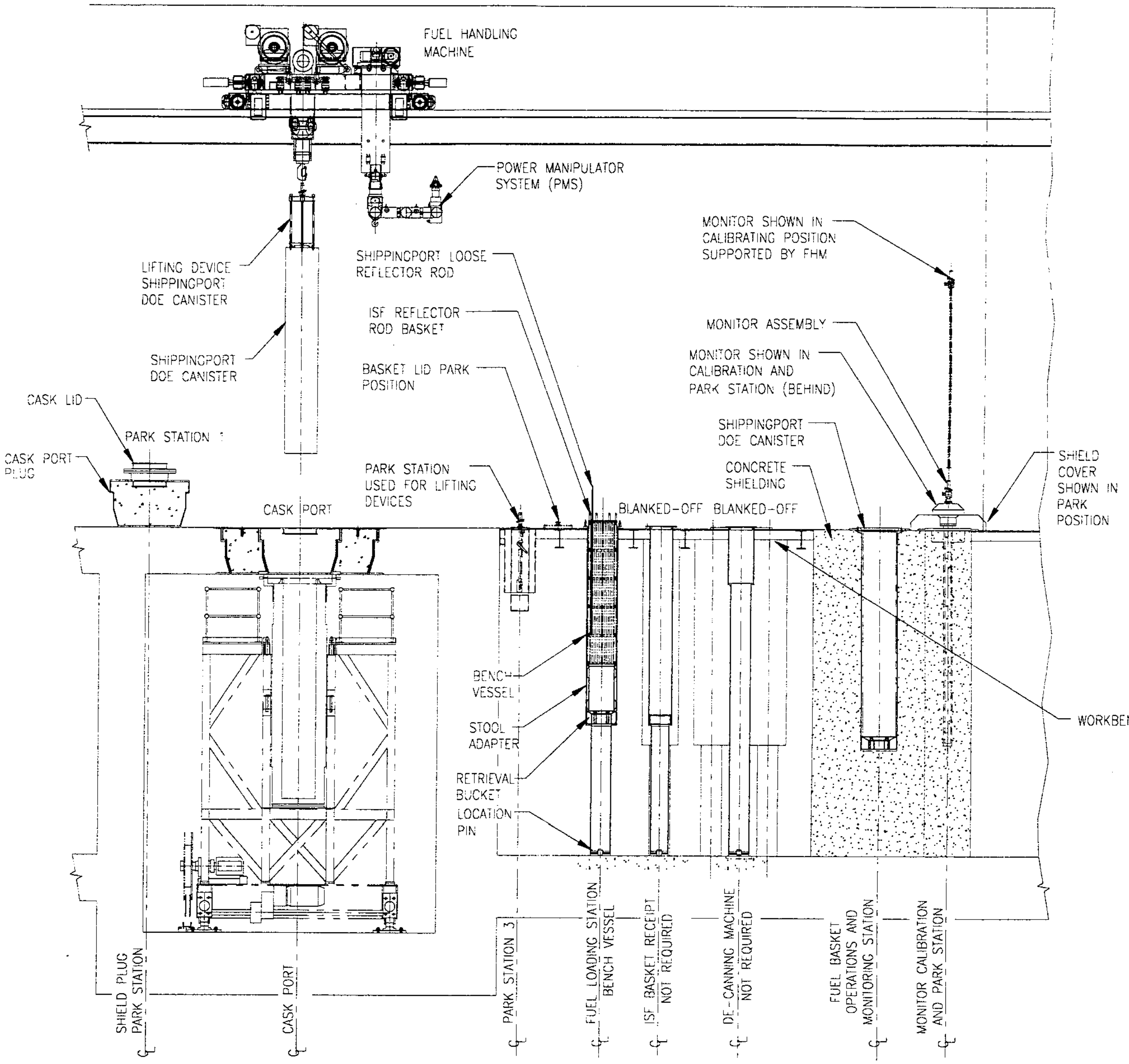
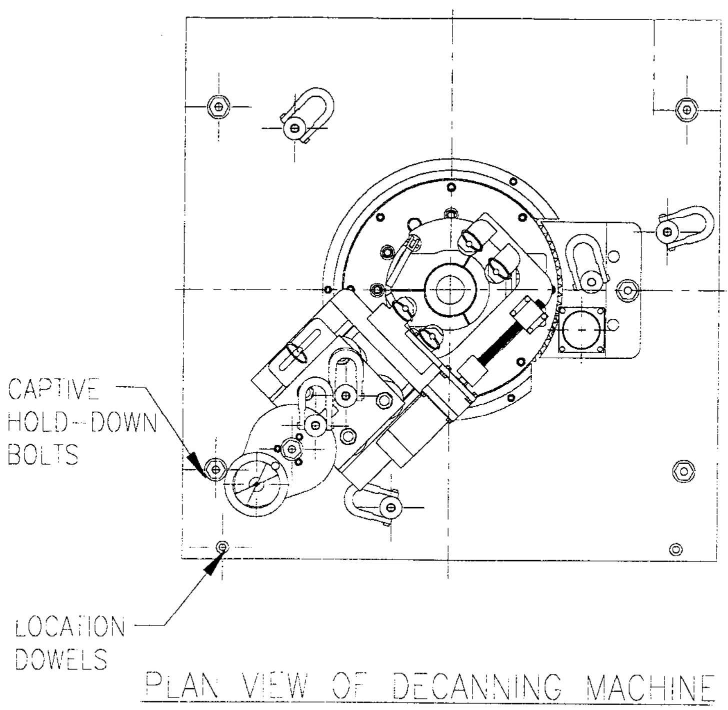


Figure 4.7-22
Shippingport Fuel Campaign
Typical Bench Vessel Arrangement



SECTION LOOKING NORTH

FIGURE 4.7-23
Decanning Station Transfer Area



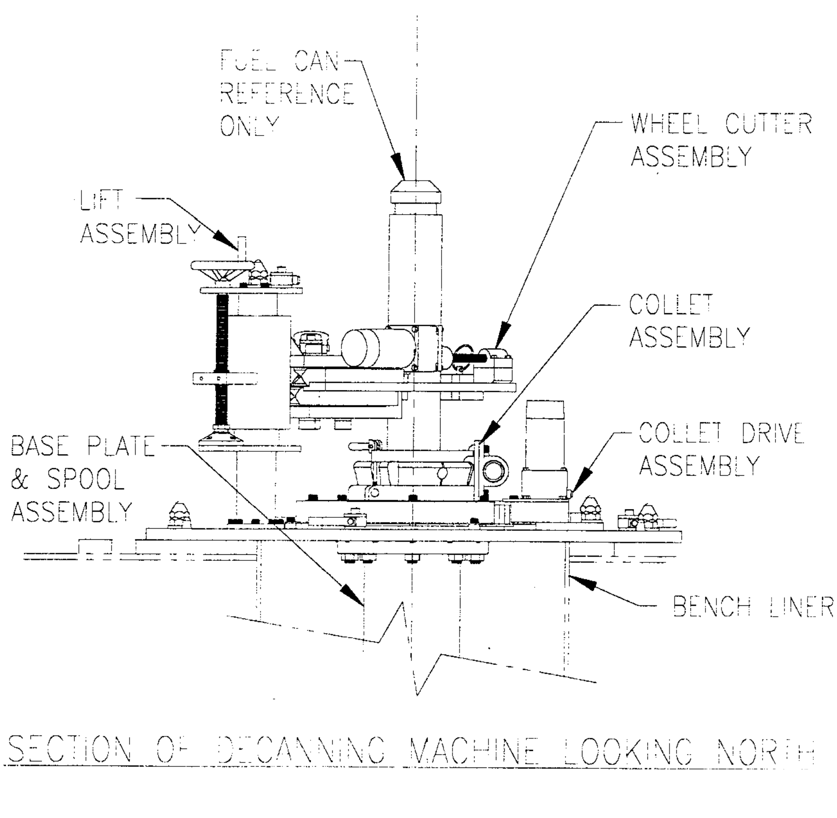


FIGURE 4.7-24
Decanning Machine Cutting Locations

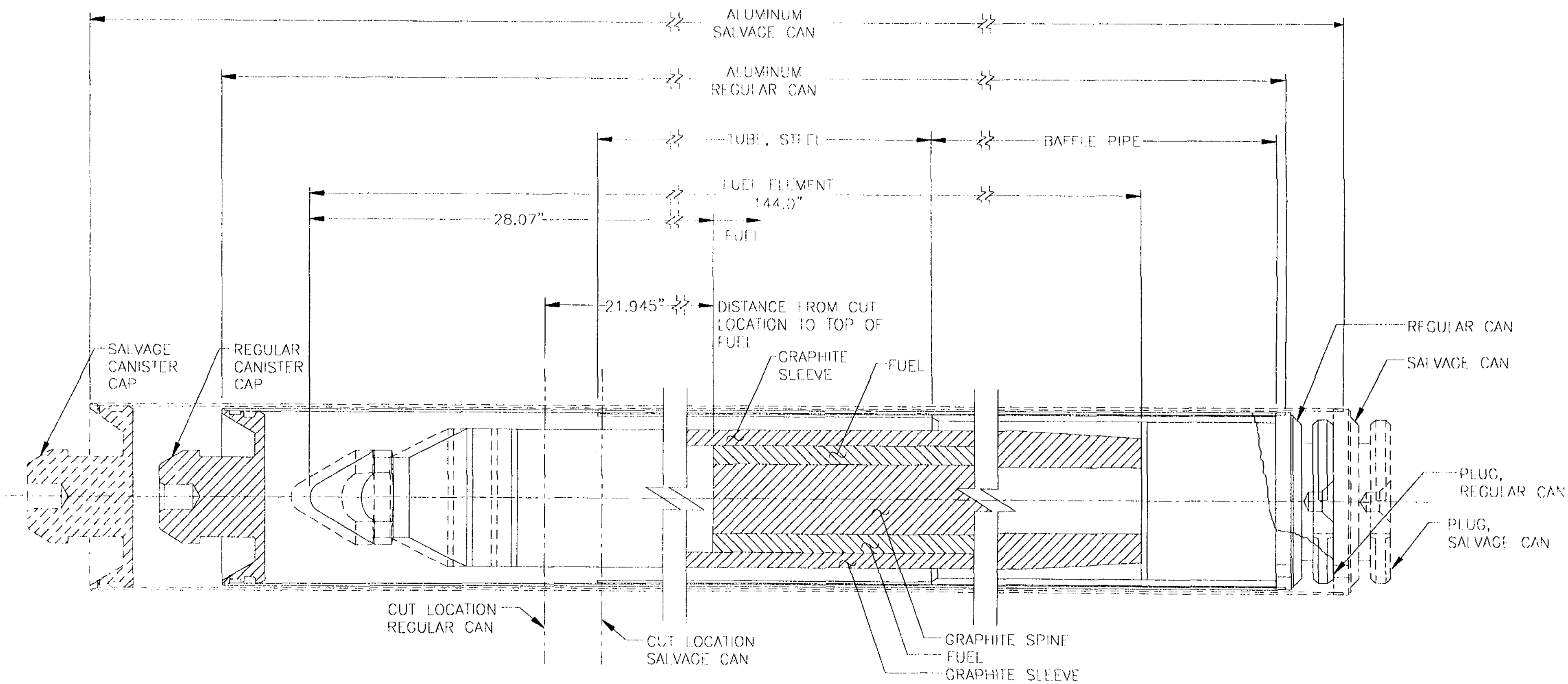
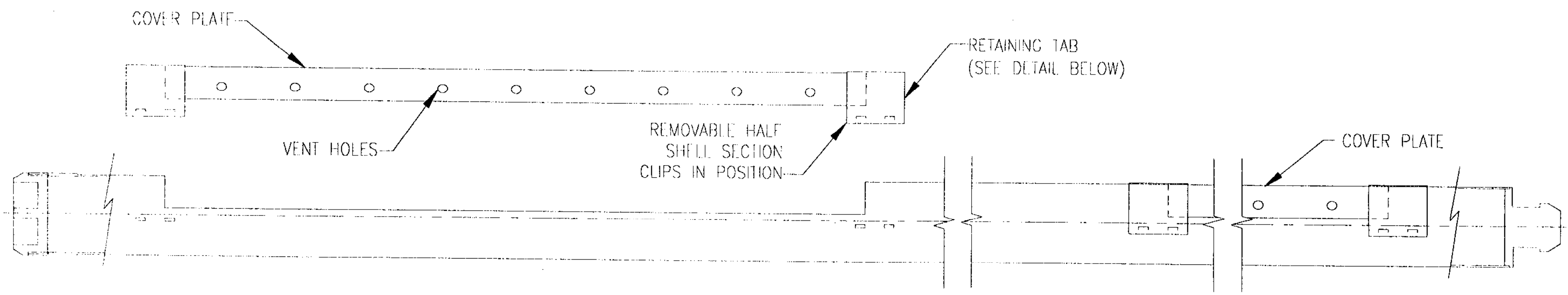
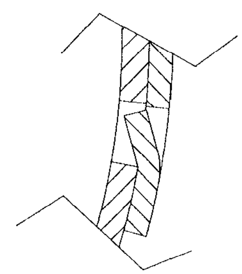


FIGURE 4.7-25
Broken Fuel Element Container Peach Bottom 1 Fuel



BROKEN FUEL ELEMENT CONTAINER



RETAINING TAB

Figure 4.7-26
Type 1 Lifting Device

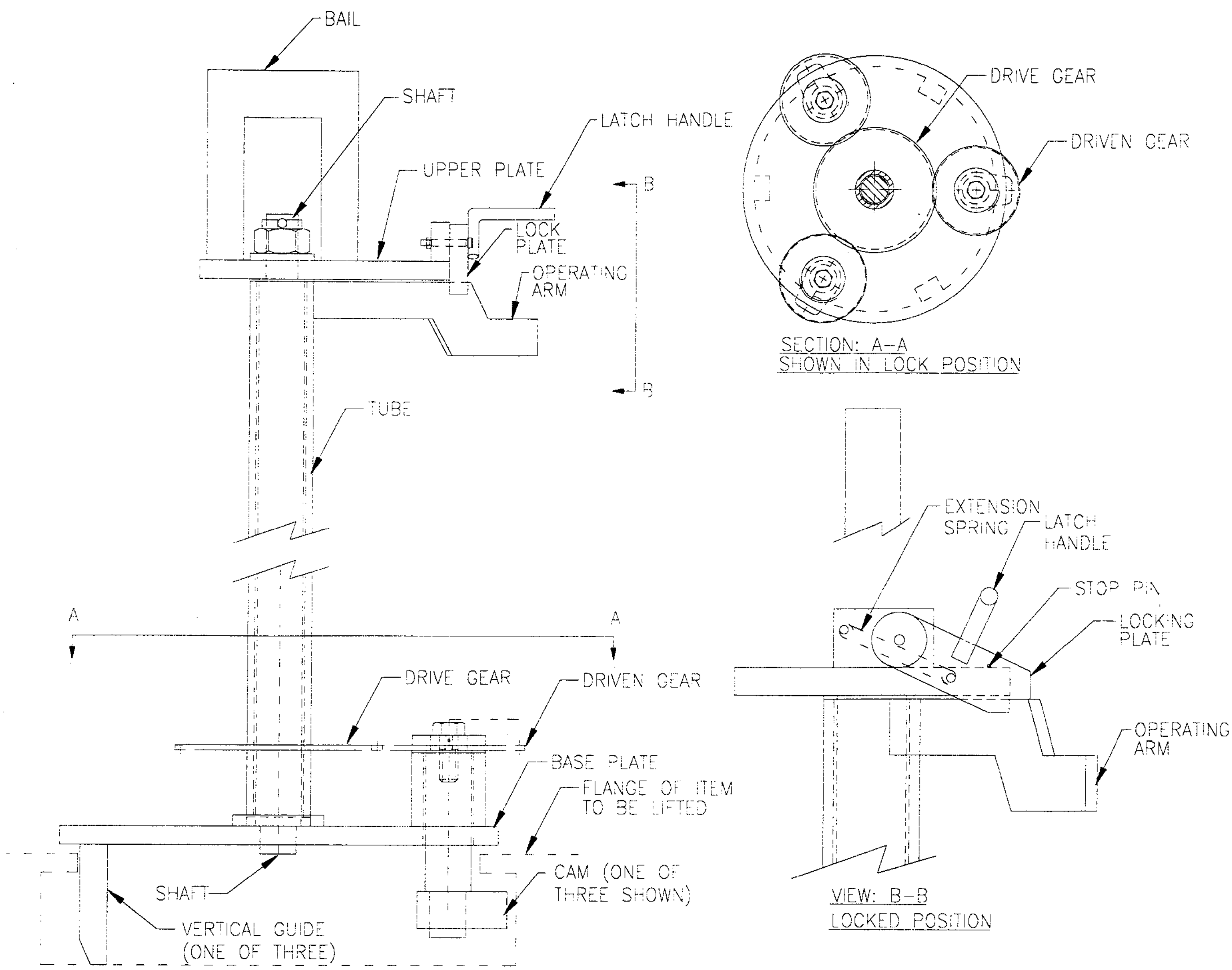


Figure 4.7-27
Type 2 Lifting Device

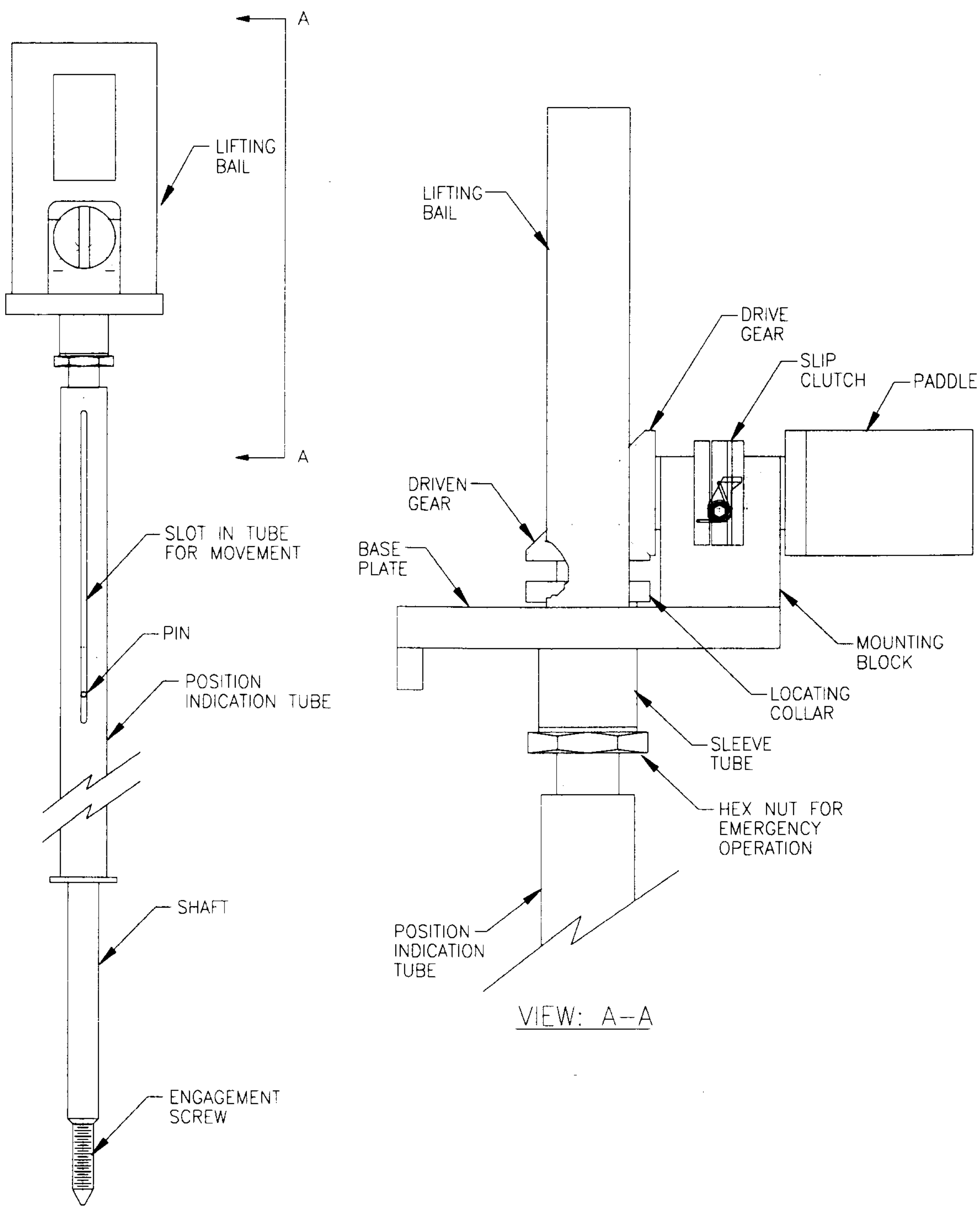


Figure 4.7-28
Type 3 Lifting Device

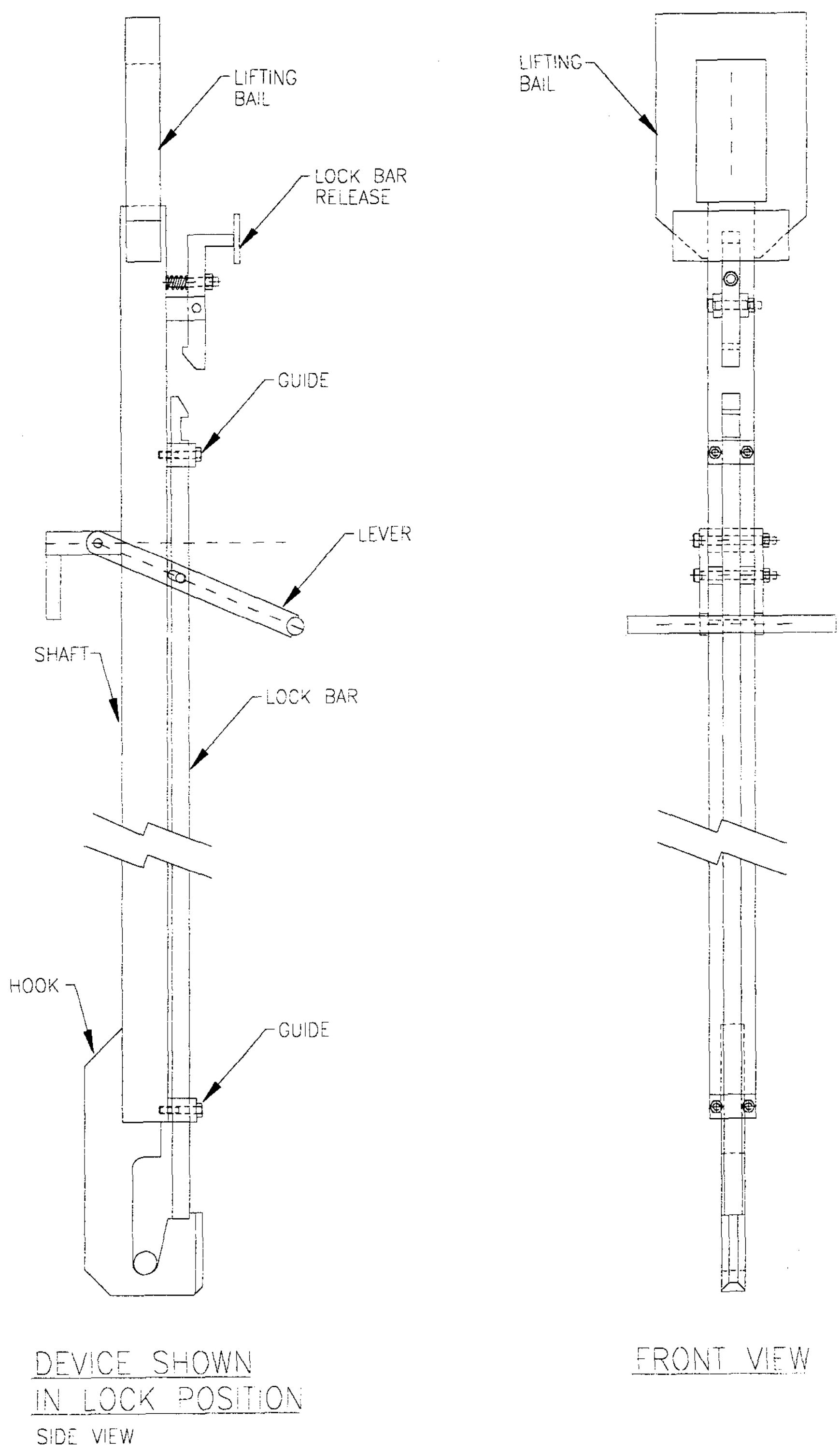


Figure 4.7-29
Type 4 Lifting Device

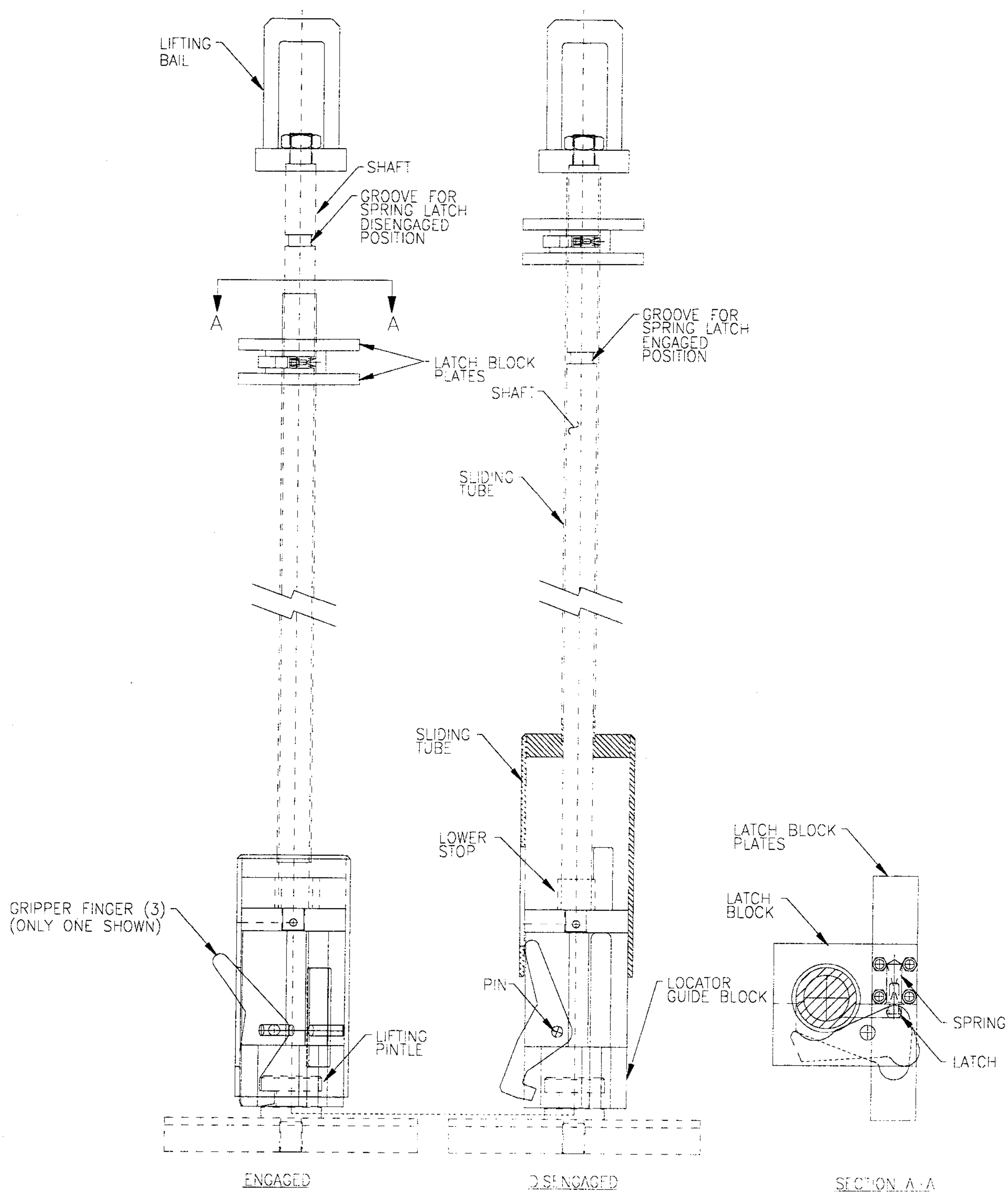


Figure 4.7-30
Type 5 Lifting Device

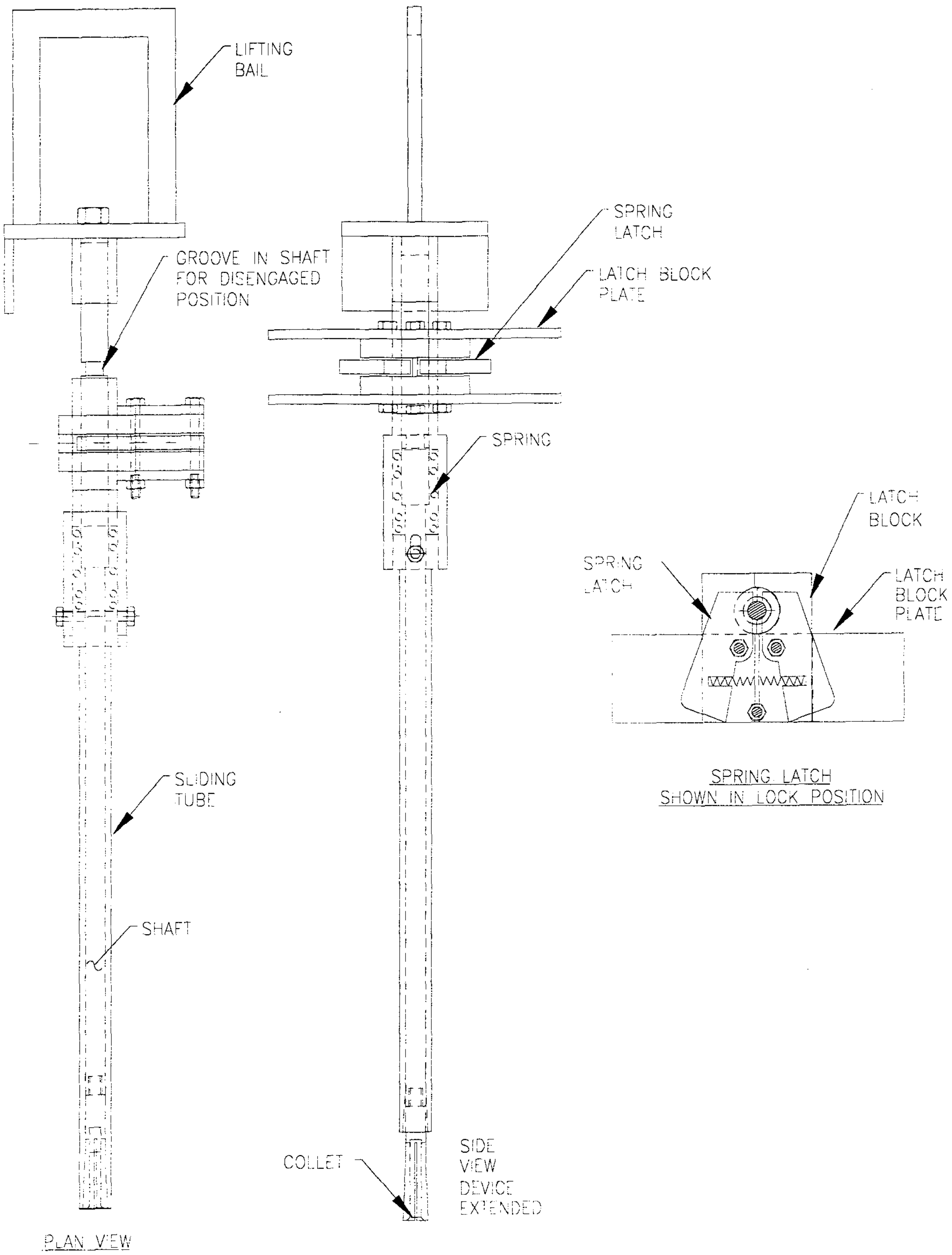


Figure 4.7-31
Type 6 Lifting Device

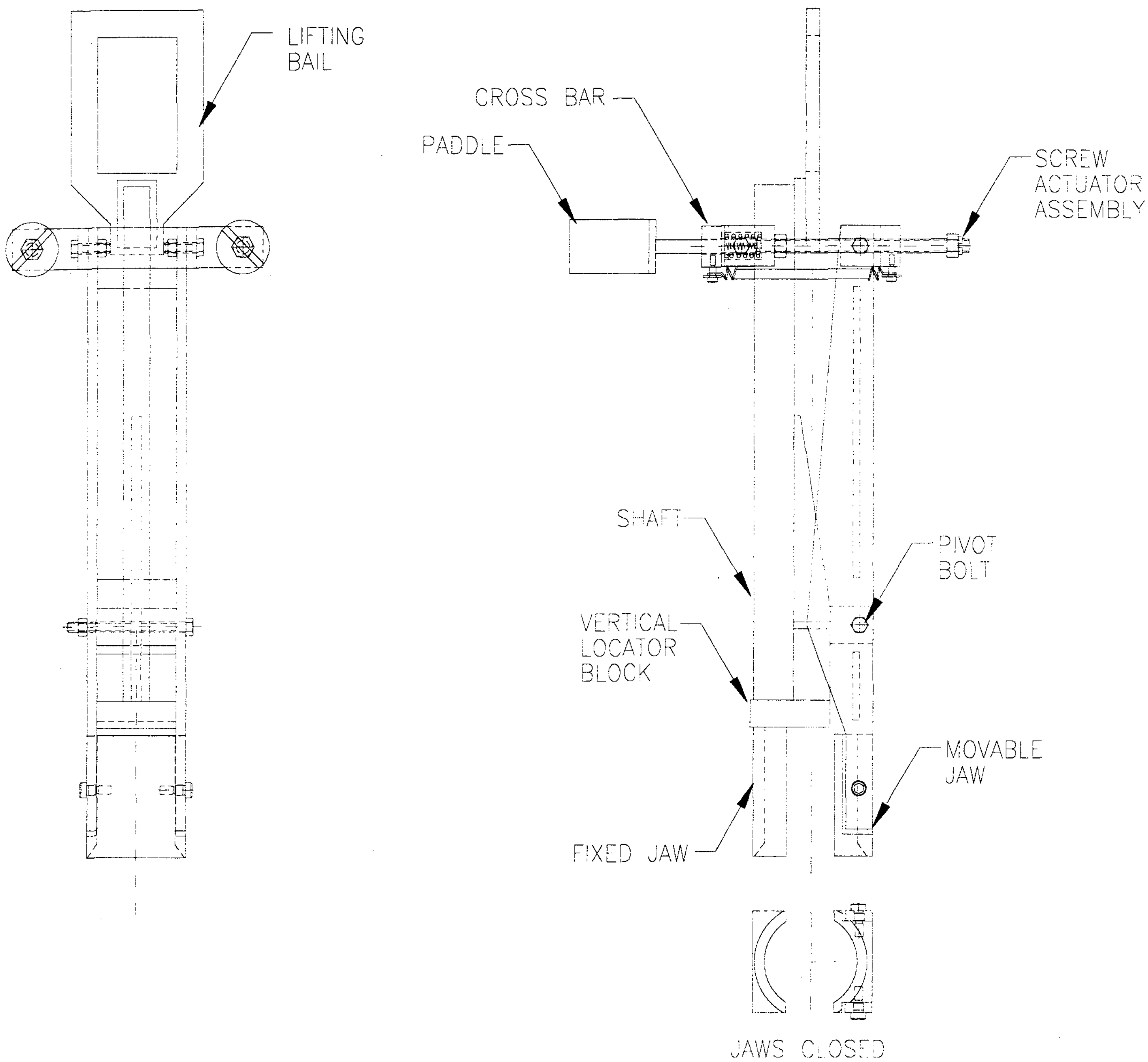


FIGURE 4.7-32
CHM Turret

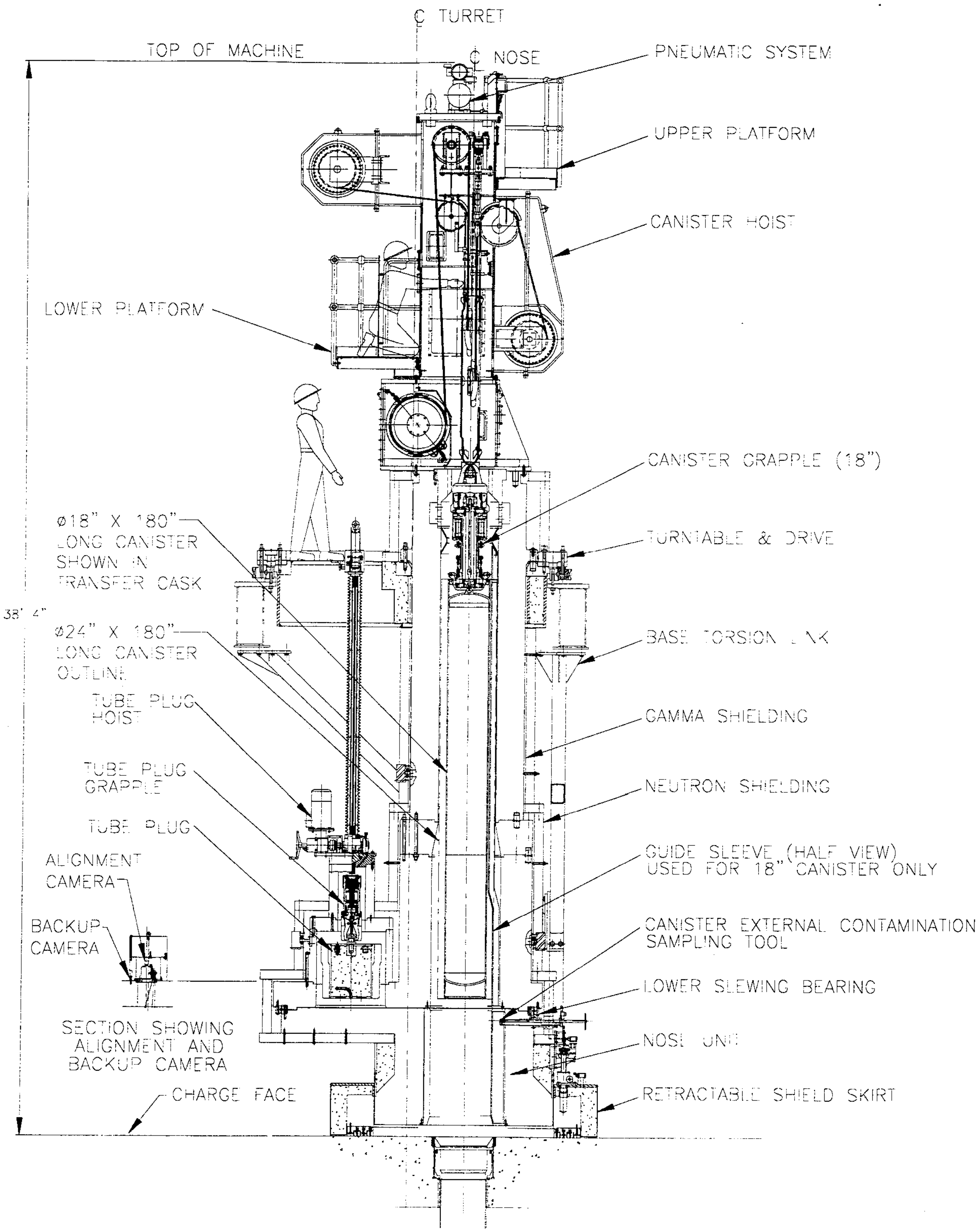


FIGURE 4.7-33
CHM Turret Isometric View

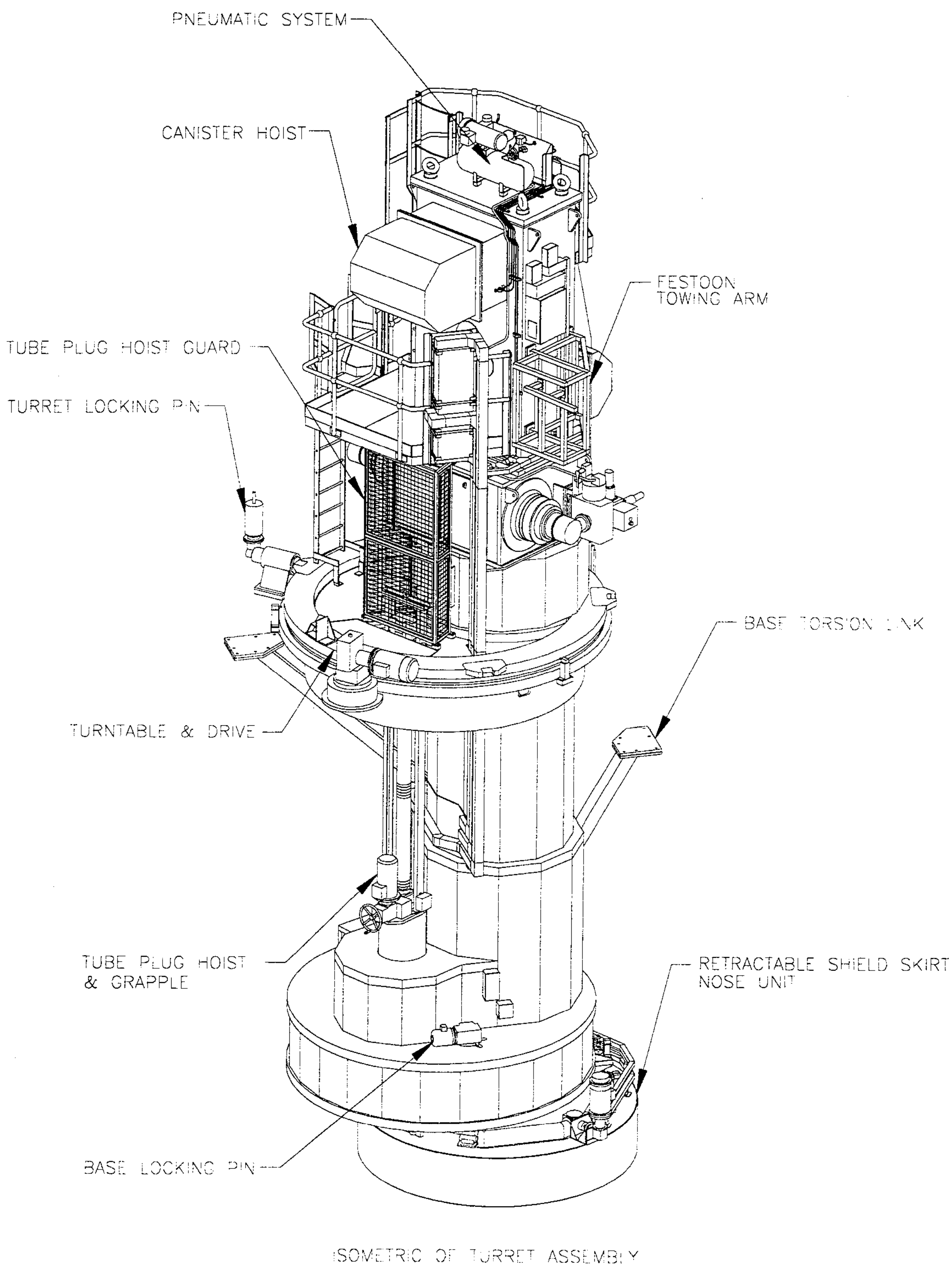


Figure 4.7-34
CHM Canister Grapple

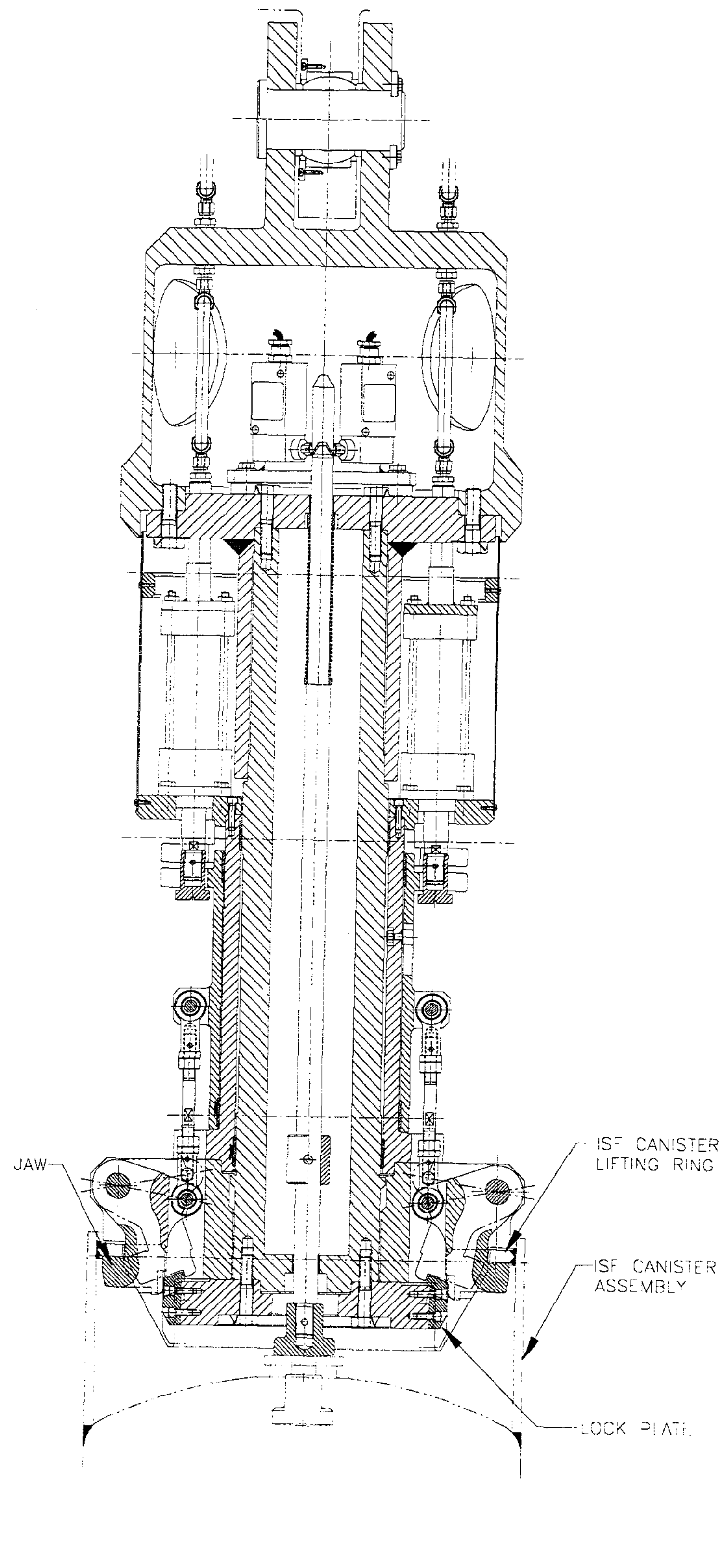


Figure 4.7-35
CRA Finite Element Model – Isometric View

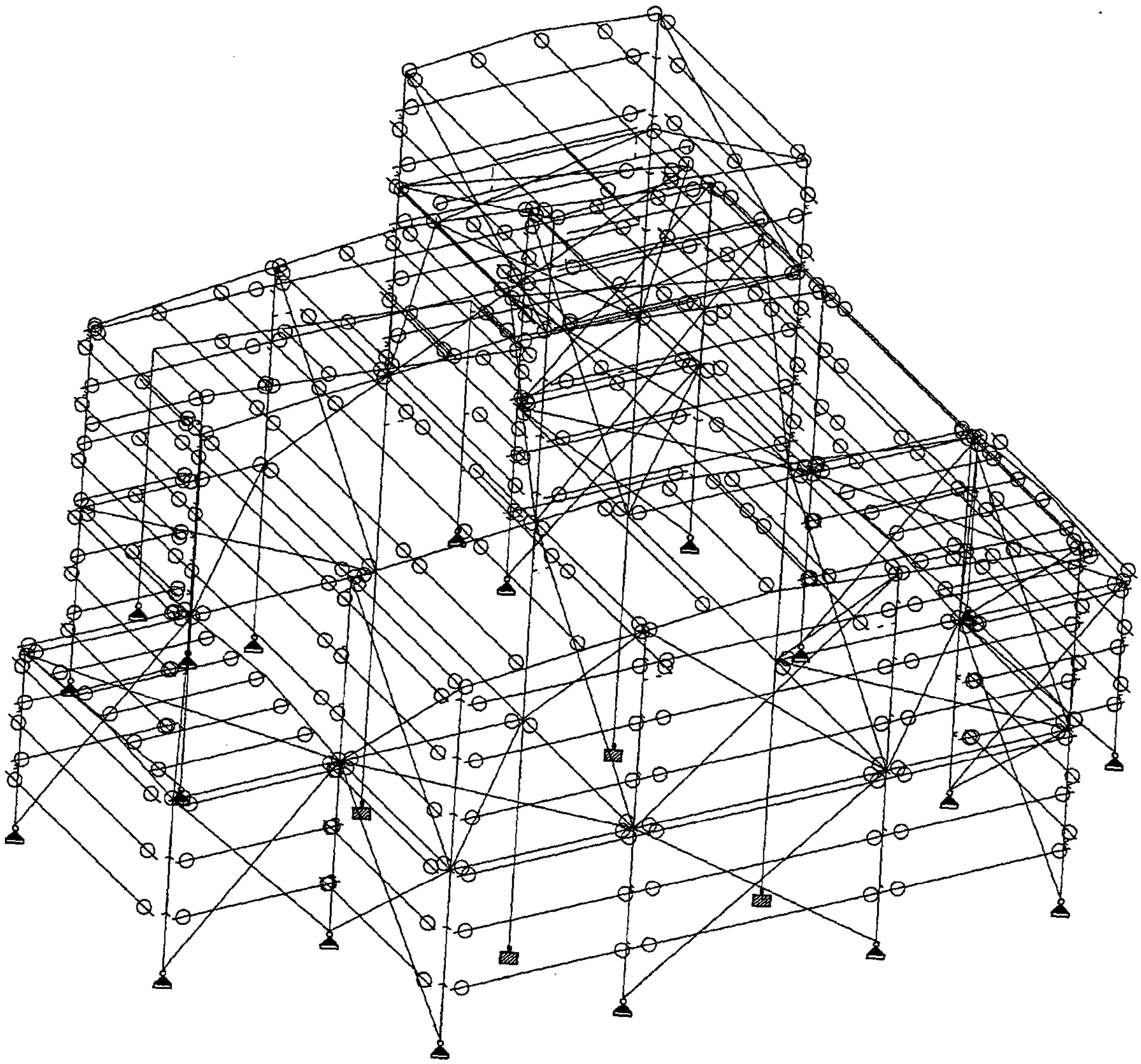


Figure 4.7-36
CRA Finite Element Model – South Elevation

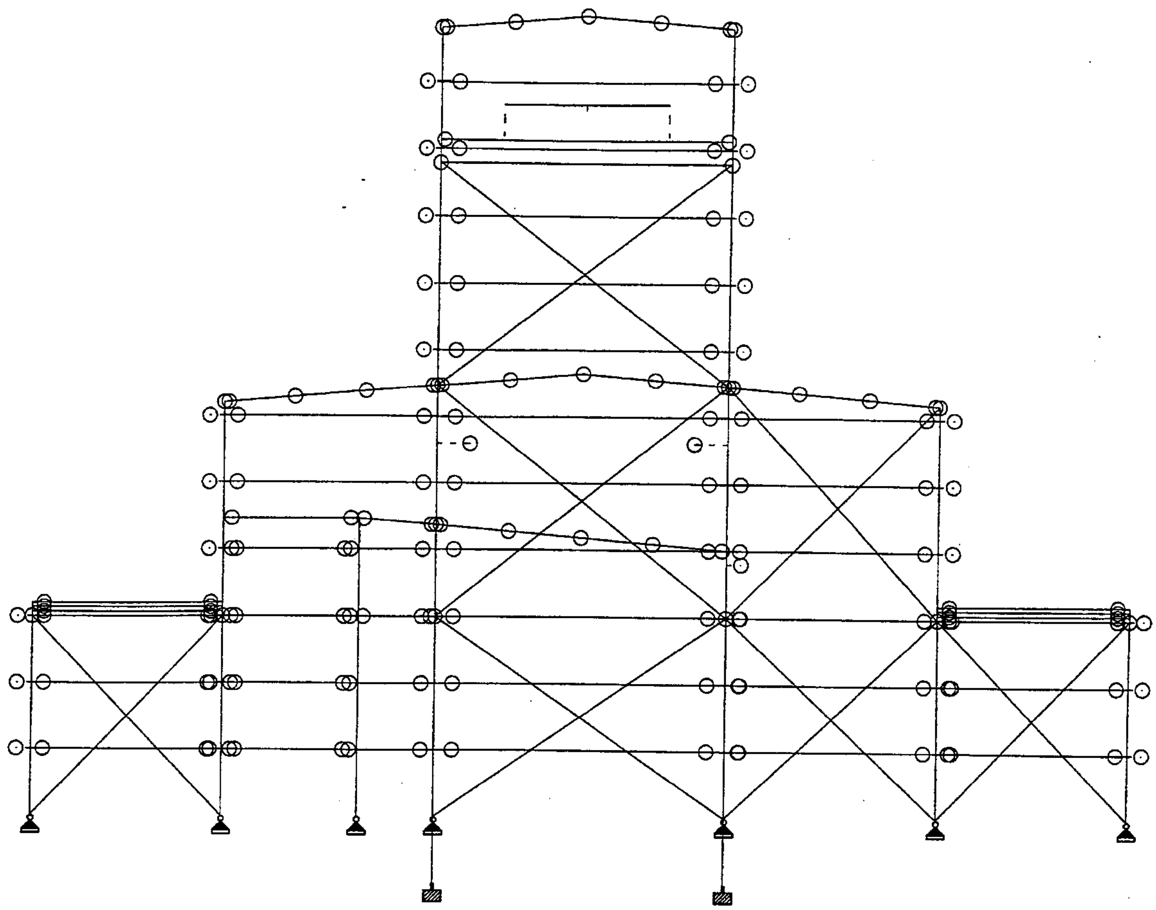


Figure 4.7-37
CRA Finite Element Model – East Elevation

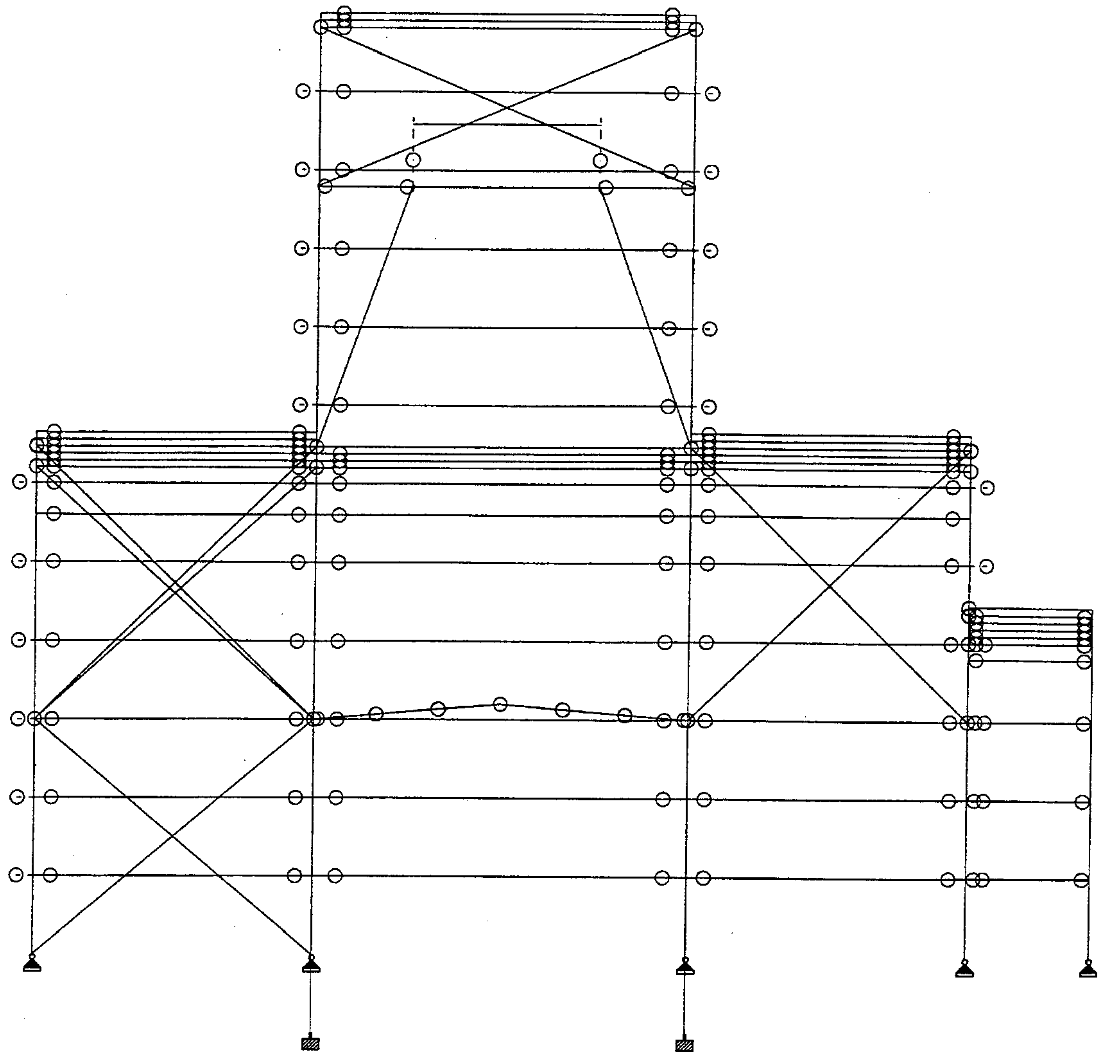


Figure 4.7-38
CRA Finite Element Model – Center Tower

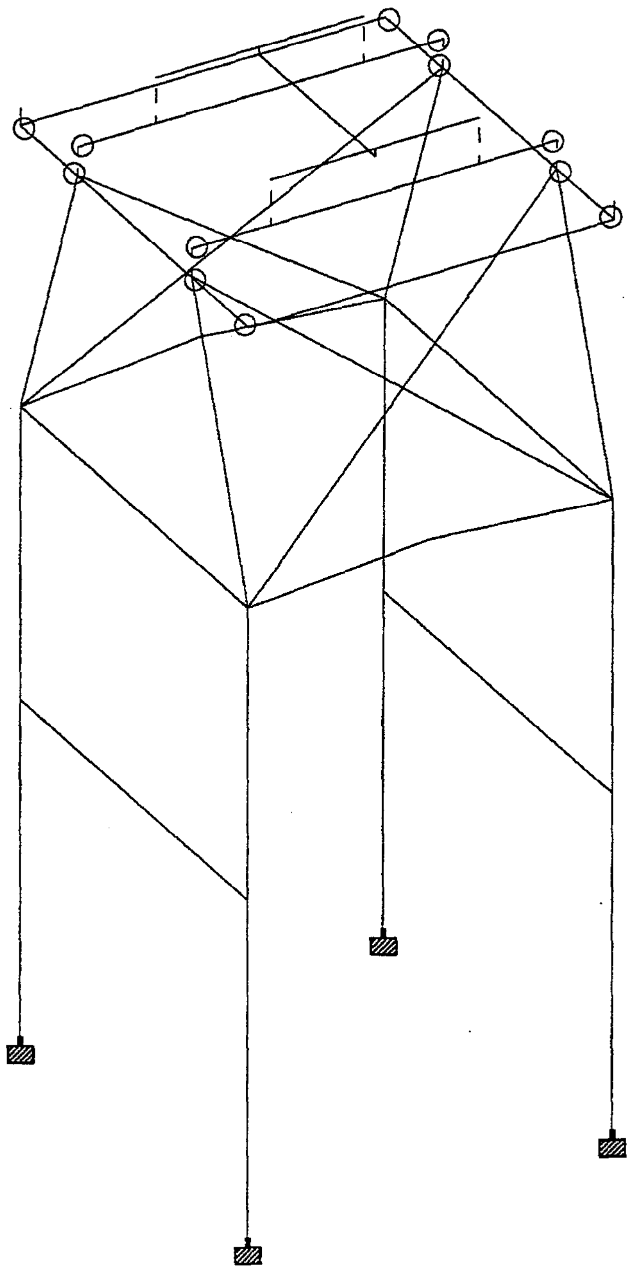


Figure 4.7-39
CRA Mat Foundation Model with Spring Elements

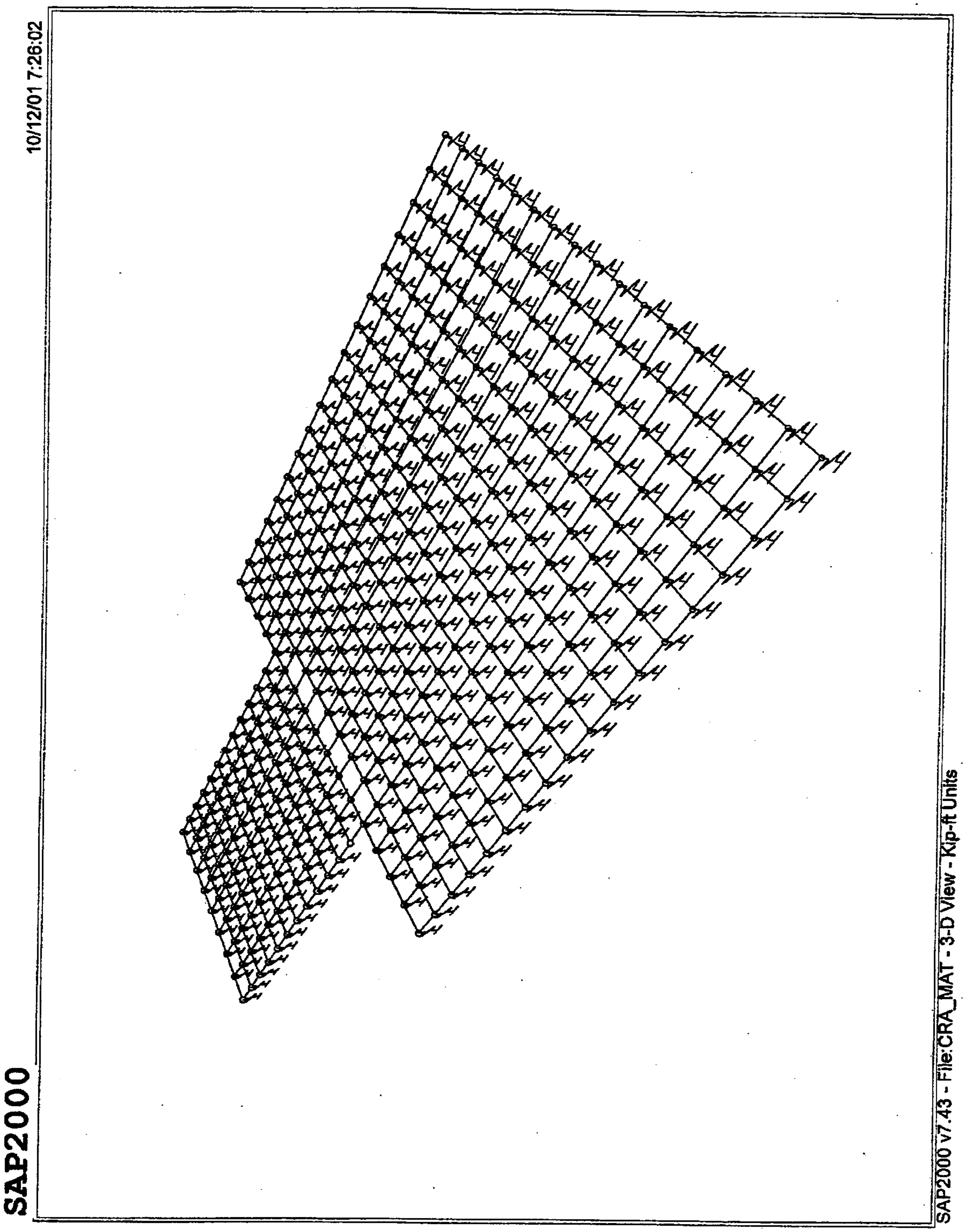


Figure 4.7-40
Transfer Area ITS Concrete Structure Shell Elements - South Elevation

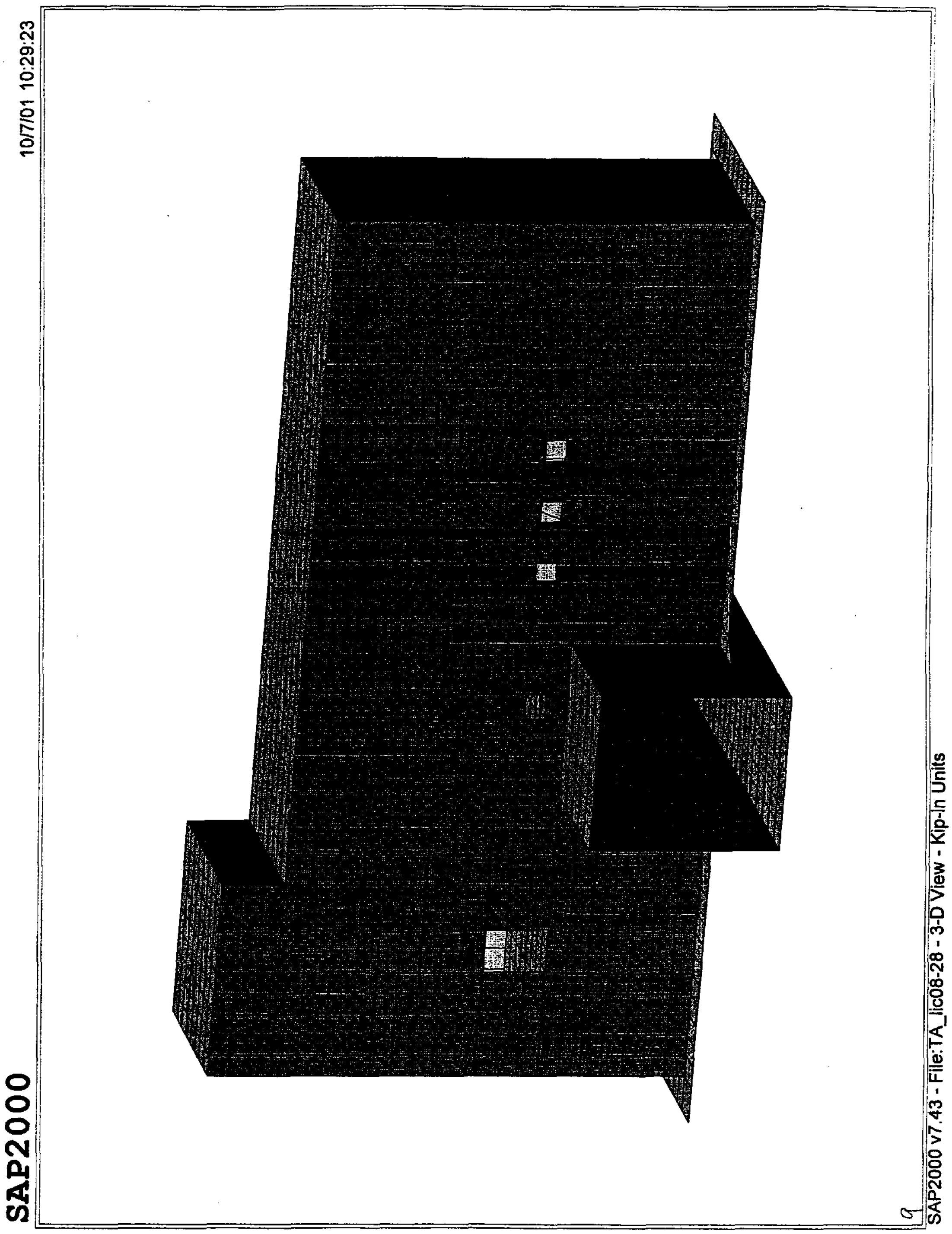


Figure 4.7-41
Transfer Area ITS Concrete Structure Extruded Elements – North Elevation

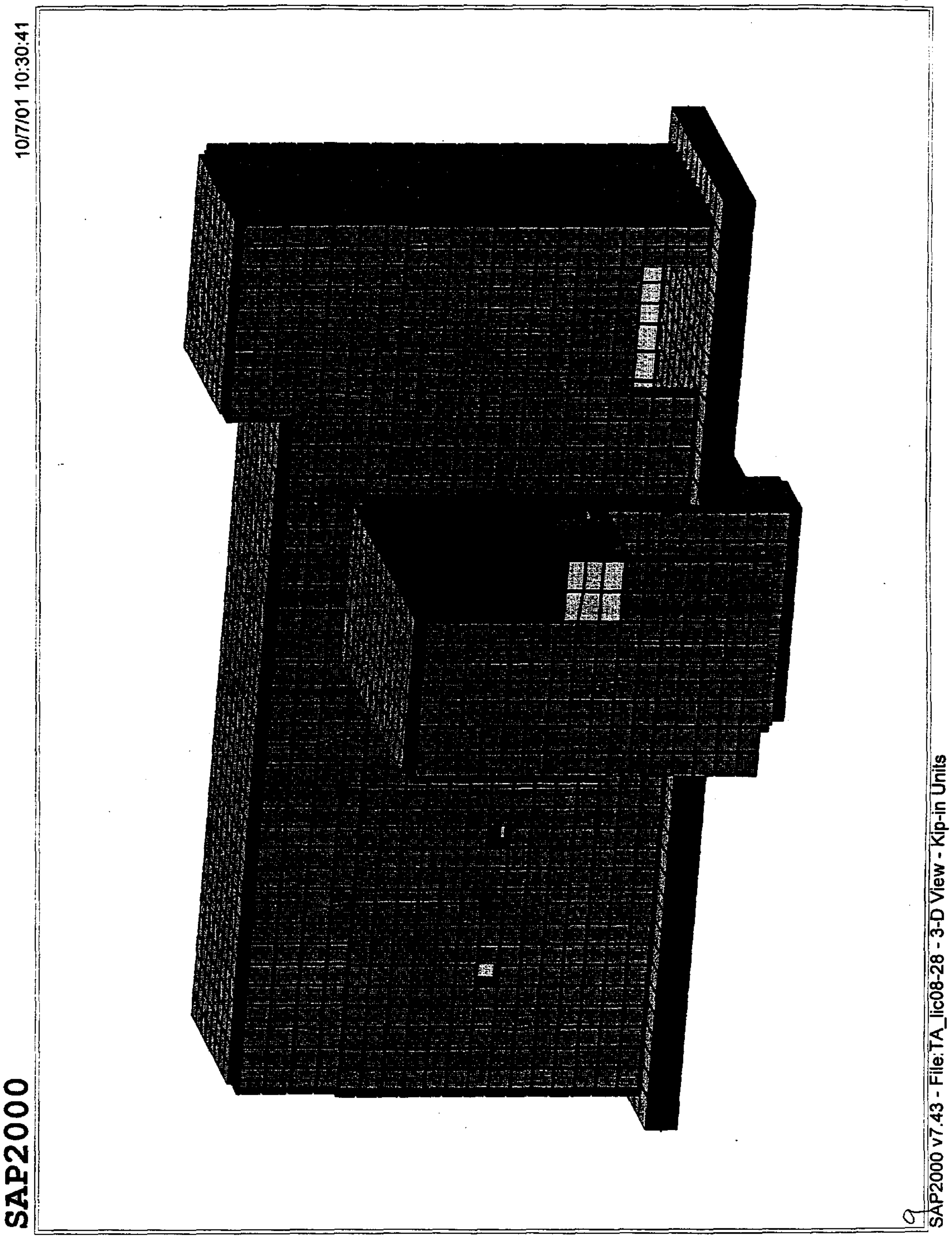


Figure 4.7-42
Transfer Area ITS Concrete Structure Shell Elements – North Elevation

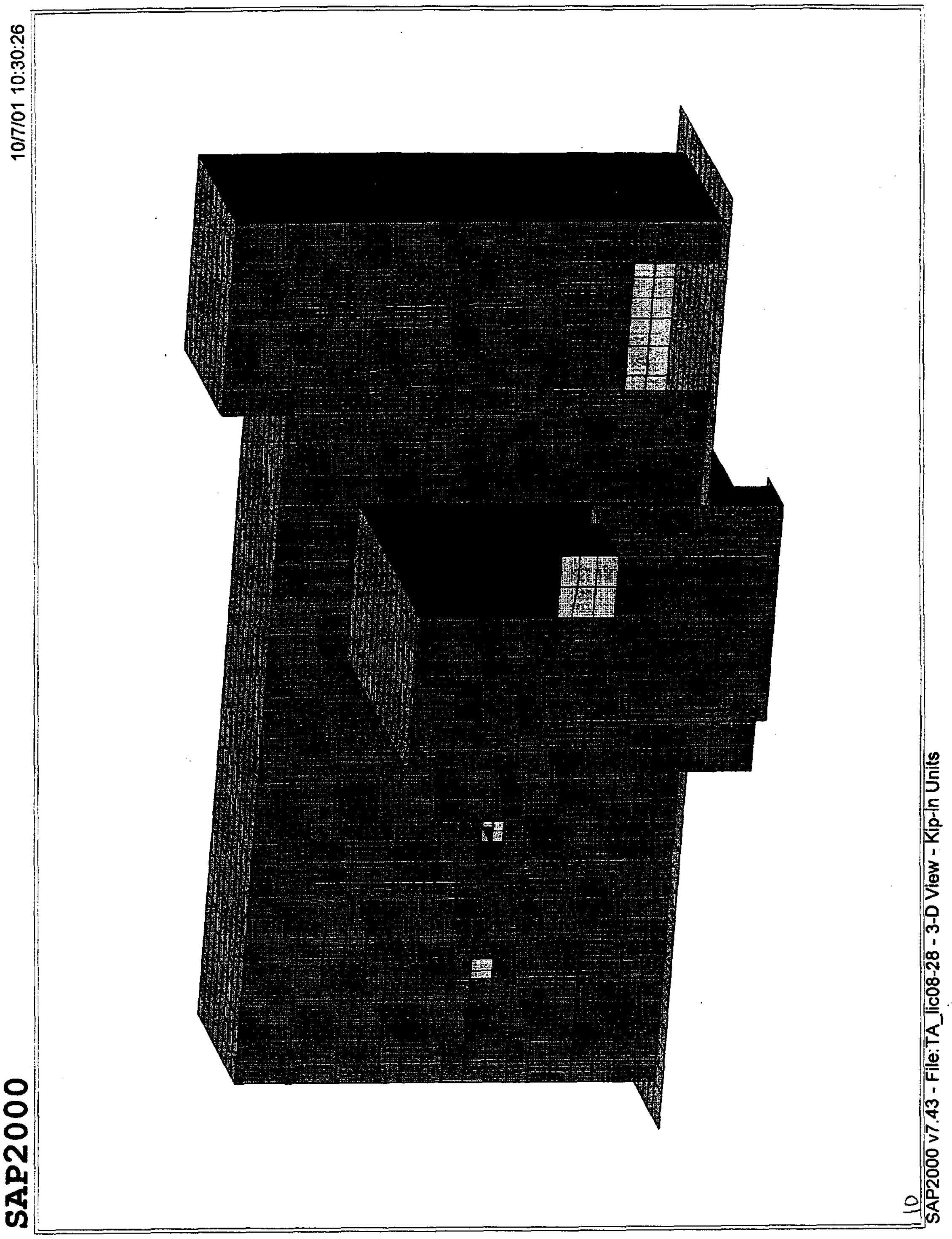


Figure 4.7-43
Tansfer Area ITS Concrete Structure Extruded Elements – South Elevation

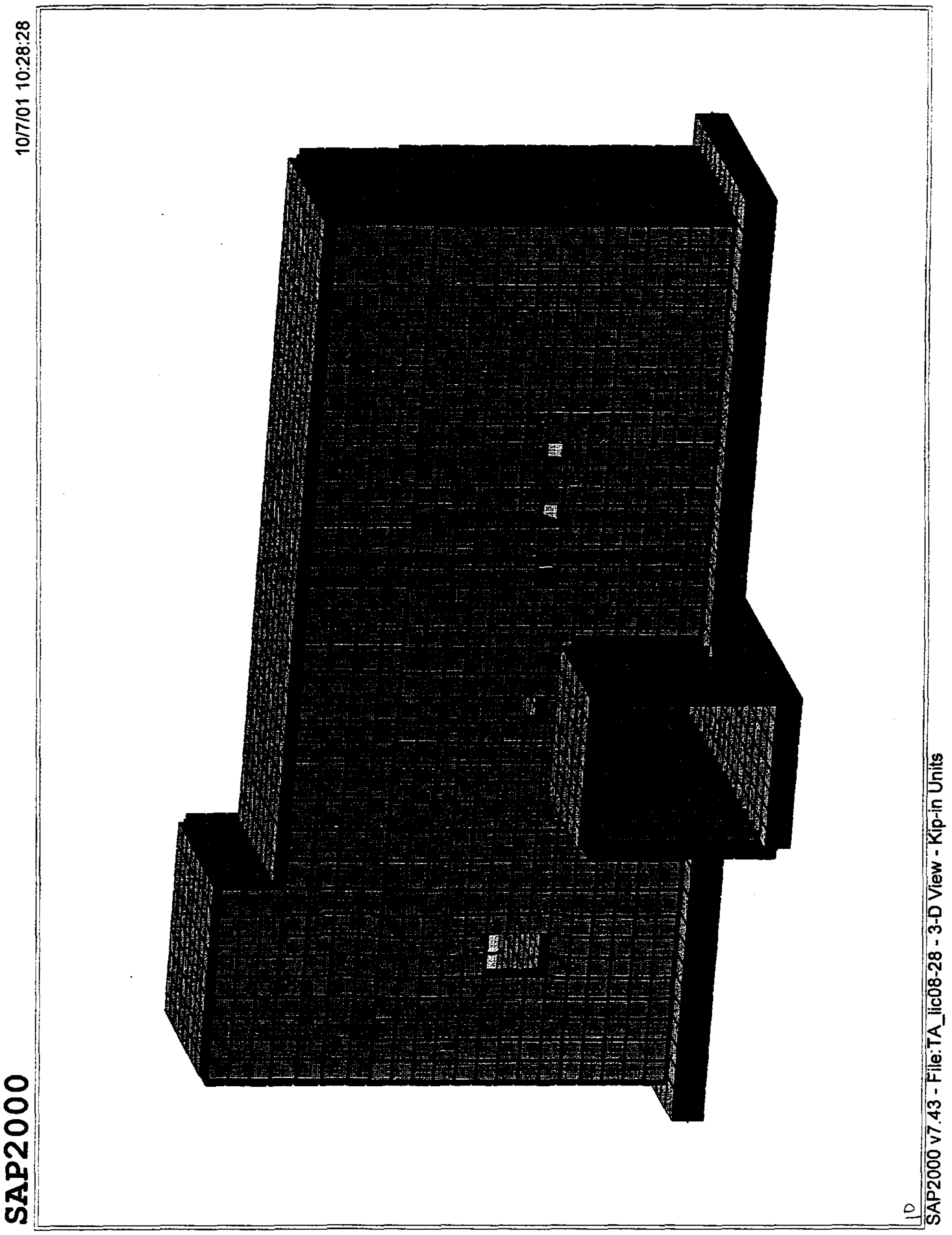


Figure 4.7-44
Transfer Area NITS Steel Structure – South Elevation

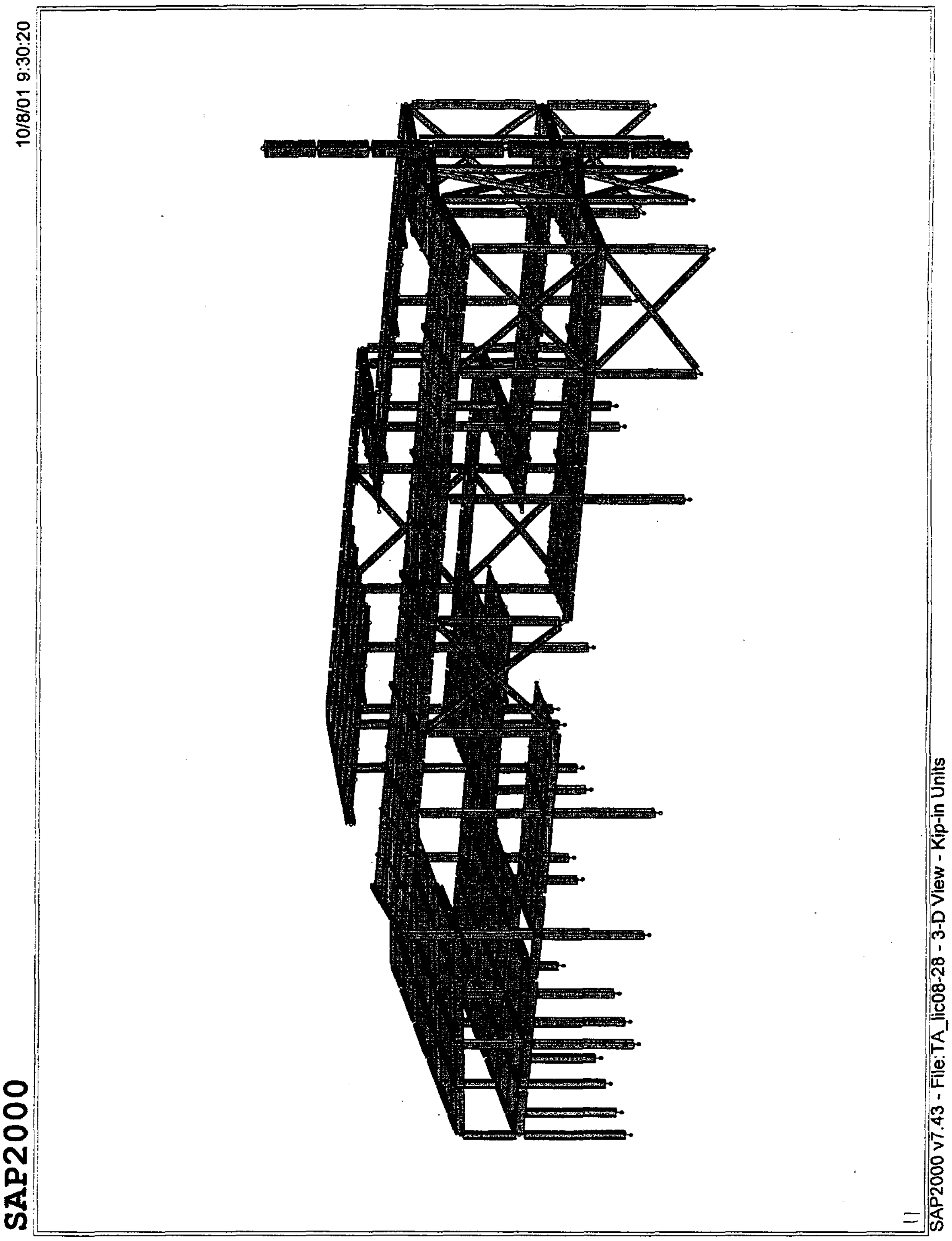


Figure 4.7-45
Transfer Area NITS Steel Structure – North Elevation

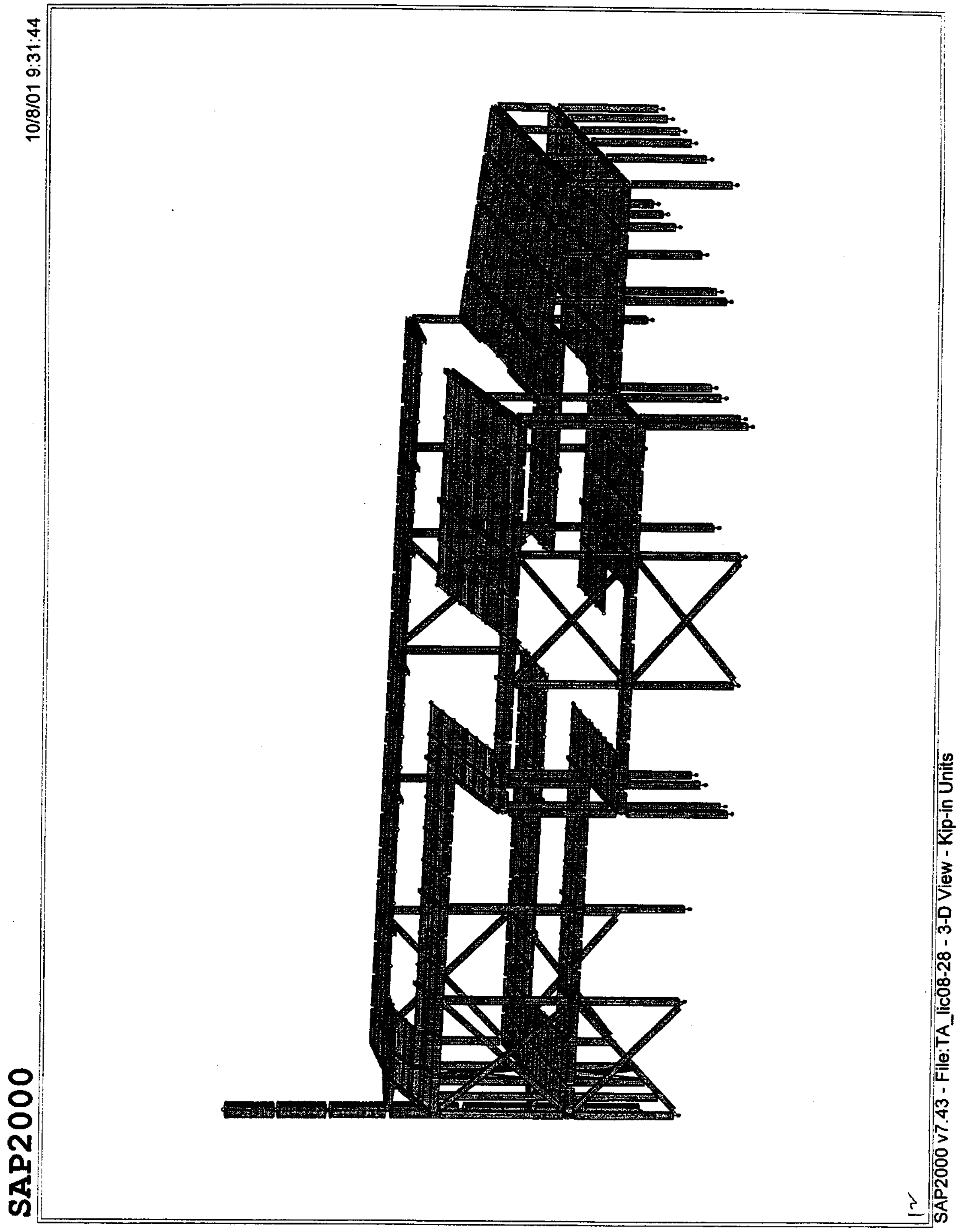


Figure 4.7-46
Transfer Area Extruded Model – South Elevation

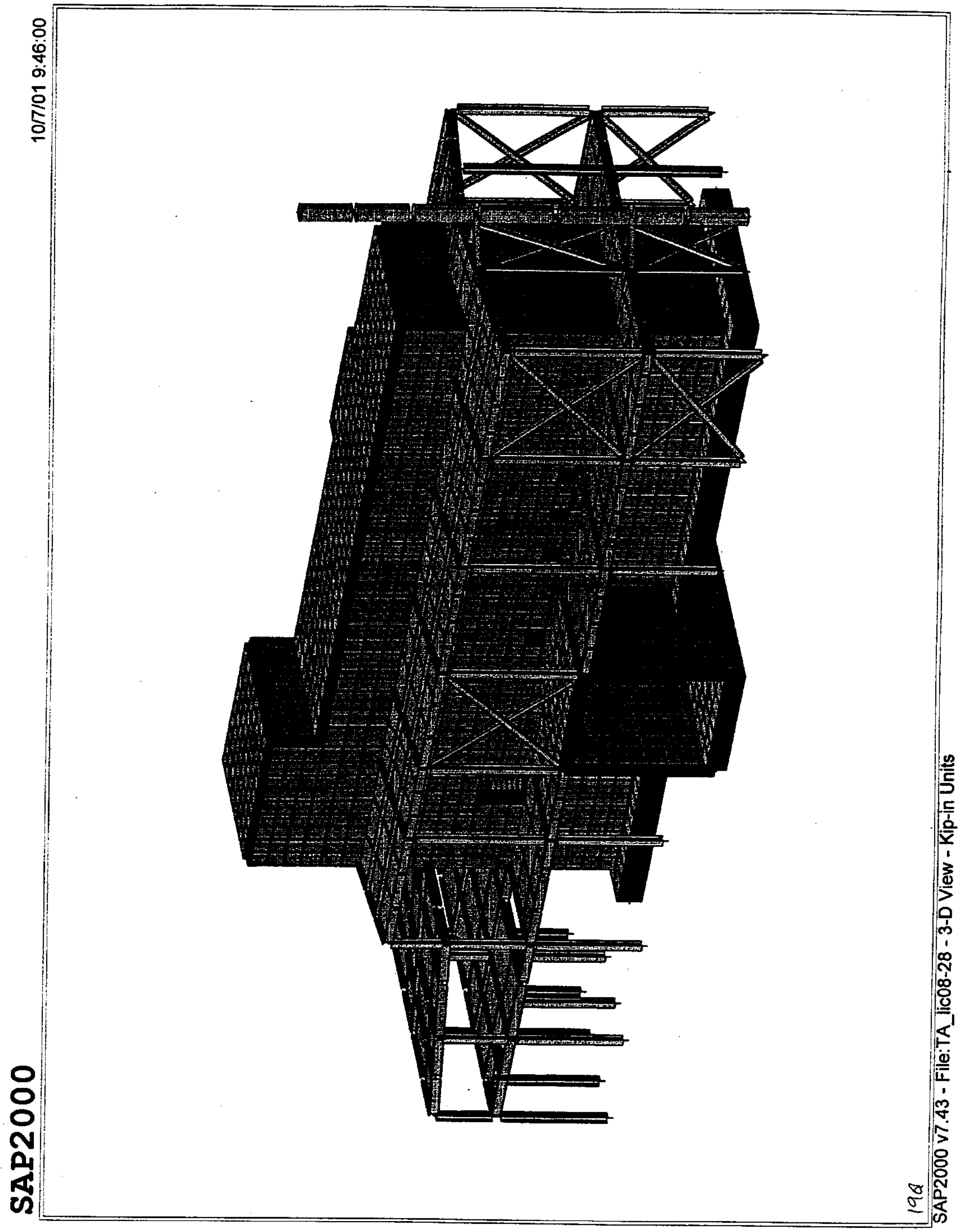


Figure 4.7-47
Transfer Area Full Extruded Model – North Elevation

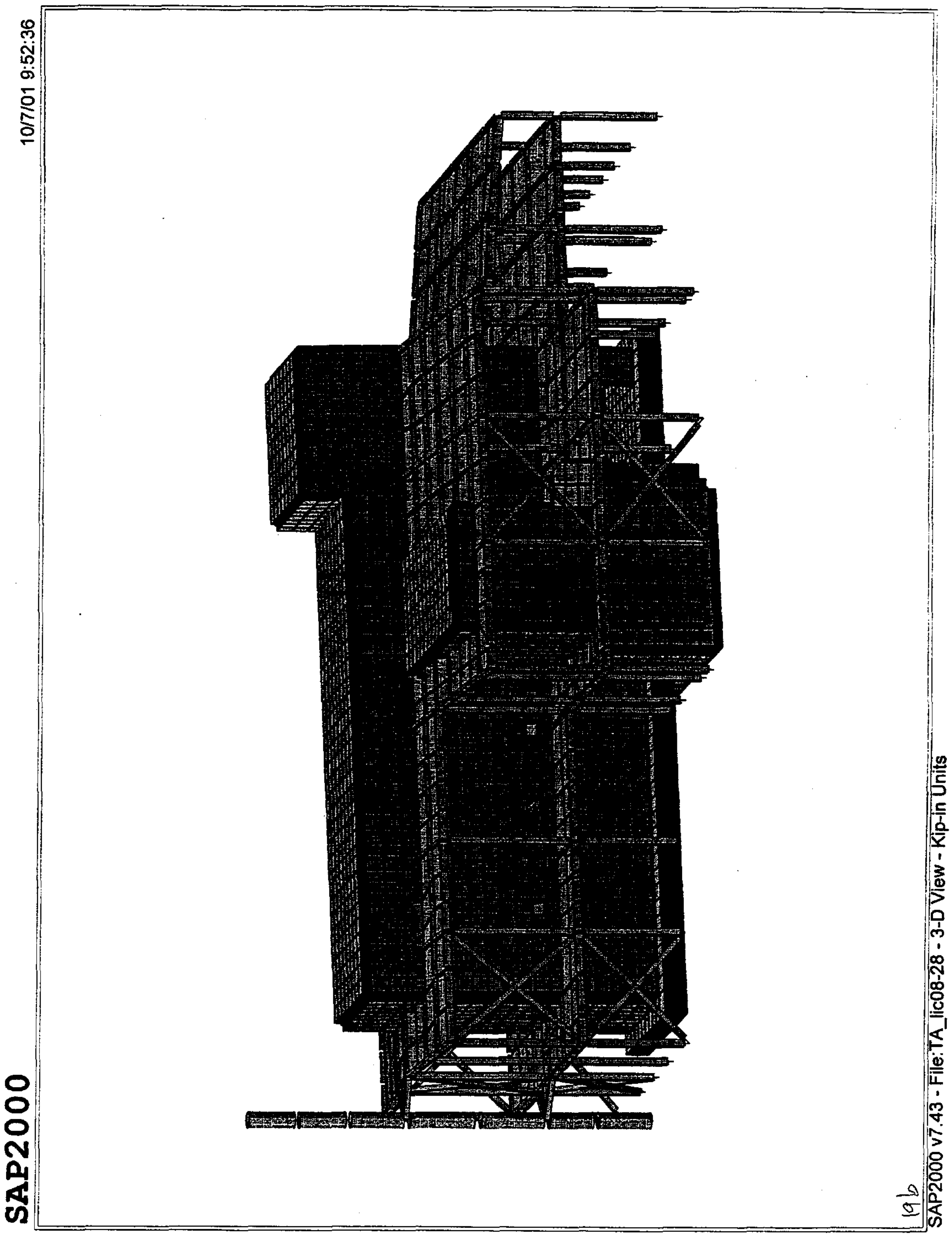


Figure 4.7-48
Transfer Area Cut-Away Extruded Model – South Elevation

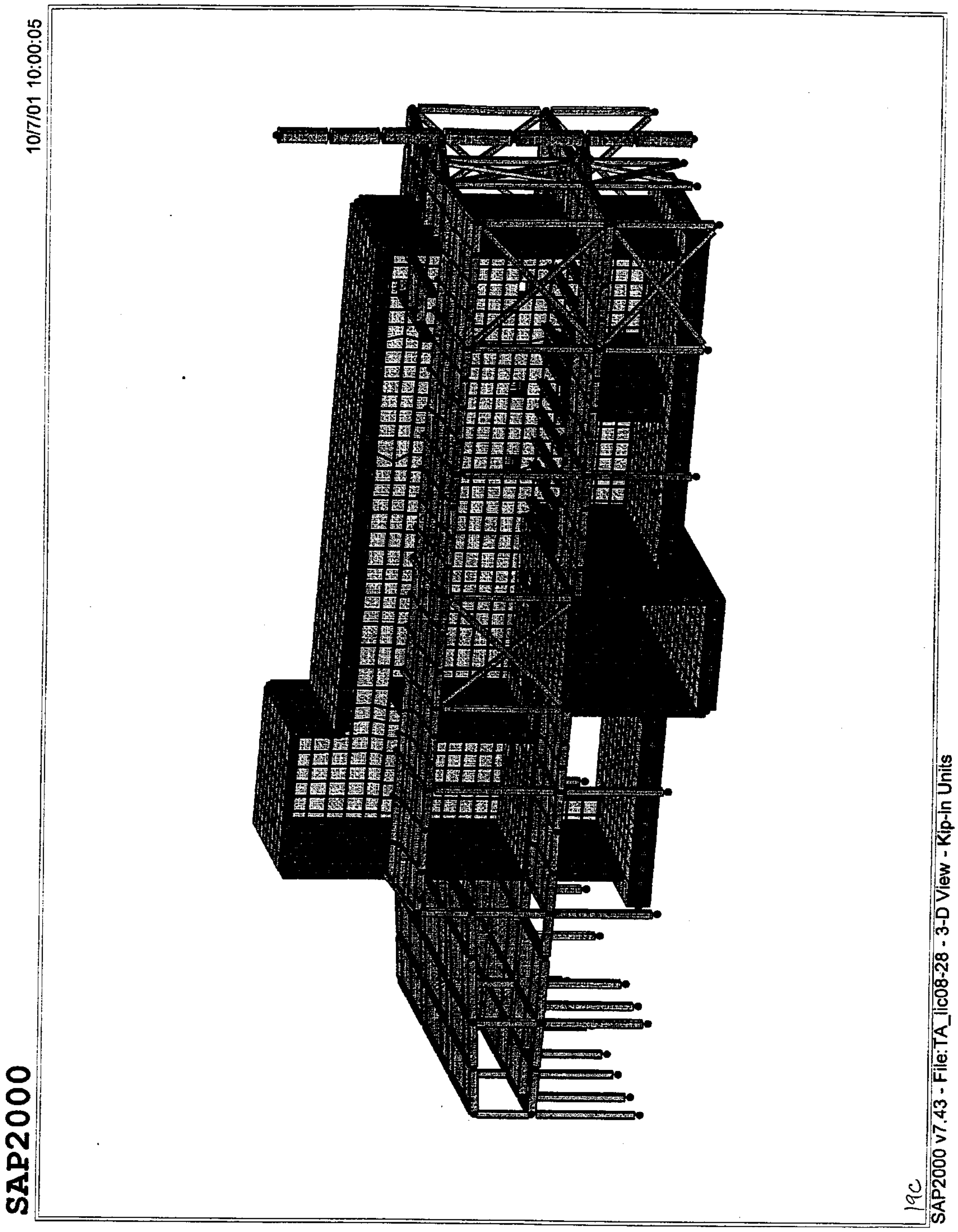


Figure 4.7-49
Transfer Area Cut-Away Extruded Model – North Elevation

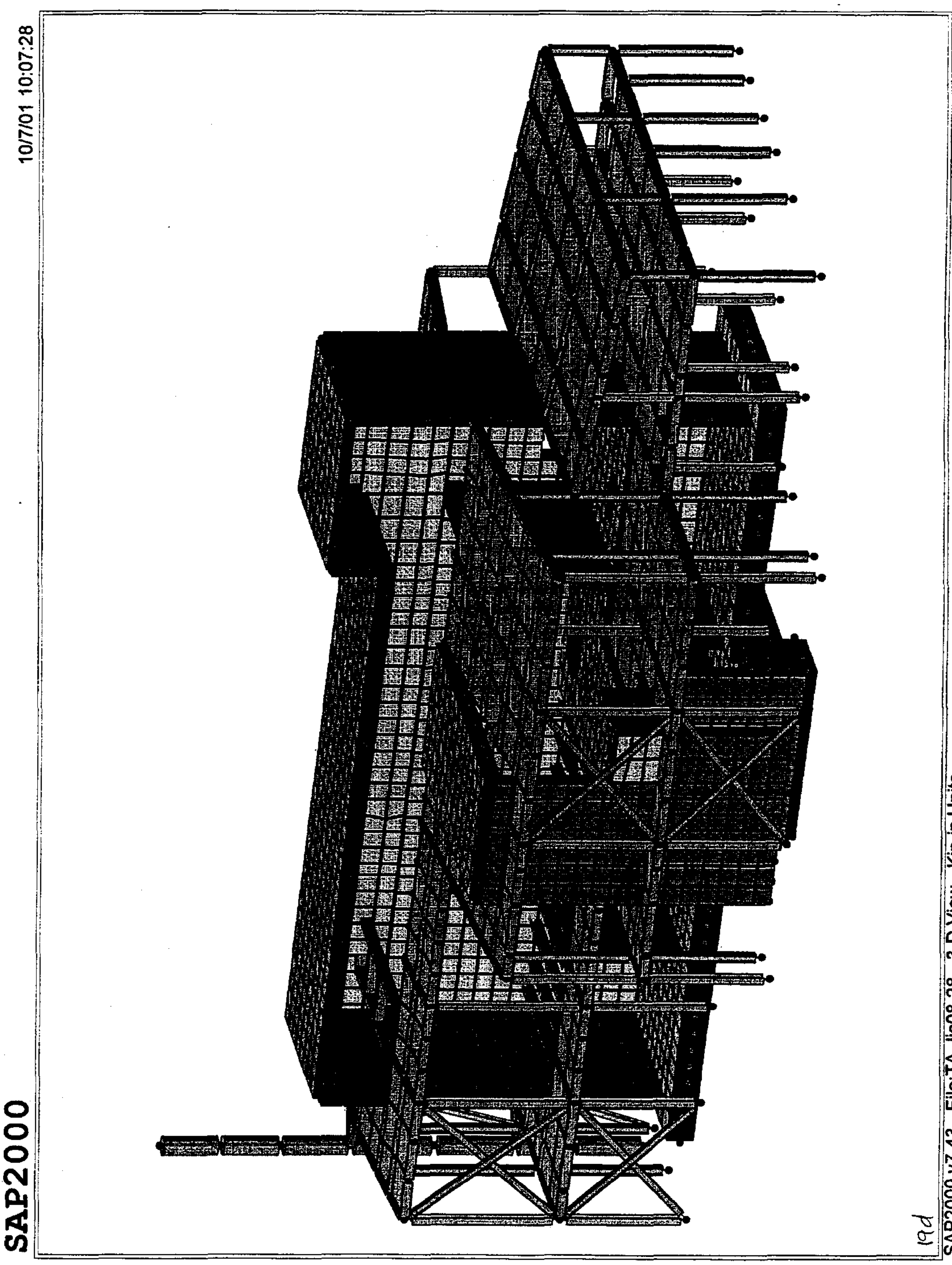


Figure 4.7-50
Transfer Area Fixed-Base Boundary Conditions

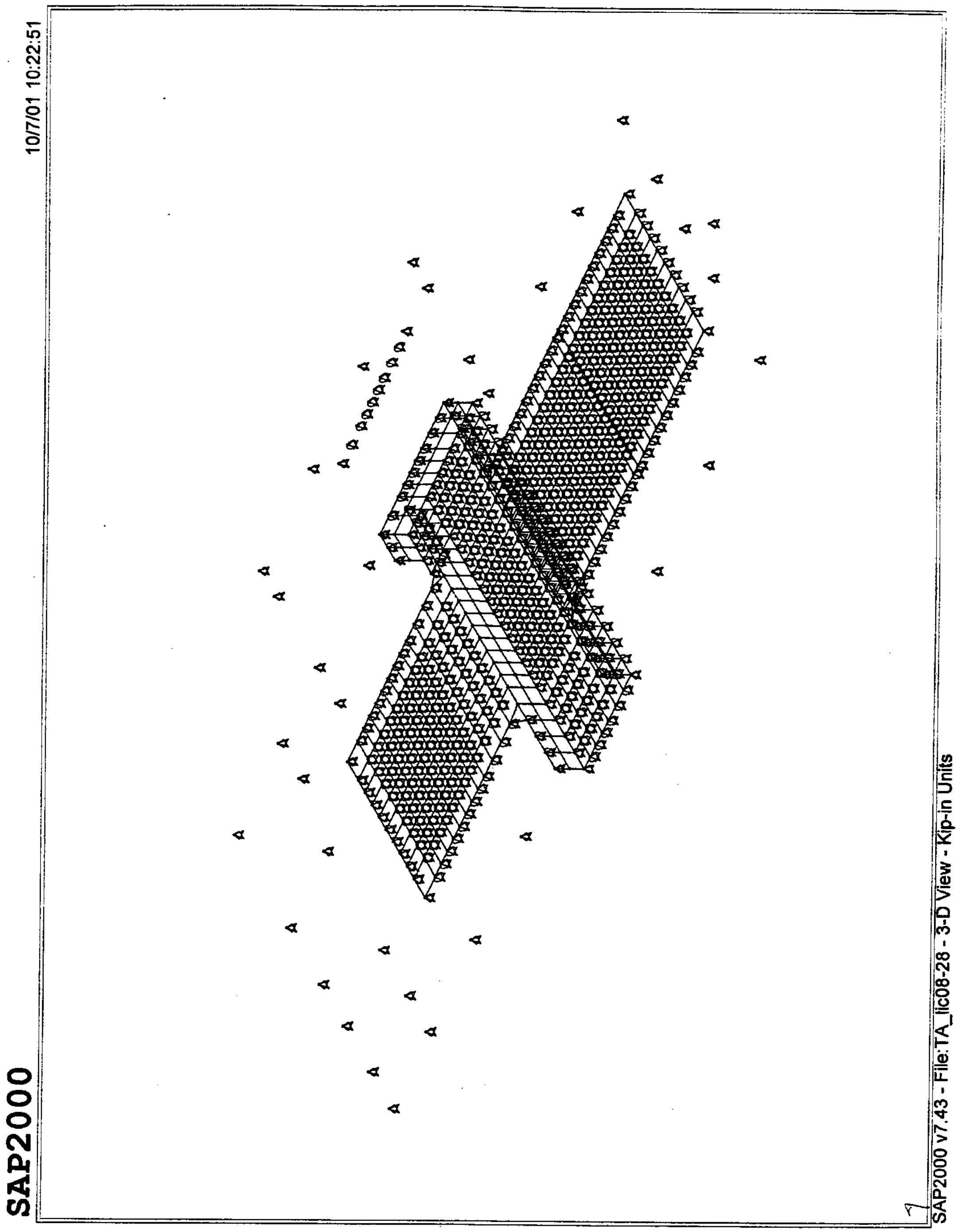
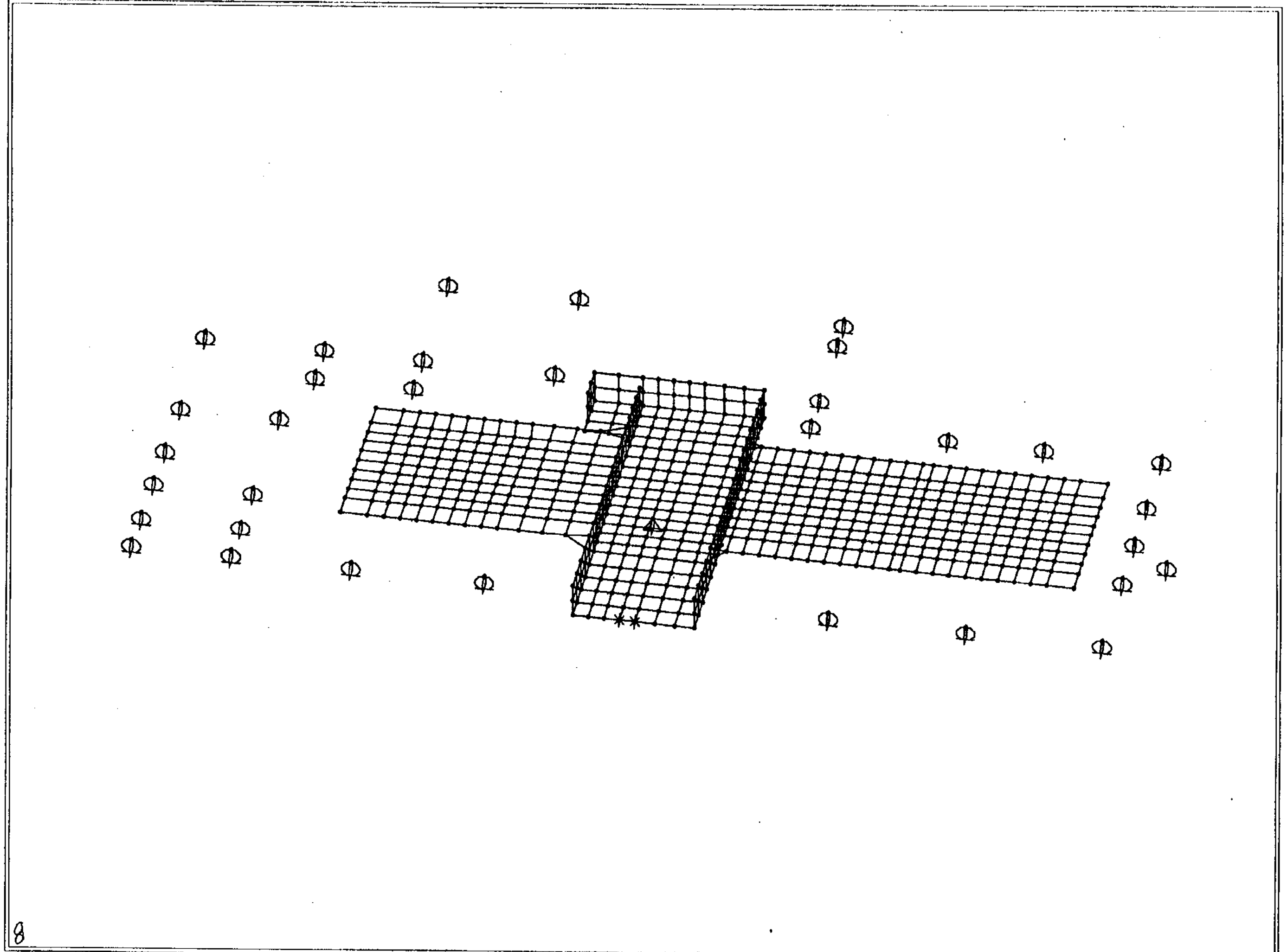


Figure 4.7-51
Transfer Area Thermal Boundary Conditions

SAP2000

10/8/01 9:13:13



SAP2000 v7.43 - File:TA_Temp09-20 - 3-D View - Kip-in Units

Figure 4.7-52
Transfer Area Mat Foundation Model with Spring Elements

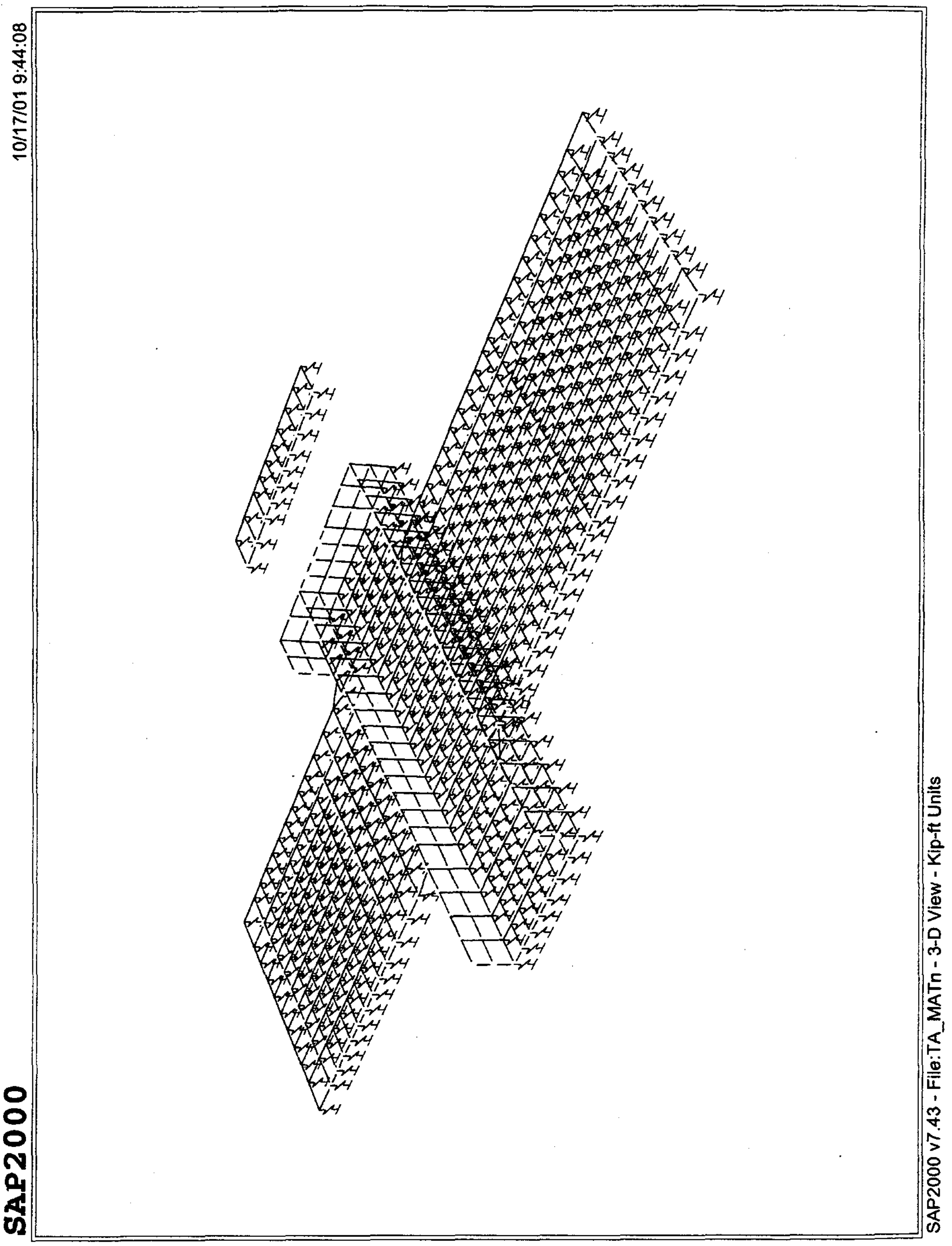


Figure 4.7-53
Transfer Area – Mode 20 Fundamental North-South Mode

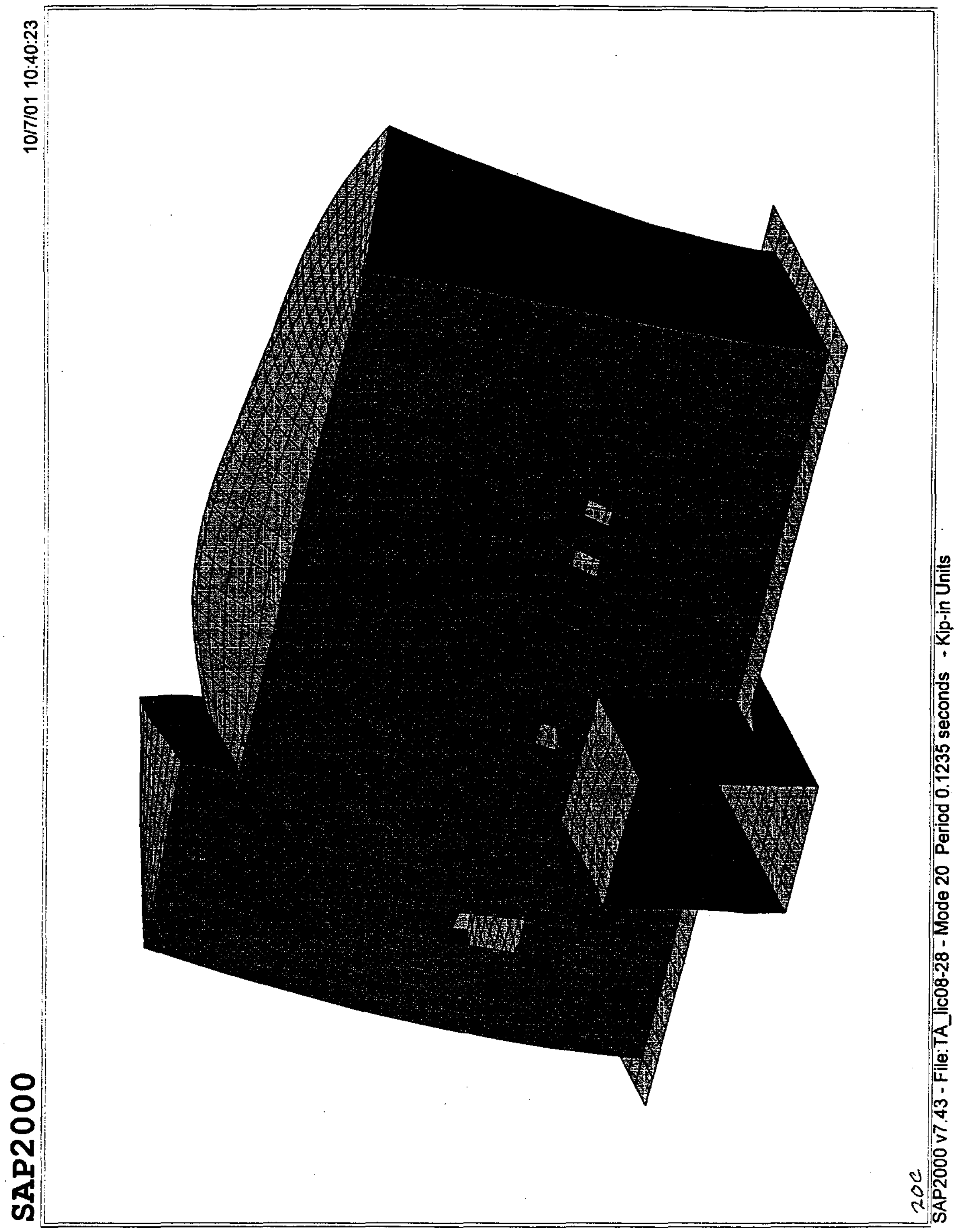


Figure 4.7-54
Transfer Area – Mode 20 Fundamental North-South Mode

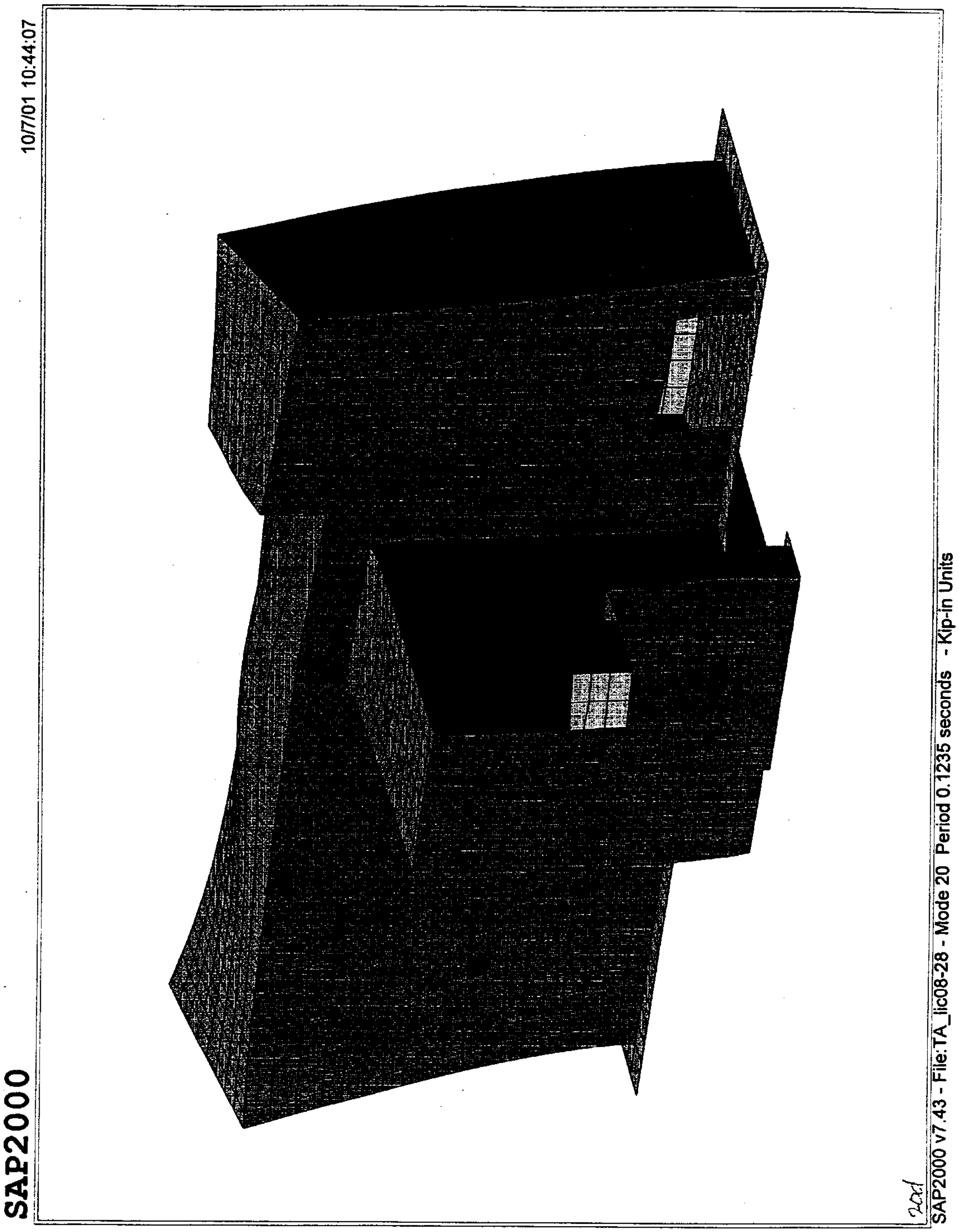


Figure 4.7-55
Transfer Area – Mode 70 Fundamental East-West Mode

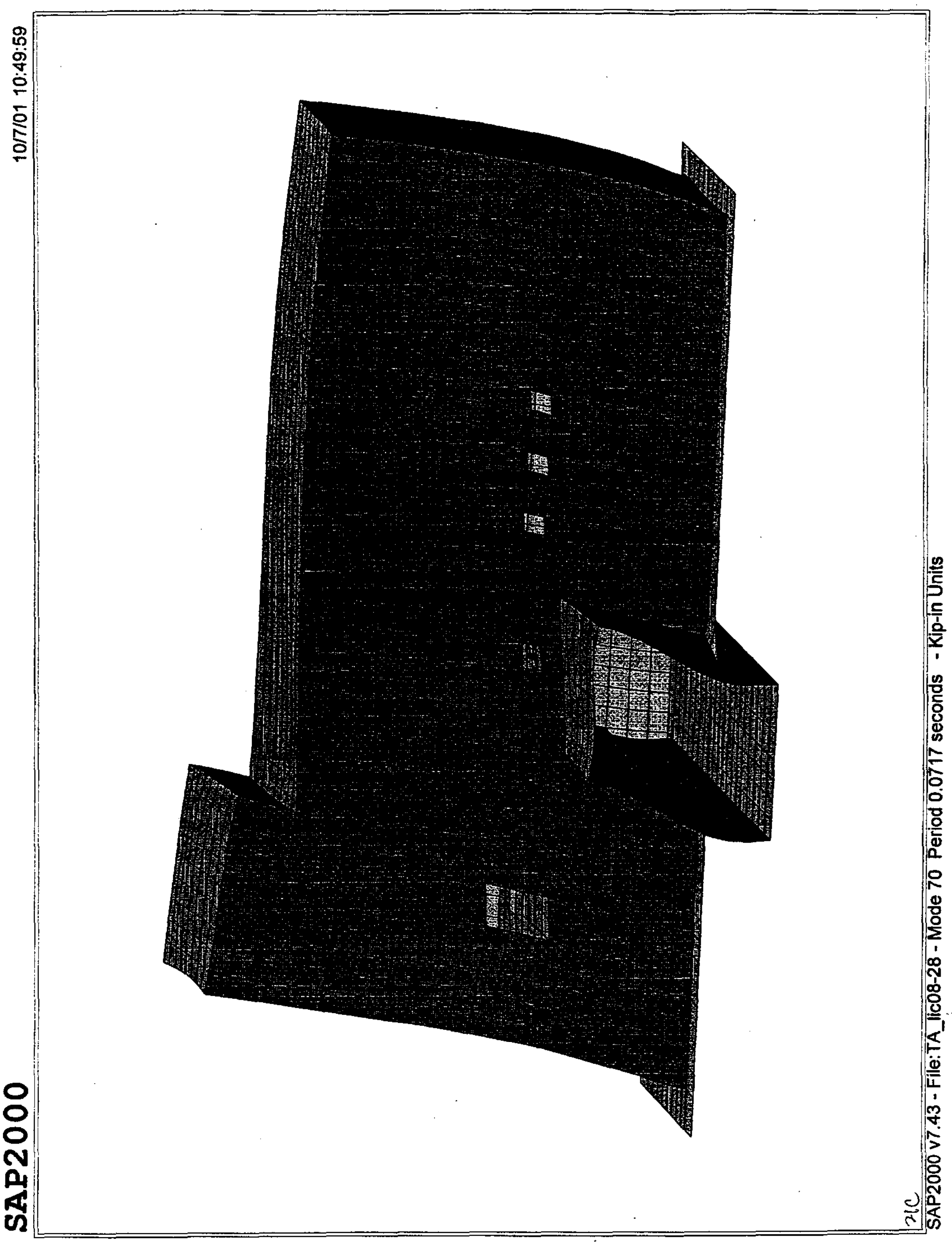


Figure 4.7-56
Transfer Area – Mode 70 Fundamental East-West Mode

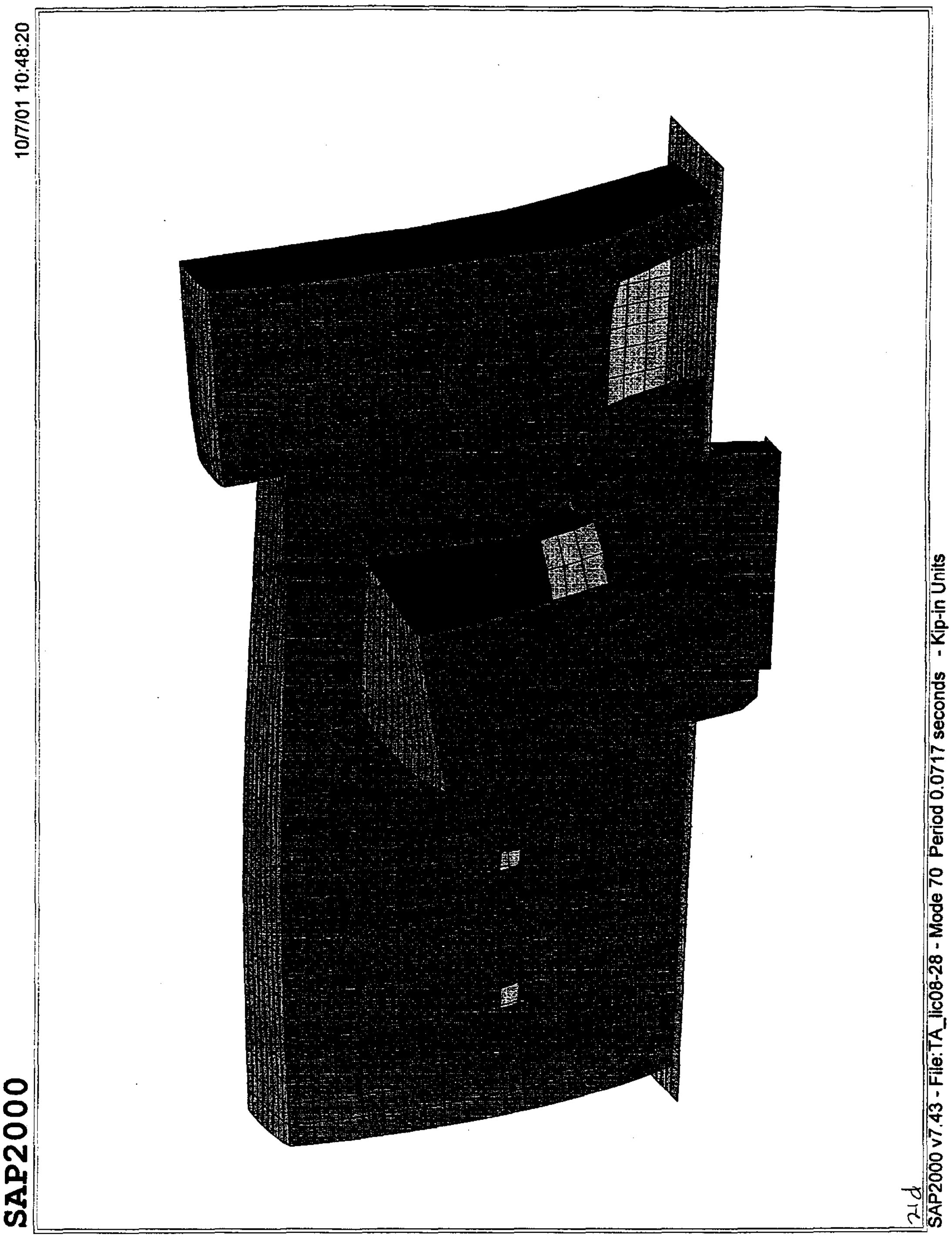


Figure 4.7-57
Transfer Area – Mode 179 Fundamental Vertical Mode

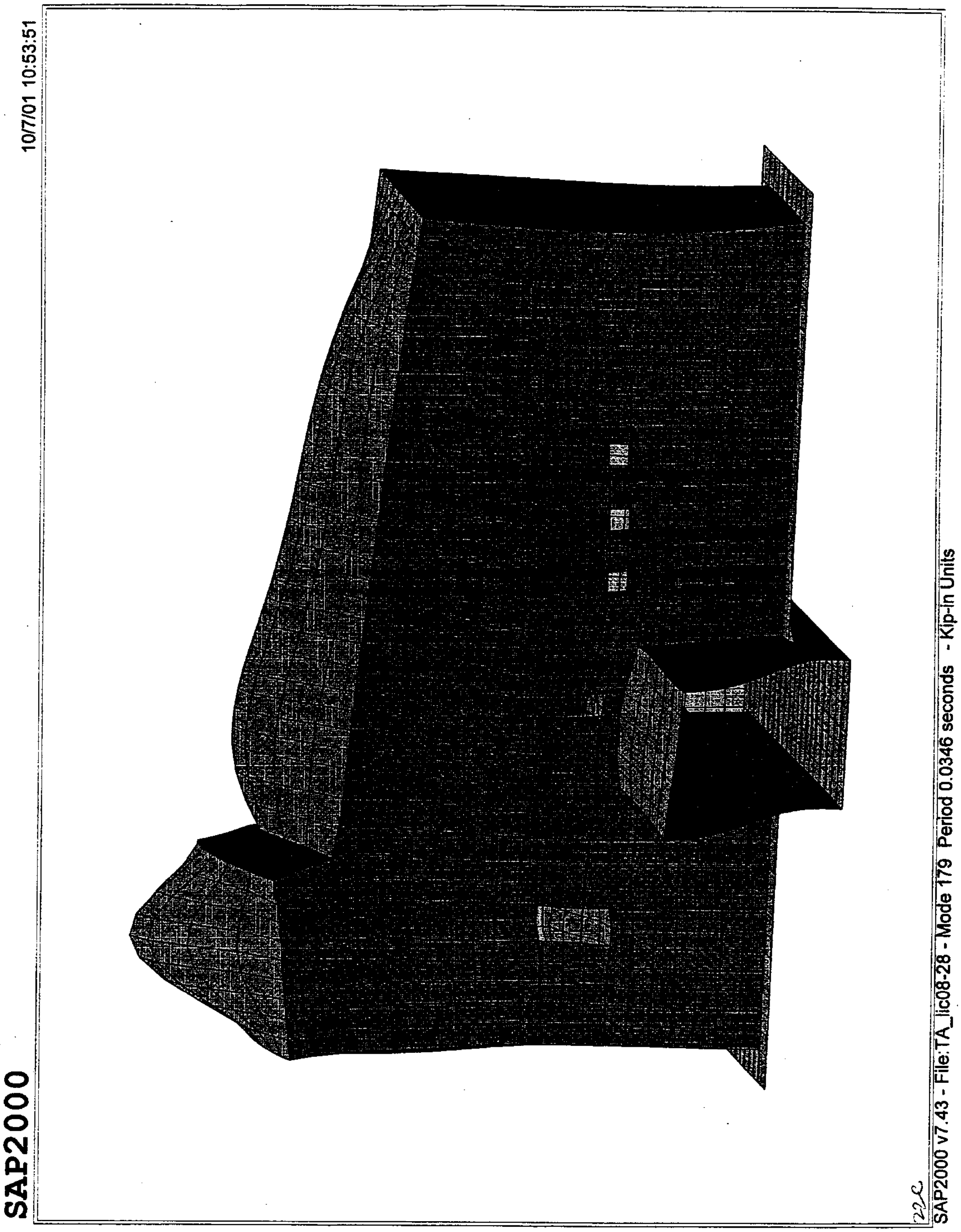


Figure 4.7-58
Transfer Area – Mode 179 Fundamental Vertical Mode

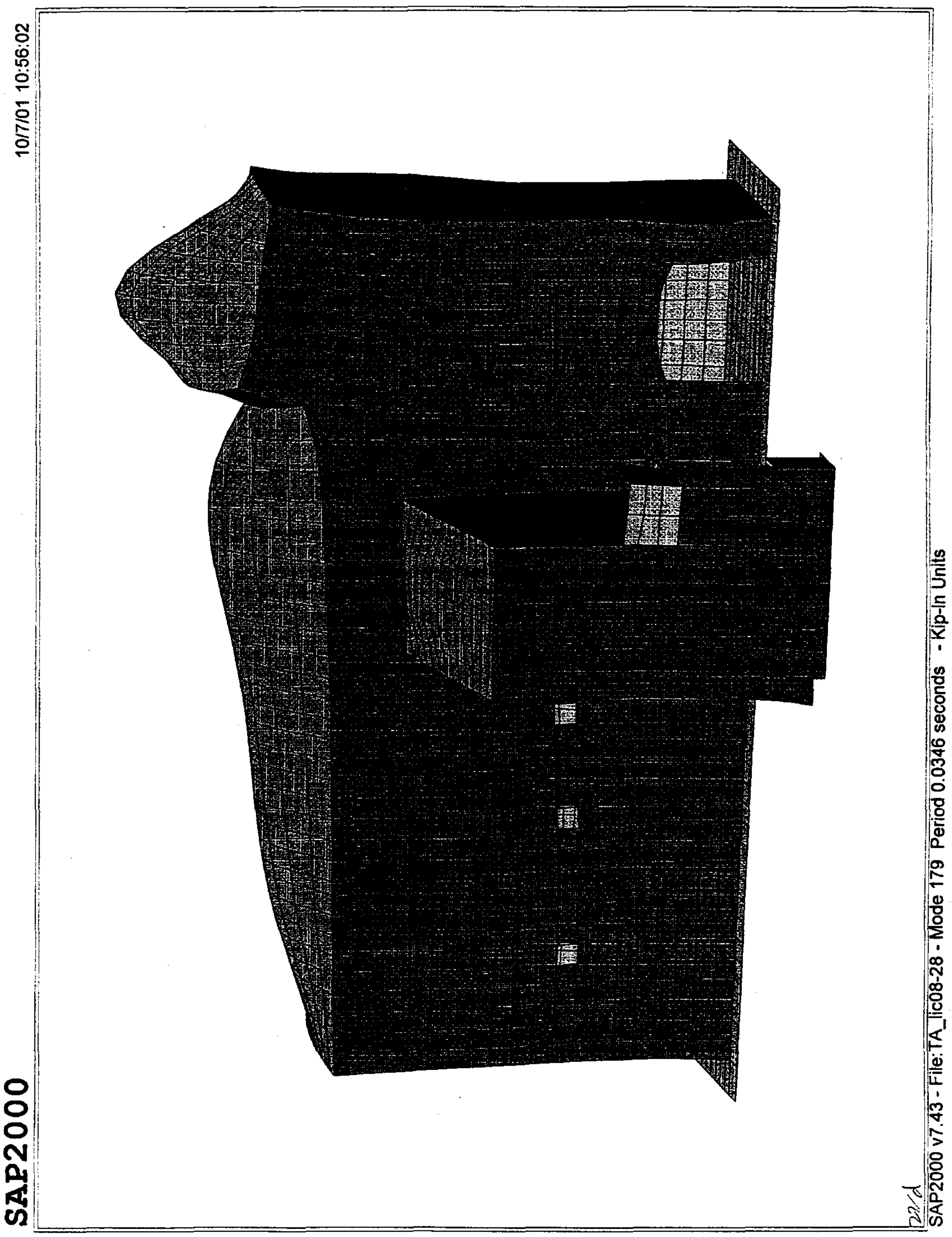


Figure 4.7-59
Storage Area ITS Concrete Structure Shell Elements – South Elevation

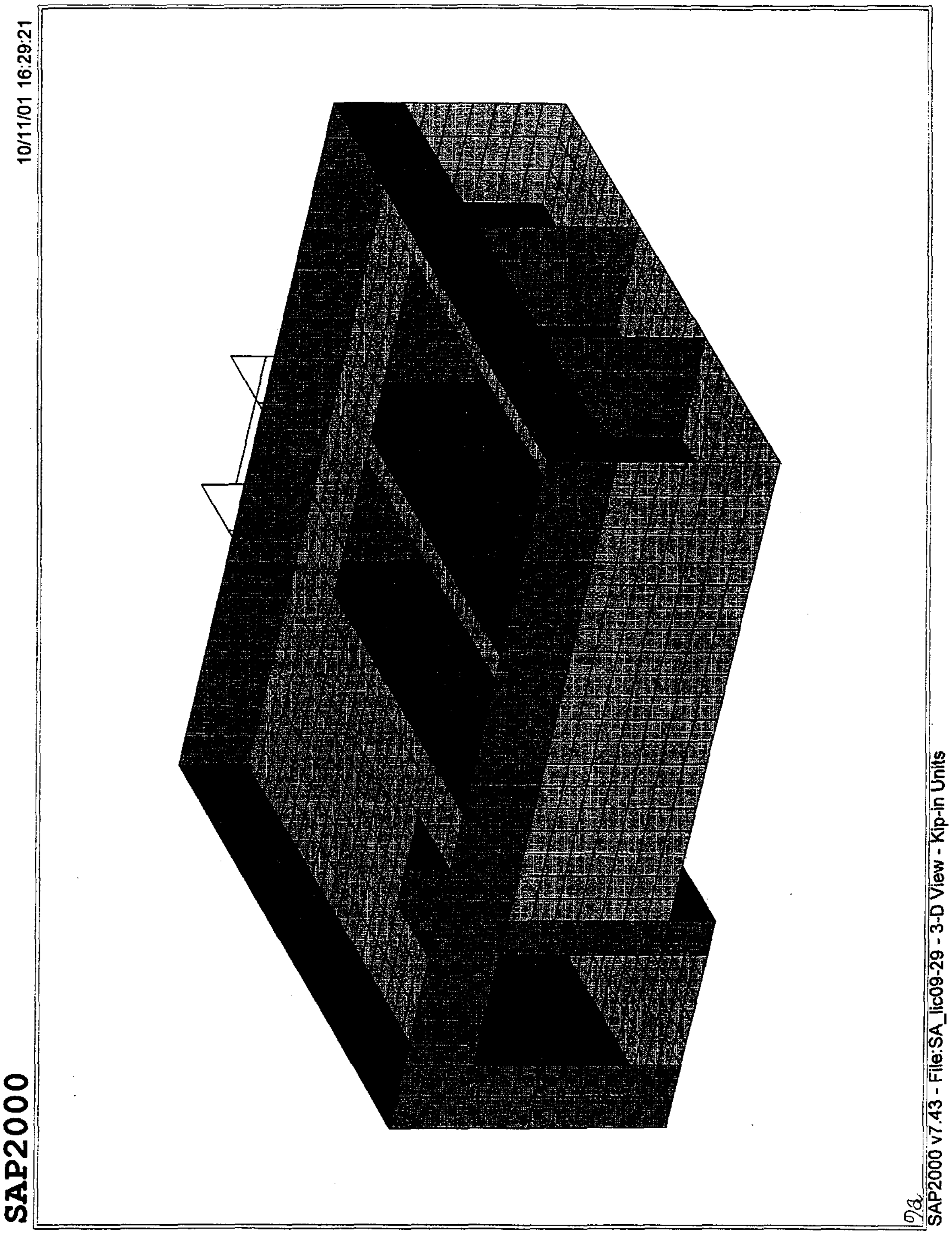


Figure 4.7-60
Storage Area ITS Concrete Structure Shell Elements – North Elevation

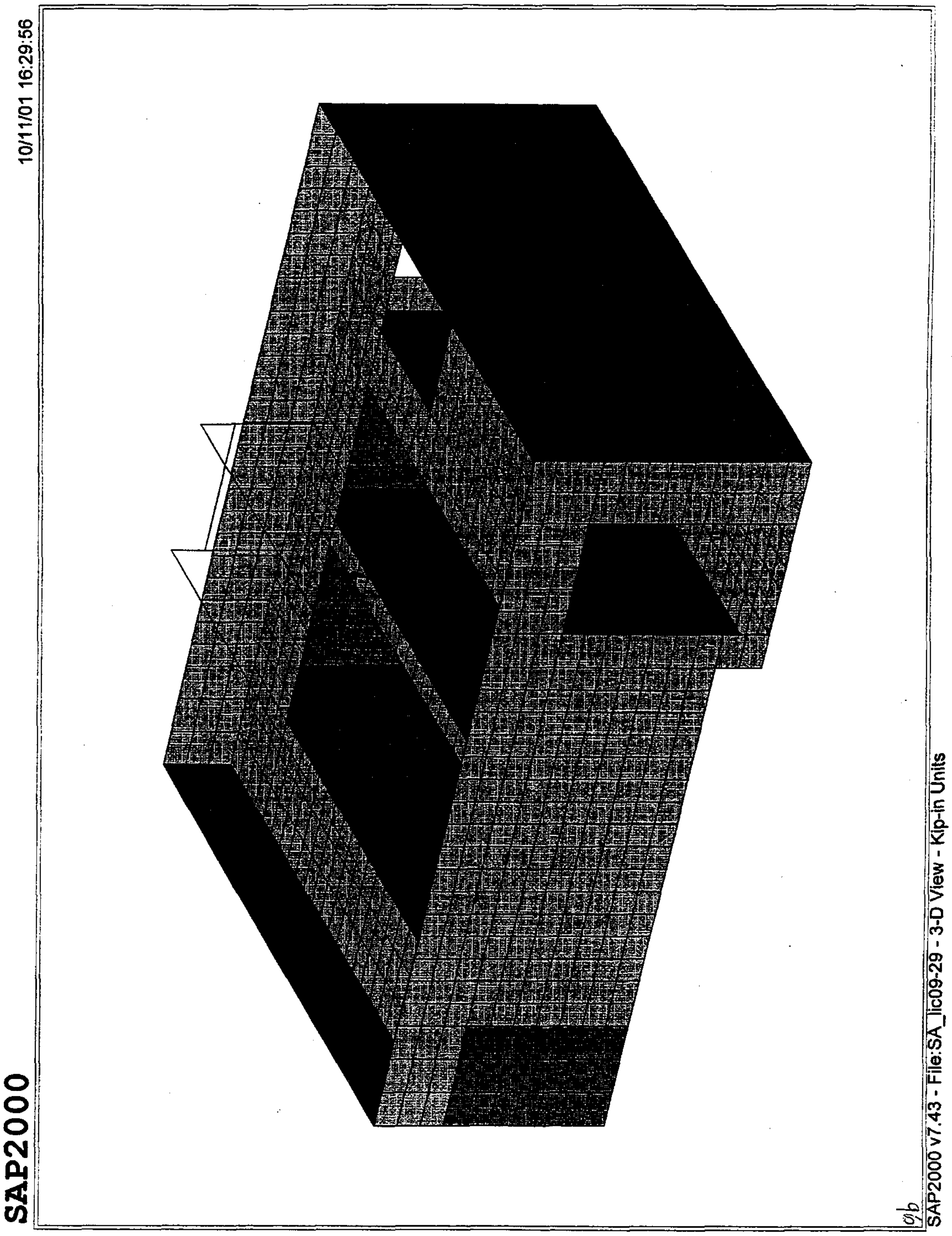


Figure 4.7-61
Storage Area ITS Concrete Structure Extruded Elements – North Elevation

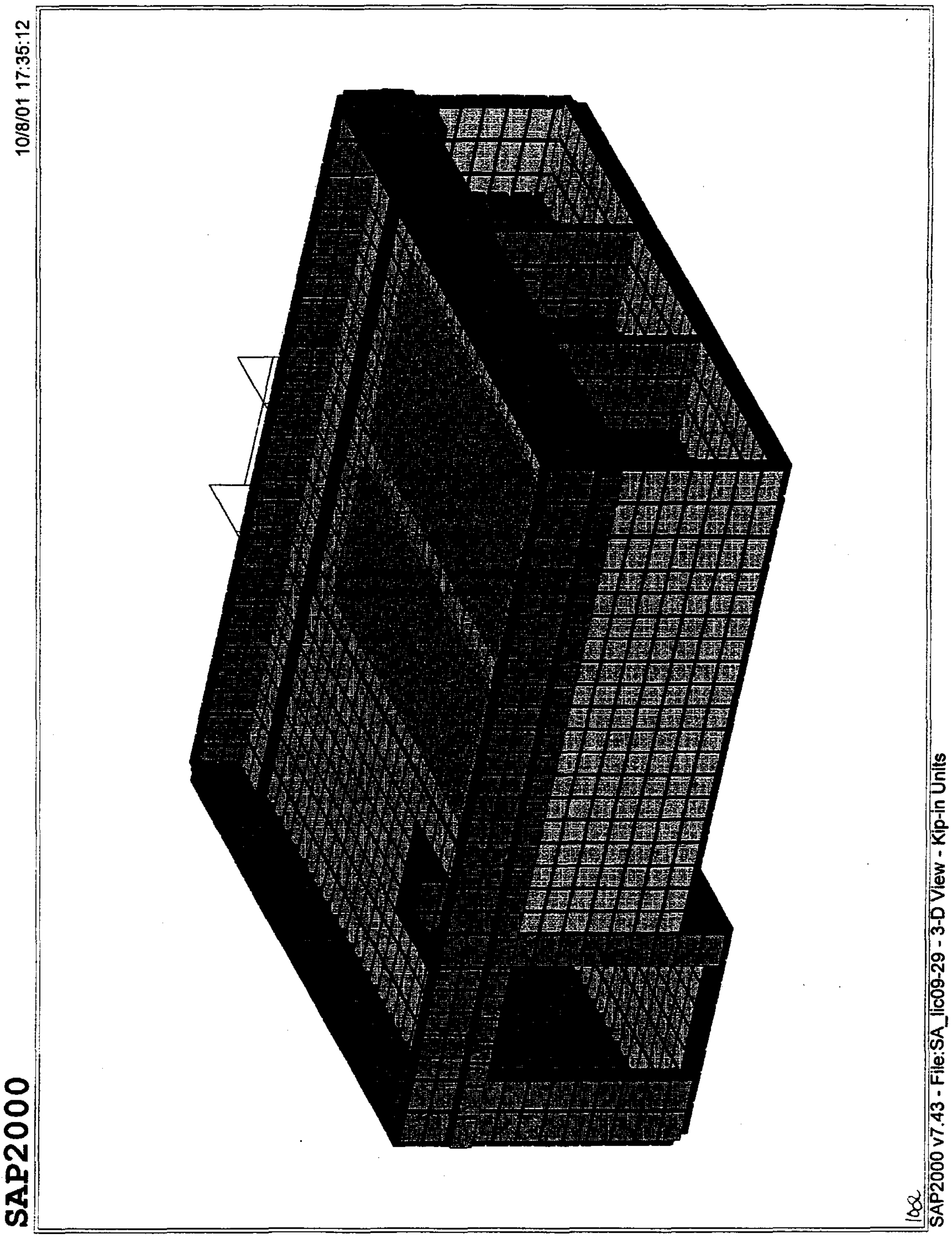


Figure 4.7-62
Storage Area ITS Concrete Structure Extruded Elements – South Elevation

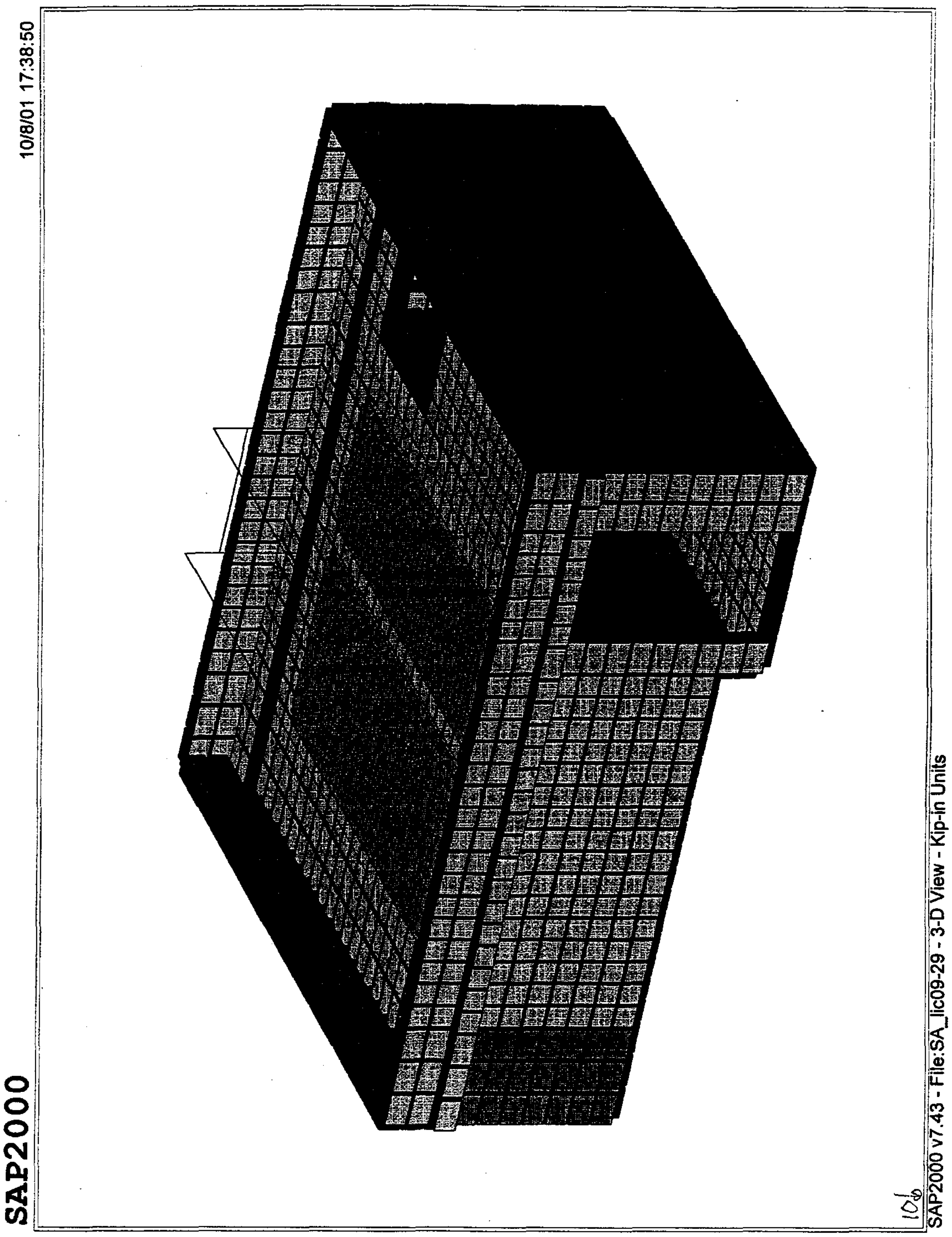


Figure 4.7-63
Storage Area NITS Steel Structure – South Elevation

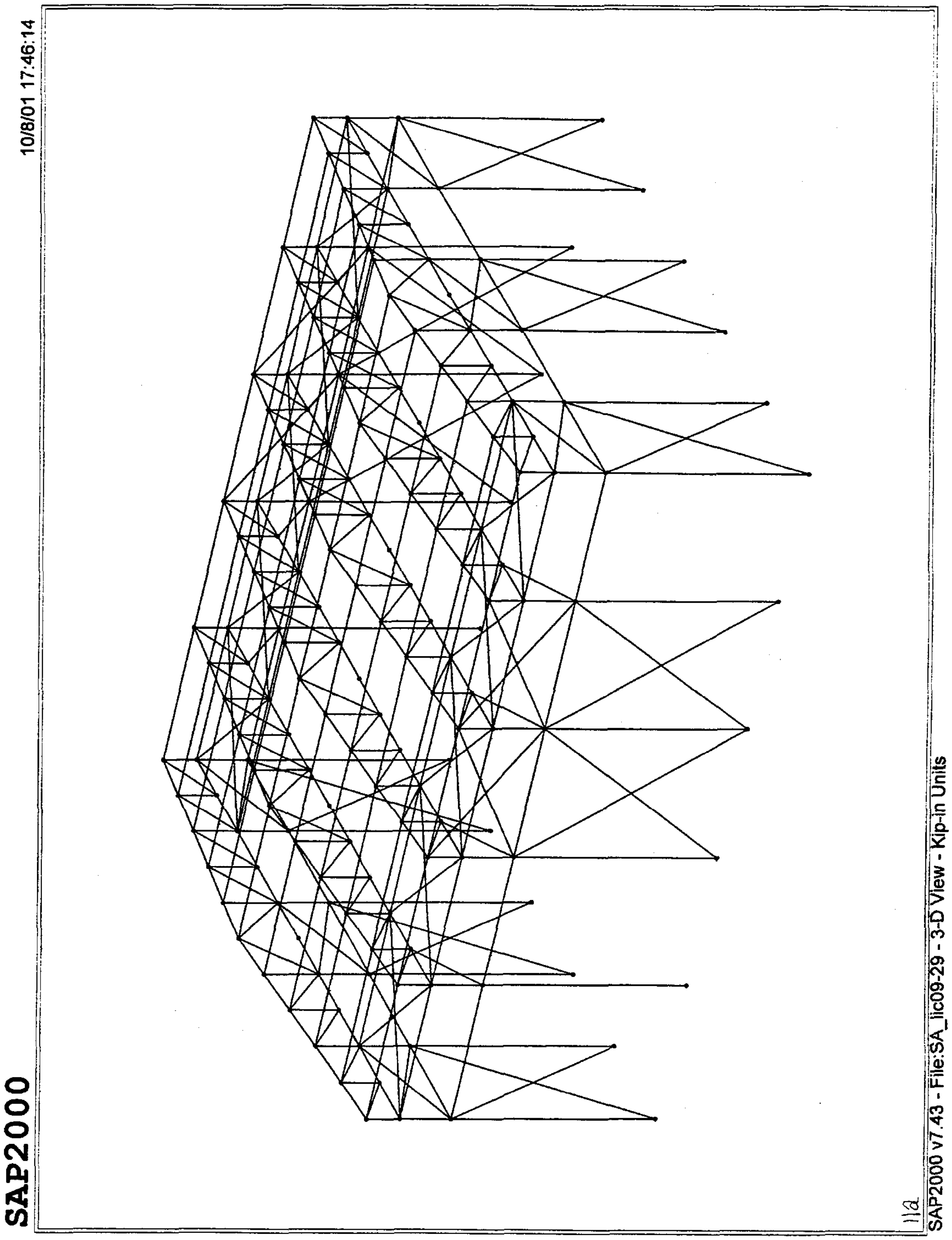


Figure 4.7-64
Storage Area NITS Steel Structure – North Elevation

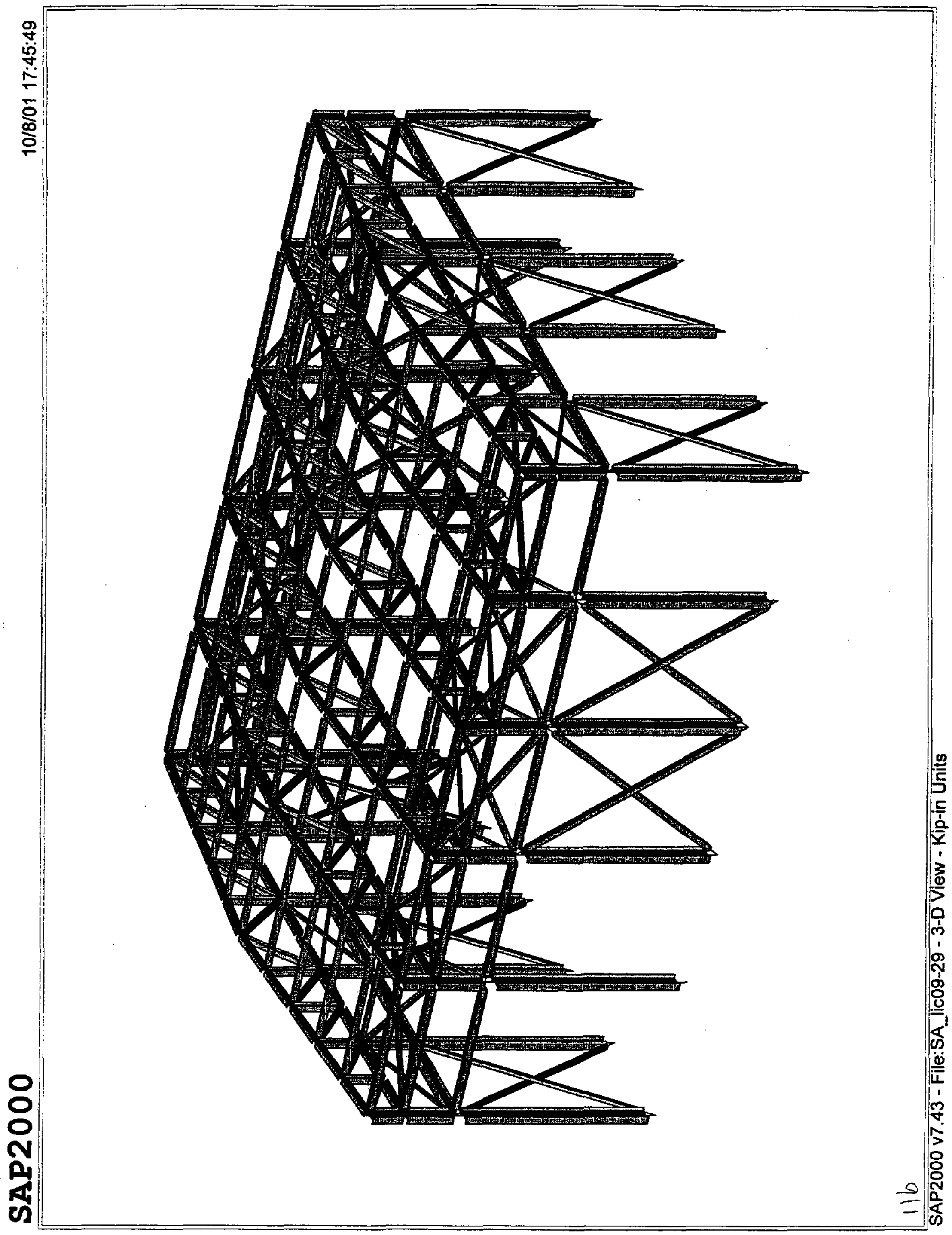
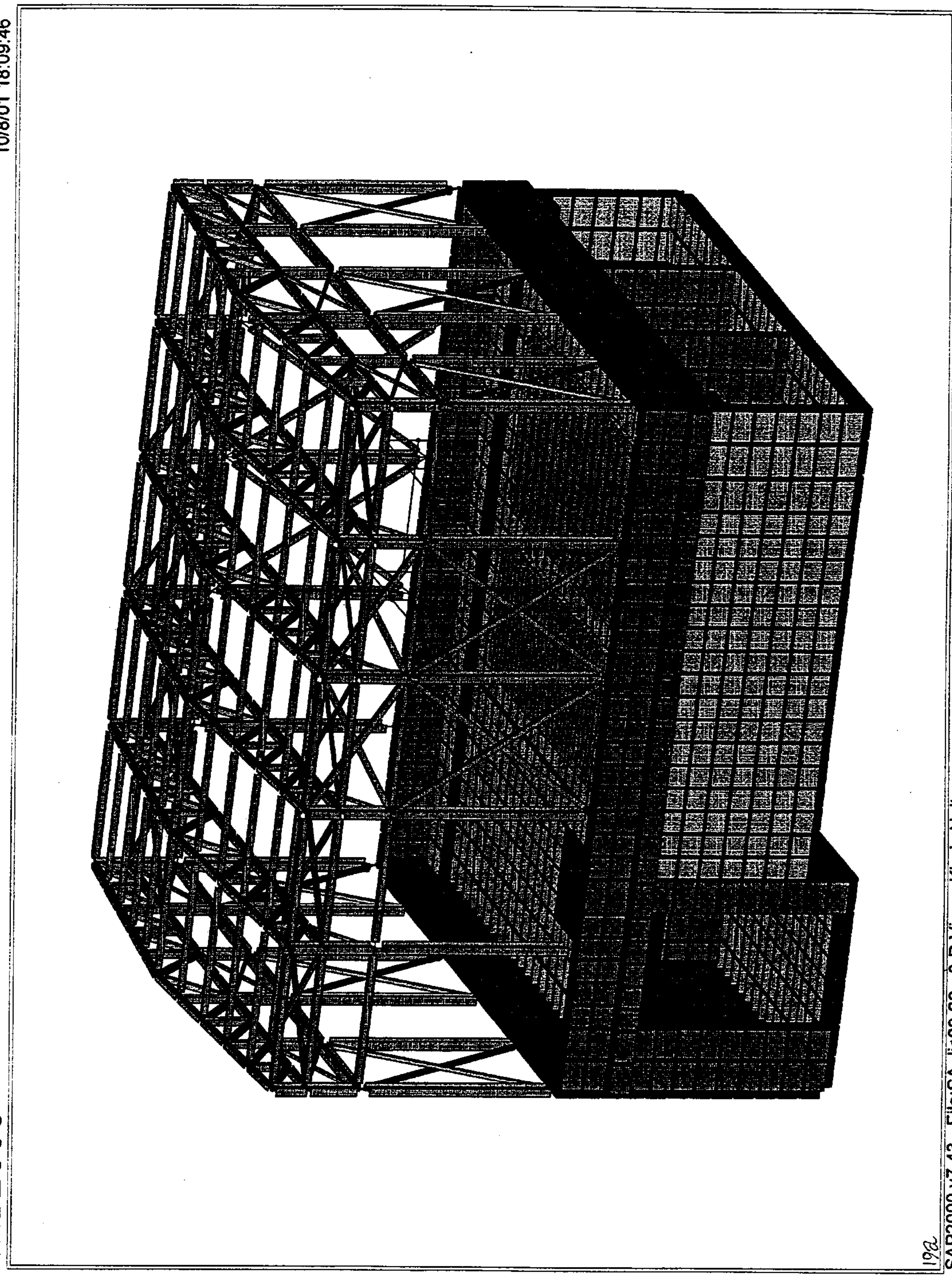


Figure 4.7-65
Storage Area Full Extruded Model – South Elevation



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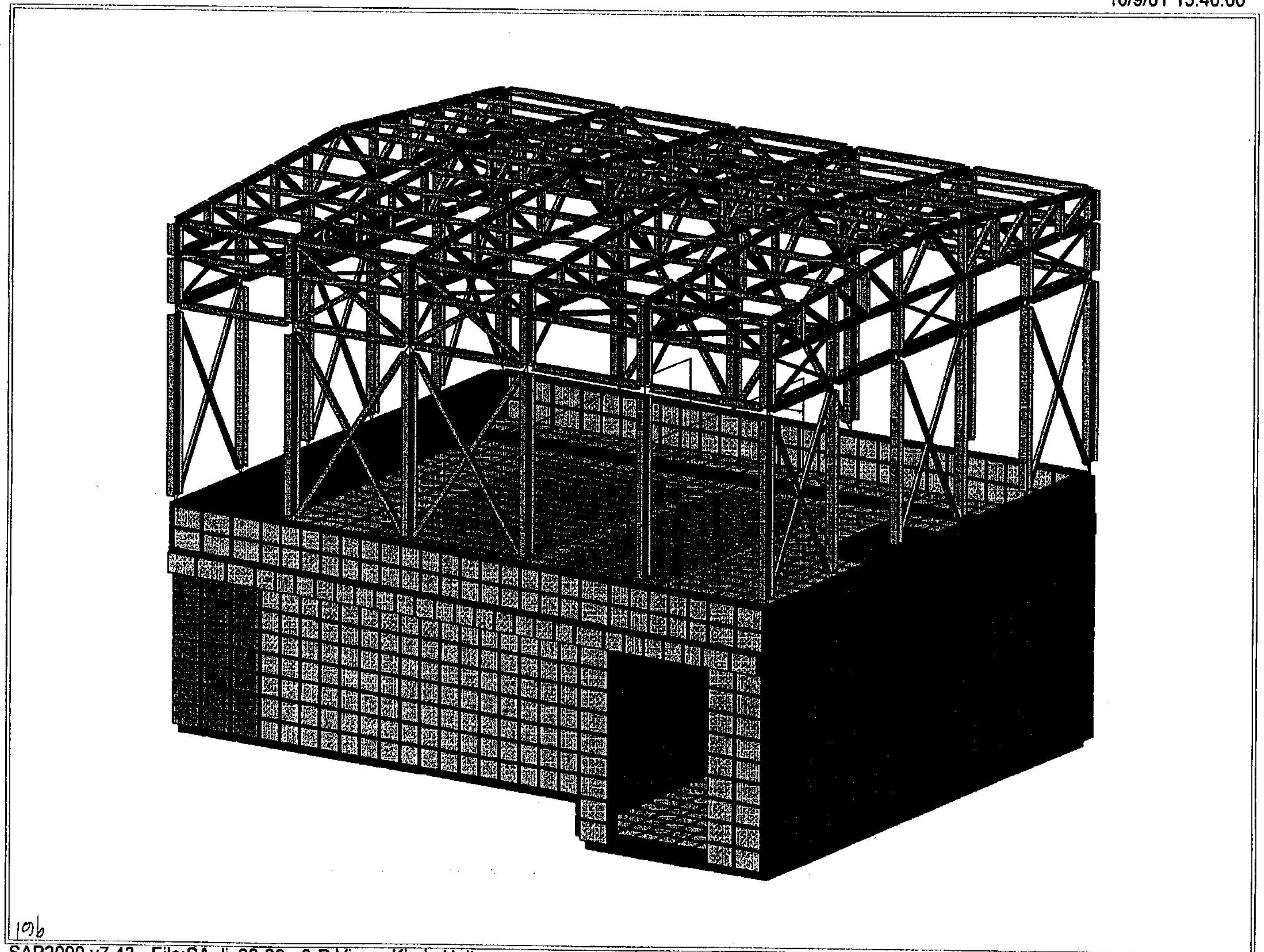


SAP2000 v7.43 - File:SA_lic09-29 - 3-D View - Kip-in Units

Figure 4.7-66
Storage Area Full Extruded Model – North Elevation

Figure 4.7-67
Storage Area Cut-Away Extruded Model – South Elevation

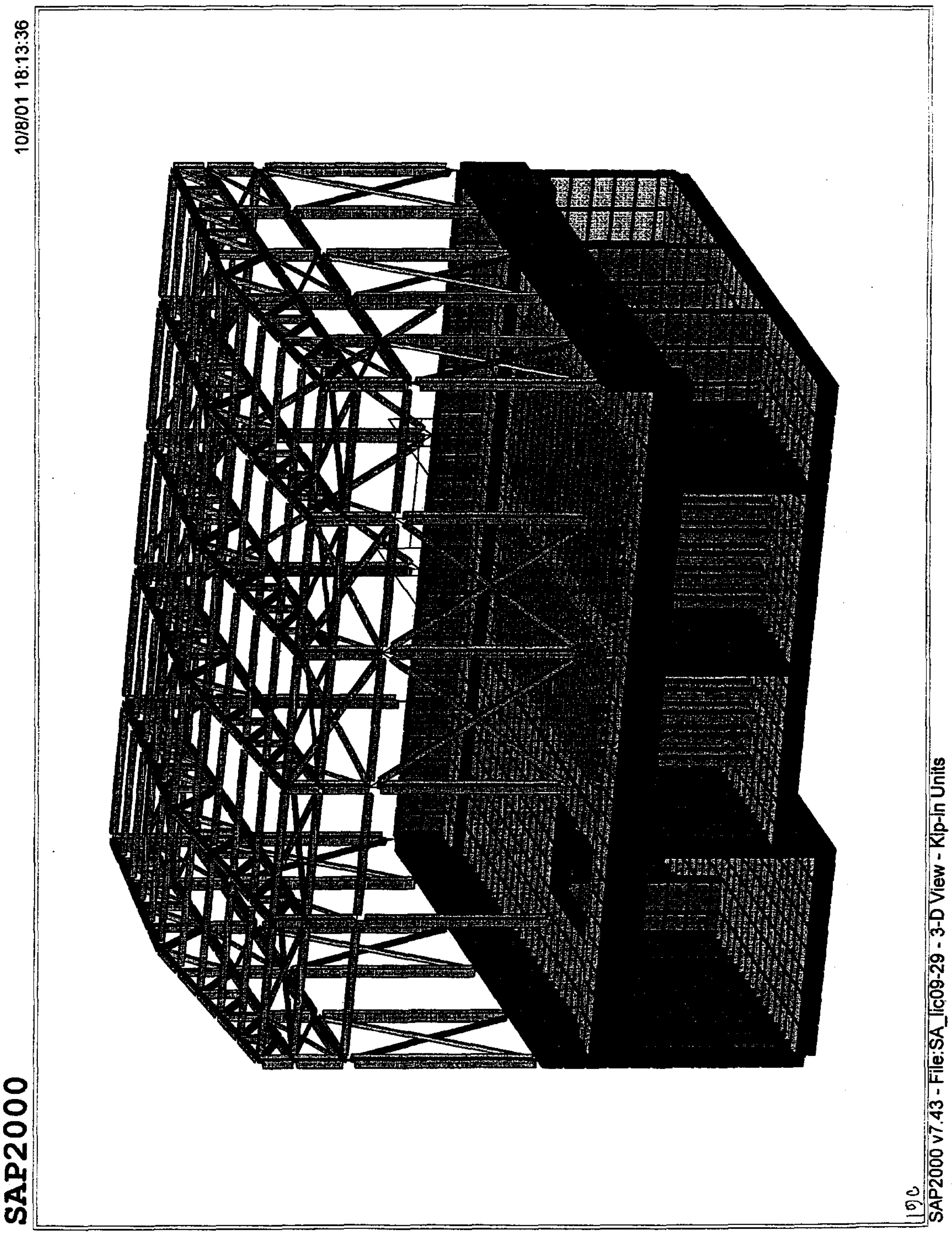


Figure 4.7-68
Storage Area Fixed-Base Boundary Conditions

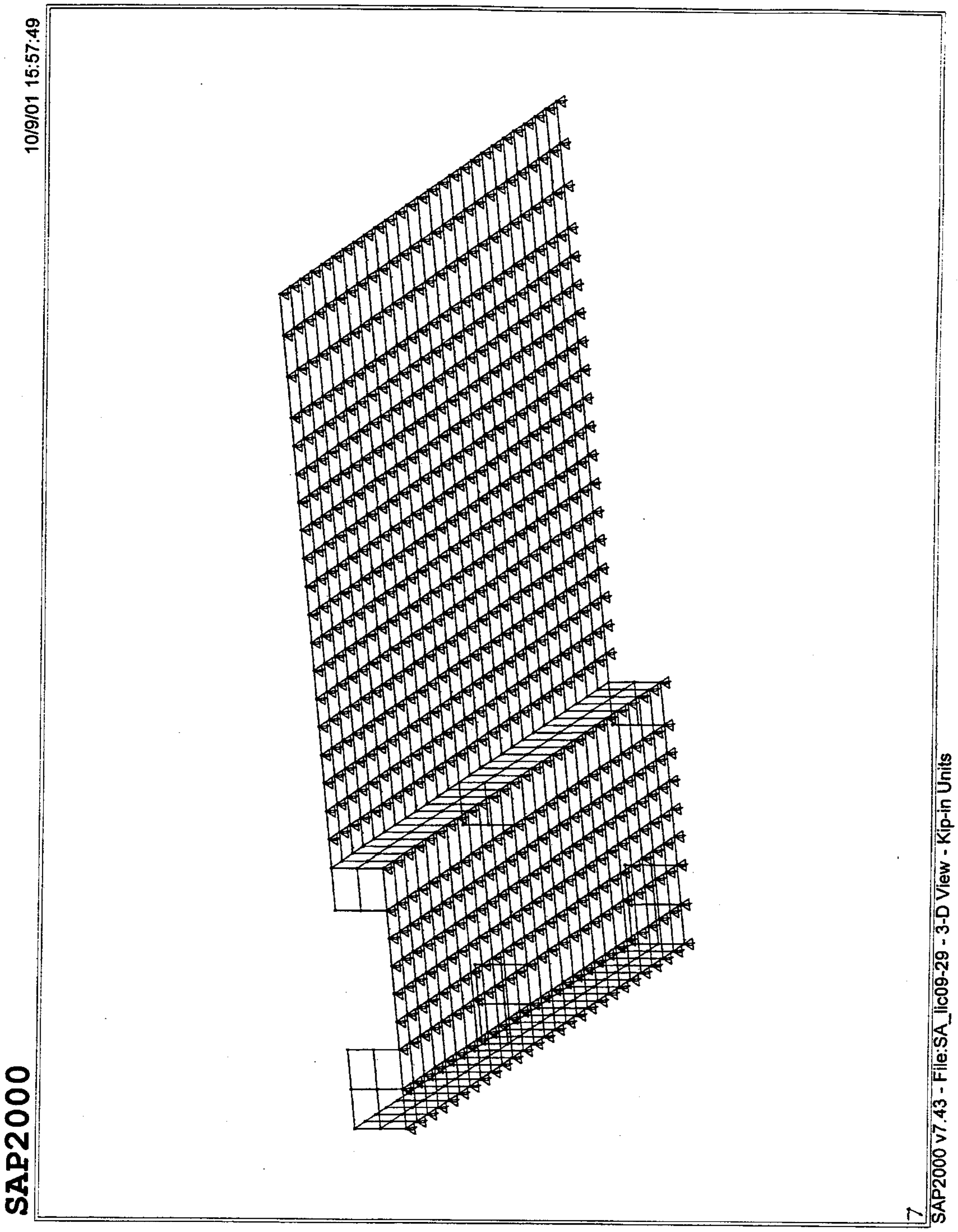


Figure 4.7-69
Storage Area Thermal Boundary Conditions

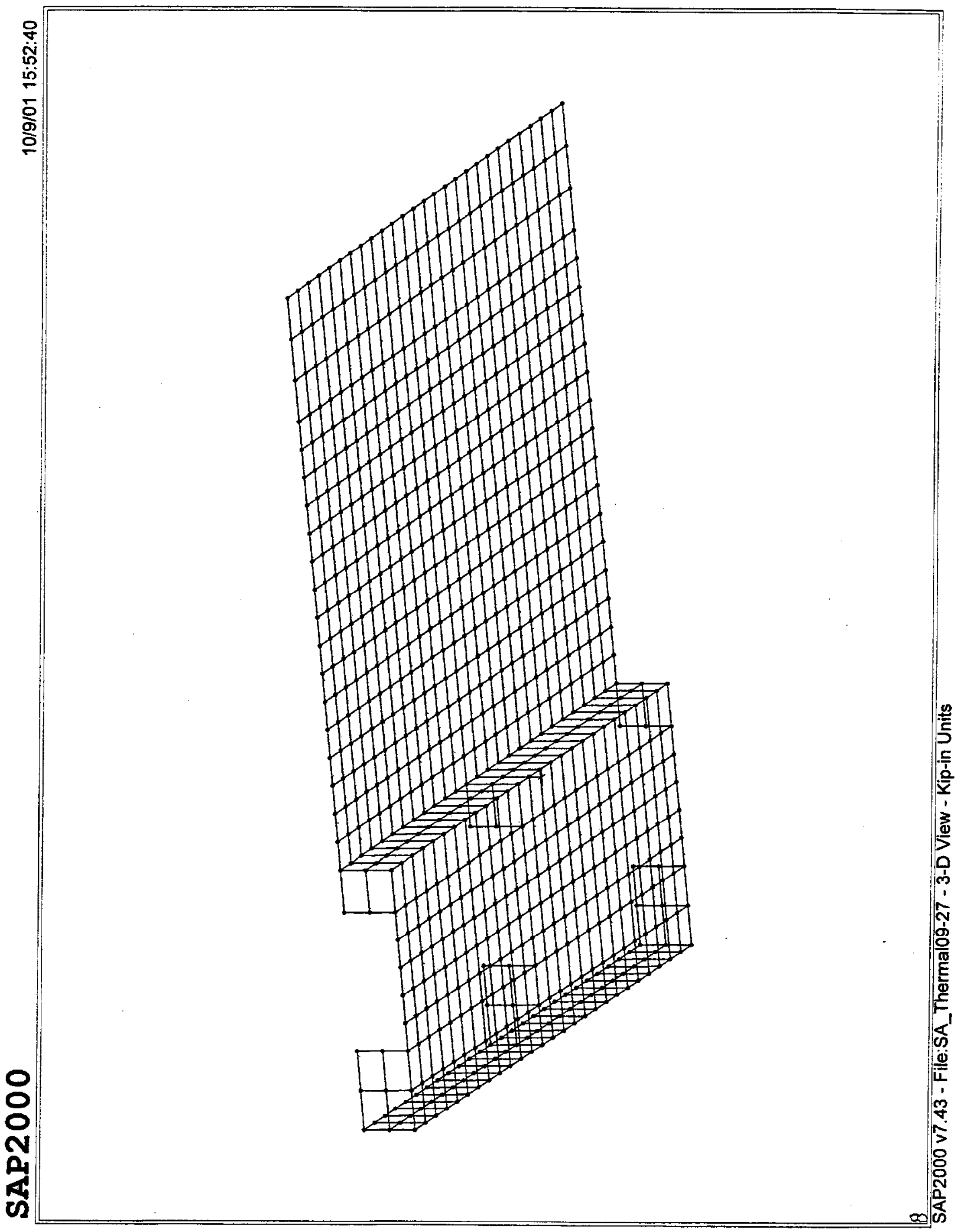


Figure 4.7-70
Storage Area Mat Foundation Model with Spring Elements

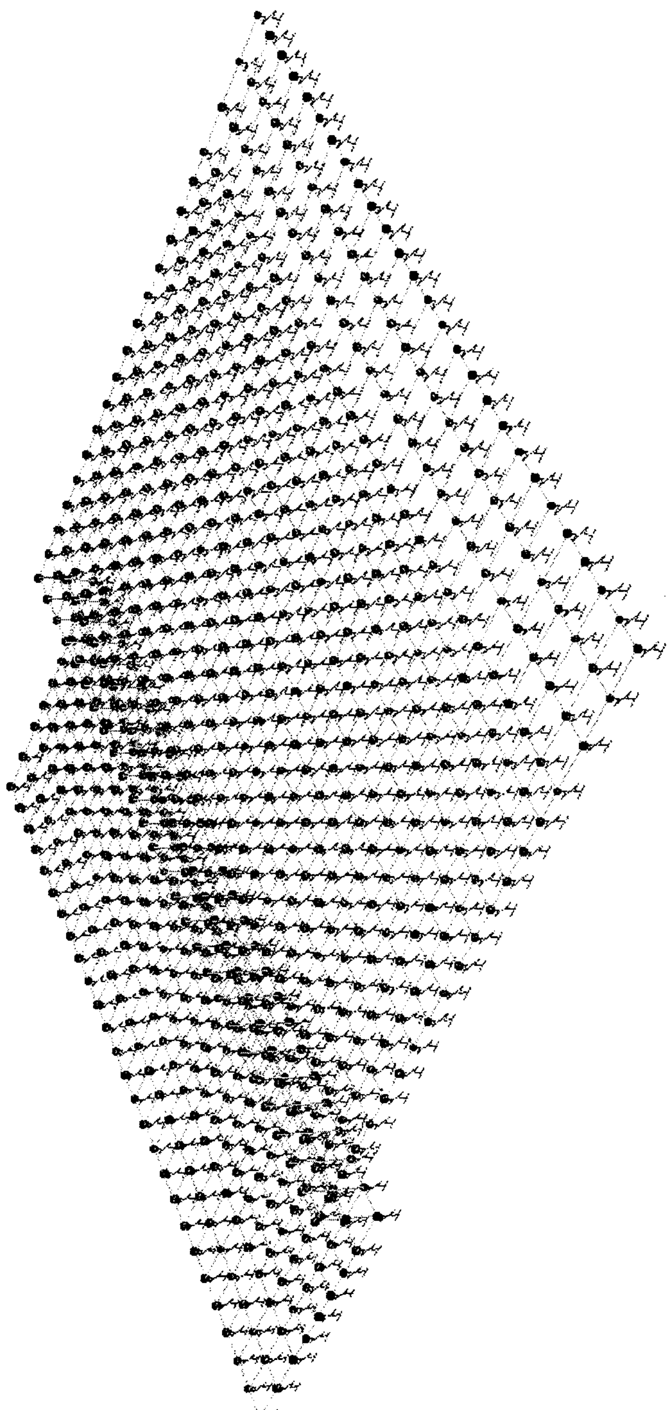


Figure 4.7-71
Storage Area – Mode 45 Vertical Vault Roof Mode

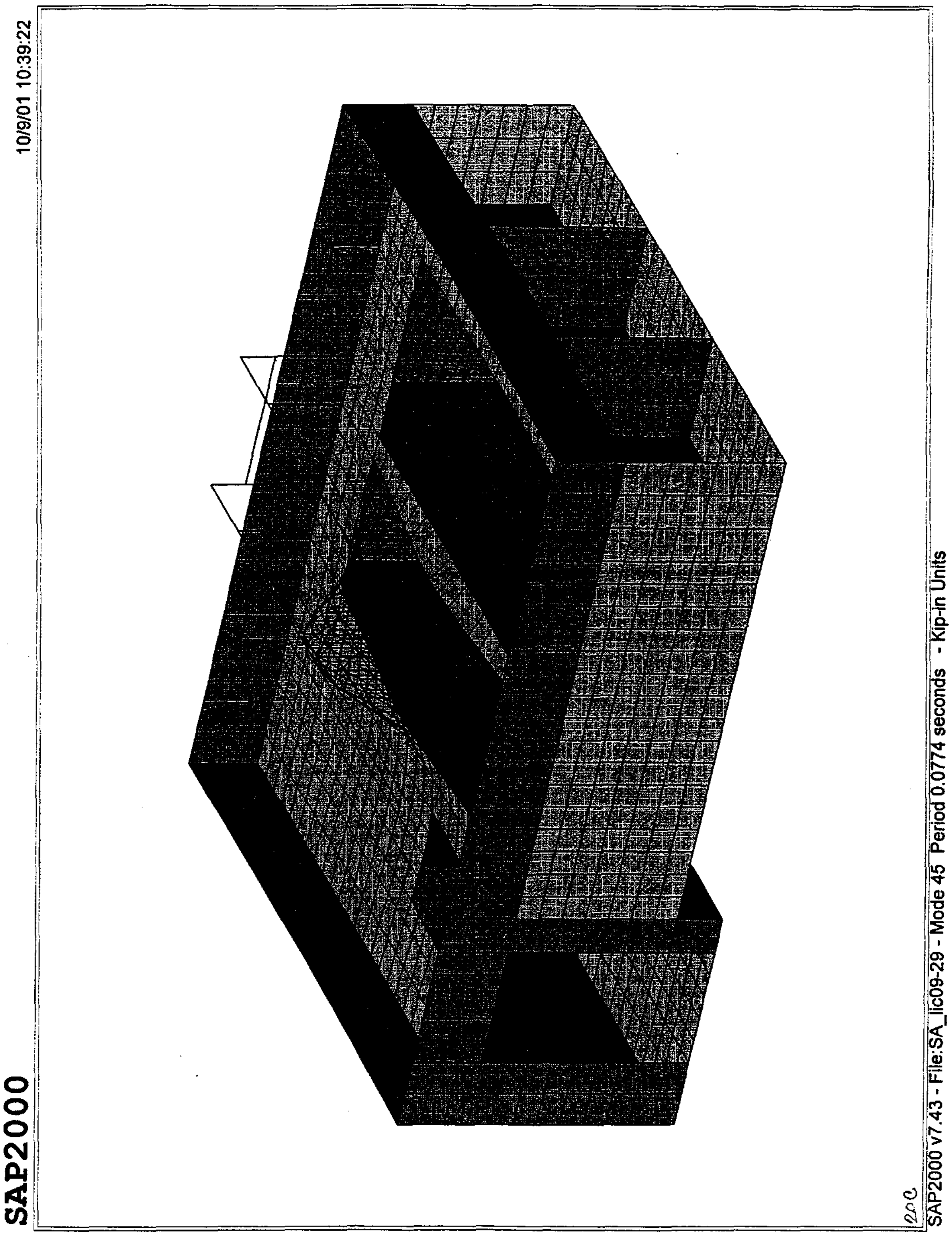


Figure 4.7-72
Transfer Area – Mode 47 Fundamental East-West Mode

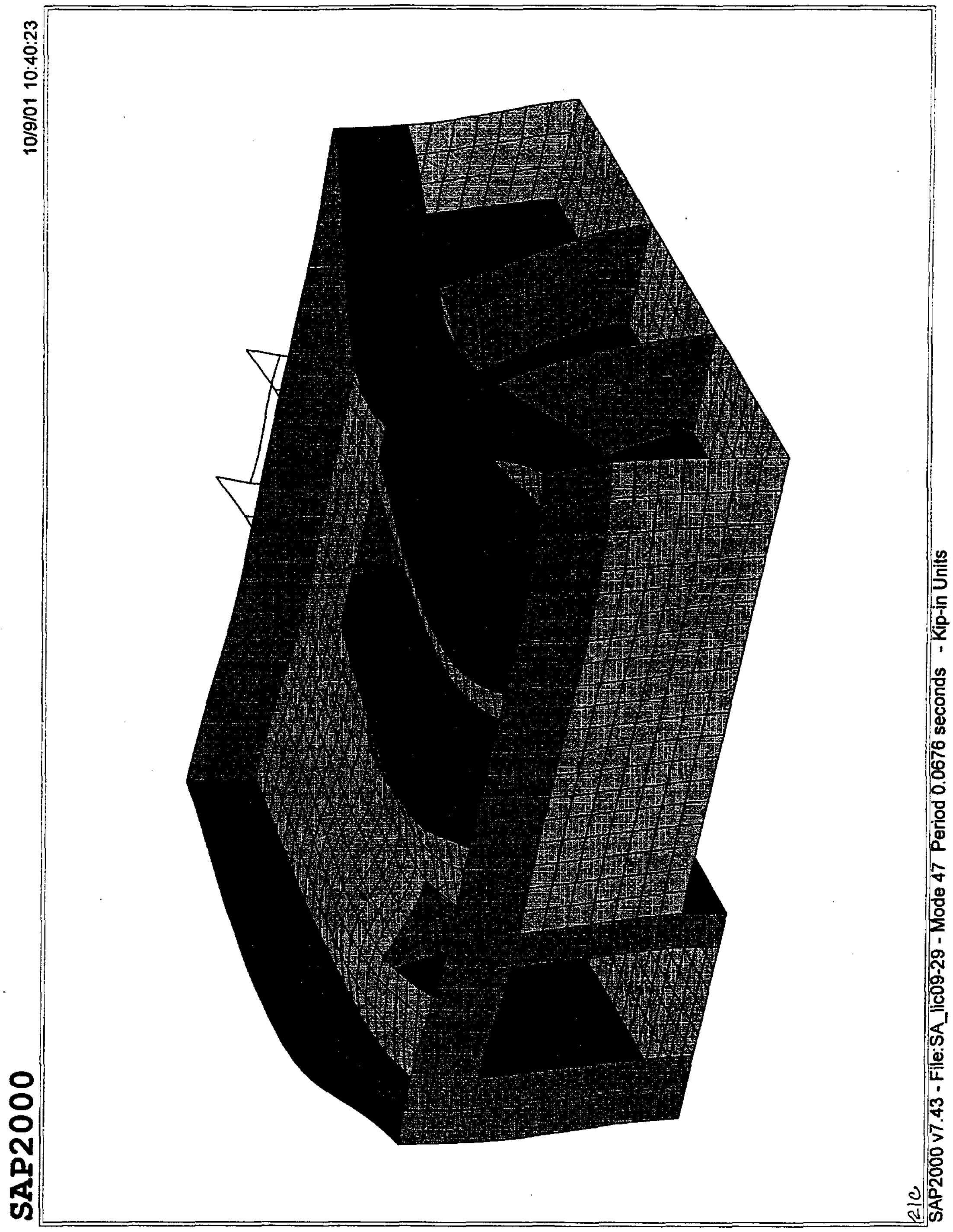


Figure 4.7-73
Transfer Area – Mode 75 Fundamental North-South Mode

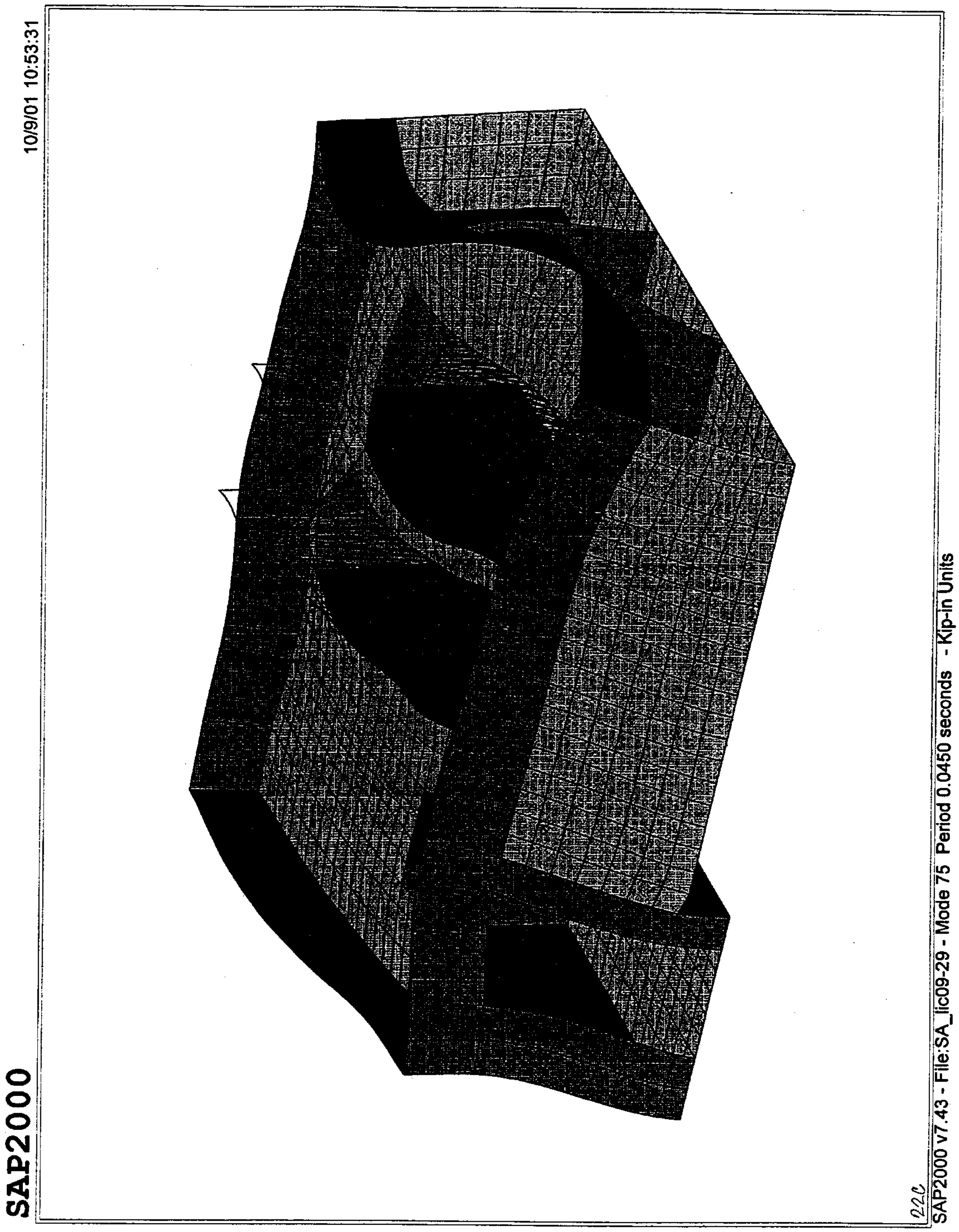


Figure 4.7-74
Cask Receipt Crane (Hook-up) Seismic Model

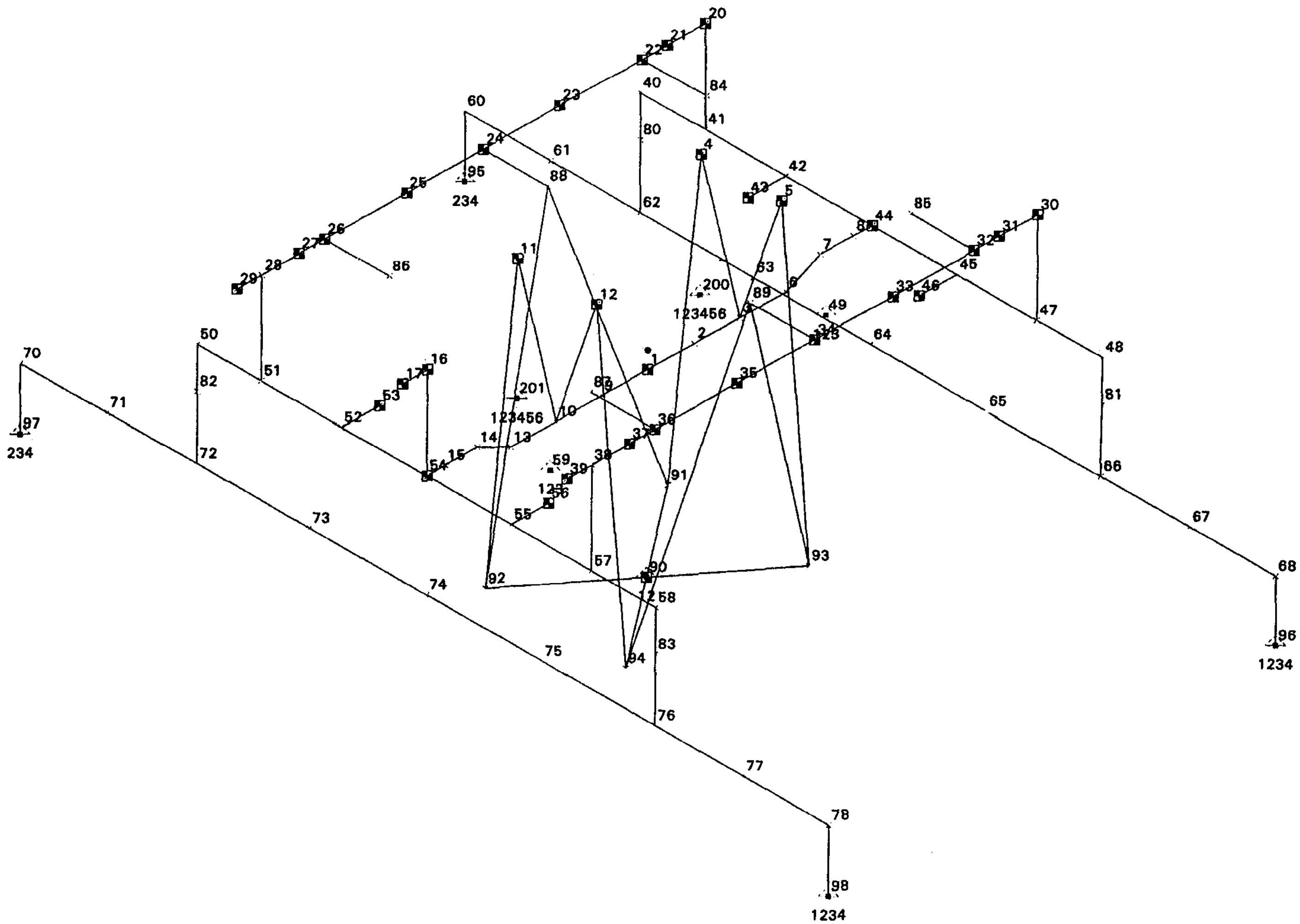


Figure 4.7-75
Cask Trolley Model

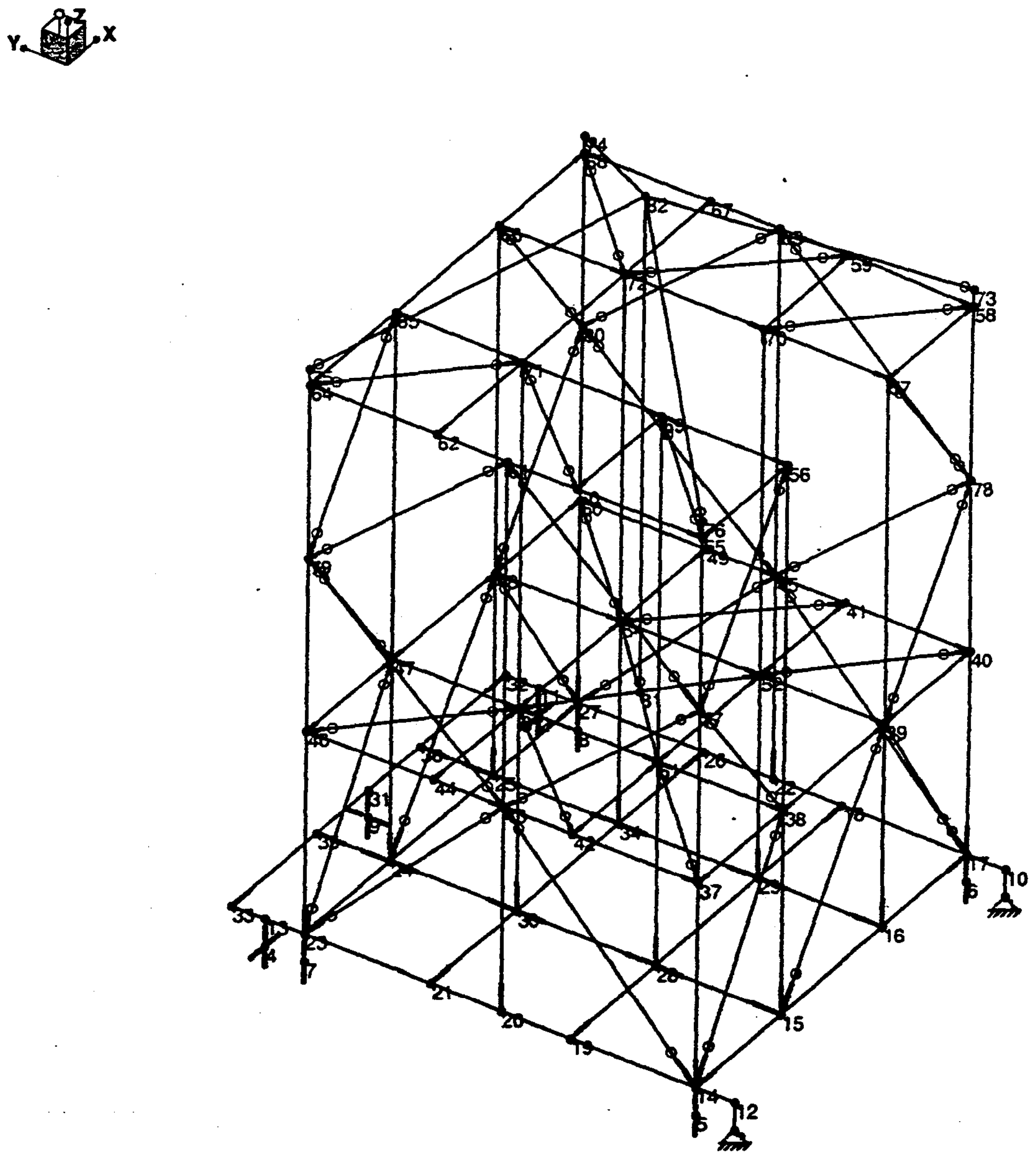


Figure 4.7-76
Canister Trolley Model

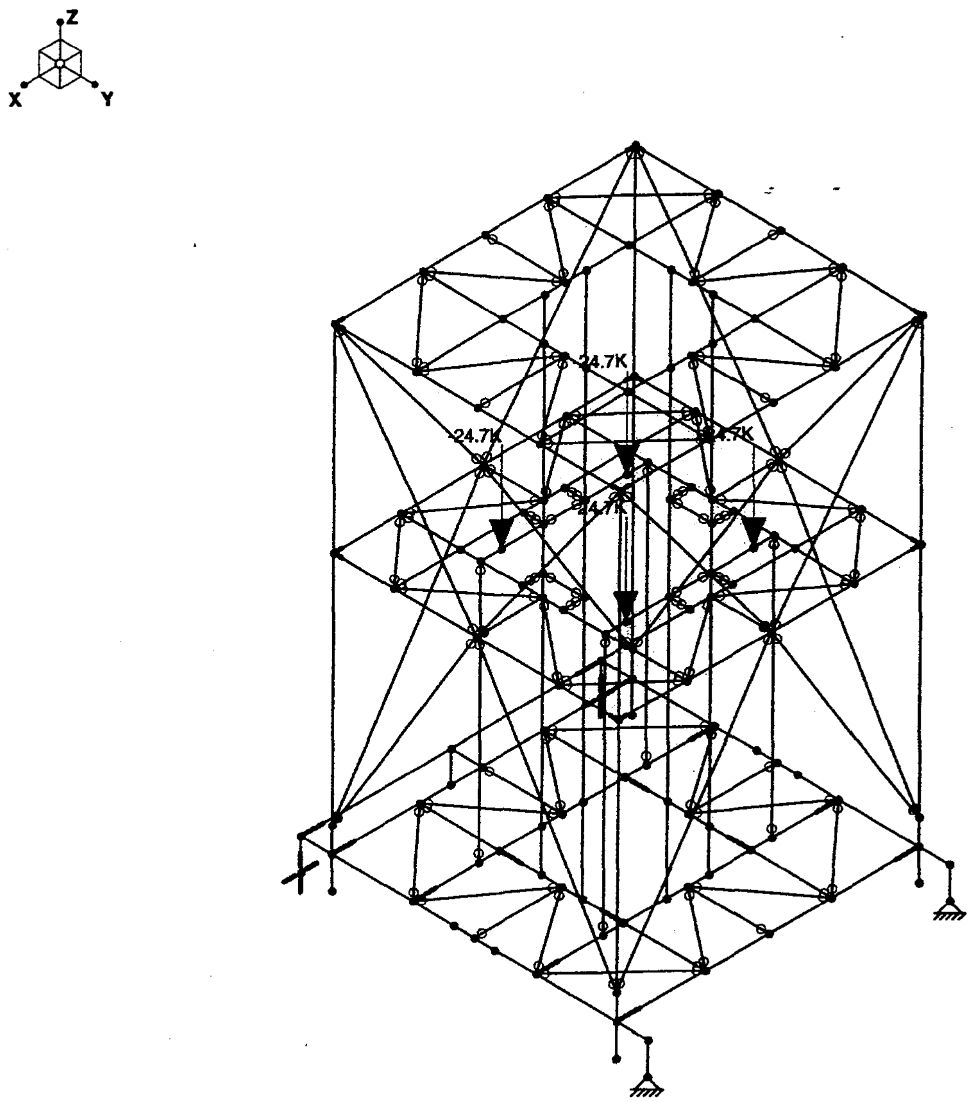


Figure 4.7-77
Fuel Handling Machine Bridge Model

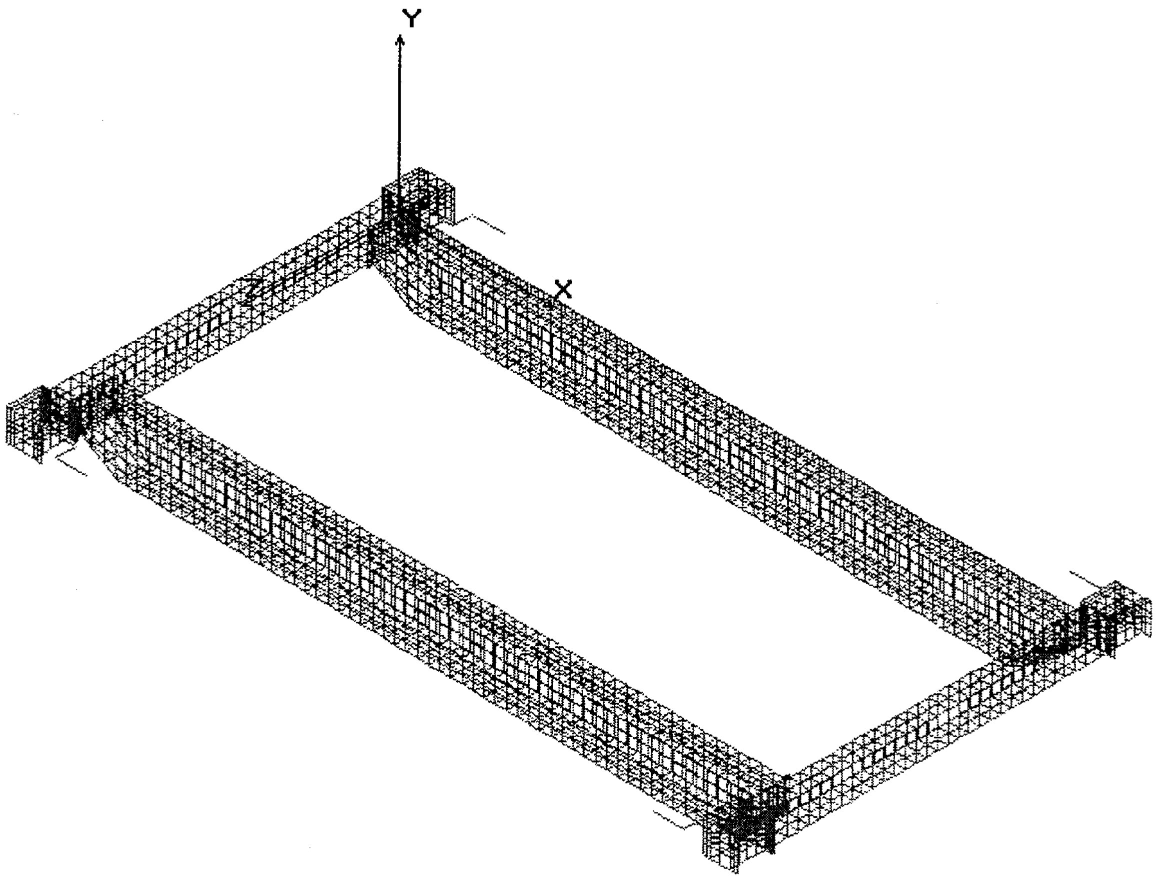


Figure 4.7-78
Fuel Handling Machine Trolley Model

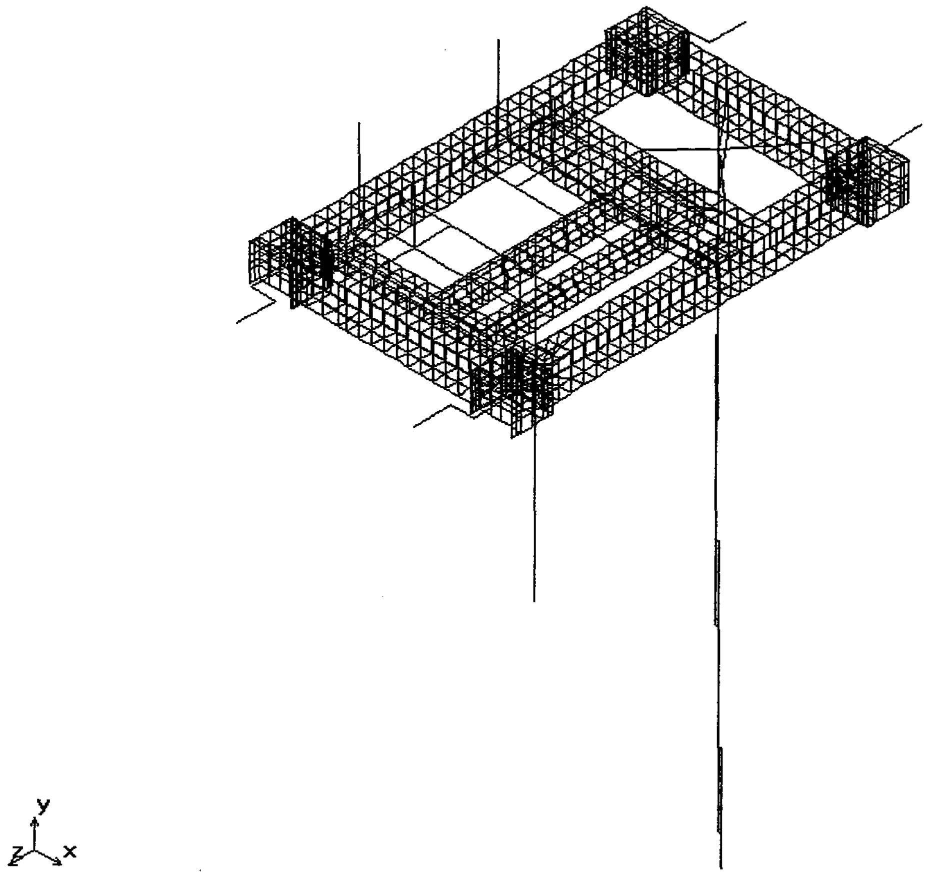
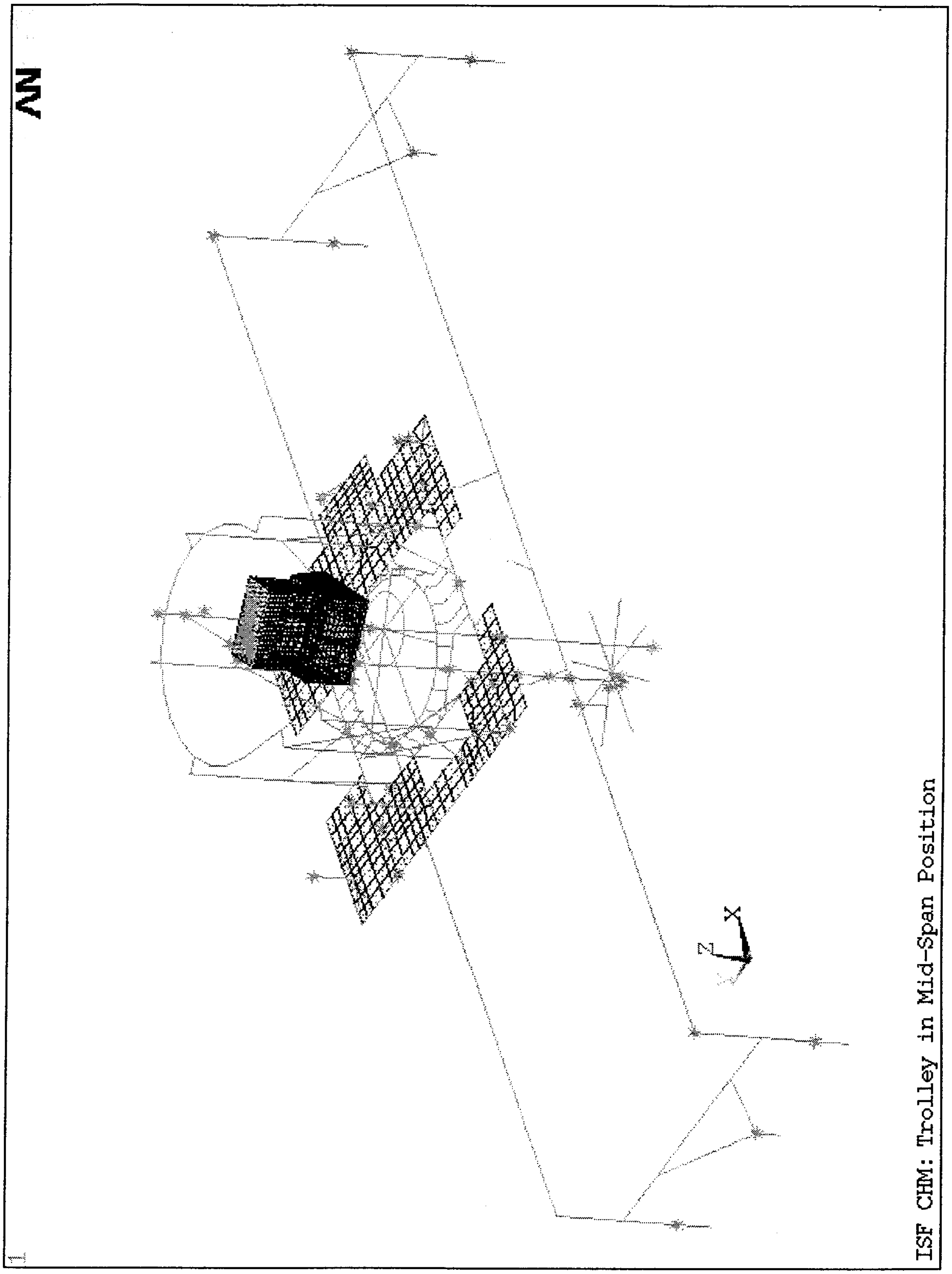


Figure 4.7-79
CHM Model



Appendix A
Criticality Models

Appendix 4A
Criticality Models

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1.0 INTRODUCTION

The purpose of this report is to provide a summary of criticality calculations performed for the ISF Facility to demonstrate compliance with the ISF SAR Table 3.3-5, "Control Methods for Prevention of Criticality."

This appendix covers the fuel handling process as it flows through the ISF. The fuel is received in a DOE transfer cask and is moved to the fuel packaging area (FPA). In the FPA the fuel is removed from the transfer cask and placed in ISF containers that ultimately end up in the storage tubes of the storage area (SA) portion of the facility. The transfers that occur in the FPA expose the fuel to the greatest risk of upset, off-normal, or accident conditions. Therefore, analyses are performed for the credible upset conditions. There are also normal fuel handling events that are analyzed such as loading a cask or placement of fuel canisters into storage tubes.

There are three basic fuel types analyzed: TRIGA fuel, Peach Bottom Fuel, and Shippingport reflectors. The analyses are developed such that the double contingency principle is not violated.

Sections 2 through 4 summarize key information from the criticality calculations performed for the ISF. Section 2 covers the six criticality calculations written for TRIGA fuel, Section 3 addresses five calculations for the Peach Bottom Fuel and Section 4 covers the single calculation written for the Shippingport reflector fuel. Each calculation is contained in a separate subsection for the section addressing that fuel type. For example, key information from the calculation for "Two DOE Canisters Loaded with 90 TRIGA Elements" is summarized in Section 2.2 because Section 2 addresses TRIGA fuel.

Both credible and non-credible scenarios were analyzed. Credible scenarios were explicitly modeled to determine k_{eff} for comparison against the design basis multiplication factor of 0.95. These cases included routine handling, packaging, transfer and storage scenarios. Non-credible scenarios were analyzed to determine the bounding quantity of fissile material that results in an effective multiplication factor of 0.95. These non-credible scenarios included:

- TRIGA elements with three sides of concrete reflection
- Peach Bottom microspheres
- Crushed Peach Bottom fuel assemblies moderated with graphite
- Reflector rods in an infinite array

Each subsection consists of the following information which was extracted from the criticality calculations:

1) Purpose of the calculation
2) Summary of results
3) Description of the spent fuel loading
4) Description of the model specification
5) Table with material densities used in the models

6) Summary of calculation methodology
7) Description of fuel loading and other contents optimization
8) Detailed summary of the criticality calculation results
9) List of references applicable to that calculation.

2.0 TRIGA FUEL

2.1 TWO DOE CANISTERS LOADED WITH 90 TRIGA ELEMENTS

2.1.1 Criticality Evaluation

An analysis was performed to show that the TRIGA fuel will be critically safe when 90 elements are placed into a DOE canister, and when two loaded DOE canisters are placed end-to-end.

2.1.2 Discussion and Results

MCNP (MCNP4B2) calculations were performed to determine the k_{eff} of one or two DOE canisters, each of which contain 90 TRIGA fuel elements, placed end-to-end and closely reflected with 12 inches of water. The maximum $k_{eff} + 2\sigma$ value of 0.5494 was found with water inside the canister and reflected with 12 inches of water.

The results of these calculations are summarized in Table 1. Note that all cases have a 12-inch water reflector.

Table 1
Summary of Criticality Results

MCNP Case	Configuration*	Canister Flooded	Fuel Arrangement	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$
1-1	Single Canister	Yes	Close-packed	0.5183 ± 0.0021	0.5225
1-2	Single Canister	No	Close-packed	0.3717 ± 0.0019	0.3755
1-3	Single Canister	Yes	Cross-shape	0.5446 ± 0.0024	0.5494
1-4	Single Canister	No	Cross-shape	0.3494 ± 0.0019	0.3534
1-5	2 End-to-End	Yes	Close-packed	0.5178 ± 0.0023	0.5224
1-6	2 End-to-End	No	Close-packed	0.3719 ± 0.0018	0.3755

* All cases have a 12-inch water reflector.

2.1.3 Spent Fuel Loading

Each DOE canister contained 90 TRIGA fuel elements for a total 3.95 kilograms of ^{235}U per canister. The nominal TRIGA fuel element fissile material content specified in the ISF Contract (39g ^{235}U) was adjusted to account for variations in post-1964 fuel elements to provide the most reactive and bounding source term for criticality analysis. Manufacturing variations resulted in a higher uranium content and a greater H:Zr atom ratio. The total fissile loading for the configuration consisting of 2 DOE canisters placed end-to-end is 7.9 kilograms of ^{235}U.

2.1.4 Model Specification

2.1.4.1 Description of Calculational Model

The MCNP models for 90 close packed (in contact) TRIGA fuel elements in a DOE canister reflected with 12 inches of water are illustrated in Figures 1 and 2. Figures 3 and 4 illustrate the MCNP model when the 5 fuel elements in the can are arranged in a "cross" shape. Figure 5 shows an axial view for the arrangement of 2 DOE canisters placed end-to-end. The radial view for this configuration is identical to that shown in Figure 1. Table 2 summarizes the modeled configuration.

Table 2
Modeled Configuration in DOE Container

Region	Documented Configuration		Modeled Configuration	
	Material (g/cc)	Dimensions, cm	Material (g/cc)	Dimensions, cm
		Fuel Description		
Fuel (Zr rod)	Zr (6.4)	OR=0.28575 Length=38.1	Zr (6.4)	OR=0.28575 Length=38.1
Fuel (meat)	U-$ZrH_{1.7}$ (6.0875)	IR=0.3175 OR=1.82245 Length=38.1	U-$ZrH_{1.7}$ (6.0875)	IR=0.3175 OR=1.82245 Length=38.1
Fuel Clad	SS-304 (7.92)	IR=1.82626 OR=1.87706 Length=55.4736	SS-304 (7.92)	IR=1.82245 OR=1.87325 Length=55.4736
		Graphite Cylinders		
Graphite Reflector	Graphite	OR=1.82245	Graphite (2.3)	OR=1.82245
		Length=2 @ 8.6868		Length=2 @ 8.6868
		End Fittings		
End Fittings	SS	OR=irregular	Void	OR=1.87325
		Length=2 @ 9.0932		Length=2 @ 9.0932
		Can Description		
Can	SS-304 (7.92)	IR=6.0452 OR=6.35	SS-304 (7.92)	IR=6.0452 OR=6.35
		Length=91.44 $Top_{thickness}$=none $Bottom_{thickness}$=0.635		Length=91.44 $Top_{thickness}$=0.635 $Bottom_{thickness}$=0.635

Bucket Description				
Bucket Shell	SS-304 (7.92)	IR=7.3152 OR=7.467092	SS-304 (7.92)	IR=7.3152 OR=7.467092
		$Length_{wall}$=95.25 $Length_{pedestal}$ =8.255 $Top_{thickness}$=none $Bottom_{thickness}$=0.635		$Length_{wall}$=95.25 $Length_{pedestal}$ =8.255 $Top_{thickness}$=none $Bottom_{thickness}$=0.635
DOE Canister Description				
Canister Shell	SS-304 (7.92)	IR=not given OR=not given	SS-304 (7.92)	IR=22.5425 OR=22.8595
		Length=n. g. $Top_{thickness}$=n.g. $Bottom_{thickness}$=n. g.		Length=311.09 $Top_{thickness}$=none $Bottom_{thickness}$=none
Reflector description				
Reflector			Water (1.00)	T_{radial}=30.48 T_{end}=30.48

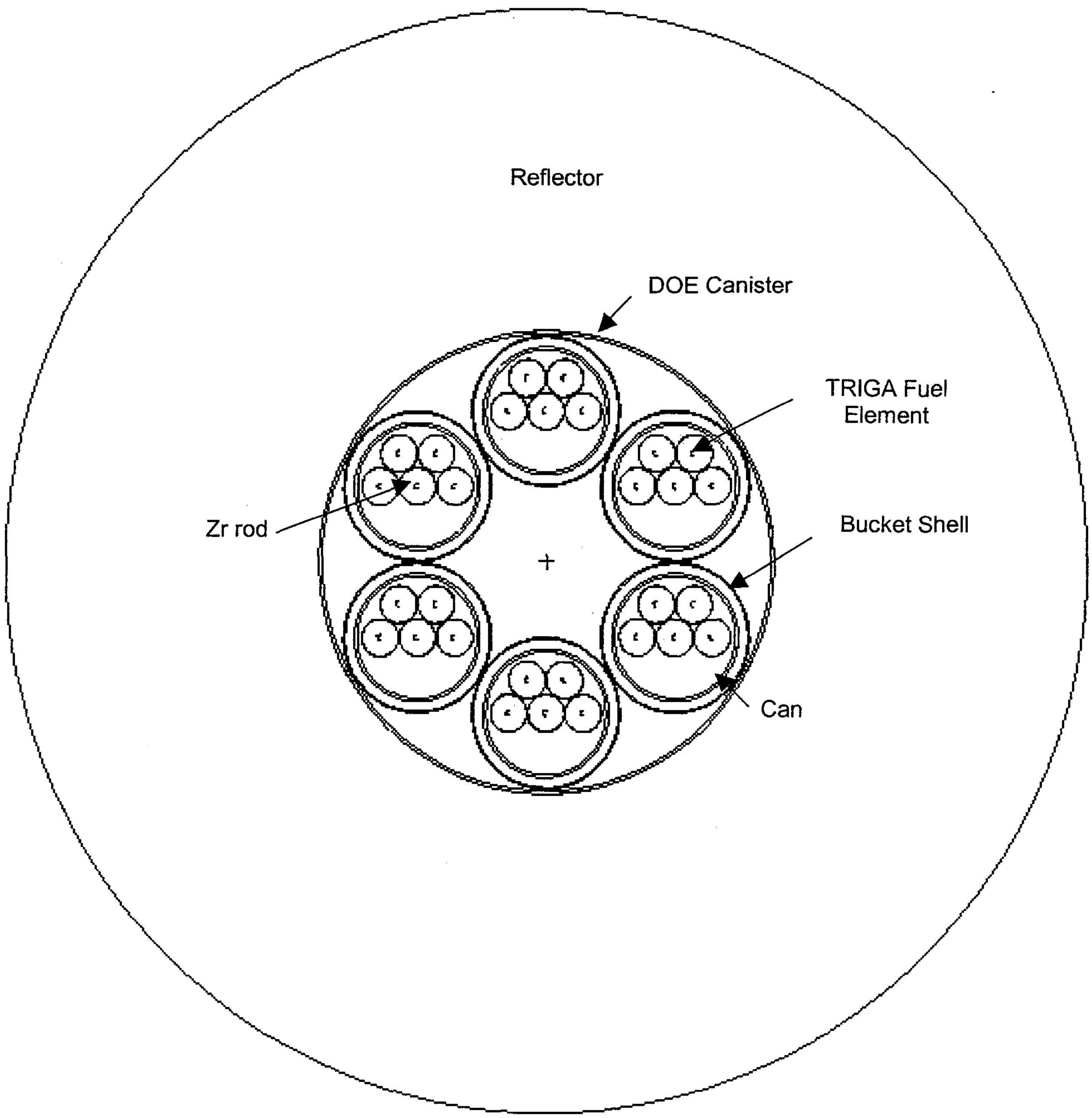

Figure 1
Radial View of MCNP Model for a Single DOE Canister with 90 TRIGA Fuel Elements (3 layers of 30 elements) – Close Packed Fuel Arrangement

[Through A – A' fig 2]

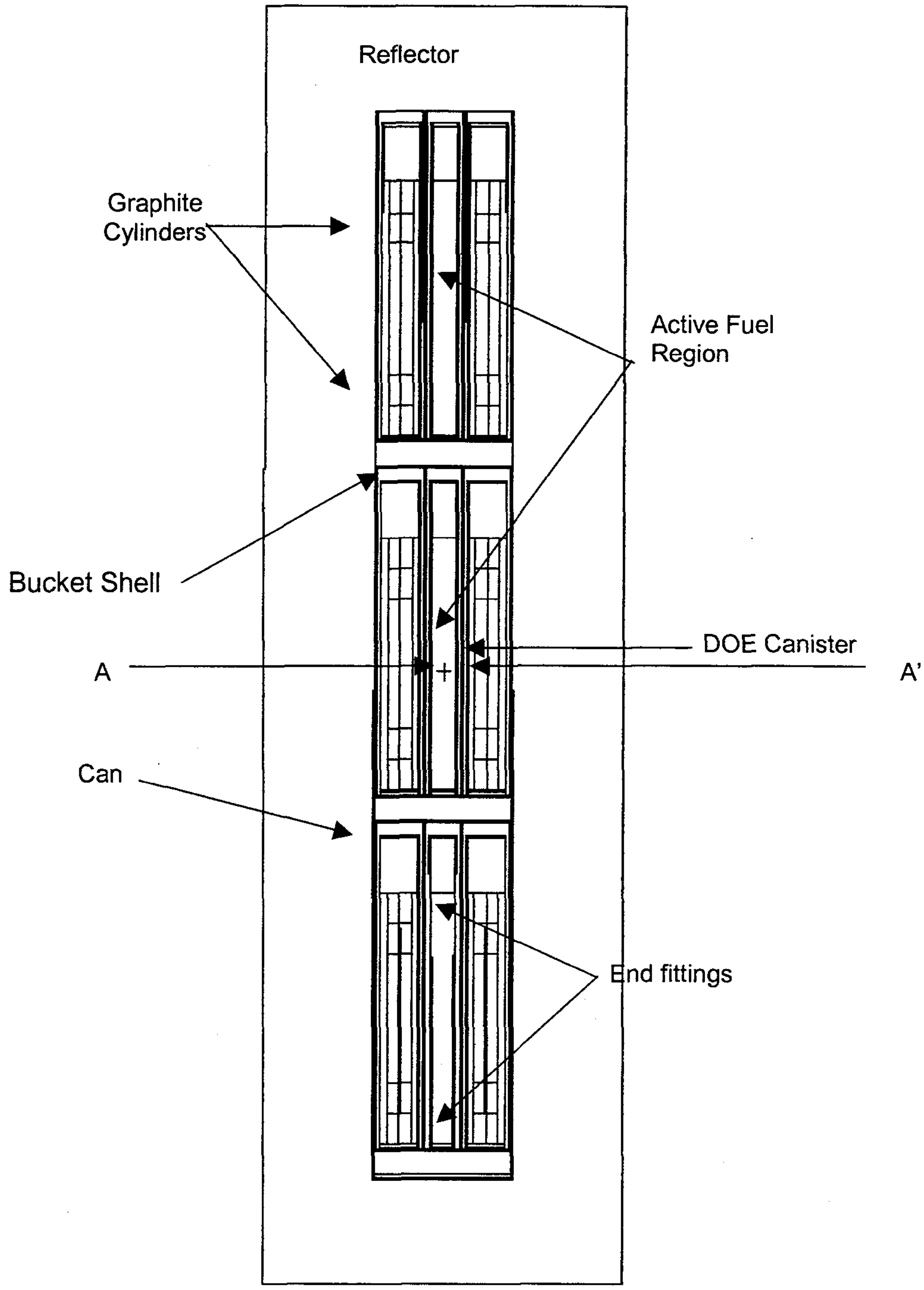

Figure 2
Axial View of MCNP Model for a Single DOE Canister with 90 TRIGA Fuel Elements – Close Packed Fuel Arrangement

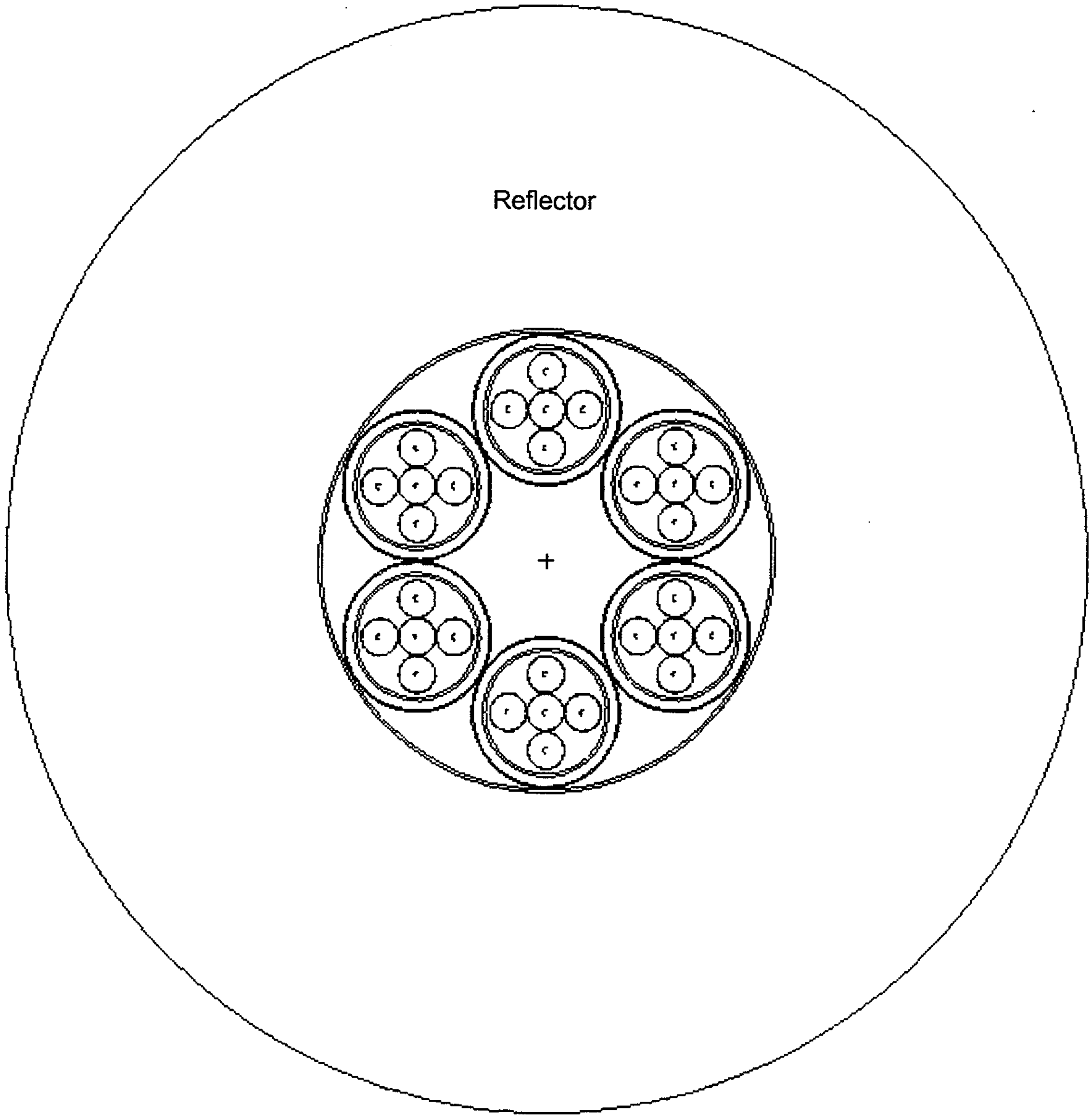

Figure 3
Radial View of MCNP Model for a Single DOE Canister with 90 TRIGA Fuel Elements – "Cross Shape" Fuel Arrangement [A-A' of Fig. 4]

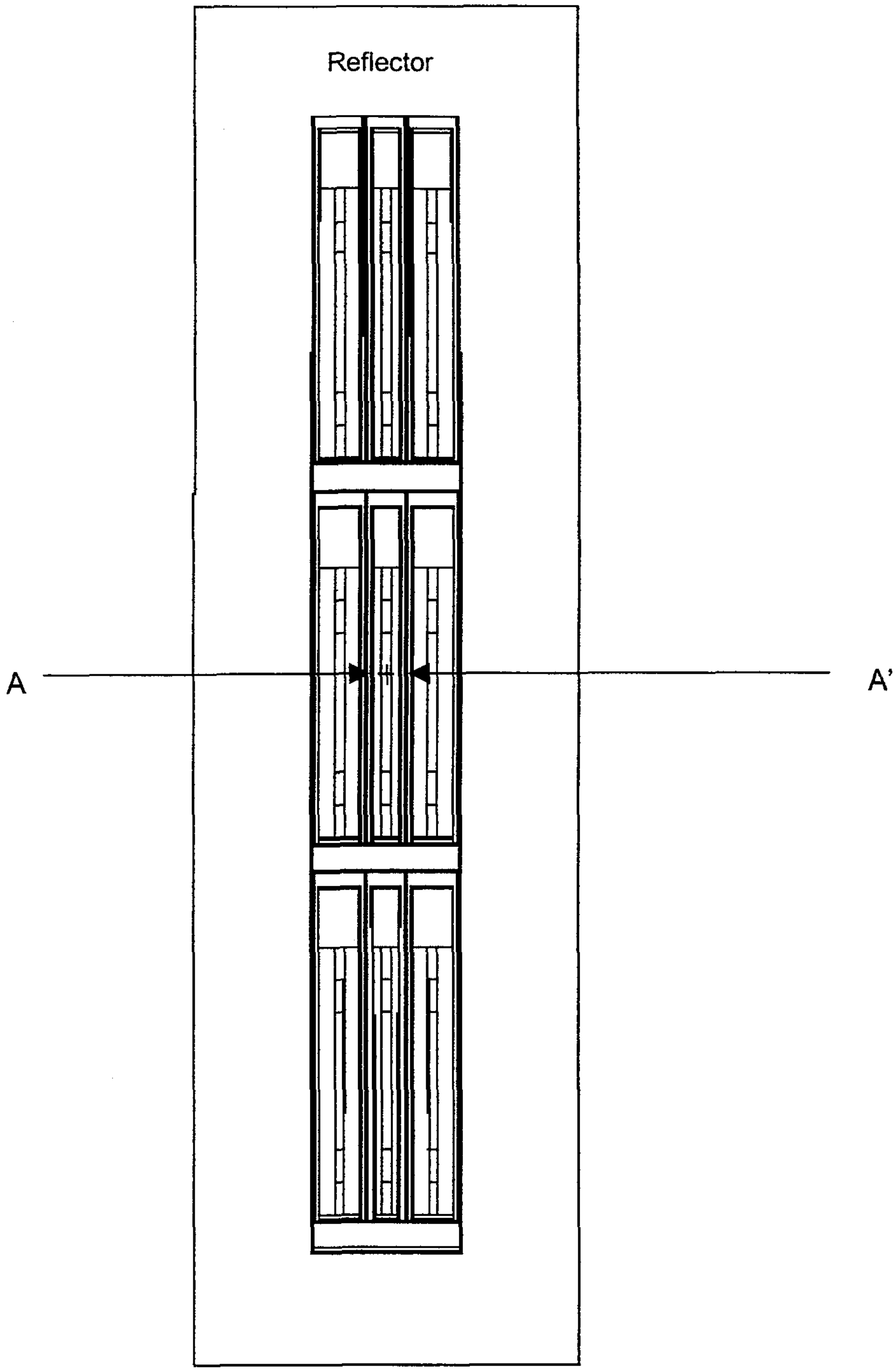

Figure 4
Axial View of MCNP Model for a Single DOE Canister with 90 TRIGA Fuel Elements – "Cross Shape" Fuel Arrangement

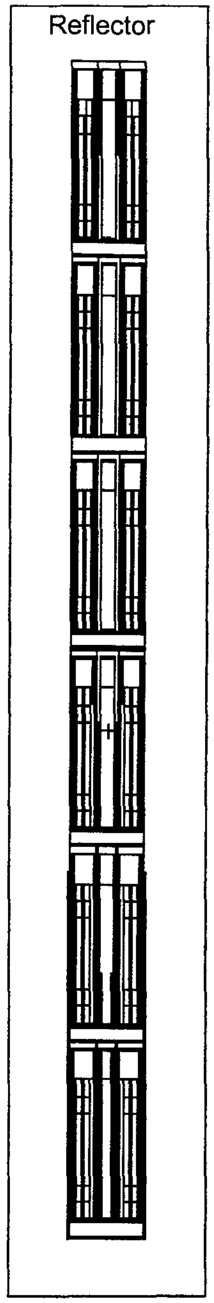

Figure 5
Axial View of MCNP Model for 2 DOE Canister with 90 TRIGA Fuel Elements Placed End-to-end – Close Packed Fuel Arrangement

2.1.4.2 Regional Densities

Material specific densities used in this calculation are presented in Table 3.

Table 3
Material Number Densities Used in Models

NAME	ISOTOPE	atom/b-cm	ELEM SUM	MAT SUM	ITEM
92U	U235	0.000292			Fuel (6.0875 g/cc)
	U238	0.001152	0.00144336		
40Zr		0.035758	0.03575764		
1H		0.060788	0.06078798	0.0979884	
40Zr		0.042249	0.042249	0.042249	Zr rod (6.4 g/cc)
6C		0.115422	0.115422	0.115422	Graphite (2.3 g/cc)
1H		0.066872	0.066872	0.100309	Water (1.0 g/cc)
8O		0.033436	0.033436		
26Fe		0.057374	0.057374	0.086091	304 ss (7.92 g/cc)
24Cr		0.016933	0.016933		
28Ni		0.010000	0.010000		
25Mn		0.001785	0.001785		

2.1.5 Criticality Calculations

2.1.5.1 Calculational Methodology

The MCNP code (MCNP4B2, Monte Carlo N-Particle Transport Code System) was used to determine the k_{eff} for a single DOE canister filled with 90 stainless steel clad post-1964 TRIGA fuel elements at 5 fuel elements per can, 3 cans per bucket, 2 buckets per layer and three layers in a canister. Post 1964 TRIGA fuel elements were used because they have a greater amount of ^{235}U per element compared to elements from 1964 and before. The reactivity of a dry system was greatest when the fuel elements were close packed in a can. However, in the flooded system, the reactivity increased when the elements were arranged in a "cross" configuration that permits more effective moderation of the fuel elements. The canister was reflected with 12 inches of water to provide full reflection. Two canisters also were modeled end-to-end and reflected with 12 inches of water. The MCNP models used are depicted in Figures 1 through Figure 5.

2.1.5.2 Fuel Loading and Other Contents Optimization

Each DOE canister contains a maximum of 90 TRIGA fuel elements at 43.875 g ^{235}U per element, for a total 3.95 kilograms of ^{235}U per canister. The nominal TRIGA fuel element fissile material content specified in the ISF Contract (39g ^{235}U) was adjusted to account for variations in post-1964 fuel elements to provide the most reactive and bounding source term for criticality analysis. Manufacturing variations resulted in a higher uranium content and a greater H:Zr atom ratio. The total fissile loading for the configuration consisting of 2 DOE canisters placed end-to-end is 7.9 kilograms of ^{235}U. Cases were run for two different geometric configurations of the TRIGA fuel elements (see Figures 1 and 3), and for flooded and dry conditions inside the canisters as well as full water reflection. This fuel loading and these configurations address the maximum reactivity conditions for the DOE canister.

2.1.5.3 Criticality Results

The DOE canister will be loaded with 90 stainless steel clad post-1964 TRIGA fuel elements. The internal cavity of the DOE canister will normally be dry; however, cases were also run to address the potential for the DOE canister being flooded, although the likelihood of this occurring is considered extremely small. Additional cases were run for two DOE canisters loaded with 90 TRIGA fuel elements placed end-to-end. The single DOE canisters was reflected with 12 inches of water to provide full reflection. The two canister that were modeled end-to-end were also reflected with 12 inches of water.

For close packed fuel elements in a flooded container reflected with 12 of inches water (see Figures 1 and 2), the calculated $k_{eff} = 0.5183 \pm 0.0021$ (Case 1-1). If the container is not flooded but is reflected, the calculated $k_{eff} = 0.3717 \pm 0.0019$ (Case 1-2). If the 5 fuel elements in the can are arranged in a "cross" shape (see Figures 3 and 4), the calculated $k_{eff} = 0.5446 \pm 0.0024$ (Case 1-3) for the flooded and reflected system and drops to $k_{eff} = 0.3494 \pm 0.0019$ (Case 1-4) for the dry DOE canisters with full reflection.

For 2 DOE canisters placed end-to-end, the calculated k_{eff} is 0.5178 ± 0.0023 (Case 1-5) for close packed fuel elements in a flooded container reflected with 12 inches of water. Figure 5 contains an axial view of the model, and Figure 1 is a radial view showing the close packed fuel arrangement. If the container is not flooded but is reflected, the calculated $k_{eff} = 0.3719 \pm 0.0018$ (Case 1-6). If two DOE canisters were placed end-to-end with the fuel elements arranged in a "cross" shape (see Figure 3) instead of in a close packed arrangement, it is anticipated that the k_{eff} values would be similar to that for the single canister. This conclusion is based on the fact that the k_{eff} values for a single DOE canister and those for 2 canisters placed end on end are nearly the same for the close packed fuel arrangement, and similar behavior is expected for the "cross" shape fuel arrangement.

These results indicate that a single DOE canister or 2 DOE canisters loaded with TRIGA fuel remains safely subcritical for all of the conditions described above. Table 1 summarizes the results of these calculations.

2.1.6 References

Characterization of TRIGA Fuel, N Tomsio, ORNL/Sub/86-22047/3, GA-C18542, October 1986.

CPP-603 TRIGA Fuel Stainless Steel Storage Can, Dwg. No. 090489, Original, September 12, 1989, Westinghouse Idaho Nuclear Company, Inc.

CPP-603 IFSF Fuel Caning Station Fuel Storage Bucket TRIGA, Dwg No. 448940 Sheet 1 Rev 4, Sheet 2 Rev B, Sheet 3 Rev b, August 21, 1995, Lockheed Idaho Technology Company.

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2.2 TRIGA ISF BASKETS SIDE-BY-SIDE

2.2.1 Criticality Evaluation

This evaluation was made with MCNP (MCNP4B2) to determine whether the TRIGA ISF fuel baskets will remain safely subcritical when they are passed side-by-side under dry conditions.

2.2.2 Discussion and Results

The MCNP code (MCNP4B2, Monte Carlo N-Particle Transport Code System) was used to determine the k_{eff} for the unmoderated and unreflected array of TRIGA ISF baskets. The k_{eff} value was used to demonstrate that TRIGA baskets passed side-by-side would be subcritical.

This calculation shows that the k_{eff} was 0.7884 (σ=0.0008) for an array consisting of two layers of 7 steel storage baskets under dry moderation conditions with no reflector. This results in a $k_{eff} + 2\sigma$ value of 0.7901, which is well below the subcritical k_{eff} limit of 0.95.

2.2.3 Spent Fuel Loading

Each TRIGA ISF basket contained 54 TRIGA fuel elements for a total 2.369 kilograms of ^{235}U per basket. The nominal TRIGA fuel element fissile material content specified in the ISF Contract (39g ^{235}U) was adjusted to account for variations in post-1964 fuel elements to provide the most reactive and bounding source term for criticality analysis. Manufacturing variations resulted in a higher uranium content and a greater H:Zr atom ratio. Two layers of baskets was modeled with a 7-basket hexagonal array per layer. These 14 baskets contain a total of 33.17 kilograms of ^{235}U.

2.2.4 Model Specification

2.2.4.1 Description of Calculational Model

The MCNP model for the unmoderated/unreflected 2x7 array of TRIGA ISF baskets is shown in Figures 6 and 7. Table 4 summarizes the modeled configurations.

There is a potential for baskets containing TRIGA fuel to be passed side-by-side during operations in the FPA. No water would be present during these operations, so the model assumes dry conditions within the baskets, between the baskets, and around the baskets. The analysis was done for an array consisting of two layers of 7 TRIGA fuel baskets.

Table 4
Modeled Configuration in TRIGA Baskets

Region	Documented Configuration		Modeled Configuration	
	Material (g/cc)	**Dimensions, cm**	**Material (g/cc)**	**Dimensions, cm**
Fuel Description				
Fuel (Zr rod)	Zr (6.49)	OR=0.28575 Length=38.1	Zr (6.49)	OR=0.28575 Length=38.1
Fuel (meat)	U-$ZrH_{1.7}$ (6.0875)	IR=0.3175 OR=1.82245	U-$ZrH_{1.7}$ (6.0875)	IR=0.3175 OR=1.82245
		Length=38.1		Length=38.1
Fuel Clad	SS-304 (7.93)	IR=1.82626 OR=1.87706	SS-304 (7.93)	IR=1.82626 OR=1.87706
		Length=55.4736		Length=55.4736
Graphite Cylinders				
Graphite Reflector	Graphite	OR=1.82245	Graphite (1.7)	OR=1.82245
		Length=2 @ 8.6868		Length=2 @ 8.6868
End Fittings				
End Fittings	SS	OR=irregular	SS-316 (8.0)	OR=1.82245
		Length=2 @ 9.0932		Length=2 @ 9.0932
Basket Description				
Basket		OR=21.3995		OR=21.3995
		Length=83.185		Length=83.185
Tubes (54)	SS-316 (8.0)	OR=2.2225 IR=2.05994	SS-316 (8.0)	OR=2.2225 IR=2.05994
	Pitch=5.08 cm	Length=74.295	Pitch=5.08 cm	Length=74.295
Lifting Plate		Thickness=6.985		Thickness=6.985
Bottom Plate		Thickness=3.175		Thickness=1.905

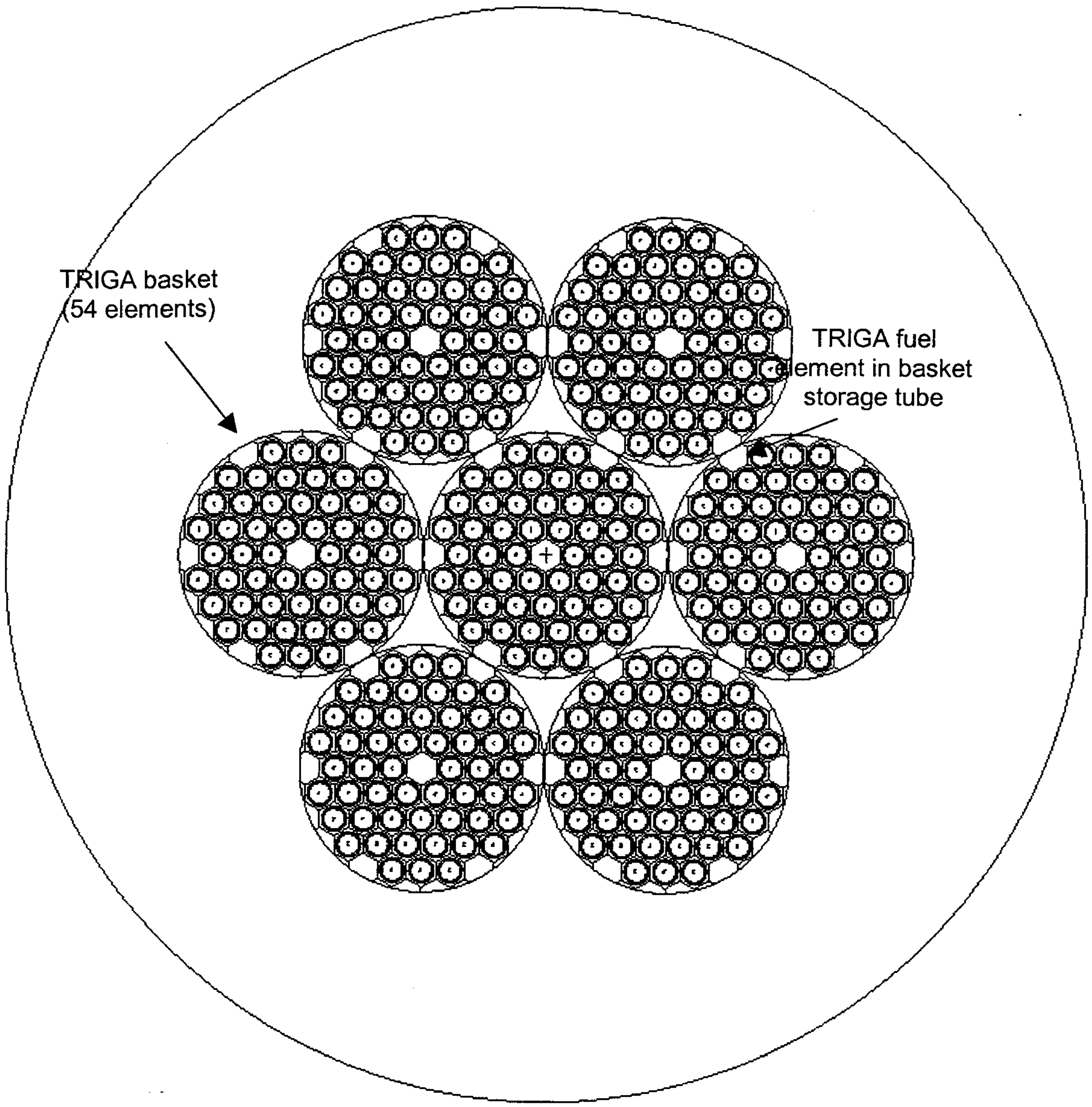

Figure 6
Radial View of MCNP Model for a 2x7 Array of TRIGA Fuel Baskets Under Dry Moderation Conditions in the FPA

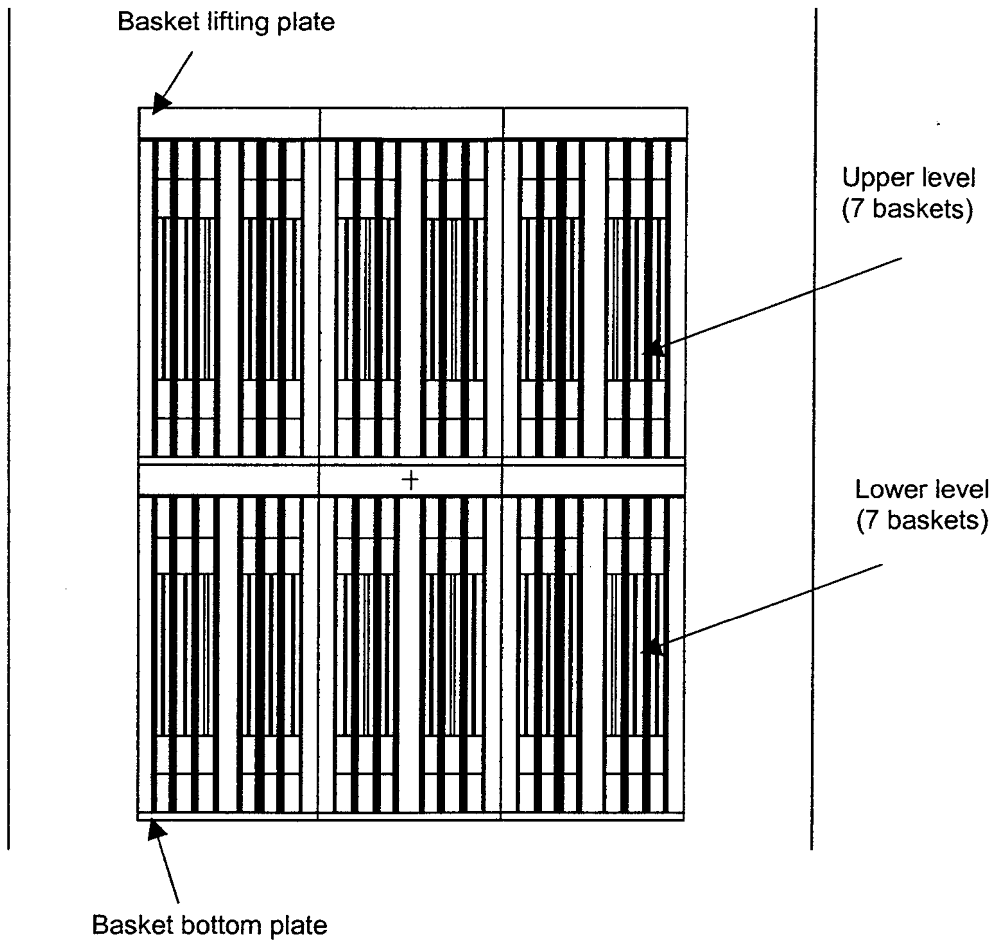

Figure 7
Axial View of MCNP Model for a 2x7 Array of TRIGA Fuel Baskets Under Dry Moderation Conditions in the FPA

2.2.4.2 Regional Densities

Table 5
Material Number Densities Used In Model

NAME	ISOTOPE	atom/b-cm	ELEM SUM	MAT SUM	ITEM
92U	U235	0.000292			Fuel (6.0875 g/cc)
	U238	0.001152	0.00144336		
40Zr		0.035758	0.03575764		
1H		0.060788	0.06078798	0.09798898	
40Zr		0.042843	0.04284336	0.04284336	Zr rod (6.49 g/cc)
6C		0.085235	0.08523495	0.08523495	Graphite (1.7 g/cc)
26Fe	Fe54	0.003506			304 ss (7.93 g/cc)
26Fe	Fe56	0.054509			
26Fe	Fe57	0.001248			
26Fe	Fe58	0.000166	0.05943004		
24Cr	Cr50	0.000758			
24Cr	Cr52	0.014622			
24Cr	Cr53	0.001658			
24Cr	Cr54	0.000413	0.01745038		
28Ni	Ni58	0.005277			
28Ni	Ni60	0.002018			
28Ni	Ni61	8.74E-05			
28Ni	Ni62	0.000278			
28Ni	Ni64	7.03E-05	0.00773002		
25Mn	Mn55	0.001739	0.00173851	0.08634895	
26Fe	Fe54	0.003334			316 ss (8.0 g/cc)
26Fe	Fe56	0.051826			
26Fe	Fe57	0.001187			
26Fe	Fe58	0.000158	0.05650403		
24Cr	Cr50	0.000684			
24Cr	Cr52	0.013198			
24Cr	Cr53	0.001496			
24Cr	Cr54	0.000373	0.01575132		
28Ni	Ni58	0.006725			
28Ni	Ni60	0.002571			
28Ni	Ni61	0.000111			

NAME	ISOTOPE	atom/b-cm	ELEM SUM	MAT SUM	ITEM
28Ni	Ni62	0.000354			
28Ni	Ni64	8.96E-05	0.00985043		
42Mo		0.001255	0.00125539		
25Mn	Mn55	0.001754	0.00175386		
14 Si		0.001715	0.00171536	0.08683039	

2.2.5 Criticality Calculations

2.2.5.1 Calculational Methodology

The MCNP code (MCNP4B2, Monte Carlo N-Particle Transport Code System) was used to determine the k_{eff} for the unmoderated and unreflected array of TRIGA ISF baskets. The k_{eff} value was used to demonstrate that TRIGA ISF baskets passed side-by-side would be safely subcritical.

2.2.5.2 Fuel Loading and Other Contents Optimization

Each TRIGA basket contained 54 TRIGA fuel elements for a total 2.369 kilograms of ^{235}U per basket. The nominal TRIGA fuel element fissile material content specified in the ISF Contract (39g ^{235}U) was adjusted to account for variations in post-1964 fuel elements to provide the most reactive and bounding source term for criticality analysis. Manufacturing variations resulted in a higher uranium content and a greater H:Zr atom ratio. An array of 2x7 baskets was modeled, which contain a total of 33.17 kilograms of ^{235}U.

2.2.5.3 Criticality Results

This calculation shows that the k_{eff} was 0.7884 (σ=0.0008) for an array consisting of two layers of 7 steel storage baskets under dry moderation conditions with no reflector. This results in a $k_{eff} + 2\sigma$ value of 0.7901, which is well below the subcritical k_{eff} limit of 0.95. These conditions conservatively bound a configuration consisting of baskets passed side-by-side.

2.2.6 References

Characterization of TRIGA Fuel, N Tomsio, ORNL/Sub/86-22047/3, GA-C18542, October 1986.

2.3 TRIGA FUEL IN STORAGE VAULT

2.3.1 Criticality Evaluation

An analysis was performed to show that the TRIGA fuel will be critically safe when put into the ISF storage vault.

2.3.2 Discussion and Results

MCNP (MCNP4B2) calculations were performed to determine the k_{eff} of an infinite array of TRIGA fuel canisters in the storage vault configuration. Analyses were made with various combinations of water moderation inside and outside the storage tubes. The maximum $k_{eff} + 2\sigma$ of 0.8418 was found with water inside the storage tubes and none outside the tubes. Table 6 summarizes the results of these calculations. The most reactive case is with water in the storage tubes and no water between tubes.

Table 6
k_{eff} for Infinite Array of TRIGA Fuel
Contained in Storage Canisters in the ISF Storage Vault

MCNP Case	Moderator in Tube	Moderator Between Tubes	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$
6-1	yes	Yes	0.8314 ± 0.0020	0.8354
6-2	Yes	No	0.8372 ± 0.0023	0.8418
6-3	No	No	0.7439 ± 0.0021	0.7481

2.3.3 Spent Fuel Loading

Each TRIGA fuel assembly used in these calculations contained 43.875 grams of ^{235}U. The nominal TRIGA fuel element fissile material content specified in the ISF Contract (39g ^{235}U) was adjusted to account for variations in post-1964 fuel elements to provide the most reactive and bounding source term for criticality analysis. Manufacturing variations resulted in a higher uranium content and a greater H:Zr atom ratio. There are 108 fuel assemblies per canister, 54 for assemblies per basket, and 2 baskets per canister.

2.3.4 Model Specification

2.3.4.1 Description of Calculational Model

The MCNP model of the TRIGA fuel in the vault storage tubes is shown in Figures 8 through 10. Reflecting the model of a single tube on 4 sides forms an infinite array. Table 7 summarizes the modeled configuration. The k_{eff} of the system was found for all combinations of water moderation in the storage tubes and around the storage tubes. One case was also run with no water moderation.

Table 7
Modeled Configuration in Storage Tubes

Region	Documented Configuration		Modeled Configuration	
	Material (g/cc)	Dimensions, cm	Material (g/cc)	Dimensions, cm
Fuel Description				
Fuel (Zr rod)	Zr (6.49)	OR=0.28575 Length=38.1	Zr (6.4)	OR=0.28575 Length=38.1
Fuel (meat)	U-ZrH$_{1.7}$ (6.0875)	IR=0.3175 OR=1.82245	U-ZrH$_{1.7}$ (6.0875)	IR=0.3175 OR=1.82245
		Length=38.1		Length=38.1
Fuel Clad	SS-304 (7.92)	IR=1.82626 OR=1.87706	SS-304 (7.92)	IR=1.82245 OR=1.87325
		Length=55.4736		Length=55.4736
Graphite Cylinders				
Graphite Reflector	Graphite	OR=1.82245	Graphite (2.3)	OR=1.82245
		Length=2 @ 8.6868		Length=2 @ 8.6868
End Fittings				
End Fittings	SS	OR=irregular	Void	OR=1.82245
		Length=2 @ 9.0932		Length=2 @ 9.0932
Basket Description				
Basket		OR=21.3995		**OR=21.3995**
		Length=83.185		Length=83.185
Tubes (54)	SS-316 (7.92)	OR=2.2225 IR=2.05994	SS-316 (7.92)	OR=2.2225 IR=2.05994
	Pitch=5.08 cm	Length=74.295	Pitch=5.08 cm	Length=74.295
Lifting Plate		Thickness=6.985		Thickness=6.985
Bottom Plate		Thickness=3.175		Thickness=1.905

Canister				
Canister Shell	SS-316 (7.92)	IR=21.9075 OR=22.86	SS-316 (7.92)	IR=22.027 OR=22.86
		$Top_{Thickness}$=1.27 $Bottom_{Thickness}$=1.27		$Top_{Thickness}$ =1.271 $Bottom_{Thickness}$ =1.27
Steel Plug				
Cylinder	SS-316 (7.92)	OR=22.02656 Thickness=25.4	SS-316 (7.92)	OR=22.02656 Thickness=25.4
Storage Tube				
Tube Shell	C. Steel (7.82)	IR=24.4475 OR=25.4	C. Steel (7.82)	IR=24.4475 OR=25.4
		$Total_{Length}$=607.06 $Bottom_{Thickness}$=5.08		$Total_{Length}$=607.06 $Bottom_{Thickness}$=5.08
		$Top_{Thickness}$=13.97 $OR_{s\ plug}$=25.4		$Top_{Thickness}$=13.97 $OR_{s\ plug}$=25.4
Concrete Top	Concrete (2.3)	OR=22.4475 Conc $Plug_{Thickness}$=62.23	Concrete (2.3)	OR=22.4475 Conc $Plug_{Thickness}$=62.23
Concrete Pedestal				
Concrete Pedestal	Concrete (2.3)	OR=25.4 Thickness=3.81	Concrete (2.3)	OR=25.4 Thickness=3.81
Concrete Foundation				
Concrete Foundation	Concrete (2.3)	Thickness=91.44	Concrete (2.3)	Thickness=91.44
Reflector				
Reflector	Water (1.0)	Thickness=35.56	Water (1.0)	Thickness=35.56

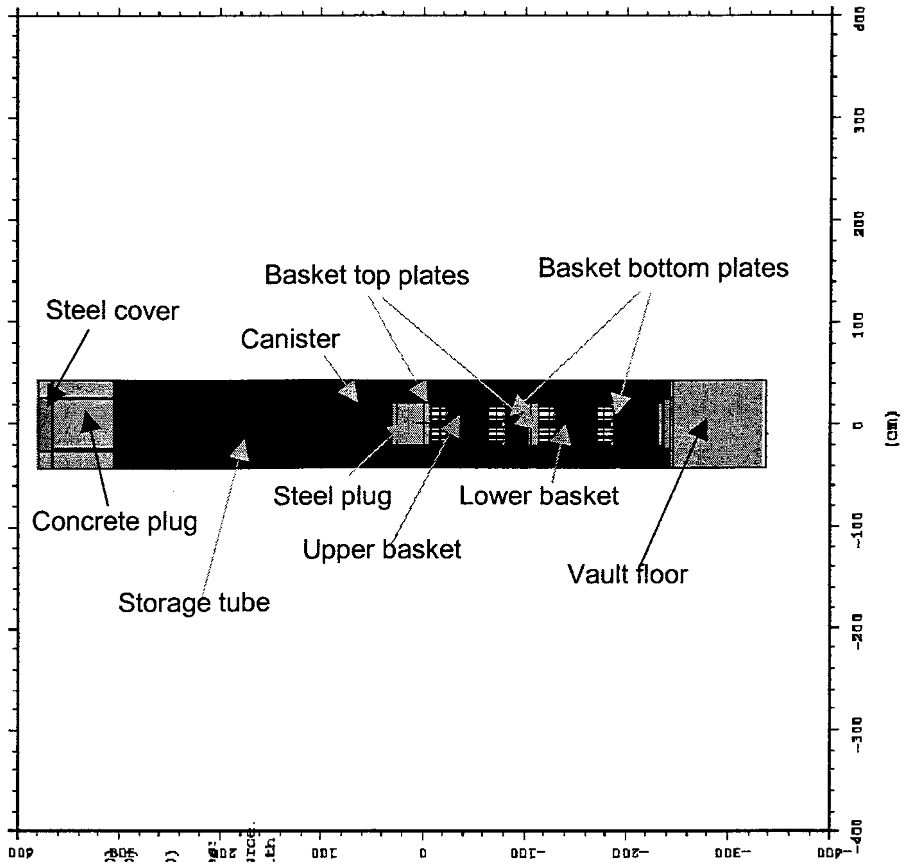

Figure 8
MCNP Model, Cut parallel to the Longitudinal Axis of TRIGA Canister in Storage Tube in Storage Vault, Model Reflected on 4 Sides to Represent an Infinite Array

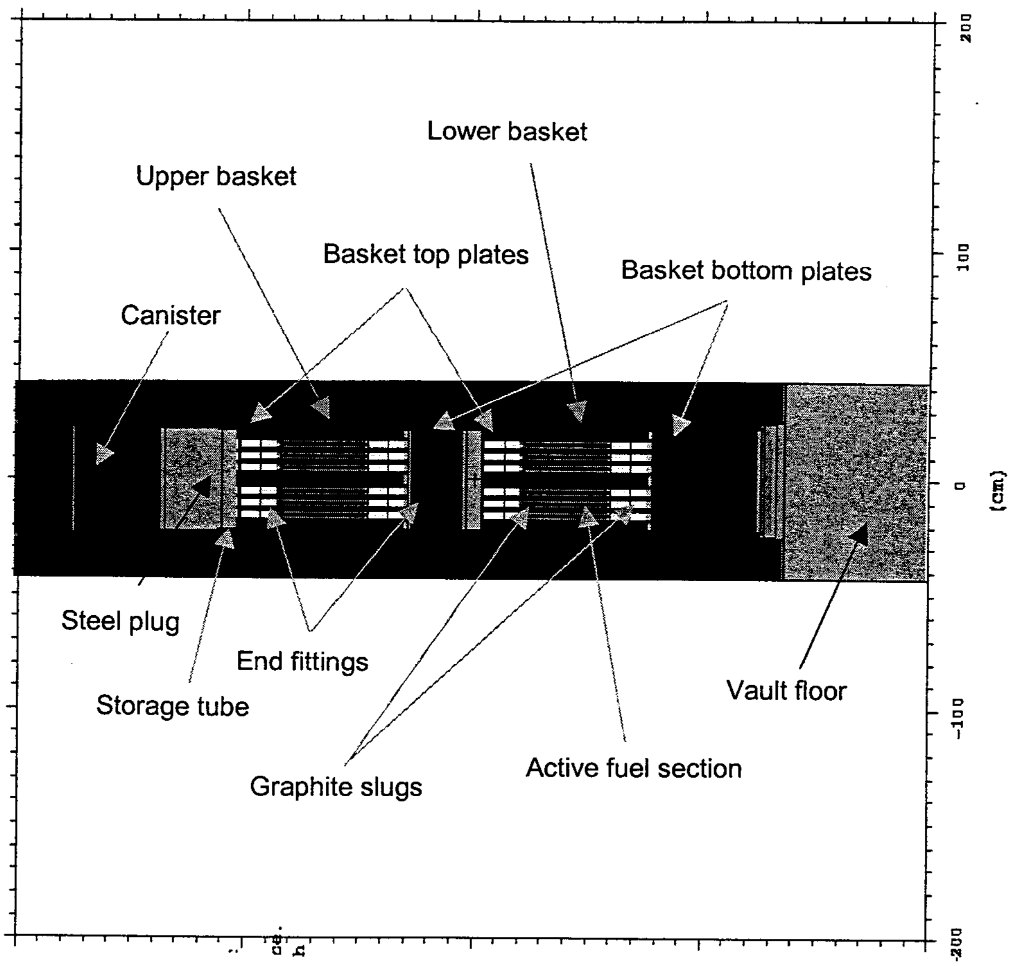

Figure 9
Enlarged View of MCNP Model, Cut parallel to the Longitudinal Axis of TRIGA Canister in Storage Tube in Storage Vault, Model Reflected on 4 Sides to Represent an Infinite Array

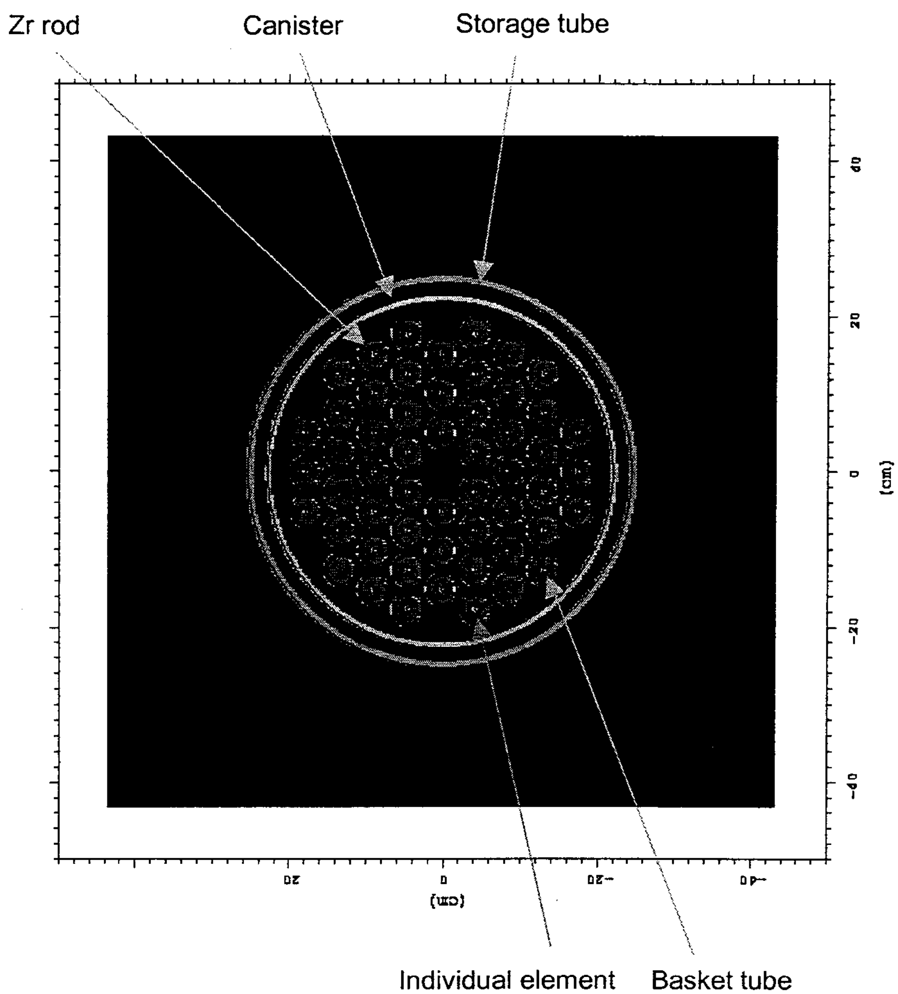

Figure 10
MCNP Model, Transverse Cut through TRIGA Fuel Canister in Storage Tube in Storage Vault, Model Reflected on 4 Sides to Represent an Infinite Array

2.3.4.2 Regional Densities

Table 8
Material Compositions Used

U-$ZrH_{1.7}$	density (g/cc)=	6.08748
		atom density
material	atom fraction	(atoms/b-cm)
hydrogen	6.20355E-01	6.07876E-02
zirconium	3.64913E-01	3.57571E-02
U-238	1.17540E-02	1.15175E-03
U-235	2.97600E-03	2.91612E-04
	atom dens. =	9.79881E-02
Water	density (g/cc)=	1.00000E+00
		atom density
material	atom fraction	(atoms/b-cm)
hydrogen	6.66666E-01	6.68726E-02
oxygen	3.33333E-01	3.34363E-02
	atom dens. =	1.00309E-01
316 SS	density (g/cc)=	7.92000E+00
		atom density
	material	(atoms/b-cm)
	Fe	5.59400E-02
	Cr	1.55900E-02
	Ni	9.75000E-03
	Mo	1.24000E-03
	Mn-55	1.74000E-03
	Si	1.70000E-03
	atom dens. =	8.59600E-02
Carbon	density (g/cc)=	2.30000E+00
		atom density
	material	(atoms/b-cm)
	C	1.15422E-01
	atom dens. =	1.15422E-01

304 SS	density (g/cc)=	7.92000E+00
		atom density
material	atom fraction	(atoms/b-cm)
Fe	6.66428E-01	5.73741E-02
Cr	1.96688E-01	1.69333E-02
Ni	1.16154E-01	9.99995E-03
Mn-55	2.07291E-02	1.78461E-03
	atom dens. =	8.60919E-02
Zirconium	density (g/cc)=	6.40000E+00
		atom density
material	atom fraction	(atoms/b-cm)
Zirconium	1.00000E+00	4.22490E-02
	atom dens. =	4.22490E-02
Concrete	density (g/cc)=	2.30000E+00
		atom density
	material	(atoms/b-cm)
	H	1.37400E-02
	O-16	4.60600E-02
	Si	1.66200E-02
	Al-27	1.75000E-03
	Na-23	1.75000E-03
	Ca	1.52000E-03
	Fe	3.50000E-04
	atom dens. =	8.17900E-02
C-Steel	density (g/cc)=	7.82000E+00
		atom density
	material	(atoms/b-cm)
	Fe	8.39000E-02
	C-12	1.96000E-03
	atom dens. =	8.58600E-02

2.3.5 Criticality Calculations

2.3.5.1 Calculational Methodology

The MCNP code (MCNP4B2, Monte Carlo N-Particle Transport Code System) was used to determine the k_{eff} for an infinite array of TRIGA fuel canisters in vault storage tubes with a square 34 inch pitch (current vault design dimensions). The MCNP model used is depicted in Figures 8 through 10.

Figure 10 is a transverse cut through the model. In the case shown, the storage tube is flooded with water and there is water in between storage locations. The infinite array is formed by reflecting surfaces on all four sides of the figure shown. The vault concrete floor and ceiling of the model can be seen in Figure 8.

2.3.5.2 Fuel Loading and Other Contents Optimization

Each TRIGA fuel assembly used in these calculations contained 43.875 grams of ^{235}U. The nominal TRIGA fuel element fissile material content specified in the ISF Contract (39g ^{235}U) was adjusted to account for variations in post-1964 fuel elements to provide the most reactive and bounding source term for criticality analysis. Manufacturing variations resulted in a higher uranium content and a greater H:Zr atom ratio. There are 108 fuel assemblies per canister, i.e., 54 assemblies per basket and 2 baskets per canister for a total of 4.74 kg ^{235}U.

2.3.5.3 Criticality Results

MCNP (MCNP4B2) calculations were performed to determine the k_{eff} of an infinite array of TRIGA fuel in the storage vault configuration. Analyses were made with various combinations of water moderation inside and outside the storage tubes. The maximum $k_{eff} + 2\sigma$ of 0.8418 was found with water inside the storage tubes and none outside the tubes.

2.3.6 References

Characterization of TRIGA Fuel, N Tomsio, ORNL/Sub/86-22047/3, GA-C18542, October 1986.

2.4 TRIGA CANISTERS

2.4.1 Criticality Evaluation

This evaluation was made with MCNP (MCNP4B2) to determine whether a single ISF canister containing TRIGA fuel elements is safely subcritical and if two TRIGA canisters will remain subcritical if they are passed side-by-side or end-to-end.

2.4.2 Discussion and Results

MCNP (MCNP4B2) calculations show that a single dry ISF canister loaded with 108 TRIGA fuel elements with a 1-inch water reflector is subcritical, with a $k_{eff} + 2\sigma$ equal to 0.5741. The use of nominal reflection (equivalent to one inch of water) to allow for minor reflection from the building surfaces and equipment is standard practice. If a single dry canister is reflected with 12-inches of water, the $k_{eff} + 2\sigma$ value increases to 0.6063, which is also subcritical. A 12-inch water reflector was used to represent the maximum standard practice reflection for the canister.

Two dry canisters loaded with 108 TRIGA fuel elements each and passed side-by-side will remain safely subcritical, with a $k_{eff} + 2\sigma$ equal to 0.6056 for a 1-inch water reflector. Two dry canisters passed end-to-end with a 1-inch water reflector also remain subcritical, with a $k_{eff} + 2\sigma$ value of 0.5755. If two dry canisters passed end-to-end are reflected with 12 inches of water, the $k_{eff} + 2\sigma$ value increases to 0.6060, which is also subcritical.

If two canisters passed side-by-side are assumed to be flooded and reflected with 12 inches of water, the $k_{eff} + 2\sigma$ value increases to 0.8405, which is still subcritical. The SA and FPA design minimizes the possibility for any appreciable amount of water to enter these areas. Therefore, conditions analyzed in the flooded and reflected scenario are considered unlikely events to occur in either the SA or the FPA.

The results of these calculations are summarized in Table 9.

Table 9
Summary of Criticality Results

MCNP Case	Configuration	Canister Flooded	Water Reflector	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$
9-1	Single Canister	No	1-inch	0.5725 ± 0.0008	0.5741
9-2	Single Canister	No	12-inches	0.6047 ± 0.0008	0.6063
9-3	2 Side-by-Side	No	1-inch	0.6040 ± 0.0008	0.6056
9-4	2 Side-by-Side	Yes	12-inches	0.8389 ± 0.0008	0.8405
9-5	2 End-to-End	No	1-inch	0.5739 ± 0.0008	0.5755
9-6	2 End-to-End	No	12-inches	0.6044 ± 0.0008	0.6060

2.4.3 Spent Fuel Loading

The nominal TRIGA fuel element fissile material content specified in the ISF Contract (39g ^{235}U) was adjusted to account for variations in post-1964 fuel elements to provide the most reactive and bounding source term for criticality analysis. Manufacturing variations resulted in a higher uranium content and a greater H:Zr atom ratio. A single TRIGA ISF canister contains 108 TRIGA fuel elements for a total of 4.74 kilograms of ^{235}U. Two canisters passed side-by-side or end-to-end contains a total of 9.48 kilograms of ^{235}U for each configuration.

2.4.4 Model Specification

2.4.4.1 Description of Calculational Model

The MCNP model for a single dry TRIGA ISF canister with a 1-inch water reflector is shown in Figures 11 and 12. The MCNP model for a single dry TRIGA canister with a 12-inch water reflector is shown in Figures 13 and 14. The MCNP model for 2 dry TRIGA canisters passed side-by-side with a 1-inch water reflector is shown in Figures 15 and 16. Note that a reflective surface was used on one side of the canister to simulate 2 canisters side-by-side. The MCNP model for 2 flooded TRIGA canisters passed side-by-side with a 12-inch water reflector is shown in Figures 17 and 18. Figure 19 shows an axial view of the model for 2 dry TRIGA canisters passed end-to-end with a 1-inch water reflector. The radial view for this model is identical to Figure 11, and is therefore not repeated as a separate figure. An axial view of the MCNP model for 2 dry TRIGA canisters passed end-to-end with a 12-inch water reflector is shown in Figure 20. The radial view for this model is identical to Figure 13, and is therefore not repeated as a separate figure. Table 10 summarizes the modeled configuration.

Table 10
Modeled Configuration in Canister

Region	Documented Configuration		Modeled Configuration	
	Material (g/cc)	**Dimensions, cm**	**Material (g/cc)**	**Dimensions, cm**
Fuel Description				
Fuel (Zr rod)	Zr (6.49)	OR=0.28575 Length=38.1	Zr (6.49)	OR=0.28575 Length=38.1
Fuel (meat)	U-$ZrH_{1.7}$ (6.0875)	IR=0.3175 OR=1.82245	U-$ZrH_{1.7}$ (6.0875)	IR=0.3175 OR=1.82245
		Length=38.1		Length=38.1
Fuel Clad	SS-304 (7.93)	IR=1.82626 OR=1.87706	SS-304 (7.93)	IR=1.82626 OR=1.87706
		Length=55.4736		Length=55.4736
Graphite Cylinders				
Graphite Reflector	Graphite	OR=1.82245	Graphite (1.7)	OR=1.82245
		Length=2 @ 8.6868		Length=2 @ 8.6868
End Fittings				
End Fittings	SS	OR=irregular	SS-316 (8.0)	OR=1.82245
		Length=2 @ 9.0932		Length=2 @ 9.0932
Basket Description				
Basket		OR=21.3995		OR=21.3995
		Length=83.185		Length=83.185
Tubes (54)	SS-316 (8.0)	OR=2.2225 IR=2.05994	SS-316 (8.0)	OR=2.2225 IR=2.05994
	Pitch=5.08	L=74.295	Pitch=5.08	L=74.295
Lifting Plate		Thickness=6.985		Thickness=6.985
Bottom Plate		Thickness=3.175		Thickness=1.905
Canister				
Canister Shell	SS-316 (8.0)	IR=21.9075 OR=22.86	SS-316 (8.0)	IR=22.027 OR=22.86

		$Top_{Thickness}$=1.27 $Bottom_{Thickness}$=1.27		$Top_{Thickness}$ =1.271 $Bottom_{Thicknes}$=1.27
Steel Plug				
Cylinder	SS-316 (8.0)	OR=22.02656 Thickness=25.4	SS-316 (8.0)	OR=22.02656 Thickness=25.4
Reflector				
Reflector	None		Water (1.0)	Thickness=2.54 (or) Thickness=30.48

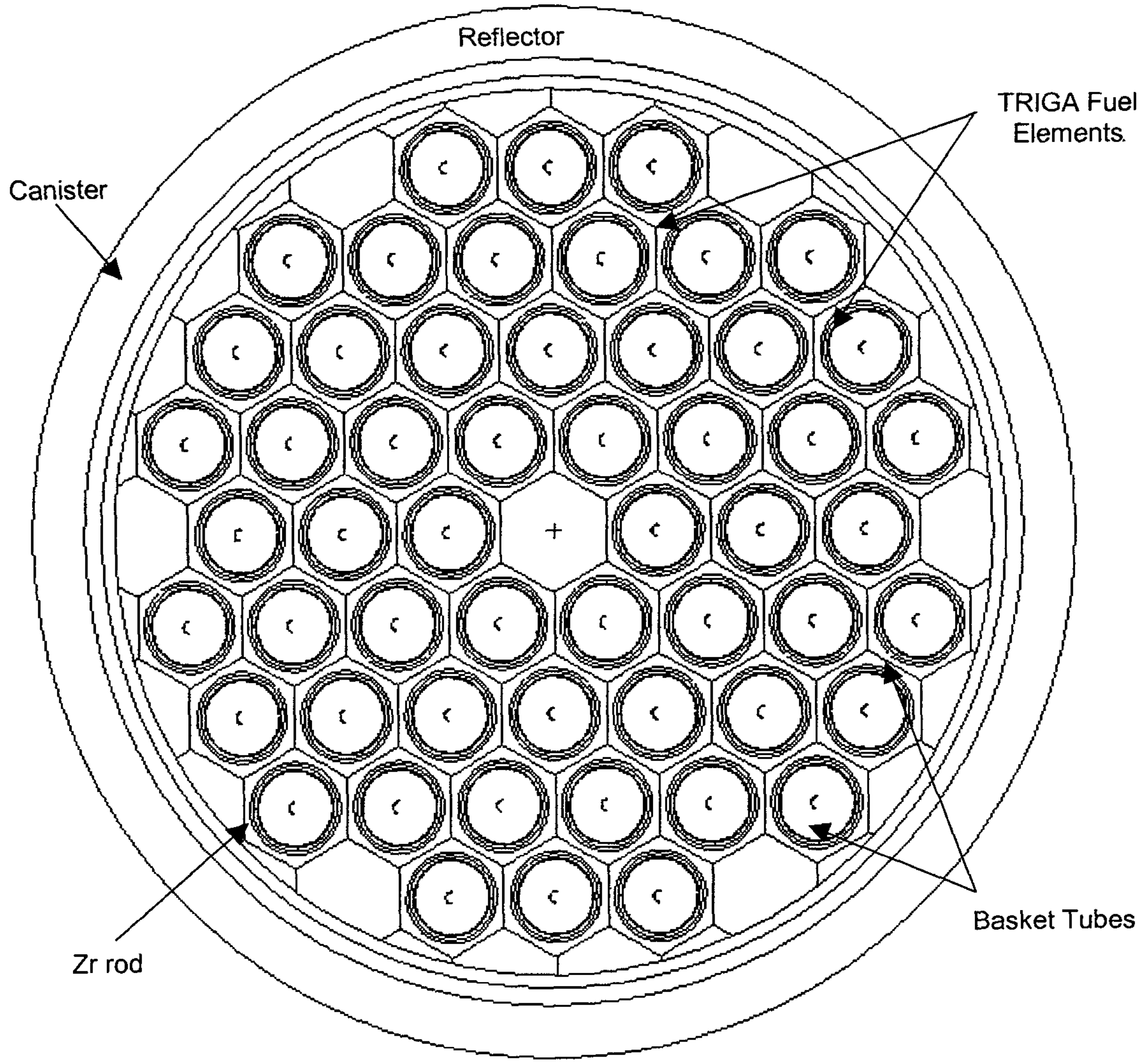

Figure 11
Radial View of MCNP Model for a Single TRIGA Canister Under Dry Moderation Conditions with 1 inch Water Reflection

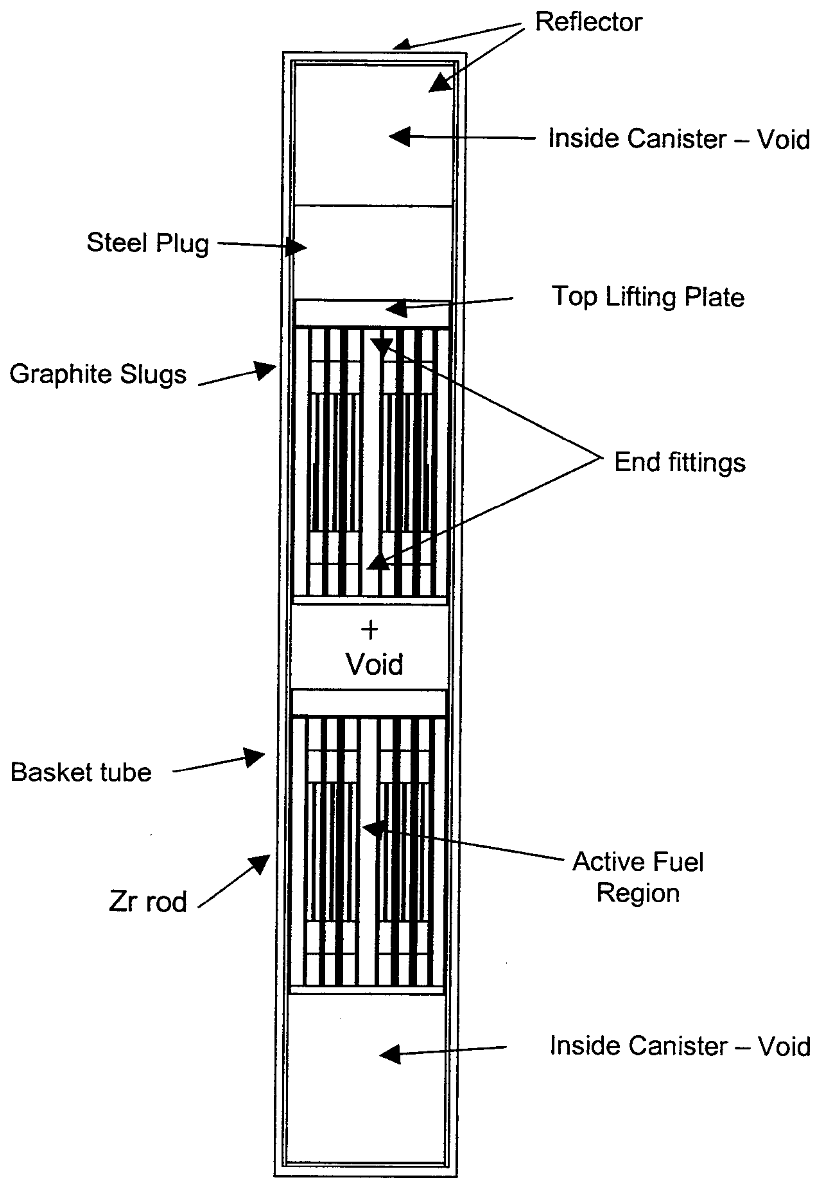

Figure 12
Axial View of MCNP Model for a Single TRIGA Canister Under Dry Moderation Conditions with 1 inch Water Reflection

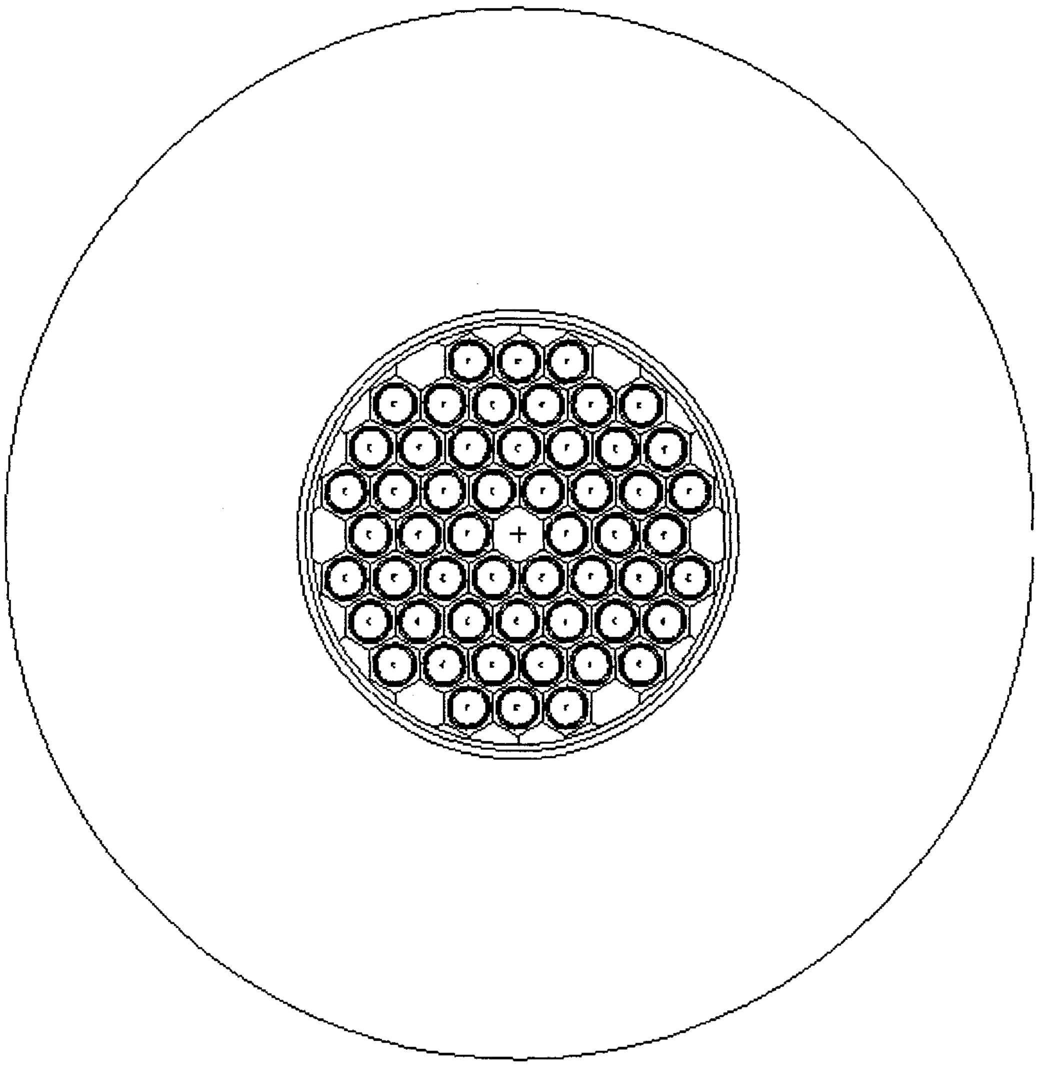

Figure 13
Radial View of MCNP Model for a Single TRIGA Canister Under Dry Moderation Conditions with 12 inches Water Reflection

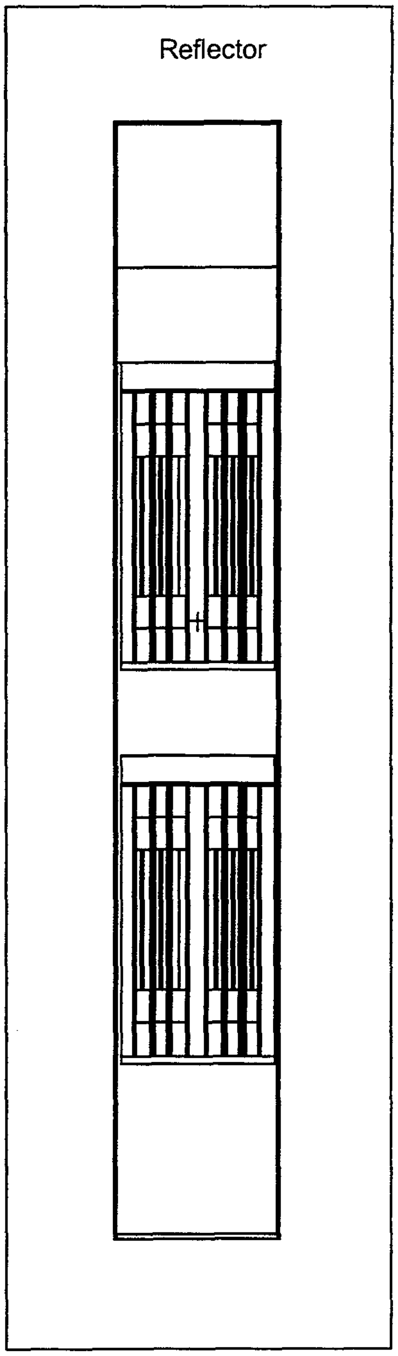

Figure 14
Axial View of MCNP Model for a Single TRIGA Canister Under Dry Moderation Conditions with 12 inches Water Reflection

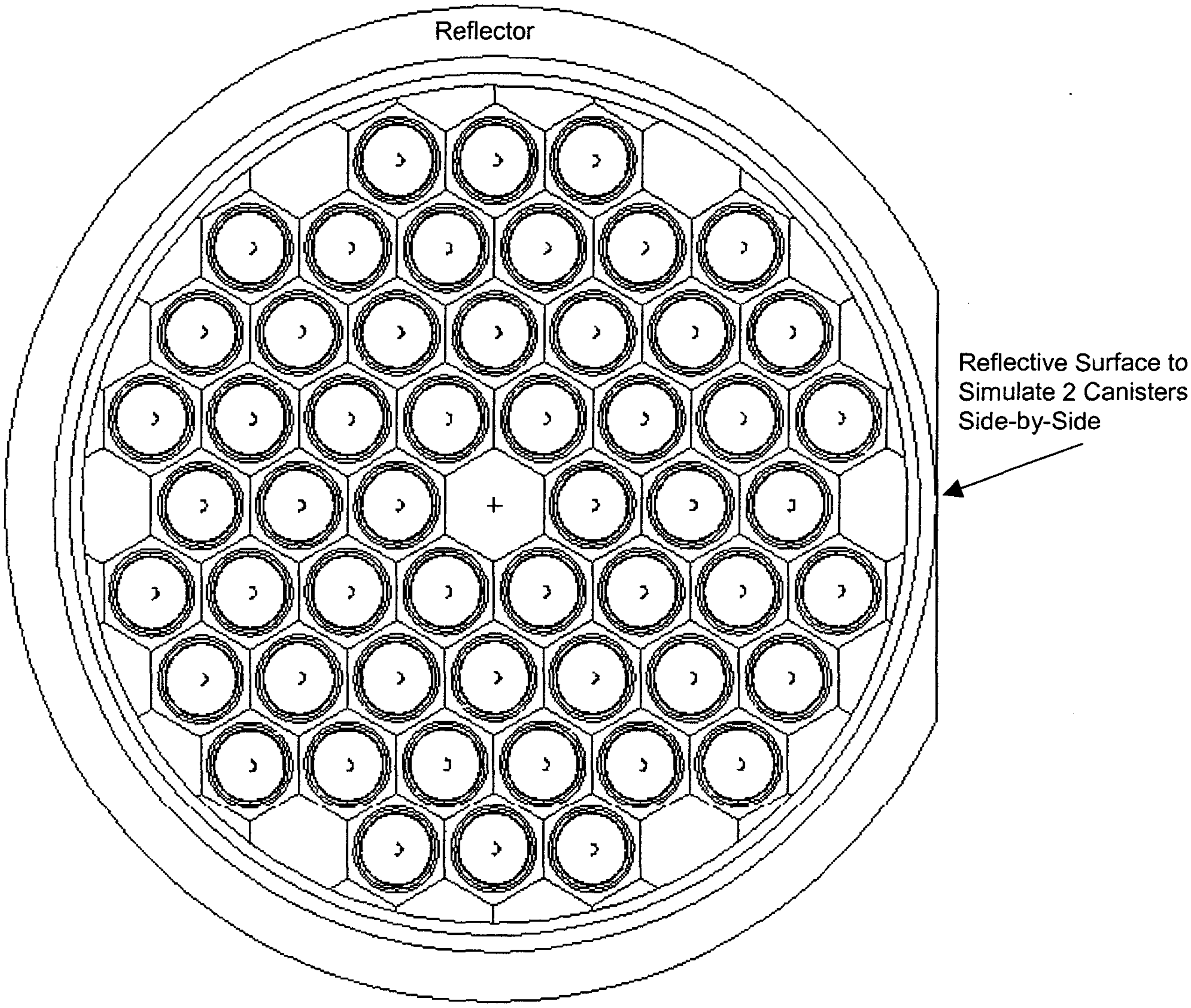

Figure 15
Radial View of MCNP Model for Two TRIGA Canisters Side-by-Side Under Dry Moderation Conditions with 1 inch Water Reflection

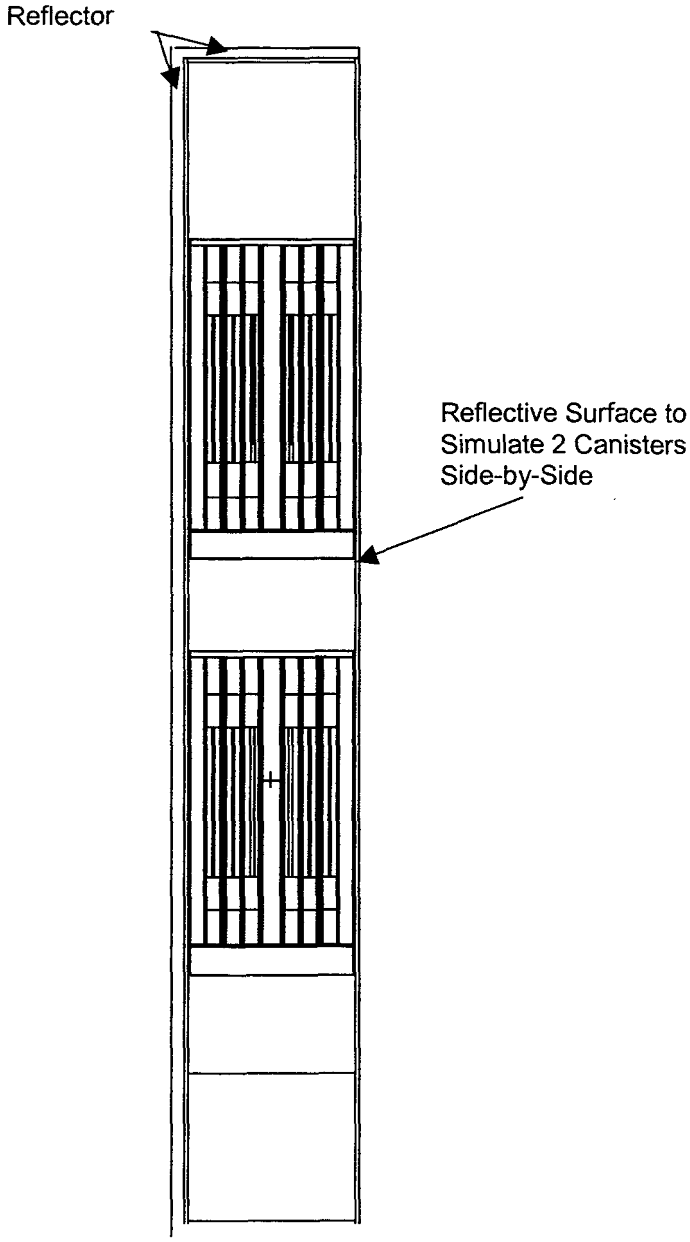

Figure 16
Axial View of MCNP Model for Two TRIGA Canisters Side-by-Side Under Dry Moderation Conditions with 1 inch Water Reflection

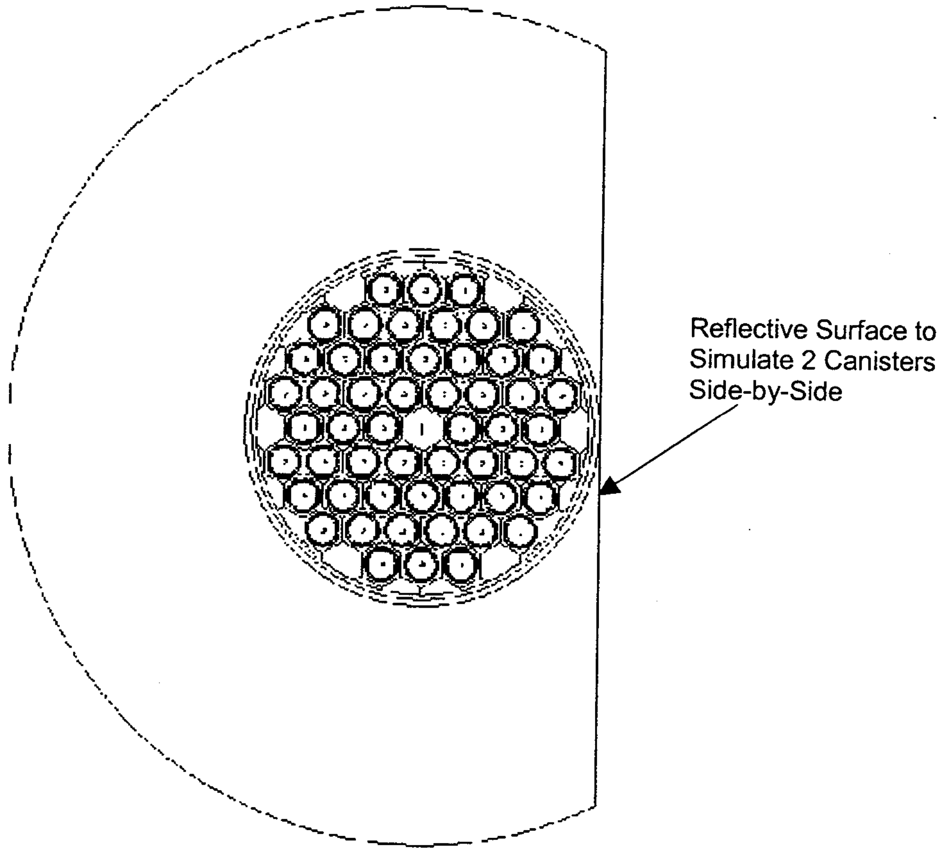

Figure 17
Radial View of MCNP Model for Two Flooded TRIGA Canisters Placed Side-by-Side with 12 inches Water Reflection

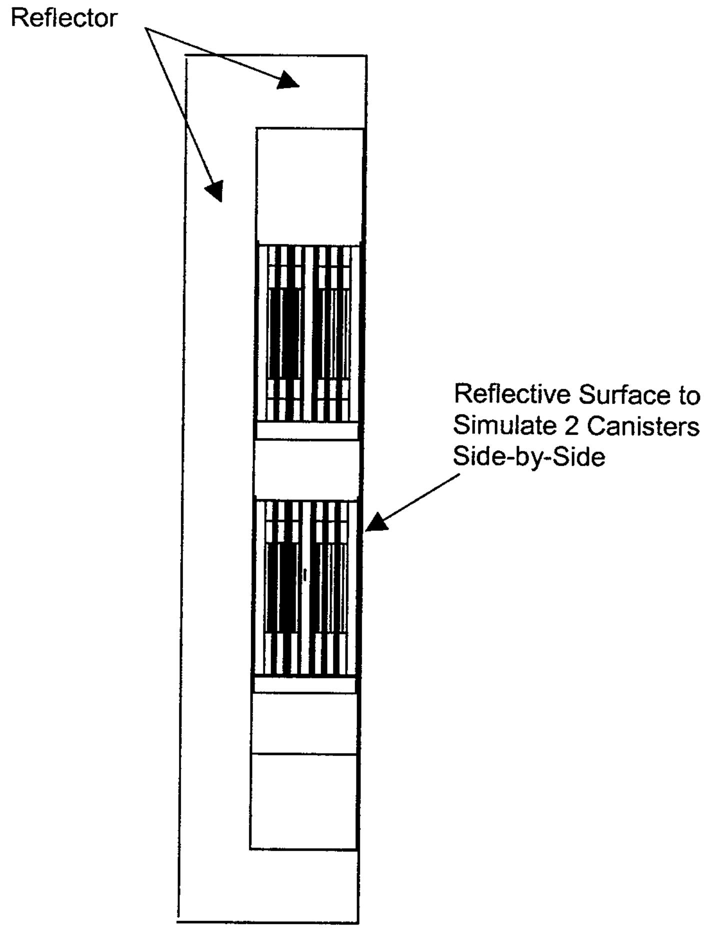

Figure 18
Axial View of MCNP Model for Two Flooded TRIGA Canisters Placed Side-by-Side with 12 inches Water Reflection

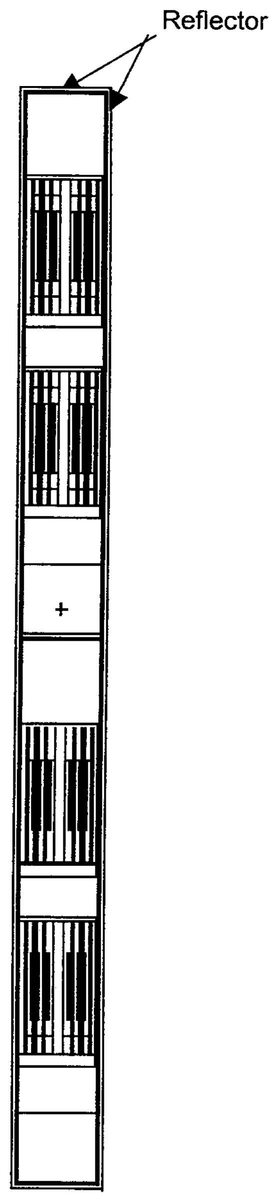

Figure 19
Axial View of MCNP Model for Two TRIGA Canisters End-to-End Under Dry Moderation Conditions with 1 inch Water Reflection

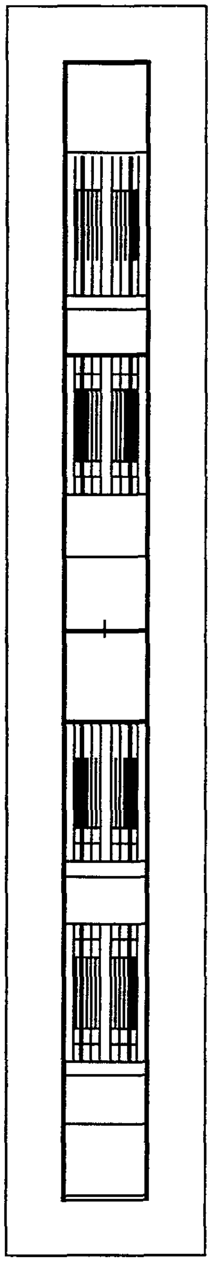

Figure 20
Axial View of MCNP Model for Two TRIGA Canisters End-to-End Under Dry Moderation Conditions with 12 inches Water Reflection

2.4.4.2 Regional Densities

Table 11
Material Number Densities Used In Models

NAME	ISOTOPE	Atom/b-cm	ELEM SUM	MAT SUM	ITEM
92U	U235	0.000292			Fuel (6.0875 g/cc)
	U238	0.001152	0.00144336		
40Zr		0.035758	0.03575764		
1H		0.060788	0.06078798	0.09798898	
40Zr		0.042843	0.04284336	0.04284336	Zr rod (6.49 g/cc)
6C		0.085235	0.08523495	0.08523495	Graphite (1.7 g/cc)
1H		0.066872	0.066872	0.100309	Water (1.0 g/cc)
8O		0.033436	0.033436		
26Fe	Fe54	0.003506			304 ss (7.93 g/cc)
26Fe	Fe56	0.054509			
26Fe	Fe57	0.001248			
26Fe	Fe58	0.000166	0.05943004		
24Cr	Cr50	0.000758			
24Cr	Cr52	0.014622			
24Cr	Cr53	0.001658			
24Cr	Cr54	0.000413	0.01745038		
28Ni	Ni58	0.005277			
28Ni	Ni60	0.002018			
28Ni	Ni61	8.74E-05			
28Ni	Ni62	0.000278			
28Ni	Ni64	7.03E-05	0.00773002		
25Mn	Mn55	0.001739	0.00173851	0.08634895	
26Fe	Fe54	0.003334			316 ss (8.0 g/cc)
26Fe	Fe56	0.051826			
26Fe	Fe57	0.001187			
26Fe	Fe58	0.000158	0.05650403		
24Cr	Cr50	0.000684			
24Cr	Cr52	0.013198			

NAME	ISOTOPE	Atom/b-cm	ELEM SUM	MAT SUM	ITEM
24Cr	Cr53	0.001496			
24Cr	Cr54	0.000373	0.01575132		
28Ni	Ni58	0.006725			
28Ni	Ni60	0.002571			
28Ni	Ni61	0.000111			
28Ni	Ni62	0.000354			
28Ni	Ni64	8.96E-05	0.00985043		
42Mo		0.001255	0.00125539		
25Mn	Mn55	0.001754	0.00175386		
14 Si		0.001715	0.00171536	0.08683039	

2.4.5 Criticality Calculations

2.4.5.1 Calculational Methodology

The MCNP code (MCNP4B2, Monte Carlo N-Particle Transport Code System) was used to determine the k_{eff} for a single dry canister loaded with 108 TRIGA fuel elements, for two loaded canisters placed side-by-side and for two loaded canisters placed end-to-end. The dry canisters were nominally reflected with one inch of water as a standard practice to allow for minor reflection from the building surfaces and equipment. A single canister and two canisters placed end-to-end were also reflected by 12 inches of water. In addition, two flooded canisters placed side-by-side were reflected by 12 inches of water. The MCNP models used are depicted in Figure 11 through Figure 20.

2.4.5.2 Fuel Loading and Other Contents Optimization

A single TRIGA ISF canister contained 108 TRIGA fuel elements for a total of 4.74 kilograms of ^{235}U. Two canisters passed side-by-side or end-to-end contained a total of 9.48 kilograms of ^{235}U for each configuration. These fuel loadings and configurations address the maximum reactivity conditions for the TRIGA canister. The nominal TRIGA fuel element fissile material content specified in the ISF Contract (39g ^{235}U) was adjusted to account for variations in post-1964 fuel elements to provide the most reactive and bounding source term for criticality analysis. Manufacturing variations resulted in a higher uranium content and a greater H:Zr atom ratio.

2.4.5.3 Criticality Results

These calculations show that a single dry ISF canister loaded with 108 TRIGA fuel elements with a 1-inch water reflector is subcritical, with a $k_{eff}+2\sigma$ equal to 0.5741 (Case 9-1). The use of nominal reflection (equivalent to one inch of water) to allow for minor reflection from the building surfaces and equipment is standard practice. If a single dry canister is reflected with 12 inches of water, the $k_{eff}+2\sigma$ value increases to 0.6063 (Case 9-2), which is also safely subcritical. A 12-inch water reflector was used to represent a maximum reflection for the canister.

Two dry canisters loaded with 108 TRIGA fuel elements each and passed side-by-side with a 1-inch water reflector will remain safely subcritical, with a $k_{eff}+2\sigma$ equal to 0.6056 (Case 9-3). Two dry canisters passed end-to-end with a 1-inch water reflector also remain subcritical, with a $k_{eff}+2\sigma$ value of 0.5755 (Case 9-5). If two dry canisters passed end-to-end are reflected with 12 inches of water, the k_{eff} $+2\sigma$ value increases to 0.6060 (Case 9-6), which is also safely subcritical. Cases 9-5 and 9-6 provide an indication of the sensitivity of the effective neutron multiplication to the water reflector thickness.

If two canisters passed side-by-side are assumed to be flooded and reflected with 12 inches of water, the $k_{eff}+2\sigma$ value increases to 0.8405, which is still safely subcritical. The SA and FPA design minimizes the possibility for any appreciable amount of water to enter these areas. Therefore, conditions analyzed in the flooded and reflected scenario are considered unlikely events to occur in either the SA or the FPA. The results of these calculations are summarized in Table 9.

2.4.6 References

Characterization of TRIGA Fuel, N Tomsio, ORNL/Sub/86-22047/3, GA-C18542, October 1986.

2.5 TRIGA WITH THREE SIDES OF CONCRETE REFLECTION

2.5.1 Criticality Evaluation

A criticality evaluation was performed to determine the maximum number of TRIGA fuel elements that can safely be handled in an uncontrolled, unconfined, and unmoderated condition in the ISF facility without exceeding criticality limits. In determining the maximum number of TRIGA fuel elements needed for critical conditions, the fuel was assumed to be reflected on three sides with concrete and reflected on three sides with one inch of water to account for minor reflection from the building surfaces and equipment.

2.5.2 Discussion and Results

These calculations show that the subcritical $k_{eff} + 2\sigma$ limit of 0.95 will be reached with 48 TRIGA fuel elements in a hexagonal array and 57 elements in a square pitch array. The results of these calculations are summarized in Table 12 and Figure 21.

Table 12
MCNP Calculated k_{eff} with TRIGA Fuel Elements in the Corner of a 36 inch Thick Concrete Cell with a One Inch of Water Reflector on the other Three Sides, Both Hexagonal and Square Pitch Arrays were Analyzed, The Fuel Pitch was 3.7542 cm (touching) in all Runs, No Moderation Present Between Elements

MCNP Case	Type of Array	Number of Fuel Elements	keff ± σ	keff + 2σ
12-1	Hexagonal	39	0.8721 ± 0.0010	0.8741
12-2	Hexagonal	46	0.9179 ± 0.0010	0.9199
12-3	Square	36	0.8135 ± 0.0009	0.8153
12-4	Square	49	0.8905 ± 0.0010	0.8925
12-5	Square	64	0.9549 ± 0.0009	0.9567

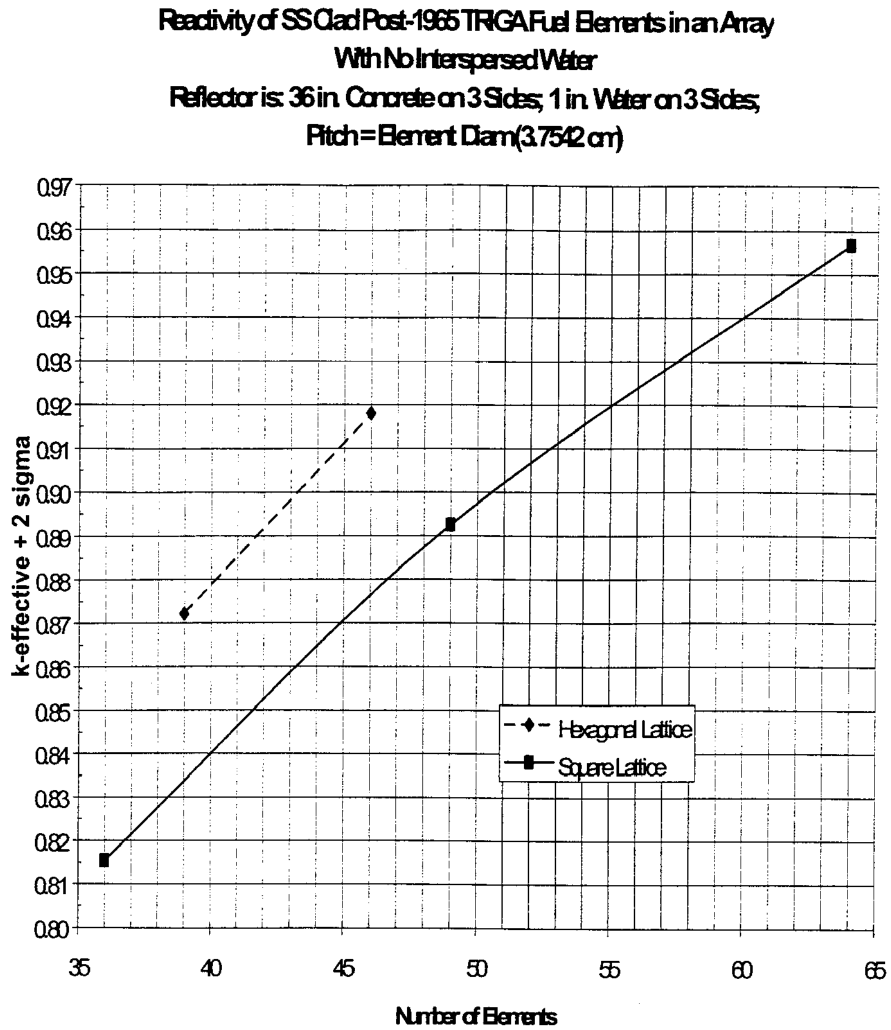

Figure 21
k_{eff} + 2σ for Arrays of TRIGA Fuel Elements

2.5.3 Spent Fuel Loading

Each TRIGA fuel with SS cladding assembly used in these calculations contained 43.875 grams of ^{235}U. The nominal TRIGA fuel element fissile material content specified in the ISF Contract (39g ^{235}U) was adjusted to account for variations in post-1964 fuel elements to provide the most reactive and bounding source term for criticality analysis. Manufacturing variations resulted in a higher uranium content and a greater H:Zr atom ratio.

2.5.4 Model Specification

2.5.4.1 Description of Calculational Model

Typical MCNP models of the unmoderated and reflected fuel assemblies are shown in Figures 22 through 24. Table 13 summarizes the modeled configuration. The number of assemblies was varied from problem to problem.

One model used was a hexagonal array of fuel elements that is as closely packed as possible. The other used a square pitch array with fuel packed as closely as possible. The dry array models were placed in the corner of 36-inch thick concrete walls and were closely reflected with one inch of water on the other boundaries of the array. The use of nominal reflection (equivalent to one inch of water) to allow for minor reflection from the building surfaces and equipment is standard practice.

Table 13
Modeled Configuration of TRIGA Fuel in Concrete Corner

Region	Documented Configuration		Modeled Configuration	
	Material (g/cc)	Dimensions, cm	Material (g/cc)	Dimensions, cm
Fuel Description				
Fuel (Zr rod)	Zr (6.49)	OR=0.28575 Length=38.1	Zr (6.49)	OR=0.28575 Length=38.1
Fuel (meat)	U-$ZrH_{1.7}$ (6.0875)	IR=0.3175 OR=1.82245	U-$ZrH_{1.7}$ (6.0875)	IR=0.3175 OR=1.82245
		Length=38.1		Length=38.1
Fuel Clad	SS-304 (7.93)	IR=1.82626 OR=1.87706	SS-304 (7.93)	IR=1.82626 OR=1.87706
		Length=55.4736		Length=55.4736
Graphite Cylinders				
Graphite Reflector	Graphite	OR=1.82245	Graphite (1.7)	OR=1.82245
		Length=2 @ 8.6868		Length=2 @ 8.6868
End Fittings				
End Fittings	SS	OR=irregular	SS-316 (8.0)	OR=1.82245
		Length=2 @ 9.0932		Length=2 @ 9.0932
Reflector				
Reflector	Concrete (2.3)	$Conc_{Thickness}$=121.92	Concrete (2.3) Water (1.0)	$Conc_{Thicknes}$=91.44 $Water_{Thickness}$=2.54

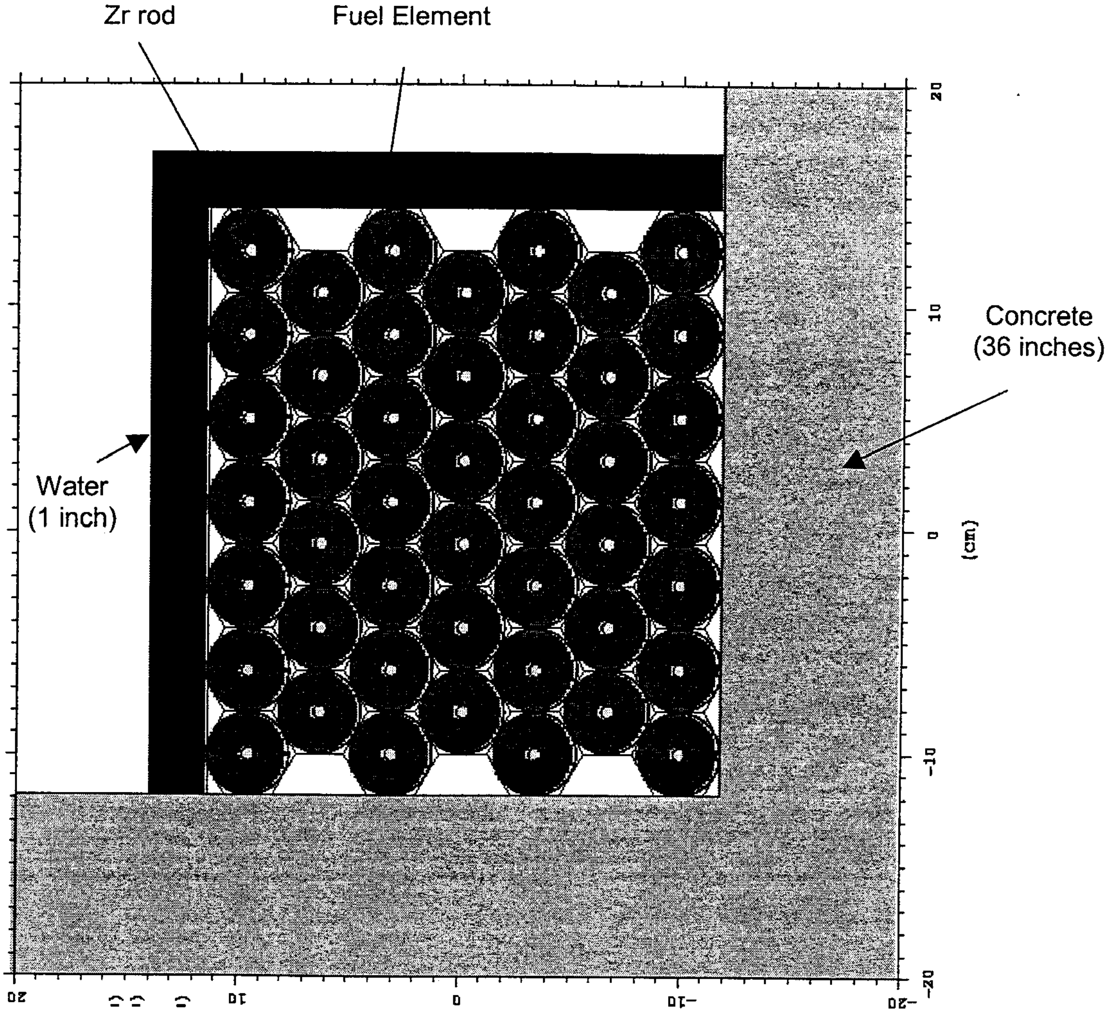

Figure 22
Hexagonal Pitched MCNP Model, Transverse Cut through Fuel Stacked in Concrete Corner with Water Reflection

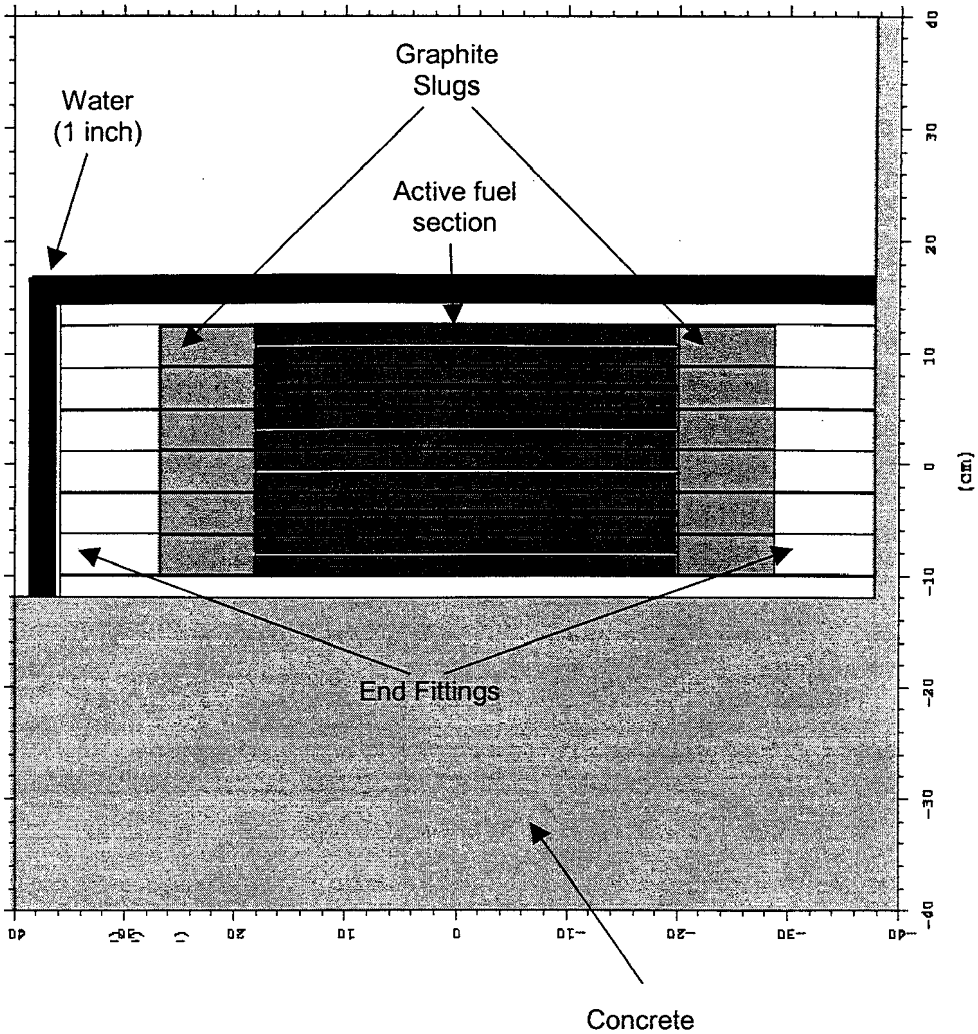

Figure 23
MCNP Model, Cut Parallel to the Longitudinal Axis of Fuel Stacked in Concrete Corner with Water Reflection

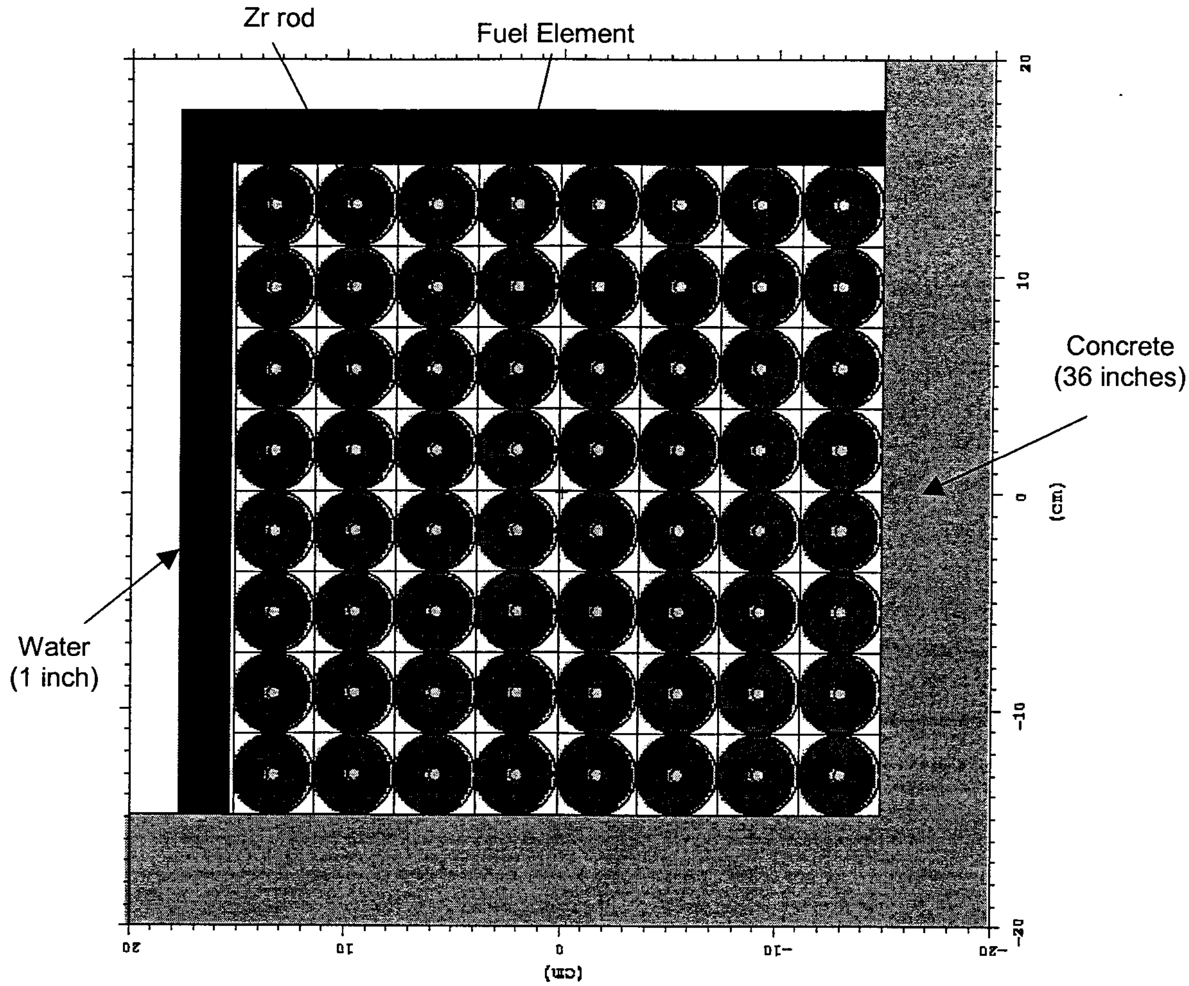

Figure 24
Square Pitched MCNP Model, Transverse Cut through Fuel Stacked in Concrete Corner with Water Reflection

2.5.4.2 Regional Densities

Table 14
Material Number Densities Used In Models

NAME	ISOTOPE	atom/b-cm	ELEM SUM	MAT SUM	ITEM
92U	U235	0.000290			Fuel (6.0875 g/cc)
	U238	0.001196	0.00144336		
40Zr		0.035758	0.03575764		
1H		0.060788	0.06078798	0.09798898	
40Zr		0.042843	0.04284336	0.04284336	zr rod (6.49 g/cc)
6C		0.085235	0.08523495	0.08523495	graphite (1.7 g/cc)
26Fe	Fe54	0.003506			304 ss (7.93 g/cc)
26Fe	Fe56	0.054509			
26Fe	Fe57	0.001248			
26Fe	Fe58	0.000166	0.05943004		
24Cr	Cr50	0.000758			
24Cr	Cr52	0.014622			
24Cr	Cr53	0.001658			
24Cr	Cr54	0.000413	0.01745038		
28Ni	Ni58	0.005277			
28Ni	Ni60	0.002018			
28Ni	Ni61	8.74E-05			
28Ni	Ni62	0.000278			
28Ni	Ni64	7.03E-05	0.00773002		
25Mn	Mn55	0.001739	0.00173851	0.08634895	
26Fe	Fe54	0.003334			316 ss (8.0 g/cc)
26Fe	Fe56	0.051826			
26Fe	Fe57	0.001187			
26Fe	Fe58	0.000158	0.05650403		
24Cr	Cr50	0.000684			

NAME	ISOTOPE	atom/b-cm	ELEM SUM	MAT SUM	ITEM
24Cr	Cr52	0.013198			
24Cr	Cr53	0.001496			
24Cr	Cr54	0.000373	0.01575132		
28Ni	Ni58	0.006725			
28Ni	Ni60	0.002571			
28Ni	Ni61	0.000111			
28Ni	Ni62	0.000354			
28Ni	Ni64	8.96E-05	0.00985043		
42Mo		0.001255	0.00125539		
25Mn	Mn55	0.001754	0.00175386		
14 Si		0.001715	0.00171536	0.08683039	
8O		0.045796	0.04579602		Port conc (2.3 g/cc)
14Si		0.01662	0.01661971		
1H		0.013742	0.01374227		
13 Al		0.001745	0.00174537		
20 Ca		0.001521	0.00152063		
11 Na		0.000964	0.00096396		
19 K		0.000461	0.00046053		
26 Fe	Fe54	2.05E-05			
27 Fe	Fe56	0.000318			
28 Fe	Fe57	7.29E-06			
29 Fe	Fe58	9.72E-07	0.00034722		
12 Mg		0.000114	0.00011398		
6 C		0.000115	0.00011532	0.08142501	
1 H		0.066856	0.06685577		water
8 O		0.033428	0.03342788	0.10028365	

2.5.5 Criticality Calculations

2.5.5.1 Calculational Methodology

The MCNP code was used to determine the k_{eff} for various numbers of unmoderated and reflected arrays of TRIGA fuel elements. These values were used to determine the maximum number of assemblies that may be safely handled without presenting a criticality problem.

2.5.5.2 Fuel Loading and Other Contents Optimization

Each TRIGA fuel assembly used in these calculations contained 43.875 grams of ^{235}U. The nominal TRIGA fuel element fissile material content specified in the ISF Contract (39g ^{235}U) was adjusted to account for variations in post-1964 fuel elements to provide the most reactive and bounding source term for criticality analysis. Manufacturing variations resulted in a higher uranium content and a greater H:Zr atom ratio.

Since there is no restriction on the geometry of the pile of fuel it was assumed that the fuel could collect in a corner of the cell, which would provide full concrete reflection on three sides. The reflection on the other three sides was taken to be nominal, equivalent to once inch of water, as is standard practice to allow for minor reflections from the building surfaces and equipment. Therefore, analyses were made with TRIGA fuel in a concrete corner, unmoderated, and reflected on the other three sides by one inch of water. Calculations were made for the fuel with a hexagonal pitch. This was expected to be the most reactive configuration, but calculations were also made with a square pitch because the fuel can be modeled with more tightly reflecting material.

2.5.5.3 Criticality Results

These calculations show that the subcritical $k_{eff} + 2\sigma$ limit of 0.95 will be reached with 48 TRIGA fuel elements in a tightly packed dry hexagonal array reflected by one inch of water that is in a corner of the FPA. It will take 57 elements to reach the limit with the fuel packed in a square pitched array. Therefore, the hexagonal limit is controlling. Table 12 and Figure 21 summarize these results.

2.5.6 References

Characterization of TRIGA Fuel, N Tomsio, ORNL/Sub/86-22047/3, GA-C18542, October 1986.

2.6 BASKETS WITH TRIGA ELEMENTS IN THE FUEL PACKAGING AREA

2.6.1 Criticality Evaluation

This evaluation was made with MCNP (MCNP4B2) to determine whether two baskets containing TRIGA fuel elements will remain safely subcritical if they are passed side-by-side in the ISF Fuel Packaging Area (FPA).

2.6.2 Discussion and Results

These calculations show that 2 dry ISF storage baskets loaded with 54 TRIGA fuel elements each, and passed side-by-side in the FPA, remain safely subcritical, with a $k_{eff} + 2\sigma$ equal to 0.6273. The use of nominal reflection (equivalent to one inch of water) to allow for minor reflection from the building surfaces and equipment is standard practice. The $k_{eff} + 2\sigma$ value drops to 0.5332 with no water reflector.

If the ISF baskets are assumed to be flooded, the $k_{eff} + 2\sigma$ value increases to 0.8543 with a 12-inch water reflector, which is still subcritical. The possibility of these conditions existing in the FPA is considered very unlikely because there is no water available in the facility and it is located above the maximum 100 year floodplain. Also, the basket does not contain an external shell to hold the water.

The results of these calculations are summarized in Table 15.

Table 15
Summary of Criticality Results

MCNP Case	Canister Flooded	Water Reflector	keff ± σ	keff + 2σ
15-1	No	1-inch	0.6257 ± 0.0008	0.6273
15-2	No	None	0.5316 ± 0.0008	0.5332
15-3	Yes	12-inch	0.8527 ± 0.0008	0.8543

2.6.3 Spent Fuel Loading

Each TRIGA ISF basket contained 54 TRIGA fuel elements for a total of 2.37 kilograms of ^{235}U per basket. The nominal TRIGA fuel element fissile material content specified in the ISF Contract (39g ^{235}U) was adjusted to account for variations in post-1964 fuel elements to provide the most reactive and bounding source term for criticality analysis. Manufacturing variations resulted in a higher uranium content and a greater H:Zr atom ratio. The two baskets contained a total of 4.74 kilograms of ^{235}U.

2.6.4 Model Specification

2.6.5 Description of Calculational Model

The MCNP model for the dry TRIGA ISF baskets with a 1-inch water reflector is shown in Figures 25 and 26. Note that a reflective surface was used on one side of the basket to simulate 2 baskets side-by-side. Table 16 summarizes the modeled configurations.

Table 16
Modeled Configuration of TRIGA Fuel in Two ISF Baskets

Region	Documented Configuration		Modeled Configuration	
	Material (g/cc)	**Dimensions, cm**	**Material (g/cc)**	**Dimensions, cm**
Fuel Description				
Fuel (Zr rod)	Zr (6.49)	OR=0.28575 Length=38.1	Zr (6.49)	OR=0.28575 Length=38.1
Fuel (meat)	U-$ZrH_{1.7}$ (6.0875)	IR=0.3175 OR=1.82245	U-$ZrH_{1.7}$ (6.0875)	IR=0.3175 OR=1.82245
		Length=38.1		Length=38.1
Fuel Clad	SS-304 (7.93)	IR=1.82626 OR=1.87706	SS-304 (7.93)	IR=1.82626 OR=1.87706
		Length=55.4736		Length=55.4736
Graphite Cylinders				
Graphite Reflector	Graphite	OR=1.82245	Graphite (1.7)	OR=1.82245
		Length=2 @ 8.6868		Length=2 @ 8.6868
End Fittings				
End Fittings	SS	OR=irregular	SS-316 (8.0)	OR=1.82245
		Length=2 @ 9.0932		Length=2 @ 9.0932
Basket Description				
Basket		OR=21.3995		OR=21.3995
		Length=83.185		Length=83.185
Tubes (54)	SS-316 (8.0)	OR=2.2225 IR=2.05994	SS-316 (8.0)	OR=2.2225 IR=2.05994
	Pitch=5.08	L=74.295	Pitch=5.08	L=74.295
Lifting Plate		Thickness=6.985		Thickness=6.985
Bottom Plate		Thickness=3.175		Thickness=1.905
Reflector				
Reflector	None		Water (1.0)	Th_{water}=2.54 (or) Th_{water}=30.48

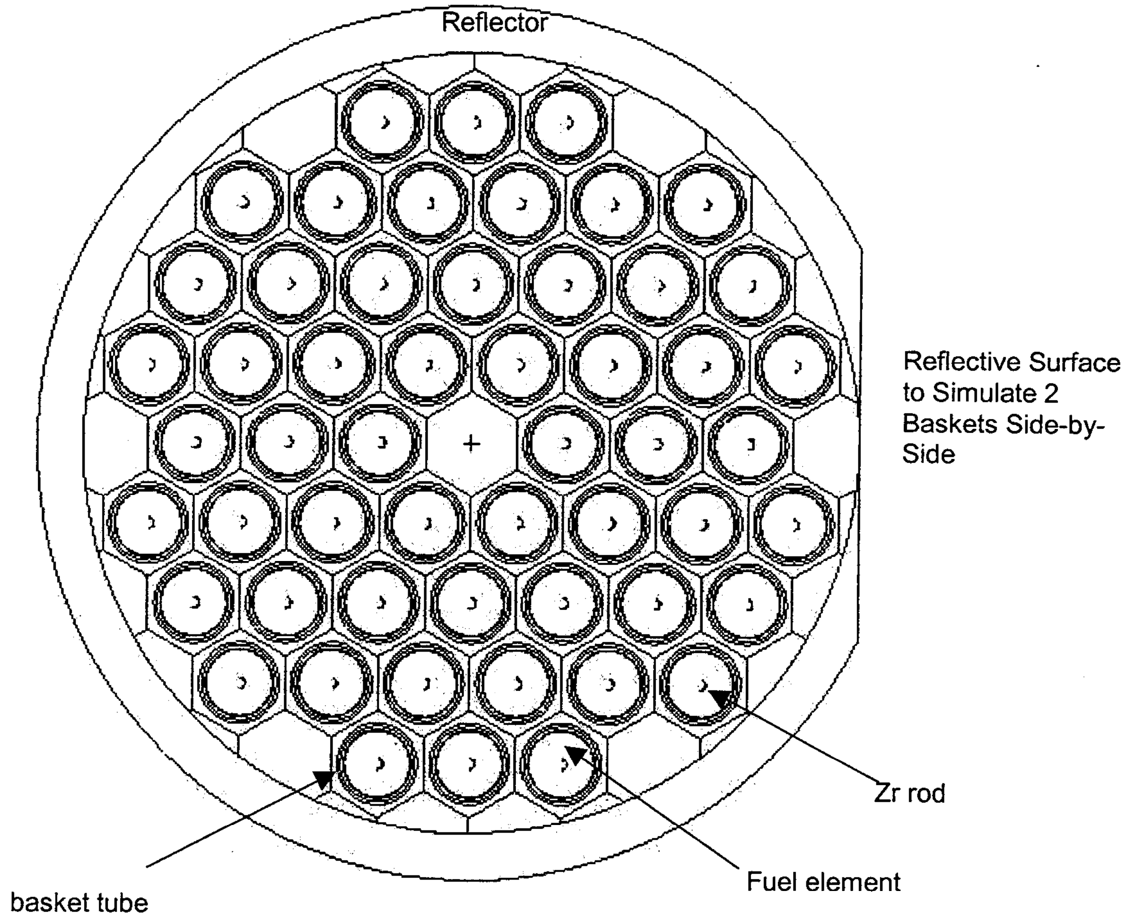

Figure 25
Radial View of MCNP Model for Two TRIGA Fuel Baskets Under Dry Moderation Conditions in the FPA with 1 inch Water Reflection

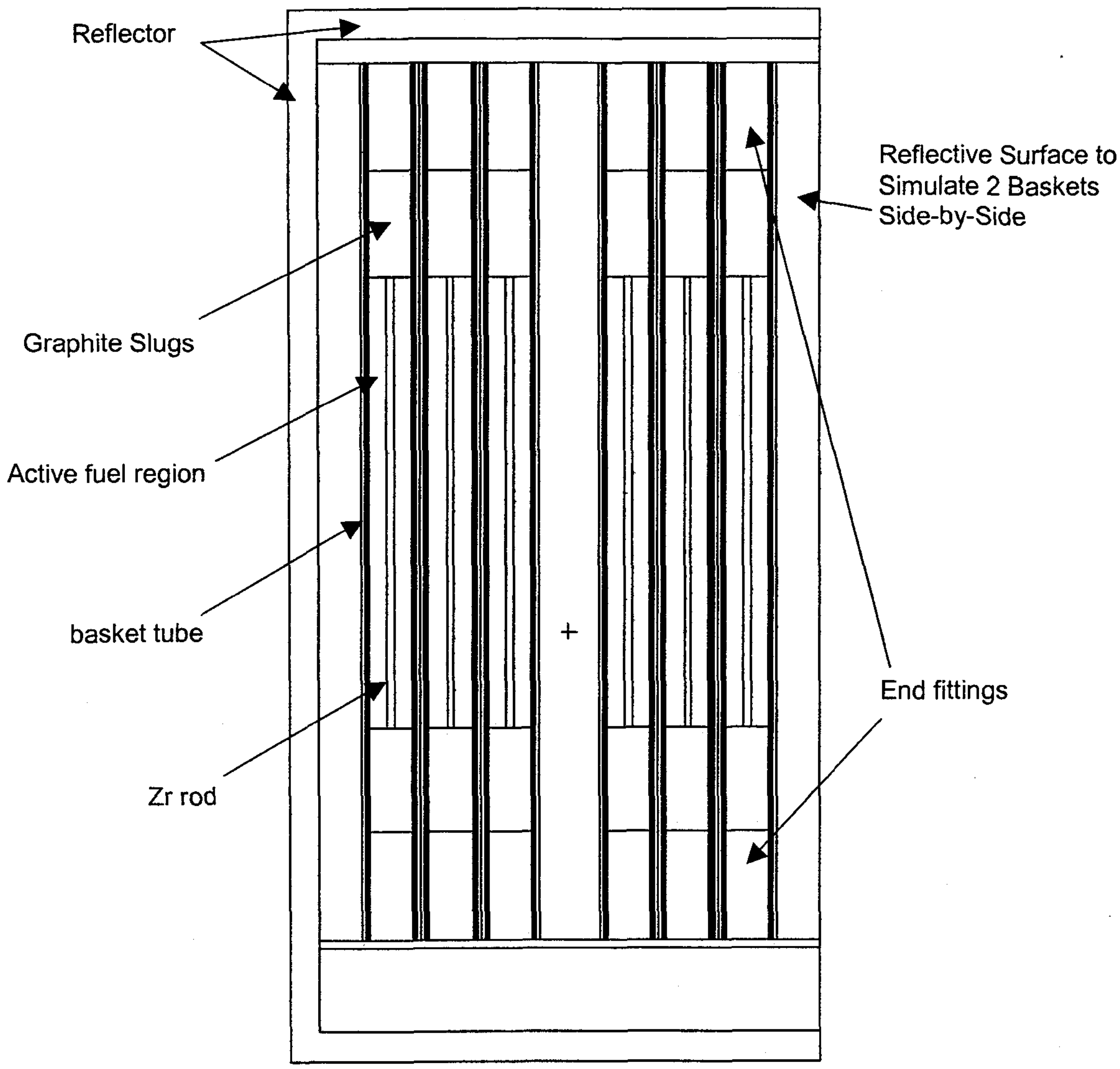

Figure 26
Axial View of MCNP Model for Two TRIGA Fuel Baskets Under Dry Moderation Conditions in the FPA with 1 inch Water Reflection

2.6.5.1 Regional Densities

Table 17
MATERIAL NUMBER DENSITIES USED IN MODELS

NAME	ISOTOPE	atom/b-cm	ELEM SUM	MAT SUM	ITEM
92U	U235	0.000292			Fuel (6.0875 g/cc)
	U238	0.001152	0.00144336		
40Zr		0.035758	0.03575764		
1H		0.060788	0.06078798	0.09798898	
40Zr		0.042843	0.04284336	0.04284336	Zr rod (6.49 g/cc)
6C		0.085235	0.08523495	0.08523495	Graphite (1.7 g/cc)
1H		0.066872	0.066872	0.100309	Water (1.0 g/cc)
8O		0.033436	0.033436		
26Fe	Fe54	0.003506			304 ss (7.93 g/cc)
26Fe	Fe56	0.054509			
26Fe	Fe57	0.001248			
26Fe	Fe58	0.000166	0.05943004		
24Cr	Cr50	0.000758			
24Cr	Cr52	0.014622			
24Cr	Cr53	0.001658			
24Cr	Cr54	0.000413	0.01745038		
28Ni	Ni58	0.005277			
28Ni	Ni60	0.002018			
28Ni	Ni61	8.74E-05			
28Ni	Ni62	0.000278			
28Ni	Ni64	7.03E-05	0.00773002		
25Mn	Mn55	0.001739	0.00173851	0.08634895	
26Fe	Fe54	0.003334			316 ss (8.0 g/cc)
26Fe	Fe56	0.051826			
26Fe	Fe57	0.001187			
26Fe	Fe58	0.000158	0.05650403		
24Cr	Cr50	0.000684			
24Cr	Cr52	0.013198			

NAME	ISOTOPE	atom/b-cm	ELEM SUM	MAT SUM	ITEM
24Cr	Cr53	0.001496			
24Cr	Cr54	0.000373	0.01575132		
28Ni	Ni58	0.006725			
28Ni	Ni60	0.002571			
28Ni	Ni61	0.000111			
28Ni	Ni62	0.000354			
28Ni	Ni64	8.96E-05	0.00985043		
42Mo		0.001255	0.00125539		
25Mn	Mn55	0.001754	0.00175386		
14 Si		0.001715	0.00171536	0.08683039	

2.6.6 Criticality Calculations

2.6.6.1 Calculational Methodology

The MCNP code (MCNP4B2, Monte Carlo N-Particle Transport Code System) was used to calculate the k_{eff} value to demonstrate that two baskets of TRIGA fuel passed side-by-side in the FPA would be safely subcritical.

2.6.6.2 Fuel Loading and Other Contents Optimization

Each TRIGA fuel assembly used in these calculations contained 43.875 grams of ^{235}U. There are 108 fuel assemblies per canister. The nominal TRIGA fuel element fissile material content specified in the ISF Contract (39g ^{235}U) was adjusted to account for variations in post-1964 fuel elements to provide the most reactive and bounding source term for criticality analysis. Manufacturing variations resulted in a higher uranium content and a greater H:Zr atom ratio.

There is a potential for two ISF baskets containing TRIGA fuel to be passed side-by-side during operations in the FPA. No water would normally be present during normal or accident conditions, so the model assumes dry conditions within the baskets and between the baskets. A 1-inch water reflector was used to account for minor reflection from building surfaces and equipment. The use of nominal reflection (equivalent to one inch of water) to allow for minor reflection from the building surfaces and equipment is standard practice. A second case was run with no water reflection to assess the impact of far field reflection on the calculated k_{eff} value. A third case was run with the baskets flooded and with a 12-inch reflector.

2.6.6.3 Criticality Results

These calculations show that two dry ISF storage baskets loaded with 54 TRIGA fuel elements each, and passed side-by-side in the FPA, remain safely subcritical, with a $k_{eff} + 2\sigma$ equal to 0.6273 (Case 15-1). A 1-inch water reflector was included to account for reflection from the floor, walls, etc. The $k_{eff} + 2\sigma$ value drops to 0.5332 (Case 15-2) with no water reflector.

If the baskets are assumed to be flooded, the $k_{eff} + 2\sigma$ value increases to 0.8543 with a 12-inch water reflector, which is still safely subcritical. The possibility of these conditions existing in the FPA is considered very unlikely because there is no water available in the facility and it is located above the maximum 100 year floodplain. Also, the basket does not contain an external shell to hold the water.

Table 15 summarizes the results of these calculations.

2.6.7 References

Characterization of TRIGA Fuel, N Tomsio, ORNL/Sub/86-22047/3, GA-C18542, October 1986.

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3.0 PEACH BOTTOM FUEL

3.1 PEACH BOTTOM MICROSPHERES

3.1.1 Criticality Evaluation

The purpose of this analysis was to determine the k_{eff} of water-moderated Peach Bottom UC_2 microspheres, assuming that they can separate from the surrounding materials. The UC_2 microspheres are normally in a graphite matrix with ThC_2 microspheres, which will be much less reactive. This is considered a non-credible event, since no known physical or chemical process exists in the ISF Facility capable of separating the UC microspheres from the Peach Bottom fuel graphite matrix. Collection or buildup of microspheres over time in handling equipment is not considered possible.

3.1.2 Discussion and Results

A critical mass must be assumed for a sphere of 13.8 cm radius and a ^{235}U mass of about 885 g. A subcritical limit of k_{eff} = 0.93 (0.95 minus benchmark bias of 0.02) is reached with 680 g of ^{235}U. The 680 grams of ^{235}U is equivalent to the ^{235}U in about 2.3 fuel assemblies.

3.1.3 Spent Fuel Loading

N/A

3.1.4 Model Specification

3.1.4.1 Description of Calculational Model

The Peach Bottom Core 1 fuel compacts consisted of carbides of uranium enriched to 93.15% ^{235}U at the beginning of life and thorium, uniformly dispersed as coated particles in a graphite matrix. The total carbon within the carbide substrates was between 11% and 16%, by weight. The pyrolytic carbon-coated particles were between 210 and 595 μm in diameter, with a coating thickness of 55 μm. Figure 27 illustrates a Peach Bottom fuel element.

The first step performed was to determine the most reactive $H/^{235}U$ ratio for the matrix of fuel, graphite and water. The value used for the $H/^{235}U$ ratio in these calculations was approximately 300:1. This ratio was verified graphically (Pruvost and Paxton 1996) for the graphite content of concern.

Then a spherical matrix of cubes (containing water, fuel, and graphite) was generated for MCNP. Each cube contained a graphite coated 210 μm (0.0210 cm) microsphere of uranium. The graphite coating was 55 μm thick. The remainder of each cube was water to obtain a 300:1 ratio of $H/^{235}U$. The containing sphere was reflected by 30.48 cm of water. See Figure 28 for typical MCNP details of the model. Table 18 summarizes the modeled configurations.

Table 18
Modeled Configuration

Region	Documented Configuration		Modeled Configuration	
	Material (g/cc)	Dimensions, cm	Material (g/cc)	Dimensions, cm
Spine Description				
Spine	Graphite (2.107)	OR=2.225 Length=228.6	Graphite (2.107)	OR=2.225 Length=228.6
Fuel Description				
Fuel	UC_2 & ThC_2 (2.143)	IR=2.2225 OR=3.429	UC_2 & ThC_2 (2.143)	IR=2.225 OR=3.429
		Length=228.6		Length=228.6
Reflector Description				
Reflector	Graphite (2.107)	IR=3.429 OR=4.445	Graphite (2.107)	IR=3.429 OR=4.445
		Length=228.6		Length=228.6

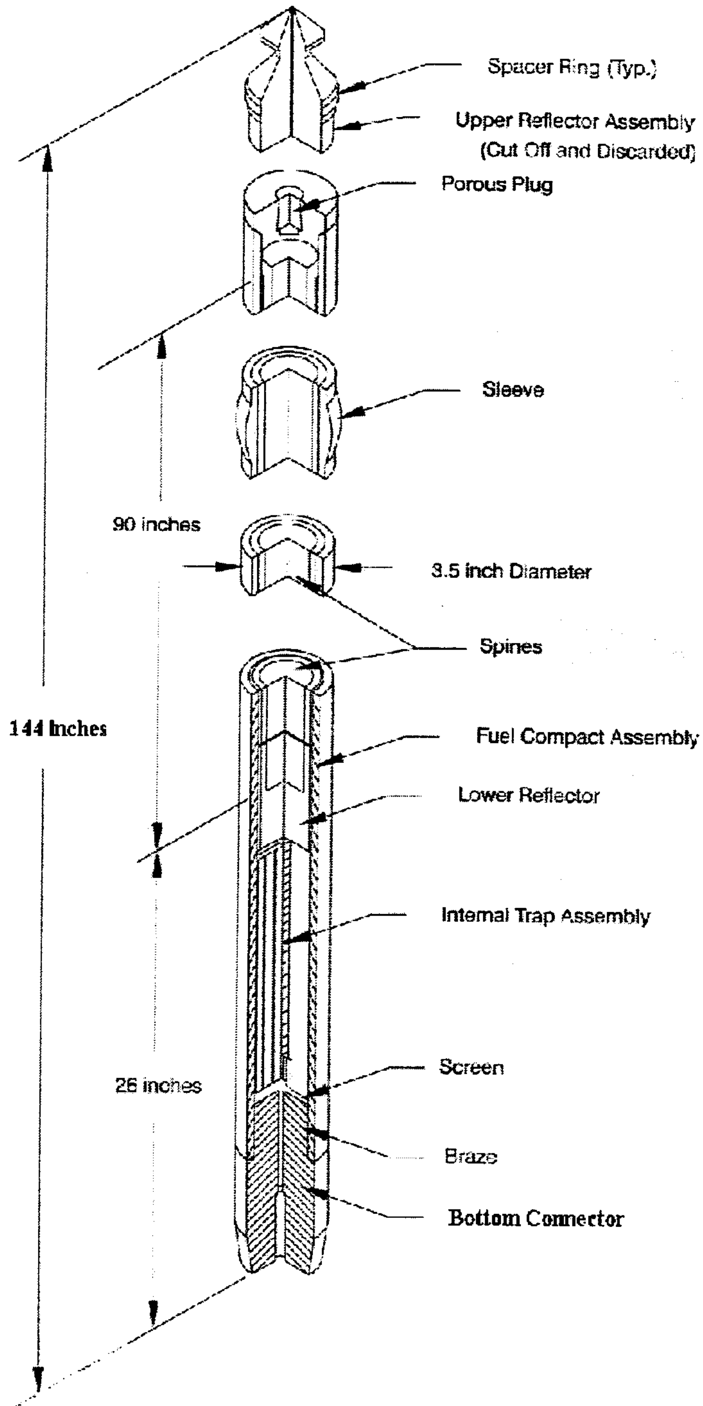


Figure 27
Peach Bottom Fuel Element

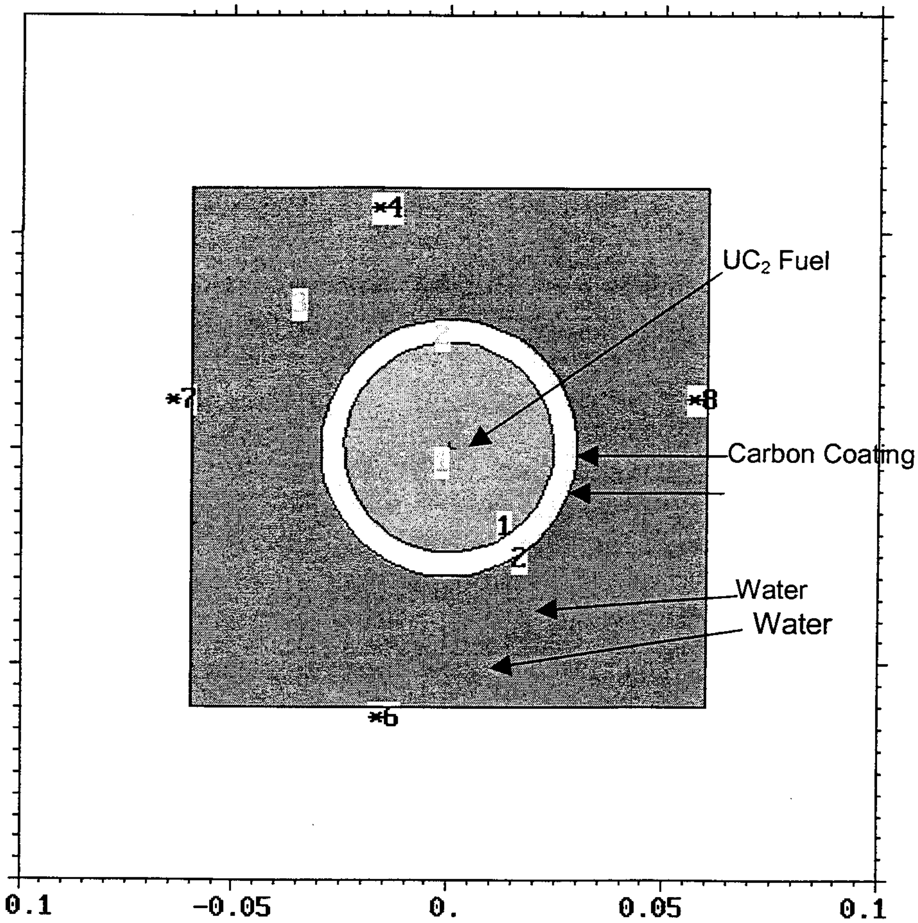


Figure 28
Typical "Cube" Containing Microsphere Surrounded by Water

3.1.5 Regional Densities

The input data for the size and composition of the microspheres and the composition of the surrounding matrix was taken from ISF Contract Attachment C-A-A and DOE/SNF/REP-041. Table 19 contains the material densities used in this analysis.

Table 19
Material Compositions used in the Models

UC2	Density (g/cc)=	1.12800E+01
		atom density
Material	Atom fraction	atoms/b-cm
U-235	3.11616E-01	2.44174E-02
U-238	2.29130E-02	1.79540E-03
C	6.65471E-01	5.21445E-02
	Atom dens. =	7.83573E-02
Carbon	Density (g/cc)=	2.20000E+00
		atom density
Material	Atom fraction	atoms/b-cm
C	1.00000E+00	1.10303E-01
	Atom dens. =	1.10303E-01
Water	Density (g/cc)=	1.00000E+00
		atom density
Material	Atom fraction	atoms/b-cm
H-1	6.66564E-01	6.68590E-02
H-2	9.99977E-05	1.00302E-05
O-16	3.33202E-01	3.34215E-02
O-17	1.33337E-04	1.33742E-05
	Atom dens. =	1.00304E-01

3.1.6 Criticality Calculations

3.1.6.1 Calculational Methodology

The MCNP Monte Carlo radiation transport program, MCNP4B2, Monte Carlo N-Particle Transport Code System, CCC-660, Radiation Safety Information Computational Center, Oak Ridge National Laboratory, Oct 1997 (MCNP1997) was used for the criticality calculations. These MCNP calculations were performed on a large matrix of water immersed microspheres. That is somewhat unusual, but the results are well verified by homogenized calculations that are given in the Criticality Handbook (ARH600).

3.1.6.2 Fuel Loading and Other Contents Optimization

N/A

3.1.6.3 Criticality Results

Table 20 and Figures 29 and 29A show that a critical mass might be possible in a spherical geometry and with full water reflection at a radius of about 13.8 cm and a ^{235}U mass of about 885 grams. A criticality limit of keff + $2\sigma \leq 0.93$ (0.95 minus benchmark bias of 0.02) is reached with 680 g of ^{235}U. Because the 885 g is very close to the minimum critical mass (~800 g) for a homogenized water-moderated ^{235}U system (ARH-600), no further evaluation will be needed.

3.1.7 References

Attachment C-A-A, "Fuel and Fuel Package Description", to DOE Contract DE-AC07-00ID13729.

ARH600, Criticality Handbook, Volume II, Carter et al. May 23, 1969 (with additions through May 2, 1982).

Pruvost and Paxton, 1996, Nuclear Criticality Safety Guide LA-12808/UC.

Table 20
Results of MCNP Calculations for Sphere Containing a Large Number of Cubes Each cube contained a 100 μm (0.0100 cm) Diameter Microsphere of $^{235}UC_2$

Each Microsphere had a Graphite Coating of 55 μm ;

Total Microsphere Diameter = 210 μm (0.0210 cm),

The remainder of the volume of the 0.0396 cm/side Cube Was Water,

For an Atom Ratio of $H/^{235}U$ of 300:1.

The Container Sphere Was Reflected by 30.48 cm of Water

Containing Sphere Radius (cm)	Containing Sphere Vol. (cm^3)	# of Cubes in Containing Sphere	U-235 mass (g)	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	MCNP Case
13.138	9.499E3	1.530E8	7.635E2	0.951 (0.004)	0.959	20-1
14.000	1.149E4	1.850E8	9.232E2	0.992 (0.004)	1.000	20-2
14.500	1.277E4	2.056E8	1.026E3	1.017 (0.005)	1.027	20-3

Plot of U-235 mass as a Function of Container Radius See Table 20

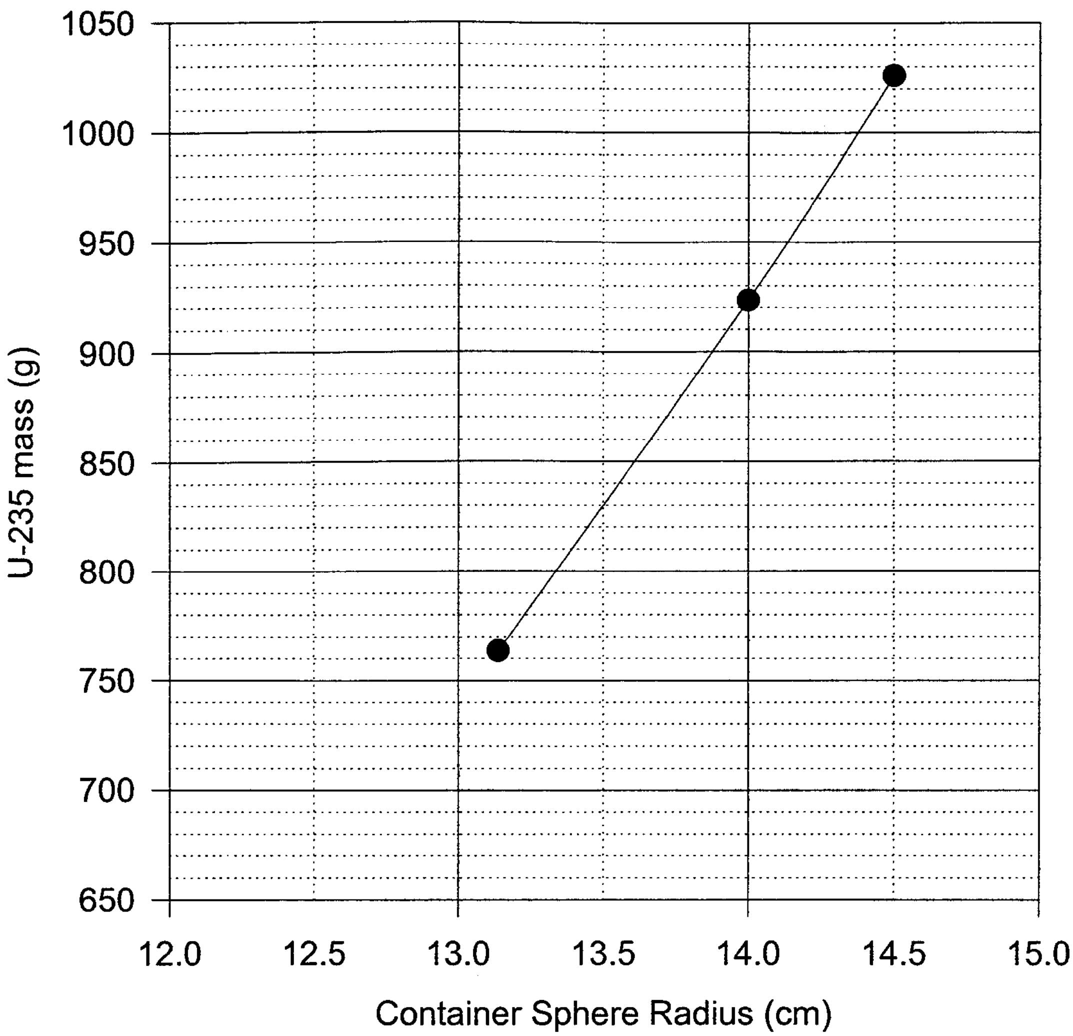


Figure 29
U-235 Mass for Large Sphere Containing Peach Bottom (U-235) Microspheres

MCNP Calculations

**for a Sphere (Reflected by 30.5 cm of H2O)
with the Radius Shown, Containing
an Array of Cubes 0.0396 cm on a Side
The Cubes Each Have a 210 um Carbon Clad
Microsphere in the Center Surrounded by H2O**

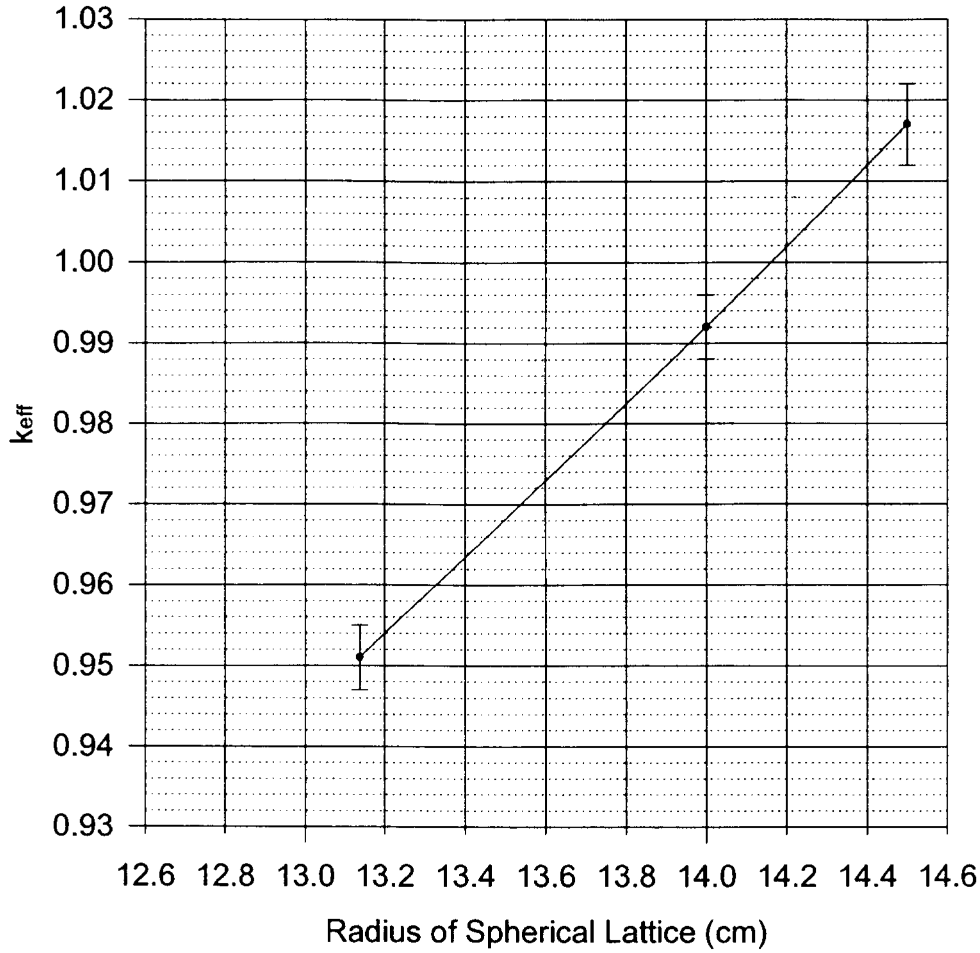


Figure 29A
k_{eff} (1σ uncertainty shown) of Large Sphere Containing Peach Bottom U-235 Microspheres

3.2 CRUSHED PEACH BOTTOM FUEL ASSEMBLIES MODERATED WITH GRAPHITE

3.2.1 Criticality Evaluation

FWENC performed bounding calculations to determine the k_{eff} of graphite moderated Peach Bottom fuel, assuming that all the fuel and graphite in multiple fuel elements was crushed. The FWENC analyses assumed that the fragmented fuel assemblies formed a graphite reflected sphere. These FWENC calculations determined the number of crushed/shattered fuel assemblies that are needed to reach the criticality safety limit of keff + $2\sigma \leq 0.95$.

The DOE also performed criticality analyses for the Peach Bottom fuel. Although DOE assumed that the Peach Bottom fuel was rubblized, they did not consider the non-mechanistic separation of graphite from the fuel and subsequent redistribution as a sphere surrounding the fuel material.

3.2.2 Discussion and Results

The FWENC results, based on the non-mechanistic separation of fuel and graphite in which the fuel assumed a spherical shape surrounded by graphite, show that in the crushed condition, assumed geometry, and a mix density of 1.8 g/cm^3, up to 14 assemblies can be crushed before the limit set by the validation study of $k_{eff} + 2\sigma \leq 0.95$ is reached. A density of 1.8 g/cm^3 was used because it is estimated to be an upper limit for crushed fuel. The ISF fuel baskets are limited to a maximum of 10 Peach Bottom fuel elements which is less than the 14 fuel crushed fuel elements needed to achieve a k_{eff} of greater than 0.95.

The DOE analyses, which assumed that the fuel is rubblized into a homogenous mixture, required greater than 18 Peach Bottom fuel elements to achieve a k_{eff} of greater than 0.95. Since no more than 18 Peach Bottom fuel elements will be transferred to the ISF Facility in a single fuel container, no criticality concern has been identified.

3.2.3 Spent Fuel Loading

N/A

3.2.4 Model Specification

3.2.4.1 Description of Calculational Model

The Peach Bottom Core 1 fuel compacts consisted of carbides of uranium enriched to 93.15% ^{235}U at the beginning of life and thorium, uniformly dispersed as coated particles in a graphite matrix. The total carbon within the carbide substrates was between 11% and 16%, by weight. The pyrolytic carbon-coated particles were between 210 and 595 μm in diameter, with a coating thickness of 55 μm.

For this model the graphite in each element was evenly homogenized into the fuel. The homogenized mixture was modeled as a sphere with a 30.5 cm graphite reflector around it. While 30.5 cm of graphite does not represent full reflection, it certainly is as much reflection as could reasonably be expected. The sphere size was varied from a volume equal to that from 10 assemblies to 25 assemblies. Figure 30 illustrates a Peach Bottom fuel element. Figure 31 shows the MCNP model that was used to support the analysis.

The fuel region of a Peach Bottom fuel element is composed of 30 fuel compacts (disks). Each compact is 6.858 cm in diameter and has a 4.445 cm hole in the center, with a thickness of 7.5692 cm.

Table 21 summarizes the modeled configuration.

Table 21
Modeled Configuration

	Documented Configuration		Modeled Configuration	
Region	**Material (g/cc)**	**Dimensions, cm**	**Material (g/cc)**	**Dimensions, cm**
Spine Description				
Spine	Graphite (2.107)	OR=2.225 Length=228.6	Graphite (2.107)	OR=2.225 Length=228.6
Fuel Description				
Fuel	UC_2 & ThC_2 (2.143)	IR=2.2225 OR=3.429	UC_2 & ThC_2 (2.143)	IR=2.225 OR=3.429
		Length=228.6		Length=228.6
Reflector Description				
Reflector	Graphite (2.107)	IR=3.429 OR=4.445	Graphite (2.107)	IR=3.429 OR=4.445
		Length=228.6		Length=228.6

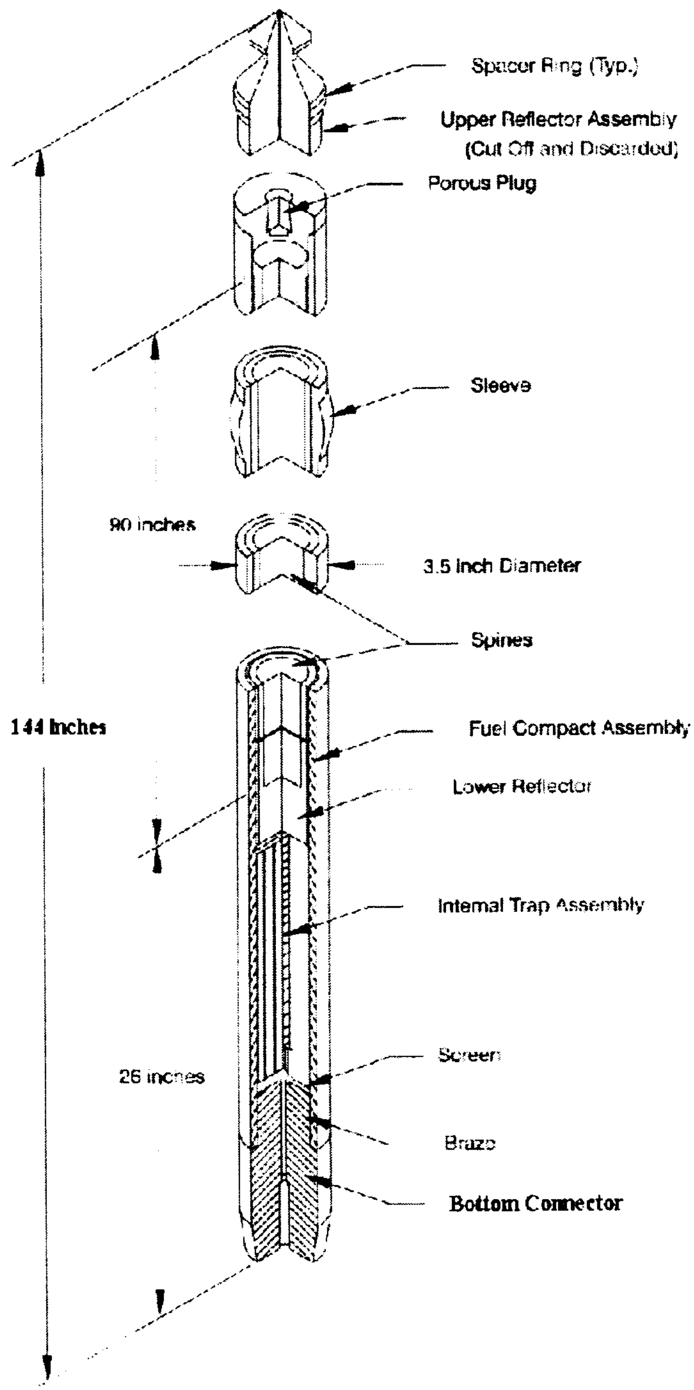


Figure 30
Peach Bottom Fuel Element

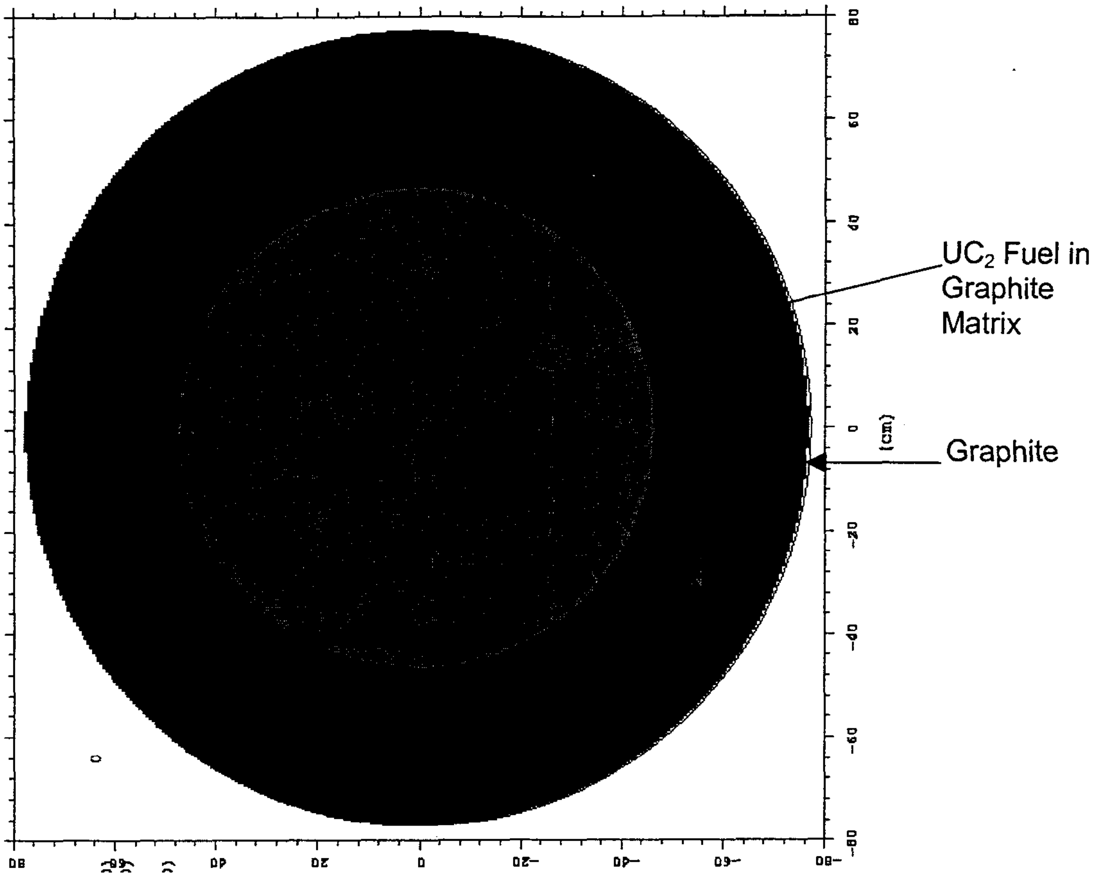


Figure 31
MCNP Geometry for Homogenized Peach Bottom Fuel Surrounded by Graphite Reflector, Material Densities Shown

3.2.4.2 Regional Densities

The input data for the size and composition of the microspheres and fuel /graphite mixtures was taken from DOE/SNF/REP-041 and Contract Attachment C-A-A. In addition GA-C18525, ORNL/Sub/86-22047/2 shows that there are 33 kg of carbon per element. Therefore, 33 kg of carbon was homogenized in with the fuel mixture. Since each element contains 33 kg of carbon, it is assumed to be a realistic amount to mix with the fuel.

The MCNP material densities used in these calculations follow in Table 22.

Table 22
Material Densities

Fuel (UC2/ThC2/C)	**Density (g/cc)=**	**1.80000E+00**
		atom density
material	Atom fraction	atoms/b-cm
Rh-103	2.17206E-05	1.86029E-06
Th-232	2.44474E-03	2.09383E-04
U-235	4.49093E-04	3.84632E-05
U-238	2.30962E-05	1.97811E-06
Carbon	9.97061E-01	8.53948E-02
	atom dens. =	8.56465E-02
Carbon	Density (g/cc)=	2.20000E+00
		atom density
material	atom fraction	atoms/b-cm
C	1.00000E+00	1.10303E-01
	atom dens. =	1.10303E-01

3.2.5 Criticality Calculations

3.2.5.1 Calculational Methodology

The MCNP Monte Carlo radiation transport program, MCNP4B2, Monte Carlo N-Particle Transport Code System, CCC-660, Radiation Safety Information Computational Center, Oak Ridge National Laboratory, Oct 1997 (MCNP1997) was used for the criticality calculations. The k_{eff} was determined for graphite moderated Peach Bottom fuel in a spherical configuration (see Figure 31) with the MCNP code.

3.2.5.2 Fuel Loading and Other Contents Optimization

N/A

3.2.5.3 Criticality Results

Two sets of computer runs were made. The first set assumed that the fuel/graphite density was 2.14 g/cm^3. The second set was for a density of 1.8 g/cm^3. A density of 1.8 g/cm^3 was used because it is estimated to be an upper limit for crushed fuel. The 2.14 g/cm^3 was used as a possible, but very improbable value. The results of these calculations are shown in Table 23 and Figure 32. It can be seen that the higher density mixture is more reactive. However, the lower density is representative of what would happen if the fuel were actually dropped and broken. The 2.14 g/cm^3 could only be produced if all the broken pieces were highly compressed into a solid mass, and there is no mechanism for that to happen. It only represents a limiting case.

3.2.6 References

Attachment C-A-A, "Fuel and Fuel Package Description", to DOE Contract DE-AC07-00ID13729.

GA-C18525, ORNL/Sub/86-22047/2, Characteristics of Peach Bottom Unit 1 Fuel, R. P. Morissette et al., October 1986.

Table 23
Reactivity from the Fuel/graphite in the Indicated Number of Assemblies Homogenized into a Sphere, with a 30.5 cm graphite reflector

Fuel/graphite ρ=2.14 g/cm^3				
Assemblies per Sphere	k_{eff}	σ	$k_{eff} + 2\sigma$	**MCNP Case**
10	0.900	0.0024	0.905	23-1
15	0.973	0.0023	0.978	23-2
16	0.985	0.0023	0.990	23-3
17	0.999	0.0024	1.004	23-4
20	1.030	0.0023	1.035	23-5

Fuel/graphite ρ=1.80 g/cm^3				
Assemblies per Sphere	k_{eff}	σ	$k_{eff} + 2\sigma$	**MCNP Case**
10	0.862	0.0025	0.867	23-6
15	0.936	0.0025	0.941	23-7
20	0.994	0.0024	0.999	23-8
22	1.008	0.0023	1.013	23-9
25	1.029	0.0024	1.034	23-10

Reactivity from the Fuel/graphite in the Indicated Number of Assemblies Homogenized into a Sphere

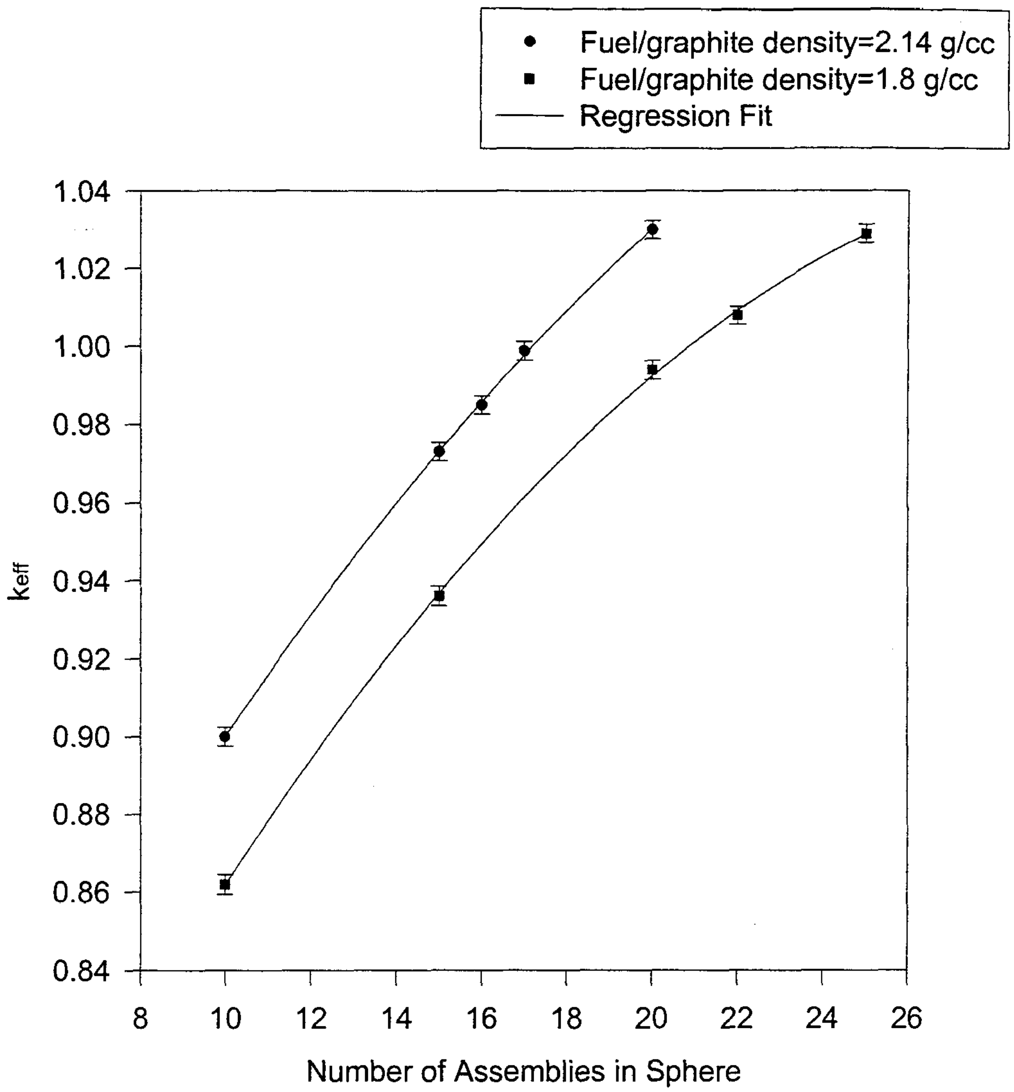


Figure 32
Peach Bottom, keff (1σ shown) as a Function of Homogenized Fuel/Graphite in a Sphere

3.3 PEACH BOTTOM ELEMENTS IN STORAGE CANISTER

3.3.1 Criticality Evaluation

The purpose of this calculation is to determine the reactivity of the Peach Bottom spent fuel elements in the ISF storage canister configuration as a function of spacing between the elements and as a function of moderation and reflection. The results of these calculations will be used in a nuclear criticality safety assessment for handling the Peach Bottom spent fuel elements in ISF Facility.

3.3.2 Discussion and Results

The criticality analyses for moderated conditions with the 18 elements in a hexagonal array and 0.1 cm separation distance edge to edge shows that 18 Peach Bottom fuel elements will have a maximum $k_{eff} + 2\sigma = 0.913$ for full density water between the fuel elements. Hexagonal arrays of Peach Bottom fuel elements ranging from 6 to 37 fuel elements were analyzed.

3.3.3 Spent Fuel Loading

N/A

3.3.3.1 Description of Calculational Model

The number of Peach Bottom fuel elements was varied from 6 to 37 and the analyses were done with and without moderation and reflection for these criticality analyses. The number of fuel elements was varied by removing the fuel elements from an outer surface of the hexagonal model. As an example, four elements along one surface were removed to change the MCNP model for 37 elements (Case 26C-1), to the model for 33 elements (Case 26C-2). Figure 33 illustrates a Peach Bottom fuel element. Typical Peach Bottom arrays used in these analyses are shown in Figures 34, 35, 36 and 37. The fuel elements and the graphite reflector and spine were modeled both dry and containing entrained water (saturated). Table 24 summarizes the modeled configuration.

Fuel compact composition types A and C in Table 29 were used for the criticality analyses to make the Type II fuel elements which are the majority of the fuel elements, as shown in Table 30. As shown in Table 29 and 30, Type II fuel is the combination with the maximum amount of U235 and the minimum amount of thorium, rhodium, or poison in the spines. It is therefore the most reactive element.

Table 24
Modeled Configuration

Region	Documented Configuration		Modeled Configuration	
	Material (g/cc)	**Dimensions, cm**	**Material (g/cc)**	**Dimensions, cm**
Spine Description				
Spine	Graphite (2.107)	OR=2.225 Length=228.6	Graphite (2.107)	OR=2.225 Length=228.6
Fuel Description				
Fuel	UC_2 & ThC_2 (2.143)	IR=2.2225 OR=3.429	UC_2 & ThC_2 (2.143)	IR=2.225 OR=3.429
		Length=228.6		Length=228.6
Reflector Description				
Reflector	Graphite (2.107)	IR=3.429 OR=4.445	Graphite (2.107)	IR=3.429 OR=4.445
		Length=228.6		Length=228.6
Basket Tube				
Tube	SS-304 (7.92)	IR=4.917 OR=5.08	SS-304 (7.92)	IR=4.917 OR=5.08
		Length=228.6		Length=228.6
Canister				
Canister	SS-304 (7.92)	IR=21.755 OR=22.86	SS-304 (7.92)	IR=21.755 OR=22.86
		Length=397.29		Length=397.29

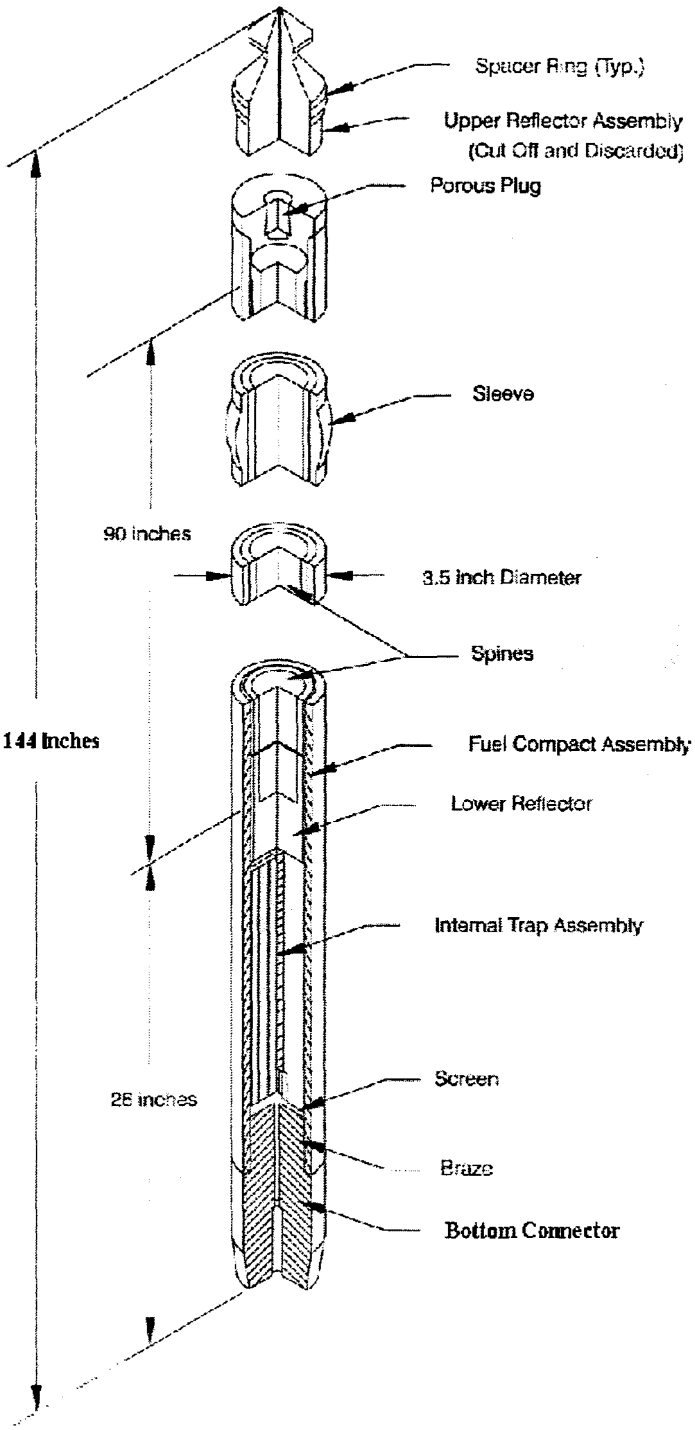


Figure 33
Peach Bottom Fuel Element

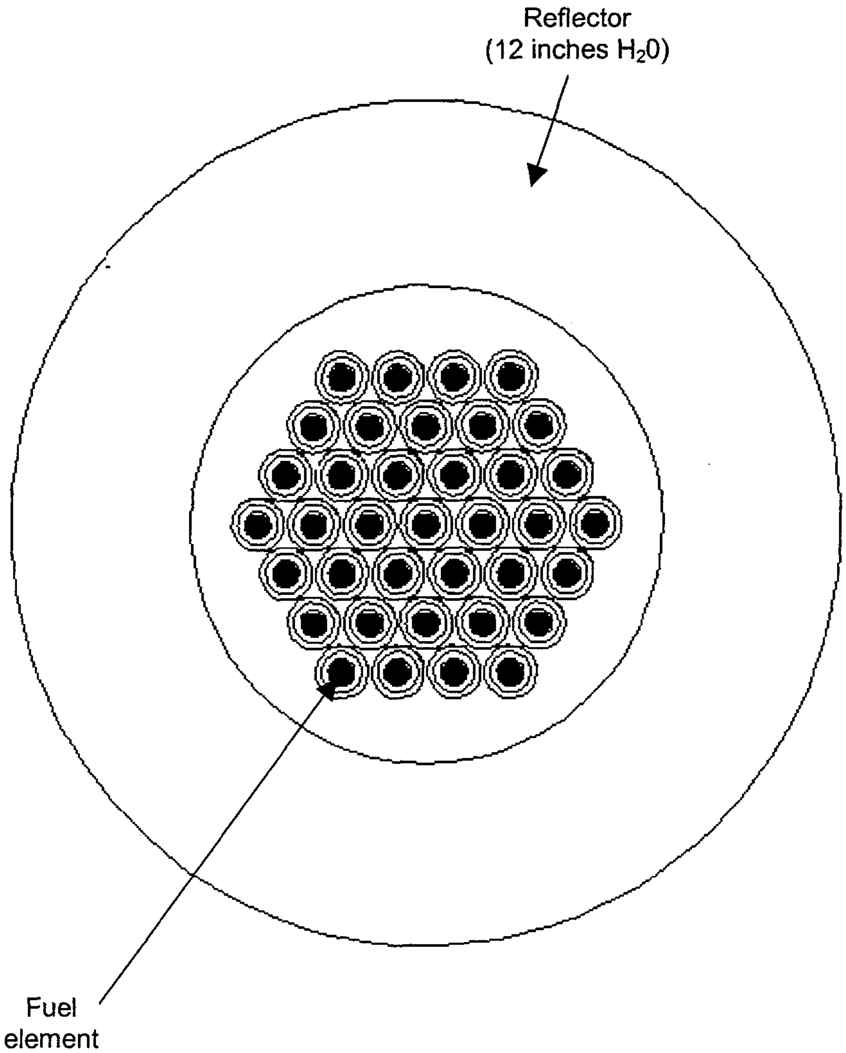


Figure 34
Cross Section of MCNP Model with 37 Peach Bottom Fuel Elements.

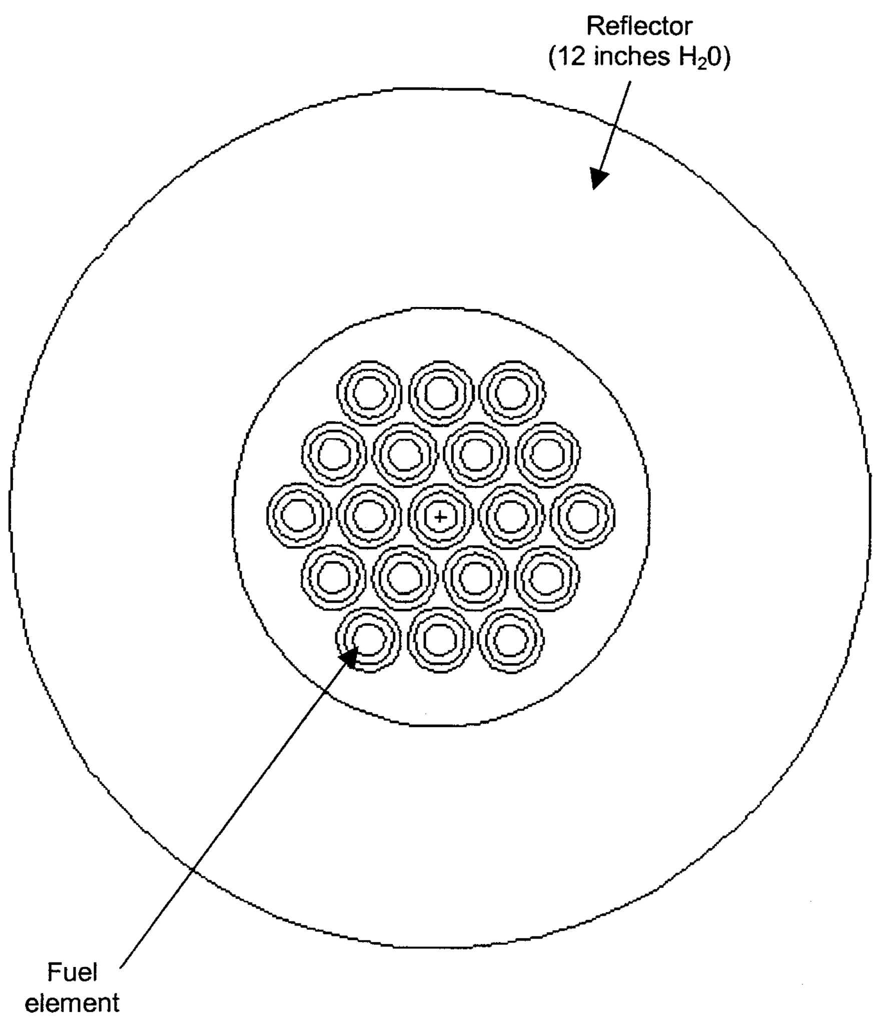


Figure 35
Cross Section View of MCNP Model with 19 Peach Bottom Fuel Elements in a Hexagonal Array Within a Water Reflector.

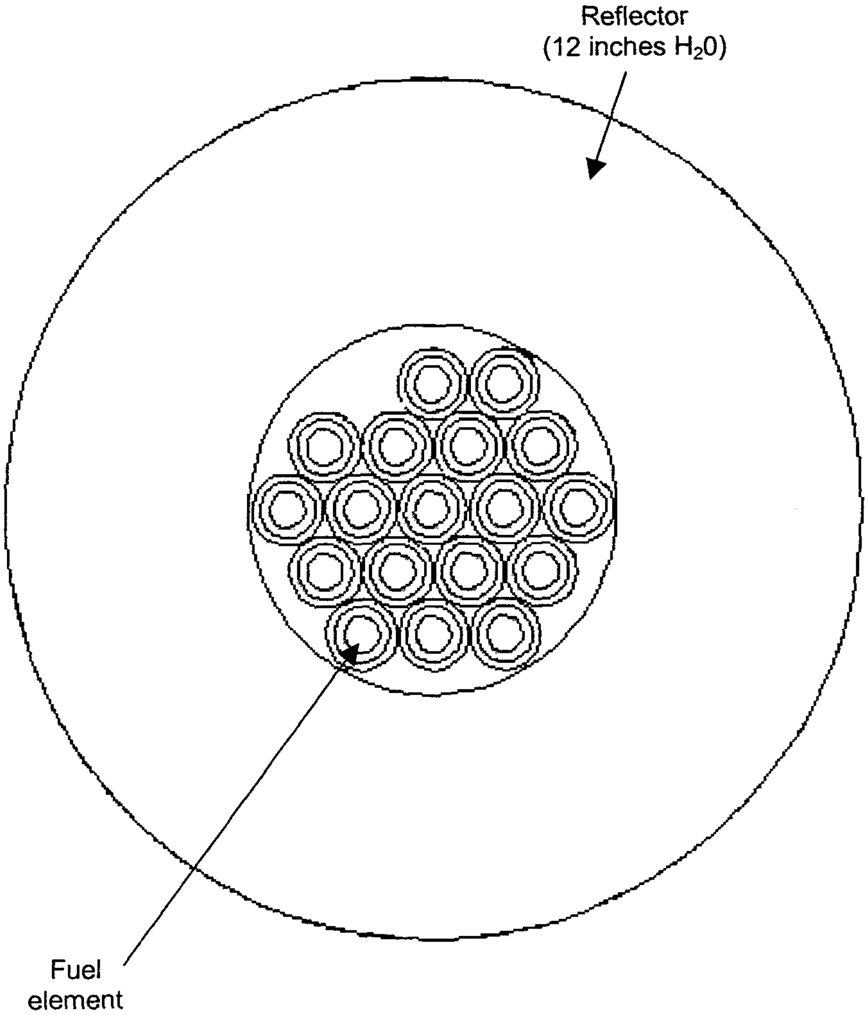


Figure 36
Cross Section View of MCNP Model with 18 Peach Bottom Fuel Elements in a Hexagonal Array Within a Water Reflector.

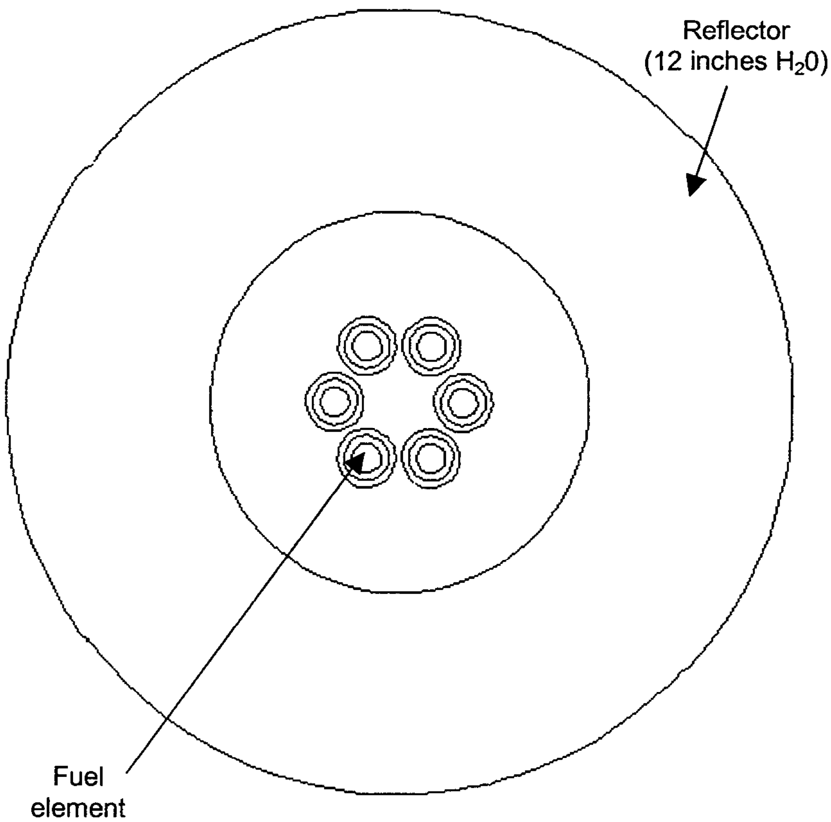


Figure 37
Cross Section View of MCNP Model with 6 Peach Bottom Fuel Elements in a Hexagonal Array Within a Water Reflector.

3.3.3.2 Regional Densities

Table 25
Peach Bottom Fuel Atom Densities

		Fuel Type A	**Fuel Type C**
		Atom	Atom
Component	Isotope	Density	Density
		(atom/b-cm)	(atom/b-cm)
Fuel ρ=2.575 g/cm^3			
	Th-232	8.284E-04	8.284E-04
	U-234	2.459E-06	2.459E-06
	U-235	1.523E-04	1.523E-04
	U-236	8.128E-07	8.128E-07
	U-238	7.827E-06	7.827E-06
	Carbon	8.754E-02	8.754E-02
	Rhodium	0.000E+00	1.226E-05
	Hydrogen	1.380E-02	1.380E-02
	Oxygen	6.898E-03	6.898E-03
	Total (Saturated)[a]	1.092E-01	1.092E-01
	Total (Dry)	8.853E-02	8.855E-02
Reflectors ρ=2.107 g/cm^3			
	Carbon	9.526E-02	
	Hydrogen	1.380E-02	
	Oxygen	6.898E-03	
	Total (Saturated)[a]	1.160E-01	
	Total (Dry)	9.526E-02	
Spine ρ=2.057 g/cm^3			
	Carbon	9.276E-02	
	Hydrogen	1.380E-02	
	Oxygen	6.898E-03	
	Total (Saturated)[a]	1.135E-01	
	Total (Dry)	9.276E-02	

(a) The analyses in this document considered both the saturated and the dry fuel.

3.3.4 Criticality Calculations

3.3.4.1 Calculational Methodology

The MCNP Monte Carlo radiation transport program, MCNP4B2, Monte Carlo N-Particle Transport Code System, CCC-660, Radiation Safety Information Computational Center, Oak Ridge National Laboratory, Oct 1997 (MCNP1997) was used for the criticality calculations.

3.3.4.2 Fuel Loading and Other Contents Optimization

Hexagonal arrays of Peach Bottom fuel elements ranging from 6 to 37 fuel elements were analyzed.

3.3.4.3 Criticality Results

The criticality analyses for moderated conditions with the 18 elements in a hexagonal array and 0.1 cm separation distance edge to edge shows that 18 Peach Bottom fuel elements will have a maximum value of $k_{eff} + 2\sigma = 0.913$ for full density water between the fuel elements. Hexagonal arrays of Peach Bottom fuel elements ranging from 7 to 37 fuel elements were analyzed. Results of the calculation are shown in Tables 26 and 27 and Figures 38 through 43.

3.3.5 References

Fuel 2000, Section C, Attachment C-A-A, DOE Contract No. DE-AC07-00ID13729, 'Fuel and Fuel Package Descriptions.

D: Fuel Elements Dry, Reflected, with no Water Between Elements. 0.1 cm Separation Edge to Edge Between Elements.			
Case D	**k_{eff}**	**Standard Deviation ± 1σ**	**Number of Elements**
26D-1	0.545	± 0.00074	37
26D-2	0.503	± 0.00074	33
26D-3	0.474	± 0.0007	30
26D-4	0.441	± 0.00067	27
26D-5	0.407	± 0.00062	24
26D-6	0.368	± 0.00061	21
26D-7	0.343	± 0.00059	19
26D-8	0.304	± 0.00056	16
26D-9	0.262	± 0.0005	13
26D-10	0.220	± 0.00044	10
26D-11	0.171	± 0.0004	7

Table 27
Peach Bottom Criticality as a Function of Moderation for 19 Fully Reflected and Saturated Fuel Elements. The elements are in a hexagonal array with 0.1 cm edge to edge separation.

Case	k_{eff}	Standard Deviation ± 1σ	Water Density (g/cm^3)
27-1	0.9309	± 0.00078	1
27-2	0.9293	± 0.00054	0.95
27-3	0.9272	± 0.00055	0.9
27-4	0.9262	± 0.00055	0.85
27-5	0.9227	± 0.00055	0.8
27-6	0.9160	± 0.00078	0.7
27-7	0.9069	± 0.00078	0.6
27-8	0.8995	± 0.00079	0.5
27-9	0.8866	± 0.00079	0.4
27-10	0.8745	± 0.00082	0.3
27-11	0.8597	± 0.00084	0.2
27-12	0.8422	± 0.0008	0.1
27-13	0.8318	± 0.0008	0.05
27-14	0.8284	± 0.00078	0.025

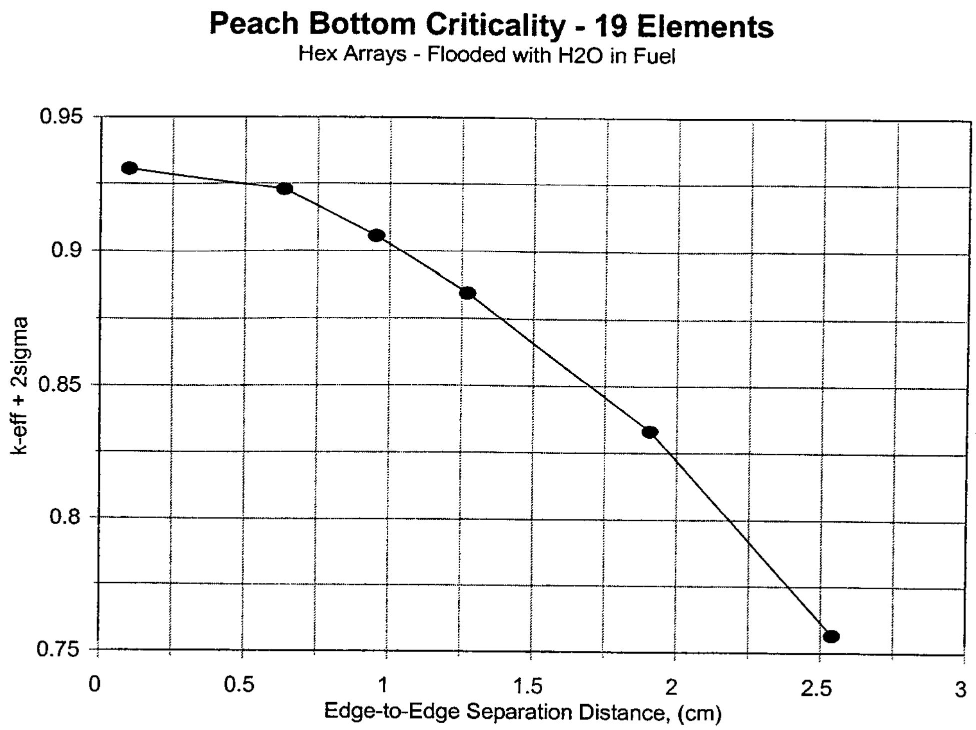


Figure 38

Calculated Criticality as a Function of Separation Distance for 19 Peach Bottom Fuel Elements in a Hexagonal Array. The fuel, the graphite reflectors, and the spine are assumed saturated with water. The array is fully flooded and water reflected.

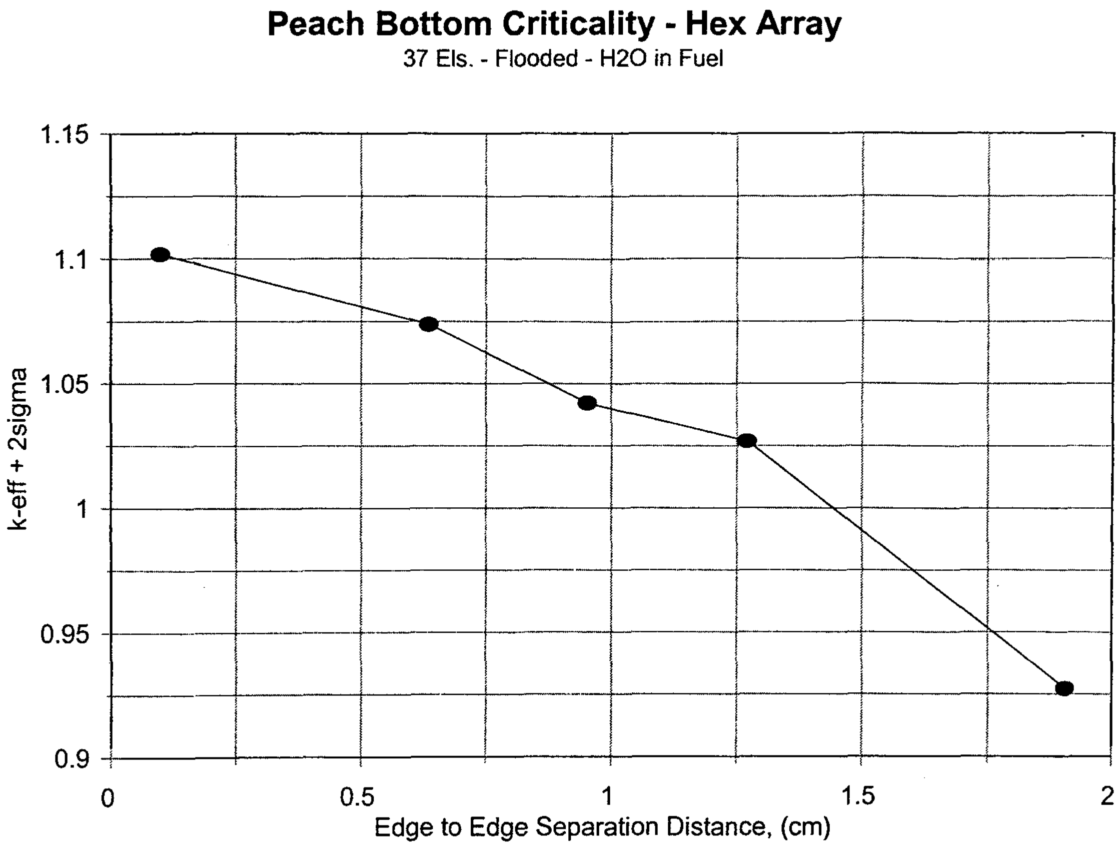


Figure 39
Calculated Criticality as a Function of Separation Distance for 37 Peach Bottom Fuel Elements in a Hexagonal Array. The fuel, the graphite reflectors, and the spine are assumed saturated with water. The array is fully flooded and water reflected.

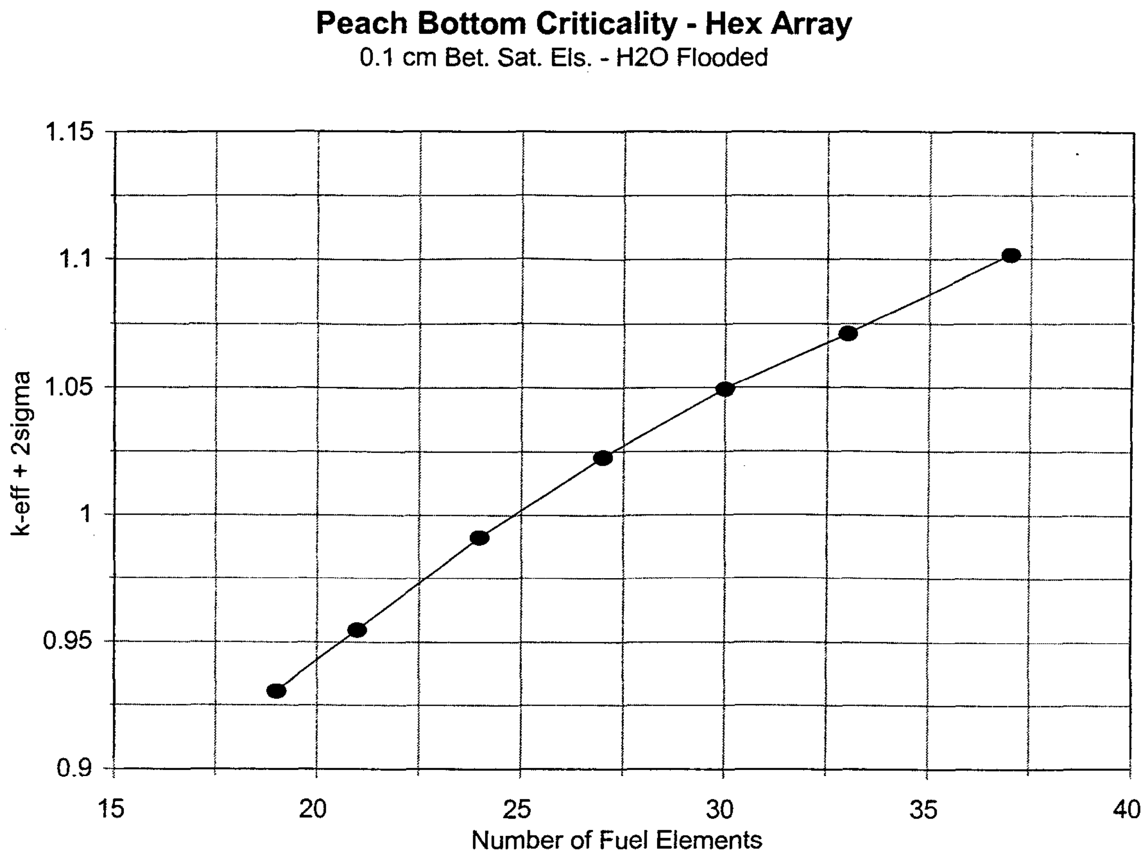


Figure 40
Calculated Criticality as a Function of Number of Fuel Elements for Peach Bottom Fuel Elements in a Hexagonal Array. The fuel, the graphite reflectors, and the spine are assumed saturated with water. The array is fully flooded and water reflected. The elements are separated by 0.1 cm edge to edge.

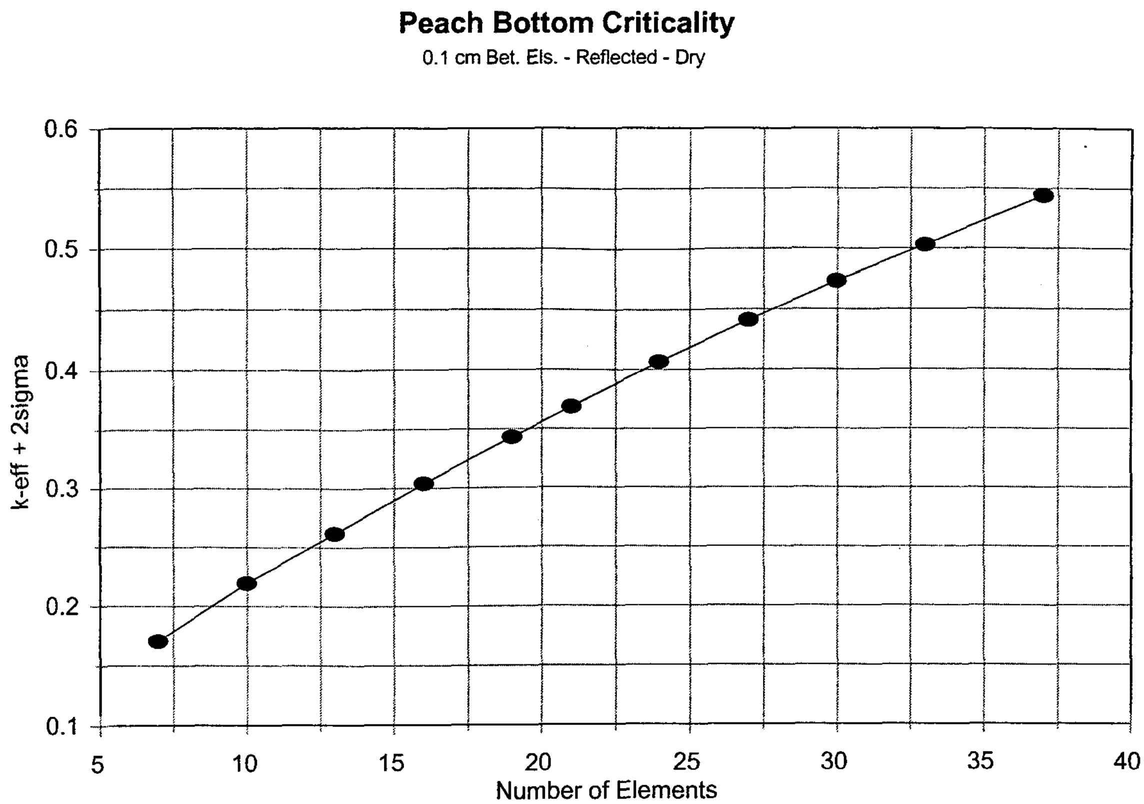


Figure 41
Calculated Criticality as a Function of Number of Fuel Elements for Peach Bottom Fuel Elements in a Hexagonal Array. The fuel, the graphite reflectors, and the spine are assumed dry. The array is water reflected with no water between the fuel elements. The elements are separated by 0.1 cm edge to edge

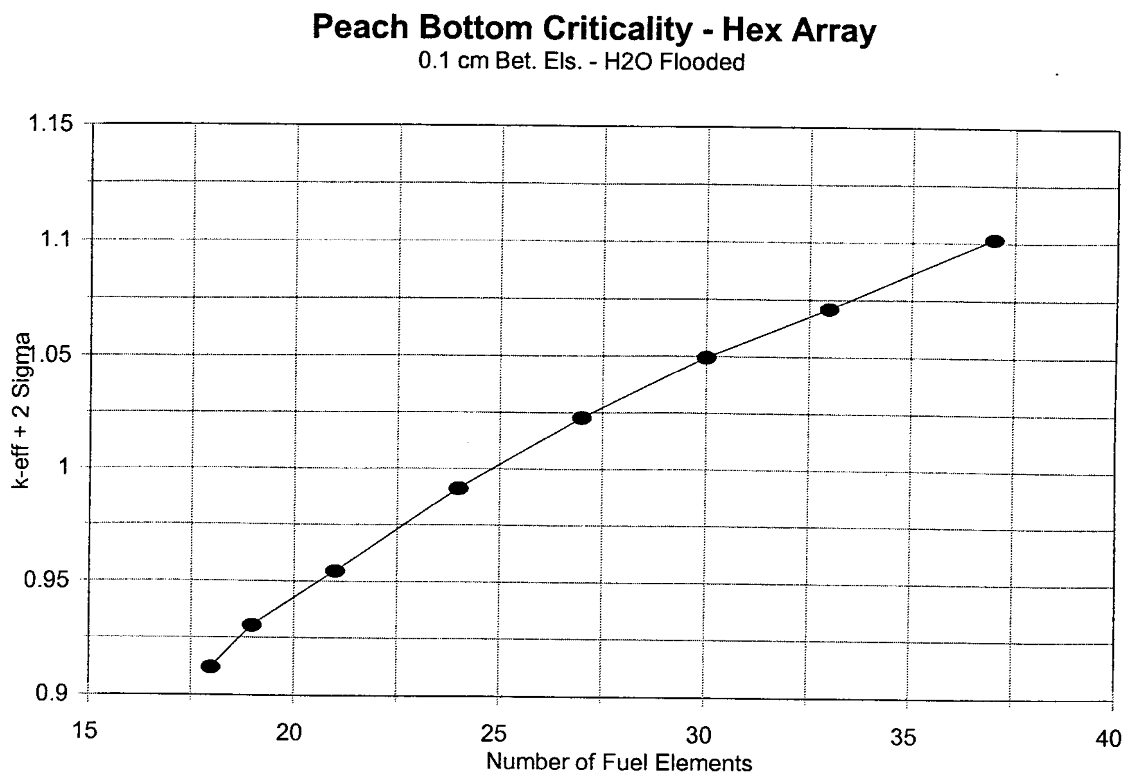


Figure 42
Calculated Criticality as a Function of Number of Fuel Elements for Peach Bottom Fuel Elements in a Hexagonal Array. The fuel, the graphite reflectors, and the spine are saturated. The array is water reflected with full density water between the fuel elements. The elements are separated by 0.1 cm edge to edge The model for the 18 fuel elements was similar to that for the 19 elements except that an exterior element was removed.

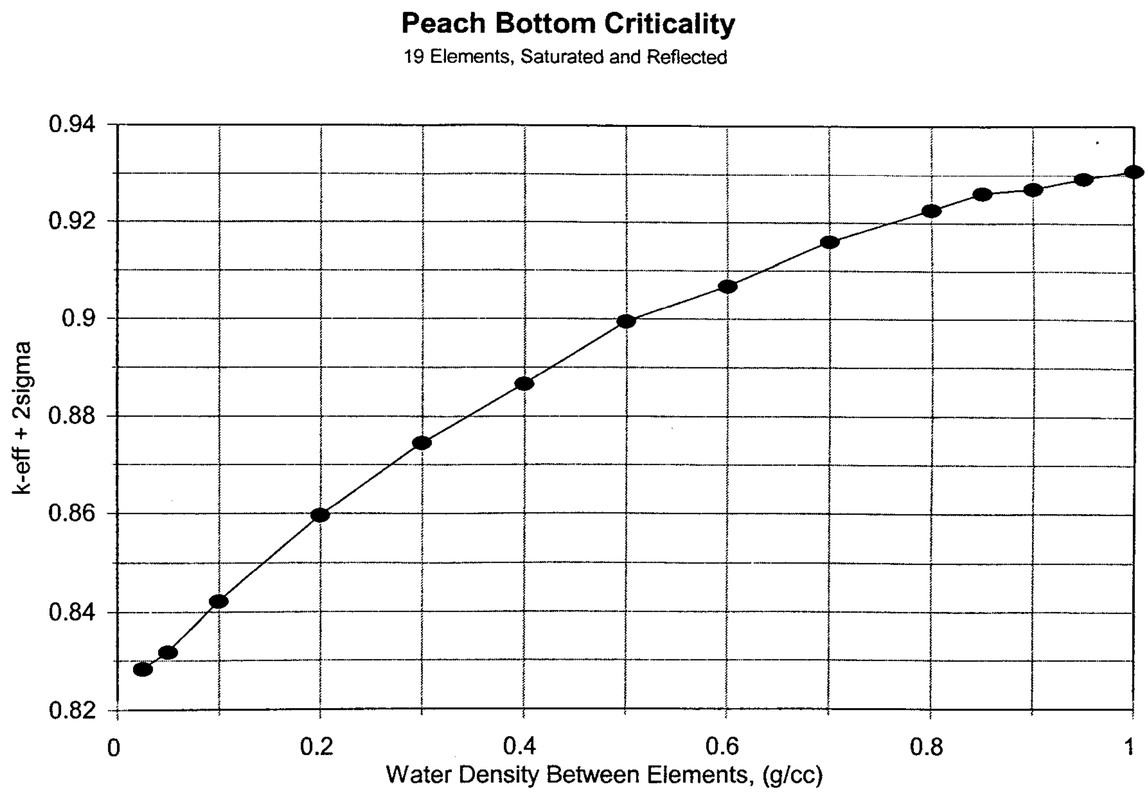


Figure 43
Peach Bottom Criticality as a Function of Moderation. The model contains 19 fuel elements in a hexagonal array separated by 0.1 cm edge to edge. The array is fully reflected and the fuel elements are saturated.

3.4 PEACH BOTTOM CANISTERS IN STORAGE TUBES

3.4.1 Criticality Evaluation

The purpose of this calculation is to calculate the reactivity of Peach Bottom ISF canisters filled with 10 elements and placed in the storage tubes. The reactivity of a single tube up to an infinite array of tubes was evaluated as a function of moderation and reflection. The results of these calculations are used in the nuclear criticality safety assessment for handling the Peach Bottom spent fuel canisters in the ISF Facility. This calculation was used as the basis for estimating the reactivity associated with the movement of a filled canisters past another filled canister.

3.4.2 Discussion and Results

The maximum calculated value of reactivity was $k_{eff} + 2\sigma = 0.496$ for an infinite array of storage tubes at optimum spacing, 1.1 cm edge to edge. This is more reactive than will be encountered with the actual storage tube spacing. The criticality analyses for the stored fuel show that the reactivity does not change significantly if the storage vault is flooded or if the storage tube steel walls were replaced with water. The movement of one filled canister past another filled canister is not a possibility but it does bound the reactivity associated with any type of charging accident. Reactivity of double stacking in a tube is less because the neutron interaction between side-by-side canisters is greater than the interaction between canisters end-to-end.

3.4.3 Spent Fuel Loading

A Peach Bottom fuel element contains 173.2 grams of ^{235}U, which results in a total of 1.73 kilograms of ^{235}U for a Peach Bottom ISF basket containing 10 Peach Bottom fuel elements.

3.4.4 Model Specification

3.4.4.1 Description of Calculational Model

The Peach Bottom fuel elements were modeled using the dimensions in Figure 1-1(Fuel 2000, Section C-A-A), which is included in this document as Figure 44. Table 1-4 describes the fuel elements and is included here as Table 28, the fuel compositions in Table 1-1 (Fuel 2000) are included in Table 29. Table 1-2 (Fuel 2000) is included as Table 30 and shows the four different types of fuel elements that were fabricated and used in the Peach Bottom reactor. Tables 29 and 30 indicate that fuel compacts were types A,B,C, and D and fuel elements are types I,II,III, and IV. The majority of elements were type II, which were also the most reactive, and the majority of fuel compacts were type C. Therefore the Type C fuel compact composition was used for these criticality calculations. The fuel elements and the graphite reflector and spine were analyzed both dry and containing entrained water (saturated). Table 31 summarizes the model configurations.

The Peach Bottom fuel storage basket loaded with 10 fuel elements was analyzed for a number of wet and dry conditions. The basket was modeled in the canister in a storage tube. These analyses used reflecting planes to model arrays of 2 storage tubes, 4 storage tubes, and an infinite array of storage tubes. The infinite array was also analyzed with the storage tube metal replaced with water. Views of the model are included as Figures 45, 46, and 47. The fuel elements are loaded into the ISF fuel baskets and the fuel basket is then placed in the ISF canister which is then inserted into the storage tubes.

Table 28
Physical Fuel Configuration for Peachbottom Fuel Elements.

Element Shape	Right circular cylindrical rod
Element Dim.	3.5" O. D. x 12' long
Compact Shape	Flat annular cylinders (A doughnut shape)
Compact Dimension	2.7" O. D. X 2.98" long. Center hole 1.75" dia.
Element "Cladding" Material	Low-permeability Graphite and nuclear-grade graphite
Compact "Cladding" Material	None (Graphite matrix was not designed to be cladding)
No. Of compacts/element	30 compacts
Enrichment	93.15%
Active Fuel Length	89" – 90"
Fuel Meat	UC, ThC particles
Particle Cladding	Pyrolytically deposited carbon (PyC). Monocoated
Particle Cladding thickness	55 +/- 10 um
Particle Diameter	Between 210 and 595 um
Added material:	
Spines:	
• Solid spines, Dim.	1.75" O. D. x 30" long
• Hollow Spines, Dim.	1.75" O. D. x 30" long (hole = 0.89" dia.)
Burnable Poison Compacts	
• Shape	Solid cylindrical pellets
• Poison Compact, Dim.	0.89" O. D. x 2.0" long
• Poison material	ZrB_2 particles pressed into a graphite matrix
• Poison particle diameter	100 um
• Stainless Steel Screen	18-8 SST
• Internal trap	Activated Charcoal
• Brazing ring	Silicon
• Thermocouple (Instrumented elements only)	Inconel sheath, tungsten-rhenium, chromel-alumel Nb-1% Zr sheath
• Bottom Connector (Instrumented)	Graphite, stainless steel, Inconel

Table 29
Peachbottom Fuel Compact Loading (in grams)

Compact Type	A	B	C	D
Description	**Standard**	**Heavy Rhodium**	**Light Rhodium**	**Heavy Thorium**
Th^{232}	52.10	52.10	52.10	115.36
U^{234} *	0.156	0.156	0.156	0.082
U^{235}	9.70	9.70	9.70	5.14
U^{236} *	0.052	0.052	0.052	0.028
U^{238}	0.505	0.505	0.505	0.268
Rh^{103}	0	1.028	0.342	0
Carbon	285.00	285.00	285.00	273.00

* U^{234} and U^{236} loading were not required. These are the maximum amounts expected in the fully enriched fuel material.

Table 30
Peachbottom Types of Fuel Elements Based on Nuclear Properties

	Fuel Element Type			
Description	**I Heavy Rhodium**	**II Light Rhodium**	**III Light Rhodium with burnable poison**	**IV Heavy Thorium: Light Uranium**
Spine	Solid Graphite	Solid Graphite	Hollow with poison compacts	Solid Graphite
	Compact Type			
In upper 9 inches	A	A	A	D
In middle 54 inches	B	C	C	D
In lower 27 inches	A	A	A	D
Number of types in a nominal core loading	54	588	60	102

Table 31
Modeled Configuration

Region	Documented Configuration		Modeled Configuration	
	Material (g/cc)	**Dimensions, cm**	**Material (g/cc)**	**Dimensions, cm**
		Spine Description		
Spine	Graphite (2.107)	OR=2.225 Length=228.6	Graphite (2.107)	OR=2.225 Length=228.6
		Fuel Description		
Fuel	UC_2 & ThC_2 (2.143)	IR=2.2225 OR=3.429	UC_2 & ThC_2 (2.143)	IR=2.225 OR=3.429
		Length=228.6		Length=228.6
		Reflector Description		
Reflector	Graphite (2.107)	IR=3.429 OR=4.445	Graphite (2.107)	IR=3.429 OR=4.445
		Length=228.6		Length=228.6
		Basket Tube		
Tube	SS-304 (7.92)	IR=4.917 OR=5.08	SS-304 (7.92)	IR=4.917 OR=5.08
		Length=228.6		Length=228.6
		Canister Cylinder		
Canister Cylinder	SS-304 (7.92)	IR=21.755 OR=22.86	SS-304 (7.92)	IR=21.755 OR=22.86
		Length=397.29		Length=397.29
		Storage Tube		
Storage Tube	C. Steel (7.82)	IR=24.4475 OR=25.4	C. Steel (7.82)	IR=23.495 OR=24.4475
		Length=607.06		Length=395.29

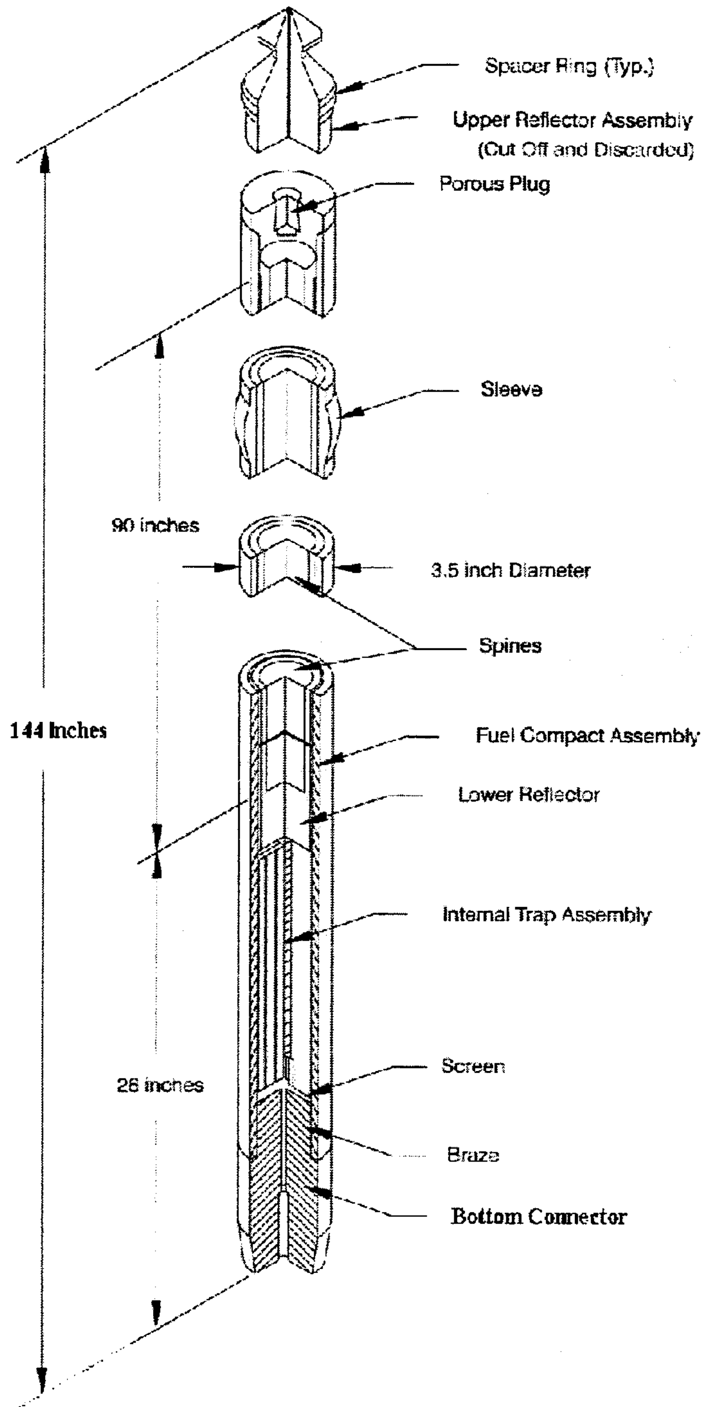


Figure 44
Peach Bottom Fuel Element

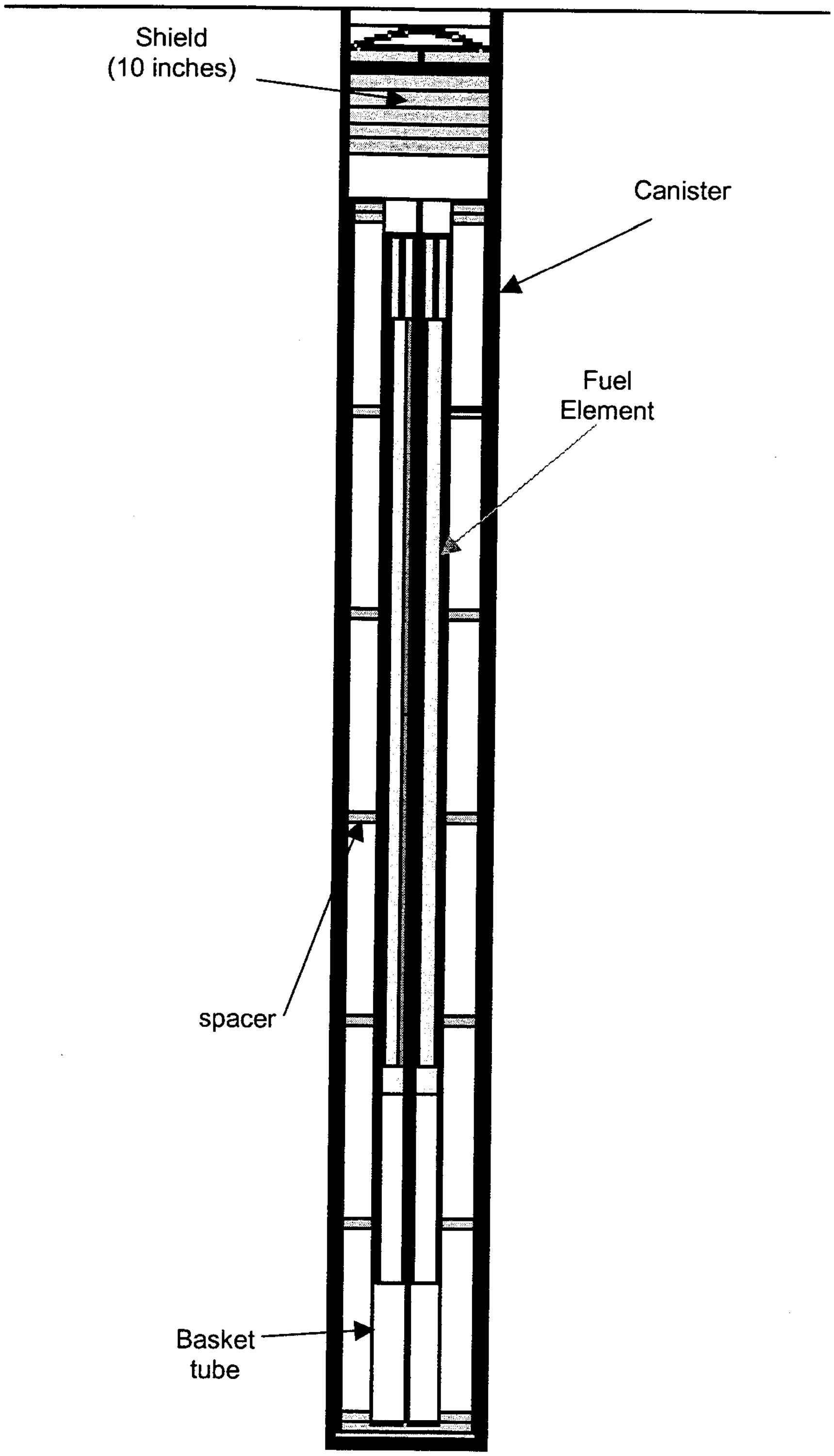


Figure 45
Elevation View of Peach Bottom Fuel Elements in Storage Canister.

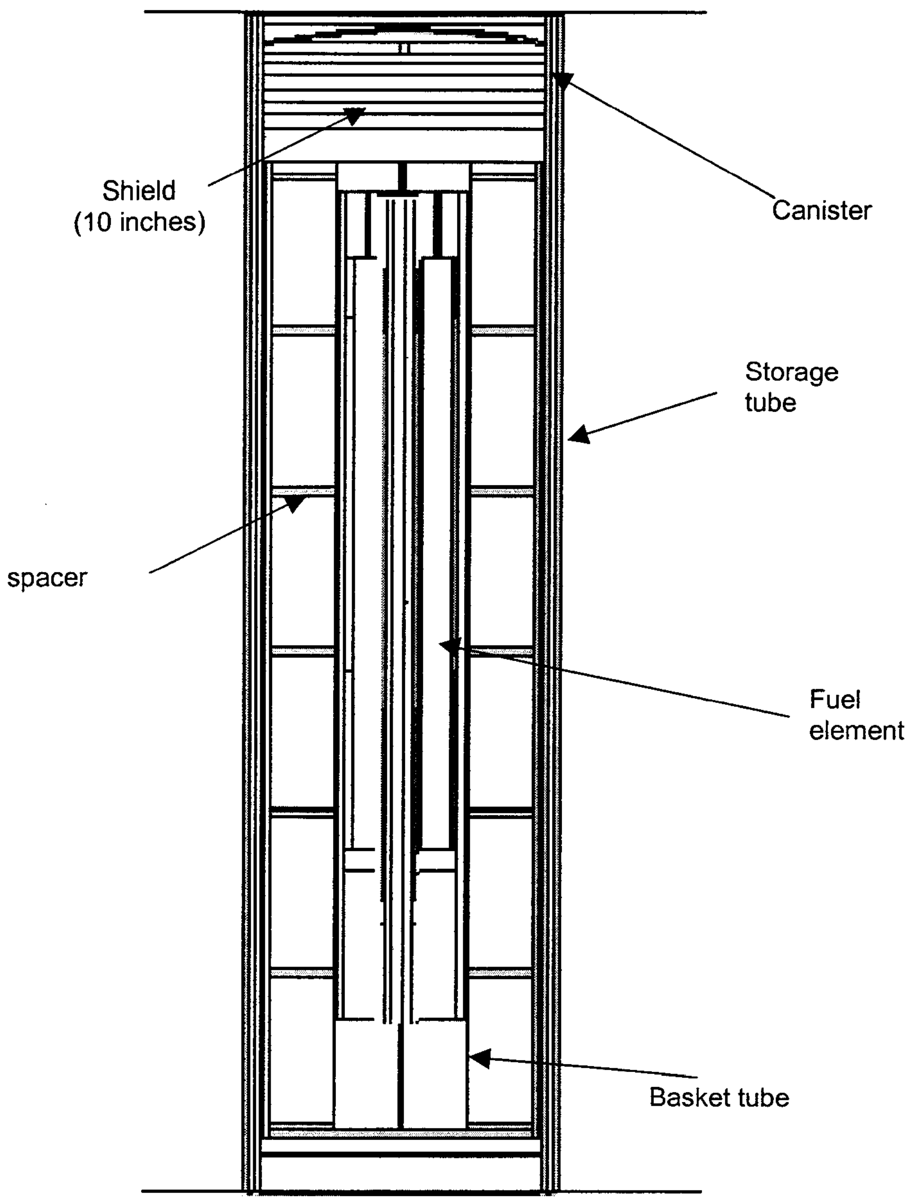
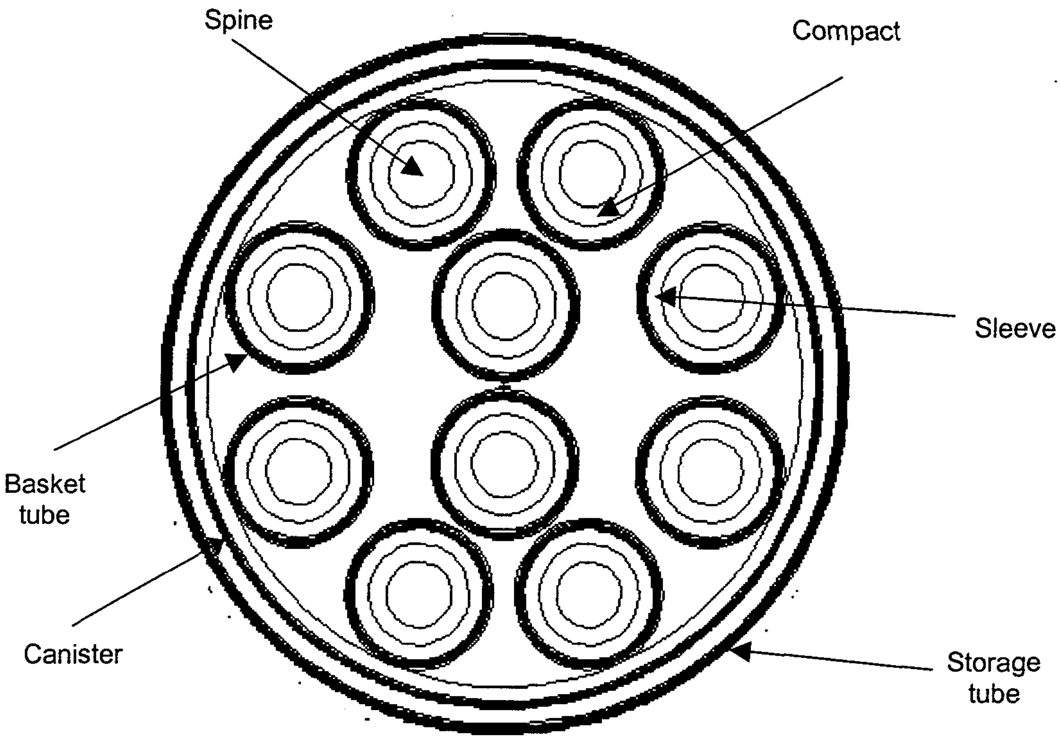


Figure 46
Elevation View of Peach Bottom Fuel Elements in Storage Canister and the Canister Storage Tube.



Peach Bottom Basket with 10 fuel Elements
in Canister and Storage Tube

Figure 47
Cross Section Through MCNP Model of the 18 Inch Diameter Basket Loaded with 10 Peach Bottom Fuel Elements. The basket is in the Canister in the Storage Tube.

3.4.4.2 Regional Densities

Table 32
Peach Bottom Fuel Atom Densities.

		Fuel Type A	Fuel Type C
Component	**Isotope**	**Atom Density (at/bn-cm)**	**Atom Density (at/bn-cm)**
Fuel			
ρ=2.575 g/cm^3	Th-232	8.284E-04	8.284E-04
	U-234	2.459E-06	2.459E-06
	U-235	1.523E-04	1.523E-04
	U-236	8.128E-07	8.128E-07
	U-238	7.827E-06	7.827E-06
	Carbon	8.754E-02	8.754E-02
	Rhodium	0.000E+00	1.226E-05
	Hydrogen	1.380E-02	1.380E-02
	Oxygen	6.898E-03	6.898E-03
	Total (Saturated)[(a)]	1.092E-01	1.092E-01
	Total (Dry)	8.853E-02	8.855E-02
Reflectors			
ρ=2.107 g/cm^3	Carbon	9.526E-02	
	Hydrogen	1.380E-02	
	Oxygen	6.898E-03	
	Total (Saturated)[(a)]	1.160E-01	
	Total (Dry)	9.526E-02	
Spine			
ρ=2.057 g/cm^3	Carbon	9.276E-02	
	Hydrogen	1.380E-02	
	Oxygen	6.898E-03	
	Total (Saturated)[(a)]	1.135E-01	
	Total (Dry)	9.276E-02	

(a) The analyses in this document considered both the saturated and the dry fuel.

3.4.5 Criticality Calculations

3.4.5.1 Calculational Methodology

The MCNP Monte Carlo radiation transport program, MCNP4B2, Monte Carlo N-Particle Transport Code System, CCC-660, Radiation Safety Information Computational Center, Oak Ridge National Laboratory, Oct 1997 (MCNP1997) was used for the criticality calculations

3.4.5.2 Fuel Loading and Other Contents Optimization

A Peach Bottom fuel element contains 173.2 grams of ^{235}U, which results in a total of 1.73 kilograms of ^{235}U for a Peach Bottom basket containing 10 Peach Bottom fuel elements.

3.4.5.3 Criticality Results

Table 33 summarizes the results of the criticality calculations. The maximum calculated value of reactivity was $k_{eff} + 2\sigma = 0.496$ for an infinite array of storage tubes at optimum spacing of 1.1 cm edge to edge. This is more reactive than will be encountered with the actual storage tube spacing. The criticality analyses for the stored fuel show that the reactivity does not change significantly if the storage vault is flooded or if the storage tube steel walls were replaced with water. The fuel is expected to be dry rather than the saturated condition used in the most reactive configuration.

3.4.6 References

Fuel 2000. Section C, Attachment C-A-A, DOE Contract No. DE-AC07-00ID13729, 'Fuel and Fuel Package Descriptions'.

Table 33
Peach Bottom MCNP Criticality Analysis for Basket Modeled with 10 Fuel Elements in a Canister in a Storage Tube.

A: Steel Storage Tube Modeled Explicitly							
Case	Storage Tube Array[(a)]	Fuel Condition	Moderated Between Elements	Reflected Around Elements	H2O bet. Between Storage Tubes	Calculation Results: k-eff	Calculation Results: 1 Sigma
33A-1	1 Tube	dry	No	No	N.A.	0.0183	5E-05
33A-2	1 Tube	dry	Yes	Yes	N.A.	0.383	0.0003
33A-3	1 Tube	Sat.	Yes	Yes	N.A.	0.439	0.00032
33A-4	2 Tubes	Sat.	Yes	Yes	No	0.443	0.00032
33A-5	4 Tubes	Sat.	Yes	Yes	No	0.461	0.00032
33A-6	Inf. Array	Sat.	Yes	Yes	No	0.461	0.00032
33A-7	Inf. Array	Sat.	Yes	Yes	Yes	0.495	0.00031
B. Model As Above Except Storage Tubes Replaced With Water							
33B-1	Inf. Array	Sat.	Yes	Yes	No	0.455	0.00032
33B-2	Inf. Array	Sat.	Yes	Yes	Yes	0.477	0.00032

(a) The storage tube arrays are modeled as a square array with edge to edge separation distances of 1.1 cm for all applicable analyses.

3.5 PEACH BOTTOM AND TRIGA CANISTERS IN STORAGE TUBES

3.5.1 Criticality Evaluation

The purpose of this calculation is to calculate the reactivity of the Peach Bottom and TRIGA spent fuel element storage canisters in storage tubes in the storage facility array configuration. The results of these calculations will be used in a nuclear criticality safety assessment for handling the Peach Bottom spent fuel canisters in ISF Facility.

3.5.2 Discussion and Results

The maximum calculated value of reactivity was $k_{eff} + 2\sigma = 0.838$ for a single Peach Bottom fuel canister in a storage tube combined with a single TRIGA fuel canister in a storage tube for a storage tube spacing of 34 inches on centers. There is no criticality concern for the spent fuel storage facility as long as the fuel elements are retained within the basket and canister.

The neutron interactions between the Peach Bottom fuel and the TRIGA fuel for the side-by-side configuration are greater than the interactions for an end-to-end configuration. Thus, the results serve as an upper limit for the end-to-end configuration.

3.5.3 Spent Fuel Loading

A Peach Bottom fuel element contains 173.2 grams of ^{235}U, which results in a total of 1.73 kilograms of ^{235}U for a Peach Bottom basket containing 10 Peach Bottom fuel elements. A TRIGA fuel element contains 45.24 grams of ^{235}U, which results in a total of 2.44 kilograms of ^{235}U for a full TRIGA basket containing 54 TRIGA fuel elements. The nominal TRIGA fuel element fissile material content specified in the ISF Contract (39g ^{235}U) was adjusted to account for variations in post-1964 fuel elements to provide the most reactive and bounding source term for criticality analysis. Manufacturing variations resulted in a higher uranium content and a greater H:Zr atom ratio.

3.5.4 Model Specification

3.5.4.1 Description of Calculational Model

The Peach Bottom fuel element dimensions are included as Figure 48. Fuel element descriptions are included in Table 34. The fuel compositions are included as Table 35. Table 36 shows the four different types of fuel elements that were fabricated and used in the Peach Bottom reactor. Fuel compacts of Type C are the most reactive and the majority of fuel elements from Table 36. Therefore, the Type C fuel composition was used for these criticality calculations. The Peach Bottom fuel elements and graphite reflector and spine are modeled containing entrained water (saturated) for these analyses. The saturated fuel elements include a 20% void fraction that is assumed to be filled with water.

The Peach Bottom fuel elements were modeled using the dimensions from Figure 48 and Tables 34 and 35.

The spent fuel ISF storage basket in each ISF canister in the ISF storage tube were modeled as shown in Figure 49. The Peach Bottom fuel storage basket contains 10 fuel elements as shown in Figure 50. The fuel elements are stored in fuel storage tubes in the basket in the locations as shown in Figure 50.

The TRIGA fuel elements were modeled using the dimensions in Figure 3-1 and the material descriptions in Table 3-1, both of Fuel 2000. Figure 3-1 is included as Figure 51 and Table 3-1 is included as Table 37. The fuel rod ISF basket model was based on the basket drawing, shown in Figure 52. The TRIGA ISF canister containing two baskets is shown in Figure 53. The TRIGA impact plate and canister head details are included in Figure 53. Each basket contains 54 fuel elements as shown in the cross-section view through the MCNP model in Figure 54. The fuel elements are stored in the ISF basket in storage pipes in the locations as shown in Figure 54. Figure 55 is a plan view for the MCNP model of the TRIGA and Peach Bottom fuel canisters and storage tubes. A poison rod is placed in the TRIGA basket center position and it is not possible to load fuel elements in that position. No credit was taken for the neutron poison rod in the calculation. Table 38 summarizes the modeled configuration.

The water density between the storage tubes was varied from dry (0 g/cm^3) to 1 g/cm^3 to evaluate the sensitivity of the reactivity as a function of interspersed moderation. Results from varying the density are shown in Table 41.

Table 34
Physical Fuel Configuration for Peachbottom Fuel Elements

Element Shape	Right circular cylindrical rod
Element Dim.	3.5" O. D. x 12' long
Compact Shape	Flat annular cylinders (A doughnut shape)
Compact Dimension	2.7" O. D. X 2.98" long. Center hole 1.75" dia.
Element "Cladding" Material	Low-permeability Graphite and nuclear-grade graphite
Compact "Cladding" Material	None (Graphite matrix was not designed to be cladding)
No. Of compacts/element	30 compacts
Enrichment	93.15%
Active Fuel Length	89" – 90"
Fuel Meat	UC_2, ThC_2 particles
Particle Cladding	Pyrolytically deposited carbon (PyC). Monocoated
Particle Cladding thickness	55 +/- 10 um
Particle Diameter	Between 210 and 595 um
Added material:	
Spines:	
• Solid spines, Dim.	1.75" O. D. x 30" long
• Hollow Spines, Dim.	1.75" O. D. x 30" long (hole = 0.89" dia.)
Burnable Poison Compacts	
• Shape	Solid cylindrical pellets
• Poison Compact, Dim.	0.89" O. D. x 2.0" long
• Poison material	ZrB_2 particles pressed into a graphite matrix
• Poison particle diameter	100 um
• Stainless Steel Screen	18-8 SST
• Internal trap	Activated Charcoal

• Brazing ring	Silicon
• Thermocouple (Instrumented elements only)	Inconel sheath, tungsten-rhenium, chromel-alumel Nb-1% Zr sheath
• Bottom Connector (Instrumented)	Graphite, stainless steel, Inconel

Table 35
Peachbottom Fuel Compact Loading (in grams) (Table 1-1, Fuel 2000)

Compact Type	A	B	C	D
Description	**Standard**	**Heavy Rhodium**	**Light Rhodium**	**Heavy Thorium**
Th^{232}	52.10	52.10	52.10	115.36
U^{234} *	0.156	0.156	0.156	0.082
U^{235}	9.70	9.70	9.70	5.14
U^{236} *	0.052	0.052	0.052	0.028
U^{238}	0.505	0.505	0.505	0.268
Rh^{103}	0	1.028	0.342	0
Carbon	285.00	285.00	285.00	273.00

* U^{234} and U^{236} loading were not required. These are the maximum amounts expected in the fully enriched fuel material.

Table 36
Peachbottom Types of Fuel Elements Based on Nuclear Properties (Table 1-2, Fuel 2000)

	Fuel Element Type			
Description	**I** **Heavy Rhodium**	**II** **Light Rhodium**	**III** **Light Rhodium with burnable poison**	**IV** **Heavy Thorium: Light Uranium**
Spine	Solid Graphite	Solid Graphite	Hollow with poison compacts	Solid Graphite
	Compact Type			
In upper 9 inches	A	A	A	D
In middle 54 inches	B	C	C	D
In lower 27 inches	A	A	A	D
Number of types in a nominal core loading	54	588	60	102

Table 37
Physical Characteristics of the Standard TRIGA Fuel Elements

Characteristics	Al Clad Elements	Standard SST Clad Elements
Element dim., in.	1.47 dia x 28 long	1.478 dia x 28.94 long
Geometry of fuel meat	Solid rod	Hollow rod
Effective fuel length, in.	1.41 dia x 14 long	1.435 dia x 15 long
Plenum gap length	NA	0.25 in.
Fuel meat material	$UZrH_1$	$UZrH_{1.7}$
Nominal ^{235}U	36 g	39 g
Nominal $^{Total}U$	180 g	195 g
Nominal fuel meat weight	2250 g	2283 g
Total element weight	2.9 kg	3.4 kg
U ppt size	NA	NA
Burnable poisons	Samarium trioxide	None Used
Poison dim., in.	1.42 dia x 0.05 thick	---
Rod-Cladding gap	NA	NA
Cladding	1100F Al	Type 304 SST
Clad thickness	0.03 in.	0.02 in.
Weld filler material	NA	NA
2 end fixtures	140 g	530 g
2 Graphite end reflectors	1.41 dia x 3.95 long each	1.435 dia x 3.42 long each
Material added to element	None known	0.225 in dia. Zr rod inside hollow fuel rod. Molybdenum disc,[a] 1.435 in. dia. X 0.031 inches thick

(a) Located between the fuel meat and the bottom graphite end reflector, ONLY in elements produced after 4/15/71.

Table 38
Modeled Configuration TRIGA

Region	Documented Configuration		Modeled Configuration	
	Material (g/cc)	**Dimensions, cm**	**Material (g/cc)**	**Dimensions, cm**
Fuel Description				
Fuel (Zr rod)	Zr (6.4)	OR=0.28575 Length=38.1	Zr (6.4)	OR=0.28575 Length=38.1
Fuel (meat)	U-ZrH$_{1.7}$ (6.0875)	IR=0.3175 OR=1.82245	U-ZrH$_{1.7}$ (6.0875)	IR=0.3175 OR=1.82245
		Length=38.1		Length=38.1
Fuel Clad	SS-304 (7.93)	IR=1.82626 OR=1.87706	SS-304 (7.93)	IR=1.82626 OR=1.87706
		Length=55.4736		Length=55.4736
Basket Tube				
Tube	SS-304 (7.92)	IR=2.06 OR=2.2225	SS-304 (7.92)	IR=2.06 OR=2.2225
		Length=91.44		Length=91.44
Canister				
Canister	SS-304 (7.92)	IR=21.6535 OR=22.86	SS-304 (7.92)	IR=7.3152 OR=7.467092
		Length=299.72		Length=95.25

Table 38-A
Modeled Configuration Peach Bottom

Region	Documented Configuration		Modeled Configuration	
	Material (g/cc)	**Dimensions, cm**	**Material (g/cc)**	**Dimensions, cm**
Spine Description				
Spine	Graphite (2.107)	OR=2.225 Length=228.6	Graphite (2.107)	OR=2.225 Length=228.6
Fuel Description				
Fuel	UC_2 & ThC_2 (2.143)	IR=2.2225 OR=3.429	UC_2 & ThC_2 (2.143)	IR=2.225 OR=3.429
		Length=228.6		Length=228.6
Reflector Description				
Reflector	Graphite (2.107)	IR=3.429 OR=4.445	Graphite (2.107)	IR=3.429 OR=4.445
		Length=228.6		Length=228.6
Basket Tube				
Tube	SS-304 (7.92)	IR=4.917 OR=5.08	SS-304 (7.92)	IR=4.917 OR=5.08
		Length=228.6		Length=228.6
Canister				
Canister	SS-304 (7.92)	IR=21.755 OR=22.86	SS-304 (7.92)	IR=21.755 OR=22.86
		Length=397.29		Length=397.29
Storage Tube				
Storage Tube	C. Steel (7.82)	IR=24.4475 OR=25.4	C. Steel (7.82)	IR=23.495 OR=24.4475
		Length=607.06		Length=395.29

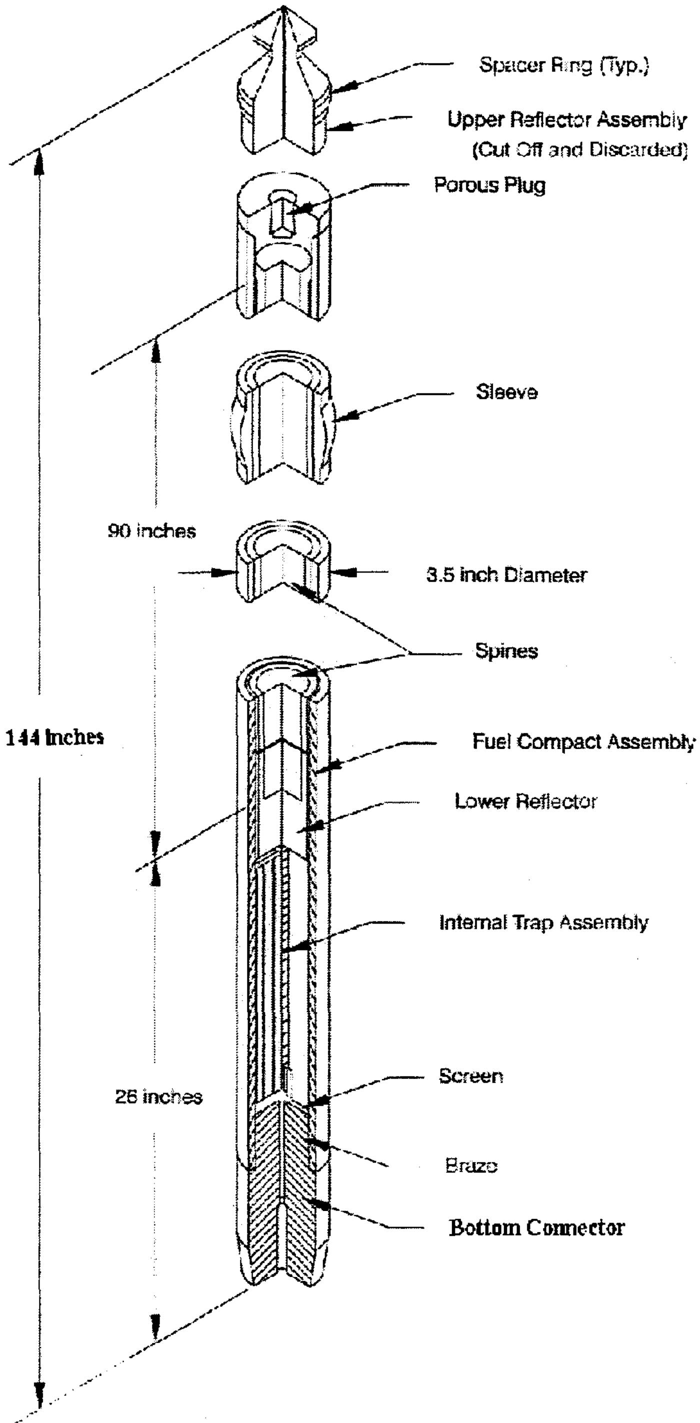


Figure 48
Peach Bottom Fuel Element

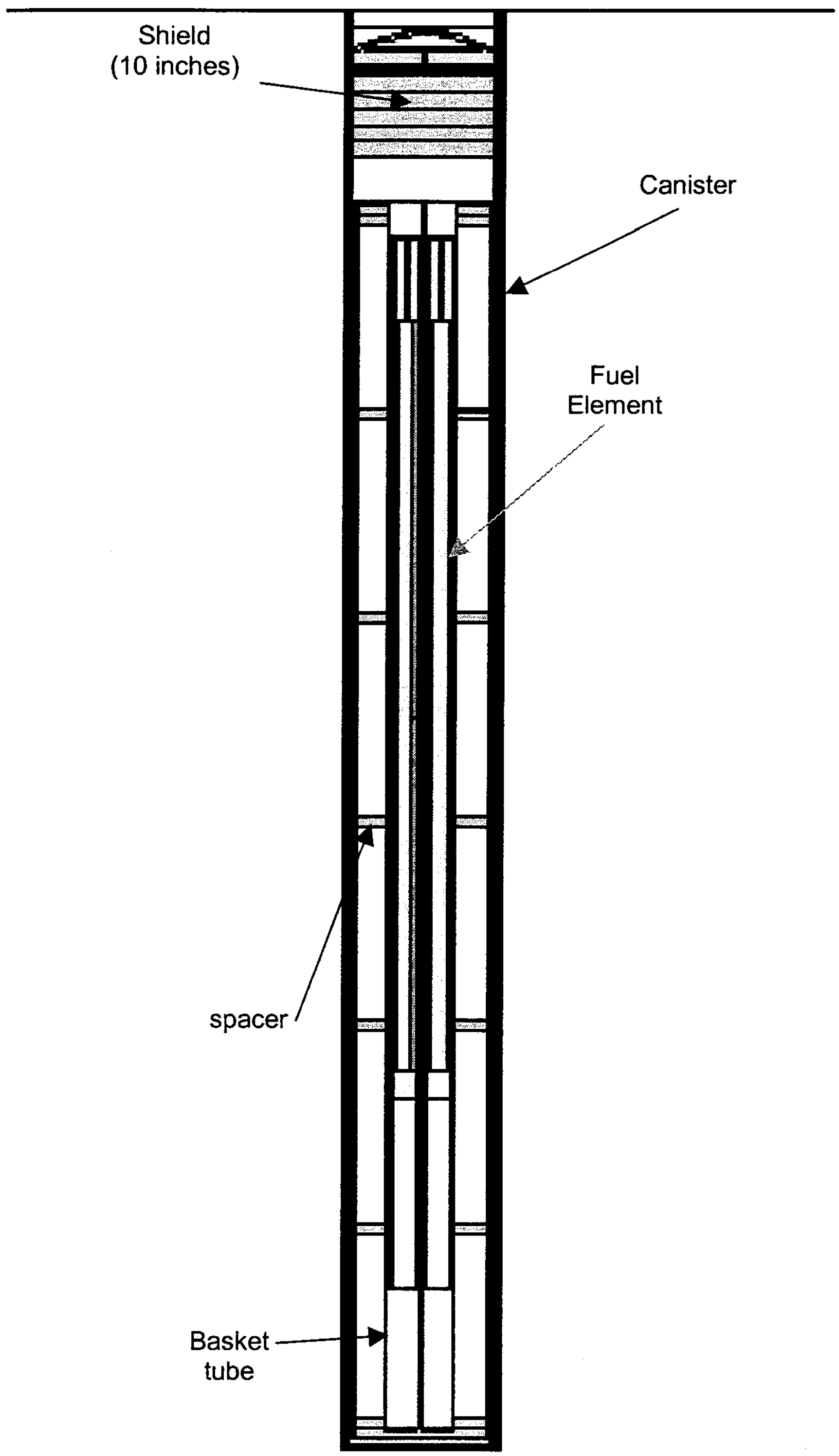
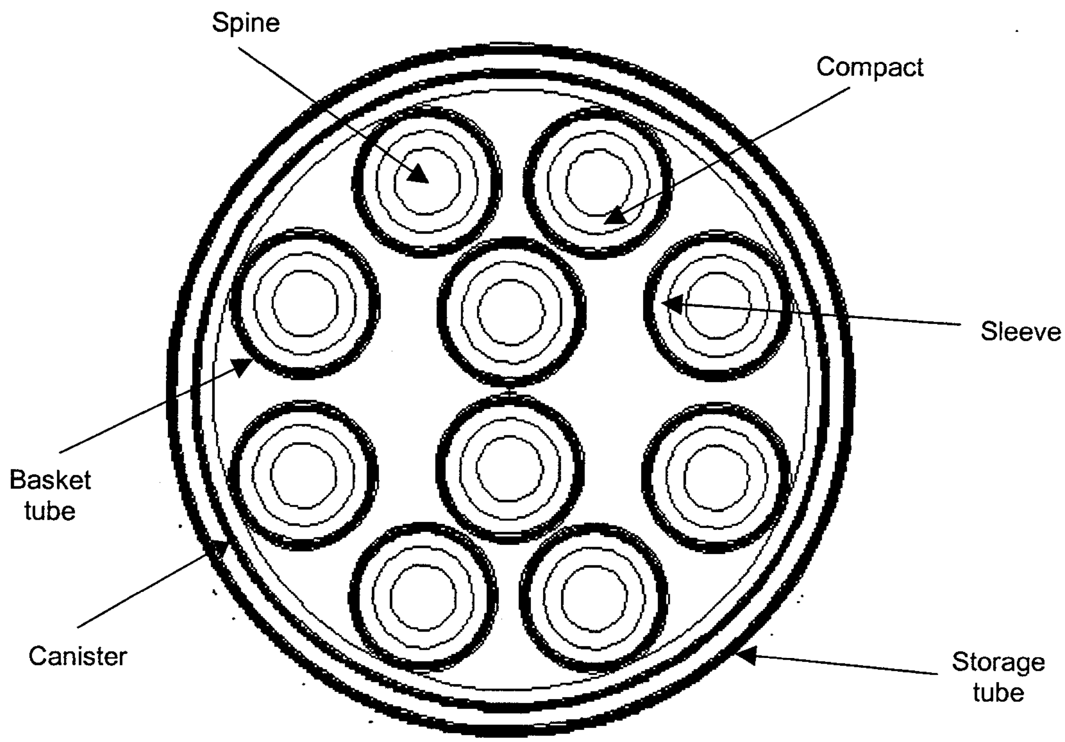


Figure 49
Elevation View of Peach Bottom Fuel Elements in Storage Canister



Peach Bottom Basket with 10 fuel Elements
in Canister and Storage Tube

Figure 50
Cross Section Through MCNP Model of the 18 Inch Diameter Basket Loaded with 10 Peach Bottom Fuel Elements. The Basket is in the Canister in the Storage Tube.

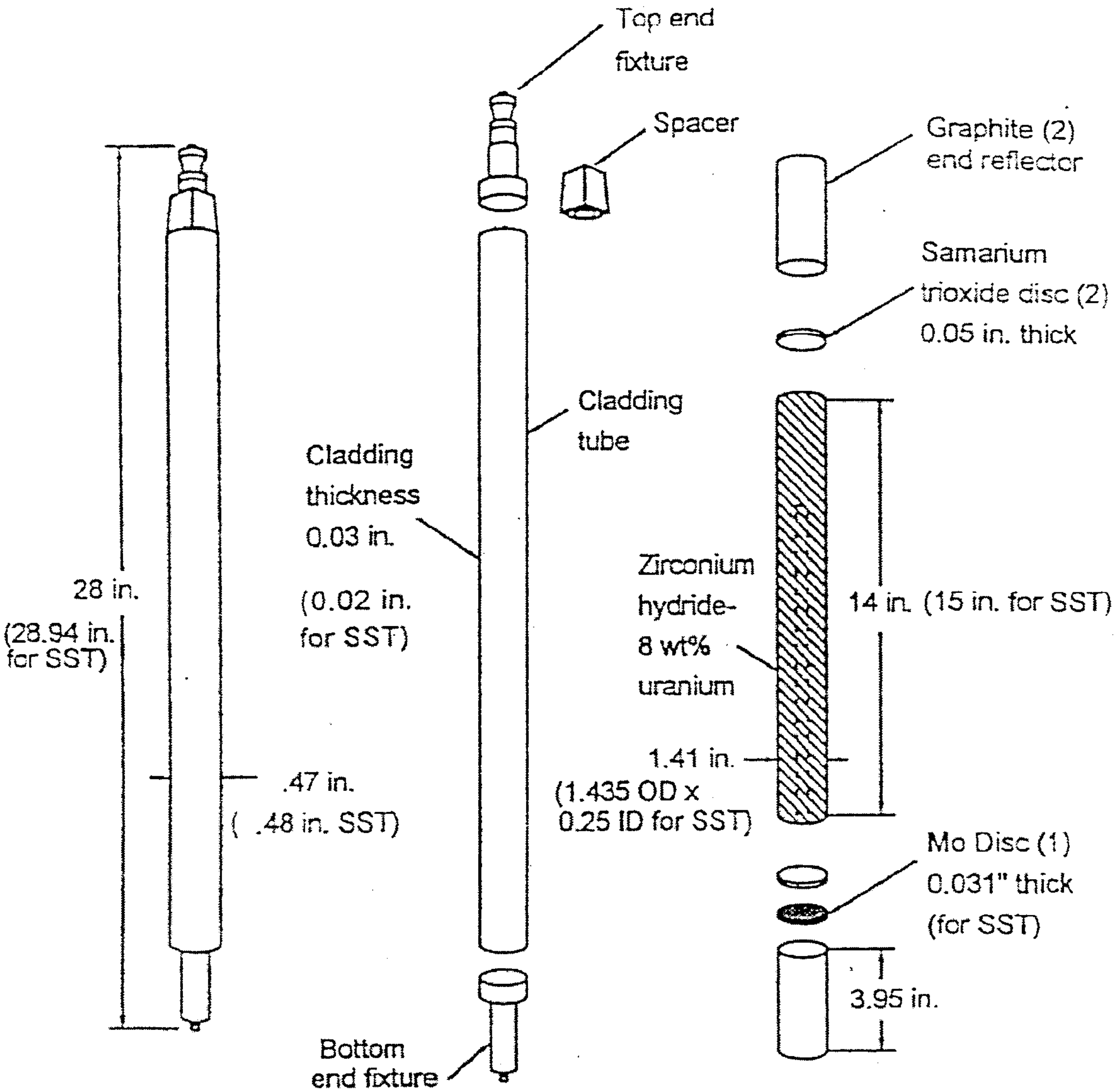


Figure 51
TRIGA Fuel element (Figure 3-1, Fuel 2000)

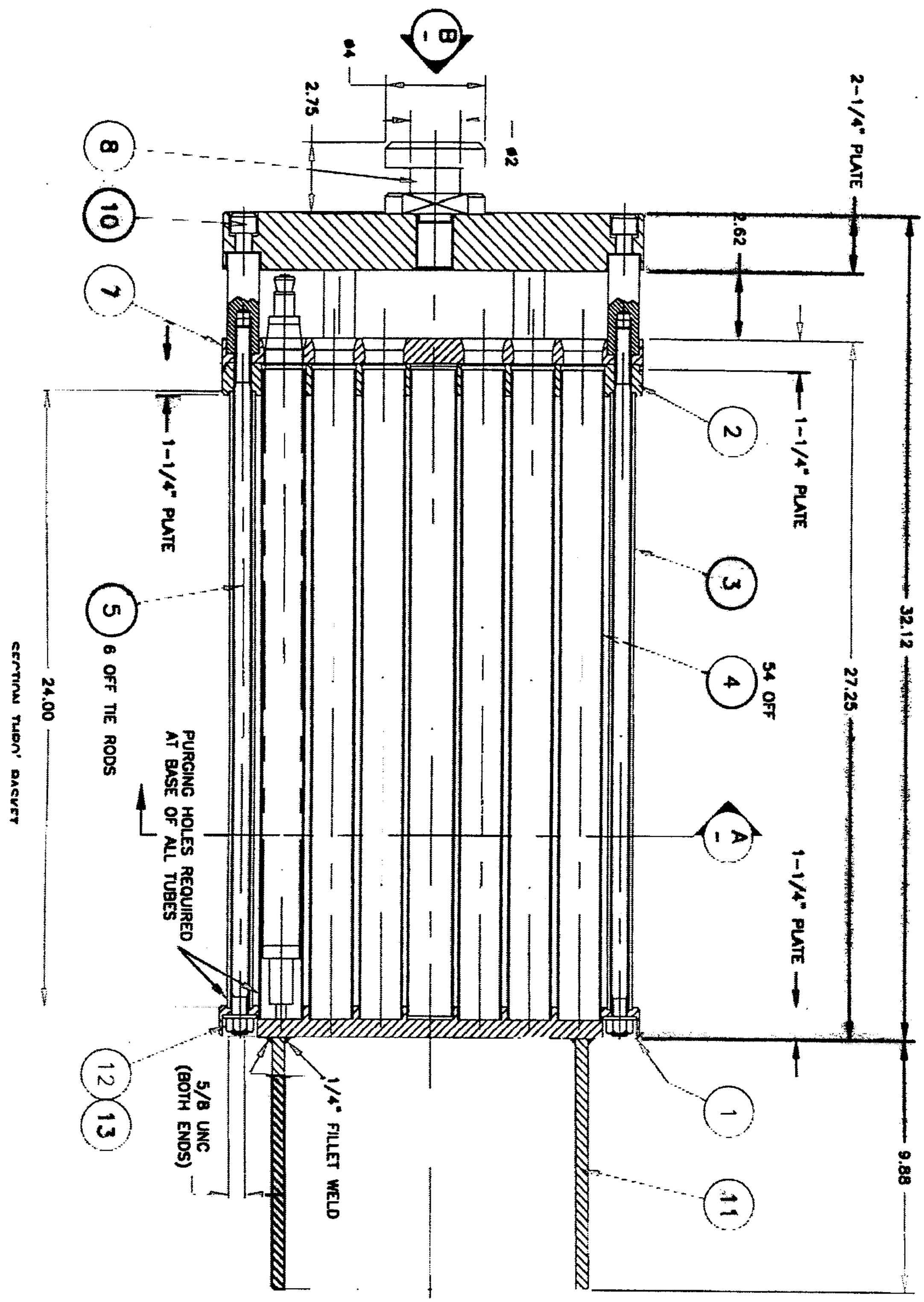


Figure 52
TRIGA Spent Fuel Basket (FW 2000a)

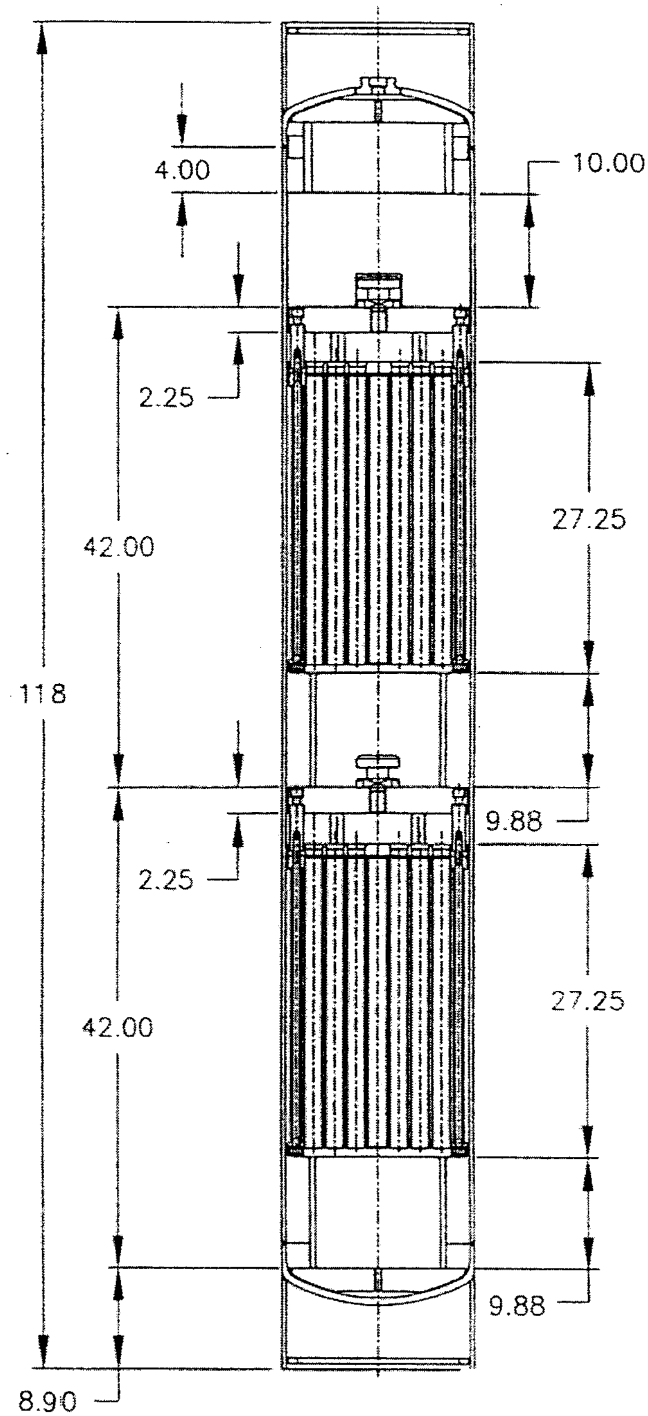


Figure 53
Two TRIGA Baskets in 18 inch Canister (FW 2000b)

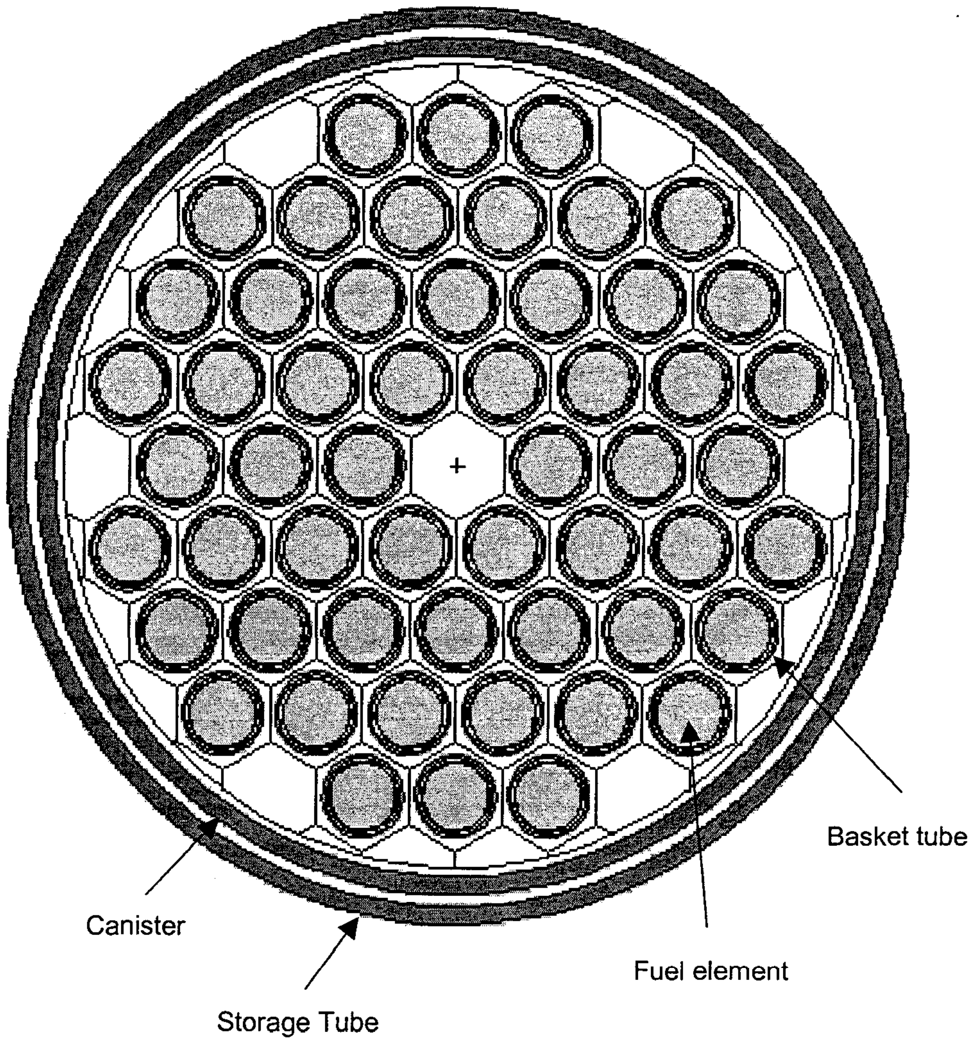


Figure 54
Cross Section from the MCNP Model for the Fueled Regions in the TRIGA Basket in the Storage Canister and Storage Tube

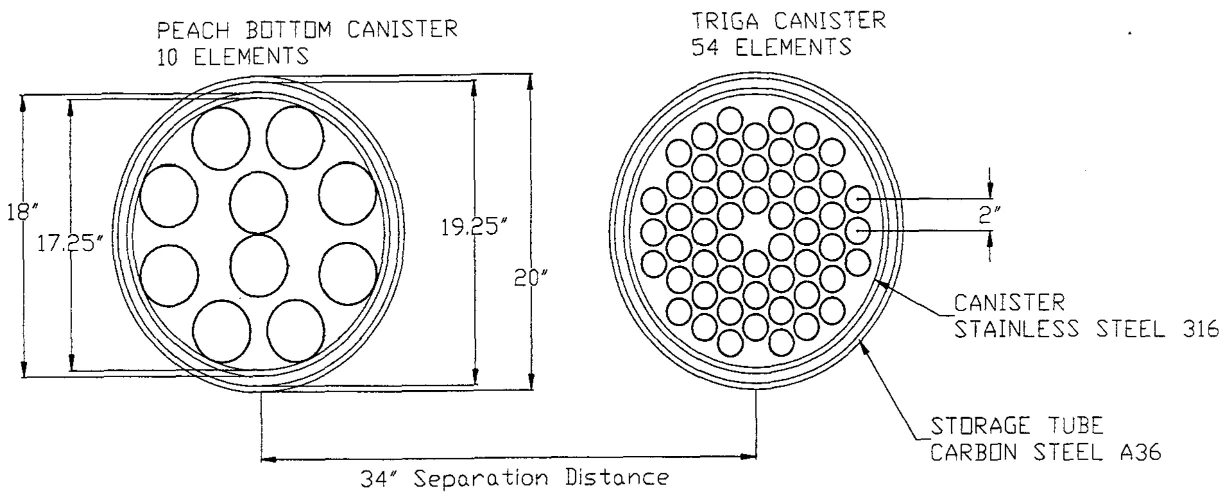


Figure 55
TRIGA and Peach Bottom ISF Fuel Canisters Showing Basic Canister Dimensions and Spacing used in the Criticality Analysis

3.5.4.2 Regional Densities

Table 39
Peach Bottom Fuel Atom Densities

		Fuel Type A	Fuel Type C
Component	**Isotope**	**Atom Density (atom/b-cm)**	**Atom Density (atom/b-cm)**
Fuel ρ=2.34 g/cm^3			
	Th-232	8.284E-04	8.284E-04
	U-234	2.459E-06	2.459E-06
	U-235	1.523E-04	1.523E-04
	U-236	8.128E-07	8.128E-07
	U-238	7.827E-06	7.827E-06
	Carbon	8.754E-02	8.754E-02
	Rhodium	0.000E+00	1.226E-05
	Hydrogen	1.380E-02	1.380E-02
	Oxygen	6.898E-03	6.898E-03
	Total (Saturated)[(a)]	1.092E-01	1.092E-01
	Total (Dry)	8.853E-02	8.855E-02
Reflectors ρ=2.107 g/cm^3			
	Carbon	9.526E-02	
	Hydrogen	1.380E-02	
	Oxygen	6.898E-03	
	Total (Saturated)[(a)]	1.160E-01	
	Total (Dry)	9.526E-02	
Spine ρ=2.057 g/cm^3			
	Carbon	9.276E-02	
	Hydrogen	1.380E-02	
	Oxygen	6.898E-03	
	Total (Saturated)[(a)]	1.135E-01	
	Total (Dry)	9.276E-02	

(a) Note: The analyses assumed that about 20% of the fuel volume was saturated with water. This analysis used the saturated dry fuel.

Table 40
Material Compositions in MCNP TRIGA Analysis

Material	MCNP Isotope	Element Atom Density (atoms/b-cm)
Fuel (6.0875 g/cm^3)	1001	0.036191
	40000	0.021289
	92235	0.000157
	92238	0.000621
	26000	0.001804
	7000	2.362E-05
	8000	6.358E-06
	18000	3.028E-07
Graphite (2.3 g/cm^3)	6012	0.11532
Fe (7.86 g/cm^3)	26000	0.084758

3.5.5 Criticality Calculations

3.5.5.1 Calculational Methodology

The MCNP Monte Carlo radiation transport program, MCNP4B2, MCNP1997 was used for the criticality calculations. All calculations associated with this report were performed using the MCNP4B2 Monte Carlo Code, and the ENDF/B-VI cross section library.

3.5.5.2 Fuel Loading and Other Contents Optimization

A Peach Bottom fuel element contains 173.2 grams of ^{235}U, which results in a total of 1.73 kilograms of ^{235}U for a Peach Bottom basket containing 10 Peach Bottom fuel elements. A TRIGA fuel element contains 45.24 grams of ^{235}U, which results in a total of 2.44 kilograms of ^{235}U for a full TRIGA basket containing 54 TRIGA fuel elements. Note that the TRIGA fuel element was conservatively modeled without the 0.25-inch diameter hole through the center of the fuel. Because the density was not adjusted the resulting fissile mass loading is approximately 3% higher than it would be if the hole were included in the model.

Table 41
MCNP Criticality Analysis for a Peach Bottom Spent Fuel Canister and a TRIGA Spent Fuel Canister in the Storage Tube Storage Configuration

Problem ID	H2O Density Between Storage Tubes (g/cm^3)	k_{eff}	1 σ
Comc4	0	0.534	0.00041
Comc4h	0.02	0.578	0.00043
Comc4g	0.1	0.672	0.00041
Comc4f	0.2	0.691	0.00044
Comc4e	0.4	0.748	0.00042
Comc4d	0.6	0.793	0.00042
Comc4c	0.8	0.821	0.00041
Comc4b	0.9	0.830	0.00042
Comc4a	1.0	0.837	0.00040

Note: The storage tube arrays are modeled with center-to-center separation distances of 34 inches.

3.5.5.3 Criticality Results

The maximum calculated value of reactivity was $k_{eff} + 2\sigma = 0.838$ for a single Peach Bottom fuel canister and a single TRIGA fuel canister in separate storage tubes spaced 34 inches on centers. The criticality analyses for the stored Peach Bottom fuel in an infinite array of fuel canisters in storage tubes showed that the reactivity does not change significantly for a flooded storage vault or if the storage tube steel walls are replaced with water. This is documented in Section 3.4. The maximum calculated value of reactivity for an infinite array of Peach Bottom fuel canisters in storage tubes was $k_{eff} + 2\sigma = 0.496$.

The maximum calculated value of reactivity for an infinite array of TRIGA fuel canisters in storage tubes was $k_{eff} + 2\sigma = 0.748$. This is documented in Section 2.3. Thus there is no criticality concern as long as the fuel elements are intact and retained within the basket and canister.

The neutron interactions between the Peach Bottom fuel and the TRIGA fuel for the side-by-side configuration are greater than the interactions for an end-to-end configuration. Thus, the results serve as an upper limit for the end-to-end configuration.

3.5.6 References

Fuel 2000, Section C, Attachment C-A-A, Contract No. DE-AC07-00ID13729, 'Fuel and Fuel Package Descriptions.

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4.0 SHIPPINGPORT FUEL

4.1 REFLECTOR RODS IN AN INFINITE ARRAY

4.1.1 Criticality Evaluation

Criticality analyses are required for all fuel that will be brought into the ISF storage facility. The only Shippingport components that are currently planned to be stored in the ISF storage vault are the reflector assemblies. Therefore, bounding criticality analyses were performed for the reflector rods. The active region of the fuel rods is composed of reflector pellets (about 140 pellets/rod). This is considered a non-credible event, since it is not possible to create an infinite array of fuel pellets or rods. This case was performed to determine if the Shippingport reflector fuel (Type IV and V assemblies, and loose rods) represents any criticality hazard.

4.1.2 Discussion and Results

These MCNP (MCNP4B2) calculations show that an infinite array of dry reflector pellets will have a k_{eff} of 0.185 (k_{eff} of 0.184 + 2σ=0.001). The array of pellets was considered to be dry because water flooding of the pellets after an accident involving the release of the pellets from the rods is considered incredible.

The calculations show that an infinite array of water moderated reflector rods with an optimum triangular pitch spacing of one inch will have a k_{eff} of 0.652 (k_{eff} of 0.649 +2σ of 0.003). Therefore, reflector assemblies will be critically safe in all credible condition in the ISF Facility.

4.1.3 Spent Fuel Loading

The maximum post irradiation fissile content measured for any rod was 39.7 grams (WAPD-TM-1614). The entire 39.7 grams was assumed to be U-233 for all rods in these calculations.

4.1.4 Model Specification

4.1.4.1 Description of Calculational Model

Calculations were performed for an infinite array of unmoderated reflector pellets, and for an infinite array of moderated rods with varying pitch. The pellet and rod dimensions were taken from WAPD-TM-1208.

The MCNP geometry for the rod calculations is shown in Figures 56 and 57. The model is a single rod with a triangular pitch. The infinite array is generated by putting reflecting surfaces on all sides of the model. An inch of water was placed above and below the rod prior to the reflecting surfaces on the top and bottom. Table 42 summarizes the modeled configuration.

Table 42
Modeled Configuration

Region	Documented Configuration		Modeled Configuration	
	Material (g/cc)	**Dimensions, cm**	**Material (g/cc)**	**Dimensions, cm**
Reflector Description				
Pellet	$^{233}UO_2$-ThO_2 (9.69)	R=0.9414 Length=1.88	$^{233}UO_2$-ThO_2 (9.69)	R=0.9414 Length=1.88
Clad	Zr (6.49)	IR=0.950 OR=1.057	Zr (6.49)	IR=0.950 OR=1.057
		Length=256.39		Length=256.39

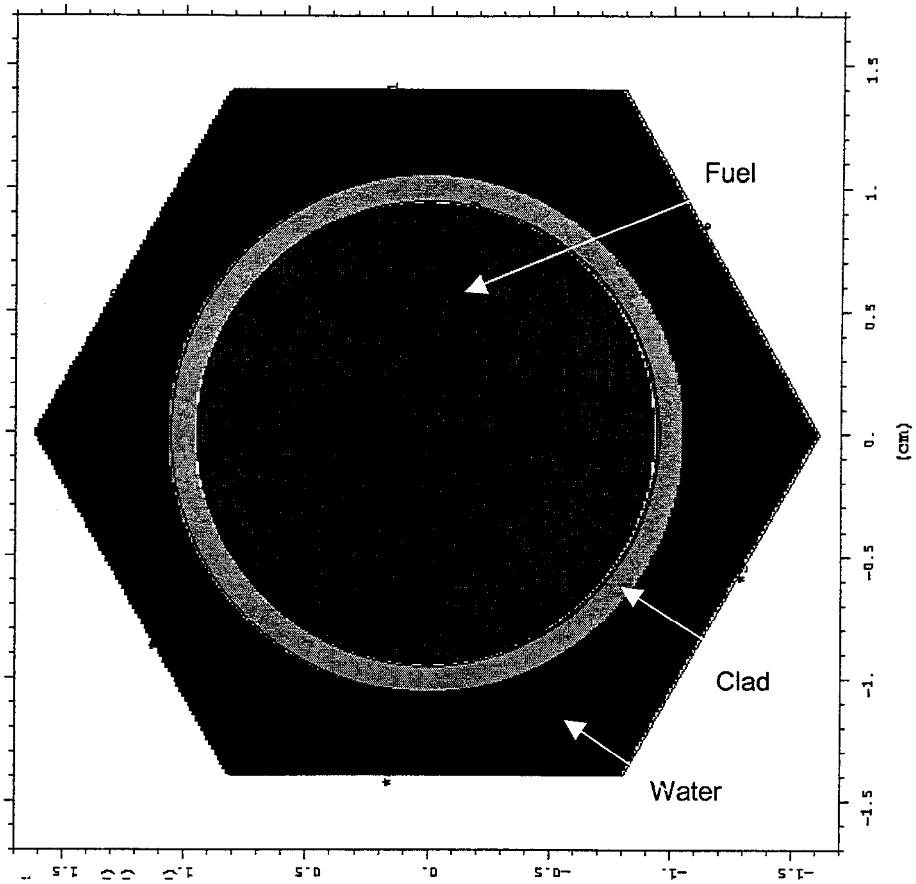

Figure 56
Water Moderated Reflector Rod Cell, Reflected on all 6 Surfaces

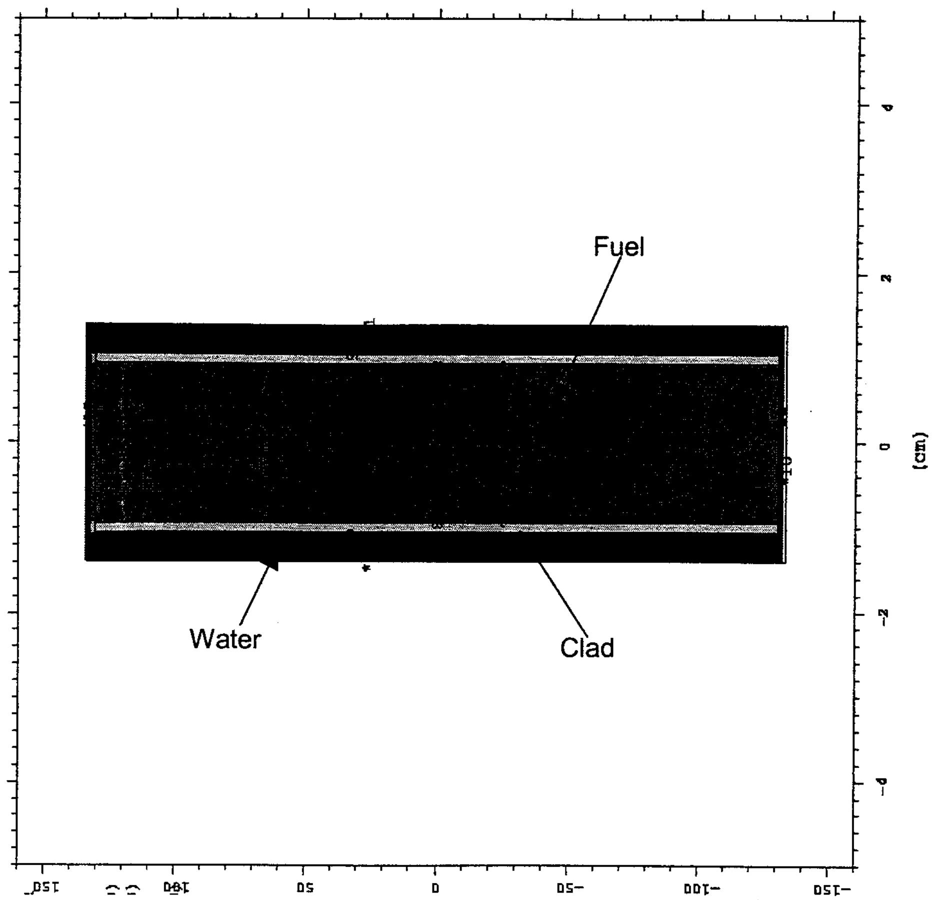

Figure 57
Axial Cut of Water Moderated Reflector Rod, Model Reflected on all Sides
(note scale difference)

4.1.5 Criticality Calculations

4.1.5.1 Calculational Methodology

MCNP (MCNP4B2) was used to determine the reactivity of this fuel. At the beginning of life the reflector assembly rods were composed of Zr clad ThO_2 pellets only, but reactor operation bred U-233 (and significantly less other fissile materials) into the assemblies. Therefore, criticality calculations were performed for post irradiation reflector components. The U-233 content for these calculations was taken from the maximum post-irradiation measurement of reflector rods (WAPD-TM-1614). The remainder of the post irradiation composition was taken from Attachment C-A-A. Calculations were performed for an infinite array of unmoderated reflector pellets, and for an infinite array of moderated rods with varying pitch.

4.1.5.2 Fuel Loading and Other Contents Optimization

The maximum post irradiation fissile content measured for any rod was 39.7 grams (WAPD-TM-1614). The entire 39.7 grams was assumed to be U-233 for all rods in these calculations. The maximum post irradiation rod loadings were taken from WAPD-TM-1614 and the resulting MCNP input data are given in Table 43.

Table 43
Post Irradiation, Type V Shippingport Reflector

MCNP Case	Isotope	Activity (Ci)	Specific Activity (Ci/g)	Mass (g)	Mass per Pellet (g/pellet)	Mass per Rod (g/rod)
42-1	Th230	8.82E-04	2.02E-02	4.37E-02	1.86E-06	2.63E-04
42-2	Th232	1.15E-01	1.10E-07	1.05E+06	4.45E+01	6.30E+03
42-3	U232	5.21E+00	2.14E+01	2.43E-01	1.04E-05	1.47E-03
42-4	U233	6.38E+01	9.68E-03	6.59E+03	2.80E-01	3.97E+01
42-5	U234	1.66E-01	6.25E-03	2.66E+01	1.13E-03	1.60E-01
42-6	U235	1.20E-06	2.16E-06	5.56E-01	2.36E-05	3.35E-03
42-7	U236	2.92E-07	6.47E-05	4.51E-03	1.92E-07	2.72E-05
42-8	U238	2.54E-07	3.36E-07	7.56E-01	3.22E-05	4.55E-03
42-9	Pu236	2.08E-12	5.31E+02	3.92E-15	1.67E-19	2.36E-17
42-10	Pu238	1.39E-05	1.71E+01	8.13E-07	3.46E-11	4.90E-09
42-11	Pu239	6.65E-04	6.22E-02	1.07E-02	4.55E-07	6.44E-05
42-12	Pu240	1.58E-04	2.28E-01	6.93E-04	2.95E-08	4.17E-06
42-13	Pu241	4.88E-03	1.03E+02	4.74E-05	2.02E-09	2.85E-07
42-14	Pu242	1.45E-08	3.82E-03	3.80E-06	1.62E-10	2.29E-08
42-15	Am241	2.76E-04	3.43E+00	8.05E-05	3.42E-09	4.85E-07
42-16	O16			1.45E+05	6.15E+00	8.70E+02

4.1.5.3 Criticality Results

These MCNP (MCNP4B2) calculations show that an infinite array of dry reflector pellets will have a k_{eff} of 0.184 and 1 σ of 0.0005.

The calculations show that an infinite array of water moderated reflector rods with an optimum triangular pitch spacing of one inch will have a k_{eff} of 0.649 and σ of 0.0015. Table 44 and Figure 58 show the results of the calculations as a function of rod spacing.

Since the reflector rods will be critically safe in any configuration the reflector assemblies will also be safe in any configuration.

Table 44
MCNP Calculated k_{eff} for Infinite Array of Shippingport Reflector Rods
Post-Irradiation, Water Moderated, Triangular Pitch

Pitch (inches)	k_{eff}	Uncertainty (1 σ)	MCNP Case
0.9000	0.6210	0.0016	43-1
0.9500	0.6410	0.0015	43-2
1.0000	0.6490	0.0015	43-3
1.0500	0.6420	0.0013	43-4
1.1000	0.6370	0.0013	43-5

4.2 REFERENCES

Attachment C-A-A, Fuel and Fuel Package Descriptions, DOE Contract No. DE-AC07-00ID13729

WAPD-TM-1614, Nondestructive Assay of Spent Fuel Rods from a Light Water Breeder Reactor, G Tessler et al, September 1987.

WAPD-TM-1208, Design of the Shippingport Light Water Breeder Reactor, D. R. Connors et al., January 1979.

Infinite Array of Shippingport Reflector Pins Water Moderated, Post-Irradiation Triangular Pitch

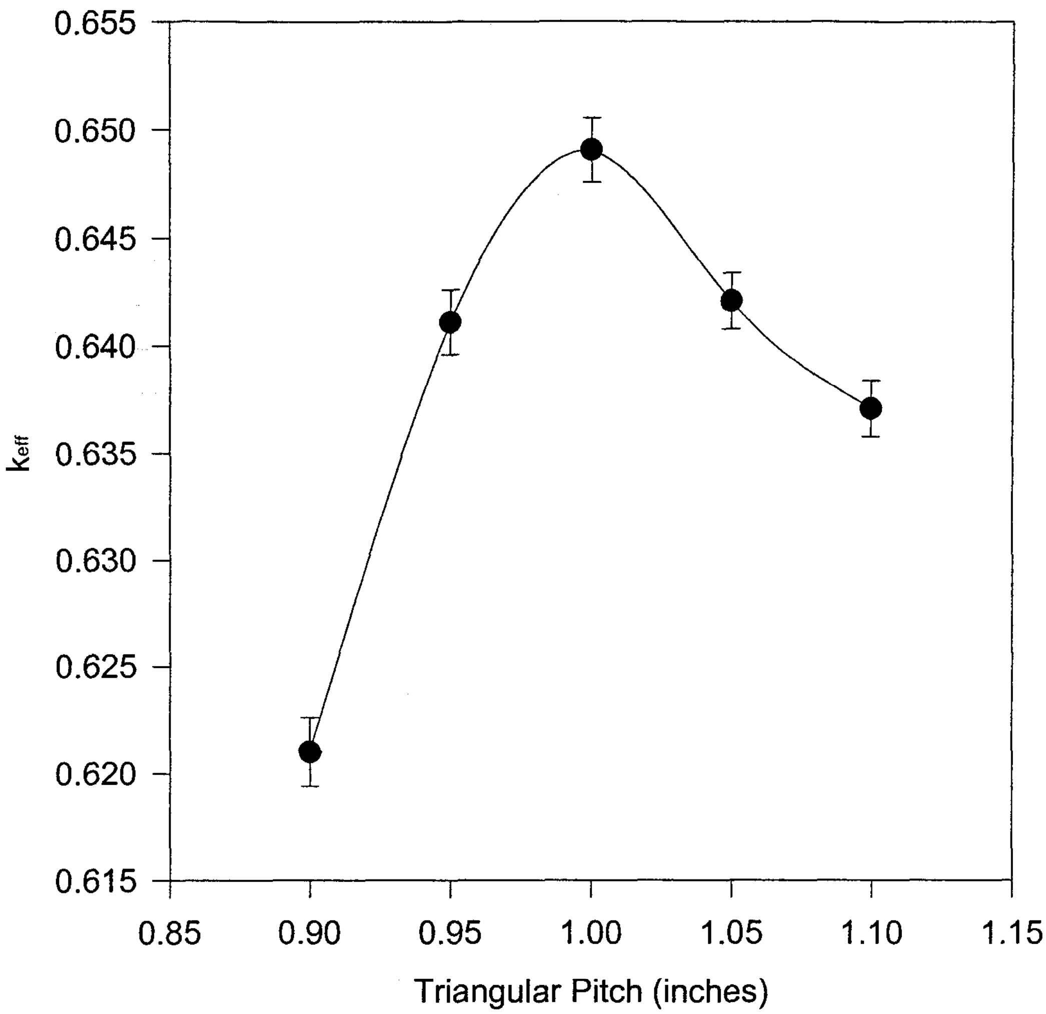

Figure 58
keff as a Function of Triangular Pitch for Infinite Array of Water Moderated Shippingport Reflector Rods, nominal +1σ uncertainty shown