Attachment 6

AREVA Proprietary Document E-42038 (REDACTED)
TN-32B HBU Demonstration Cask Design/Licensing Basis Document

North Anna Power Station
Independent Spent Fuel Storage Installation
Virginia Electric and Power Company
(Dominion)

Public

AREVA

DOCUMENT COVER SHEET

PROJECT NUMBER: 19885	CLIENT: AREVA Federal Services LLC.

PROJECT NAME: TN-32B HBU Demonstration Cask

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DOCUMENT TITLE: TN-32B HBU Demonstration Cask Design/Licensing Basis Document

SYSTEM, STRUCTURE, OR COMPONENT NAME (AS REQUIRED): TN-32B HBU Demonstration Cask

SUMMARY DESCRIPTION:

This Design/ Licensing Basis Document (DLBD) addresses the safety related aspects of storing high burn-up fuel (HBU) in a modified TN-32B dry storage cask (HBU demonstration cask) on the North Anna Power Station's (NAPS's) Independent Spent Fuel Storage Installation (ISFSI). The HBU demonstration cask is intended for storage of HBU fuel on the existing ISFSI pad at the NAPS. The DLBD also includes an evaluation of the interactions of the TN-32B HBU demonstration cask among the existing TN-32 casks located on the NAPS's ISFSI.

This DLBD is issued as a summary document, which provides a supplemental description of the various calculations and other design and licensing documents to support licensing of a modified TN-32B HBU demonstration cask for use in a site specific license amendment request in accordance with 10 CFR 72. Revision 1 of this document provides for proprietary marking / annotation throughout and some editorial changes. Revision 2 of this document includes changes to proprietary marking / annotation throughout; revision in Section 1.2 to delete the discussion on average burnup; and to remove an internal tracking number in Sects. 2.5 and 8.2. Revision 2 of this document is issued without revision bars for legibility. Revision 3 removes Proprietary marking on Figure 3.2-1 at customer request.

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0	Initial Issue	All
1	Added proprietary markings	All
2	Modification of proprietary markings Deleted discussion on average burnup Removed internal tracking number	All
3	Revise Figure 3.2-1 to indicate that the entire page is Non-Proprietary because the heat loads listed were already made public by being placed in the North Anna plant Tech Specs.	35

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1.0 INTRODUCTION

This DLBD addresses the safety related aspects of storing high burn-up fuel (HBU) in a modified TN-32B dry storage cask (HBU demonstration cask) on the North Anna Power Station's (NAPS's) Independent Spent Fuel Storage Installation (ISFSI).

The TN-32B HBU demonstration cask is a storage cask that satisfies applicable requirements associated with the confinement, shielding, criticality control, and passive heat removal safety functions for storage of thirty-two (32) HBU spent fuel assemblies (FAs). HBU fuel is defined as having a burn-up greater than 45,000 MWd/MTU. In addition to these safety functions, the HBU demonstration cask is modified to include seven (7) thermocouple lances installed thru the cask lid to indirectly monitor the temperature of the fuel assembly cladding during the demonstration storage period.

The objective of the DLBD is to provide supplemental analyses to support licensing of a modified TN-32B dry storage cask for use in a site-specific license amendment request in accordance with 10 CFR 72 [Reference 1.5.1]. The HBU demonstration cask is intended for storage of HBU fuel on the existing ISFSI pad at the NAPS. The DLBD also includes an evaluation of the interactions of the TN-32B HBU demonstration cask among the existing TN-32 casks located on the NAPS's ISFSI.

1.1 TN-32B HBU Demonstration Cask Physical Description

The TN-32B HBU demonstration cask accommodates thirty-two (32) intact PWR HBU fuel assemblies, with or without Poison Rod Assemblies (PRAs). The cask for this demonstration was fabricated in 2003 in accordance with the TN-32 Safety Analysis Report (SAR) [Reference 1.5.2], and certified to comply with the NRC Certificate of Compliance (CoC) No. 72-1021. The modifications to the licensed standard TN-32B cask design for the HBU demonstration cask consist of the following:

- The lid is modified with seven (7) new penetrations installed in the lid's confinement boundary and shield plate, providing access into the cask cavity.
- Thermocouple lance assemblies are mounted and secured in each of the penetrations, as noted above. Each lance, which contains nine (9) Type K thermocouples, is inserted into a designated guide tube in selected fuel assemblies. The penetration, thermocouple lance assembly, and associated confinement boundary is illustrated in Figure 1.1-1 and Figure 1.1-2. Additional discussion of the confinement boundary is provided in Section 6.1, *Confinement Boundary*.
- A funnel guide assembly is installed into the upper end fitting of each of the seven (7) fuel assemblies that receive the thermocouple lance assemblies. The funnel assembly guides the lance into the fuel assembly guide tube during installation. Refer to Figure 1.1-3.
- The overpressure (OP) monitoring system is modified to provide leakage monitoring of the inner seal space of each of the double metallic silver O-ring seals for the instrumentation assemblies.

- The protective cover is provided with an additional access cover above the lid vent port cover for maintenance purposes. An instrumentation junction box closure is located on the perimeter surface of the lid to permit worker access to the thermocouple conductors in accordance with ALARA principles.
- Lid closure bolts are upgraded with a reduced diameter shank of [ ] and a captured hardened flat washer. The hole diameter for the lid bolts is increased to [ ] These changes are implemented for consideration of future transportation of the HBU demonstration cask.
- Four-paired bolting bars are attached to each end of the outer shell for attaching impact limiters to the HBU demonstration cask for future transportation.
- The top neutron shield is elevated approximately one (1) inch by four (4) 1-inch thick steel bars that are welded to the through bolt holes on the bottom steel plate. This elevation is to provide space for the thermocouple wiring, and for the OP system tubing routed to the instrument seals.

As with the vent and drain port covers, each thermocouple lance penetration is provided with a double-seal, mechanical closure. Aside from the modifications, the cask body and basket for the HBU demonstration cask are the same as in a standard TN-32 configuration. The TN-32B HBU demonstration cask is identified as TN-32B-81, which includes Basket Number 2. The HBU demonstration cask is also marked with its nominal loaded and empty weights of 117.14 tons and 92.33 tons, respectively. The pertinent dimensions and weights for the TN-32B HBU demonstration cask are provided in Table 1.1-1. The drawings for the TN-32B HBU demonstration cask are provided in Section 8.1, *Licensing Drawings*.

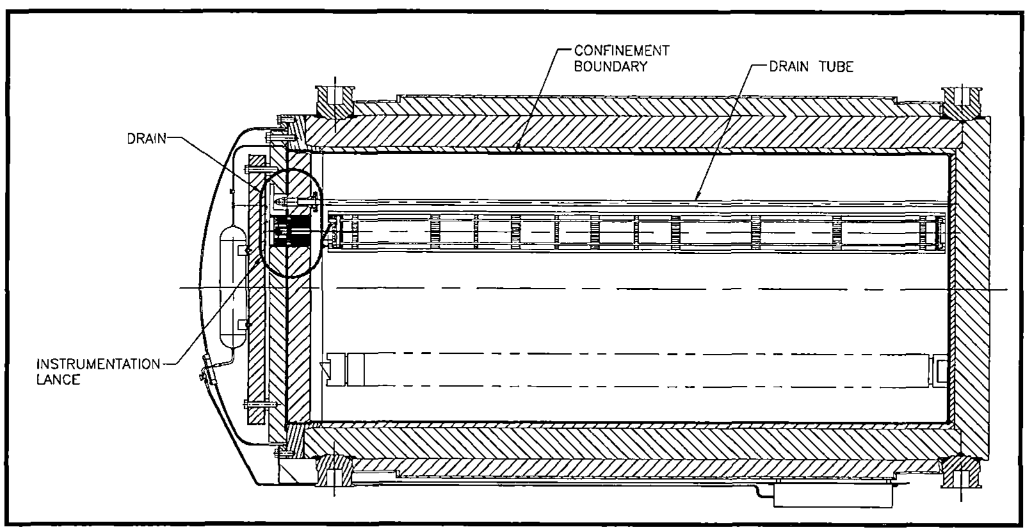

Figure 1.1-1 - TN-32B HBU Demonstration Cask – Confinement Boundary

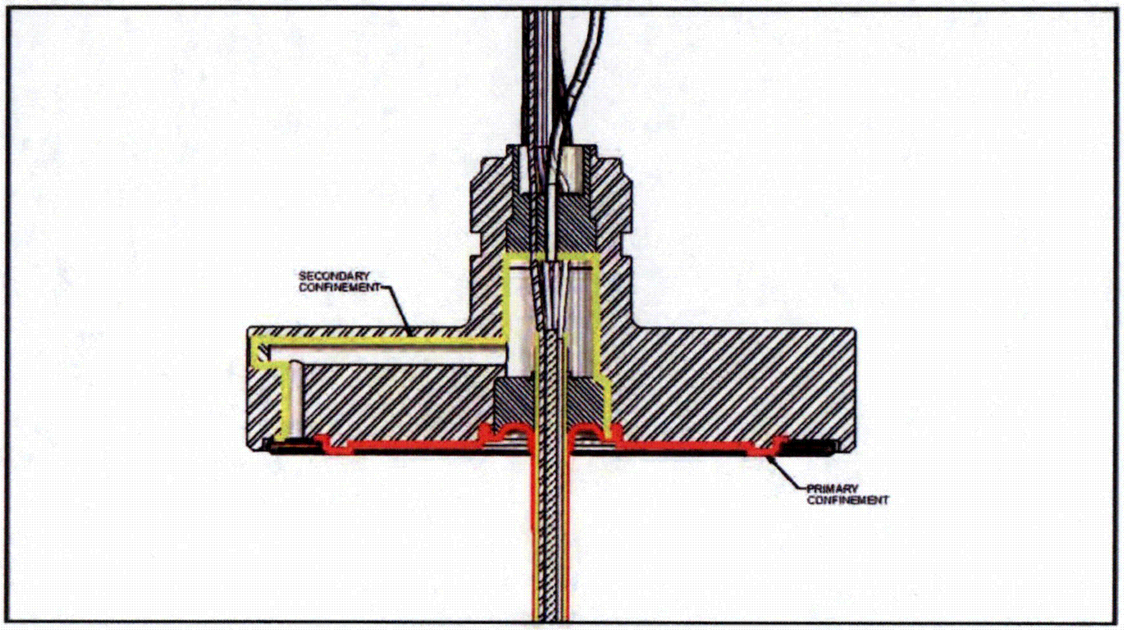

Figure 1.1-2 - Thermocouple Instrument Lance Assembly – Confinement Boundary

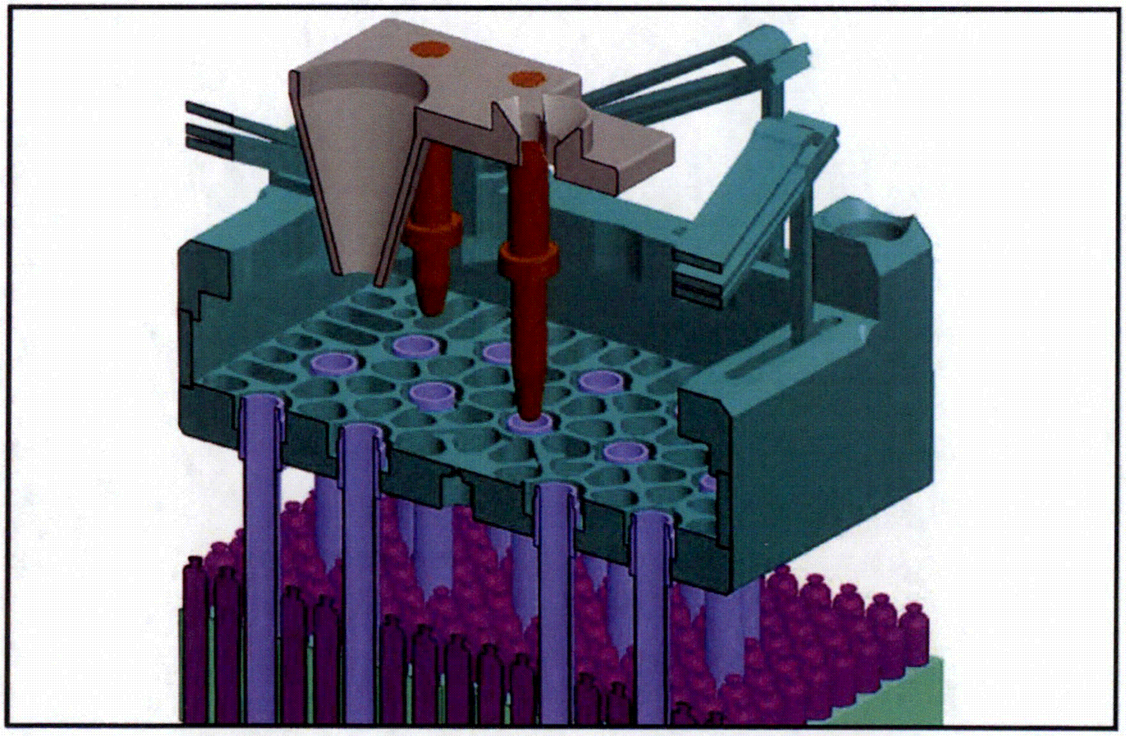

Figure 1.1-3 - Funnel Guide Assembly – Sectional View

Table 1.1-1 - Dimensions and Weights of the TN-32B-81 HBU Demonstration Cask

Description	Value
As-built overall length with protective cover	201.95 in
As-built maximum width at trunnions	102.25 in
As-built outside body diameter	98.14 in
As-built cavity diameter	68.80 in
As-built cavity length	163.36 in
As-built body wall thickness	9.59 in
As-built lid thickness	10.53 in
As-built bottom thickness	10.25 in
As-built resin compound thickness	4.52 in
Outer gamma shield shell thickness	0.50 in
Cask weight loaded on ISFSI pad	117.14 tons
Loaded on pool crane hook without water or lift beam	114.56 tons
Loaded on pool crane hook with water and lift beam	124.45 tons

1.2 TN-32B HBU Demonstration Cask Contents Description

The TN-32B HBU demonstration cask is designed to store thirty-two (32) intact HBU PWR fuel assemblies with or without PRAs. The maximum nominal enrichment of the HBU fuel to be stored is 4.55 wt. % U-235 with a maximum assembly-average burn-up of 60,000 MWd/MTU. The HBU fuel assemblies must be cooled a minimum of 5.31 years prior to storage in the HBU demonstration cask. The HBU demonstration cask has been evaluated for a maximum total decay heat load of 36.96 kW. The HBU fuel that will be stored in the TN-32B HBU demonstration cask are Westinghouse LOPAR, NAIF 17 × 17, and AREVA Advanced MK-BW (AMBW) 17 × 17 fuel assemblies, provided that they satisfy the burn-up, enrichment, and minimum required cooling time. The data for the HBU fuel that will be stored within the TN-32B HBU demonstration cask is presented in Table 1.2-1.

The quantity and type of radionuclides in the HBU fuel assemblies are described and tabulated in Chapter 4.0, *Shielding Evaluation.* Chapter 5.0, *Criticality Evaluation,* discusses the criticality safety of the TN-32B HBU demonstration cask and its HBU contents, listing material densities, moderator ratios, and geometric configurations.

Table 1.2-1 - TN-32B HBU Demonstration Cask HBU Fuel Data

Parameter	Value		
	AMBW	LOPAR	NAIF
Top nozzle inside height to corner post	2.842 in.	2.842 – 3.000 in. (upper bounding)	2.842 – 3.000 in. (upper bounding)
Length between top of inner flat part of top nozzle to top of bottom end plug	152.5 – 153.8 in.	152.5 – 153.8 in. (upper bounding)	152.5 – 153.8 in. (upper bounding)
Fuel assembly max length	159.85 in.	159.765 in.	159.975 in.
Fuel assembly overall length including non-compressed hold down springs	161.62 in.	161.50 - 162.00 in. (upper bounding)	161.50 - 162.00 in. (upper bounding)
Fuel assembly max width	8.425 in.	8.426 in.	8.426 in.
Fuel density, % theoretical	96.0%	95.0%	≤ 96.0% (bounding)
Fuel rod pitch	0.496 in.	0.496 in.	0.496 in.
Number of fuel rods	264	264	264
Maximum uranium weight per fuel assembly	469 kg	≤ 467 kg (bounding)	≤ 467 kg (bounding)
Fuel rod fill gas	Helium	Helium	Helium
Fuel assembly max growth, end of life	0.611 in.	≤ 0.611 in.	≤ 0.611 in.
Guide tube inside diameter	0.450 in.[1]	≤ 0.45 in.[1]	≤ 0.442 in.[1]
Guide tube outside diameter	0.482 in.	0.482 in.	0.474 in.
Guide tube wall thickness	0.016 in.	0.016 in.	0.016 in.
Guide tube radial centerline spacing	1.488 in.[1]	1.488 in.[1] (bounding)	1.488 in.[1] (bounding)
Number of guide tubes	24	24	24
Instrumentation tube outside diameter	0.482 in.	≤ 0.482 in. (bounding)	≤ 0.482 in. (bounding)
Instrumentation tube wall thickness	0.016 in.	≤ 0.016 in. (bounding)	≤ 0.016 in. (bounding)
Number of instrumentation tubes	1	1	1
Dashpot inside diameter	0.397 in.	≤ 0.397 in.	≤ 0.397 in.
Fuel rod cladding thickness	0.0225 in.	≤ 0.0225 in.	≤ 0.0225 in.
Fuel pellet diameter	0.3225 in.	≤ 0.3225 in.	≤ 0.3225 in.

Parameter	Value		
	AMBW	LOPAR	NAIF
Active fuel column length	144 in.	≤ 144 in.	≤ 144 in.
Fuel rod diameter	0.374 in.	≤ 0.374 in.	≤ 0.374 in.
Fuel assembly dry weight	1,488 lbs.	≤ 1,488 lbs.	≤ 1,488 lbs.
Guide tube material	M5™ (Zircaloy)*	Zirc-4 (similar to Zr alloy)	Low-Sn Zirc-4, Zirc-4, or Zirlo™ (similar to Zr alloy)
Top nozzle material	Type 304 SS	Similar to 300 series SS	Similar to 300 series SS
Fuel orientation – nomenclature	Face 3 – West	Face 1 – East	Face 1 – East

* For M5™ material properties, see [Reference 1.5.4]
Note: 1. Per Dominion, 1.488 inch pitch and 0.430 inch pin diameter is sufficient for design considerations [Reference 1.5.4].

1.3 Operations and Auxiliary Equipment

1.3.1 Operations

A typical sequence of operations to be performed in loading HBU fuel into the TN-32B HBU demonstration cask is summarized below.

Upon receipt at North Anna, the HBU demonstration cask will be up-righted and transferred into the North Anna crane enclosure in accordance with existing procedures and practices. The overhead cask crane provides lifting and placement of the cask in the north bay of the station's Decontamination Building. The lid, protective cover, overpressure tank and associated tubing connections, top neutron shield are removed and inspected. The HBU demonstration cask, basket and cavity are visually inspected.

Fuel assemblies scheduled to be loaded into the cask will be inspected and prepared for loading prior to cask loading operations. Inspection and preparation would include visual examinations, and as necessary, verification of guide tube free-path travel to ensure that no obstructions exist in the fuel assemblies designated for thermocouple monitoring. Any insert components which are planned to be installed in the HBU demonstration cask, such as PRAs, are installed in designated fuel assemblies.

When the HBU demonstration cask is ready for final loading, a new silver metallic O-ring seal will be installed on the lid assembly and set aside. The lid is then prepared and staged for submerged installation on the cask body. The cask is transferred to the cask loading area in the North Anna spent fuel pool in accordance with existing site procedures. The (32) HBU fuel assemblies that are designated for loading are moved from their respective spent fuel storage rack locations and emplaced into their designated basket location, in accordance with fuel move sheets developed from the spent fuel storage certification documents and applicable fuel handling procedures.

After the cask is fully loaded, funnel guides, for installation of the thermocouple lances are installed in seven (7) designated fuel assemblies guide tubes that are to be monitored during storage. Once all loading and pre-assembly is complete, which includes verification of loaded fuel identification, the closure lid is lowered into position using special long handling tools and guide pins for true alignment to preclude damage to the silver metallic O-ring and mating surfaces. The pneumatic lifting yoke is installed on the overhead cask crane 125 ton hook and function is verified then moved to engage the cask trunnions. The cask is then lifted to the pool surface, where the lid is accessible for workers to prepare the cask for safe movement to the north bay of the Decontamination Building. The lid bolt holes are dewatered, as required, and a minimum of six lid bolts are installed and tightened to 100 ft.-lbs. torque, per site procedures. Additional preparation consisting of dewatering the cask to approximately seven (7) inches below the flange surface, to support ALARA activities associated with lance installation, and decontamination of the exposed cask surfaces are performed. The lid guide pins may be removed. The HBU demonstration cask is then transferred to the north bay of the Decontamination Building. Remaining lid bolts are installed, and all bolts tightened, per procedure, to required torque values.

The thermocouple lance assemblies are installed in their designated penetrations, each with a double metallic silver seal, a jacking plate assembly and a retaining ring, and the fasteners are tightened, per procedure, to required torque values. Thermocouple leads are temporarily connected to a data logger to collect temperatures during the dewatering, vacuum drying, and helium back-fill processes. The water is removed from the cask cavity, then backed filled with helium gas to maintain the temperature of the fuel assemblies below 752 °F (400 °C) during drying. The vacuum drying process is performed to ensure the HBU demonstration cask meets Technical Specifications requirements. Once the Technical Specifications requirement is met for drying, the cask is again backfilled with helium gas to the Technical Specifications backfill pressure requirement.

The cask will remain in the north bay of the Decontamination Building, with a pressure gauge attached to the vent port to allow direct monitoring of cask cavity pressure during the thermal stabilization period. The purpose of the thermal stabilization period is to collect temperature measurements as the cask and contents approach thermal equilibrium, monitor cavity pressure, and collect cask cavity gas samples for fission gas, composition, and moisture analysis. These data will be utilized to more fully understand the loading and drying temperature transients for benchmarking thermal analysis techniques, and to identify any rod failures, should they occur.

After completion of thermal stabilization, the temporary thermocouple leads will be disconnected from the data logger and cask seal leak testing is performed. Once the leak testing is verified to meet the existing North Anna Technical Specification requirements, the top neutron shield, overpressure system (that part existing beneath the protective cover assembly), and protective cover assembly package are installed. External surface radiation readings are collected and verified to ensure that they are within Technical Specifications limits.

The HBU demonstration cask is transferred to the ISFSI pad using the cask transporter and prime mover. The cask is emplaced in the designated storage location, and the cask's external OP system components are installed and connected to the site storage cask monitoring and alarm system. The

thermocouple lance conductors, conduit and associated supporting hardware are assembled on the ISFSI pad, to support long-term data collection.

To unload the HBU demonstration cask, the above steps may be performed in reverse. A North Anna procedure exists to unload an existing TN-32 cask, and the procedure/process has been tested on a loaded TN-32 at Dominion's Surry Power Station. The thermocouple lance conductors and associated external hardware are removed. The HBU demonstration cask is returned to the north bay of the Decontamination Building using the cask transporter and prime mover. The protective cover, pressure monitoring system, overpressure tank, and top neutron shield will be removed. Prior to opening the HBU demonstration cask, the cavity gas will be sampled through the vent port, and analyzed for potential nuclear and moisture composition. The cavity is depressurized to atmospheric pressure, and all but six of the lid bolts would be removed. The six lid bolts will then be tightened to 100 ft.-lb. torque in according with site procedures. The cask is transferred to the cask loading area of the North Anna spent fuel pool. Water is introduced into the cask through the drain port. Off-gas hosing is connected to the vent port, with its effluent discharging directly into the pool water. The water/steam effluent from the vent line may contain radioactive gas. ALARA practices and engineering controls are planned and in place to support these activities. The exit pressure and temperature are typically monitored during this operation. Once the HBU demonstration cask is filled with water, the remaining six lid bolts are removed, and the cask is lowered into the place for completion of disassembly, access to fuel and unloading, as necessary.

1.3.2 Auxiliary Equipment

The objective of the HBU demonstration cask is to monitor the fuel cladding temperatures of HBU fuel during storage. To support this objective, auxiliary equipment for the TN-32B dry storage cask is provided, as required. Specifically, the seven (7) thermocouple lances are connected to a junction box on the protective cover, and conductors routed through conduit to a data logger, which measures and records the thermocouple output. A solar cell is attached to the HBU demonstration cask to supply power to the data logger battery system. No additional supplemental site power is required for the auxiliary equipment.

1.4 Design Criteria

The design criteria that are utilized for the TN-32B HBU demonstration cask modifications are identical to the criteria delineated in the original TN-32 SAR [Reference 1.5.2]. Properties for materials that were unavailable in the 1992 ASME Boiler and Pressure Vessel (B&PV) Code utilized for the TN-32 SAR are extracted from the 2013 ASME B&PV Code. Additionally, applicable NUREG/CR and/or Regulatory Guide documents that were not used in or issued subsequently to the design and licensing of the TN-32 dry storage cask were utilized, e.g., NUREG/CR-6007 [Reference 1.5.3], for evaluation of the lid, vent, drain, thermocouple lance bolted assemblies, and penetration welds. These added documents are incorporated into the design criteria for this demonstration cask.

1.5 References

1. Title 10, Code of Federal Regulations - Energy, Part 72 (10 CFR 72), "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste", U.S. Nuclear Regulatory Commission, Washington, D.C.
2. "TN-32 Dry Storage Cask Safety Analysis Report", Revision 2, Transnuclear, Inc., April 2002.
3. G.C. Mok, L.E. Fischer, S.T. Hsu, "Stress Analysis of Closure Bolts for Shipping Casks", NUREG/CR–6007, UCRL–ID–110637, April 1992, U.S. Nuclear Regulatory Commission, Washington, D.C.
4. "AREVA Federal Services LLC, Engineering Information Record (EIR-3011071-004) Design Basis Requirements, TN-32B HBU Demonstration Cask Project" DI-19885-05, Rev. 4.

2.0 STRUCTURAL EVALUATION

This section of the DLBD summarizes the structural evaluations that were performed to demonstrate that the TN-32B HBU demonstration cask complies with the requirements of 10 CFR 72 [Reference 2.5.1] for the normal, off-normal, and accident conditions defined by the NAPS ISFSI Safety Analysis Report (SAR) [Reference 2.5.2]. For the structural evaluations, the weight and center of gravity for the demonstration cask and the HBU fuel payload are provided in the weight calculation [Reference 2.5.3]. Except as noted, the design criteria utilized for the structural evaluations of the demonstration cask is the same as identified Section 3.1.2 in the TN 32 Dry Storage Cask Topical SAR [Reference 2.5.4].

The finite element models for the cask body, cask lid, the basket (normal, off-normal conditions), and the basket rails, were modeled and analyzed utilizing the ANSYS® program [Reference 2.5.19]. For the accident load conditions of the basket and the fuel assemblies, a finite element model was modeled and analyzed utilizing the LS DYNA® dynamic program [Reference 2.5.20]. For single lid components, such as the lid bolts, covers for the drain and vent ports, and the protective cover, detailed finite element models were not required. For these components, analyses were performed utilizing classical manual methods. Temperature-dependent material properties utilized in the structural analyses were based on the temperatures provided in Chapter 3.0, *Thermal Evaluation.*

Since the HBU fuel payload results in slightly higher temperatures for the structure, the cask body was re-evaluated for the normal, off-normal, and accident load cases that apply under the NAPS ISFSI license. The results of the re-evaluations are discussed in the following sections, with the referenced calculation or document provided in Section 8.2, *Design Calculations.*

2.1 TN-32B HBU Demonstration Cask Body

The body of the TN-32B HBU demonstration cask is essentially unchanged from a standard TN-32 cask body. The only difference between the demonstration cask body and a standard TN-32 cask body is the addition of four-paired, 3/4-inch thick ×10-inch long bars welded at each end of the 1/2 inch thick outer steel shell. The purpose of these bars is to attach impact limiters for the future transportation of the cask off site. Because the impact limiter attachment bars are only applicable for future transportation of the cask, no structural evaluation of these bars is performed for the storage conditions addressed by this document.

2.1.1 Normal and Off-Normal Conditions

The TN-32B HBU demonstration cask body was analyzed for the following normal and off-normal load conditions:

- 1g down, cask vertical supported on bottom
- 100 psig internal pressure
- 25 psig external pressure
- Thermal stress due to 100 °F (38 °C) ambient hot environment with maximum decay heat load

- 3g vertical lift using upper trunnions

The analyses have demonstrated that the cask body satisfies the required design criteria for all of the normal and off-normal conditions for the NAPS ISFSI. The stress ratios for each load case combination are summarized in Table 2.1-1.

2.1.2 Accident Conditions

The TN-32B HBU demonstration cask body was analyzed for the following accident load conditions:

- Seismic event in vertical storage position for the NAPS ISFSI Design Basis Earthquake (DBE), and the 2011 earthquake centered near Mineral, VA
- 50g bottom end drop
- 50g tip over impact
- Tornado, wind, and missile impacts
- 3g vertical lift plus 1g lateral

The analyses have demonstrated that the cask body satisfies the required design criteria for all of the accident conditions for the NAPS ISFSI. The stress ratios for the accident load case combinations and a summary of the cask stability are summarized in Table 2.1-2.

Table 2.1-1 - Summary of Cask Body Normal and Off-Normal Structural Load Case Results

Load Case		Supporting Document
• Lid Bolt Preload, Lid Sealing Pressure • 1g down, cask vertical • 100 psig internal pressure • Thermal Stress		
• Lid Bolt Preload, Lid Sealing Pressure • 1g down, cask vertical • 25 psig external pressure • Thermal Stress		
• Lid Bolt Preload, Lid Sealing Pressure • 100 psig internal pressure • Thermal Stress • 3g vertical lift using upper trunnions		Reference 2.5.5
• Lid Bolt Preload, Lid Sealing Pressure • 25 psig external pressure • Thermal Stress • 3g vertical lift using upper trunnions		
Single Failure-Proof Upper Trunnions Lower Trunnions		Reference 2.5.6

Table 2.1-2 - Summary of Cask Body Accident Structural Load Case Results

Load Case		Supporting Document
Missile Impacts		Reference 2.5.7
Cask Stability Due to Tornado Missile Impacts, Wind, and Seismic Inputs		Reference 2.5.8
• Lid Bolt Preload, Lid Sealing Pressure • 50g bottom end drop • 100 psig internal pressure • Thermal Stress		References 2.5.5 and 2.5.10
• Lid Bolt Preload, Lid Sealing Pressure • 50g bottom end drop • 25 psig external pressure • Thermal Stress		
• Lid Bolt Preload, Lid Sealing Pressure • 50g tip over impact • 100 psig internal pressure • Thermal Stress		
• Lid Bolt Preload, Lid Sealing Pressure • 50g tip over impact • 25 psig external pressure • Thermal Stress		
• Lid Bolt Preload, Lid Sealing Pressure • 3g vertical + 1g lateral • 100 psig internal pressure • Thermal Stress		
• Lid Bolt Preload, Lid Sealing Pressure • 3g vertical + 1g lateral • 25 psig external pressure • Thermal Stress		

2.2 TN-32B HBU Demonstration Cask Lid Assembly

As noted in Section 1.1, *TN-32B HBU Demonstration Cask Physical Description*, the cask lid assembly is modified with the following changes and additions:

- The addition of seven (7) penetrations to accommodate a thermocouple lance assembly. [ ]
- Lid closure bolts are upgraded with a reduced shank diameter of [ ] A captured hardened flat washer has also been included with each lid bolt, and the through-hole diameter in the lid increased to [ ] These changes and modifications were implemented to accommodate the future transportation of the demonstration cask.
- The protective cover is modified by the addition of an additional access cover above the vent port to permit samples of the cavity gas to be collected. In addition, an electrical junction box for the thermocouple conductors is installed on the perimeter of the cover.
- The OP monitoring system is modified to include leakage monitoring of the inner space between the inner confinement boundary and the outer seal of the silver metallic O-ring seal that form part of the thermocouple lance assemblies in the lid recesses.
- The top neutron shield is elevated approximately one (1) inch by 1-inch thick spacers to provide space for the thermocouple wiring and for OP system tubing routed to the instrument seals.

For the modified lid assembly, analyses were performed for the normal, off-normal, and accident load conditions. The lid bolts, the covers for the vent and drain ports, the covers for the access ports on the protective cover, and the lance assemblies were analyzed independently from the lid finite element ANSYS® model.

2.2.1 Normal and Off-Normal Conditions

The TN-32B HBU demonstration cask lid was analyzed for the following normal and off-normal load conditions:

- 1g down, cask vertical supported on bottom
- 100 psig internal pressure
- 25 psig external pressure
- Thermal stress due to 100 °F (38 °C) ambient hot environment with maximum decay heat load
- 3g vertical lift using upper trunnions

The analyses have demonstrated that the cask lid satisfies the required design criteria for all of the normal and off-normal conditions for the NAPS ISFSI. The stress ratios for the load case combinations are summarized in Table 2.2-1.

The lid bolts were analyzed in accordance with NUREG/CR-6007 [Reference 2.5.9] for the following normal and off-normal load conditions:

- Lid bolt tightening torque
- Lid bolt preload, lid sealing pressure
- 100 psig internal pressure
- 25 psig external pressure
- Thermal stress due to 100 °F (38 °C) ambient hot environment

The minimum margin of safety (M.S.) for the lid bolts under the worst-case normal and off-normal load conditions are [ ] Therefore, the lid bolts have been demonstrated to satisfy the design criteria for all normal and off-normal load conditions. The complete analysis of the lid bolts is provided in [Reference 2.5.10].

The fasteners for the vent port cover, drain port cover, and the lance assemblies were analyzed in accordance with NUREG/CR-6007 [Reference 2.5.9] to verify that the tightening torque would seat the silver metallic O-ring seal. Additionally, the fasteners were evaluated for the following normal and off-normal load conditions:

- 100 psig internal pressure (vent, drain, and lance assemblies only)
- Thermal expansion due to 100 °F (38 °C) ambient to 300 °F (149 °C) for the maximum decay heat load
- Fastener initial preload

For these load conditions, the minimum margin of safety (M.S.) for any of the covers or fasteners is [ ] which is for the 1/2-13UNC fasteners that secure the OP port closure. The analyses for all of the fasteners and covers on the lid and protective cover have been demonstrated to satisfy all of the applicable design criteria for normal and off-normal load conditions. The complete analyses of these covers and the fasteners are provided in [Reference 2.5.11 and 2.5.12].

2.2.2 Accident Conditions

The TN-32B HBU demonstration cask lid was analyzed for the following accident load conditions:

- 100 psig internal pressure
- Seismic event in vertical storage position for the NAPS ISFSI design basis earthquake (DBE) event, and the 2011 earthquake centered near Mineral, VA
- 50g bottom end drop

- 50g tip over impact
- Tornado, wind, and missile impacts
- 3g vertical lift plus 1g lateral

The analyses have demonstrated that the cask lid satisfies the required design criteria for all of the accident conditions for the NAPS ISFSI. The stress ratios for the accident load case combinations are summarized in Table 2.2-2.

The lid bolts were analyzed in accordance with NUREG/CR-6007 [Reference 2.5.9] for the following accident load conditions:

- 100 psig internal pressure
- Thermal expansion from 100 °F (38 °C) ambient to 400 °F (204 °C) fire event
- 50g tip over impact
- 30-ft side free drop
- 30-ft end free drop
- 30-ft CG-over-top corner free drop

The maximum interaction ratio for the worst-case accident load condition is [ ] which is significantly lower than the maximum interaction ratio of 1.0. Therefore, the lid bolts have been demonstrated to satisfy the design criteria for all postulated accident conditions. The complete analysis of the lid bolts is provided in [Reference 2.5.10].

The fasteners for the vent port cover, drain port cover, and the lance assemblies were analyzed for the following accident load conditions:

- 100 psig internal pressure
- Thermal expansion from 100 °F (38 °C) ambient to 400 °F (204 °C) fire event
- 50g tip over event
- Fastener preload

For these load conditions, the minimum margin of safety (M.S.) for any of the covers or fasteners is [ ] which is the (size) fasteners that secure the lance assemblies. The analyses for all of the fasteners and covers on the lid have been demonstrated to satisfy all of the applicable design criteria for all accident load conditions. The complete analysis for the covers and the fasteners is provided in [Reference 2.5.12].

Table 2.2-1 - Summary of Cask Lid Normal and Off-Normal Structural Load Case Results

Load Case		Supporting Document
• Lid Bolt Preload • 1g down, cask vertical • 100 psig internal pressure • Thermal Stress		Reference 2.5.13
• Lid Bolt Preload • 1g down, cask vertical • 25 psig external pressure • Thermal Stress		
• Lid Bolt Preload • 100 psig internal pressure • Thermal Stress • 3g vertical lift using upper trunnions		
• Lid Bolt Preload • 25 psig external pressure • Thermal Stress • 3g vertical lift using upper trunnions		

Table 2.2-2 - Summary of Cask Lid Accident Structural Load Case Results

Load Case		Supporting Document
• Lid Bolt Preload • 50g bottom end drop • 100 psig internal pressure • Thermal Stress		Reference 2.5.13
• Lid Bolt Preload • 50g bottom end drop • 25 psig external pressure • Thermal Stress		
• Lid Bolt Preload • 50g side drop • 100 psig internal pressure • Thermal Stress		
• Lid Bolt Preload • 50g side drop • 25 psig external pressure • Thermal Stress		
• Lid Bolt Preload • 3g vertical + 1g lateral • 100 psig internal pressure • Thermal Stress		
• Lid Bolt Preload • 3g vertical + 1g lateral • 25 psig external pressure • Thermal Stress		

2.3 TN-32B HBU Demonstration Cask Basket and Rails Assembly

The basket and rails of the TN-32B HBU demonstration cask are unchanged from a standard TN 32 cask basket. The only difference between the currently licensed TN-32 and the demonstration cask baskets and rails is the HBU fuel assembly payload that results in increased temperatures in the basket/rail structure from the increased decay heat-load. For this payload, the applicable normal, off-normal, and accident load conditions of the NAPS ISFSI license were analyzed, and are discussed in the following sections. Note that only accident load conditions apply for analysis of the basket rails.

2.3.1 Normal and Off-Normal Conditions

The TN-32B HBU demonstration cask basket was analyzed for the following normal and off-normal load conditions:

- 3g vertical lift plus 1g lateral
- Thermal stress due to 100 °F (38 °C) ambient hot environment with maximum decay heat load

The analysis has demonstrated that the cask basket satisfies the required design criteria for these normal and off-normal conditions for the NAPS ISFSI. The minimum margin of safety (M.S.) for this load case combination is provided in Table 2.3-1.

2.3.2 Accident Conditions

The TN-32B HBU demonstration cask basket was analyzed for the following accident load conditions:

- Thermal stress due to 100 °F (38 °C) ambient hot environment with maximum decay heat load
- 50g bottom down drop
- 55g tip over impact (treated as a side drop for basket)

The analysis has demonstrated that the cask basket satisfies the required design criteria for these accident conditions for the NAPS ISFSI. The minimum margins of safety (M.S.) for these load case combinations are summarized in Table 2.3-2.

As part of the evaluation of the basket assembly, the aluminum basket rails were modeled and analyzed using the ANSYS® computer program for the 55g side drop load condition with the maximum thermal condition. To comply with the existing NAPS ISFSI license, the applied impact load was analyzed as a tip over event with a 1.6 dynamic load factor (DLF) applied to the peak acceleration (55g), and linearly varying the impact deceleration from zero (0) at the cask bottom edge to a maximum of 88g (1.6 × 55g) at the top of the cask. For this load condition, the maximum combined moment and bending stress ratio for the basket rails is [ ] [Reference 2.5.14], which is well below the maximum allowed stress ratio of 1.0.

During the side drop accident event, the basket/fuel assemblies are laterally displaced relative to the thermocouple lances, which are inserted into guide tubes in the fuel assemblies. For this accident condition, the predicted maximum lateral displacement of a guide tube that contains a thermocouple lance is [ ] To maintain the confinement boundary of the cask, the thermocouple lance will be analyzed to demonstrate that the lance sheath confinement boundary satisfies the required design criteria for this lateral displacement [Reference 2.5.15]. The thermocouple lance resulting stresses due to tipping of the cask (50g acceleration) and lateral displacement [ ] are anticipated to be within the allowable stress margins due to the lightweight construction of the lance and high strength material properties of Alloy 600 material. Additionally, the thermocouple lance sheath tubing is supported in the closure flange of the instrument assembly thus there is no structural weld between the lance and the closure flange. The lance contains two seal welds, one at the bottom of the closure flange and one at the upper end of the lance to retain

confinement boundary if the bottom seal weld fails. There is reasonable assurance that the structural integrity of the lance due to a side drop accident will be maintained.

For criticality considerations, the minimum, average, and maximum change in the fuel spacing are [ ] respectively [Reference 2.5.16]. These displacements occur for the 45-degree drop orientation (minimum) and the 90-degree side drop orientation (average and maximum), and represent the worst-case condition.

Table 2.3-1 - Summary of Cask Basket Normal and Off-Normal Structural Load Case Results

Load Case	[ ]	Supporting Document
• 3g vertical + 1g lateral • Thermal Stress		Reference 2.5.17

Table 2.3-2 - Summary of Cask Basket Accident Structural Load Case Results

Load Case	[ ]	Supporting Document
• 55g bottom end drop • Thermal Stress		Reference 2.5.16
• 55g side drop • Thermal Stress		

2.4 HBU Fuel Structural Analysis

The HBU fuel assemblies have been analyzed to demonstrate the structural integrity for both a postulated 18-inch end drop, and a 50g side drop during the storage period of the TN-32B HBU demonstration cask. Internal pressure within the fuel rod is included in the structural evaluation of the cladding material. A finite element model was created utilizing the LS-DYNA® program for the 18-inch end drop, and the ANSYS® program for the side drop. Since there are three different types of fuel assemblies in the HBU payload, the AREVA AMBW 17 × 17 fuel assembly was determined to be the bounding assembly because it contains the thinnest cladding and the lowest yield strength. Material properties were conservatively taken at 750 °F (399 °C) for both the cladding and structural materials of the assembly. For the 18-inch end drop, the analysis determined that the maximum principal strain for the cladding was [ ] which is significantly below the strain limit of 0.485% at 750 °F (399 °C). For the 50g side drop, the minimum margin of safety (M.S.) against yielding of the cladding is [ ] Therefore, the analysis has demonstrated that the HBU fuel assemblies will maintain their structural integrity for all accident conditions during the storage period on the NAPS ISFSI. The complete analysis is provided in [Reference 2.5.18].

2.5 References

1. Title 10, Code of Federal Regulations - Energy, Part 72 (10 CFR 72), "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste", U.S. Nuclear Regulatory Commission, Washington, D.C.
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11. "TN-32B HBU, Protective Cover Evaluation", AREVA TN Calculation [ ]
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15. "Thermocouple Lance Structural Verification", AREVA Inc. Calculation [ ]
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20. "LS-DYNA® Keyword User's Manual, Volumes I& II," Version 971, Livermore Software Technology Corporation, Livermore, CA, May 2007.

3.0 THERMAL EVALUATION

This section of the DLBD summarizes the thermal evaluations that were performed to demonstrate that the TN-32B HBU demonstration cask with the HBU fuel assemblies complies with the requirements of 10 CFR 72 [Reference 3.5.1] for the normal, off-normal, and accident conditions defined by the NAPS ISFSI Safety Analysis Report (SAR) [Reference 3.5.2].

The TN-32B HBU demonstration cask is designed to passively reject decay heat under normal, accident and loading/unloading conditions while maintaining appropriate cask temperatures and pressures within the specified temperature limits discussed in the subsequent sections.

To establish the confinement and heat removal capability, several thermal design criteria are established for the TN-32B HBU demonstration cask. These are:

- Confinement of radioactive material and gases is a major design requirement. Seal temperatures must be maintained within specified limits to satisfy the leak-tight confinement function during normal storage conditions. The silver-jacketed metallic O-ring seals used in the confinement vessel of the TN-32B HBU demonstration cask have a maximum temperature limit of 669 °F (354 °C), as interpolated for the 0.161-inch cross section seal from [Reference 3.5.3]. This maximum temperature is the lowest temperature for any of the structural components of the TN-32B HBU demonstration cask, and is therefore, considered the temperature-limiting component for the thermal evaluation.
- To maintain the stability of the neutron shield resin during normal storage conditions, an allowable temperature range of -40 to 300 °F (-40 to 149 °C) is set for the neutron shield per [Reference 3.5.4].
- Maximum and minimum temperatures of the confinement structural components must not adversely affect the confinement function.
- Maintaining fuel cladding integrity during storage is another design consideration. For normal conditions and all short term loading operations (including vacuum drying and backfilling of the cask cavity with helium), a fuel cladding temperature limit of 752 °F (400 °C) is established in accordance with NUREG-1536 [Reference 3.5.5]. For accident conditions, the fuel cladding temperature limit is 1,058 °F (570 °C) per NUREG-1536.

3.1 Thermal Analysis of TN-32B HBU Demonstration Cask

Details of thermal analysis of the TN-32B HBU demonstration cask are provided in [Reference 3.5.6].

The TN-32B HBU demonstration cask is similar to the existing TN-32 casks currently in use at the NAPS ISFSI under site-specific license SNM-2507 [Reference 3.5.7]. The TN-32B HBU demonstration cask is designed to allow the storage of thirty-two (32) HBU fuel assemblies within the TN-32B HBU demonstration cask with a maximum decay heat load of 36.96 kW [Reference 3.5.10] for normal, accident, and loading/unloading conditions, while maintaining appropriate cask temperatures within the above specified limits. The maximum decay heat load is based on a

7/1/2017 load date. Note that the TN-32 dry storage cask is currently licensed for a total decay heat load of 32.7 kW, as shown in Section 4.1 of [Reference 3.5.7].
The normal conditions of storage are used for the determination of the maximum temperatures for fuel cladding and TN-32B HBU demonstration cask component temperatures. These steady-state environmental conditions correspond to the maximum daily averaged conditions: a daily averaged ambient temperature of 100 °F and the 10 CFR §71.71(c) insolation of [Reference 3.5.8] averaged over a 24-hour period. The analyses include the effect of storing the TN-32B HBU demonstration cask in a 2 × infinite array with a 16-foot pitch. The total design basis heat load for the existing TN-32 casks located on the NAPS's ISFSI is 27.1 kW per cask as noted in Section 4.1 of [Reference 3.5.4].

During transfer operations to the ISFSI pad, the TN-32B HBU demonstration cask is exposed to the ambient conditions and is not surrounded by other casks. This ensures that there is no radiation heat transfer between the casks as it is during storage on the ISFSI pad. Therefore, the thermal evaluation performed for normal storage bounds the thermal performance of the TN-32B HBU demonstration cask during transfer to the NAPS ISFSI pad. In addition, since helium is used for blowdown operation, its presence is credited during the vacuum drying operation. With helium being present during vacuum drying operations, the maximum temperatures including fuel cladding and cask components are bounded by those calculated for transfer operation. Since the thermal evaluation for normal storage conditions bounds the transfer operations as discussed above, no further evaluation for loading/unloading conditions is required.

The results from the thermal analyses of the TN-32B HBU demonstration cask performed for normal and fire accident conditions for the 36.96 kW decay heatload are listed in Table 8-1 of [Reference 3.5.6], and summarized below:

- The maximum fuel cladding temperatures for the TN-32B HBU demonstration cask are 658 °F (348 °C) and 765 °F (407 °C) for normal and fire accident conditions, respectively. These temperatures are well below the temperature limits of 752 °F (400 °C) and 1,058 °F (570 °C), respectively, for normal and accident conditions of storage.
- The maximum seal temperature for all cask seals is 280 °F (138 °C) and 427 °F (219 °C) for normal and fire accident conditions, respectively. These temperatures are well below the long-term limit of 669 °F (354 °C) for continued seal function specified in [Reference 3.5.3].
- Under the minimum daily average temperature condition of -20 °F (-29 °C) ambient, the resulting cask component temperatures will approach -20 °F (-29 °C) if no credit is taken for decay heat load. The cask materials including confinement structures and the seals continue to function at the temperature range between -40 °F (-40 °C) and 669 °F (354°C) as specified in [Reference 3.5.2].

- The average bulk resin temperature in the radial neutron shield at the hottest cross section is 294 °F (146 °C) for normal conditions. The maximum bulk temperature of the resin in the top neutron shield is 277 °F (136 °C). The resin temperatures are below the allowable limit of 300 °F (149 °C) specified in Section 4.1 of [Reference 3.5.4]. Therefore, no degradation of the neutron shielding is expected for the storage period.

The thermal evaluation documented in [Reference 3.5.6] concludes that maximum and minimum temperatures are within the allowable temperature ranges, and all thermal design criteria for the TN-32B HBU demonstration cask are satisfied for normal, accident and loading/unloading conditions.

3.2 Models and Methods for Transfer and Storage

3.2.1 Normal Storage Condition

To evaluate the thermal performance of the TN-32B HBU demonstration cask for the normal storage conditions, a 3D model of the ISFSI pad is developed by using ANSYS® [Reference 3.5.9], as shown in Figure 6-1 of [Reference 3.5.6]. The ISFSI thermal model includes the soil, concrete pad, homogenized models of existing TN-32 casks, and the explicit model of the TN 32B HBU demonstration cask developed in [Reference 3.5.10].

In this evaluation, five rows of casks are modeled to account for the impact on the view factor of the TN-32B HBU demonstration cask. Since the effect of casks further away from the TN-32B HBU demonstration cask on the view factor is negligible, five rows of casks are sufficient to evaluate the view factor due to the surrounding casks. [

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The detailed model of the TN-32B HBU demonstration cask includes the same gaps as utilized for the existing TN-32 cask model [Reference 3.5.11], with an additional [ ] air gap between the lid outer plate and top neutron shield plate.

The heat zone configuration (HLZC) for the TN-32B HBU demonstration cask is shown in Figure 3.2-1 [Reference 3.5.10]. The heat loads shown in this figure are the maximum heat loads allowed in each fuel compartment opening. Within each fuel compartment opening, alternative fuel assemblies with either the same heat load or lower heat load can be loaded without any additional thermal evaluations.

Material properties used in the evaluation of the TN-32B HBU demonstration cask are identical to those utilized for the existing TN-32 cask. The effective thermal conductivities of the various segments of the existing TN-32 casks are provided in [Reference 3.5.10]. The bounding effective properties of homogenized fuel assembly in the TN-32B HBU demonstration cask is calculated in [Reference 3.5.12].

The effective thermal conductivities for homogenized model of the existing TN-32 cask are listed in [Reference 3.5.10]. The decay heat load of 27.1 kW [Reference 3.5.4] is applied to the homogenized model of the existing TN-32 casks as heat generation over the homogenized basket region.

An additional sensitivity study considering a 16 foot center-to-center spacing between the TN 32B HBU cask and the adjacent TN-32 casks and a 14 foot center-to-center spacing between the TN-32 casks is also performed. The results of this sensitivity study showed that the maximum temperatures of the TN-32B HBU cask are not affected by this change.

3.2.2 Fire Accident Conditions

An average flame temperature of 1,550 °F (843 °C) with an average convective heat transfer coefficient of 4.5 Btu/hr-ft^2-°F [Reference 3.5.13] are considered during the 15-minute fire accident condition.

Two sub-models as shown in Figure 6-4 of [Reference 3.5.6] are developed to evaluate thermal performance of the TN-32B HBU demonstration cask for the fire accident condition.

1) A cask cross-section sub-model to predict maximum temperatures for fuel cladding, basket components and cask shell components.

The cask cross-section model is developed using a cross-sectional slice of the TN-32B HBU demonstration cask model from the normal storage condition in Section 3.2.1, *Normal Storage Condition*. A [ ] length cask slice is selected at the location such that the decay heat generation and the resultant temperatures are at their highest for the normal storage conditions.

The initial temperatures for the cross-section model at the beginning of the fire accident condition are transferred from the result file for the normal storage conditions by using ANSYS® sub-modeling commands [Reference 3.5.9].

The average view factor used for calculating radiation heat transfer for the TN-32B HBU demonstration cask to the ambient is retrieved from the result file for normal storage conditions, and is used for the cool down period.

2) A cask top model including protective cover to predict maximum seal temperatures

A finite element model of the top portion of the TN-32B HBU demonstration cask is a quarter symmetric model, and includes the geometry and material properties of the cask flange, upper region of the cask body shells, cask top shield plate, cask lid, protective cover, and the OP tank. Radiation heat transfer among the top neutron shield, OP tank and protective cover is modeled to determine the maximum temperatures of the O-ring metallic seals during the fire accident condition. [

]

[

]

The initial temperatures for the cask top model are recalculated using the same boundary conditions applied in the full-length model of the TN-32B HBU demonstration cask for normal storage conditions. Since the cask top surface does not "see" the ISFSI pad from a radiative heat transfer viewpoint, these initial temperatures are unaffected by the ISFSI pad.

According to the heat balance results summarized in [Reference 3.5.11], the total decay heat dissipated from the protective cover is about 2.6% of the total cask heat load. Considering the similar geometry for the cask top design, a heat flow of [ ] of the total heat load for the TN-32B HBU demonstration cask (36.96 kW as shown in Figure 3.2-1 as of 7/1/2017), is conservatively considered to be transferred to the cask top in the cask top sub-model. This heat flow is applied as a uniform heat flux at the bottom of the cask top model to bound any uncertainties.

	Z1	Z2	Z3	Z4	
Z5	Z6	Z7	Z8	Z9	Z10
Z11	Z12	Z13	Z14	Z15	Z16
Z17	Z18	Z19	Z20	Z21	Z22
Z23	Z24	Z25	Z26	Z27	Z28
	Z29	Z30	Z31	Z32	

Zone No.	Heat Load(1) (W)	Zone No.	Heat Load(1) (W)
1	1013	17	1165
2	1167	18	1492
3	1015	19	1037
4	909	20	725
5	914	21	1496
6	1276	22	1121
7	1503	23	1036
8	1477	24	1031
9	1163	25	1495
10	903	26	1511
11	882	27	1178
12	1496	28	1035
13	858(2)	29	1073
14	1281	30	1155
15	1482	31	1031
16	1120	32	918
		Total Heat Load (kW)	**36.96**

Notes: (1) Heat load is calculated as of July 1, 2017.

(2) Heat load is for FA 52, which was replaced by FA 40 that has a decay heat load of 696 kW.

Figure 3.2-1 - Heat Load Zone Configuration for TN-32B HBU Demonstration Cask

3.3 Pressure Evaluation

The maximum internal pressures for the TN-32B HBU demonstration cask cavity at normal, off-normal, and accident conditions during the storage and transfer operations are provided in [Reference 3.5.14].

Using the ideal gas law, the design pressures in the TN-32B HBU demonstration cask cavity are calculated based on the amount of cavity gas with the average gas temperatures for normal, off-normal, and accident conditions.

According to Section 4.4.2 of [Reference 3.5.5], fuel rod fill and fission gases released into the cavity are calculated based on an assumed percentage of ruptured fuel rods: 1% for normal conditions, 10% for off-normal conditions, and 100% for accident conditions. In addition to the release of 100% of the fill gas, 30% of the fission gas generated within the fuel rods during operation is also considered.

As shown in Table 7 of [Reference 3.5.14], the maximum calculated internal pressures for normal, off-normal, and accident conditions in the TN-32B HBU demonstration cask cavity are 21.3 psig, 26.9 psig, and 95.5 psig, respectively. Therefore, the maximum internal pressure of 100 psig that is utilized in the evaluation of the TN-32B HBU cask and basket, as discussed in Chapter 2.0, *Structural Evaluation*, is a bounding pressure.

3.4 Thermal Expansion

Thermal expansion analysis of the TN-32B HBU demonstration cask is performed to evaluate if fuel assemblies and cask components have sufficient clearances for thermal expansion including:

- Evaluate if a fuel spacer is required for the TN-32B HBU demonstration cask with modified closure lid when loaded with irradiated fuel assemblies to minimize the clearance between the FAs and the lid.
- Evaluate if an adequate gap existed between the basket assemblies and the basket rails bolted to the cask body.

Thermal expansion evaluation for the TN-32B HBU demonstration cask is documented in [Reference 3.5.15], and is summarized in the following sections.

3.4.1 Thermal Expansion of Fuel Assemblies

No fuel spacer is required for storage of all three types of fuel assemblies (AMBW, LOPAR and NAIF) in the TN-32B HBU demonstration cask. The maximum axial gap between the fuel assemblies and the cask lid is [ ] which is for a nominal length NAIF assembly. This maximum gap is less than the required maximum allowable gap of [ ] [Reference 3.5.15]. The minimum gap between the fuel assemblies and the lid is [ ] which is for a nominal length LOPAR assembly. This minimum gap is larger than the required minimum gap [ ] [Reference 3.5.15].

3.4.2 Thermal Expansion of Basket Assembly

The evaluation demonstrates that there will be an adequate hot radial gap between the basket assemblies and basket rails. The minimum gap between the basket assembly and the basket rails is [ ] and thus, adequate to provide sufficient clearance for thermal expansion [Reference 3.5.15].

The basket plates are free to expand in the axial direction, since sufficient clearance is provided between the lid and the top of the basket for the maximum decay heat load of 36.96 kW.

3.5 References

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4.0 SHIELDING EVALUATION

This section of the DLBD summarizes the shielding evaluations that were performed to demonstrate that the TN 32B HBU demonstration cask with the HBU fuel assemblies (FAs) comply with the requirements of 10 CFR 72 [Reference 4.6.1] for the normal, off-normal, and accident conditions defined by the NAPS ISFSI SAR [Reference 4.6.2]. The results of the re-evaluations are discussed in the following sections, with the referenced calculation provided in Section 8.2, *Design Calculations.*

4.1 Source Terms

Source terms, primary gamma and neutron, for the thirty-two (32) North Anna high burn-up (HBU) fuel assemblies to be stored in the TN-32B HBU demonstration cask are determined in [Reference 4.6.3]. A conservative uranium loading of 476 kg is utilized for all the assemblies. Enrichments ranged for the selected HBU assemblies from 3.59 wt. % U-235 to 4.55 wt. % U-235, and burn-ups ranging from 50.0 to 58.1 GWd/MTU per assembly. An average specific power of 21.015 MW/assembly is utilized for all assemblies with the actual number of irradiation cycles used for each assembly. All assemblies have three irradiation cycles, except assembly 0A4 that had two irradiation cycles. Cycle durations are determined accordingly per the above parameters.

The source terms are generated for the active fuel region utilizing ORIGEN-ARP/ORIGEN-S modules of the SCALE code [Reference 4.6.9]. A conservative B&W high burn-up library, compared to the built-in ORIGEN-ARP WE17x17_ofa library, is used with the ORIGEN-ARP code. Material compositions for input into ORIGEN-ARP are generated in [Reference 4.6.4]. The source terms were conservatively determined as of January 1, 2017, even though the storage period is scheduled to occur no earlier than July 1, 2017.

Bounding Source

[Reference 4.6.5] defines response functions that are utilized to calculate the expected dose rate at the cask surface for each of the thirty-two (32) HBU FAs. The assembly producing the largest total dose rate is selected as the bounding assembly whose source terms are conservatively used for all assemblies in the dose rate calculations.

The response functions (primary gamma, neutron, and secondary gamma) are generated using the basic normal condition MCNP5 [Reference 4.6.10] TN-32B HBU demonstration cask model with a dose point at the mid-plane of the active fuel on the cask outer radial surface. The only goal during the ranking of radiological sources using response functions is determining which fuel assembly results in the largest relative dose rates. Note: no Burnable Poison Rod Assemblies (BPRAs) or thimble plug assemblies (TPAs) are inserted in any of the HBU assemblies.

A conservative axial profile containing 18 axial zones is utilized in the shielding evaluation. The axial zones are approximately equal and each zone represents between 5% and 6% of the total active fuel zone. The peaking factors range from a slightly more than 0.5 at the bottom and top, to a maximum of 1.11 just below the middle. The gamma source is directly proportional to the burnup and the neutron source is proportional to the fourth power of the burnup.

Fuel assembly 54B was determined to be the bounding source because it yields the highest total dose rate [Reference 4.6.5]. Thus, in the detailed dose rate evaluations, the MCNP5 cask model contains thirty-two (32) fuel assemblies with the sources from only FA 54B. The parameters for this assembly are 4.55 wt. % enrichment, 51.340 GWd/MTU burnup, and a cooling time of 4.81 years. This assumption will result in conservative calculated dose rates for the TN-32B HBU demonstration cask.

An ORIGEN-ARP/ORIGEN-S evaluation is also performed in calculation [Reference 4.6.5] to determine the gamma sources from activated hardware in the plenum, top and bottom end fitting regions for FA 54B.

The bounding radiological source terms for FA 54B are listed in Table 4.1-1.

Table 4.1-1 - Bounding Radiological Source Terms

4.2 Shielding Analysis Models

The neutron and gamma dose rates on the surface of the TN-32B HBU demonstration cask (side, top and bottom surfaces) and at 1 meter and 2 meters from the surface of the cask are evaluated with the three-dimensional Monte Carlo transport code MCNP5 in [Reference 4.6.5], which is a general-purpose Monte Carlo N-Particle code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport. The code treats an arbitrary three-dimensional configuration of materials in geometric cells bounded by first- and second-degree surfaces and some special fourth-degree surfaces. Pointwise (continuous energy) cross-section data are used. For neutrons, all

reactions given in a particular cross-section evaluation are accounted for in the cross section set. For photons, the code considers incoherent and coherent scattering, the possibility of fluorescent emission after photoelectric absorption, absorption in pair production with local emission of annihilation radiation, and bremsstrahlung. Mesh tallies capabilities (F4 type tallies) were utilized in calculating dose rates distributed over and around the surface of the TN 32B HBU demonstration cask. The MCNP5 code is selected for its ability to handle thick, multi-layered shields, like the TN-32B HBU cask body, using 3-D geometry. Determination of far field dose rates [Reference 4.6.6] uses the same basic MCNP5 model(s). The flux-to-dose conversion factors specified by ANSI/ANS 6.1.1-1977 [Reference 4.6.7] are used in both calculations. Material compositions and densities for the models are provided in [Reference 4.6.4].

4.2.1 Thermal Expansion of Basket Assembly

A single shielding configuration is utilized for the TN-32B HBU design for both normal and off-normal conditions of storage. A three-dimensional MCNP5 model, which includes a discrete basket and fuel assembly model, was developed for this purpose. In the MCNP5 model, the TN 32B HBU demonstration cask longitudinal axis is modeled along the Z-direction. The X and Y axes in the MCNP5 model represent the cask in the radial direction. The cask is assumed to rest on a concrete pad (Z-direction) with the center of the active fuel at Z=0.

The MCNP5 model for these shielding configurations is based on a discrete basket with the homogenized fuel assembly zones (with an active height of 144 inches) positioned within fuel compartments. The cask trunnions and the resin cutouts (flats) are modeled explicitly. The neutron resin boxes/radial neutron shield, top neutron shield and protective cover are also modeled explicitly.

The basket is modeled discretely using the advanced geometry features of MCNP5. The fuel is modeled as a cuboid based on an [ ] square with homogenized plenum, active fuel, top and bottom fittings zones. The fuel compartment inside dimension is [ ] and is surrounded by [ ] stainless steel plates and [ ] aluminum plates. The poison plates (0.040 inch thick) are modeled as pure aluminum. The stainless steel and aluminum peripheral plates are modeled explicitly.

The TN-32B HBU demonstration cask lid contains seven (7), identical penetrations utilized to insert thermocouple instrument lances into designated fuel assemblies. Details of these penetrations are provided in [Reference 4.6.5]. For the MCNP5 model, the bottom [ ] of the thermocouple penetration is modeled discretely as a [ ] ID diameter tube. The hardware in the top [ ] of the thermocouple instrument penetration is homogenized, with a homogenized stainless steel density calculated to be [ ] The holes for the fasteners are ignored as they are assumed to be completely filled with the fasteners.

Two MCNP5 models are developed for determining the normal and off-normal dose rates. The gamma model containing a detailed segmentation of the thicker cask steel body is utilized to calculate the primary gamma dose rates. The neutron model is utilized to calculate the neutron and secondary gamma dose rates. Various views of the MCNP5 model can be seen in the figures

contained in [Reference 4.6.5].

For near field dose rates, tallies are based on the F4-type mesh tally feature of MCNP5 to provide the average flux in the defined volume. The radial tallies are located just off the cask surface, 1 meter from cask outer surface, and 2 meters from cask outer surface. Similarly, axial tallies are located at the cask top (protective cover) and bottom that determine the average flux at the top and bottom surfaces, and at 1 meter and 2 meters from the top surface.

4.2.2 Shielding Configuration Under Accident Conditions

The MCNP5 design basis model for accident conditions is essentially identical to that of the normal (and off-normal) conditions model, except that all neutron shielding and the outer steel shell materials are replaced with a void. This scenario is based on a cask drop accident that results in the complete removal of the neutron shielding materials including the polypropylene disk and the protective cover at the top. This configuration is implemented in MCNP5 by replacing the appropriate materials in the MCNP5 models with a void.

4.2.3 Shielding Configuration at Long Distances from the Cask

To calculate the far-field dose rates, the normal condition model is used. The protective cover and top neutron shield are present since this configuration is the cask configuration that would exist on the ISFSI pad, referred to as the storage configuration.

F5-point detector tallies are used to calculate the far-field dose rates at distances from 2 meters to 500 meters. Two sets of MCNP5 cases are run to calculate the direct and skyshine components of the far-field dose rates. One set has a void (0 importance) above the top of the cask. One set models the air above the cask. The dose rates calculated in the cases with the void above the cask are considered the direct dose rates, since there would be no skyshine component. The set of cases with air above the cask are the total dose rates. The difference between the total dose rate and the direct dose rate is the skyshine dose rate. Primary gamma, secondary gamma, and neutron dose rates are also determined.

4.3 Near Field Dose Rates

Near-field dose rates are determined in [Reference 4.6.5] utilizing the MCNP5 code identified previously. Gamma (primary and secondary) and neutron dose rates are calculated around the TN 32B HBU demonstration cask at contact, 1 meter and 2 meters from the cask surface, both axially and radially. Primary gamma sources from the four fuel assembly zones and the neutron source from the active fuel zone provide the source components. The primary gamma and neutron source terms shown in Table 4.1-1 are utilized. The neutron source from Table 4.1-1 is increased by the axial peaking factor of 1.15, and also to account for subcritical multiplication a factor of 1/ (1-dry_k_{eff}), which is **[ ]** The Cm-244 spectra from MCNP5 is utilized for the neutron source. Dose rates are calculated for normal/off-normal and accident conditions of storage.

4.3.1 Normal and Off-Normal Conditions of Storage

For normal and off-normal conditions of storage, dose rates around a single TN-32B HBU demonstration cask are calculated assuming the lid, top neutron shield, and protective cover are installed. A summary of the maximum and average dose rates around the cask are presented in Table 4-3-1.

These near field dose rates calculated for the TN-32B HBU demonstration cask with high burnup fuel are lower than those calculated for the TN-32 dry storage cask listed in the TN-32 Updated Safety Analysis Report (UFSAR) [Reference 4.6.8]. Analyses [Reference 4.6.6] have demonstrated that the main reason for the lower dose rates is the TN-32B HBU MCNP5 analyses modeled fuel assemblies and basket discretely. In the TN-32 UFSAR shielding evaluation, the basket and fuel assemblies are homogenized to fill the cask cavity in the SCALE SAS4 (Monte Carlo) model. These modeling differences result in lower calculated dose rates for the TN-32B HBU demonstration cask with HBU fuel than the TN-32 dry storage cask with the homogenized fuel/basket.

4.3.2 Accident Conditions of Storage

Dose rates for the accident condition are calculated assuming the protective cover, top neutron shield, and the radial neutron shield are removed from the cask. A summary of the maximum and average dose rates around the cask are presented in Table 4-3-2.

As in the normal/off-normal near filed dose rates, the TN-32B HBU accident dose rates are lower than the accident dose rates shown in the TN-32 UFSAR for the reason described above.

Table 4.3-1 - Summary of TN-32B HBU Average Dose Rates, Normal & Off-Normal

	Average Dose Rates (mrem/hr) for Normal and Off-Normal Conditions							
	Side Surface Above Shield[1]	Side Surface Along Shield[5]	Side Surface Below Shield[2]	Top Surface[3] (Protective Cover)	Side Surface[6]	Bottom Surface[4]	1 Meter from Side	2 Meter from Side
Gamma	204	59.7	48.0	93.6	65.4	238	25.4	15.4
Neutron	64.9	17.2	127	2.56	25.8	363	7.40	4.21
Total	269	76.9	175	96.1	91.1	600	32.8	19.6

Notes:

(1) Maximum surface dose rates above the neutron shield are 277 mrem/hr gamma and 83.9 mrem/hr neutron.

(2) Maximum surface dose rates below the neutron shield are 87.1 mrem/hr gamma and 169 mrem/hr neutron.

(3) Top surface dose rate is on the protective cover. Maximum surface dose rates are 281 mrem/hr gamma and 5.32 mrem/hr neutron.

(4) Maximum surface dose rates on the cask bottom are 539 mrem/hr gamma and 648 mrem/hr neutron.

(5) Maximum surface dose rates on the cask side are 277 mrem/hr gamma and 169 mrem/hr neutron.

(6) Includes surfaces above and below the radial neutron shield.

Note: Maximum gamma and neutron dose rates may not occur at the same location

Table 4.3-2 - Summary of TN-32B HBU Average Dose Rates, Accident Conditions

	Average Dose Rates (mrem/hr) for Accident Conditions							
	Side Surface Above Shield[1]	Side Surface Along Shield[5]	Side Surface Below Shield[2]	Top Surface[3] (Protective Cover)	Side Surface[6]	Bottom Surface[4]	1 Meter from Side	2 Meter from Side
Gamma	206	238	48.8	324	211	237	93.2	57.7
Neutron	60.7	829	126	34.4	622	352	254	146
Total	267	1067	174	358	833	589	347	203

Notes:

(1) Maximum surface dose rates above the neutron shield are 283 mrem/hr gamma and 79.0 mrem/hr neutron.

(2) Maximum surface dose rates below the neutron shield are 89.2 mrem/hr gamma and 166 mrem/hr neutron.

(3) Top surface dose rate is on the protective cover. Maximum surface dose rates are 918 mrem/hr gamma and 54.4 mrem/hr neutron.

(4) Maximum surface dose rates on the cask bottom are 539 mrem/hr gamma and 660 mrem/hr neutron.

(5) Maximum surface dose rates on the cask side are 283 mrem/hr gamma and 966 mrem/hr neutron.

(6) Includes surfaces above and below the radial neutron shield.

Note: Maximum gamma and neutron dose rates may not occur at the same location

4.4 Occupational Exposures

Estimated occupational exposures to ISFSI personnel during the loading, processing, transport, and placement of the TN-32B HBU demonstration cask are determined in [Reference 4.6.6]. The estimated exposures assume no temporary shielding is utilized during cask loading operations.

Personnel exposure is determined for a given task by defining the number of personnel involved, the working distance, which determines the dose rate, and the amount of time required to perform the task.

The MCNP5 normal/off-normal models from the near-field dose rate calculation are utilized with the addition of a mesh tally added at 10 inches above the lid. Two different configurations are modeled; a dry cask cavity and a wet cask cavity. For loading and processing operations, the top neutron shield and protective cover are removed.

Table 4-4-1 provides the estimated person –hours, working distance, and cask configuration (wet or dry cavity) for the tasks required to load, process, transport, and place the cask on the storage pad. The dose associated with each task is obtained from the MCNP5 analyses for the cask configuration, work location and personnel working distance.

Table 4-4-2 lists the applicable dose rates and the total personnel exposure by task to load the TN-32B HBU demonstration cask, place it in storage and perform quarterly monitoring. The personnel exposure for the TN-32B HBU to be loaded and placed on the ISFSI pad is estimated to be 3.45 person-rem.

Table 4.4-1 - Task Estimates for Cask Operations

Person-hours (Estimated Staff * Estimated hours/evolution)	Evolution	Distance	Configuration
6	Cask Loading (pool) (low dose evolution – dose rate over pool is about 1 mrem/hr)		
2	Install 6 lid bolts to 100 ft-lbs and drain 10 inches at pool side	Contact	
5	Cleaning surfaces (Decon)	10"	
4	Installing lances, including torqueing	10 "	
4	Dewatering – follow draining with helium	2/3 side 1/3 top	
4	Vacuum drying (setup)	10"	
3	Vacuum drying and dryness test: installing and removing equipment	10"	
2	Vacuum drying and dryness test: Remote Operations	2m	
2	Backfill	10"	
6	Assembling tubing & temporary TC connections	10"	
6	Gas sampling	10"	
4	Disconnect temp connections, complete assembly of upper package (N-shield, overpressure protection system, partial assembly of electrical data package	Contact	
4	Transfer to ISFSI	1.5m	
4	Final assembly of data package at ISFSI	1.5m	
1 per calendar quarter	Long term monitoring	contact	

Table 4.4-2 - Occupational Dose-to-Personnel

Evolution	Gamma (mrem/hr)	Neutron (mrem/hr)	Total (mrem/hr)	Gamma Dose* (mrem)	Neutron Dose* (mrem)	Total Dose* (Rem)
Cask Loading (pool) (low dose evolution – dose rate over pool is about 1 mrem/hr						0.01
Install 6 lid bolts to 100 ft-lbs and drain 10 inches at pool side						0.09
Cleaning surfaces (Decon)						0.16
Installing lances, including torqueing						0.95
Dewatering – follow draining with helium						0.24
Vacuum drying (setup)						0.35
Vacuum drying and dryness test: installing and removing equipment						0.26
Vacuum drying and dryness test: Remote Operations						0.04
Backfill						0.17
Assembling tubing & temporary TC connections						0.52
Gas sampling[1]						0.52
Disconnect temp connections, complete assembly of upper package (N-shield, overpressure protection system, partial assembly of electrical data package						0.14
					Total from Loading Operations	**3.45**
Transfer to ISFSI						0.10
Final assembly of data package at ISFSI						0.10
Long term monitoring						0.03

Note: 1. For gas sampling on the ISFSI pad, assume three (3) samples with the same personnel exposure as above for a total personnel exposure of 1.56 person-rem.

4.5 Far Field Dose Rates

Contributions to dose rates around the ISFSI (far field dose rates) due to a single TN-32B HBU cask on the storage pad are determined in [Reference 4.6.6].

The normal/off-normal condition MCNP5 model, which includes the top neutron shield and protective cover, is utilized in this calculation. F5-point detector tallies are used to calculate the far field dose rates at the following distances from the cask surface: 2 meters, 5 meters, 50 meters, 100 meters, 150 meters, 200 meters, 300 meters, 400 meters, and 500 meters. Two sets of MCNP5 cases are evaluated to calculate the direct and skyshine components of the far field dose rates. One set (direct dose) has a void region boundary above the protective cover. This configuration effectively prevents any contribution to the dose rate detectors from scattered radiation above the cask (skyshine). The second set of cases contains air in place of the void above the protective cover. Thus, contributions from skyshine radiation are included at the dose rate detectors (total dose rate). The difference between the total dose rate and the direct dose rate is defined as the skyshine dose rate.

The estimated far field total dose rates and annual dose as a function of distance from the TN-32B HBU demonstration cask are presented in Table 4-5-1. Table 4-5-2 lists the calculated skyshine component of the total far field dose rates.

The far field total dose rates for the TN-32B HBU demonstration cask from 100 meters to 500 meters are approximately half of the values presented in Chapter 5 and Chapter 10 of the TN-32 UFSAR, again mainly due to the discrete MCNP5 modeling of the basket and the fuel assemblies in the TN-32B HBU shielding analyses.

Table 4.5-1 - Total Dose Rates as a Function of Distance from TN-32B HBU Cask

Distance from Cask (meters)	Neutron (mrem/hr)	Secondary Gamma (mrem/hr)	Primary Gamma (mrem/hr)	Total (mrem/hr)	Annual Dose (rem/yr)
2	5.24E+00	1.28E+00	1.74E+01	2.40E+01	2.10E+02
5	1.86E+00	3.59E-01	7.05E+00	9.27E+00	8.12E+01
10	6.55E-01	1.10E-01	2.16E+00	2.92E+00	2.56E+01
20	1.96E-01	3.06E-02	5.84E-01	8.10E-01	7.10E+00
50	3.09E-02	4.99E-03	9.51E-02	1.31E-01	1.15E+00
100	6.75E-03	1.11E-03	2.00E-02	2.78E-02	2.44E-01
150	2.21E-03	4.16E-04	6.62E-03	9.24E-03	8.09E-02
200	9.23E-04	1.94E-04	2.88E-03	3.99E-03	3.50E-02
300	2.11E-04	5.94E-05	6.99E-04	9.69E-04	8.49E-03
400	6.21E-05	2.21E-05	2.19E-04	3.03E-04	2.65E-03
500	2.12E-05	1.02E-05	7.54E-05	1.07E-04	9.37E-04

Table 4.5-2 - Skyshine Dose Rates vs. Distance from TN-32B HBU Cask

Distance from Cask (meters)	Neutron (mrem/hr)	Secondary Gamma (mrem/hr)	Primary Gamma (mrem/hr)	Total (mrem/hr)	Annual Dose (rem/yr)
2	1.57E-01	4.24E-03	1.44E+00	1.60E+00	1.40E+01
5	1.00E-01	5.59E-03	1.39E+00	1.49E+00	1.31E+01
10	7.28E-02	3.61E-03	2.51E-01	3.28E-01	2.87E+00
20	4.97E-02	2.69E-03	5.24E-02	1.05E-01	9.18E-01
50	1.54E-02	1.13E-03	1.66E-02	3.31E-02	2.90E-01
100	4.69E-03	3.91E-04	5.35E-03	1.04E-02	9.14E-02
150	1.73E-03	1.71E-04	1.48E-03	3.38E-03	2.96E-02
200	7.49E-04	8.62E-05	1.30E-03	2.13E-03	1.87E-02
300	1.89E-04	2.83E-05	3.57E-04	5.75E-04	5.04E-03
400	5.79E-05	9.77E-06	1.23E-04	1.91E-04	1.67E-03
500	2.01E-05	4.69E-06	4.58E-05	7.06E-05	6.19E-04

4.6 References

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5.0 CRITICALITY EVALUATION

This section of the DLBD summarizes the criticality evaluations that were performed to demonstrate that the TN-32B HBU demonstration cask with the HBU fuel assemblies complies with the requirements of 10 CFR 72 [Reference 5.3.1] for normal, off-normal, and accident conditions defined by the NAPS ISFSI Safety Analysis Report (SAR) [Reference 5.3.2]. The results of the re-evaluations are discussed in the following sections, with the referenced calculation provided in Section 8.2, *Design Calculations*.

The TN-32B high burnup (HBU) demonstration cask is a modified standard TN-32 cask, as described in Chapter 1.0, *Introduction*. The criticality analysis of the TN-32B HBU demonstration cask is performed with the use of the SCALE 6.0 computer code [Reference 5.3.3] using the fresh fuel assumption, i.e., no burnup credit. The TN-32B HBU demonstration cask stores thirty-two (32) HBU PWR 17 × 17 spent fuel assemblies of three fuel types: AMBW, LOPAR and NAIF. These fuel assemblies include four cladding types; M5™, ZIRLO™, Zirc-4 and Low-SN Zirc-4, which are all modeled as Zircaloy-4. Each thermocouple lance is modeled as a solid aluminum cylindrical rod with a diameter of [ ] The poison rod assembly (PRA) design values are provided in Table 5.1-1. The thermocouple lance and PRA locations are illustrated in Figure 5.1-1.

The standard TN-32 cask was previously analyzed with older versions of the SCALE computer software [References 5.3.4 and 5.3.5]. The TN-32B HBU demonstration cask is analyzed with the same SCALE control sequence, cross-section data, modeling methods, and code options as the standard TN-32 cask, but Version 6.0 of the SCALE computer code is employed for the analysis. Furthermore, the SCALE models for both casks are essentially identical, as compared in Table 5.1-2, except that the TN-32B HBU demonstration cask is instrumented with thermocouple lances, and uses poison rod assemblies (PRAs) in addition to borated water and poison plates for criticality control. As far as the criticality analysis is concerned, neither the thermocouple lance nor the PRA affects the most reactive configuration. Therefore, the most reactive configuration of the standard TN-32 dry storage cask is also the most reactive configuration for the TN-32B HBU demonstration cask.

The maximum initial enrichments of the AMBW, LOPAR and NAIF fuel classes are 4.55, 3.59 and 4.45 wt. % U-235 respectively, and their lattice geometrical data are identical except that the NAIF fuel class has a smaller guide tube outside diameter (0.474 inch vs. 0.482 inch), as shown in Table 5.1-3. Under the fresh fuel assumption, the AMBW, LOPAR and NAIF fuel classes are equivalent in reactivity for equivalent enrichments. Therefore, the AMBW fuel class is identified as the most reactive fuel assembly type since its maximum initial enrichment is the highest among the three fuel classes. In the criticality analysis, all 32 fuel assemblies are modelled as fresh AMBW fuel with the initial enrichment conservatively modeled at 4.60 wt. % U-235.

5.1 Criticality Analysis

The criticality analysis is performed with the SCALE 6.0 CSAS5 control sequence with the 44 group ENDF/B-V cross-section library and the NITAWL options. The CSAS5 control module

allows simplified data input to the functional modules BONAMI, NITAWL, and KENO V.a. These modules process the required cross sections and calculate the k_{keno} and σ_{keno} of the system. BONAMI performs resonance self-shielding calculations for nuclides that have Bondarenko data associated with their cross sections. NITAWL applies a Nordheim resonance self-shielding correction to nuclides having resonance parameters. Finally, KENO V.a calculates the k_{keno} of a three-dimensional system. The effective multiplication factor (k_{eff}) is calculated with the following formula:

$$k_{eff} = k_{keno} + 2 \times \sigma_{keno}$$

The criticality analysis is performed for the TN-32B HBU demonstration cask loaded with 32 fresh fuel assemblies of the most reactive fuel type in the most reactive configuration under normal, off-normal, and accident conditions with various moderations. The k_{eff} of each configuration is then compared to the Upper Subcriticality Limit (USL), which is determined to be 0.9388 in Section 5.2, *Criticality Benchmarks*. The results for the normal and off-normal conditions are provided in Table 5.1-4. The limiting case is the 90% moderation case, and the k_{eff} is under the USL value of 0.9388.

The criticality analysis considers two accident conditions; the single fuel misplacement accident and the cask tip-over accident. The single fuel misplacement accident is analyzed based on the limiting case identified for the normal and off-normal condition, which is 90% moderation. The initial enrichment of the misplaced fuel is 5.00 wt. % U-235. Five misplacement locations, 13, 14, 21, 27, and 32 as shown in Figures 5.1-1 and 5.1-2, are analyzed. Location 13 and 14 are loaded with a PRA and a thermocouple lance respectively. In the analysis, the PRA and the thermocouple lance remain loaded in the misplaced fuel. The results of the single fuel misplacement accident are given in Table 5.1-5. The limiting misplacement case is at Location 27, and the k_{eff} is under the USL of 0.9388.

The cask tip-over accident is represented by the side drop accidents which are performed for both the fuel rod and the basket, as described in Chapter 2. 0, *Structural Evaluation*. The criticality modeling of the cask tip-over accident analysis focuses on the integrity of the fuel rod location, fuel cladding, the grid spacers and the fuel compartment. Based on the results from the TN-32B HBU fuel structural evaluation, the cladding integrity is maintained. Based on the results from the TN-32B HBU basket accident analysis, the maximum transverse deformation of the fuel compartments is zero. Based on the results from the TN-32 FSAR, the grid spacers are assumed to crush and the fuel rod slides axially. The fuel rod axial sliding relative to the poison plate is already modeled in the intact fuel analysis, as shown in Table 5.1-2. Thus, only the fuel rod pitch reduction is modeled to account for the grid spacer collapse. The limiting case identified for the normal and off-normal condition, which is 90% moderation at zero fuel rod pitch reduction, is modified with four (4) fuel rod pitch reductions: [ ] In the [ ] reduction configuration, the fuel rod pitch is reduced to the magnitude of the guide tube diameter. The results for the fuel rod pitch reductions are shown in Table 5.1-6. The reactivity effect of the fuel rod pitch reduction is negative, thus, does not reduce the criticality safety margin.

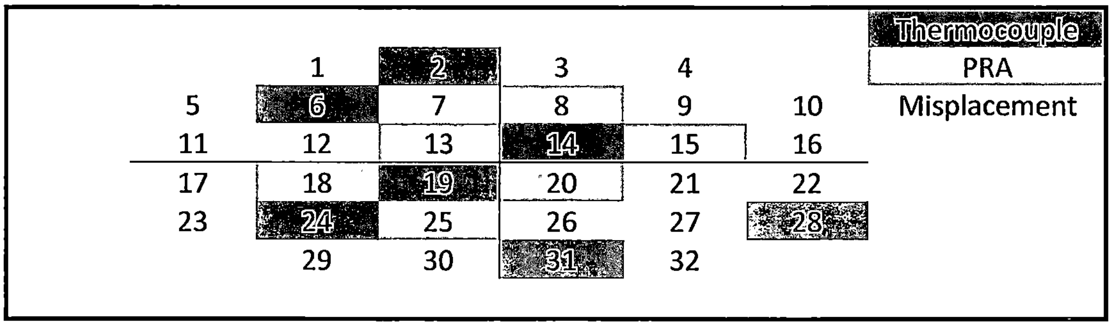

Figure 5.1-1 - Standard View - Thermocouple lance, PRA and Misplacement Locations

[ ]

Figure 5.1-2 - SCALE - Thermocouple Lance, PRAs, and Misplacement Locations

Table 5.1-1 - PRA Design Values for Criticality Control

Design Parameter	Design Value
Number of PRAs	6
PRA Locations	See Figure 5.1-1
Number of Poison Rods per PRA	24
Poison Pellet Diameter	0.295 inch
Poison Pellet Material	B_4C
Credit Taken per PRA	50%
Poison Rod Diameter	0.374 inch
Poison Rod Clad Thickness	0.0225 inch

Table 5.1-2 - SCALE Modeling Approach

Model Feature	
Fuel Loading Position	
Fuel Compartment Width	
Poison Plate Width	
Borated Water Draining	
Soluble Boron Concentration	
Active Fuel Axial Shift Relative to Poison Plate	
Fuel top/Bottom Nozzle Regions	
Aluminum Rail Region	
Stainless Steel Plug inside poison plate and aluminum plate	
Gap on either side of poison plate during fuel loading	
Neutron Shield	
Fuel Compartment Thickness	
Fuel Compartment Inner Width	
Poison Plate Thickness	
Poison Plate Width	
Poison Plate Boron-10 Loading	
Aluminum Plate Thickness	

Table 5.1-3 - Fuel Data

Parameter	AMBW	LOPAR	NAIF
Maximum Initial Enrichment (wt. % U-235)[(1)]	4.55	3.59	4.45
Theoretical Fuel Density, %	96.0	95.0	≤ 96.0
Fuel Rod Pitch, inch	0.496	0.496	0.496
Guide Tube Outside Diameter, inch	0.482	0.482	0.474
Guide Tube Wall Thickness, inch	0.016	0.016	0.016
Instrument Tube Outside Diameter, inch	0.482	≤ 0.482	≤ 0.482
Instrument Tube Wall Thickness, inch	0.016	≤ 0.016	≤ 0.016
Fuel Rod Clad Thickness, inch	0.0225	≤ 0.0225	≤ 0.0225
Fuel Pellet Diameter, inch	0.3225	≤ 0.3225	≤ 0.3225
Fuel Rod Diameter, inch	0.374	≤ 0.374	≤ 0.374
Active Fuel Length, inch	144	≤ 144	≤ 144

Note: 1. The maximum initial enrichment is the maximum nominal enrichment. A 0.05 wt. % U-235 uncertainty is added to the maximum initial enrichment in the criticality evaluation.

Table 5.1-4 - Criticality Analysis – Normal and Off-Normal Conditions

Fuel Type	Moderation Density Variation	k_{keno}	σ_{keno}	k_{eff}
AMBW				0.8794
				0.8934
				0.9021
				0.9027
				0.9058
				0.9046
				0.9039

Table 5.1-5 - Criticality Analysis - Single Fuel Misplacement Accident

Misplaced Fuel	Misplacement Location (per Figure 5.1-2)	k_{keno}	σ_{keno}	k_{eff}
AMBW with 5.00 wt. % U-235				0.9058
				0.9057
				0.9057
				0.9064
				0.9051
				0.9061

Table 5.1-6 - Criticality Analysis - Cask Tip-Over Accident

Fuel Class and Moderation Density	Fuel Rod Pitch Reduction	k_{keno}	σ_{keno}	k_{eff}
AMBW at 90% Moderation Density				0.9058
				0.9014
				0.8984
				0.8928
				0.8920

5.2 Criticality Benchmarks

Ninety-two (92) IHECSBE thermal spectrum critical experiments [Reference 5.3.6] are benchmarked with the use of the SCALE 6.0 computer code. All 92 critical experiments are characterized with low-enriched UO_2 fresh fuel with water-moderation in a square-pitched fuel rod lattice geometry configuration. In addition, the experiment configuration and material are also similar to that of the TN-32B HBU Demonstration cask. Thus, they adequately represent the TN-32B HBU demonstration cask and fuel features and parameters that are important to reactivity. The IHECSBE benchmark employs identical SCALE control sequence, cross-section data, modeling methods, and code options as employed in the criticality analysis. 92 pairs of the neutron multiplication factors (k_{keno}) and associated standard deviations (σ_{keno}) are generated, and used to calculate 92 k_{keno} values. The 92 k_{keno} values are first correlated against six (6) parameters; initial enrichment, fuel rod pitch, fuel assembly separation distance, soluble boron concentration, moderator to fuel volume ratio and EALF of the critical experiments, as shown in Table 5.2-1. Next, the parameter with the strongest correlation to the k_{keno} values is used to determine the USL. The correlation of the six parameters to the k_{keno} values is shown in Table 5.2-2. Correlation strength is measured on a scale of 0.0 to 1.0 with a weak correlation demonstrated by a correlation value closer to 0.0, and a strong correlation demonstrated by a correlation value closer to 1.0.

The USLSTATS computer program [Reference 5.3.7] is used to determine the USL with a 95% confidence band for a single future calculation with an administrative subcritical margin of 5%. The methodology of the USL generation with a 95% confidence band for a single future calculation, along with the statistical treatment and input preparation, is detailed in the NRC NUREG/CR-6361 [Reference 5.3.8]. Fuel assembly separation distance has the strongest correlation of the six that were examined. The second strongest correlation parameter is soluble boron concentration. Sixty-four (64) experiments have fuel assembly separation distance data, but only forty-one (41) experiments have soluble boron concentration data. Furthermore, only three (3) experiments have higher boron concentration values than 2500 ppm. Thus, fuel assembly separation distance was chosen as the appropriate correlation parameter to base the USL on. The USL function of the fuel assembly separation distance is generated by the USLSTATS computer program, as shown in Table 5.2-3. For the normal and off-normal conditions, the USL is 0.9388. For the accident conditions, the single fuel misplacement has the same separation distance. However, the fuel rod pitch reduction increases the separation distance, and in turn increases the USL. Therefore, it is conservative to apply the normal and off-normal condition USL of 0.9388 to the accident condition cases.

Table 5.2-1 - IHECSBE Experimental Parameters
(Part 1 of 3)

Case	Initial Enrichment (wt.% U-235)	Fuel Pitch (cm)	Separation Distance (cm)	Soluble Boron Concent-ration (ppm)	Moderator to Fuel Ratio	EALF (eV)	k_{keno}	σ_{keno}
leu-comp-therm-001-001	2.350	2.032	-	-	2.918			
leu-comp-therm-001-002	2.350	2.032	11.92	-	2.918			
leu-comp-therm-001-003	2.350	2.032	8.41	-	2.918			
leu-comp-therm-001-004	2.350	2.032	10.05	-	2.918			
leu-comp-therm-001-005	2.350	2.032	6.39	-	2.918			
leu-comp-therm-001-006	2.350	2.032	8.01	-	2.918			
leu-comp-therm-001-007	2.350	2.032	4.46	-	2.918			
leu-comp-therm-001-008	2.350	2.032	7.57	-	2.918			
leu-comp-therm-002-001	4.310	2.540	-	-	3.882			
leu-comp-therm-002-002	4.310	2.540	-	-	3.882			
leu-comp-therm-002-003	4.310	2.540	-	-	3.882			
leu-comp-therm-002-004	4.310	2.540	10.62	-	3.882			
leu-comp-therm-002-005	4.310	2.540	7.11	-	3.882			
leu-comp-therm-008-001	2.459	1.636	-	1511	1.841			
leu-comp-therm-008-002	2.459	1.636	-	1336	1.841			
leu-comp-therm-008-003	2.459	1.636	-	1336	1.841			
leu-comp-therm-008-004	2.459	1.636	-	1182	1.841			
leu-comp-therm-008-005	2.459	1.636	-	1182	1.841			
leu-comp-therm-008-006	2.459	1.636	-	1033	1.841			
leu-comp-therm-008-007	2.459	1.636	-	1033	1.841			
leu-comp-therm-008-008	2.459	1.636	-	794	1.841			
leu-comp-therm-008-009	2.459	1.636	-	779	1.841			
leu-comp-therm-008-010	2.459	1.636	-	1245	1.841			
leu-comp-therm-008-011	2.459	1.636	-	1384	1.841			
leu-comp-therm-008-012	2.459	1.636	-	1348	1.841			
leu-comp-therm-008-013	2.459	1.636	-	1348	1.841			
leu-comp-therm-008-014	2.459	1.636	-	1363	1.841			
leu-comp-therm-008-015	2.459	1.636	-	1363	1.841			
leu-comp-therm-008-016	2.459	1.636	-	1158	1.841			
leu-comp-therm-008-017	2.459	1.636	-	921	1.841			
leu-comp-therm-010-005	4.310	2.540	14.26	-	3.882			
leu-comp-therm-010-016	4.310	1.892	15.39	-	1.597			
leu-comp-therm-010-017	4.310	1.892	15.36	-	1.597			
leu-comp-therm-010-018	4.310	1.892	14.97	-	1.597			
leu-comp-therm-010-019	4.310	1.892	13.34	-	1.597			

Table 5.2-1 - IHECSBE Experimental Parameters
(Part 2 of 3)

Case	Initial Enrichment (wt.% U-235)	Fuel Pitch (cm)	Separation Distance (cm)	Soluble Boron Concent-ration (ppm)	Moderator to Fuel Ratio	EALF (eV)	k_{keno}	σ_{keno}
leu-comp-therm-017-003	2.350	2.032	10.51	-	2.918			
leu-comp-therm-017-004	2.350	2.032	11.09	-	2.918			
leu-comp-therm-017-005	2.350	2.032	13.19	-	2.918			
leu-comp-therm-017-006	2.350	2.032	13.37	-	2.918			
leu-comp-therm-017-007	2.350	2.032	12.96	-	2.918			
leu-comp-therm-017-008	2.350	2.032	9.95	-	2.918			
leu-comp-therm-017-009	2.350	2.032	7.82	-	2.918			
leu-comp-therm-017-010	2.350	2.032	9.89	-	2.918			
leu-comp-therm-017-011	2.350	2.032	10.44	-	2.918			
leu-comp-therm-017-012	2.350	2.032	10.44	-	2.918			
leu-comp-therm-017-013	2.350	2.032	9.60	-	2.918			
leu-comp-therm-017-014	2.350	2.032	8.75	-	2.918			
leu-comp-therm-017-015	2.350	1.684	8.57	-	1.600			
leu-comp-therm-017-016	2.350	1.684	9.17	-	1.600			
leu-comp-therm-017-017	2.350	1.684	9.10	-	1.600			
leu-comp-therm-017-019	2.350	1.684	8.87	-	1.600			
leu-comp-therm-017-020	2.350	1.684	8.65	-	1.600			
leu-comp-therm-017-021	2.350	1.684	8.13	-	1.600			
leu-comp-therm-017-022	2.350	1.684	7.26	-	1.600			
leu-comp-therm-017-023	2.350	1.684	9.65	-	1.600			
leu-comp-therm-017-024	2.350	1.684	9.70	-	1.600			
leu-comp-therm-017-025	2.350	1.684	8.09	-	1.600			
leu-comp-therm-017-028	2.350	1.684	7.65	-	1.600			
leu-comp-therm-017-029	2.350	1.684	9.09	-	1.600			
leu-comp-therm-042-001	2.350	1.684	8.28	-	1.600			
leu-comp-therm-042-002	2.350	1.684	4.80	-	1.600			
leu-comp-therm-042-003	2.350	1.684	2.69	-	1.600			
leu-comp-therm-042-004	2.350	1.684	2.98	-	1.600			
leu-comp-therm-042-005	2.350	1.684	3.86	-	1.600			
leu-comp-therm-042-006	2.350	1.684	7.79	-	1.600			
leu-comp-therm-042-007	2.350	1.684	5.43	-	1.600			

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Table 5.2-1 - IHECSBE Experimental Parameters
(Part 3 of 3)

Case	Initial Enrichment (wt.% U-235)	Fuel Pitch (cm)	Separation Distance (cm)	Soluble Boron Concent-ration (ppm)	Moderator to Fuel Ratio	EALF (eV)	k_{keno}	σ_{keno}
leu-comp-therm-050-001	4.738	1.300	-	-	2.032			
leu-comp-therm-050-002	4.738	1.300	-	-	2.032			
leu-comp-therm-050-003	4.738	1.300	-	822	2.032			
leu-comp-therm-050-004	4.738	1.300	-	822	2.032			
leu-comp-therm-050-005	4.738	1.300	-	5030	2.032			
leu-comp-therm-050-006	4.738	1.300	-	5030	2.032			
leu-comp-therm-050-007	4.738	1.300	-	5030	2.032			
leu-comp-therm-051-001	2.459	1.636	4.91	143	1.841			
leu-comp-therm-051-002	2.459	1.636	1.64	510	1.841			
leu-comp-therm-051-003	2.459	1.636	1.64	514	1.841			
leu-comp-therm-051-004	2.459	1.636	1.64	501	1.841			
leu-comp-therm-051-005	2.459	1.636	1.64	493	1.841			
leu-comp-therm-051-006	2.459	1.636	1.64	474	1.841			
leu-comp-therm-051-007	2.459	1.636	1.64	462	1.841			
leu-comp-therm-051-008	2.459	1.636	1.64	432	1.841			
leu-comp-therm-051-009	2.459	1.636	3.27	217	1.841			
leu-comp-therm-051-010	2.459	1.636	1.64	15	1.841			
leu-comp-therm-051-011	2.459	1.636	1.64	28	1.841			
leu-comp-therm-051-012	2.459	1.636	1.64	92	1.841			
leu-comp-therm-051-013	2.459	1.636	1.64	395	1.841			
leu-comp-therm-051-014	2.459	1.636	3.27	121	1.841			
leu-comp-therm-051-015	2.459	1.636	1.64	487	1.841			
leu-comp-therm-051-016	2.459	1.636	3.27	197	1.841			
leu-comp-therm-051-017	2.459	1.636	1.64	634	1.841			
leu-comp-therm-051-018	2.459	1.636	3.27	320	1.841			
leu-comp-therm-051-019	2.459	1.636	4.91	72	1.841			

Table 5.2-2 - IHECSBE Experiment Parameter Correlation with K_{keno}

Parameter	
Initial Enrichment	
Fuel Rod Pitch	
Fuel Assembly Separation Distance	
Soluble Boron Concentration	
Moderator to Fuel Volume Ratio	
EALF	

Table 5.2-3 - USL Function – Separation Distance

5.3 References

1. Title 10, Code of Federal Regulations - Energy, Part 72 (10 CFR 72), "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste", U.S. Nuclear Regulatory Commission, Washington, D.C.
2. "North Anna Power Station, Units 1 & 2, Independent Spent Fuel Storage Installation (ISFSI) Safety Analysis Report", Revision 8.01, Dominion, 10/15/14.
3. SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluations, ORNL/TM-2005/39, Version 6, Vols. I–III, January 2009. Available from Radiation Safety Information Computational Center at Oak Ridge National Laboratory as CCC-750.
4. "TN-32 Updated Final Safety Analysis Report, Revision 6 (Proprietary)", Transnuclear, Inc., April 2014.
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6. International Handbook of Evaluated Criticality Safety Benchmark Experiments (IHECSBE), NEA/NSC/DOC(95)03, NEA Nuclear Science Committee, September 2009. (http://icsbep.inel.gov/).
7. USLSTATS: A Utility to Calculate Upper Subcritical Limits for Criticality Safety Applications, Version 6, Oak Ridge National Laboratory, January 26, 2009.

8. J. J. Lichtenwalter, S. M. Bowman, M. D. DeHart, and C. M. Hopper, "Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages," NUREG/CR-6361, March 1997.

6.0 CONFINEMENT EVALUATION

This section of the DLBD summarizes the confinement evaluations that were performed to demonstrate that the TN 32B HBU demonstration cask with the HBU fuel assemblies complies with the requirements of 10 CFR 72 [Reference 6.4.1] for normal, off-normal, and accident conditions defined by the NAPS ISFSI Safety Analysis Report (SAR) [Reference 6.4.2]. The results of the re-evaluations are summarized in the following sections, with the referenced calculation provided in Section 8.2, *Design Calculations.*

6.1 Confinement Boundary

The confinement boundary for the TN-32B HBU demonstration cask consists of the inner shell, the bottom plate, the lid outer plate, lid bolts, the seven (7) thermocouple penetration sleeve inserts, the thermocouple instrument head and lance, the jacking plates and retainer ring, the vent and drain cover plates and fasteners, and the inner metallic O-ring seals of the lid and the thermocouple instruments. The confinement boundary for the TN-32B HBU demonstration cask is illustrated in Figures 1.1-1 and 1.1-2.

6.1.1 Confinement Vessel

The portion of the TN-32B HBU demonstration cask confinement vessel that was not modified consists of: an inner welded shell, which is a welded carbon steel shell with an integrally-welded, carbon steel bottom closure plate; a welded flange forging; a flanged and bolted carbon steel lid with bolts and inner metallic O-ring seal, and the vent and drain cover plates with fasteners and inner metallic O-ring seals. This boundary is identified in Appendix A.1 of the NAPS ISFSI SAR [Reference 6.4.2].

To accommodate the thermocouple lance assemblies, the lid is modified to include seven (7) penetration sleeves. The penetration sleeves, which form part of the confinement boundary, are fabricated from SA-350 Grade LF3 material, which is the same material as the lid. To secure the lance assembly, a groove is machined into the penetration sleeve to accommodate a retaining ring that is fabricated from Type 316 stainless steel material. The retaining ring provides bearing support for the jacking plate assemblies, which consist of two plates that are fabricated from SA-387 Type 91 Class 2 material. The screws for the jacking plates are fabricated from SA-193 Grade B7 material.

6.1.2 Confinement Penetrations

In addition to the existing vent and drain penetrations, seven (7) penetrations are provided for installation of the thermocouple lance assemblies. The thermocouple closure is fabricated from Type 304 stainless steel material, and the lance is fabricated from SB-163 UNS N06600 material. Since the lance is inserted into the cask cavity, the outer lance sheath becomes part of the confinement boundary. A silver metallic mechanical closure, which is fabricated of the same material as the drain and vent port penetrations, is provided for each thermocouple instrument.

6.1.3 Seals and Welds

The only difference to the confinement boundary welds and seals for the TN-32B demonstration cask from a standard TN-32 dry storage cask is the addition of the seven (7) penetration sleeves, and the thermocouple lances.

The penetration sleeves are welded to the lid and the shield plate with partial penetration groove welds, which make them integral to the lid. To verify the integrity of these welds (which are classified as a Category C weld under Section NB of the ASME B&PC Code), the welds are visually and nondestructively examined (NDE) in accordance with the requirements of Sections 9.1.1, *Visual Inspection*, and 9.1.2, *Structural*, of the TN-32 UFSAR [Reference 6.4.3], respectively. As an alternative to the NDE requirements of Subsection NB-5230 for Category C welds, all of these closure welds will be multi-layer welds and will receive a multi-level liquid penetrant (PT) examination in accordance with the guidance provided in [Reference 6.4.4] for NDE. The multi-level PT examination provides reasonable assurance that flaws of interest will be identified. The PT examination is done by qualified personnel, in accordance with Section V, and the acceptance standards of Section III, Subsection NB-5000 of the ASME B&PV Code. The analysis of the penetration sleeve-to-closure lid welds also applied a 0.8 stress-reduction factor in accordance with Section 8.4.7.3 of [Reference 6.4.4].

The seal utilized for the thermocouple closure assembly is a double metallic, silver-jacketed O-ring seal, which is identical used for the seal for the vent and drain closures. The sealing weld overlay is also identical to that utilized for the vent and drain sealing surfaces, i.e., stainless steel overlay. As with the vent and drain seals, the thermocouple closure seals are connected to the overpressure (OP) monitoring system. The use of the metallic seal and OP monitoring system ensures that the confinement boundary is maintained during the demonstration storage period.

6.1.4 Closure

The confinement vessel contains an integrally-welded bottom closure, and a bolted and flanged top closure lid. The flange lid plate is attached to the cask body with forty-eight (48) high strength bolts and hardened washers. The lid bolts are tightened to 1,085 ±145 lb-ft torque.

The vent and drain penetration cover plates consist of flanged cover and fasteners, with eight bolts each. The bolts for these plates are tightened to 85 ±15 lb-ft torque to seal the metallic seals. The seven (7) thermocouple penetrations consist of a machined groove in each penetration sleeve with integral ring seated in the groove, a jacking plate assembly bearing on the ring, which compresses the instrument closure on the confinement metallic seal. The fasteners for these penetrations are tightened to 65 ±5 lb-ft torque.

6.2 Release Calculations for Off-Normal and Accident Conditions

6.2.1 Radionuclide Contents

Analyses have been completed to determine the composition of any postulated release during off-normal or accident conditions. The radionuclide inventory contained within the TN-32B

demonstration cask was modeled with the depletion-decay module, ORIGEN-ARP, in the SCALE sequence of computer codes [Reference 6.4.5].

The radiological inventories were developed utilizing realistic parameters for the fuel assemblies identified to be stored in the TN-32B demonstration cask. These fuel parameters are provided in Table 6.2-1. Given these realistic parameters, the fuel inventory off-normal and accident releases were all calculated with release fractions consistent with the Standard Review Plan [Reference 6.4.4]. Release fractions used in the analysis are contained in Table 6.2-2.

The crud inventory was calculated according to the estimate of areal density of 140 µCi of Co-60 per cm^2, which is specified in the Standard Review Plan for pressurized water reactors. The released radionuclide concentration for each operating condition is contained in Table 6.2-3.

Table 6.2-1 - Fuel Assembly Input Parameters Used

Fuel Assembly	Cooling Time (years)(1)	Burnup (GWd/MTU)
6T0	11.25	54.223
3K7	7.82	53.414
3T6	11.25	54.298
6F2	12.67	51.904
3F6	12.67	52.138
30A	6.31	52.020
22B	4.81	51.155
20B	4.81	50.477
5K6	7.82	53.268
5D5	16.64	55.496
5D9	16.64	54.579
28B	4.81	50.966
F52(2)	27.85	58.093
57A	6.31	52.154
30B	4.81	50.623
3K4	7.82	51.841
5K7	7.82	53.335
50B	4.81	50.870
3U9	9.79	53.074
0A4	22.31	50.047
15B	4.81	50.972
6K4	7.82	51.868
3T2	11.25	55.087

Fuel Assembly	Cooling Time (years)(1)	Burnup (GWd/MTU)
3U4	9. 79	52.850
56B	4.81	50.952
54B	4.81	51.340
6V0	7.82	53.506
3U6	9.79	52.968
4V4	8.3	51.183
5K1	7.82	53.012
5T9	11.25	54.890
4F1	12.67	52.285

Note: 1. Cooling time as of January 1, 2017.

2. Fuel assembly F52 was replaced by fuel assembly F40, which has a 29.71 year cooling time and a 50.646 GWd/MTU burnup. Since the F52 radiological properties are greater than the F40 properties, it is conservative to utilize the F52 properties for this evaluation.

Table 6.2-2 - Release Fractions Used to Calculate Radioactive Release

Form	Off-Normal	Accident
Gas	3×10^{-2}	3×10^{-1}
Volatile	2×10^{-5}	2×10^{-4}
Fine	3×10^{-7}	3×10^{-6}
Crud	1.5×10^{-1}	1.0

Table 6.2-3 - Radionuclide Release Concentrations for Off-Normal and Accident Conditions

Radionuclide	Release Type	Off-Normal Concentration (Ci/cm^3)	Accident Concentration (Ci/cm^3)
^{238}Pu	fine	5.85×10^{-9}	5.85×10^{-8}
^{239}Pu	fine	3.72×10^{-10}	3.72×10^{-9}
^{240}Pu	fine	6.17×10^{-10}	6.17×10^{-9}
^{241}Pu	fine	1.14×10^{-7}	1.14×10^{-6}
^{241}Am	fine	2.27×10^{-9}	2.27×10^{-8}
^{244}Cm	fine	6.23×10^{-9}	6.23×10^{-8}
^{3}H	gas	6.49×10^{-5}	6.49×10^{-4}
^{85}Kr	gas	7.57×10^{-4}	7.57×10^{-3}
^{90}Sr	volatile	5.58×10^{-6}	5.58×10^{-5}
^{90}Y	fine	8.37×10^{-8}	8.37×10^{-7}
^{106}Ru	volatile	5.55×10^{-7}	5.55×10^{-6}
^{106}Rh	fine	8.33×10^{-9}	8.33×10^{-8}
^{125}Sb	fine	1.78×10^{-9}	1.78×10^{-8}
^{125m}Te	fine	4.34×10^{-10}	4.34×10^{-9}
^{134}Cs	volatile	1.43×10^{-6}	1.43×10^{-5}
^{137}Cs	volatile	8.18×10^{-6}	8.18×10^{-5}
^{137m}Ba	fine	1.16×10^{-7}	1.16×10^{-6}
^{144}Ce	fine	5.40×10^{-9}	5.40×10^{-8}
^{144}Pr	fine	5.40×10^{-9}	5.40×10^{-8}
^{144m}Pr	fine	7.56×10^{-11}	7.56×10^{-10}
^{147}Pm	fine	2.48×10^{-8}	2.48×10^{-7}
^{154}Eu	fine	5.57×10^{-9}	5.57×10^{-8}
^{155}Eu	fine	1.25×10^{-9}	1.25×10^{-8}
^{129}I	gas	3.93×10^{-9}	3.93×10^{-8}
^{60}Co	crud	1.42×10^{-5}	9.44×10^{-5}

6.2.2 Leakage Rate

The TN-32B demonstration cask leakage rates, under off-normal and accident conditions were calculated according to the methodologies presented in the ANSI Standard for assessing leak testing of transport packages [Reference 6.4.6]. The basis of the leakage rate calculation is the assumption

of a normal leakage rate of 1×10^{-5} std. cm^3/sec, which corresponds to the sensitivity of the leakage rate testing. The assumed conditions within the demonstration cask for off-normal and accident scenarios are contained in Table 6.2-4. The resulting leakage rates for both off-normal and accident conditions are shown in Table 6.2-5.

Table 6.2-4 - Leakage Rate Flow Conditions for Off-Normal and Accident Conditions

Condition	Cask Temperature (°F)	Cask Pressure (atm)	Ambient Temperature (°F)	Ambient Pressure (atm)
Off-Normal	400	2.9	100	1.0
Accident	570	7.8	Fire conditions	1.0

Table 6.2-5 - Leakage Rates for Off-Normal and Accident Conditions

Condition	Leakage Rate (cm^3/sec)
Off-Normal	1.96×10^{-5}
Accident	4.89×10^{-5}

6.2.3 Release of Contents

There are two scenarios that are considered:

Off-Normal Conditions- This condition exists over a one year period; seals are leaking at the test leak rate of 1×10^{-5}std cm^3/sec and the fraction of rods that have failed is 10%. Meteorological conditions assume a Stability Category D and 5 meter/sec wind speed.

Accident Conditions - This condition exists over a 30 day period, seals are leaking at the leakage test rate of 1×10^{-5}std cm^3/sec, the fraction of rods that fail is 100%, and the temperatures inside the cask is consistent with the fire accident conditions. The meteorological conditions assume a Stability Category F and 1 meter/sec wind speed.

The dispersion parameters used were calculated in the exact same method as in the TN-32 UFSAR, and are reproduced in Table 6.2-6.

Table 6.2-6 - Meteorological Dispersion Parameters for Off-Normal and Hypothetical Accident Conditions

Distance (meters)	Off-Normal χ/Q (sec/m^3)	Accident χ/Q (sec/m^3)
500	7.23×10^{-5}	1.90×10^{-3}

6.2.4 Dose Calculations

The dose assessments were made following the methods set out in Regulatory Guide 1.109 [Reference 6.4.7], and used the dose conversion factors from the Federal Guidance Reports 11 [Reference 6.4.8], and 12 [Reference 6.4.9]. Using the source terms contained in Table 6.2-3, the release fractions presented in Table 6.2-2, and the meteorological dispersion parameters in Table 6.2-6, the inhalation and immersion doses were evaluated at 100 meters and 500 meters for both off-normal and hypothetical accident conditions.

Given the postulated conditions for off-normal and accident scenarios described in Section 6.1.2, the TN-32B demonstration cask was found to release no amount of radionuclides that would result in absorbed doses approaching the limits specified in 10 CFR §72.104(a) or 10 CFR §72.106(b).

Table 6.2-7 - Deep and Committed Dose on Organ and Total Effective Basis under Off-Normal Conditions

Organ	Dose at 500 m (mrem/yr)
Gonad	2.63×10^{-2}
Breast	1.54×10^{-2}
Lung	1.00
R. Marrow	1.92×10^{-1}
B. Surface	1.43
Thyroid	1.44×10^{-2}
Remainder	7.31×10^{-2}
Skin	2.04×10^{-3}
Lens	1.94×10^{-1}
TEDE	1.92×10^{-1}

Table 6.2-8 - Deep and Committed Dose on Organ and Total Effective Basis under Hypothetical Accident Conditions

Organ	Dose at 500 m (mrem/30 days)
Gonad	1.36
Breast	0.63
Lung	50.30
R. Marrow	10.10
B. Surface	76.80
Thyroid	0.60
Remainder	3.55
Skin	0.10
Lens	9.82
TEDE	9.71

6.3 Latent Leak Calculations

By design, the overpressure monitoring system does not immediately alarm if there is a leak in a seal or the overpressure system. The time period from when a leak is initiated and when the overpressure system alarm is activated, is dependent on the size of the leak.

Two conditions that could exist in the TN-32B demonstration cask confinement system are:

Case 1: The outer seal (or the OP system) is leaking to the atmosphere. In this case the inner seal is intact and there is no release of the contents of the cask cavity to the atmosphere.

Case 2: The inner seal is leaking (or the OP system is leaking into the cask cavity). In this case the outer seal is intact and there is no release of the cavity contents to the atmosphere.

There are two points in time which are considered:

1. The time at which the overpressure system alarms, and
2. The time at which the overpressure system is equalized with the cavity pressure.

Results for all leakage rates in Case 1 are contained in Table 6.3-1, and for Case 2 in Table 6.3-2.

Another condition which has been considered is one in which the latent seal failure has occurred, and the overpressure system is removed due to an accident.

1. If the outer seal has a latent failure and the overpressure system is removed, there is no release of cavity contents to the atmosphere.
2. If the inner seal has a latent failure and the overpressure system is removed.

3. Table 6.3-3 provides the time before the dose limits of 10 CFR §72.106 (b) are exceeded (based on the accident conditions presented in Table 6.2-4 and Table 6.2-5).

Table 6.3-1 - Leakage of Overpressure System to Atmosphere

Leakage Rate (std cm^3/sec)	Estimated time to Alarm	Estimated Time to Loss of OP System Pressure
1×10^{-3}	15 days	25 days
1×10^{-4}	159 days	260 days
1×10^{-5}	9 years (See Figure 6.3-1)	20+ years

Table 6.3-2 - Leakage of Overpressure System to Cask Cavity

Leakage Rate (std cm^3/sec)	Estimated time to Alarm	Estimated Time to Loss of OP System Pressure
1×10^{-3}	16 days	19 days
1×10^{-4}	171 days	203 days
1×10^{-5}	11 years (See Figure 6.3-1)	20+ years

Table 6.3-3 - Leakage of Overpressure System to Cask Cavity

Leakage Rate (std cm^3/sec)	Estimated Time to Exceed 10 CFR §72.106 Dose Limit
1×10^{-3}	143 days
1×10^{-4}	1,473 days (4.04 years)
1×10^{-5}	15,445 days (42.32 years)

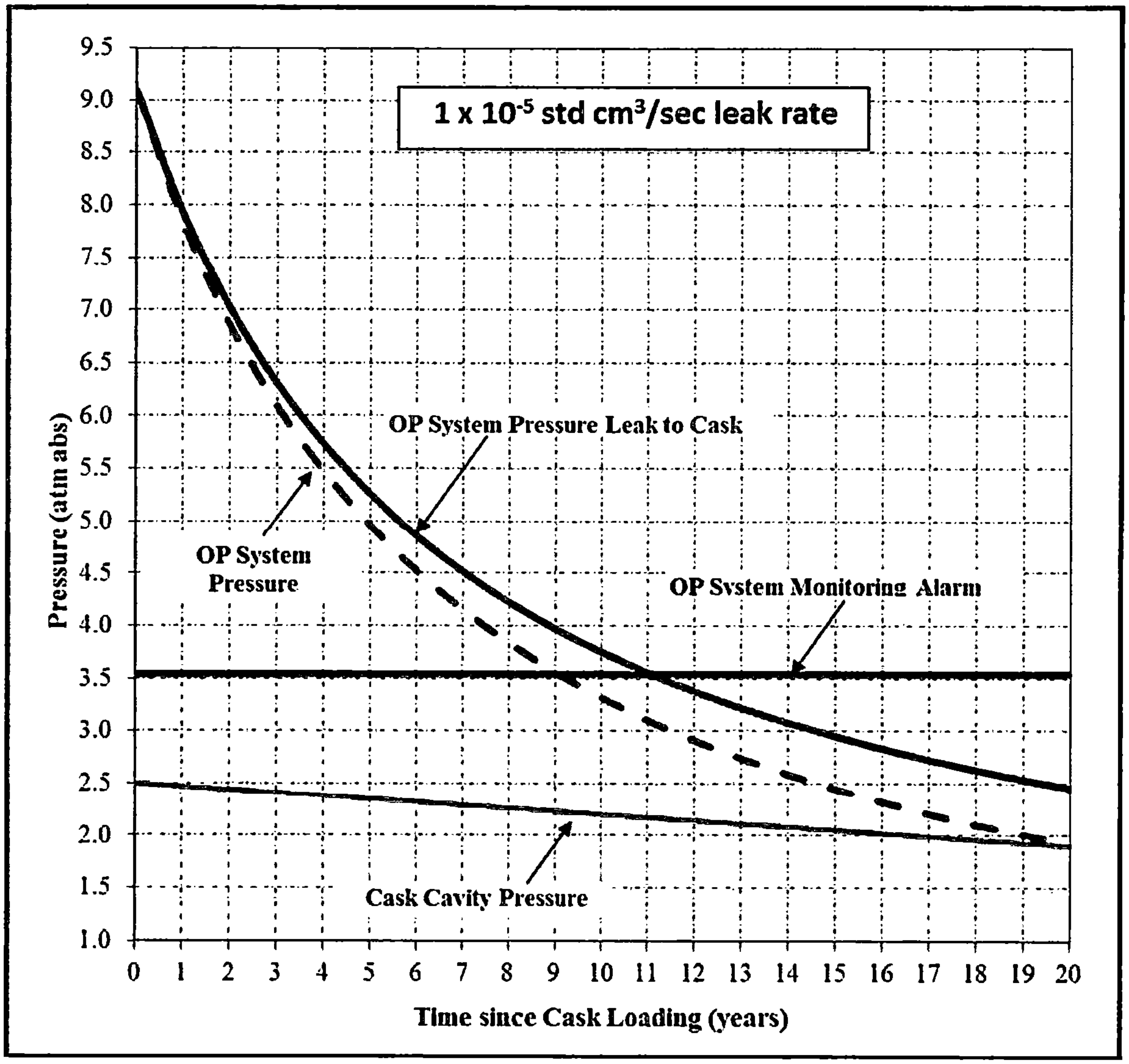

Figure 6.3-1 - Overpressure System Pressure vs. Storage Time for Overpressure System Backfilled to 7.5 atm (abs) with a leakage rate of 1 × 10^{-5} std cm^3/sec.

6.4 References

1. Title 10, Code of Federal Regulations - Energy, Part 72 (10 CFR 72), "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste", U.S. Nuclear Regulatory Commission, Washington, D.C.
2. "North Anna Power Station, Units 1 & 2, Independent Spent Fuel Storage Installation (ISFSI) Safety Analysis Report", Revision 8.01, Dominion, 10/15/14.
3. "TN-32 Updated Final Safety Analysis Report, Revision 6 (Proprietary)", Transnuclear, Inc., April 2014.
4. "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility," NUREG-1536, Revision 1, U.S. Nuclear Regulatory Commission, Washington, D.C.
5. Gauld, I. C., Bowman S.M., Horwedel, J.E., "ORIGEN-ARP: Automatic Rapid Processing for Spent Fuel Depletion, Decay and Source Term Analysis," ORNL/TM-2005/39, Vol. I, Sect. D1, Version 6.
6. ANSI N14.5-2014, "Standard for Radioactive Materials – Leakage Tests on Packages for Shipments," American National Standards Institute Inc., NY, NY.
7. Regulatory Guide 1.109, "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR 50, Appendix I," March 1976, U.S. Nuclear Regulatory Commission, Washington, D.C.
8. Eckerman, K.F., Wolbarst, A.B., Richardson, A.C.B., "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion," Federal Guidance Report 11, September 1988, U.S. Environmental Protection Agency.
9. Eckerman, K.F., Ryman, J.C., "External Exposure to Radionuclides in Air, Water and Soil," Federal Guidance Report 12, September 1993, U.S. Environmental Protection Agency.

7.0 ACCEPTANCE TESTING AND MAINTENANCE PROGRAM

This section of the DLBD describes the acceptance tests and maintenance program for the TN-32B HBU demonstration cask that are required to be performed to comply with the requirements of the TN-32 Updated Final Safety Analysis Report (UFSAR) [Reference 7.3.1].

7.1 Acceptance Criteria

The original acceptance tests for the TN-32 dry storage cask are identified in Chapter 9.1, *Acceptance Criteria*, of the TN-32 UFSAR. The modifications to the standard TN-32B dry storage cask that are subject to supplemental acceptance tests are the items/components as described in this section. The TN-32B HBU demonstration cask modifications are as described in Section 1.1, *TN-32B HBU Demonstration Cask Physical Description.*

7.1.1 Visual Inspection

Visual inspections of the TN-32B dry storage cask were previously performed as described in Section 9.1.1 of the TN-32 UFSAR. Additional visual inspections of the cask modifications for the TN-32B demonstration cask will be performed at the fabricator's facility ensure conformance with the drawings and specifications.

Upon arrival at NAPS, the TN-32B demonstration cask will again be visually inspected once it is properly staged in the Decontamination Building to ensure that the cask has not been damaged during shipment. Any noted damage and/or non-conformances to the drawings will be repaired or evaluated for the effect on the safety function of the affected components in accordance with 10 CFR §72.248 [Reference 7.3.2].

7.1.2 Structural

The material acceptance requirements of Section 9.1.2 of the TN-32 UFSAR will be implemented for the cask modifications. Additionally, all welding for the modifications will be performed in accordance with the ASME Boiler and Pressure Vessel (B&PV) Code, Section III, Subsection NB requirements [Reference 7.3.3], as delineated on the drawings. For the partial penetration confinement welds that attached the thermocouple lance penetration sleeves to the lid, liquid penetrant (PT) or magnetic particle (MT) non-destructive examination (NDE) inspection of each layer of weld filler material will be performed in accordance Subsection NB requirements.

7.1.3 Leakage Rate Tests

In addition to the lid, and the vent and drain cover seals, leakage rate tests of the thermocouple lance assembly metallic O-ring seals will be performed at the fabricator's facility in accordance with ANSI N14.5 [Reference 7.3.4] and Section 9.1.3 of the TN-32 UFSAR.

To ensure its continued long-term functionality, the modified overpressure (OP) system will also be leakage rate tested in accordance with ANSI N14.5 and Section 9.1.3 of the TN-32 UFSAR.

7.1.4 Components

7.1.4.1 Valves

The TN-32B HBU demonstration cask modification provides eight (8) additional valves for the overpressure (OP) leak detection system. This portion of the system does not perform a function important to safety. The quick disconnect coupling in the cask vent portion of the vent and drain system provides confinement during the gas sampling activities. The quick disconnect valves shall be tested to the same pressure as the cask lid sub-assemblies. The coupling shall be tested to a minimum of 1.25 times the design pressure of 2.2 atm, i.e., 2.75 atm (40.5 psig).

7.1.4.2 Gaskets

The testing requirements in Section 9.1.4.2 of the UFSAR remain unchanged. The TN-32B HBU demonstration cask modification provides seven (7) additional double metallic O-ring seals.

7.1.4.3 Thermocouple Lance Assemblies

The thermocouple lances are part of the confinement boundary. The instrument head and brazed in-place metallic sheathing on the outside of the lance form the confinement boundary of the assembly. Therefore, each lance assembly shall be leakage rate tested to be leaktight per the requirements of ANSI 14.5.

7.1.5 Shielding Integrity

Since no modifications of the gamma or neutron shields were performed, no additional acceptance tests for shielding integrity are required for the TN-32B HBU demonstration cask. The only change in the shielding configuration is the top neutron shield is elevated approximately one (1) inch to provide spacing for routing of the thermocouple wiring and the OP system tubing for the thermocouple lance assemblies. Additionally, a top neutron shield plug is added to allow access to the vent port for collection of cavity gas samples during the storage period. Neither of these configuration changes affects the shielding integrity of the TN-32B demonstration cask.

7.1.6 Thermal Acceptance

Since no modifications of the thermal heat removal structure, no additional acceptance tests for thermal performance are required for the TN-32B HBU demonstration cask.

7.1.7 Neutron Absorber Tests

Since no modifications of the neutron absorber were performed, no additional acceptance tests for neutron absorber integrity are required for the TN-32B HBU demonstration cask.

7.2 Maintenance Program

The TN-32B HBU demonstration cask does not require maintenance other than that which is currently required for the OP system on the TN-32 dry storage cask, except as noted here.

Collection of in-situ gas samples requires the OP system to be vented, the access port on the protective cover, and the top neutron shield plug to be removed to gain access to the vent port flange and fasteners. The vent port cover and fasteners are then removed, and the gas sample is collected, utilizing the quick disconnect in the vent port. The double metallic silver O-ring seal is removed; and the sealing surfaces are cleaned and inspected. Since the metallic O-ring seal is a one-time use seal, a new double metallic silver O-ring seal is installed, the vent port cover and fasteners installed and tightened per site procedures to the specified torque. The top neutron shield plug re-installed, and the protective cover, gasket, and fasteners installed per site procedures. The overpressure system is refilled with helium to the specified pressure.

Although the solar cell charging system is passive and requires very little maintenance, the surface of the solar cell should be periodically inspected for accumulation of debris or dirt that could affect its charging function. If the solar cell surface is found to be dirty, the surface is to be cleaned following the manufacturer's recommendations.

7.3 References

1. "TN-32 Updated Final Safety Analysis Report", Revision 6, Transnuclear, Inc., April 2014.
2. Title 10, Code of Federal Regulations - Energy, Part 72 (10 CFR 72), "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste", U.S. Nuclear Regulatory Commission, Washington, D.C.
3. ASME Boiler and Pressure Vessel Code, Section III, "Rules for Construction of Nuclear Facility Components", Division 1, Subsection NB, "Class 1 Components", 2013 Edition, American Society of Mechanical Engineers, NY, NY.
4. ANSI N14.5-2014, "Standard for Radioactive Materials – Leakage Tests on Packages for Shipments," American National Standards Institute Inc., NY, NY.

8.0 APPLICABLE DOCUMENTS

8.1 Licensing Drawings

The applicable Licensing drawings for the TN-32B HBU Demonstration Cask are (see *Appendix A* for attachments):

1. AREVA TN Drawing [ ] "TN-32B HBU Demonstration Cask General Arrangement".
2. AREVA TN Drawing [ ] "TN-32B HBU Demonstration Cask General Arrangement Cross Section and Details".
3. AREVA TN Drawing [ ] "TN-32B HBU Demonstration Cask Lid Assembly and Details".
4. AREVA TN Drawing [ ] "TN-32B HBU Demonstration Cask Protective Cover".
5. AREVA TN Drawing [ ] "TN-32B HBU Demonstration Cask Overpressure System Arrangement".
6. AREVA TN Drawing [ ] "TN-32B HBU Demonstration Cask Top Neutron Shield".
7. AREVA TN Drawing [ ] "TN-32B HBU Demonstration Cask Loading Pattern and Details".

8.2 Design Calculations

The applicable design calculations for the TN-32B HBU Demonstration Cask are identified by category in the following sections.

8.2.1 Structural Calculations

1. AREVA TN Calculation [ ] "TN-32B HBU, Weight Calculation".
2. AREVA TN Calculation [ ] "TN-32B HBU Lid Bolts Evaluation".
3. AREVA TN Calculation [ ] "TN-32B HBU, Protective Cover Evaluation".
4. AREVA TN Calculation [ ] "TN-32B HBU, Vent, Drain, and Other Miscellaneous Lid Closure Evaluation".
5. AREVA TN Calculation [ ] "TN-32B HBU, Cask Lid Evaluation".
6. AREVA TN Calculation [ ] "TN-32B HBU Fuel Structural Evaluation".

7. AREVA TN Calculation [ ] "TN-32B HBU Demonstration Cask Stability Calculation".
8. AREVA TN Calculation [ ] "TN-32B HBU, Cask Body Evaluation".
9. AREVA TN Calculation [ ] "TN-32B HBU, Basket Evaluation, Normal Off-Normal".
10. AREVA TN Calculation [ ] "TN-32B HBU Basket Accident Analysis".
11. AREVA TN Calculation [ ] "TN-32B Cask Lid Lifting Evaluation".
12. AREVA TN Calculation [ ] "TN-32B HBU Basket Rail Accident Analysis".
13. AREVA Inc. Calculation [ ] "Thermocouple Lance Structural Verification."
14. AREVA TN Document [ ] "Documentation of Previously Analyzed Bounding Missiles for TN-32B HBU Demonstration Cask".
15. AREVA TN Document [ ] "Documentation of Previously Analyzed Bounding Cask Outer Shell Analysis for TN-32 in Support of the TN-32B HBU Project".
16. AREVA TN Document [ ] "Reconciliation of TN-32B HBU Demonstration Cask Trunnions and the Gamma Shield Shell Evaluation".

8.2.2 Thermal Calculations

1. AREVA TN Calculation [ ] "Bounding Effective Thermal Properties of the Selected Spent Fuel Assembly in TN-32B HBU Fuel Cask".
2. AREVA TN Calculation [ ] "Detailed Model of TN-32B HBU Cask and Effective Thermal Conductivities of the TN-32 Cask".
3. AREVA TN Calculation [ ] "Thermal Evaluation of TN-32B HBU Cask for Normal and Accident Conditions".
4. AREVA TN Calculation [ ] "TN-32B HBU, Pressure".
5. AREVA TN Calculation [ ] "TN-32B HBU, Latent Leak Evaluation".
6. AREVA TN Calculation [ ] "TN-32B HBU Thermal Expansion Detailed Analysis".

8.2.3 Shielding Calculations

1. AREVA TN Calculation [ ] "Neutron and Gamma Source Terms for In-Core Region of All Fuel Candidates for TN-32B HBU Cask".
2. AREVA TN Calculation [ ] "TN-32B HBU Shielding Analysis".
3. AREVA TN Calculation [ ] "TN-32B HBU Occupational Dose and ISFSI Site Dose".
4. AREVA TN Calculation [ ] "Material Densities for TN-32B HBU Design Basis Shielding Evaluations".

8.2.4 Criticality Calculations

1. AREVA TN Calculation [ ] "IHECSBE Benchmark with SCALE 6.0".
2. AREVA TN Calculation [ ] "TN-32B HBU Demonstration Cask Criticality Analysis for Intact Fuel Storage".
3. AREVA TN Calculation [ ] "TN-32B HBU Demonstration Cask Criticality Analysis for Accident Conditions".

8.2.5 Confinement Calculation

1. AREVA TN Calculation [ ] "TN-32B HBU, Confinement Dose Evaluation".

8.3 Design Input Documents

The other applicable design input documents for the TN-32B HBU Demonstration Cask are:

1. AREVA TN Document [ ] "Documentation of Previously Analyzed Bounding Missiles for TN-32B HBU Demonstration Cask."
2. AREVA TN Document [ ] "Reconciliation of TN-32B HBU Demonstration Cask Trunnions and the Gamma Shield Shell Evaluation."
3. AREVA TN Document [ ] "Documentation of previously analyzed bounding Cask Outer Shell Analyses for TN-32 in support of the TN-32B HBU project."
4. AREVA TN Design Input Document [ ] "HELICOFLEX® Spring Energized Seals Catalog, Technetics Group, EnPro Industries Companies, TN-32B HBU Demonstration Cask Project."
5. "AREVA Federal Services LLC, Engineering Information Record (EIR-3011071-004) Design Basis Requirements, TN-32B HBU Demonstration Cask Project", [ ]

6. AREVA TN Document [ ] "Design Criteria Document (DCD) – TN-32B High Burnup Demostration Cask."

Appendix A-Licensing Drawings

Proprietary Information on Pages A-1 through A-11
Withheld Pursuant to 10 CFR 2.390