71-9253

Department of Energy
Washington, DC 20585

APR 23 2009

Attn: Document Control Desk
Director, Spent Fuel Project Office
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

On December 28, 2007 the U. S. Department of Energy submitted an application for amendment of Certificate of Compliance No. 9253 for the Model No. TN-FSV package. We requested the addition of high burnup pressurized water reactor (PWR) fuel rods as authorized contents within a PWR fuel rod shielded basket, and to include the "-96" designation in the Package Identification Number. The NRC assigned references for this action are Docket No. 71-9253 and TAC No. L24166.

In a letter dated February 3, 2009, the NRC requested additional information (RAIs) in support of this revision. This submittal is the response to the RAIs and also includes the updates to the Safety Analysis Report (SAR).

The original of this letter, with attachment is being sent to the Document Control Desk. Six copies of this letter with attachments are being delivered to Michele Sampson, Senior Project Manager, Licensing Branch, Division of Spent Fuel Storage and Transportation, Office of Nuclear Material Safety and Safeguards shortly after this letter is sent.

If you have any questions, please contact me at 301-903-5513 or James.Shuler@em.doe.gov.

James M. Shuler

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Attachment

cc: / without attachment
James Wade, DOE-ID

NMSS01

Instructions for Adding/Replacing Pages

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Safety Analysis Report for the TN-FSV Packaging

Revision 0
31 March 1993

Revision 1
24 February 1994; 02 June 1994, 14 June 1994

Revision 2
11 September 1995; 07 December 1995

Revision 3
15 June 2001; 18 September 2001

Revision 4
01 March 2002

Revision 5
21 June 2002

Revision 6
21 July 2003

Revision 7
21 December 2007

Revision 8
17 April 2009

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1.3 APPENDIX

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1090-SAR-2	Shell Assembly	3
1090-SAR-3	Details and Shell Parts List	4
1090-SAR-4	Shell Details	5
1090-SAR-5	Lid Assembly and Parts List	5
1090-SAR-6	Front Impact Limiter Assembly	3
1090-SAR-7	Front Impact Limiter Details & Parts List	3
1090-SAR-8	Rear Impact Limiter Assembly	3
1090-SAR-9	Rear Impact Limiter Details & Parts List	3
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Figure Withheld Under 10 CFR 2.390

AREVA	AREVA Federal Services LLC Packaging Projects Tacoma, WA 98402
TN-FSV PACKAGE SHELL ASSEMBLY SAR DRAWING	
SCALE: NOTED	WT. N/A
REV: 4	SHEET 1 OF 1
DWG SIZE D	DWG NO. 1090-SAR-3
	CADFILE: 1090SAR34.DWG

Figure Withheld Under 10 CFR 2.390

AREVA

AREVA Federal Services LLC
Packaging Projects
Tacoma, WA 98402

TN-FSV PACKAGE
LID ASSEMBLY
SAR DRAWING

SCALE: NOTED	WT. N/A
REV: 5	SHEET 1 OF 1
DWG SIZE D	DWG NO. 1090-SAR-5
	CADFILE: 1090SAR55.DWG

The other mechanical properties of the wood used in the analysis of the impact limiters are shown in Table 2.10.2-2. The crush stress properties used cover the range of expected values for the density and moisture content specified in the procurement specification. These ranges also cover the expected variation in wood properties over the operating temperature range of interest; i.e., -20°F to 170°F.* During procurement, wood samples are tested for density and moisture content in accordance with an approved sampling plan.

If the density and moisture content are not within the specified range, the wood blocks from which samples are taken would be rejected. Note that two complete TN-FSV packagings were fabricated in 1995, and no new impact limiters will be fabricated.

For the end drop, all of the wood in the central part of the impact limiter that is directly "backed-up" by the cask body will crush. The wood in the corner and side of the limiter will tend to slide around the side of the cask since it is not supported or backed-up by the body and it will not crush or absorb energy as effectively as the wood that is backed-up. During the side or oblique drop the wood backed up by the cask will crush, while the wood beyond the end of the cask body will have a tendency to slide around the end of the cask. The analyses assume that the effectiveness of the portion of the wood that is not backed-up would be 20%. Effectiveness is defined as the actual crush force developed at the target by this

* Von Riessman, W. A. and Guiss, T. R. The Effects of Temperature on the Energy-Absorbing Characteristics of Redwood, Sandia Laboratories SAND-77-1509, Aug. 1978

Knoell, A. C., Environmental and Physical Effects in the Response Balsa Wood in an Energy Dissipation, Jet Propulsion Laboratory, Technical Report No. 32-944, June 15, 1966

DOCKET 71-9253

Safety Analysis Report for the TN-FSV Packaging

Addendum B: PWR Fuel Rod Shielded Basket

Safety Analysis Report

Revision 1
April 2009

TN-FSV SAR
Addendum B
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Chapter B7	B7.1-1	0
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B1.2 Package Description

B1.2.1 Packaging

B1.2.1.1 TN-FSV Cask

In Addendum B, the TN-FSV cask refers to a modified version of the TN-FSV. In comparison to TN-FSV Configuration 1, which is described in detail in Section 1.2.1 of the SAR, the principal design modification made to the TN-FSV packaging is the revision of the leakage rate criterion of the containment boundary from 1 x 10^{-3} ref·cm^3/s to a more stringent requirement of 1 x 10^{-7} ref·cm^3/s (leak-tight). To meet this more stringent requirement and to permit leak testing of the containment boundary of the package to the revised leakage rate requirement, the material for the elastomer seals is changed from silicone to butyl.

Note that for the Oak Ridge Addendum (Configuration 2), butyl rubber seals were also used in place of silicone seals. Therefore, the cask seal configuration is the same for Configurations 2 and 3, although the contents and package internals are different. The cask and impact limiter drawings are provided in Appendix 1.3 of the main SAR.

The only other modification to TN-FSV Configuration 1 is removal of the lower aluminum spacer used in the cask cavity. The TN-FSV Configuration 1 contents consist of a Fuel Storage Container (FSC) and its HTGR spent fuel assemblies. The FSC is located axially in the cask cavity with a spacer above and below it. For Configuration 3, the lower aluminum spacer is removed and replaced with a stainless steel spacer, although the upper aluminum spacer (attached to the lid) is retained.

B1.2.1.2 PWR Fuel Rod Shielded Basket (PSB) and Spacer

The internals of Configuration 3 include a PWR fuel rod shielded basket (PSB) that rests on a stainless steel spacer. A sketch of the PSB and spacer is provided in Figure B1.2-1. A view of the PSB and spacer inside of the TN-FSV cask is shown in Figure B1.2-2. The PSB has an overall length of 166.0-in and consists of seven (7) stainless steel tubes with a 1.25-in OD and 0.065-in wall thickness. These tubes are used to contain up to seven (7) PWR spent fuel rods (or guide tubes), with no more than one item per tube. The tubes are 150.5-in long so that the fuel rods will protrude past the end of the tubes. The spent fuel is shielded laterally with a solid stainless steel forging with an ID of 4.0-in and OD of 10.5-in. The OD of the PSB lid, bottom plate, and lateral support disks is 17.5-in. The stainless steel lid is recessed in the center, and the total cavity length is 157.0-in. The lid is 8.0-in thick at the center and 11.0-in thick at the edge. The lid is secured to the 1-in thick canister body flange by four (4) socket head cap screws. The PSB has no containment function and is designed to easily drain water through the bottom drain holes.

Figure Withheld Under 10 CFR 2.390

AREVA
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Packaging Projects
Tacoma, WA 98402

TN-FSV PWR FUEL ROD SHIELDED BASKET

SCALE: 1/12	WT. ~N/A
REV: 1	SHEET 1 OF 3
DWG SIZE D	DWG NO. P03FM108-SAR

Figure Withheld Under 10 CFR 2.390

REV: 1	SHEET 2 OF 3
DWG NO. P03FM108-SAR	

P03FM108-SAR | 3 | 1

Figure Withheld Under 10 CFR 2.390

REV: 1	SHEET 3 OF 3
DWG NO. P03FM108-SAR	

B3.0 THERMAL EVALUATION

This addendum chapter documents the thermal safety of the PWR Fuel Rod Shielded Basket (PSB) for normal conditions of transport (NCT) and hypothetical accident conditions (HAC) when transported within the TN-FSV packaging. The PSB payload represents Configuration 3 of the potential payloads for the TN-FSV packaging. Payload Configuration 1, consisting of irradiated High Temperature Gas Reactor (HTGR) fuel, is described in the main body of the Safety Analysis Report (SAR) for the TN-FSV Package, as is the safety basis for the TN-FSV packaging. Payload Configuration 2, described in an Addendum to the main SAR, is the safety basis for transport of Oak Ridge spent nuclear fuel.

The combination of the Configuration 3 payload and TN-FSV packaging are shown to be in compliance with the thermal requirements of 10 CFR 71 [1]. Specifically, all package components are shown to remain within their respective temperature limits under both NCT and HAC conditions and all internal pressures remain below their allowable limits. Further, per 10 CFR 71.43(g), the maximum accessible package surface temperature is demonstrated to be less than 185 °F for the maximum decay heat loading, an ambient temperature of 100 °F, and no insolation.

B3.1 Description of the Thermal Design

The TN-FSV packaging is an approved Type B(U)-85 package for the exclusive use transportation of spent nuclear fuel [2]. This package has a current U.S. NRC Certificate of Compliance No. 9253 that includes both Configurations 1 and 2 [3]. See Section B.1.2, *Package Description*, for a description of the TN-FSV packaging and the Configuration 3 payload of the PSB and spacer.

The design features of the PSB pertinent to its thermal performance are described in the following section.

B3.1.1 Design Features

The PSB and its spacer are designed to passively dissipate the decay heat of its payload of up to seven (7) spent fuel rods and/or guide tubes. The PSB is vented and provides no containment function. The PSB has a 166.0-in overall length and consists of the following principal components: a lid, seven (7) fuel tubes, and a basket body. The OD of the PSB lid, bottom plate, and disks are 17.5-in. The PSB serves no containment function and, as such, is designed with bottom drain holes to permit easy draining of water.

The lid has a 17.5-in OD and is 8.0-in thick at the center and 11.0-in thick at the edge. The stainless steel lid contains a recess in its center to create a total cavity length of 157.0-in within the PSB. The lid is secured to the basket body by four (4) socket head cap screws.

The fuel tubes are stainless steel with a 1.25-in OD and 0.065-in wall thickness. The fuel tubes house up to seven (7) PWR spent fuel rods or guide tubes, with no more than one item per tube, within the PSB. The fuel tubes are 150.5-in long so that the fuel rods will protrude past the end of the tubes to allow placement and extraction.

Due to the potential activity level of the fuel rods to be transported, additional lateral shielding is provided by a solid, 3.25-in thick Type 304 stainless steel forging (i.e., the basket body) that has an ID of 4.0-in and OD of 10.5-in and which is fitted with a bottom plate, a bolting flange, and seven (7) Type 304 stainless steel disks spaced along its length. The bottom plate and bolting flange of the shielded basket body are 1-in thick with a 17.5-in OD, while the disks have the same OD, but are 0.75-in thick. Fillet welds on either side of the disks/flange/bottom plate provide an intimate thermal connection with the basket body.

Since the overall length of the PSB is shorter than the cavity within the TN-FSV cask, a stainless steel spacer is used to position the PSB within the TN-FSV cask for ease of loading and unloading. The spacer also ensures that the active region of the fuel rods to be transported lies between the impact limiters on the cask, thus minimizing the thermal resistance for the heat transfer between the fuel rods and the ambient environment. The spacer has an overall length of 31.4-in. The spacer is fabricated entirely of stainless steel components consisting of a 10-in Schedule 80S pipe welded to 1-in plates on each end. The OD of the plates is 17.5-in.

No surface treatment or coating is used on the PSB and its spacer.

B3.1.2 Content's Decay Heat

The contents of the PSB are up to seven (7) PWR spent fuel rods or guide tubes clad in zirconium-alloy. Any PWR fuel rod type is acceptable (e.g., from 14x14, 15x15, 17x17 type assemblies) as long as the thermal decay heat of the rod is bounded by the basis for this analysis. The fuel rods are limited to a minimum length of 151.5-in and a maximum length of 156.6-in to interface properly with the PSB. Fuel rods shorter than 151.5-in in length require the use of a fuel tube spacer to raise the fuel rods to the desired elevation.

Zirconium-alloy guide tubes may also be transported in place of spent fuel rods. As guide tubes have no fissile material and little decay heat, guide tubes are bounded by fuel rods in this analysis.

The decay heat load dissipated by the payload is a maximum of 360 watts and assumed to exhibit a variation in its heat generation (i.e., peaking factor) along the active fuel length as taken from Table B5.2-4, Section B5.2, *Source Specification*, and shown in Figure B3.1-1. This heat load limitation is equivalent to 51.4 watts per fuel rod if seven PWR fuel rods are to be transported, 60 watts per fuel rod if six rods are to be transported, or 72 watts per fuel rod if five rods are to be transported. Shipments of less than five fuel rods are to have a decay heat dissipation of 72 watts or less per rod, thus yielding a total decay heat load of less than 360 watts. Administrative controls will be used to limit the number of fuel rods and their minimum decay time as required to achieve the required decay heat load limitations described above, as shown in the Fuel Qualification Table provided in Chapter B1, Table B1.2-2.

The active fuel region of the PSB begins approximately 33.4-in above the base of the TN-FSV cask (assuming 31.4-in for the spacer, 1-in for the end flange plate on the PSB, and 1-in for the end plug of the fuel rod) and ends approximately 21.6-in from the inside of the cask lid (assuming 199-in cavity length minus 33.4-in starting position minus 144-in active fuel length if using the longer active fuel length). In contrast, the decay heat loading applied for the main TN-FSV SAR thermal evaluation begins approximately 4.6-in above the base of the TN-FSV cask and ends approximately 7.1-in from the inside of the cask lid (assuming 199-in cavity length minus 4.6-in starting position minus 187.3-in active fuel length). As such, the impact of the decay heat dissipation on the TN-FSV package temperatures at the ends of the package are bounded by the main TN-FSV SAR thermal evaluations. See Section B1.2.2, *Contents*, for more information regarding the contents of the PSB payload.

B3.1.3 Summary Tables of Temperatures

The maximum temperatures for the TN-FSV Packaging under NCT and HAC conditions are summarized in Table 3-4 and Table 3-5, respectively, in the main body of the TN-FSV Package SAR. The maximum temperatures for the PSB under NCT and HAC conditions within the TN-FSV Packaging are summarized in Table B3.3-1 and Table B3.4-1, respectively, within this addendum chapter. The presented results demonstrate that all components of both the TN-FSV Packaging and the PSB payload will remain well within their allowable temperature limits.

The main body of the TN-FSV Package SAR also demonstrates that all accessible package surfaces remain below the temperature limit of 185 °F when transported in an ambient temperature of 100 °F and without insolation, as stipulated by 10 CFR §71.43(g) for exclusive use packages.

The evaluation of the PSB under both normal and accident conditions of transport within the TN-FSV packaging presented in this chapter demonstrates that large thermal margins exists for all components. These thermal margins are sufficient to compensate for any credible fabrication tolerance or anomaly for this relatively simple geometry. Further, given that the thermal evaluations are based on well defined heat transfer mechanisms, using established thermal properties, and with conservative modeling assumptions, the actual thermal margins are expected to be even larger. The modeling conservatisms include:

1) ignoring the potential heat transfer due to direct contact between the fuel rods and the PSB and between the PSB and the inner shell of the TN-FSV cask,
2) the use of a conservative combination of the fuel rod surface heat flux and the fuel rod's active length,
3) use of a conservatively low PSB emissivity,
4) a conservatively low level of convection between the PSB and the inner shell of the TN-FSV cask, and
5) a conservative representation of the PSB's decay heat loading when housing less than its full payload of 7 (seven) fuel rods.

As such, no thermal tests are required to confirm the thermal performance of the PSB in the TN-FSV.

B3.1.4 Summary Tables of Maximum Pressures

The maximum normal operating pressure (MNOP) for the TN-FSV Packaging loaded with the PSB containing its bounding payload of PWR fuel rods is 3.6 psig. Further details of the pressure analysis are presented in Section B3.3.2, *Maximum Normal Operating Pressure*.

The maximum peak pressure generated within the package cavity under HAC conditions assumes that the entire payload of fuel rods experiences cladding failure and releases their contained fill and fission gas inventory. The maximum pressure under HAC conditions is estimated to be 6.4 psig

(21.1 psia). The pressure will then decrease as the package cools. Further details of the analysis are presented in Section B3.4.3, *Maximum Temperatures and Pressure*.

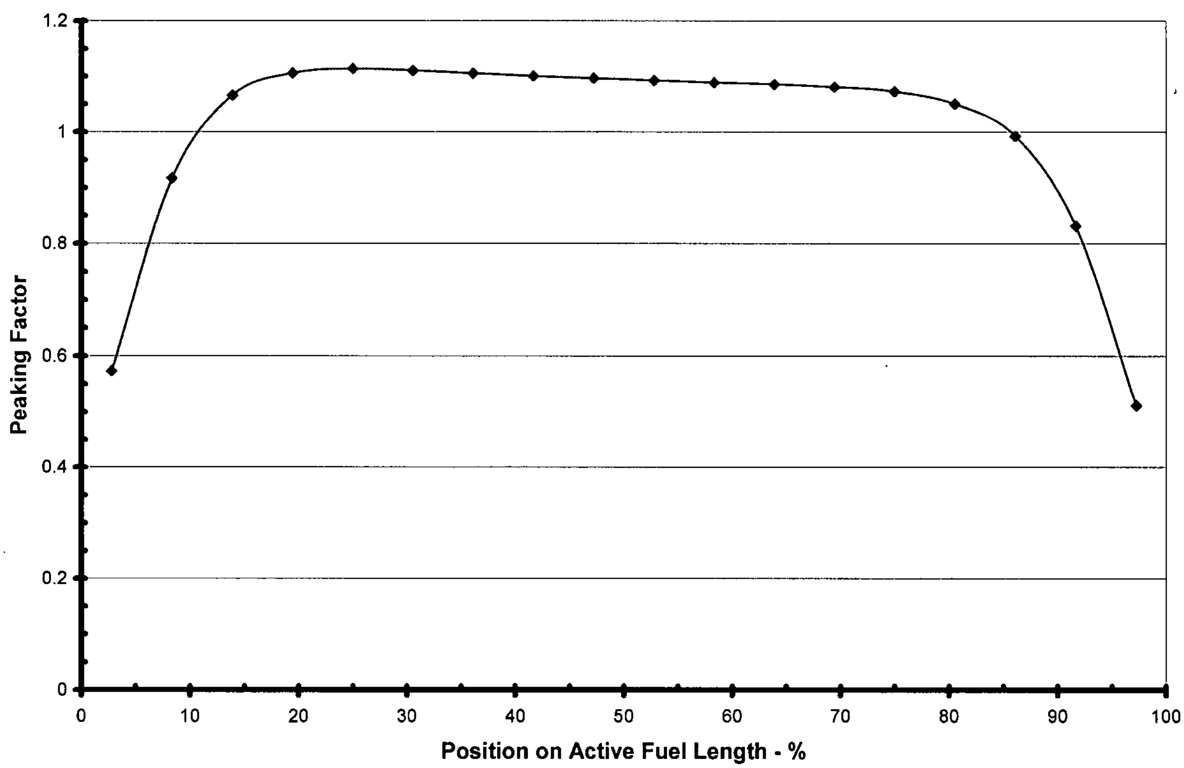


Figure B3.1-1 – Fuel Peaking Factor vs. Active Fuel Length

B3.2 Material Properties and Component Specifications

The TN-FSV PSB and its spacer are fabricated primarily of Type 304 stainless steel. While the design basis assumes that air fills all void spaces within the TN-FSV cask and PSB cavities, the actual transportation operations are to be conducted using helium or nitrogen as the fill gas to avoid exposing the payload to an oxidizing environment. Argon gas may be used during loading operations in a hot cell, but it is not proposed as a backfill gas for transport conditions. The zirconium-alloy (zircaloy) used for the fuel rod cladding is the only payload material important to the safety evaluation. The material specifications for the TN-FSV Packaging are defined in the main body of the Safety Analysis Report (SAR) for the TN-FSV Package.

B3.2.1 Material Properties

Table B3.2-1 lists the thermal properties for Type 304 stainless steel as used in this analysis. The thermal conductivity and specific heat values are taken from the ASME B&PV Code [8], while the density is taken from an on-line database [7]. Property values at temperatures between the tabulated values are calculated via linear interpolation within the heat transfer code.

Table B3.2-1 also provides the material properties for the zircaloy cladding of the PWR fuel rods. The properties are taken from MATPRO library of materials properties [17].

The thermal properties for air presented in Table B3.2-2 are derived from curve fits provided in [9]. As a design basis, all void spaces within the TN-FSV Packaging and the PSB are assumed filled with air at atmospheric pressure, but the transportation operations will actually use helium or nitrogen as the fill gas. Thermal properties for these gases are not presented since the assumption of air as the fill gas will yield predicted component temperatures that are similar to or bound those achieved using nitrogen or helium as the backfill gas. The thermal properties for argon, presented in Table B3.2-3 and also derived from curve fits provided in [9], are considered for its potential use during operations in a hot cell and/or under vacuum drying operations.

The emissivity of 'as-received' Type 304 stainless steel has been measured as 0.25 to 0.28 [10], while the emissivity of weathered Type 304 stainless steel has been measured as being between 0.46 to 0.50 [11]. For the purpose of this analysis, a conservative emissivity of 0.25 is assumed for all surfaces of the PSB. While the emissivity for the inner surfaces of the TN-FSV cask will be significantly higher due to its weathered condition, it is conservatively assumed to be 0.30 for the purposes of this analysis.

The emissivity of oxidized zircaloy (i.e., the spent fuel cladding) is 0.8, per [17].

B3.2.2 Component Specifications

The technical specifications associated with components of the TN-FSV Packaging are defined in the main body of the SAR for the TN-FSV Package. The Type 304 stainless steel used in the PSB has a melting point above 2,700°F [7], but in compliance with the ASME B&PV Code [12], its allowable temperature is limited to 800°F. The minimum allowable temperature is less than -40°F.

The thermal limits imposed on the cladding of the fuel rods are 752 °F for NCT and 1058 °F for HAC [6]. The minimum allowable temperature is less than -40°F.

The butyl rubber O-rings used for the containment seals on the TN-FSV packaging have a continuous service temperature range of approximately -75 °F to +250 °F, per the Oak Ridge Addendum, Section 3.1, *Discussion.*

Table B3.2-1 – Thermal Properties of PSB Solid Materials

Material	Temperature (°F)	Thermal Conductivity (BTU/hr-ft-°F)	Density[1] (lb/in^3)	Specific Heat (BTU/lb-°F)
Type 304 Stainless Steel [2]	-40	8.23	0.289	0.112
	70	8.6		0.114
	100	8.7		0.115
	200	9.3		0.119
	300	9.8		0.123
	400	10.4		0.126
	500	10.9		0.129
	600	11.3		0.130
	700	11.8		0.132
	800	12.2		0.133
	1000	13.1		0.135
	1200	14.0		0.138
	1400	14.9		0.141
	1500	15.3		0.142
Zircaloy [3]	-40	4.73	0.237	0.064
	80	7.35		0.067
	260	8.11		0.072
	440	8.86		-
	620	9.50		-
	692	-		0.079
	800	10.22		-
	1502	-		0.090
	1520	13.39		-

Table B3.2-1 Notes:

(1) Single value is shown since this material property does not vary significantly with temperature.

(2) Material properties are obtained from ASME B&PVC [8]. Value for -40°F extrapolated from values for 70 and 100°F.

(3) Material properties are obtained from MATPRO [17] Value for -40°F extrapolated from values for 80 and 260°F.

Table B3.2-2 – Thermal Properties of Air

Temperature (°F)	Density (lb_m/in^3)	Specific Heat (Btu/lb_m-°F)	Dynamic Viscosity (lb_m /ft-hr)	Thermal Conductivity (Btu/hr-ft-°F)	Prandtl No.	Coef. of Thermal Exp. ($°R^{-1}$)
-40	Use Ideal Gas Law w/ Molecular wt = 28.966 g/mole	0.240	0.0367	0.0121	Compute as $Pr = c_p\mu / k$	Compute as $\beta = 1/(°F+459.67)$
0		0.240	0.0395	0.0131		
50		0.240	0.0429	0.0143		
100		0.241	0.0461	0.0155		
200		0.242	0.0521	0.0178		
300		0.243	0.0576	0.0199		
400		0.245	0.0629	0.0220		
500		0.248	0.0678	0.0240		
600		0.251	0.0724	0.0259		
700		0.253	0.0768	0.0278		
800		0.256	0.0810	0.0297		
900		0.259	0.0850	0.0315		
1000		0.262	0.0889	0.0333		

Note: Data taken from [9] curve fit equations on pp 2.4

Table B3.2-3 – Thermal Properties of Argon

Temperature (°F)	Density (lb_m/in^3)	Specific Heat (Btu/lb_m-°F)	Dynamic Viscosity (lb_m /ft-hr)	Thermal Conductivity (Btu/hr-ft-°F)	Prandtl No.	Coef. of Thermal Exp. ($°R^{-1}$)
-40	Use Ideal Gas Law w/ Molecular wt = 39.948 g/mole	0.124	0.0444	0.0083	Compute as $Pr = c_p\mu / k$	Compute as $\beta = 1/(°F+459.67)$
0			0.0480	0.0089		
50			0.0524	0.0097		
100			0.0566	0.0105		
200			0.0645	0.0120		
300			0.0718	0.0134		
400			0.0788	0.0148		
500			0.0853	0.0160		
600			0.0914	0.0172		
700			0.0972	0.0183		
800			0.1028	0.0194		
900			0.1081	0.0205		
1000			0.1133	0.0215		

Note: Data taken from [9] curve fit equations on pp 2.4

B3.3 Thermal Evaluation under Normal Conditions of Transport

The evaluation of the thermal performance for the TN-FSV Packaging with the PSB is conducted using analytical methods to demonstrate compliance with the requirements of §71.71. The evaluations are performed using conservative analytical techniques to ensure that all materials are maintained within their applicable minimum and maximum allowable temperature during all modes of operation.

Given that the PSB is designed to fit within the existing TN-FSV Packaging and given that the maximum heat dissipation from the PSB is equal to or less than the 360 watts for which the TN-FSV Packaging is currently licensed, the methodology used to evaluate the thermal performance of the PSB within the TN-FSV Packaging is based on the use of a 3-D thermal model of a segment of the PSB. The 3-D thermal model represents a 60 degree section of the lower half of the PSB plus the spacer. In lieu of modeling the TN-FSV Packaging, the thermal model uses the maximum inner shell temperature reported in Table 3-4 of the main body of the SAR for the TN-FSV Package as a boundary condition.

The analytical thermal model of the PSB is developed for use with the Thermal Desktop® [13] and SINDA/FLUINT [14] computer programs. These programs work together to provide the functions needed to build, exercise, and post-process a thermal model. The Thermal Desktop® computer program provides graphical input and output display functions, as well as computing the thermal mass, conduction, and radiation exchange conductors for the defined geometry and thermal/optical properties.

The SINDA/FLUINT computer program is a general purpose code that handles problems defined in finite difference (i.e., lumped parameter) and/or finite element terms and can be used to compute the steady-state and transient behavior of the modeled system. Although the code can be used to solve any physical problem governed by diffusion-type equations, specialized functions used to address the physics of heat transfer and fluid flow make the code primarily a thermal code.

The SINDA/FLUINT and Thermal Desktop® computer programs have been validated for safety basis calculations for nuclear related projects [15 and 16].

Figure B3.3-1 illustrates hidden views of the 3-dimensional thermal model of the simulated section of the PSB and its payload. Figure B3.3-2 expands the model illustration provided in Figure B3.3-1 by adding views of the modeling used for the spacer and the cask inner shell boundary condition. The thermal modeling represents a 60° segment of the PSB with a length of approximately 77.48-in (i.e., about one-half the length of the shielded basket without the lid) plus the 31.4-in spacer. Symmetry conditions are assumed on all sides of the modeled segment. A total of approximately 2250 nodes, 90 surface elements, 280 solid elements, and 39 heat surface loads are used to provide model resolution.

The thermal model uses cylindrical elements to represent the cladding for the payload of PWR fuel rods. These cylindrical elements are combined with a specified thickness to capture the thermal mass and axial conductance along the fuel cladding. The modeling conservatively ignores the presence of the fuel pellets on the axial heat transfer within the fuel rods. The modeling divides the fuel rod cladding into 14 axial segments along the simulated 76.48-in length. For the purposes of this evaluation, the active fuel region is assumed to begin 1-in above the bottom of the fuel tube to account for the end plug. The use of a single thermal node in the radial direction through the cladding is justified since the expected temperature rise through the cladding thickness is small. The encapsulated fuel pellets are not specifically modeled since the temperature of the fuel cladding is the principal safety parameter of interest for this analysis and since ignoring the axial and radial heat transfer within the fuel pellets provides a conservative estimate of the peak temperature within the PSB. The decay heat dissipated by the fuel rods is simulated using a surface heat flux on the cylindrical elements representing the fuel cladding. The surface heat flux applied within the model is computed via the following equation:

$$SF = \frac{Q_{Decay}}{\#\text{ of rods}} \times 3.412 \frac{\text{Btuh}}{\text{watt}} \times PF \div [143\text{ inches} \times \pi \times 0.3515\text{ inches}]$$

where: SF = surface heat flux on fuel cladding (Btuh/in^2)
Q_{Decay} = total PSB decay heat, watts
\# rods = total number of fuel rods to be loaded within the PSB
PF = maximum peaking factor on the decay heat dissipation per Table B5.2-4, Section B5.2, *Source Specification*
143" = active fuel length, per Table B5.2-1, Section B5.2, *Source Specification*
0.3515" = mean diameter of fuel cladding, per Table B5.2-1, Section B5.2, *Source Specification*. The mean diameter used since it is the basis of the cylindrical element modeling used to represent the cladding

Combining the surface heat flux based on a 143-in active fuel region with the geometric modeling of an active fuel length of approximately 151-in (i.e., 76.48-in minus 1-in for half the length of the fuel rod, see above) bounds both the longest PWR fuel rod and worst case heat flux. As such, the simulated decay heat is conservatively over-estimated by about 6%.

The peaking factor (PF) is incorporated into the model by multiplying the surface heat flux applied at each modeled fuel rod cladding section by a length-weighted peaking factor appropriate for the section's length and axial location along the active fuel length. Based on the above equation, SF = PF x 1.1112 Btuh/in^2 for a payload of seven (7) fuel rods dissipating 360 watts. The surface heat flux, SF, rises to PF x 1.5557 Btuh/in^2 for a payload of five (5) fuel rods dissipating 360 watts. However, given that a symmetry thermal model is used for this evaluation and that the model cannot accurately differentiate between a payload containing 6 fuel rods vs. 5 fuel rods, the thermal analysis presented herein for 5 fuel rods effectively simulates a total decay heat load of 6 x 72 watts/rod = 432 watts instead of 5 x 72 watts/rod = 360 watts.

The 1.25-in OD stainless steel tubes with 0.065-in wall thickness used for the PSB fuel tubes are also simulated using cylindrical elements with a specified wall thickness. This modeling approach captures the thermal mass and axial conductance along the fuel tubes. Like the fuel cladding, the fuel tubes are divided into 14 axial segments along the simulated 76.48-in length (i.e., 77.48-in PSB basket model length minus the 1-in thickness of bottom plate) and with a single node in the radial direction. The use of a single thermal node in the radial direction through the tubing is justified since the expected temperature rise through the tubing wall is expected to be vanishingly small in comparison with the overall temperature rise through the PSB assembly.

Heat transfer between the fuel cladding and the fuel tubes is simulated as radiation and conduction across an air gap. For conservatism, the fuel rods are assumed to be centered within the fuel tubes; no credit is taken for potential direct contact between the fuel rods and the fuel tubes. To compute the radial distance for the conduction heat transfer a conservatively small 0.374-in fuel cladding diameter is assumed for the fuel rods, per fuel assembly data in Table B5.2-1.

Heat transfer between the individual fuel tubes of the PSB and between the fuel tubes and the inner wall of the forging used for the basket shielding is computed as combination of radiation and conduction through the intervening airspace.

The 3.25-in thick forging used to provide shielding for the PSB is simulated using 4 nodes in the radial direction, 5 nodes in the circumferential direction. Its axial length is divided into 16 segments. The shield basket disks are simulated using 4 nodes in the radial direction, 5 nodes in the circumferential direction, and 2 nodes for the thickness of the disk. Since symmetry conditions are assumed at the axial ends of the thermal model, only one-half of the thickness of the disk located at the top of the thermal model is simulated.

The PSB support spacer is simulated using 229 nodes and 13 solid elements. The wall of the spacer shell or tube is simulated with 3 nodes in the radial direction, 4 segments along the circumferential direction, and 8 segments along its axial length. The spacer flanges are simulated using a similar node distribution as used for the PSB disks.

Heat transfer between the exterior of the PSB and the TN-FSV cask's inner shell is simulated as conduction, convection, and radiation across the air filled void. Conduction is assumed in the air gap separating the disks from the cask's inner shell, while the potential for convection heat transfer is examined for the air-filled gap between the PSB basket body and the cask's inner shell. The potential for natural convection in the air void between the shielded basket and the cask's inner wall is evaluated using standard equations for concentric cylinders [9]. These equations are based on semi-empirical relationships using the local Rayleigh number and the characteristic length (i.e., the gap between the cylinders). The Rayleigh number is defined as:

$$Ra_L = \frac{\rho^2 g_c \beta L^3 \Delta T}{\mu^2} \times Pr$$

where:

g_c = gravitational acceleration, 32.174 ft/s^2

β = coefficient of thermal expansion, R^{-1}

ΔT = temperature difference, °F

ρ = density of air at the film temperature, lb_m/ft^3

μ = dynamic viscosity, lb_m /ft-hr

Pr = Prandtl number = (c_p μ) / k

L = characteristic length, ft

k = thermal conductivity of air, Btu/ft-hr-°F

c_p = specific heat, Btu/ lb_m-°F

Ra_L = Rayleigh #, based on length 'L'

Note that k, c_p, and μ are each a function of air temperature as taken from Table B3.2-2. Values for ρ are computed using the ideal gas law, β for an ideal gas is simply the inverse of the absolute temperature of the gas, and Pr is computed using the values for k, c_p, and μ from Table B3.2-2. Unit conversion factors are used as required to reconcile the units for the various properties used.

Per equation 4.120 of [9],

$$Nu = 0.603 \times C_L \frac{\ln(D_o/D_i) \times Ra^{0.25}}{\left[(L/D_i)^{3/5} + (L/D_o)^{3/5}\right]^{5/4}}$$

$$C_L = \frac{0.671}{\left[1 + (0.492/Pr)^{9/16}\right]^{4/9}} = 0.516 \text{ for } Pr = 0.72$$

$$D_o = 18" = 1.5 \text{ ft}$$

$$D_i = 10.5" = 0.875 \text{ ft}$$

$$L = (D_o - D_i)/2 = 0.3125 \text{ ft}$$

Per the results presented in Section B3.3.1, *Heat and Cold*, the average gas temperature between the shielded basket and the cask inner wall is approximately 185°F and the average temperature of the shielded basket is 205°F. Based on this condition, the average Rayleigh number is computed as:

$$Ra_L = \frac{(0.062\ \text{lbm/ft}^3)^2 \times 32.174\text{ft/sec}^2 \times (1/(185^o F + 459.67)) \times (0.3125\text{ft})^3 (205 - 167^o F)}{(0.0512\ \text{lbm/ft-hr} \times \dfrac{\text{hr}}{3600\ \text{sec}})^2} \times 0.72$$

$$Ra_L \approx 791{,}922$$

$$Nu = 0.603 \times 0.516 \frac{\ln(1.5/0.875) \times (791{,}922)^{0.25}}{\left[(0.3125/0.875)^{3/5} + (0.3125/1.5)^{3/5}\right]^{5/4}}$$

$$Nu = 5.48$$

Similarly for the spacer, the results presented in Section B3.3.1, *Heat and Cold*, the average gas temperature between the spacer and the cask inner wall is approximately 170°F and the average temperature of the spacer is 174°F. Based on this condition, the average Rayleigh number is computed as:

$$Ra_L = \frac{(0.063\ \text{lbm/ft}^3)^2 \times 32.174\text{ft/sec}^2 \times (1/(170^o F + 459.67)) \times (0.3125\text{ft})^3 (174 - 167^o F)}{(0.0503\ \text{lbm/ft-hr} \times \dfrac{\text{hr}}{3600\ \text{sec}})^2} \times 0.72$$

$$Ra_L \approx 159{,}780$$

$$Nu = 0.603 \times 0.516 \frac{\ln(1.5/0.875) \times (159{,}780)^{0.25}}{\left[(0.3125/0.875)^{3/5} + (0.3125/1.5)^{3/5}\right]^{5/4}}$$

$$Nu = 3.6$$

Since value of both Nusselt numbers (Nu) are greater than 1.0, the presence of convection within the air-filled gap is demonstrated. For conservatism, the Nusselt number for the cavity air in the vicinity of the shielded basket is rounded down to 5.0, while the Nusselt number for the cavity air in the vicinity of the spacer is rounded down to 3.0. The presence of convection in these annular spaces is implemented by multiplying the thermal conductivity of the air in the radial direction by the value of the Nusselt number. For further conservatism, the conductance between the disks and the cavity air is ignored.

The TN-FSV cask inner shell/cavity wall is simulated in the model simply as a zero-thickness surface with an 18-inch ID. A uniform temperature is applied across the surface area as a boundary condition for the thermal model.

B3.3.1 Heat and Cold

The maximum temperature for the PSB is determined assuming a peak temperature of 167 °F for the inner shell of the TN-FSV cask as obtained from Table 3-4 of the main body of the SAR for the TN-FSV Package as a boundary condition. This temperature represents the maximum temperature on the inner shell of the TN-FSV cask under the NCT Hot condition (i.e., 100°F ambient temperature with regulatory insolation loading averaged over 12 hours).

The NCT evaluation was conducted for 2 heat loading scenarios: an even heat distribution with 7 fuel rods dissipating 51.4 watts each and an uneven heat distribution with 5 fuel rods dissipating 72 watts each. Since no restrictions are planned on the placement of the fuel rods for a short loading, the uneven heat distribution case with 5 fuel rods was further examined to include scenarios with and without the center fuel tube loaded.

Table B3.3-1 presents the predicted component temperatures for the evaluated loading configurations and assuming air as the backfill gas. Transportation operations will actually be conducted with nitrogen or helium as the backfill gas to avoid exposing the PWR fuel rod payload to an oxidizing environment. Since the thermal conductivity of nitrogen is similar to air, while the thermal conductivity of helium is approximately 5 times greater than air, the results presented in Table B3.3-1 bound those achieved with either nitrogen or helium gas backfills.

As seen, a substantial thermal margin exists for all components. Figure B3.3-3 illustrates the predicted temperature distribution within the modeled PSB segment and its spacer for the even heat distribution case. The temperature distributions illustrated in the figure confirm that the bulk of the temperature rise between the cask's inner shell and the peak fuel rod cladding occurs in the various air gaps and not within the components of the PSB assembly. As such, the thermal gradients within any component are small. A similar temperature distribution occurs for the uneven heat distribution case. The uneven heat distribution case assumes a short loading scenario where the fuel rods are placed in the outer fuel tubes. Since the symmetry model used to evaluate this condition effectively models a short loading of 6 fuel rods at 72 watts each, the temperature results for the uneven heat distribution case contain a degree of conservatism. A short loading that includes placement of a fuel rod in the center fuel tube position is expected to increase the maximum fuel rod temperature attained to 462 °F, but yield similar peak PSB temperatures.

Figure B3.3-4 illustrates the temperature distribution within the spacer for the case with even heat distribution in the fuel tubes. A similar temperature distribution occurs for the uneven heat distribution case.

Because the boundary temperature used for this safety evaluation was calculated for a uniform decay heat loading distributed over a 187.32-in length, whereas the decay heat load imposed by the PSB payload will originate from the active fuel region of the PWR fuel rods which may be as short as 143-in long and which will exhibit a variation in decay heat flux along its length, a sensitivity study was conducted to bound the worst case effect that would arise if the combination of the PSB structure and the inner shell/lead shield in the TN-FSV cask did not spread the decay heat from the PSB sufficiently to yield a uniform decay heat loading. The result of this sensitivity analysis (see Appendix B3.5.3, *Boundary Temperature Sensitivity Analysis*) showed that the maximum potential increase in the predicted component temperatures (i.e., <23 °F) would be insignificant when compared to the available thermal margins shown in Table B3.3-1. As such, given the maximum level of potential temperature increase, the fact that some level of axial heat spreading does occur, and the fact that the effect of radiation heat transfer will reduce the ΔT required to accommodate a potential increase in the boundary temperature, the overall effect is that the difference in the decay heat load profile between this application and that assumed for the main TN-FSV SAR is not significant to the safety evaluation of the PSB payload

The minimum temperature distribution occurs with a zero decay heat load and an ambient air temperature of -40 °F per 10 CFR §71.71(c)(2). The steady-state analysis of this condition represents a trivial case that requires no thermal calculations be performed. Instead, it is assumed that all package components will eventually achieve the -40 °F temperature under steady-state conditions. The -40 °F temperature is within the allowable range of all of the packaging components. The package temperatures for the NCT Cold condition of -20 °F and no insolation are bounded by those presented in Table B3.3-1. Given the low level of decay heat involved, a specific analysis is not presented since the thermal gradients will be similar to those seen for the NCT Hot condition.

The use of butyl rubber O-rings for the containment seals on the TN-FSV cask for transportation of the PSB payload vs. the silicone seals assumed in the main TN-FSV SAR presents no safety issues. This conclusion is based on the facts that the total decay heat load is equal to or less than the 360 watts assumed by the main TN-FSV SAR and because the placement of the decay heat source of the PSB payload is further from the seals (see Section B3.1.2, *Content's Decay Heat*). As such, the peak seal temperatures reported in the main TN-FSV SAR will bound those seen for this payload. The main TN-FSV SAR states that the maximum TN-FSV cask seal temperature under NCT conditions is 166 °F. This temperature level is well within the long term allowable temperature of 225 °F for the butyl rubber seals defined in Section B3.2.2, *Component Specifications*. As such, the switch from silicone to butyl rubber for the cask closure seals will not present a safety issue for NCT conditions.

Similarly for the other package components, the fact that the total decay heat for the PSB payload is equal to or less than the 360 watts assumed by the main TN-FSV SAR and since the placement of the decay heat source of the PSB payload is further from the ends of the package, the temperatures reported in the main TN-FSV SAR for the cask lid, bottom, and impact limiters bound those seen for this payload. Although the component temperatures at the center of the packaging may rise because the PSB payload has a higher heat flux due to its shorter length and non-uniform peaking factor (see Appendix B3.5.3, *Boundary Temperature Sensitivity Analysis*), the potential temperature increase is predicted to be less than 23 °F. This potential temperature increase is significantly less than the available temperature margin for the inner and outer shells and the lead shield reported in the main TN-FSV SAR. As such, no safety impact on the TN-FSV packaging will occur as a result of transporting the PSB payload.

The main TN-FSV SAR also demonstrates that all accessible package surfaces remain below the temperature limit of 185 °F when transported in an ambient temperature of 100 °F and without insolation, as stipulated by 10 CFR §71.43(g) for exclusive use packages. This surface temperature limit will be maintained for the transportation of the PSB payload.

The above conclusions are valid for the use of nitrogen or helium as the backfill gas.

B3.3.2 Maximum Normal Operating Pressure

The maximum normal operating pressure (MNOP) for NCT is presented in Table B3.3-2 for the evaluated payload configurations. The MNOP is based on an initial cask backfill of air at atmospheric pressure at 70 °F, an assumed cladding failure for one of the fuel rods, and heat up of the gases in cask cavity as predicted in Section B3.3.1, *Heat and Cold* above. As the PSB is vented and provides no containment function, any gas released within the PSB will be available to pressurize the cask cavity. For the purpose of pressure rise determination, both the initial fuel rod backfill gas and the generated fission gas within the fuel rod are considered.

The MNOP is calculated as follows:

$$\mathrm{MNOP} = \frac{N_{cask} R T_{NCT}}{V_{free}}$$

$$N_{cask} = N_{fill} + \text{Rod Failure Rate} \times \left(N_{Rod\ Fill} + N_{Fission\ gas}\right)$$

where:

N_{cask} = total moles of gas in cask and PSB cavities

N_{fill} = g-moles air within cask and PSB cavities at time of cask closure

Rod Failure = A 3% failure rate is assumed for normal conditions of transport of spent fuel assemblies. For conservatism, one fuel rod is assumed to fail (i.e., 14.3%).

$N_{Rod\ Fill}$ = moles of fuel rod fill gas

$N_{Fission\ gas}$ = moles gas generated by irradiation of the fuel rod

T_{NCT} = Bulk average gas temperature within cask at the specific condition

The gross void volume within the cask cavity is computed as:

Cask Gross Void Volume = Volume of Enlarged Area at Top + Volume of Main Cavity – Volume of Aluminum spacer

$$\text{Cask Gross Void Volume} = 7.12''\times\pi\times\left(\frac{20.83''}{2}\right)^2 + (199.0''-7.12'')\times\pi\times\left(\frac{18.0''}{2}\right)^2 - 0.56''\times\pi\times\left(\frac{17.63''}{2}\right)^2$$

Cask Gross Void Volume = 51,117.1 in^3

The displacement or gross volume of the PSB assembly and its spacer support is computed as:

PSB Gross Volume = Volume of Lid + Volume of Forging + Volume of Disks + Volume of Spacer + Volume of Spacer Plates

$$\text{PSB Gross Volume} = 11''\times\pi\times\left(\frac{17.5''}{2}\right)^2 + 155''\times\pi\times\left(\frac{10.5''}{2}\right)^2 + (2\times1.0''+7\times0.75'')\times\pi\times\left[\left(\frac{17.5''}{2}\right)^2 - \left(\frac{10.5''}{2}\right)^2\right] + (31.4-2\times1.0)\times\pi\times\left(\frac{10.75}{2}\right)^2 + 2\times1.0\times\pi\times\left(\frac{17.5''}{2}\right)^2$$

PSB Gross Volume = 20,332.8 in^3

The net free volume between the PSB assembly and its spacer and the cask's inner wall is then 51,117.1 in^3 - 20,332.8 in^3 = 30,784.3 in^3.

The net free volume within the PSB assembly is computed as:

PSB Net Interior Volume = Volume of PSB Cavity - Volume of Fuel Tubes - Volume of PWR Fuel Rods

$$\text{PSB Gross Interior Volume} = 157''\times\pi\times\left(\frac{4''}{2}\right)^2 - 7\times150.5''\times\pi\times\left[\left(\frac{1.25''}{2}\right)^2 - \left(\frac{1.12''}{2}\right)^2\right] - 7\times155''\times\pi\times\left(\frac{0.43}{2}\right)^2$$

PSB Net Interior Volume = 1,560.4 in^3

It should be noted that the calculation of the net interior volume of the PSB assembly excludes the void volume within the spacer since seal welds are used in its fabrication to prevent the inflow of water during loading operations.

Total net void volume within the TN-FSV cask with the PSB and spacer is then 51,117.1 in^3 - 20,332.8 in^3 + 1,560.4 in^3 = 32,344.7 in^3 = 0.530 m^3.

The bulk average gas temperature within the TN-FSV cask is computed as a volume-weighted average of the gas within the PSB and the gas between the PSB and the cask. The average gas temperature within the PSB is assumed to be equal to the average temperature of the fuel tubes, while the average gas temperature in the PSB-cask cavity is computed by the thermal model. For the purposes of this calculation, the cooler gas in the vicinity of the spacer is conservatively ignored. The bulk average temperature is computed via the following equation:

$$\text{Bulk Avg. Gas} = (30{,}784.3\ \text{in}^3 \times \text{PSB-Cask Cavity Avg. Gas} + 1{,}560.4\ \text{in}^3 \times \text{PSB Fuel Tube Avg.}) / 32{,}344.7\ \text{in}^3$$

The void volume within the TN-FSV cask is filled with air at atmospheric pressure following loading and vacuum drying. Assuming the ambient conditions are 70°F (21°C) and a pressure of 14.69 psia (101.3 kPa), the gram-moles of air within the cask cavity is computed via the equation:

$$N_{fill} = 101.3\,\text{kPa} \times \frac{1000\,\text{Pa}}{\text{kPa}} \times 0.530\,\text{m}^3 \div \left[\frac{8.314\ \text{Joules}}{\text{g-moles-K}}\left(21°\text{C} + 273.15\,\text{K}\right)\right]$$

N_{fill} = 22.0 g-moles

The bounding quantity of fill gas within the PWR fuel rods is a function of both the initial charge pressure and the rod free volume. Both of these quantities vary with fuel assembly design. The bounding configuration for PWR fuel rods is WE 14x14 with a total fill gas quantity of 11.1 g-moles [18]. Given that the WE 14x14 fuel assembly has 196 fuel and control rods, the fill gas per fuel rod is $N_{Rod\ Fill}$ = 0.057 g-moles.

In addition to the initial fill gas, the PWR fuel rods will contain fission gases generated as a result of their irradiation. While the majority of the generated fission gas will remain bound to the fuel material matrix, up to 30% of the generated fission gas will be available for release should the fuel cladding fail. The quantity of fission gas generated is a function of the fuel assembly configuration and its burnup history. Of the various PWR fuel rod configurations, the B&W 15x15 fuel assembly with 208 fuel rods generates fission gas quantities that are at or near bounding values [18]. At burnups of 45 GWD/MTU, the total quantity of fission gas per assembly is 27.4 g-moles, of which 30% or 8.2 g-moles is available for release. Since the potential maximum burnup for the fuel rods to be transported is 80 GWD/MTU and given that the generation of fission gas scales with burnup, the available fission gas for release at 80 GWD/MTU will be:

$N_{Fission\ gas}$ = Fission gas quantity per fuel rod

$N_{Fission\ gas}$ = 8.2 g-moles/208 fuel rods x 80/45 burnup ratio

= 0.0701 g-moles/fuel rod

Therefore, the total quantity of gas that may exist within the TN-FSV cask cavity under NCT conditions is computed as:

$$N_{cask} = N_{fill} + \text{Pin Failure Rate} \times \left(N_{Rod\,Fill} + N_{Fission\ gas}\right)$$

$$N_{cask} = 22.0\ \text{g - moles} + 14.3\% \times 7\ \text{fuel rods}\ (0.057 + 0.0701)\ \text{g - moles}$$

$$N_{cask} = 22.13\ \text{g - moles}$$

The MNOP is then calculated via:

$$\text{MNOP} = \frac{N_{cask} R T_{NCT}}{V_{free}}$$

$$\text{MNOP} = \text{g - moles gas} \times \left(\frac{\text{psia}}{6894.8\ \text{Pa}}\right) \times \left[\frac{8.314\ \text{Joules}}{\text{g - moles - K}}\left(T_{NCT}\,{}^{\circ}\text{C} + 273.15\ \text{K}\right)\right] \div 0.530\ \text{m}^3$$

As seen from Table B3.3-2, the maximum MNOP is estimated to be 3.6 psig.

B3.3.3 Evaluation for Vacuum Drying Condition

The TN-FSV cask with the PSB configuration payload is to be vacuum dried prior to transportation. The gas to be used during this procedure may be argon, nitrogen, or helium. Since the PSB shielded basket is vented, the vacuum drying procedure calls for the simultaneous draining of the water in both the cask and PSB cavities, followed by a blow down of the PSB cavity using compressed argon, nitrogen, or helium gas. The vacuum drying pressure to be used is 3 torr. Evaluation of the peak temperatures that may arise under steady-state condition during the vacuum drying process is accomplished using the same thermal model developed for the NCT conditions of transport with the exception that the heat transfer through the fill gas is computed as conduction only everywhere since the gas pressure will be too low to support convective heat transfer. The thermal conductivity of the fill gas is assumed to be equal to that at atmospheric pressure since the mean free path for the gas molecules is much less than the smallest dimension in the model (see Appendix B3.5.4, *Gas Thermal Conductivity at Low Pressures*).

For conservatism, the maximum vacuum drying temperatures are determined assuming a peak temperature of 167 °F for the inner shell of the TN-FSV cask as obtained from Table 3-4 of the TN-FSV package SAR [2] for the NCT Hot condition (i.e., 100°F ambient temperature with regulatory insolation loading averaged over 12 hours). Since the vacuum drying will be conducted indoors, the assumption of a 100°F ambient temperature with the regulatory insolation will conservatively bound the indoor conditions present during vacuum drying.

The vacuum drying evaluation was conducted for the bounding heat load configuration of 5 fuel rods, each dissipating 72 watts, with the assumption that the center fuel tube position is filled, and assuming the use of air or argon as the fill gas during the blow down and subsequent vacuum drying. While in actual practice air will not be used, the evaluation of the vacuum drying condition with air yields peak temperatures that bound those achieved with either helium or nitrogen as the fill gas. As seen from Table B3.3-3, all component temperatures are predicted to remain within their allowable limits for either an air (i.e., nitrogen or helium) or argon backfill environment. Since the results for vacuum drying with argon gas demonstrates that all component temperatures remain below their associated long term temperature limits, the use of argon gas for all other hot cell operations is also permissible.

The results also demonstrate that the restrictions of ISG-11 [21] will not affect the vacuum drying of the TN-FSV cask with the PSB configuration payload in that the peak cladding temperature is below 752°F (400°C) for all potential backfill gases. Further, although no vacuum cycling is expected to be needed, the cladding temperature variation between heatup and cooldown cycles would less than 117°F (65°C) as required by ISG-11 as evident by comparison of the peak cladding temperatures reported in Table B3.3-1 and Table B3.3-3. Since air is not proposed as a potential backfill gas for vacuum drying, the directives of ISG-22 [22] do not apply.

Table B3.3-1 – NCT Hot Temperatures

Location / Component	Seven (7) Fuel Rods w/ 360 Watts	Five (5) Fuel Rods w/ 360 Watts	Maximum Allowable (1)
Fuel Rod Cladding, Max. Fuel Rod Cladding, Avg.	397°F 341°F	419°F (4) 374°F	752°F n/a
PSB Fuel Tubes, Max. PSB Fuel Tubes, Avg.	323°F 283°F	322°F 299°F	800°F n/a
Shielded Basket, Max. Shielded Basket, Avg.	217°F 206°F	226°F 214°F	800°F n/a
Disks	212°F	220°F	800°F
Spacer Tube, Max. Spacer Tube, Avg.	189°F 175°F	194°F 177°F	800°F n/a
Inner Shell of TN-FSV Cask	167°F (2)	167°F (2)	800°F
PSB-Cask Cavity Gas, Avg.	185°F	189°F	n/a
Spacer Cavity Gas, Avg.	171°F	172°F	n/a
Bulk Avg. Gas	190°F (3)	194°F (3)	n/a

Table Notes:

(1) The maximum allowable temperatures under NCT conditions are provided in Section B3.2.2, *Component Specifications*.

(2) TN-FSV cask inner shell temperature of 167 °F is applied as boundary condition to the thermal analysis. This temperature represents the maximum inner shell temperature under the NCT Hot conditions, per Table 3-4 of the main safety analysis report [2].

(3) The bulk average gas temperature is computed as a volume weight average of the gas volume within and exterior to the PSB. The average gas temperature in the PSB cavity is assumed to be equal to the average temperature of the 7 fuel tubes.

(4) Temperature assumes center fuel tube not loaded. Max fuel rod temperature could rise to 462°F if a payload of five fuel rods dissipating 72 watts each is loaded into four outer tubes and the center fuel tube.

Table B3.3-2 – Package MNOP

Parameter	Seven (7) Fuel Rods w/ 360 Watts	Five (5) Fuel Rods w/ 360 Watts
Bulk Avg. Fill Gas Temperature	190°F	194°F
Cask-PSB Void Volume	0.530 m^3	0.530 m^3
Quantity Of Cask Fill Gas	22.0 g-moles	22.0 g-moles
Gas From Failed Fuel Rods	0.127 g-moles	0.127 g-moles
Cask Cavity Pressure	18.2 psia (3.5 psig)	18.3 psia (3.6 psig)

Table B3.3-3 – Vacuum Drying Steady-state Temperatures

Location / Component	Five (5) Fuel Rods w/ 360 Watts (3) With Air	Five (5) Fuel Rods w/ 360 Watts (3) With Argon	Maximum Allowable (1)
Fuel Rod Cladding, Max. Fuel Rod Cladding, Avg.	478°F (4) 406°F	510 °F (4) 433 °F	752°F n/a
PSB Fuel Tubes, Max. PSB Fuel Tubes, Avg.	395°F 341°F	428 °F 369 °F	800°F n/a
Shielded Basket, Max. Shielded Basket, Avg.	262°F 242°F	267 °F 247 °F	800°F n/a
Disks	253°F	259 °F	800°F
Spacer Tube, Max. Spacer Tube, Avg.	211°F 185°F	216 °F 188 °F	800°F n/a
Inner Shell of TN-FSV Cask	167°F (2)	167 °F (2)	800°F
PSB-Cask Cavity Gas, Avg.	-	-	n/a
Spacer Cavity Gas, Avg.	-	-	n/a
Bulk Avg. Gas	-	-	n/a

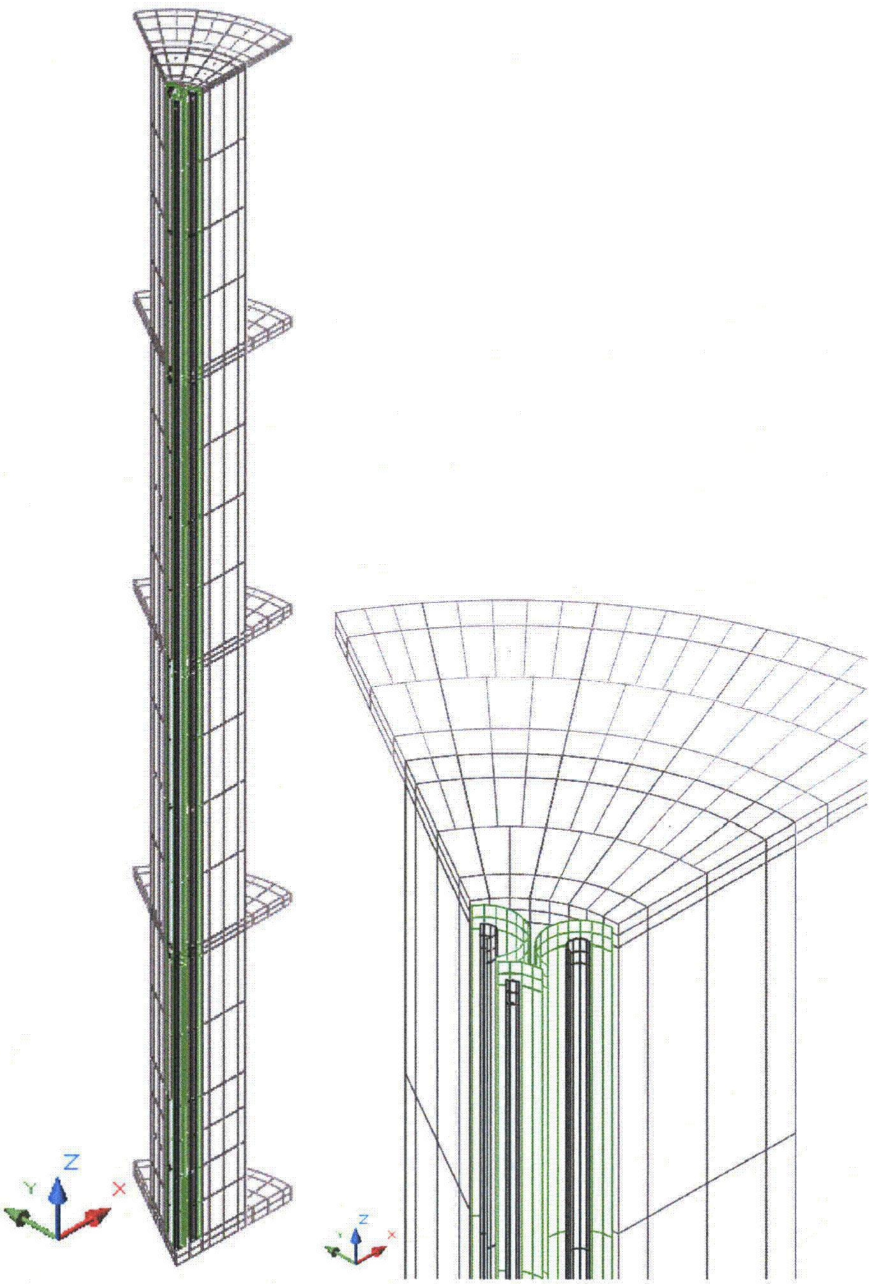
Table Notes:

(1) The maximum allowable temperatures under vacuum drying conditions are provided in Section B3.2.2, *Component Specifications*.

(2) TN-FSV cask inner shell temperature of 167 °F is conservatively applied as boundary condition to the thermal analysis. This temperature represents the maximum inner shell temperature under the NCT Hot conditions, per Table 3-4 of the main safety analysis report [2].

(3) The vacuum drying pressure is assumed to be 3 torr.

(4) Temperature assumes center fuel tube loaded.



Enlarged View

Figure B3.3-1 – Hidden and Enlarged View of 3-D Thermal Model of PSB Segment

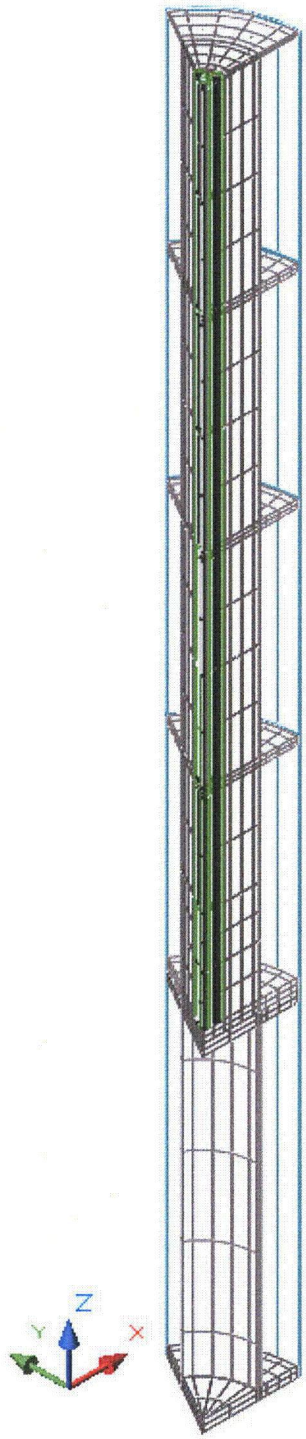
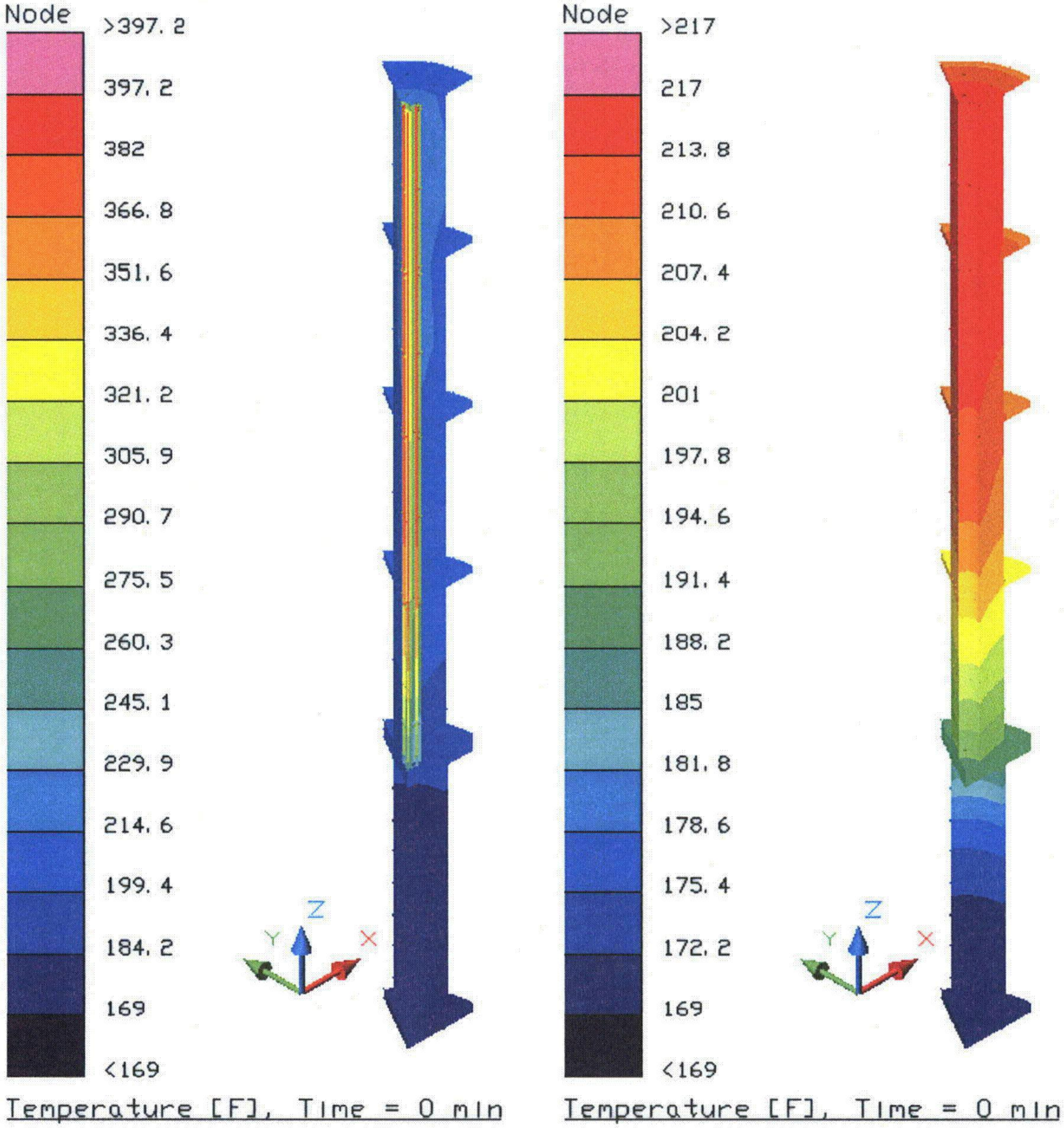


Figure B3.3-2 – Hidden View of PSB 3-D Thermal Model with Spacer and TN FSV Inner Wall Boundary Condition



Shown with Fuel Rods & Fuel Tubes

Shown without Fuel Rods & Fuel Tubes

Figure B3.3-3 – NCT Temperature Distribution within PSB for Even Heat Distribution

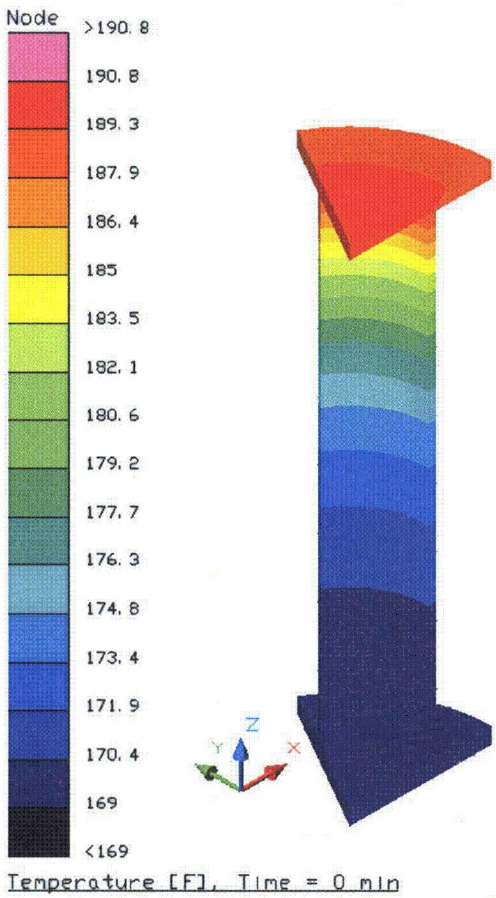


Figure B3.3-4 – NCT Temperature Distribution within Spacer for Even Heat Distribution

B3.4 Thermal Evaluation under Hypothetical Accident Conditions

The performance of the PSB and its fuel rod payload within the TN-FSV Packaging under HAC is evaluated analytically using the same methodology as that used for NCT. This methodology consists of using the maximum temperature achieved for the cask's inner shell during the HAC transient (i.e., 245°F, see Table 3-7 in the main SAR for the TN-FSV Package) as a boundary temperature for the 3-D thermal model of a segment of the PSB and its enclosed PWR fuel rods. Since the analysis is conducted as a steady-state evaluation using a transient peak inner wall temperature, conservative temperature estimates are provided for the PSB components and the enclosed PWR fuel rods. The analysis is conducted for the un-even heat distribution payload configuration with five (5) fuel rods dissipating 72 watts each since the NCT analysis showed that payload configuration resulted in the highest PSB temperatures.

B3.4.1 Initial Conditions

The condition of the TN-FSV Packaging assumed for the HAC conditions is the same as that described in the main SAR for the TN-FSV Package: i.e., it is assumed that no measurable change occurs in the thermal performance of the package as a result of the HAC free and puncture drops. Further, no damage is assumed to occur to the PSB assembly as a result of the HAC free and puncture drops due a combination of the lack of damage predicted for the packaging and the robustness of the PSB design. While it is assumed that the package begins the HAC event at steady-state conditions with an ambient temperature of 100°F and no insolation, the initial conditions are immaterial to the analysis since the HAC evaluation presented herein is conducted as a steady-state analysis.

B3.4.2 Fire Test Conditions

The fire test conditions simulated by this analysis address the 10 CFR §71.73(c) requirements via the following assumptions:

- The initial ambient condition is assumed to be 100°F with no insolation,
- At time = 0, a fully engulfing fire environment consisting of a 1,475°F ambient temperature with an effective emissivity of 0.9 is used to simulate the average flame temperature of the hydrocarbon fuel/air fire event,
- The convection heat transfer coefficients between the package and the ambient during the 30-minute fire event are based on an average gas velocity of 5 m/sec. Following the 30-minute fire event the convection coefficients are based on still air,
- The ambient condition following the 30-minute fire event is assumed to be 100°F with insolation.

B3.4.3 Maximum Temperatures and Pressure

The maximum temperatures attained in the PSB components under the HAC condition are presented in Table B3.4-1, while Figure B3.4-1 depicts the predicted temperature distribution within the PSB. Despite the conservative manner in which the HAC performance of the PSB is determined, all temperatures for the PSB component and the PWR fuel rod cladding remain well below their allowable limits.

With the exception of the assumed 100% failure rate for the PWR fuel rods, the maximum pressure attained for HAC conditions is determined in the same manner as described in Section B3.3.2, *Maximum Normal Operating Pressure*. The bounding amount of fill gas and fission gas within each fuel rod is 0.057 and 0.0701 g-moles, respectively.

As seen from Table B3.4-2, the predicted peak cask pressure under HAC conditions is 21.1 psia (6.4 psig). Given the conservative method used to evaluate the HAC condition, the actual peak pressure is expected to be less. Further, the peak pressure will exist for only a short period before decreasing as the package cools.

B3.4.4 Maximum Thermal Stresses

Thermal stresses are addressed in Section B2.7.4, *Thermal*.

B3.4.5 Accident Conditions for Fissile Material Packages for Air Transport

This section does not apply for the TN-FSV packaging with the PSB payload since air transport will not be utilized.

Table B3.4-1 – HAC Hot Temperatures

Location / Component	Five (5) Fuel Rods w/ 360 Watts	Maximum Allowable (1)
Fuel Rod Cladding, Max. Fuel Rod Cladding, Avg.	463°F 423°F	1,058°F n/a
PSB Fuel Tubes, Max. PSB Fuel Tubes, Avg.	379°F 358°F	800°F n/a
Shielded Basket, Max. Shielded Basket, Avg.	294°F 283°F	800°F n/a
Disks	288°F	n/a
Spacer Tube, Max. Spacer Tube, Avg.	266°F 252°F	800°F n/a
Inner Shell of TN-FSV Cask	245°F (2)	800°F
PSB-Cask Cavity Gas, Avg.	263°F	800°F
Spacer Cavity Gas, Avg.	248°F	n/a
Bulk Avg. Gas	268°F (3)	n/a

Table Notes:

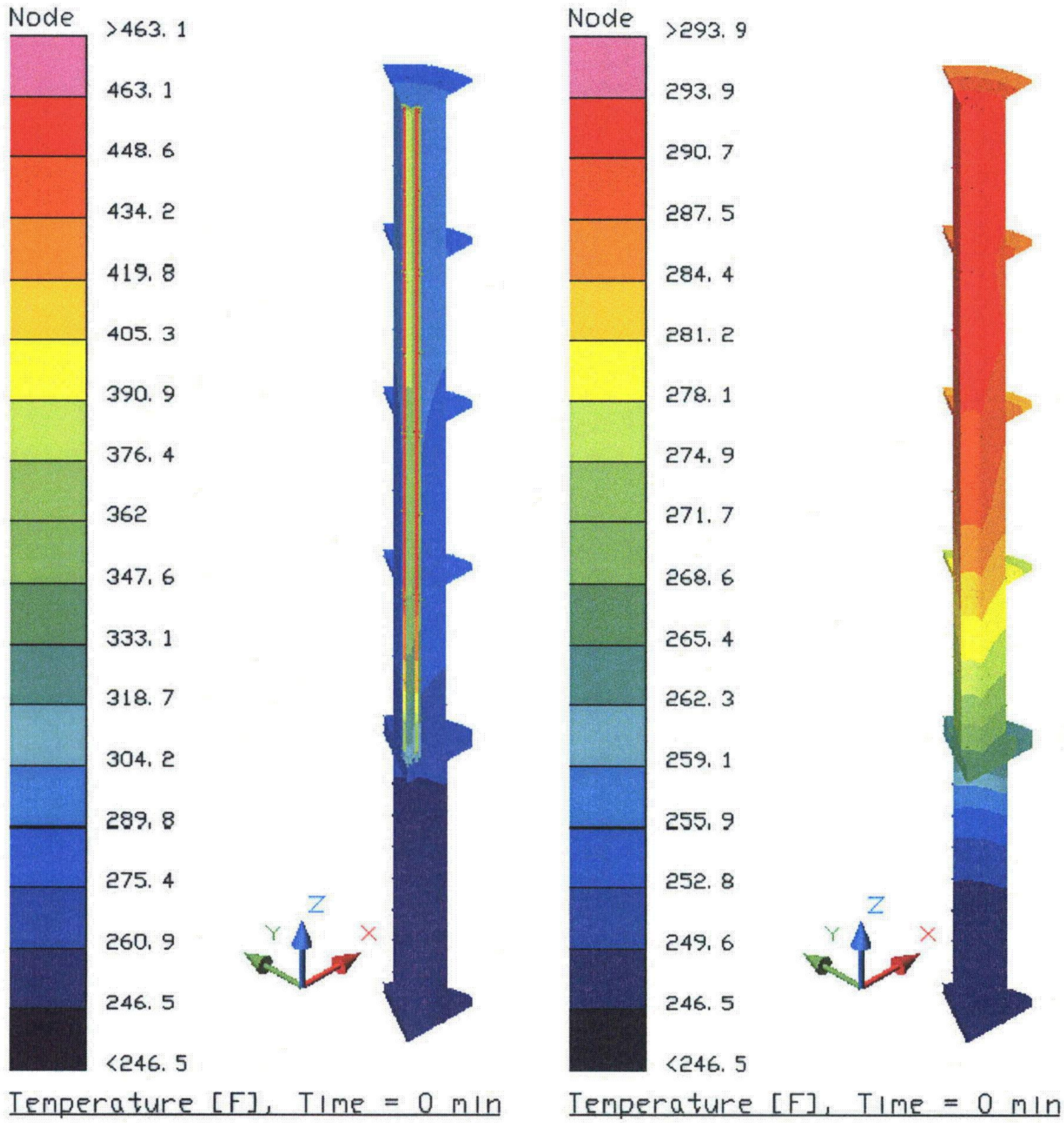
(1) The maximum allowable temperatures under HAC conditions are provided in Section B3.2.2, *Component Specifications*.

(2) TN-FSV cask inner shell temperature of 245 °F is applied as boundary condition to the thermal analysis. This temperature represents the maximum inner shell temperature under the HAC conditions, per Table 3-7 of the main safety analysis report [2].

(3) The bulk average gas temperature is computed as a volume weight average of the gas volume within and exterior to the PSB. The average gas temperature in the PSB cavity is assumed to be equal to the average temperature of the 7 fuel tubes.

Table B3.4-2 – Package HAC Pressure

Parameter	Five (5) Fuel Rods w/ 360 Watts
Bulk Avg. Fill Gas Temperature	268 °F
Cask-PSB Void Volume	0.530 m^3
Quantity Of Cask Fill Gas	22.0 g-moles
Gas From Failed Fuel Rods	0.89 g-moles
Cask Cavity Pressure	21.1 psia (6.4 psig)



Shown with Fuel Rods & Fuel Tubes **Shown without Fuel Rods & Fuel Tubes**

Figure B3.4-1 – HAC Temperature Distribution within PSB and Spacer for Uneven Heat Distribution

B3.5 Appendix

B3.5.1 References

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22. U.S. Nuclear Regulatory Commission Interim Staff Guidance No. 22, Rev. 0, *Potential Rod Splitting Due to Exposure to an Oxidizing Atmosphere During Short-term Cask Loading Operations in LWR or Other Uranium Oxide Based Fuel*, May 8, 2006.

B3.5.2 Computer Analysis Results

The size and number of the files associated with the Thermal Desktop and SINDA/FLUINT programs preclude their inclusion here. However, input and output files are available upon request.

B3.5.3 Boundary Temperature Sensitivity Analysis

As explained in Section B3.3.1, *Heat and Cold*, this safety evaluation uses the maximum inner shell temperature reported in the main SAR for the TN-FSV Package as a boundary condition. This boundary temperature was calculated for a uniform decay heat loading of 360 watts distributed over a 187.32-in length. While the decay heat load imposed by the PSB payload is equal to or less than 360 watts, it will originate from the active fuel region of the PWR fuel rods which may be as short as 143-in long. As such, without sufficient heat spreading in the shielded basket, inner shell of the cask, and the lead gamma shield of the cask, it is possible that the heat flux at the surface of the cask may be greater than that assumed by the analysis used to predict the package temperatures in the main SAR for the TN-FSV Package. While it is expected that sufficient heat spreading will occur, a sensitivity analysis is presented below for the bounding scenario where no thermal spreading occurs.

Based on a ratio of lengths, the worst case heat flux increase associated with the PSB payload vs. the basis used for the main SAR will be 183.32"/143" x 1.114 (worst case peaking factor) = 1.43, or a 43% increase. The effect of this potential increase in surface heat flux can be estimated by the information presented in Table 3-3 and Table 3-4 of the main SAR. Per Table 3-4, the temperature of the outer surface of the cask under NCT conditions with insolation is 161 °F. Interpolation from Table 3-3 for this temperature would indicate that the associated combined convection and radiation heat transfer coefficient would be 1.90952 Btu/hr-ft^2-°F. The total heat transfer per unit area is then equal to 1.90952 Btu/hr-ft^2-°F x (161 - 100°F) = 116.481 Btu/hr-ft^2. Rejection of the worst case heat flux associated with the PSB payload would require an increase to 1.43 x 116.481 Btu/hr-ft^2 = 166.6 Btu/hr-ft^2. A re-interpolation of Table 3-3 in the main SAR shows that an increase in the cask surface temperature of slightly less than 23 °F, or to 184 °F is required to achieve the required heat rejection rate.

A 23 °F increase is only 7% of the minimum available thermal margin presented in Section B3.3.1, *Heat and Cold.* In reality, the potential impact is actually less than 7% since a significant portion of the heat transfer within the PSB is via radiation. Because radiation heat transfer scales as the absolute temperature to the fourth power, a smaller increase in the PSB temperature is sufficient to accommodate the hypothetical 23°F increase in the boundary temperature. Given this level of temperature increase, the thermal margins demonstrated under both NCT and HAC evaluations, and given the various conservatisms applied in the thermal model, the impact of heat spreading for this safety evaluation is shown not to have a significant impact on the predicted peak component temperatures. The effect on structural margins of safety is discussed in Section B2.7.4.3, *Stress Calculations.*

B3.5.4 Gas Thermal Conductivity at Low Pressures

The thermal analysis of vacuum drying assumes that the thermal conductivity of the gas filling the voids of the packaging and the payload remain unchanged from its base value at atmospheric pressure conditions for vacuum pressures of 3 torr or greater. There are two states that define the process by which heat is transferred by a gas [19]:

viscous state, in which the totality of molecules is responsible for the heat transfer. The viscous state occurs as long as the pressure is higher than the range in which the molecular state occurs. Within the viscous state the thermal conductivity of a gas is independent of pressure.

molecular state, heat conductivity in the molecular state is when the gas pressure is so low that the molecular mean free path is about equal or greater than the distance between the plates. The thermal conductivity of the gas is no longer characterized by the viscous state for conductivity and therefore the conductivity is dependent on pressure. The heat transfer process under these conditions is called free molecular conduction.

The pressure at which the molecular mean free path is equal to the minimum distance between the surfaces within the TN-FSV Packaging is determined below for air and helium as the fill gas. The mean free path of the fill gas molecules is [20]:

$$L = \frac{k \times T}{\pi \times \sqrt{2} \times P \times d^2}$$

where:

$k = 1.380658 \times 10^{-23}$ J/K, the Boltzmann constant

P = pressure in Pa

T = temperature in K

d = molecule diameter, in m

At the practical lowest vacuum pressure of 3 torr (400 Pa) used for vacuum drying and a conservatively high gas temperature of 500°F (533K) based on the hottest fuel rod, the mean free path for air with a molecule diameter of about 3×10^{-10} m (based on oxygen, [20]) is:

$$L = \frac{1.380658 \times 10^{-23} \times 533}{\pi \times \sqrt{2} \times 400 \times (3 \times 10^{-10})^2}$$

$$L = 4.6 \times 10^{-5} \text{ m} = 0.002 \text{ inches}$$

Since the molecular diameters of argon and nitrogen are similar to that of air, their mean free paths are also similar. For helium with a molecule diameter of about 2.15×10^{-10} m [20], the mean free path is:

$$L = \frac{1.380658 \times 10^{-23} \times 533}{\pi \times \sqrt{2} \times 400 \times (2.15 \times 10^{-10})^2}$$

$$L = 8.96 \times 10^{-5} \text{ m} = 0.004 \text{ inches}$$

Since both these mean free paths are much smaller than the smallest significant gap in the model (i.e., the gap between fuel rod and the PSB fuel tubes, the gas heat transfer everywhere within the model can be characterized as being in the viscous state and, thus, independent of the gas pressure.

B4.0 CONTAINMENT

B4.1 Description of the Containment System

The description of the TN-FSV cask containment system for the Fort St. Vrain container payload (Configuration 1) is presented in detail in the main SAR, Section 4.1, *Containment Boundary*. With the exception of the elastomer seals, the containment system for the PWR fuel rod payload (Configuration 3) is identical. The butyl seals utilized in Configuration 3 are equivalent to the seals utilized in the Oak Ridge Addendum (Configuration 2). By utilizing butyl seals, a leaktight containment boundary (i.e., 1×10^{-7} ref·cm^3/s) may be justified.

Note that the PWR fuel rod shielded basket (PSB) is not a containment device, as it is vented to allow proper draining subsequent to removal from the spent fuel pool.

18. Remove the cask drain port cover and store for examination.
19. Examine the drain port O-ring seal and sealing surfaces for defects that may prevent a proper seal.
20. Install the PWR Fuel Rod Shielded Basket (PSB) lid lifting attachment.
21. Remove and visually inspect for damage the four (4) SHCSs that secure the PSB lid in place. Replace any screw found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement. Replace defective SHCSs and note any defect indications on the cask loading report.
22. Lift the PSB lid from the cask and store for examination.
23. Examine the mating surfaces in the PSB lid and body for defects that may prevent proper joining of the parts.
24. Inspect the lid and vent port O-rings in the cask lid for damage and replace if defects are noted. Record inspection results on the cask loading report. Note: Butyl O-ring seals are required for the TN-FSV cask in Configuration 3.
25. Visually inspect the PSB cavity for any damage or debris. If any is noted, evaluate and take corrective action as necessary.

B7.1.2 Loading of Contents

The TN-FSV may be loaded either wet or dry. Wet loading would be performed when loading fuel from a spent fuel pool. Dry loading would be performed when loading fuel from a hot cell. Because hot cells do not utilize a standard design, the dry loading operations are specific to the hot cell configuration at Idaho National Laboratory (INL). Similar procedures may be utilized for other hot cell configurations.

B7.1.2.1 Wet Loading

1. Prior to loading the contents, verify that the rods to be shipped meet the requirements of Section B1.2.2, *Contents*.
2. Verify that the correct fuel tube spacers are installed within the PSB, if required. (These spacers are required only if the fuel rod length is less than 151.5-in.)
3. OPTIONAL: Attach a quick disconnect fitting and isolation valve to the drain port and seal the drain port cover bolt holes.
4. Fill the interior cavity of the cask and PSB with demineralized water until the water level is at or near the top of the cavity.
5. Use protective covers or other means, as necessary, to seal cask penetrations (i.e., lid bolt holes, impact limiter bolt holes) and minimize potential contamination from the spent fuel pool water.
6. OPTIONAL: To minimize potential thread contamination, install the 1/4-inch NPT vent port plug into the PSB lid and tighten to a snug–tight condition.
7. Engage the cask lifting apparatus in the recessed lifting sockets.
8. Remove the cask restraints in the cask preloading station from the cask.

9. Raise the cask from the cask preloading station and lower it into the spent fuel pool.
10. Once the cask is lowered onto the in–pool cask loading station in the spent fuel pool, disengage the cask lifting apparatus from the recessed lifting sockets and place the apparatus in a storage location.
11. Utilizing appropriate handling tools, load the contents into the PSB tubes. Only one rod shall be loaded per PSB tube. The maximum number of rods allowed is dependent on the characteristics of the fuel being loaded, as described in Section B1.2.2, *Contents*.
12. After the contents have been loaded, transfer the PSB lid to a position directly over the PSB body. Establish correct lid orientation using the alignment pins and lower the lid until fully seated. Visually verify the lid for proper installation.
13. Engage the cask lifting apparatus in the recessed lifting sockets.
14. Raise the loaded cask from the in–pool cask loading station. Perform any required decontamination procedures of the cask exterior surface prior to removing from the spent fuel pool area.
15. Place the loaded cask in the cask preloading station.
16. Install the cask restraints to secure the loaded cask in the vertical orientation.
17. Disengage the cask lifting apparatus from the recessed lifting sockets.
18. If present, remove the PSB vent port plug.
19. Connect a drain line to the quick disconnect fitting (or optional isolation valve) on the cask drain. Once engaged, partially drain the water from the interior cavity of the cask until the water level is just below the bottom of the PSB bolt head counterbores. Note: Due to submersion in the spent fuel pool, the interior water may be contaminated.
20. Install the four (4) PSB lid SHCSs into their respective holes in the PSB lid. Tighten to a hand tight condition. Following a diametrically opposite tightening sequence, tighten the PSB lid SHCSs to the required value in several stages (final torque values are listed on General Arrangement Drawings in Chapter B1.0).
21. Remove the PSB lid lifting attachment.
22. Examine the O-ring seal, and sealing surfaces of the cask lid and the cask body. Ensure that there is no damage on the sealing surfaces, and that they are clean and free of debris.
23. Remove the protective covers from the cask penetrations (i.e., lid bolt holes, impact limiter bolt holes). Verify no pool water is present in the penetrations, and remove water if present.
24. Remove the cask lid vent port cover and open the vent port.
25. Transfer the cask lid to a position directly over the cask cavity. Establish correct lid orientation using the orientation marks and lower the lid until fully seated. Visually verify the lid for proper installation.
26. Apply a light coating of Neolube #2 to bolt threads and install all twelve (12) lid bolts. Tighten to a hand tight condition. Following a diametrically opposite tightening sequence, tighten the cask lid bolts to the required value in several stages (final torque values are listed on General Arrangement Drawings in Chapter 1.0).

27. Attach a source of inert gas (either helium or nitrogen) pressured 1-2 psig above atmospheric to the vent port in parallel with a vacuum pump. Isolate the vacuum pump and open the valve to the inert gas.
28. Drain the remainder of the cask interior.
29. Disconnect the drain line and any optional hardware from the drain port.
30. Verify there is no water in the cask drain port bolt holes, and remove water if present. Install the cask drain port cover and bolts. Tighten the bolts to 20 in-lbs.
31. Place a test bell over the drain port cover and use the Leak Test System (LTS) to reduce the pressure between the drain port O-ring and the O-ring on the test bell to 5.3, +2.3, -0 torr. Isolate the vacuum pump and perform an ANSI 14.5 [4] pressure rise leakage rate test of the drain port cover (see the equation in Step 42). The acceptance criterion is no detectable leakage rate. The test must have a sensitivity of at least 1×10^{-3} ref·cm^3/sec, air.
32. Isolate the inert gas line and open the valve to the vacuum pump.
33. Using the vacuum pump system, evacuate the cask cavity to a minimum of 3 torr to ensure that the cask cavity is essentially dry.
34. Isolate the vacuum pump from the cask cavity and monitor the internal pressure for a minimum of 30 minutes.
35. If the internal pressure increases more than 1 torr during this period, re-evacuate the cask cavity to a minimum of 3 torr, and repeat Step 34.
36. Following vacuum drying, back-fill the cask cavity with the inert gas.
37. Disconnect the vacuum pump system from the cask vent port.
38. Inspect the cask vent port cover, seal and bolts for damage and replace if defects are noted. Record inspection results on the cask loading report.
39. Install the cask vent port cover and bolts. Tighten the bolts to 20 in-lbs.
40. Place a test bell over the vent cover and use the LTS to reduce the pressure between the vent port O-ring and the O-ring on the test bell to 5.3, +2.3, -0 torr. Isolate the vacuum pump and perform an ANSI 14.5 [4] pressure rise leakage rate test of the vent port cover (see the equation in Step 42). The acceptance criterion is no detectable leakage rate. The test must have a sensitivity of at least 1×10^{-3} ref·cm^3/sec, air.
41. Remove cask lid O-ring test port plug. Install the LTS to the test port and evacuate the lid seal interspace until the pressure is reduced to 7.5, +1.5, -0 torr.
42. Perform an ANSI 14.5 [4] pressure rise leakage rate test for pre-shipment leakage rate testing of the cask lid inner O-ring seal.

    The leakage rate (L_r) is calculated by:

$$L_r = \frac{V \times \Delta P \times 298}{t \times 760 \times T} \qquad (\text{ref - cm}^3/\text{s})$$

    where: V = test volume (cm^3)

ΔP = measured pressure rise during test (torr)

t = elapsed time for the test (s), and

T = temperature of test (K)

It is assumed that over the relatively short duration of the test (1-2 minutes), the change in temperature is insignificant.

The test must have a sensitivity of at least 1×10^{-3} ref·cm^3/s, air.

The acceptance criterion is no detectable leakage rate.

43. Replace the cask lid O-ring test port plug and tighten until snug.
44. Remove the cask lid lifting attachments.

B7.1.2.2 Dry Loading

1. Prior to loading the contents, verify that the rods to be shipped meet the requirements of Section B1.2.2, *Contents*.
2. Verify that the correct fuel tube spacers are installed within the PSB, if required. (These spacers are required only if the fuel rod length is less than 151.5 in.)
3. Mate the cask with the hot cell and open the hot cell. OPTIONAL: Purge the cask with inert gas through the drain port to remove air from the cask cavity before opening the hot cell.
4. Install the PSB lid lifting attachment and lift the PSB into the hot cell. Secure the PSB.
5. Remove the four (4) PSB lid socket head cap screws (SHCS).
6. Remove the PSB lid and store.
7. Using suitable remote tools, load the fuel rods into the PSB tubes. Only one rod shall be loaded per PSB tube. The maximum number of rods allowed is dependent on the characteristics of the fuel being loaded, as described in Section B1.2.2, *Contents*.
8. Visually examine the PSB lid for any damage. Record inspection results on the cask loading report.
9. Transfer the PSB lid to a position directly over the PSB body. Establish correct lid orientation using the alignment pins and lower the lid until fully seated. Visually verify the lid for proper installation.
10. Inspect the PSB lid SHCSs. Replace any defective SHCSs and note any defect indications on the cask loading report. Install the four (4) PSB lid SHCSs into their respective holes in the PSB lid and verify the SHCSs are properly seated (i.e., full thread engagement). It is not necessary to fully torque the SHCSs at this step.
11. Lower the PSB from the hot cell into the cask cavity.
12. Remove the PSB lifting attachment.
13. Un-mate the cask from the hot cell.

14. Following a diametrically opposite tightening sequence, tighten the PSB lid SHCSs to the required value in several stages (torque values are listed on General Arrangement Drawings in Chapter B1.0).
15. Examine the O-ring seal, and sealing surfaces of the cask lid and the cask body. Ensure that there is no damage on the sealing surfaces, and that they are clean and free of debris.
16. Close the drain port if it has been used to purge the cask. Install the cask drain port cover and bolts. Tighten the bolts to 20 in-lbs
17. Remove the cask vent port cover and open the vent port.
18. Transfer the cask lid to a position directly over the cask cavity. Establish correct lid orientation using the orientation marks and lower the lid until fully seated. Visually verify the lid for proper installation.
19. Inspect the lid bolts. Replace defective bolts and note any defect indications on the cask loading report. Apply a light coating of Neolube #2 to bolt threads and install all twelve (12) lid bolts. Tighten to a hand-tight condition. Following a diametrically opposite tightening sequence, tighten all lid bolts to the required value in several stages (torque values are listed on General Arrangement Drawings in Chapter 1.0).
20. Attach a source of inert gas (either helium or nitrogen) to the vent port in parallel with a vacuum pump. Isolate the inert gas and open the valve to the vacuum pump.
21. Using the vacuum pump system, evacuate the cask cavity to a minimum of 3 torr.
22. Isolate the vacuum pump and open the valve to the inert gas. Backfill the cask cavity.
23. Disconnect the vacuum pump system from the cask vent port.
24. Inspect the cask vent port cover, seal and bolts for damage and replace if defects are noted. Record inspection results on the cask loading report.
25. Install the cask vent port cover and bolts. Tighten the bolts to 20 in-lbs.
26. Place a test bell over the vent cover and use the LTS to reduce the pressure between the vent port O-ring and the O-ring on the test bell to 5.3, +2.3, -0 torr. Isolate the vacuum pump and perform an ANSI 14.5 [4] pressure rise leakage rate test of the vent port cover (see the equation in Step 28). The acceptance criterion is no detectable leakage rate. The test must have a sensitivity of at least 1×10^{-3} ref•cm^3/sec, air. Repeat test for the drain port if used for purge operations.
27. Remove cask lid O-ring test port plug. Install the LTS to the test port and evacuate the lid seal interspace until the pressure is reduced to 7.5, +1.5, -0 torr.
28. Perform an ANSI 14.5 [4] pressure rise leakage rate test for pre-shipment leakage rate testing of the cask lid inner O-ring seal.

    The leakage rate (L_r) is calculated by:

    $$L_r = \frac{V \times \Delta P \times 298}{t \times 760 \times T} \qquad (\text{ref - cm}^3/\text{s})$$

    where: V = test volume (cm^3)

ΔP = measured pressure rise during test (torr)

t = elapsed time for the test (s), and

T = temperature of test (K)

It is assumed that over the relatively short duration of the test (1-2 minutes), the change in temperature is insignificant.

The test must have a sensitivity of at least 1×10^{-3} ref•cm^3/s, air.

The acceptance criterion is no detectable leakage rate.

29. Replace the cask lid O-ring test port plug and tighten until snug.
30. Remove the cask lid lifting attachments.

B7.1.3 Preparation for Transport

1. Engage the cask lifting apparatus in the recessed lifting sockets.
2. Remove the restraints from the cask.
3. Lift and move the cask from the cask preloading station to the semi–trailer.
4. Align the trunnions of the cask with the support pedestals on the semi–trailer.
5. Place trunnions on transport vehicle rear trunnion supports and rotate cask from the vertical to horizontal position.
6. Install and tighten the rear trunnion tie-downs and the front saddle tie-downs.
7. Install the front and rear impact limiters and tighten attachment bolts diametrically in several stages until the required value is obtained (torque values are listed on General Arrangement Drawings in Chapter 1.0).
8. Install a tamper-indicating seal on the front impact limiter.
9. Perform final radiation and contamination surveys to ensure compliance with 10 CFR §71.47 and §71.87 [1].
10. Apply appropriate DOT labels and placards to the vehicle in accordance with 49 CFR 172 [2].
11. Install personnel barrier, if used.
12. Prepare final shipping documentation.
13. Release the loaded cask for shipment.

12. Remove the four (4) PSB lid socket head cap screws (SHCS).
13. Remove the PSB lid and store.
14. Using suitable remote tools, remove the fuel rods from the PSB body. Verification shall be made that the fuel rods or guide tubes have been completely removed.

B7.2.3 Loading of Empty PSB

1. Visually examine the cask and PSB lids, especially the cask O-ring seals, for any damage. Record inspection results on the cask loading report.
2. Transfer the PSB lid to a position directly over the PSB body. Establish correct lid orientation using the alignment pins and lower the lid until fully seated. Visually verify the lid for proper installation.
3. Inspect the PSB lid SHCSs. Replace any defective SHCSs and note any defect indications on the cask loading report. Install the four (4) PSB lid SHCSs into their respective holes in the PSB lid and verify the SHCSs are properly seated (i.e., full thread engagement). It is not necessary to fully torque the SHCSs at this step.
4. Lower the PSB from the hot cell into the cask cavity.
5. Remove the PSB lid lifting attachment.
6. Un-mate the cask from the hot cell.
7. Following a diametrically opposite tightening sequence, tighten the PSB lid SHCSs to the required value in several stages (torque values are listed on General Arrangement Drawings in Chapter B1.0).
8. Transfer the cask lid to a position directly over the cask cavity. Establish correct lid orientation using the orientation marks and lower the lid until fully seated. Visually verify the lid for proper installation.
9. Inspect the lid bolts. Replace defective bolts and note any defect indications on the cask loading report. Apply a light coating of Neolube #2 to bolt threads and install all twelve (12) lid bolts. Tighten to a hand–tight condition. Following a diametrically opposite tightening sequence, tighten all lid bolts to the required value in several stages (torque values are listed on General Arrangement Drawings in Chapter 1.0).
10. Inspect the vent cover, seal and bolts for damage and replace if defects are noted. Record inspection results on the cask loading report.
11. Install the vent port cover and bolts. Tighten the bolts to 20 in-lbs.
12. Remove the cask lid lifting attachments.
13. Engage the cask lifting apparatus in the recessed lifting sockets.
14. Remove restraints from cask.
15. Lift and move the cask to the truck bay.

B8.1.3 Structural and Pressure Tests

The PSB does not contain any features that require structural or pressure tests.

B8.1.4 Leakage Tests

Two TN-FSV casks were fabricated in 1995. Any existing cask used in Configuration 3 shall be leak tested per the requirements of this section prior to first use as Configuration 3. Fabrication leakage rate tests for newly fabricated packagings are performed on the containment boundary at the Fabricator's facility. These tests are performed using the helium mass spectrometer leak detector (MSLD) method. The leakage rate test is performed in accordance with ANSI N14.5 [3]. The personnel performing the leakage rate test are qualified in accordance with SNT-TC-1A [2].

For the TN-FSV cask, the inner lid O-ring is tested by utilizing the test port connection for the MSLD with helium in the cask cavity. The body, vent port, and drain port will be tested with the gas filled envelope method, using a helium filled bag around the component and evacuating through one of the ports. The quick disconnect fitting is removed for the port being leak tested. The leakage rate must be less than 1×10^{-7} ref·cm^3/s, air.

The permissible leakage rate for each containment boundary is less than or equal to 1×10^{-7} ref·cm^3/sec, air (leaktight). The sensitivity of the leakage test procedure is at least 5×10^{-8} ref·cm^3/sec, air.

B8.1.5 Component and Material Tests

Installation and removal tests will be performed for the PSB lid, and other fittings and inserts.

Each component will be observed for difficulties in installation and removal. After removal, each component will be visually examined for indications of deformation, galling, ease of use and proper functioning. Any such defects will be corrected prior to acceptance of the PSB.

B8.1.6 Shielding Tests

The analyses performed to ensure sufficient shielding by the TN-FSV cask and the PSB are presented in Chapter B5.0, *Shielding Evaluation*. All PSB materials for which shielding credit is taken are American Society for Testing and Materials (ASTM) materials. No additional shielding tests are required.

B8.1.7 Thermal Tests

The evaluation of the PSB under both normal and accident conditions of transport within the TN-FSV packaging presented Chapter B3.0, *Thermal Evaluation*, demonstrates that large thermal margins exists for all components. Given that the thermal evaluations are based on well defined heat transfer mechanisms, using established thermal properties, and with conservative modeling assumptions (see Chapter B3.0 for details), the actual thermal margins are expected to be even larger. As such, no thermal tests are required for the PSB in the TN-FSV.

B8.1.8 Miscellaneous Tests

There are no miscellaneous tests required for the PSB.

B8.2 Maintenance Program

With the exception of leakage rate testing, the following maintenance activities shall be performed on the PSB. Note that Section B8.2.2, *Leakage Tests*, is applicable to the cask and not the PSB, as the PSB is not a containment boundary.

B8.2.1 Structural and Pressure Tests

No structural or pressure tests are necessary to ensure continued performance of the PSB.

B8.2.2 Leakage Tests

The requirements imposed by this section apply to the TN-FSV cask when used in Configuration 3. Maintenance leakage rate tests shall be performed on the containment boundary seals (inner lid O-ring, vent port cover O-ring, and drain port cover O-ring) when the seals are replaced and when periodic testing is required. Periodic leakage rate testing is required to be performed within the preceding 12-month period prior to use. These tests are performed using an MSLD, as described in Section B8.1.4, *Leakage Tests*. The leakage rate tests are performed in accordance with ANSI N14.5.

The permissible leakage rate for each containment boundary is less than or equal to 1×10^{-7} ref·cm^3/sec, air (leaktight). The sensitivity of the leakage test procedure is at least 5×10^{-8} ref·cm^3/sec, air.

B8.2.3 Component and Material Tests

B8.2.3.1 Fasteners

The PSB lid socket head cap screws shall be replaced after every 250 round trip shipments to preclude fatigue failure.

B8.2.3.2 Seal Areas and Grooves

The PSB does not contain any seal areas or grooves.

B8.2.4 Thermal Tests

No thermal acceptance tests are required, as stated in Section B8.1.7, *Thermal Tests*. In addition, there are no coatings or other degradable components requiring maintenance that affect the passive heat dissipation from the package.

B8.2.5 Miscellaneous Tests

B8.2.5.1 Valves and Rupture Discs

The PSB does not contain any valves or rupture discs.

B8.2.5.2 Gaskets

The PSB does not contain any gaskets.

B8.2.5.3 Shielding

No shielding tests are necessary to ensure continued performance of the PSB.