71-9253

Department of Energy

Oak Ridge Operations Office
P.O. Box 2001
Oak Ridge, Tennessee 37831—

September 18, 2001

Mr. E. William Brach, Project Director
U. S. Nuclear Regulatory Commission
Spent Fuel Project Office
One White Flint North
11555 Rockville Pike
Washington, DC 20555

Dear Mr. Brach:

TN-FSV SAFETY ANALYSIS REPORT INFORMATION

In accordance with conversations between the Department of Energy (DOE) Oak Ridge Operations Office, its Contractors, and members of your staff earlier this month, the enclosed additional information is provided to supplement our license application. As discussed with your staff, we are providing revised pages for the TN-FSV Safety Analysis Report and for the Addendum for Configuration 2.

DOE trusts that the enclosed submittal will provide the Nuclear Regulatory Commission with the information needed to complete the review of our application. DOE appreciates your timely efforts to maintain the current schedule for this important project.

If there are any questions, please contact me at (865) 241-6182.

Sincerely,

Brian DeMonia

Brian DeMonia, Program Manager
Waste Management and Technical
Integration Team

Enclosure

cc w/enclosure:
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cc w/o enclosure:
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NMSS01 Public

TN-FSV SAFETY ANALYSIS REPORT

REVISION 3

As part of the requested license amendment for the TN-FSV Package, Revision 2 of the TN-FSV SAR has been reviewed against the current requirements of the 10CFR71 regulations. As a result, several pages of the TN-FSV SAR have been revised and are also included as part of this submittal. The revised SAR pages are listed below.

Revised Page Number	Description
Table of Contents	Added SAR Addendum for Oak Ridge Container
1-1& 1-1a	Defined Configuration 1 (FSV container) and Configuration 2 (Oak Ridge Container). Exceptions to NUREG-1617.
1-11	Corrected lid spacer diameter.
1-12	Defined Configuration 1 (FSV container) and Configuration 2 (Oak Ridge Container). Discussion of optional personnel barrier.
1-12a	Spill over from revision of page 1-12.
1-18	New revision for SAR drawings
SAR drawings	Added Configuration 1 and Configuration 2 description with seal material and leak test requirements. Added fabrication tolerances
2-70 & 2-70a	Reference new lead slump analysis in Addendum and spill over from insertion.
2-87, 2-87a & 2-88	Revised immersion evaluations.
2-121 & 2-122	Revised stress Tables for immersion.
3-ii	Addition of new table.
3-19, 3-19a, 3-20, & 3-20a	Address the requirement for a convection coefficient in the thermal accident.
3-31	Addition of a new reference.

Revised Page Number	Description
4-7 & 4-9	Revised in accordance with the current A_2 value for Kr-85
4-11 & 4-12	Revised in accordance with the current accident conditions release limit for Kr-85 and ANSI N14.5 1997
5-1	Include reference to lead slump analysis and MCNP dose calculation.
7-1	Include Configuration 1 and Configuration 2 activities and remove statement on underlined steps and sequence of operations. Added option for using personnel barrier.
7-3	Removed underlining in steps and added verification of contents to C of C.
7-4 & 7-5	Removed underlining in steps.
7-6 & 7-7	Removed underlining in steps and added option for personnel barrier.
7-9	Removed underlining in steps.
7-10	Removed underlining in steps and added option for personnel barrier.

FIGURE WITHHELD UNDER 10 CFR 2.390

APPROVALS	DATE	TRANSNUCLEAR, INC. HAWTHORNE, N.Y.			
G.G. PROJ.	11 MAR. 93	TN-FSV PACKAGING ASSEMBLY			
T.J.N. CHK'D. BY	11 MAR. 93				
J.T.G. DWN. BY.	27 JAN. 93	1/10 SCALE	B SIZE	1090-SAR-1 DWG. NO.	3 REV.

4.3 CONTAINMENT REQUIREMENTS FOR HYPOTHETICAL ACCIDENT CONDITIONS

The release of radioactive material is limited to A_2 per week and 2,700 Ci Kr85 under the conditions of the hypothetical accident tests of 10CFR71.73, in accordance with 10CFR71.51(2).

4.3.1 Fission Gas Products

From the previous Section 4.2.1.1., there is about 392 Ci of Kr85 and 1.4 gram moles of gas available in each fuel element. Therefore, the total inventory in the TN-FSV packaging is 2352 Ci Kr85 (6x392) and a quantity of 8.4 gram moles of gas (Kr, Xn & I).

If it is assumed that there is 100% fuel failure in the accident, the total pressure in the cask can be calculated as follows:

- The partial pressure of the air in the cavity at the accident condition temperature of 253°F (Table 3-1) is:

$$P_{1A} = 1.0 x \frac{396}{293} = 1.35\ atm$$

- The partial pressure due to saturated water vapor at the cold wall temperature of 200°F (Table 3-1):

$$P_{2A} = 0.775\ atm$$

- The partial pressure due to the release of the fission gas into the cavity:

$$P_{3A} = \frac{8.4 x 10^{-3}\ x\ 0.0821 x 396}{0.267} = 1.02\ atm$$

The total cavity pressure is therefore 3.15 atm (31.5 psig).

CHAPTER FIVE
SHIELDING EVALUATION

5.1 DISCUSSION AND RESULTS

An evaluation of the shielding performance of the TN-FSV is performed to demonstrate compliance with the dose rate limits of 10CFR71.47. This also demonstrates compliance with the accident dose rate limit of 10CFR71.51(a)(2) because the components of the package shielding which are not an integral part of the body (the impact limiters, the lid, and the thermal shield) will remain in position under all accident conditions, as demonstrated in Appendices 2.10.1 and 2.10.2. However, a dose rate analysis to evaluate the lead slump (Addendum Appendix 2.11.8) is performed. It is the basic MCNP cask accident model, described in Appendix 5.6.1 of the Addendum, but with the FSV Canister in place of the Oak Ridge Container. The contents of the TN-FSV consist of six irradiated FSV fuel elements enclosed within a fuel storage container (FSC). The fuel elements have a maximum burnup of 70,000 MWD/MTU (Megawatt-Days/Initial Metric Tons of Thorium and Uranium)and have been decayed for at least 1600 days since discharge from the reactor.

The most significant shielding design feature of the TN-FSV is the cask body, which consists of an inner layer of stainless steel, followed by lead and an outer layer of stainless steel. The impact limiters, which consist of wood in stainless steel cases, provide additional axial shielding, and the thermal shield, a stainless steel shell, provides additional radial shielding. Additional shielding at the top of the packaging is provided by a depleted uranium plug which is inserted into the closure lid of the FSC. The shield layers and thickness are listed in Table 5-1.

The shielding analysis of the TN-FSV is performed with regulatory acceptable codes from the SCALE system (Ref. 5-1). Conservative modeling of the source provides an upper bound on the dose rates. Table 5-2 summarizes the calculated dose rates and shows that all applicable limits are satisfied

CHAPTER SEVEN
OPERATING PROCEDURES

This chapter contains TN-FSV loading and handling procedure guidelines which show the general approach to cask operational activities. The information in this chapter will be used to prepare site specific procedures. The operational steps are to be performed to maintain the validity of the cask transport regulations and safety analysis conclusions contained herein.

The procedures in this section are for those activities associated with the loading and transport of canistered spent fuel elements from the Ft. St. Vrain High Temperature Gas Cooled Reactor (Configuration 1). The loading and unloading of the cask shall be performed dry.

Configuration 2 operation activities are provided in the SAR Addendum.

The final steps of cask acceptance testing are performed at the loading site prior to the cask being transported for the initial shipment.

7.1 PROCEDURES FOR LOADING PACKAGE

7.1.1 Receipt of Empty Package

7.1.1.1 Inspect and clean the tractor and semi-trailer, removing any road dirt. Check for damage or irregularities and begin performance of radiation and contamination survey. (The radiation and contamination survey continues following removal of the personnel barrier, if used, and as shipping cask surfaces become accessible.)

7.1.1.2 Remove the personnel barrier, if used. Inspect and clean the shipping cask.

TN-FSV SAFETY ANALYSIS REPORT ADDENDUM

Summary of Revision 2 Pages

Revised Page Number	Description
SAR Addendum Drawings	Changed materials, torque requirements, and miscellaneous details as noted
2-5	Tie Rod Material changed to SA-564 Type 630
2-31 thru 2-38	Applied Stress/Maximum stress changed to Stress Intensity
2.11.1-1	Correct typo for angle of drop
2.11.1-2 thru 2.11.1-4	Include tie rod analysis
2-11.1-8	Changes due to tie rod analysis
2.11.1-18 thru 2.11.1-20c	Changes due to tie rod analysis
2.11.1-21 & 2.11.1-22	Correct error in temperature for thermal expansion
2.11.1-23 thru 2.11.1-25	Changed heading to Stress Intensity and reported values for tie rods.
2.11.2-i	Added figures for ORC bottom analysis
2.11.2-9 thru 2.11.2-10	Added ORC bottom drop analysis.
2.11.2-12 & 2.11.2-13	Added figures for ORC bottom analysis
2.11.3-10 & 2.11.3-11	Changed heading to Stress Intensity.
2.11.4-1	Included alternate bolt material.
2.11.4-20	Correct Reference numbering
2.11.6-9	Correct typo in title
2.11.7-10	Changed heading to Stress Intensity.
3-6	Correct typo for temperature.

Revised Page Number	Description
3-7 & 3-8	Correct inconsistencies in the reported temperatures.
3-10 & 3-11	Correct inconsistencies in the reported temperatures.
3-16 & 3-17	Correct inconsistencies in the reported temperatures.
4-5	Correct typo for ANSI date.
8-2	Changed drain port to vent port.
8-6	Added statistical sampling plan
8-6a	Spill over from page 8-6
8-8	Added statistical sampling plan
8-8a	Spill over from page 8-8

FIGURE WITHHELD UNDER 10 CFR 2.390

APPROVALS	DATE	TRANSNUCLEAR, INC. HAWTHORNE, N.Y.			
PROJ. M.M.	01 NOV. 00				
Q/A W.R.S.	02 NOV. 00	OAK RIDGE CONTAINER GENERAL ARRANGEMENT			
MECH. ENG. J.C.	01 NOV. 00				
CHK'D. BY M.M.	01 NOV. 00				SAR
DWN. BY. J.T.G.	24 OCT. 00	NONE SCALE	B SIZE	3044-70-1 DWG. NO.	2 REV.

FIGURE WITHHELD UNDER 10 CFR 2.390

NO.	DATE	REVISIONS	DWN.	CHK'D.	P.E.	Q/A	PROJ.

APPROVALS	DATE	
MM PROJ.	1 NOV. 00	TRANSNUCLEAR, INC. HAWTHORNE, N.Y.
WRS Q/A	2 NOV. 00	OAK RIDGE CONTAINER POISON ENCLOSURE DETAILS
JC MECH. ENG.	1 NOV. 00	
MM CHK'D. BY	1 NOV. 00	SAR
JTG DWN. BY.	24 OCT. 00	NONE SCALE / B SIZE / 3044-70-5 DWG. NO. / 2 REV.

FIGURE WITHHELD UNDER 10 CFR 2.390

APPROVALS	DATE	
M.M. PROJ.	1 NOV. 00	TRANSNUCLEAR, INC. HAWTHORNE, N.Y.
W.R.S. Q/A	1 NOV. 00	OAK RIDGE CONTAINER LID DETAILS
J.C. MECH. ENG.	1 NOV. 00	
M.M. CHK'D. BY	1 NOV. 00	SAR
J.T.G. DWN. BY.	24 OCT. 00	NONE SCALE · B SIZE · 3044-70-6 DWG. NO. · 1 REV.

FIGURE WITHHELD UNDER 10 CFR 2.390

respectively. The CG location of the TN-FSV package including the loaded Oak Ridge Container is calculated as follows:

- CG location of the Oak Ridge Container from bottom of the Container: 104.71 in.
- Distance from inside bottom of TN-FSV cask cavity to top of outer lid surface: 201.5 in.
- CG location of the Oak Ridge Container installed in the TN-FSV cask from cask outer lid surface: 201.5-104.71 = 96.79 in.
- Nominal weight of the loaded Oak Ridge Container: 4,603 lb.
- Total weight of the TN-FSV transport package loaded with the Oak Ridge Container is 42,000 lb. + 4,603 lb. = 46,603 lb.
- Therefore, the CG location of the TN-FSV package including the loaded Oak Ridge Container from the cask outer lid surface is (105.1 in. × 42,000 lb. + 96.79 in. × 4,603 lb.) / 46,603 lb = 104.28 in

C. Mechanical Properties of Material

The mechanical properties of the materials used in the TN-FSV cask are provided in the TN-FSV SAR, Section 2.3.

The Oak Ridge Container is constructed primarily of Type 304 stainless steel. The properties of this material at the maximum normal condition temperature of 250° F are as follows[2].

$S_m = 20.0$ ksi.
$S_y = 23.75$ ksi.
$S_u = 68.5$ ksi.
$E = 27.3 \times 10^6$ psi.
$\alpha = 8.90 \times 10^{-6}$ in./in. °F^{-1}

Properties of fuel basket standoff and tie rod materials (SA-564, Type 630, condition H1150) at 250° F are as follows[2].

$S_m = 45.0$ ksi.
$S_y = 95.05$ ksi.
$S_u = 135.00$ ksi.
$E = 27.5 \times 10^6$ psi.
$\alpha = 5.90 \times 10^{-6}$ in./in. °F^{-1}

The mechanical properties of the lid bolt material (SA-453, Type 651, class A) are provided in Tables 2.11.4-3 and 2.11.4-4.

Table 2-6 Summary of Support Disc Normal Condition Stress Analysis

Drop Orientation	Stress Category	Stress Intensity (ksi)	Allowable Stress (ksi)
End Drop (16 g)	P_m	0.0	20.0
	$P_m + P_b$	5.15	30.0
	Bearing	11.26	23.75
0° Side Drop (20 g)	P_m	11.47	20.0
	$P_m + P_b$	11.97	30.0
36° Side Drop (20 g)	P_m	13.76	20.0
	$P_m + P_b$	29.45	30.0

Table 2-7 Summary of Oak Ridge Container Shell Normal Condition Stress Analysis

Component	Applied Load	Stress Category	Stress Intensity (ksi.)	Allowable Stress (ksi.)
Oak Ridge Container shell	5 psi. internal & external pressure (Normal conditions)	Hoop	0.31	20.00
		Buckling	0.31	0.88
	16 g End drop (Normal conditions)	Compression	2.32	20.00
		Buckling	2.32	9.37
	20 g, 0^{o} Side Drop	Compression	10.04	20.00
		Bending + Compression	11.21	30.00
	20 g, 36^{o} Side Drop	Compression	5.70	20.00
		Bending + Compression	11.69	30.00
Oak Ridge Container bottom plate	5 psi. internal & external pressure (Normal conditions)	Compression	0.16	20.00
		Bending + Compression	0.42	30.00

Table 2-8 Summary of Normal Condition Stress Analysis for the Standoffs, Tie Rods, Flux Traps, and Fuel Compartments

Component	Applied Load	Stress Category	Stress Intensity (ksi.)	Allowable Stress (ksi.)
Standoffs	Maximum Preload (Normal conditions)	Compression	10.88	45.00
		Buckling	10.88	28.04
Tie Rods	Maximum Preload (Normal conditions)	Stress Intensity	29.09	67.50
Flux Traps	16 *g* End drop (Normal conditions)	Compression	2.52	20.00
		Buckling	2.52	10.67
Fuel Compartment	16 *g* End drop (Normal conditions)	Compression	1.04	20.00
		Buckling	1.04	5.87
	20 *g* Side drop (Normal conditions)	Bending	0.83	20.00

Table 2-9 Summary of Normal Condition Stress Analysis for the Poison Enclosures

Component	Applied Load	Stress Category	Stress Intensity (ksi.)	Allowable Stress (ksi.)
3.268 in. wide plate	20 *g* Side drop (Normal conditions)	Bending	1.72	20.00
Top and bottom support plates	20 *g* Side drop (Normal conditions)	Shear	5.02	12.00
		Compression	2.68	20.00
		Buckling	2.68	10.13
Inner and outer braces	20 *g* Side drop (Normal conditions)	Bending	4.27	20.00
Top / bottom support plate welds	20 *g* Side drop (Normal conditions)	Shear	0.57	12.00

Table 2-10 Summary of Support Disc Accident Condition Stress Analysis

Drop Orientation	Stress Category	Stress Intensity (ksi)	Allowable Stress (ksi)
End Drop (60 g)	P_m	0.0	47.95
	$P_m + P_b$	19.32	68.50
	Bearing	42.21	68.50
0° Side Drop (80 g)	P_m	29.50	47.95
	$P_m + P_b$	29.78	61.65
36° Side Drop (80 g)	P_m	10.74	47.95
	$P_m + P_b$	33.31	61.65

Table 2-11 Summary of Oak Ridge Container Shell Accident Condition Stress Analysis

Component	Applied Load	Stress Category	Stress Intensity (ksi.)	Allowable Stress (ksi.)
Oak Ridge Container shell	60 g End drop (Accident conditions)	Compression	8.70	47.95
		Buckling	8.70	18.74
	80 g, 0° Side Drop	Compression	6.38	47.95
		Buckling	27.40	61.65
	80 g, 36° Side Drop	Compression	24.03	47.95
		Buckling	29.48	61.65
	10 psi. internal & external pressure (Accident conditions)	Hoop	0.62	47.95
		Buckling	0.62	1.32
Oak Ridge Container bottom Plate	10 psi. internal & external pressure (Normal conditions)	Compression	0.31	47.95
		Bending + Compression	0.85	68.50

Table 2-12 Summary of Accident Condition Stress Analysis for the Standoffs, Tie Rods, Flux Traps, and Fuel Compartments

Component	Applied Load	Stress Category	Stress Intensity (ksi.)	Allowable Stress (ksi.)
Standoffs	60° Corner drop (Accident conditions)	Compression	34.01	94.50
		Buckling	34.01	46.46
Tie Rods	60° Corner drop (Accident conditions)	Stress Intensity	92.89	135.00
Flux Traps	60 *g* End drop (Accident conditions)	Compression	9.46	47.95
		Buckling	9.46	21.33
Fuel compartment	60 *g* End drop (Accident conditions)	Compression	3.89	47.95
		Buckling	3.89	11.74
	80 *g* Side drop (Accident conditions)	Bending	3.34	47.95

Table 2-13 Summary of Normal Condition Stress Analysis for the Poison Enclosures

Component	Applied Load	Stress Category	Stress Intensity (ksi.)	Allowable Stress (ksi.)
Poison enclosure outer sheet	80 g Side drop (Accident conditions)	Bending	6.87	47.95
Top and bottom support plates	80 g Side drop (Accident conditions)	Shear	20.09	28.77
		Compression	10.73	47.95
		Buckling	10.73	20.25
Inner and outer braces	80 g Side drop (Accident conditions)	Bending	17.08	47.95
Top / bottom support plate welds	80 g Side drop (Accident conditions)	Shear	2.27	28.77

APPENDIX 2.11.1

FUEL BASKET STRUCTURAL ANALYSIS

2.11.1.1 Approach

The Oak Ridge SNF Container includes the following components:

- Tie Rod and Standoff (spacer)
- Fuel Compartment
- Poison Enclosure
- Support disc
- Container Shell
- Container lid and lid bolt

The purpose of this appendix is to evaluate the structural adequacy of the tie rods, standoffs, fuel compartments, poison enclosures, and support disc bearing stress. Appendix 2.11.2 presents the detailed structural analysis of the container shell due to internal pressure, external pressure and end drop loads. Appendix 2.11.3 presents the finite element analysis of the support discs and container shell subjected to side and end drop accelerations. The container lid bolt analysis is presented in Appendix 2.11.4. The maximum operating temperature is taken to be 250° F. (Section 3.4).

The applied loads analyzed in this appendix are as follows.

- Thermal stresses due to a maximum temperature change of 180° F (250° F – 70° F room temp.).
- The following accelerations due to normal and accident conditions end and side drops (TN-FSV SARP Appendix 2.10.2), including a value of 1.10 for the Dynamic Amplification Factor (Appendix 2.11.6):

Summary of Applied Load Caused by Free Drop Event

Impact Load		Normal Conditions (1 foot drop)	Accident Conditions (30 foot drop)
Axial g load (end drop)		14 g × 1.10 ~ 16 *g*.	54 g × 1.10 ~ 60 *g*.
60° Corner Drop	Axial *g* load	-	37 *g* × 1.10 ~ 41 *g*.
	Transverse *g* load	-	13 *g* × 1.10 ~ 15 *g*
Transverse g load (side drop)		17 g × 1.10 ~ 20 *g*.	71 g × 1.10 ~ 80 *g*.

Properties of the fuel basket poison plate enclosures, support discs, flux traps, and fuel compartments materials (Type 304 stainless steel) at 250° F are as follows[1].

$S_m = 20.0$ ksi.
$S_y = 23.75$ ksi.
$S_u = 68.5$ ksi.
$E = 27.3 \times 10^6$ psi.
$\alpha = 8.90 \times 10^{-6}$ in./in. °F^{-1}

Properties of fuel basket standoff and tie rod materials (SA-564, type 630, Condition H1150) at 250° F are as follows[1].

$S_m = 45.0$ ksi.
$S_y = 95.05$ ksi.
$S_u = 135.00$ ksi.
$E = 28.2 \times 10^6$ psi.
$\alpha = 5.90 \times 10^{-6}$ in./in. °F^{-1}

The design criteria are described in Chapter 2. The basis for the fuel basket stress allowable is Section III, Subsection NG[3] for normal condition loads and Appendix F[2] for accident loads. The allowable stresses are as follows.

Summary of Allowable Stresses

Stress Category	Normal Conditions (Level A)		Accident Conditions (Level D)	
	Support discs, Flux traps, Fuel compartments, and Poison enclosures	Tie Rods and Standoffs	Support discs, Flux traps, Fuel compartments, and Poison enclosures	Tie Rods and Standoffs
Primary membrane (general), P_m	S_m, 20.00 ksi.	S_m, 45.0 0ksi.	Lesser {2.4 S_m, 0.7 S_u}, 47.95 ksi.	Lesser {2.4 S_m, 0.7 S_u}, = 94.50 ksi.
Primary membrane + bending, $P_m + P_b$	1.5S_m, 30.00 ksi.	1.5S_m, 67.50 ksi.	Lesser {3.6 S_m, S_u}, 68.50 ksi.	Lesser {3.6 S_m, S_u}, 135.00 ksi.
Bearing Stress	S_y, 23.75 ksi.	S_y, 95.05 ksi.	S_u, 68.50 ksi.	S_u, 135.00 ksi.
Pure shear stress	0.6 S_m, 12.00 ksi.	0.6 S_m, 27.00 ksi.	0.42 S_u, 28.77 ksi.	0.42 S_u, 56.70 ksi.

2.11.1.2 Analysis

A) Tie Rods and Standoffs (Appendix 1.4, Drawing 3044-70-7, Items 19 and 18)

Tie Rod Nut Torque Computation

The thread used at both ends of the tie rod is 1/2– 13UNC – 2A. The number of threads per inch, $N = 13$. Therefore, the thread pitch, $p = 1/13 = 0.0769$ in. The nominal tie rod diameter of the 1/2–13UNC threads, $D_b = 0.500$ in. From Reference 6, the diameter of the tie rod at the threads used for stress calculations, D_{ba}, is,

$$D_{ba} = D_b - 0.9743\,p = 0.500 - 0.9743(0.0769) = 0.425 \text{ in.}$$

The stress area at the tie rod threads is,

$$\text{Stress Area} = \pi/4\,(0.425)^2 = 0.142 \text{ in.}^2$$

A tie rod nut torque range of 14 to 16 ft. lb. has been selected. From Reference 6, using the minimum torque,

$$F_a = Q/KD_b = 14\times12/(0.1\times0.500) = 3{,}360 \text{ lb., and}$$

$$\text{Preload stress} = F_a \,/\, \text{Stress Area} = 3{,}360/0.142 = 23{,}662 \text{ psi.} < 45{,}000 \text{ psi. … o.k.}$$

Where Q is the applied nut torque, and K is the Nut factor for empirical relation between the applied torque and achieved preload (assume 0.1 with neolube lubricant). Using the maximum torque,

$$F_a = Q/KD_b = 16\times12/(0.1\times0.500) = 3{,}840 \text{ lb., and}$$

$$\text{Preload stress} = F_a \,/\, \text{Stress Area} = 3{,}840/0.142 = 27{,}042 \text{ psi.} < 45{,}000 \text{ psi. … o.k.}$$

Compressive Stress in Standoffs due to Tie Rod Nut Preload

The cross sectional area of a single standoff is,

$$A = \pi/4 \times (0.875^2 - 0.5625^2) = 0.3528 \text{ in.}^2$$

Therefore, the maximum compressive stress, σ_{cp}, generated in the standoffs by the maximum tie rod nut preload is,

$$\sigma_{cn} = \frac{F_a}{A} = \frac{3{,}840}{0.3528} = 10{,}884 \text{ psi.} < 45{,}000 \text{ psi. ... o.k.}$$

Tensile Stress in Tie Rods due to Tie Rod Nut Preload

The critical cross sectional area of the tie rod is located in the thread region, and is, $A_t = 0.142$ in^2.

Therefore the maximum tensile stress, σ_{cp}, generated in the tie rods by the maximum tie rod nut preload is,

$$\sigma_{cn} = \frac{F_a}{A} = \frac{3{,}360}{0.142} = 23{,}662 \text{ psi.} < 45{,}000 \text{ psi. ... o.k.}$$

As per reference 2, Section F-1334, for accident conditions (Level D), the allowable axial buckling stress, F_a, can be increased by the following factor.

Since $S_u > 1.2\ S_y$ (135.00 ksi. > 114.06 ksi.), F_a can be increased by,

$$\text{Lesser of } \{\ 2 \text{ or } 1.167\ S_u\ /\ S_y\ \} = 1.657.$$

Therefore, for accident conditions,

$$F_a = 28{,}036 \times 1.657 = 46{,}456 \text{ psi.}$$

For normal conditions, the maximum compressive stress in the standoffs is generated by the maximum bolt preload, which is,

Max. Normal Condition Stress = 10,884 psi. < 28,036 psi. ... o.k.

For accident conditions, the maximum compressive stress in the standoffs is generated by the accident condition 60° corner drop stress, which is,

Max. Accident Condition Stress = 34,014 psi. < 46,456 psi. ... o.k.

B) Support Disc (Appendix 1.4, Drawing 3044-70-7, Items 17A, 17B, and 17B)

Bearing Stress

The maximum bearing stress applied to the Oak Ridge support disc by the standoff is equal to the maximum compressive stress generated in the top standoff. Therefore, for normal conditions, the maximum bearing stress, σ_{bn}, is,

$$\sigma_{bn} = 10{,}884 \text{ psi.} < 23{,}750 \text{ psi. ... o.k.}$$

The maximum bearing stress, σ_{ba}, during an accident conditions is,

$$\sigma_{ba} = 34{,}014 \text{ psi.} < 68{,}500 \text{ psi. ... o.k.}$$

Buckling and Stress Analysis

The support disc buckling and stress analysis is performed using finite element analysis presented in appendix 2.11.3.

Conservatively take $V = 1{,}100$ lb. The total weld area available to take the shear force, A_v, is,

$A_v =$ [0.06 in. thick fillet weld × sin(45°) throat length × 9.14 weld perimeter length] × 5 legs = 1.939 in.^{2}

Therefore the shear stress, τ_n, in the top and bottom plates is,

$$\tau_n = \frac{V}{A_v} = \frac{1{,}100}{1.939} = 567 \text{ psi.} < 12{,}000 \text{ psi. ... o.k.}$$

Under accident conditions (80 g side drop), the shear stress, τ_a, in the top and bottom plates is,

$$\tau_a = 567 \times (80 / 20) = 2{,}268 \text{ psi.} < 28{,}770 \text{ psi. ... o.k.}$$

F) Tie Rods (Appendix 1.4, Drawing 3044-70-8, Item 19)

Shear Stress

The reaction force of the tie rods supports the inertial load of the poison plates, poison enclosure, standoffs, and the tie rod itself during a side drop event. Conservatively assume that the inertial load of the entire poison plate enclosure, with poison plates, (F_3 – see Figure 2.11.1-3), is reacted by the shear force in two tie rods (there are a total of five tie rods). The inertial load of two standoffs and the two sections of the tie rods themselves also contribute to the applied shear force. The shear stress in the tie rods occurs in the region near the support discs. The applied shear force in the tie rods during normal conditions (20 g side drop), V, is,

$V =$ [(194 / 9 lb. weight of 10 poison plates) + (285 / 9 lb. weight of 1 poison enclosure) + (112 × 2/45 lb. weight of two standoffs) + (61 × 20.21/189.63 × 2/5 lb. weight of two tie rod sections)] × 20 gs = 1,216 lb.

Conservatively take $V = 1{,}250$ lb. The area available to take the shear force, A_v, is,

$A_v = [(\pi/4) \times 0.50^2$ in.^{2} tie rod cross sectional area] × 2 tie rods × 2 two ends = 0.785 in.^{2}

Therefore, the shear stress, τ_n, in the tie rods is,

$$\tau_n = \frac{V}{A_v} = \frac{1{,}250}{0.785} = 1{,}592 \text{ psi.} < 27{,}000 \text{ psi. ... o.k.}$$

Under accident conditions (80 g side drop) the shear stress, τ_a, in the tie rods is,

$$\tau_a = 1{,}592 \times (80 / 20) = 6{,}369 \text{ psi.} < 56{,}700 \text{ psi. ... o.k.}$$

Bending Stress

The maximum bending stress generated in the tie rod and standoff is calculated by applying the maximum weight of a 20.21 in. length of a tie rod plus one standoff as a uniform load on the tie rod section and standoff supported between two adjacent support discs. The inertial load of the poison enclosure and poison plates is reacted at the ends of the tie rod section (near the spacer discs). Consequently, the inertial load of the poison enclosures and poison plates do not generate a significant bending moment or bending stress in the tie rod. The end conditions of the tie rod section are conservatively assumed to be pinned. The weights of the tie rod section and standoff are conservatively taken to be the maximum dimension weight given in Section 2.2.

Under normal conditions, (20 g side drop), the applied load, P, is,

P =[(61 × (1/5) × (20.21/189.63) lb. weight of 20.21 in length of tie rod) + (112 × (1/45) lb. weight of 1 standoff)] × 20 gs = 75.8 lb.

Conservatively take P = 80 lb. The corresponding moment, M, in the tie rod section is,

$$M = \frac{PL}{8} = \frac{80 \times 20.21}{8} = 202.1 \text{ in. lb.}$$

Where, L is the length of the tie rod section. The moment of inertia of the tie rod section and standoff, I, is,

$$I = \frac{\pi}{64}\left(0.50^4 + 0.875^4 - 0.5625^4\right) = 0.02693 \text{ in.}^4$$

Therefore, the bending stress, σ_{bnt}, generated in the tie rod section during a 20 g normal condition side drop is,

$$\sigma_{bnt} = \frac{Mc}{I} = \frac{202.1 \times 0.25}{.02693} = 1{,}876 \text{ psi.} < 67{,}500 \text{ psi. ... o.k.}$$

Where c is the maximum distance from the tie rod axis to its outer radius. Under accident conditions (80 g side drop) the bending stress, σ_{bat}, in the fuel compartment is,

$$\sigma_{bat} = 1{,}876 \times (80 / 20) = 7{,}505 \text{ psi.} < 135{,}000 \text{ psi. ... o.k.}$$

The maximum bending stress, σ_{bns}, generated in the standoff during a 20 g normal condition side drop is,

$$\sigma_{bns} = \frac{Mc}{I} = \frac{202.1 \times 0.4375}{.02693} = 3{,}283 \text{ psi.} < 67{,}500 \text{ psi. ... o.k.}$$

Where c is the maximum distance from the standoff axis to its outer radius. Under accident conditions (80 g side drop) the bending stress, σ_{bas}, in the standoff is,

$$\sigma_{bas} = 3{,}283 \times (80 / 20) = 13{,}133 \text{ psi.} < 135{,}000 \text{ psi. ... o.k.}$$

Tensile Stress

During an end drop, the compressive load generated by the inertial force of the fuel basket is reacted by the standoffs. However, immediately after an end drop impact, a rebound occurs, which could potentially generate a tensile inertial load in the basket. This tensile load must be reacted by the tie rods. Consequently, the tie rods are conservatively evaluated for tensile inertial loads equivalent to the inertial compressive loads taken by the standoffs.

The critical cross sectional area of the tie rod is located in the thread region, and is, $A_t = 0.142$ in^2.

Since the normal condition applied loads do not exceed the tie rod nut preload, the maximum tensile force in the tie rods is generated by the maximum tie rod nut preload, which is 3,840 lb. The maximum tensile stress in the tie rods, σ_{tnt}, is,

$$\sigma_{tnt} = \frac{3{,}840}{0.142} = 27{,}042 \text{ psi.} < 45{,}000 \text{ psi.}$$

For hypothetical accident conditions, the maximum axial g load is generated by a 30 foot, 60° corner drop. The maximum compressive force in the standoffs during a 30 foot, 60° corner drop is 12,000 lb. Therefore, the maximum tensile stress in the tie rods, σ_{tnt}, is,

$$\sigma_{tnt} = \frac{12{,}000}{0.142} = 84{,}507 \text{ psi.} < 94{,}500 \text{ psi.}$$

Stress Intensity

For normal conditions, the maximum stress intensity generated in the tie rods is conservatively computed by combining the shear and bending stresses resulting from the 1 foot side drop event, with the tensile stresses resulting from the maximum tie rod preload. The tie rod stress intensity, $S.I._n$, is

$$S.I._n = \sqrt{\sigma^2 + 4\tau^2} = \sqrt{(1{,}876 + 27{,}042)^2 + 4(1{,}592^2)} = 29{,}093 \text{ psi.} < 67{,}500 \text{ psi. ... o.k.}$$

For hypothetical accident conditions, the maximum stress intensity generated in the tie rods is conservatively computed by combining the shear and bending stresses resulting from the 30 foot side drop event, with the tensile stresses resulting from the 30 foot 60° corner drop. The tie rod stress intensity, $S.I._a$, is

$$S.I._a = \sqrt{\sigma^2 + 4\tau^2} = \sqrt{(7{,}505 + 84{,}507)^2 + 4(6{,}369^2)} = 92{,}890 \text{ psi.} < 135{,}000 \text{ psi. ... o.k.}$$

Shear Stress in Tie Rod, and Tie Rod Nut Threads

The maximum shear stresses generated in the tie rod and tie rod nut threads are caused by the maximum tensile load in the tie rods. For normal conditions, this tensile load is, 3,840 lb., and for accident conditions, this tensile load is 12,000 lb.

From Reference 7, the available shear area on the external and internal threads, A_s and A_n, respectively, are the following.

$$A_s = \text{shear area of external threads} = 3.1416\, nL_e K_{n\,max} [1/(2n) + .57735\, (E_{s\,min} - K_{n\,max})]$$

$$A_n = \text{shear area of internal threads} = 3.1416\, nL_e D_{s\,min} [1/(2n) + .57735(D_{s\,min} - E_{n\,max})]$$

For a 1/2 13UNC tie rod,

$K_{n\,max}$ = maximum minor diameter of internal threads = 0.434 in., [7].
$E_{s\,min}$ = minimum pitch diameter of external threads = 0.4435 in., [7].
$D_{s\,min}$ = minimum major diameter of external threads = 0.4876 in., [7].
$E_{n\,max}$ = maximum pitch diameter of internal threads = 0.4565 in., [7].
L_e = thread engagement length (tie rod nut thickness) = 0.4375 in. [7].

Therefore,

$$A_s = 3.1416(13)(0.4375)(0.434)[1/(2\times13) + .57735\, (0.4435 - 0.434)] = 0.341 \text{ in.}^2$$

$$A_n = 3.1416(13)(0.4375)(0.4876)[1/(2\times13) + .57735\, (0.4876 - 0.4565)] = 0.492 \text{ in.}^2$$

The tie rod nuts are constructed from XM19 stainless steel, which has $S_m = 32.3$ ksi. and $S_u = 96.8$ ksi. [1]. Therefore the normal and accident condition allowable shear stresses for the tie rod nuts are $0.6S_m = 19.38$ ksi. and $0.42S_u = 40.66$ ksi. respectively. The normal condition shear stress in the internal and external threads, τ_s, and τ_n, respectively, is,

$$\tau_s = \frac{3{,}840}{0.341} = 11{,}261 \text{ psi.} < 19{,}380 \text{ psi}$$

$$\tau_n = \frac{3{,}840}{0.492} = 7{,}805 \text{ psi.} < 27{,}000 \text{ psi}$$

The accident condition shear stress in the internal and external threads, τ_s, and τ_n, respectively, is,

$$\tau_s = \frac{12{,}000}{0.341} = 35{,}212 \text{ psi.} < 40{,}660 \text{ psi}$$

$$\tau_n = \frac{12{,}000}{0.492} = 24{,}413 \text{ psi.} < 56{,}700 \text{ psi}$$

G) Thermal Stresses

Since the structural components of the TN-FSV Basket are all constructed from either SA-240 type 304 stainless steel or SA-564, type 630, condition H1150 stainless steel, having very similar coefficients of thermal expansion, the container thermal stresses are negligible. The following average accident condition component temperatures (Chapter 3, Table 3-2) and coefficients of thermal expansion (Ref. 1) are used to compute the maximum component thermal expansions.

Component	Average accident condition temperature (F)	Coefficient of thermal expansion (in. in.$^{-1}$ °F^{-1})
Oak Ridge Container wall (Type 304 SST)	254	8.91×10^{-6}
Support Discs, Poison Enclosures, and Fuel Compartments (Type 304 SST)	266	8.93×10^{-6}
Tie Rods and Standoffs (SA-564, Type 630)	266	5.90×10^{-6}
Poison Plates (Borated Aluminum)	266	13.12×10^{-6}
Oak Ridge Canisters (Type 304 SST)	266	8.93×10^{-6}
Peach Bottom Canisters (Alloy 6061 Aluminum)	266	13.12×10^{-6}

Fuel Basket

The difference in axial thermal expansion between the poison plate enclosure (SA-240, type 304) and the standoffs (SA-564, type 630) due to a maximum accident condition temperature change of 196° F (266° F - 70° F) is,

Thermal expansion of standoffs = 20.21 in. × 196° F × 5.90×10^{-6} in./in. °F^{-1} = 0.0234 in.

Thermal expansion of poison enclosure = 20.15 in. ×196° F × 8.93×10^{-6} in./in. °F^{-1} = 0.0353 in.

Difference in thermal expansion = 0.0353 in. – 0.0234 in. = 0.0119 in.

A maximum thermal expansion difference of 0.0119 in. between the poison plate enclosure and the standoffs will not generate a compressive load in the poison enclosure because of the small axial gap (0.020 in., including worst case tolerances) between the poison enclosure and the support discs.

The difference in axial thermal expansion between the poison plates (borated aluminum) and the poison plate enclosures (SA-240, Type 304) due to a maximum accident condition temperature change of 196° F is,

Thermal expansion of poison plates = 20.12 in. × 196° F × 13.12×10^{-6} in./in. °F^{-1} = 0.0517 in.

Thermal expansion of poison enclosure = 20.15 in. × 196° F × 8.93×10^{-6} in./in. °F^{-1} = 0.0353 in.

Difference in thermal expansion = 0.0517 in. – 0.0353 in. = 0.0164 in.

A maximum thermal expansion difference of 0.0164 in. between the poison plates and the poison enclosure will not generate a compressive load in the poison plates, because of the small axial gap (0.028 in., including worst case tolerances) between the poison enclosure and the support discs.

Payload

The difference in axial thermal expansion between the Oak Ridge Container cavity length and the container's contents (Fuel Basket and Fuel Assemblies) is bounded by the difference in the thermal expansion between the container cavity and the fuel assembly configuration that includes one Peach Bottom Canister and one Oak Ridge Canister. This is because the Peach Bottom Canister is constructed from aluminum alloy 6061.

The axial thermal expansion of the fuel assembly configuration that includes one Peach Bottom Canister and one Oak Ridge Canister due to a maximum accident condition temperature change of 196° F (266° F - 70° F) is,

Thermal expansion of Peach Bottom Canister $= 153 \text{ in.} \times 196° \text{ F} \times 13.12\times10^{-6} \text{ in./in. °F}^{-1}$
$= 0.3934$ in.

Thermal expansion of Oak Ridge Canister $= 34.75 \text{ in.} \times 196° \text{ F} \times 8.93\times10^{-6} \text{ in./in. °F}^{-1} =$
0.0608 in.

Total fuel assembly configuration thermal expansion = 0.3934 in.+0.0608 in. = 0.4542 in.

The axial thermal expansion of the Oak Ridge Container cavity (Type 304 SST) due to a maximum accident condition temperature change of 184° F (254° F - 70° F) is,

Thermal expansion of container cavity $= 188.00 \text{ in.} \times 184° \text{ F} \times 8.91\times10^{-6} \text{ in./in. °F}^{-1} =$
0.3082 in.

Difference in thermal expansion = 0.4542 in. – 0.3082 in. = 0.1461 in.

A maximum thermal expansion difference of 0.1461 in. between the poison plates and the poison enclosure will not generate a compressive load in the poison plates, because of the axial gap (0.18 in., including worst case tolerances) between the poison enclosure and the support discs.

2.11.1.3 Results

The following tables summarize the maximum calculated and allowable stresses generated in the Oak Ridge SNF Container Fuel Basket during all normal and accident condition events.

Summary of Calculated and Allowable Stress in TN-FSV Container Standoffs, Support Disc, and Fuel Compartments

Component	Applied Load	Stress Category	Stress Intensity (ksi.)	Allowable Stress (ksi.)
Standoffs	Maximum Preload (Normal conditions)	Compression	10.88	45.00
		Buckling	10.88	28.04
	60° Corner drop (Accident conditions)	Compression	34.01	94.50
		Buckling	34.01	46.46
Support discs	16 *g* End drop (Normal conditions)	Bearing	11.53	23.75
	60 *g* End drop (Accident conditions)	Bearing	38.46	68.50
Fuel compartment	16 *g* End drop (Normal conditions)	Compression	1.04	20.00
		Buckling	1.04	5.87
	60 *g* End drop (Accident conditions)	Compression	3.89	47.95
		Buckling	3.89	11.74
	20 *g* Side drop (Normal conditions)	Bending	0.83	20.00
	80 *g* Side drop (Accident conditions)	Bending	3.34	47.95

Summary of Calculated and Allowable Stress in TN-FSV Container Flux Traps, Tie Rods

Component	Applied Load	Stress Category	Stress Intensity (ksi.)	Allowable Stress (ksi.)
Flux Traps	16 *g* End drop (Normal conditions)	Compression	2.52	20.00
		Buckling	2.52	10.67
	60 *g* End drop (Accident conditions)	Compression	9.46	47.95
		Buckling	9.46	21.33
Flux Trap Welds	16 *g* End drop (Normal conditions)	Compression	4.98	20.00
	60 *g* End drop (Accident conditions)	Compression	18.67	47.95
Flux Trap Bottom Plate	16 *g* End drop (Normal conditions)	Bending	0.16	30.00
	60 *g* End drop (Accident conditions)	Bending	0.59	68.50
Tie Rods	Maximum Preload (Normal conditions)	Stress Intensity	29.09	67.50
	60° Corner drop (Accident conditions)	Stress Intensity	92.89	135.00

Summary of Calculated and Allowable Stress in TN-FSV Container Poison Enclosure

Component	Applied Load	Stress Category	Stress Intensity (ksi.)	Allowable Stress (ksi.)
3.268 in. wide plate	20 *g* Side drop (Normal conditions)	Bending	2.23	20.00
	80 *g* Side drop (Accident conditions)	Bending	8.93	47.95
Top and bottom support plates	20 *g* Side drop (Normal conditions)	Compression	2.68	20.00
		Buckling	2.68	10.13
	80 *g* Side drop (Accident conditions)	Compression	10.73	47.95
		Buckling	10.73	20.25
Top / bottom support plate welds	20 *g* Side drop (Normal conditions)	Shear	0.57	12.00
	80 *g* Side drop (Accident conditions)	Shear	2.27	28.77
Inner and outer braces	20 *g* Side drop (Normal conditions)	Bending	4.27	20.00
	80 *g* Side drop (Accident conditions)	Bending	17.08	47.95
Outer Brace Weld	20 *g* Side drop (Normal conditions)	Shear	0.57	12.00
	80 *g* Side drop (Accident conditions)	Shear	2.27	28.77

2.11.1.4 Conclusions

From the above tables, it can be seen that all of the stresses generated in the Oak Ridge SNF Container Fuel Basket are less than their corresponding allowable stresses.

APPENDIX 2.11.2

TABLE OF CONTENTS

Page

LIST OF FIGURES

Compressive Stress:

The compressive stress at the intersection of the bottom plate and the container shell is taken to be the total force acting on the bottom plate, W, divided by the cross sectional area of the container shell, $A = 7.089$ in.^{2}. Therefore,

For normal conditions,

$$P_m = \frac{W}{A} = \frac{1{,}115}{7.089} = 157.3 \text{ psi.} < 20{,}000 \text{ psi. ... o.k.}$$

The combined membrane and bending stress is,

$$P_m + P_b = 157.3 \text{ psi.} + 266.2 \text{ psi.} = 423.5 \text{ psi.} < 30{,}000 \text{ psi. ... o.k.}$$

For accident conditions,

$$P_m = 157.3 \text{ psi.} \times (10 \text{ psi.} / 5 \text{ psi.}) = 314.6 \text{ psi.} < 47{,}950 \text{ psi. ... o.k.}$$

$$P_m + P_b = 314.6 \text{ psi.} + 532.4 \text{ psi.} = 847.0 \text{ psi.} < 68{,}500 \text{ psi. ... o.k.}$$

Stresses due to 30 foot bottom end drop:

During an end drop event, the inertial loads of the container internals and the container shell are applied to the bottom plate. The stresses generated by these loads are computed in this section.

A two-dimensional finite element model of the container bottom plate is used to perform the analysis. The model consists of the container bottom plate and a small section of the container outer shell. The model was constructed entirely from PLANE42 elements, with the axisymmetric key option turned on.

The entire bottom surface of the bottom plate is supported in the axial direction in order to simulate the support provided by the TN-FSV Cask during a bottom end drop. The inertial load of the container shell and lid is simulated by applying an equivalent pressure to the small section of the container shell. The inertial load of the container internals is simulated by applying an equivalent uniform pressure to the inside surface of the bottom plate. Figure 2.11.2-1 is a plot of the finite element model with the applied boundary conditions and loads.

From Section 2.11.2.2 A, the maximum axial force generated by the inertial load of the container shell and lid is 61,680 lb. Therefore, the equivalent pressure applied to the bottom plate at the intersection of the outer shell, P_1, is,

$$P_1 = \frac{61{,}680}{\frac{\pi}{4}\left(16.85^2 - 16.58^2\right)} = 8{,}700.7\,\text{psi.}$$

The inertial load applied to the bottom plate, by the container internals during a 60g end drop is,

60g × [4,761 lb. (Oak Ridge Container) – 334 lb. (spacer sleeve) – 540 lb. (container shell) – 488 lb. (lid and lid bolts)] = 203,940 lb.

Therefore, the equivalent pressure applied to the container bottom plate by the container internals, P_2, is,

$$P_1 = \frac{203{,}940}{\frac{\pi}{4}\left(16.58^2\right)} = 944.59\,\text{psi.}$$

Figure 2.11.2-2 shows the stress intensity distribution computed by ANSYS. The maximum stress intensity in the container bottom plate is 9,619 psi., which is much less than the accident condition membrane stress allowable of 47,950 psi. This accident condition stress intensity is also less than the normal condition membrane allowable stress of 20,000 psi.

C) Thermal Stress Analysis

Since the container shell, flange, bottom and lid are all constructed from SA-240 type 304 stainless steel, there will be very little stresses generated by thermal expansion. Stresses generated in the closure lid bolts by thermal expansion are analyzed in Appendix 2.11.4.

The TN-FSV cask is also fabricated from Type 304 stainless steel. Consequently, the Oak Ridge Container and the TN-FSV cask body expand at the same rate. No Interference between the Oak Ridge Container and the TN-FSV cask body occurs.

2.11.2.3 Results

The following table summarizes the applied and allowable stresses generated in the Oak Ridge Container during all conceivable normal and accident condition events.

Summary of Calculated and Allowable Stress in the Oak Ridge Container Shell

Component	Applied Load	Stress Category	Stress Intensity (ksi.)	Allowable Stress (ksi.)
Container shell	16 g End drop (Normal conditions)	Compression	2.32	20.00
		Buckling	2.32	9.37
	60 g End drop (Accident conditions)	Compression	8.70	47.95
		Buckling	8.70	18.74
	5 psi. internal & external pressure (Normal conditions)	Hoop	0.31	20.00
		Buckling	0.31	0.88
	10 psi. internal & external pressure (Accident conditions)	Hoop	0.62	47.95
		Buckling	0.62	1.32
Container bottom plate	5 psi. internal & external pressure (Normal conditions)	Compression	0.16	20.00
		Bending + Compression	0.42	30.00
	10 psi. internal & external pressure (Accident conditions)	Compression	0.31	47.95
		Bending + Compression	0.85	68.50
	60 g End Drop (Accident conditions)	Stress Intensity	9.62	47.95*

*The stress intensity from the finite element analysis is conservatively compared to the membrane stress intensity allowable.

2.11.2.4 Conclusions

From the above table, it can be seen that all of the stresses generated in the Oak Ridge Container shell are less than their corresponding allowable stresses.

**Figure 2.11.2-1
Oak Ridge Container, Container Bottom Plate Finite Element Model, with Boundary Conditions**

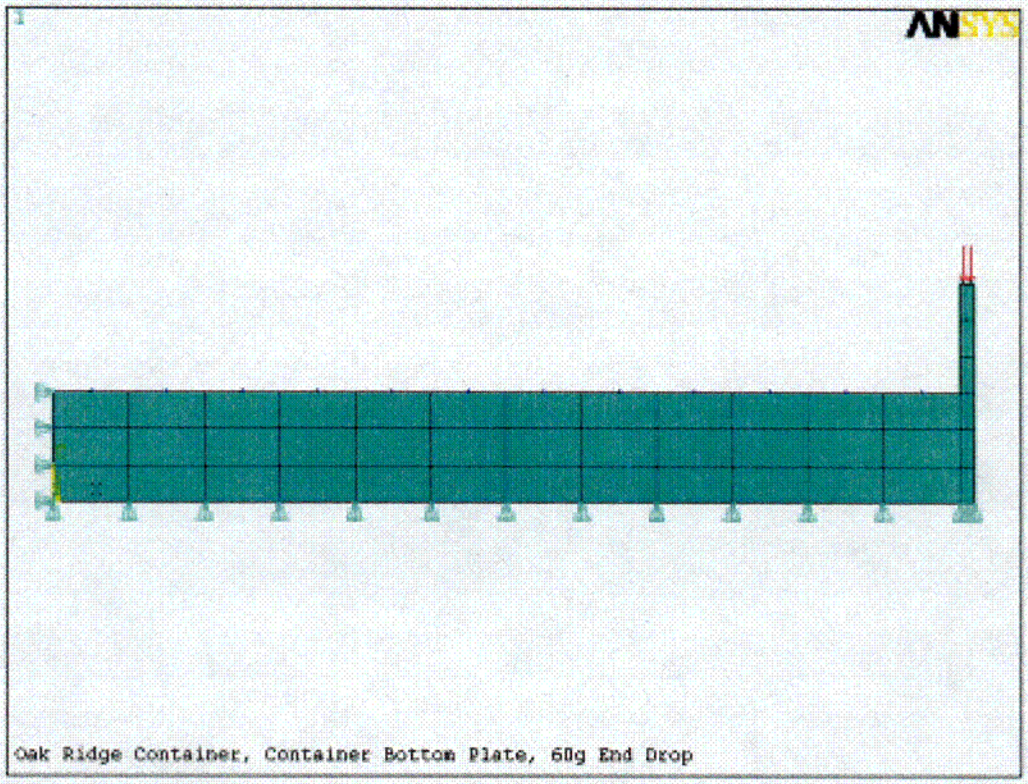

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Figure 2.11.2-2
Oak Ridge Container, Container Bottom Plate Finite Stress Intensity, due to 60g Bottom End Drop

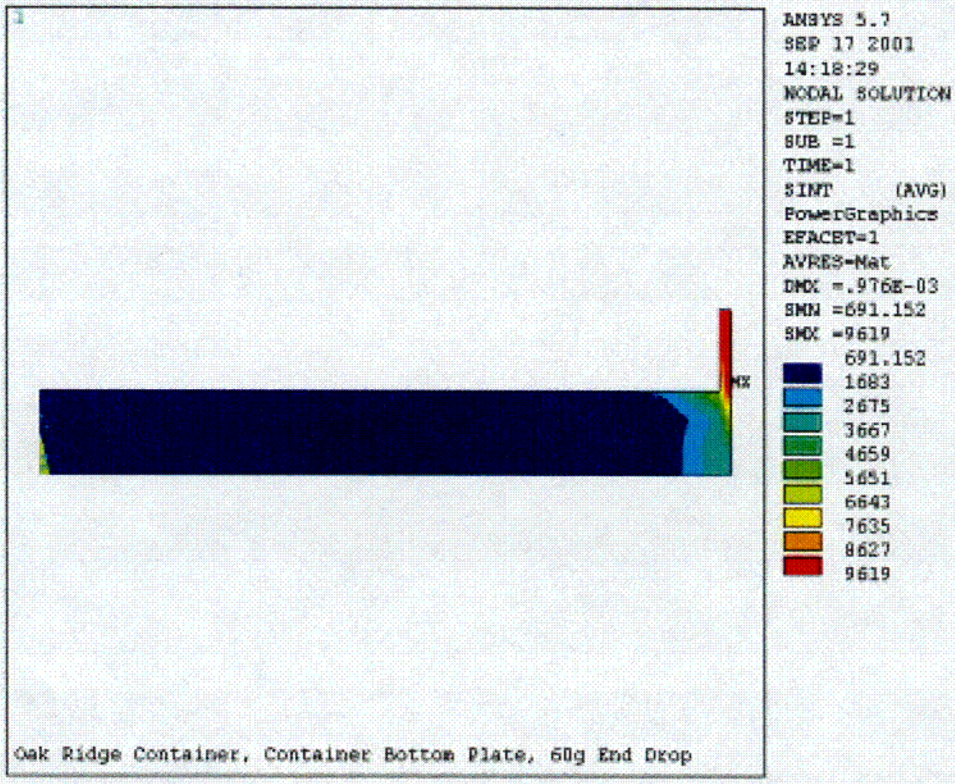

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TABLE 2.11.3-1

SUMMARY OF NORMAL CONDITION STRESS ANALYSIS

Drop Orientation	Component	Stress Category	Stress Intensity (ksi)	Allowable Stress (ksi)
End Drop (16 g)	Support Disc	P_m	0.0	20.0
		$P_m + P_b$	5.15	30.0
0° Side Drop (20 g)	Support Disc	P_m	11.47	20.0
		$P_m + P_b$	11.97	30.0
	Container Shell	P_m	10.04	20.0
		$P_m + P_b$	11.21	30.0
36° Side Drop (20 g)	Support Disc	P_m	13.76	20.0
		$P_m + P_b$	29.45	30.0
	Container Shell	P_m	5.70	20.0
		$P_m + P_b$	11.69	30.0

TABLE 2.11.3-2

SUMMARY OF ACCIDENT CONDITION STRESS ANALYSIS

Drop Orientation	Component	Stress Category	Stress Intensity (ksi)	Allowable Stress (ksi)
End Drop (60 g)	Support Disc	P_m	0.0	47.95
		$P_m + P_b$	19.32	68.4
0° Side Drop (80 g)	Support Disc	P_m	29.50	47.95
		$P_m + P_b$	29.78	61.65
	Container Shell	P_m	6.38	47.95
		$P_m + P_b$	27.40	61.65
36° Side Drop (80 g)	Support Disc	P_m	10.74	47.95
		$P_m + P_b$	33.31	61.65
	Container Shell	P_m	24.03	47.95
		$P_m + P_b$	29.48	61.65

APPENDIX 2.11.4

OAK RIDGE SNF CONTAINER LID BOLT ANALYSIS

2.11.4.1 Introduction

This appendix analyzes the ability of the Oak Ridge SNF Container closure to maintain a leak tight seal under normal and accident conditions. Also evaluated in this section, are the bolt thread and internal thread stresses, and container lid bolt fatigue. The stress analysis is performed in accordance with NUREG/CR-6007[1].

The Oak Ridge SNF Container lid closure arrangement is shown in Figure 2.11.4-1 (page 2.11.4-25). The 7.00 inch thick lid is bolted directly to the end of the container shell flange by 12, 1/2 inch diameter high strength steel bolts. Close fitting alignment pins ensure that the lid is centered in the container.

The lid bolt is shown in Figure 2.11.4-2 (page 2.11.4-26). The bolt material is SA-453, Type 651 or Type 660, class A. The yield and ultimate stresses of SA-453, Type 651 is 70 ksi. and 100 ksi. respectively, and the yield and ultimate stresses of SA-453 Type 660 is 85 and 130 ksi. respectively[2]. Also, the coefficient of thermal expansion for SA-453 Type 660 is very similar to that of the lid and flange material (Type 304 stainless steel)[2]; therefore, the material properties for SA-453 Type 651 are conservatively used for the lid bolt analysis.

The following ways to minimize bolt forces and bolt failures for shipping casks are taken directly from with NUREG/CR-6007[1], page xiii. All of the following design methods are employed in the Oak Ridge SNF Container closure system.

- Protect closure lid from direct impact to minimize bolt forces generated by free drops. (use impact limiters)
- Use materials with similar thermal properties for the closure bolts, the lid, and the cask wall to minimize the bolt forces generated by fire accident
- Apply sufficiently large bolt preload to minimize fatigue and loosening of the bolts by vibration.
- Lubricate bolt threads to reduce required preload torque and to increase the predictability of the achieved preload.
- Use closure lid design which minimizes the prying actions of applied loads.
- When choosing a bolt preload, pay special attention to the interactions between the preload and thermal load and between the preload and the prying action.

2.11.4.10 References

1 Stress Analysis of Closure Bolts for Shipping Cask, NUREG/CR-6007, 1992.

2 American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section II, Part D, 1998.

3 Machinery Handbook, 21st Ed, Industrial Press, 1979.

4 Draft American Standard, Design Basis for Resistance to Shock and Vibration of Radioactive Material Packages Greater than One Ton in Truck Transport, ANSI N14.23, 1980

5 Leakage Tests on Packages for Shipment for, Radioactive Materials, ANSI N14.5, 1997

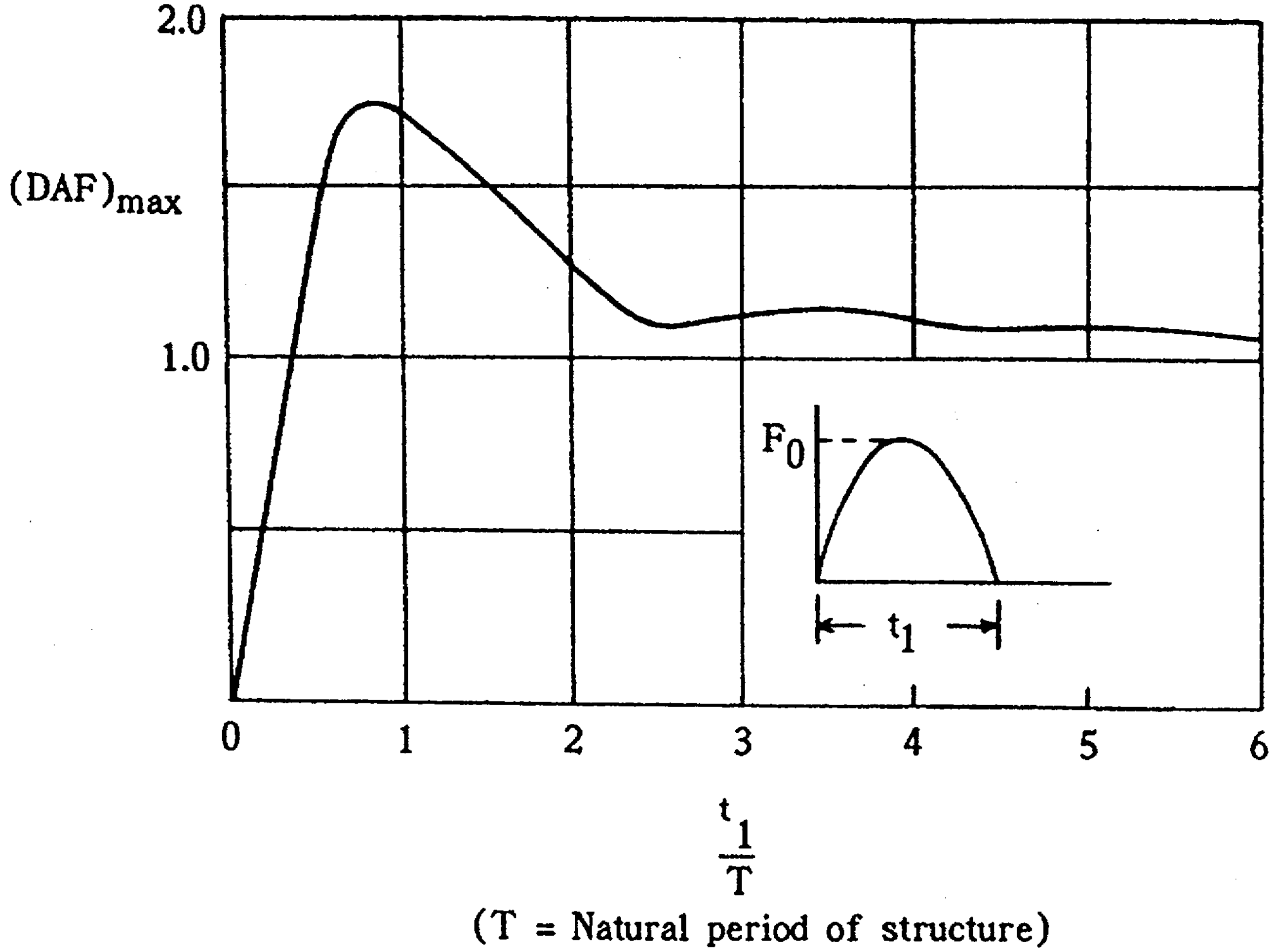
6 American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code Section III, Division 1, Appendix, 1998.

7 Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels, U. S. Nuclear Regulatory Commission, Regulatory Guide 7.6, Revision 1, March 1978.

8 Parker O-Ring Handbook, Parker Seals, 1992.

9 Baumeister, T., Marks, L. S., Standard Handbook for Mechanical Engineers, 7th Edition, McGraw-Hill, 1967.

FIGURE 2.11.6-1
DYNAMIC LOAD FACTOR FOR HALF SINE WAVE



2.11.7.4 Stress Analysis Results

The following table summarize the maximum calculated and allowable stresses generated in the Oak Ridge canister during all applicable normal and accident condition events.

Summary of Calculated and Allowable Stress in Oak Ridge Canister

Component	Applied Load	Stress Category	Stress Intensity (ksi.)	Allowable Stress (ksi.)
Canister Shell	16 *g* End drop (Normal conditions)	Compression	4.07	20.00
	60 *g* End drop (Accident conditions)	Compression	15.27	47.08
	20 *g* Side drop (Normal conditions)	Membrane	8.32	20.00
		Membrane + Bending	21.82	30.00
	80 *g* Side drop (Accident conditions)	Membrane	27.50	47.08
		Membrane + Bending	33.06	60.53
Cap Weldment	16 *g* End drop (Normal conditions)	Compression	7.02	20.00
	60 *g* End drop (Accident conditions)	Compression	26.33	47.08

From Section 2.11.7.3C, the cap weldment will not buckle during the 60g end drop, since the allowable axial impact load is 62 gs, which is greater than the maximum accident condition impact load of 60 gs. Likewise, from Section 2.11.7.3C, the canister shell will not buckle during the 60g end drop, since the plastic amplified stress (754.61 ksi) is less than the allowable buckling stress (851.44 ksi)

Administrative controls prevent the loading of canisters with a total heat load greater than 7 watts in the axial cross-section directly below the ORC lid. Heat fluxes are applied to the bottom surface of the ORC lid such that the reaction solution is equal to 7 watts (one fifth of the 35 watts maximum for the cross-section beneath the lid). The 166 °F maximum inner shell temperature from the TN-FSV SAR is applied as an isothermal condition to the nodes corresponding to the inner surface of the cask at the lid/drain seals. Due to a large thermal resistance in the axial direction, the majority of heat transfer will take place radially. This effect is complemented by the horizontal orientation of the packaging. Applying a heat load of 35 watts as a heat flux directly into the lid bounds the temperature effects of both the cross-section directly adjacent to the lid and the other fuel canisters. The applied boundary conditions on this model are shown in Figure 3-9.

To bound the heat conductance uncertainty between components of the model, the following gaps at thermal equilibrium are assumed:

a) 0.0100 in. axial gap between the ORC lid and the container.
b) 0.0625 in. axial gap between the ORC and the TN-FSV cask body.
c) 0.0205 in. radial gap between the ORC lid and the ORC.

Radiation heat transfer across the above gaps was conservatively neglected to achieve the bounding seal temperature. The temperature distribution in the model is shown in Figure 3-10. Figure 3-11 shows the temperature distribution in the lid region.

3.4.1.3 Support Disc Thermal Model

A finite element model is created to determine the steady-state temperature distribution within the support discs of the Oak Ridge Container. This temperature distribution is used in Chapter 2 for the determination of the thermal stresses. The finite element model includes the support disc, ORC wall, fill gas, and the air gap between the cask inner shell and the fuel storage container.

The model includes heat transfer via conduction and radiation between the ORC wall and TN-FSV cask cavity wall. The support disc, fill gas, and ORC wall are modeled using 2-D PLANE55 thermal solid elements. 2-D LINK32 elements are used on the outside of the appropriate surfaces for the creation of the radiation super-element using the /AUX12 processor within ANSYS. All LINK32 elements were used only during the super-element formulation phase (/AUX12), and were deleted from the model prior to solution phase. The ANSYS finite element model is shown in Figure 3-12.

All boundary conditions used in the model are identical to those used in the Oak Ridge Container cross section model. The temperature distribution in the support disc of the finite element model is shown in Figure 3-13.

3.4.2 Maximum Temperatures

The Oak Ridge Container cross section model maximum temperature distribution is shown in Figure 3-4. A summary of the results is located in Table 3-1. During normal conditions, the maximum fuel compartment temperature is 246°F, a 79°F temperature difference from the model periphery. The maximum ORC wall temperature is 201°F, a 34°F temperature difference from the model periphery.

The Oak Ridge Container seal region model maximum temperature distribution is shown in Figure 3-10 and Figure 3-11. A summary of the results is located in Table 3-1. During normal conditions, the maximum seal temperature is 206°F, a 40°F temperature difference from the model periphery.

The average cavity gas temperatures in the ORC and the cask cavity are 188°F and 172°F respectively during normal conditions of transport.

The average temperature distribution is shown in Figure 3-6. Results from the model are tabulated in Table 3-2.

3.4.3 Minimum Temperatures

Under the minimum temperature condition of –40°F ambient, the resulting packaging component temperatures will approach –40°F at equilibrium. Since the packaging materials, including the Oak Ridge Container, continue to function at this temperature, the minimum temperature condition has no adverse affect on the performance of the ORC.

3.4.4 Maximum Internal Pressures

The maximum internal pressure is calculated in Chapter 4, assuming the ORC and cask are closed and sealed at 70°F and 1 atm. The average cavity gas temperature is 188°F under normal conditions of transport and is reported in Table 3-2.

3.4.5 Maximum Thermal Stresses

The maximum thermal stresses during normal conditions of transport are calculated in Chapter 2.

3.4.6 Evaluation of Package Performance for Normal Conditions of Transport

The thermal analysis for normal conditions of transport concludes that the Oak Ridge Container design meets all applicable requirements. The maximum temperatures calculated using conservative assumptions are all below identified upper limits. The maximum seal temperature (206°F) during normal transport is well below the 250°F specified limit.

3.5 Hypothetical Accident Thermal Conditions

3.5.1 Package Temperatures

During hypothetical accident conditions, the maximum cavity wall temperature increases to 245 °F as reported in TN-FSV SAR. This is 78 °F hotter than the cavity wall temperature of 167 °F that occurs during normal conditions of transport. Component temperatures within the Oak Ridge Container during accident conditions are determined by increasing the temperatures during normal conditions by the 78 °F temperature difference experienced by the cavity wall.

The maximum ORC temperature during accident conditions is 324°F. The Oak Ridge canister maximum temperature is 349°F. The peak ORC wall temperature is 279°F. As concluded in Section 3.4.2, the maximum seal temperature is 40°F higher than the maximum wall temperature in the seal region. The maximum seal temperature during the hypothetical thermal accident is therefore 240°F. A summary of component temperatures during accident conditions is found in Table 3-1.

3.5.2 Maximum Internal Pressures

The maximum internal pressure is calculated in Chapter 4, assuming the basket and cask are closed and sealed at 70°F and 1 atm. The average cavity gas temperature is 266°F under accident conditions, and is reported in Table 3-2.

3.5.3 Maximum Thermal Stresses

The maximum thermal stresses during the hypothetical thermal accident are calculated in Chapter 2.

3.5.4 Evaluation of Package Performance for Hypothetical Accident Conditions

The thermal analysis for transport accident conditions concludes that the Oak Ridge Container design meets all applicable requirements. The maximum temperatures calculated using conservative assumptions are all below identified upper limits. The maximum seal temperature (240°F) during accident transport conditions remains below the 250°F specified limit. The average cavity gas temperatures increase to 266°F and 250°F for the ORC and the cask cavity respectively.

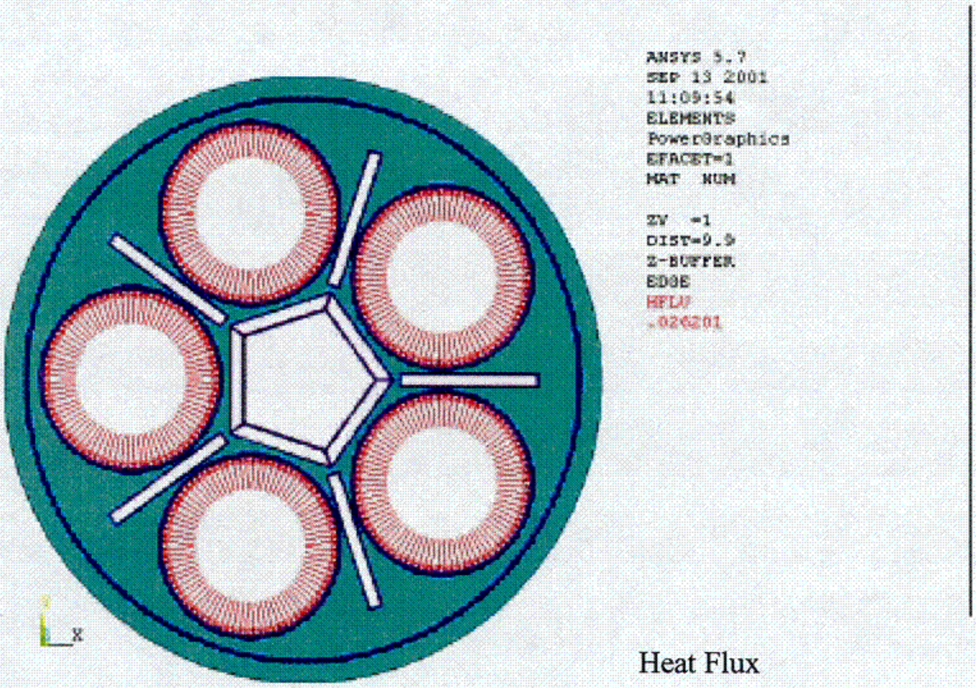
Table 3-1 Temperatures within Oak Ridge Container, Worst Case Loading

Component	$\Delta T_{Comp. - Wall}$ (°F)	Maximum Temperature (°F) Normal Conditions	Maximum Temperature (°F) Accident Conditions
TN-FSV Cavity Inner Shell	N/A	167	245
ORC Wall	34	201	279
Fuel Compartment, Support Discs, Tie Rods, And Poison Plates	79	246	324
Oak Ridge Canister	104	271	349
TN-FSV Cask Inner Shell, Seal Region	N/A	166	< 200
ORC Seals	40	206	240

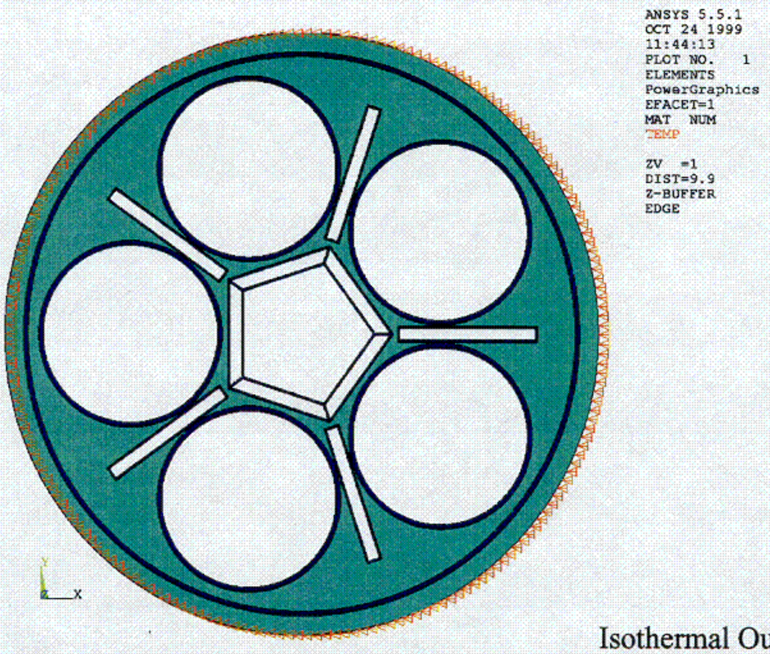
Table 3-2 Temperatures within Oak Ridge Container, Average Temperatures for Internal Pressure Determination

		Maximum Temperature (°F)	
Component	**$\Delta T_{Comp. - Wall}$ (°F)**	**Normal Conditions**	**Accident Conditions**
ORC Wall	9	176	254
Oak Ridge Container, Support Discs, Tie Rods, And Poison Plates	21	188	266
Fuel Compartment	21	188	266
Average Gas Temperature within Oak Ridge Container	N/A	188	266
Average Gas Temperature within TN-FSV Cask Cavity	N/A	172	250

Figure 3-5 Oak Ridge Container Cross Section Boundary Condition Application, Average Temperatures



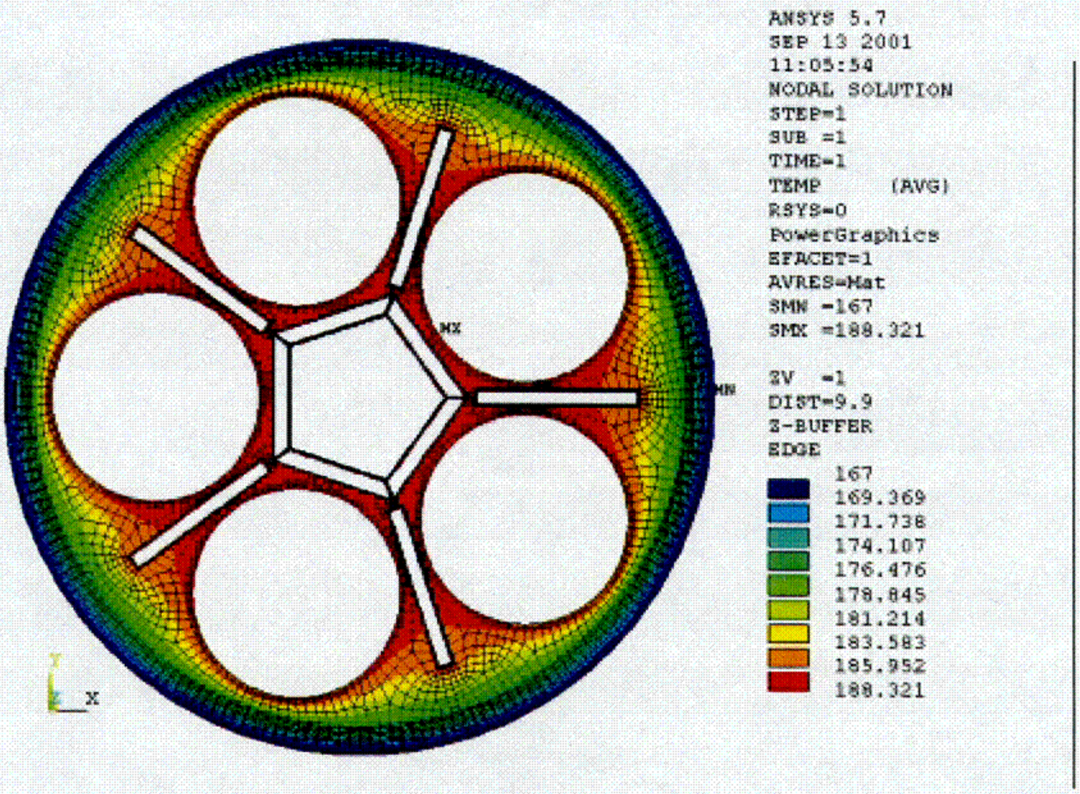
Heat Flux



Isothermal Outer Boundary

C03

Figure 3-6 Oak Ridge Container Cross Section Temperature Distribution, Average Temperatures



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4.2.3 Containment Criterion

In accordance with ANSI N14.5 paragraph 6.3.2[1], the measured fabrication, maintenance, and periodic leakage rates on the Oak Ridge Container and the TN-FSV packaging must be $\leq 10^{-7}$ ref·cm^3/s (that is, the containment boundaries are considered to be leak-tight).

The pre-shipment leakage rate test acceptance criterion (ANSI N14.5-1997, par. 7.6.4) may be either:

(a) measured leak rate $\leq 10^{-7}$ ref cm^3/s, or
(b) no detected leakage rate when tested to a sensitivity of at least 10^{-3} ref·cm^3/s.

Except for the pre-shipment leakage rate test, the leakage rate test must have a sensitivity of one-half the reference air leakage rate or 5 x 10^{-8} ref·cm^3/s.

4.3 Containment Requirements for Hypothetical Accident Conditions

4.3.1 Pressurization of Containment Vessel

Pressurization of the containment vessel is calculated for accident conditions using the methodology of Section 4.2.2. Assuming the canisters and the basket are closed at 70°F and 1 atm abs, the maximum cavity pressure during accident conditions is calculated from the ideal gas law. The mechanism contributing to containment pressurization is ideal gas heating only. The average gas temperature in the ORC under accident conditions is 261°F (Section 3.4). The pressure of the gas in the cavity is (721/530)(14.7) = 20.0 psia = 5.3 psig.

For the TN-FSV cavity, the average cavity gas temperature under accident conditions is 249°F (Section 3.4). The pressure of the gas is (709/530)(14.7) = 19.7 psia = 5.0 psig.

4.3.2 Containment of Radioactive Material

The requirements for accident conditions of transport are:

(a) no loss or dispersal of radioactive contents as demonstrated to a sensitivity of A_2 per week (10 CFR 71.51),
(b) no escape of krypton 85 exceeding $10A_2$ per week (10 CFR 71.51), and
(c) no loss or dispersal of plutonium from the inner ORC as demonstrated to a sensitivity of A_2 per week (10 CFR 71.63).

These requirements are met by demonstrating that the Oak Ridge Container is leaktight during accident conditions (i.e., structural integrity of the ORC is maintained and there is no seal degradation after the fire accident). See structural and thermal evaluations in Chapters 2.0 and 3.0 respectively.

8.1.2 Weld Inspections

Weld inspections are performed in accordance with the drawings and applicable ASME code sections specified in this Addendum. All welding is performed using qualified processes and qualified personnel, according to the ASME Boiler and the Pressure Vessel Code[1]. Welds are examined in accordance with the ASME Boiler and Pressure Vessel code requirements. NDE requirements for welds are specified on the drawings provided in Chapter 1. All NDE is performed in accordance with written and approved procedures. The inspection personnel are qualified in accordance with SNT-TC-1A[2]. Location, type, and size of the weld are confirmed by measurement.

8.1.3 Structural and Pressure Tests

The structural analyses performed on the Oak Ridge Container are presented in Chapter 2. To ensure that the ORC can perform its design function, the structural materials are chemically and physically tested to confirm that the required properties are met. Base materials are examined in accordance with the ASME Boiler and Pressure Vessel code requirements.

In accordance with 10CFR71.85(b), containment boundaries with an MNOP less than 5 psig are not required to be subjected to a structural pressure test.

8.1.4 Leakage Tests

abrication leakage tests are performed on the containment boundary for the TN-FSV cask and the Oak Ridge Container at the Fabricator's facility. These tests are performed using the helium mass spectrometer method. The leak test is performed in accordance with ANSI N14.5[3]. The personnel performing the leakage test are qualified in accordance with SNT-TC-1A.

For the Oak Ridge Container, helium is introduced into the cavity and the mass spectrometer connected to the test port in order to test both the inner lid o-ring and the vent port o-ring. The quick disconnect in the vent port will be removed. The ORC body/lid will be tested by the gas filled envelope method, i.e., placing a helium filled bag around the body and evacuating the cavity through the vent port. The combined leakage rate must be less than 1×10^{-7} ref cm^3/s.

For the TN-FSV Packaging, the inner lid o-ring is tested by utilizing the test port connection for the mass spectrometer with helium in the cask cavity. The body, vent, and drain ports 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 is removed for the port being leak tested. The combined leakage rate must be less than 1×10^{-7} ref cm^3/s.

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

Macroscopic uniformity of boron-10 distribution is verified by neutron radioscopy or radiography of the coupons. The acceptance criterion is that there be uniform luminance across the coupon. This inspection shall cover the entire coupon.

Normal sampling of coupons for neutron transmission measurements and radiography/radioscopy shall be 100%. Rejection of a given coupon shall result in rejection of the contiguous plate(s). Reduced sampling (50% - every other coupon) may be introduced based upon acceptance of all coupons in the first 25% of the lot. A rejection during reduced inspection will require a return to 100% inspection for the remainder of the lot. A lot is defined as all plates produced from a single casting.

Acceptance Testing, Visual - Boron Aluminum Alloy (Borated Aluminum)

The finished plates shall be visually examined to verify that they are free of cracks, porosity, blisters, or foreign inclusions. Such defects, where possible, are removed if it does not result in a dimensional non-conformance.

Justification for the Borated Aluminum Acceptance Test Requirements:

According to NUREG/CR-5661[4]

> "Limiting added neutron absorber material credit to 75% without comprehensive tests is based on concerns for potential 'streaming' of neutrons due to nonuniformities. It has been shown that boron carbide granules embedded in aluminum permit channeling of a beam of neutrons between the grains and reduce the effectiveness for neutron absorption."

Furthermore

> "A percentage of neutron absorber material greater than 75% may be considered in the analysis only if comprehensive tests, capable of verifying the presence *and uniformity* of the neutron absorber, are implemented." [Emphasis added]

The calculations in Chapter 6 use a boron areal density of 25 mg B10/cm^2, less than 90% of the minimum value required here of 30 mg B10/cm^2. This is justified by the following considerations.

a) The coupons for neutronic inspection are removed at the ends of the "stock plate", where under thickness of the plates or defects propagated from the pre-roll ingot would be most likely, and are approximately the full width of the plate. As such, they are taken from locations that are truly representative of the finished product. Coupons are also removed. The use of representative coupons for inspection is analogous to the removal of specimens from structural materials for mechanical testing.

b) Neutron radiography/radioscopy of coupons across the full width of the plate will detect macroscopic non-uniformities in the boron 10 distribution such as could be introduced by the fabrication process. Such defects usually originate from the ingot and propagate in the direction of rolling or extrusion.

For example, an ingot with a skin high in boron and a center depleted in boron will exhibit alternating bands of high and low boron concentration, which can be detected with radiography or radioscopy, parallel to the processing direction.

c) Neutron transmission measures effective boron 10 content directly. The term "effective" is used here because if there are any of the effects noted in NUREG/CR-5661, gram of finished composite are then determined by chemical analysis of a specimen selected from a random location on the finished coupon (ASTM D-3553[10] or equal). These three values are then multiplied together, with the composite density, and the minimum allowable plate thickness:

$$(g\ B10/g\ B)*(g\ B/g\ B_4C)*(g\ B_4C/g\ MMC)*(g\ MMC/cm^3)*(\text{min thickness, cm}) = g\ B10/cm^2$$

The value for each coupon must be ≥ 36 mg $B10/cm^2$.

A lot is defined as all of the plates and coupons made from a single billet. Inspection of coupons for B10 areal density measurements shall begin with tightened inspection (100% of coupons) for the first three lots. Inspection may be switched to normal (50%), if all coupons in the three preceding lots demonstrate a boron 10 areal density of greater than 36 mg $B10/cm^2$. Reduced sampling (25%) may be introduced, if all coupons from three preceding inspected lots demonstrate a boron 10 areal density of greater than 39.6 mg $B10/cm^2$. During normal or reduced inspection, a coupon with < 36 mg $B10/cm^2$ will require a return to the tightened inspection. A coupon below 39.6 mg $B10/cm^2$ during reduced inspection will require a return to normal inspection.

Measurement of <36 mg $B10/cm^2$ on a given coupon shall result in rejection of the contiguous plate(s).

Acceptance Testing, Visual Boron Carbide/Aluminum Metal Matrix Composite (MMC):

The finished plates shall be visually examined to verify that they are free of cracks, porosity, blisters, or foreign inclusions. Removal of such defects is permitted, where possible, if the removal does not result in a dimensional non-conformance.

Justification for Acceptance Test Requirements, Metal Matrix Composite

According to NUREG/CR-5661

> " For each calculational model, the atom density of any neutron absorber...should be limited to 75% of the minimum neutron absorber content specified in the application. This minimum neutron absorber content should be verified by chemical analysis, neutron transmission measurements, or other acceptable methods. A percentage of neutron absorber material greater than 75% may be considered in the analysis only if comprehensive tests, capable of verifying the presence and uniformity of the neutron absorber, are implemented."
>
> "...Limiting added neutron absorber material credit to 75% without comprehensive tests is based on concerns for potential 'streaming' of neutrons due to nonuniformities. It has been shown that boron carbide granules embedded in aluminum permit channeling of a beam of neutrons between the grains and reduce the effectiveness for neutron absorption."

The calculations in Chapter 6 use a boron areal density of 25 mg B10/cm^2. That is less than 75% of the minimum value required here, 36 mg B10/cm^2. Based on the recommendations above, because only 75% credit is used, comprehensive testing for presence and uniformity of boron 10 is not necessary.

Other considerations are:

a) The coupons for neutronic inspection are removed at the end of each stock plate, and are generally the full width of the plate. As such, they are taken from locations that are truly representative of the finished product, where every plate is represented by a contiguous coupon. The use of representative coupons for inspection is analogous to the removal of specimens from structural materials for mechanical testing.