APPENDIX 2.11.8

TABLE OF CONTENTS

LIST OF FIGURES

APPENDIX 2.11.8

TN-FSV CASK LEAD SLUMP ANALYSIS

2.11.8.1 Introduction

A non-linear finite element analysis is performed in order to quantify the amount of lead slump that occurs in the TN-FSV Cask lead shielding during a hypothetical accident condition end drop. The two load cases considered are the hypothetical accident condition 30 foot lid and bottom end drops. The maximum axial acceleration of the transport package during a 30 foot end drop impact is 54*g* [TN-FSV SAR, Section 2.10.2].

During a hypothetical accident condition end drop, permanent deformation of the lead gamma shield may occur. The lead gamma shield is supported by friction between the lead and cask shells, in addition to bearing at the end of the lead column. During fabrication, a small gap may develop between the lead gamma shield and the cask structural shells due to differential thermal expansion of the dissimilar materials during cooling after the lead pour. During the postulated end drop, the gap between the lead and cask shells reduces the stress in the cask shells, and increases the amount of permanent deformation in the lead column (i.e. lead slump). Consequently, an initial gap of 0.0625 in. is assumed to exist between the outer radial surface of the lead and the inner radial surface of the outer stainless steel shell in order to maximize the amount of lead slump.

The axial length of the cavity that develops between the non-impact end of the lead gamma shield and the stainless steel structural shell is computed by the FEA. The effect of this cavity size on the shielding ability of the transport package is evaluated in a separate analysis.

2.11.8.2 Finite Element Model

A 2-dimensional axisymmetric ANSYS (Ref. 1) finite element model, constructed primarily from PLANE42 elements, is used in this analysis. CONTACT12 elements are used to model the interaction between the lead gamma shield and the cask inner and outer shells. The coefficient of sliding friction for lead on mild steel varies from 0.3 for lubricated surfaces to 0.95 for dry surfaces (Ref. 2). A lower bound coefficient of static friction of 0.25 is conservatively used for the lead slump analysis.

The trunnions are not included in the finite element model. The effect of the unmodeled mass is considered to have a negligible effect on the behavior of the lead gamma shield during an end drop event.

2.11.8.2.1 Material Properties

In order to determine the amount of lead slump, an elastic-plastic analysis is required. The material properties of the lid, bottom, inner shell and outer shell of the TN-FSV Cask are modeled with linear elastic material properties, while the lead material is modeled with a multi-linear stress-strain curve.

Material properties for both the lead shielding and the stainless steel cask body are taken at 180° F. This reference temperature is considered conservative because it is higher than the maximum TN-FSV Cask body temperature (167° F.) reported in the TN-FSV SAR (TN-FSV SAR Table 3-1), which is computed based on the FSV SNF Canister (Configuration 1) payload, which has a higher heat load than that of the Oak Ridge Container (Configuration 2).

Stainless Steel Cask Body (SA-240 Type 304) @ 180°F. (Ref. 3)

$E = 27.7\times10^6$ psi.
$S_y = 25.8$ ksi.
$S_u = 71.6$ ksi.
$\nu = 0.3$
$\rho = 0.29$

Lead Shielding

The material properties used for the lead shielding are taken at 180° F. The actual maximum normal condition lead temperature is 166° F (from TN-FSV SAR Table 3-1). The following material properties are used.

$E = 2.29\times10^6$ psi. [4]
$\rho = 0.41$ lb.in.$^{-3}$ [5]
$\nu = 0.45$ [5]

A multi-linear stress-strain curve is used to model the lead's mechanical behavior. The stress-strain curve for lead at 180° F is computed by interpolating data at taken 100° F and 230° F in the following way.

The following compressive stress-strain data of high-purity lead, at room temperature, is obtained from Figure 1 of Reference 6 at strain rate 10^2 in/in/sec,

Lead Stress-Strain Curve @ R.T. (100° F)	
Strain (in/in)	**Stress (ksi)**
0.03	2.2
0.10	3.3
0.30	4.9
0.50	5.6

As per Reference 6 (pg. 6), "Available elevated temperature data suggest a 15 to 35 percent decrease in strength at 230° F for strains of 10 to 50 percent respectively, at strain rate of 10^2 in/in/sec....". Using these factors conservatively, on room temperature properties for 10^2 strain rate,

Lead Stress-Strain Curve @ 230° F	
Strain (in/in)	**Stress (ksi)**
0.03	2.0*
0.10	3.3×0.85 = 2.8
0.30	3.2*
0.50	5.6×0.65 = 3.6

*These numbers are obtained by fitting the known data to a curve and interpolating.

The following 180° F Stress-Strain data is extrapolated from the data at room temperature (assume 100° F) and at 230° F.

Lead Stress-Strain Curve @ 180° F	
Strain (in/in)	**Stress (ksi)**
0.000485*	1.11
0.03	2.08
0.10	2.99
0.30	3.85
0.50	4.37

*0.000485 in./in. is the elastic limit strain, which is assumed to be constant over the temperature range of interest. The elastic limit in this row is obtained by multiplying the elastic limit strain by the modulus of elasticity, E, at 180° F.

Even though the material properties used in this analysis are taken at the elevated temperatures generated during normal conditions of transport, the effects of differential thermal expansion are neglected. Since the coefficient of thermal expansion for lead is much higher than that of stainless steel, including the effects of thermal expansion will cause the lead to expand more than the stainless steel shell, and will reduce the effects of the lead slump. Therefore, it is conservative not to include the thermal expansion effects in the lead slump calculation.

2.11.8.2.2 Loading and Boundary Conditions

The inertial loads generated by the Oak Ridge Container, and the TN-FSV bottom impact limiter, as well as reaction forces, are accounted for by applying equivalent pressures to the model. The reaction pressure at the impact end of the cask in the central region is made equivalent to the weight of the lid/bottom plus the weight of the internals. The reaction pressure in the outer (flange) region is made equivalent to the weight of the remainder of the package. These reaction pressures are applied to the finite element model and then adjusted slightly in order to balance the reaction forces at the displacement boundary conditions.

Symmetry displacement boundary conditions are applied along the *y*-axis of the 2-dimensionsal axisymmetric model. A single node along the *y*-axis of the model at the non-impact end of the cask is held in the axial direction. The lead and cask shell nodes are coupled in the *y*-direction only at the impact end of the lead column. An inertial load of 54*g* is applied to the model. The loading and boundary conditions for lid end and bottom end drops are shown on Figures 2.11.8-1 and 2.11.8-2 respectively.

2.11.8.3 Results

In order to quantify the longitudinal length of the gap that develops between the lead shield and the structural shell on the non-impact end of the cask, the difference between the maximum axial deflections of coincident lead and structural shell nodes, at the load step corresponding to 54*g*, is determined. This difference is taken to be the maximum gap size caused by lead slump. The following table summarizes the lead slump gap size for both load cases analyzed.

Load Case	Lead Slump Gap Size
54*g* Lid End Drop	1.67 in.
54*g* Bottom End Drop	1.87 in.

Stress intensities and displacement patterns for the two load cases are shown Figures 2.11.8-3 and 2.11.8- 4. The effect of these gaps on the shielding ability of the cask is analyzed in Chapter 5.

2.11.8.4 References

1. ANSYS User's Manual, Rev 5.7.

2. Baumeister & Marks, *Standard Handbook for Mechanical Engineers*, 7th Edition.

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

4. NUREG/CR-0481, *An Assessment of Stress-Strain Data Suitable for Finite-Element Elastic-Plastic Analysis of Shipping Containers.*

5. Cask Design Guide, ORNL-NSIC-68, February 1970.

6. U. S. Energy Research and Development Administration, *A survey of Strain Rate Effects for some Common Structural Materials used in Radioactive Material Packaging and Transportation Systems*, Battelle Columbus Laboratories, August 1976.

**Figure 2.11.8-1.
TN-FSV Cask 2-Dimensional Finite Element Model
with Lid End Drop Boundary Conditions**

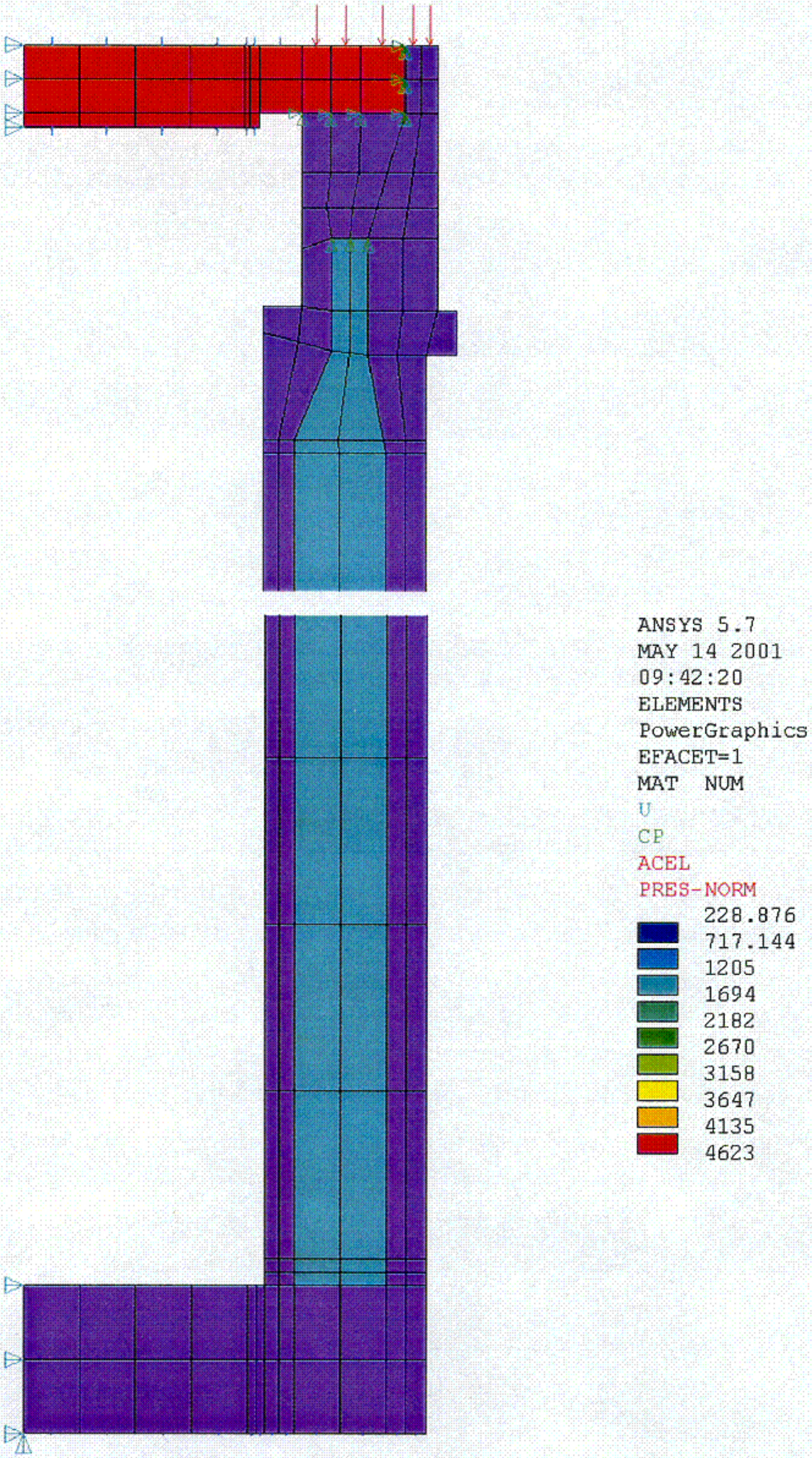

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**Figure 2.11.8-2.
TN-FSV Cask 2-Dimensional Finite Element Model
with Bottom End Drop Boundary Conditions**

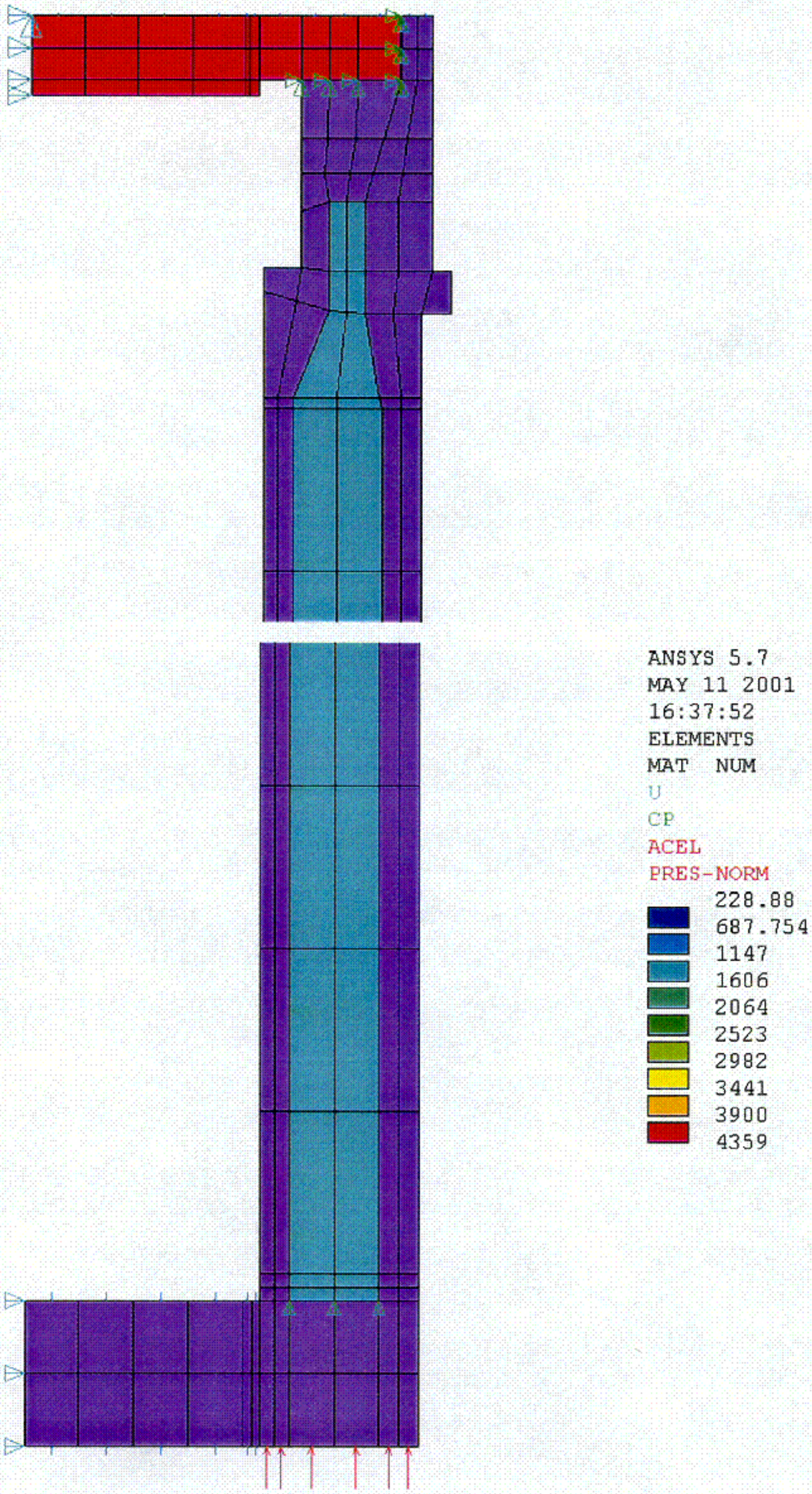

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Figure 2.11.8-3.
Stress Intensity – Lid End Drop

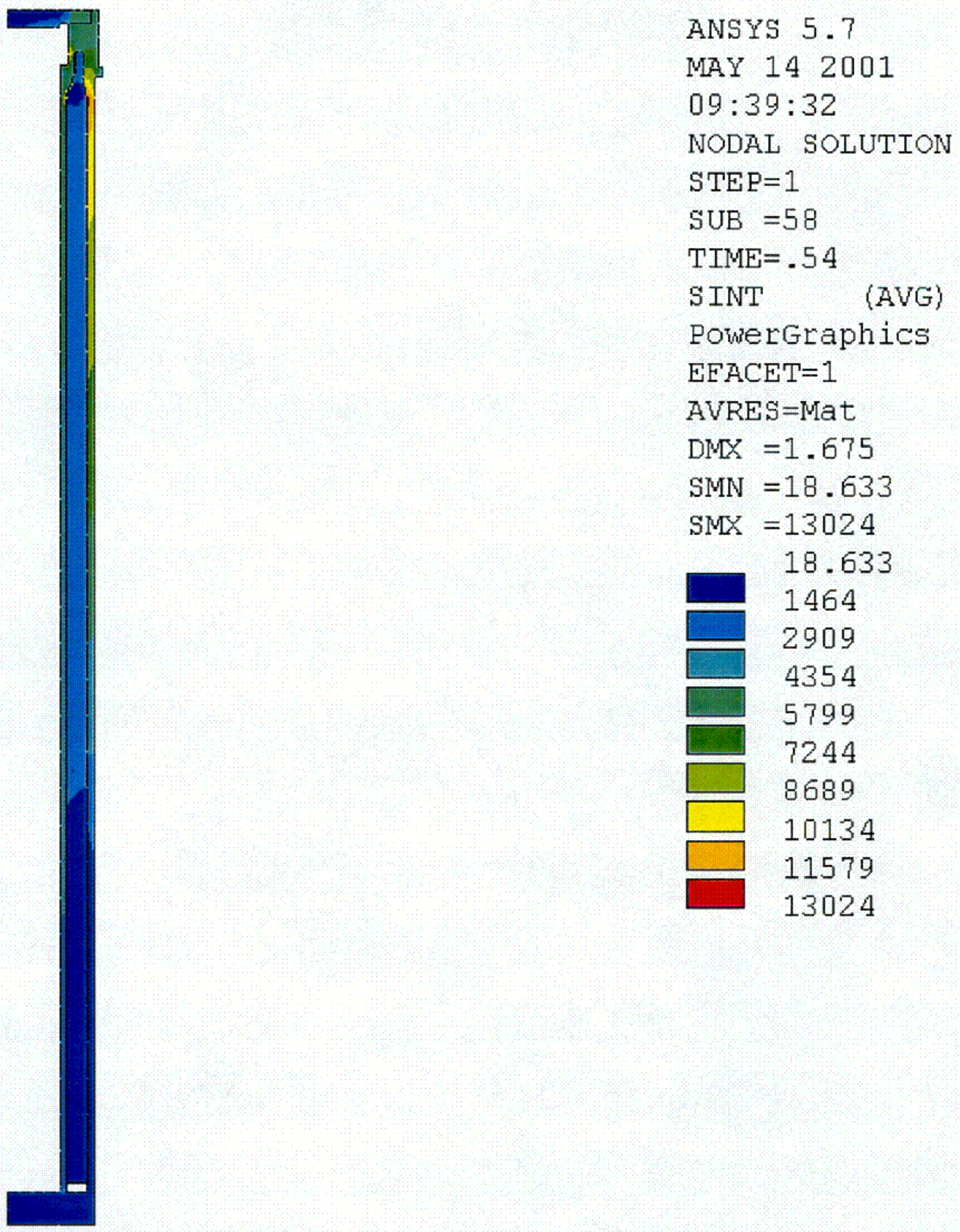

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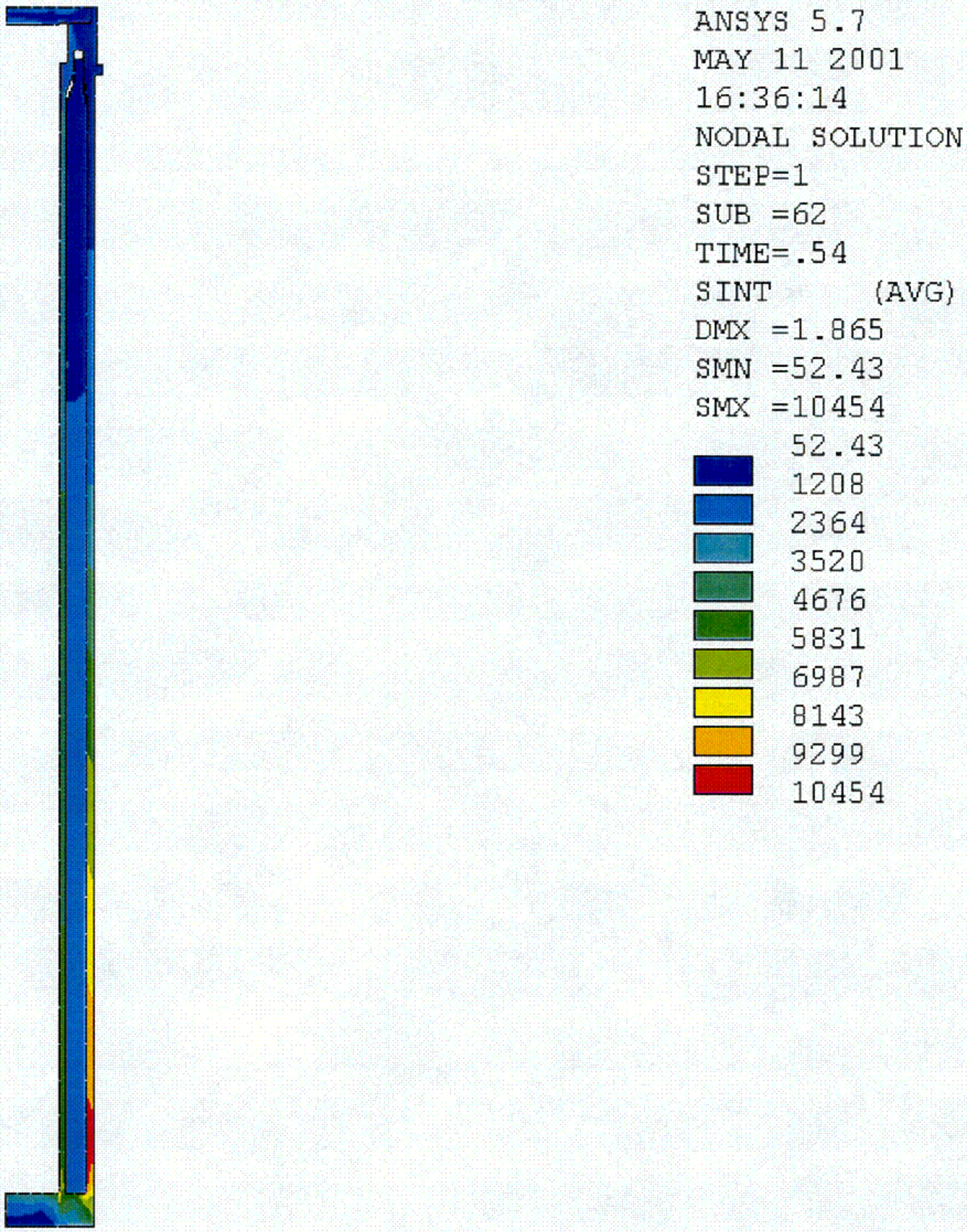
Figure 2.11.8-4.
Stress Intensity – Bottom End Drop



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3.0 THERMAL EVALUATION

3.1 Discussion

The Oak Ridge Container (ORC) is designed to passively reject payload decay heat to the TN-FSV cask under normal conditions of transport and hypothetical accident conditions while maintaining appropriate component temperatures and pressures within specified limits. Objectives of the thermal analyses performed for this evaluation include:

- Determination of maximum and minimum temperatures with respect to the ORC material limits to ensure components perform their intended safety function;
- Determination of temperature distributions to support the calculation of thermal stresses;
- Determination of the ORC and TN-FSV cask cavity temperatures to support containment pressurization calculations;
- Determination of the maximum Oak Ridge canister or Peach Bottom assembly temperature.

Chapter 2.0 presents the principal design bases for the ORC.

The design features for the ORC are described in Section 1.2. Temperatures of the components of the ORC are calculated to permit selection of appropriate temperature dependent mechanical properties used in the structural analyses.

Several thermal design criteria have been established for the Oak Ridge Container.

- Containment of radioactive material is a major design requirement. Seal temperatures must be maintained within specified limits to satisfy the leak tight containment function (Chapter 4) under normal and accident conditions. The manufacturer's[5] recommended temperature range of –75 °F to 250 °F is set for butyl o-rings (in lid and vent port cover) under normal and accident conditions. This limit applies to both containment boundary seals used in the ORC lid and vent port cover.
- Maximum temperatures of containment structural components must not adversely affect performance of the containment function.

The ambient temperature range for normal transport is –20 to 100°F per 10CFR71.71(b). In general, all the thermal criteria are associated with maximum temperatures. All materials can be subjected to the minimum environment temperature of -40°F without adverse effects as required by 10CFR71.71(c)(2).

Chapter 1.0 describes the administrative controls that will be placed on the payload to control the thermal loading distribution in the payload. The following is a summary of the thermal heat load restrictions:

1. The maximum heat load for the payload cannot exceed a maximum of 120 watts.
2. The maximum heat load in a canister cannot exceed 35 watts except at the lid end where the limit is 7 watts. (Note: the Oak Ridge canister is the limiting case since a Peach Bottom intact assembly has an estimated heat load less than 3 watts.)
3. The maximum heat load in a cross section with a length corresponding to the axial length of the Oak Ridge canister (34.75 in.) cannot exceed 55 watts.

The thermal evaluation concludes that with these administrative controls for the heat load distribution, all design criteria are satisfied.

A description of the analysis performed for normal conditions of transport is provided in Section 3.4 and for hypothetical accident conditions, in Section 3.5. A summary of results from these analyses is shown in Table 3-1. The first column ($\Delta T_{Comp.\text{-}Wall}$) lists the temperature difference between a ORC component and the TN-FSV cavity wall for the design heat load. The second and third columns list the temperatures in the ORC components for normal and accident conditions based on known TN-FSV cavity wall temperatures of 167°F and 245°F (TN-FSV SAR) for normal and accident conditions respectively.

3.2 Summary of Thermal Properties of Materials

Thermal properties of materials used in the thermal analysis of the Oak Ridge Container are listed below. The analysis uses linearly interpolated values for intermediate temperatures where the temperature dependence of a specific parameter is deemed significant.

1. SA-240 Type 304 / SA-182 F304 Stainless Steel

Temperature (°F)	Conductivity[(1)] (Btu/hr-ft-°F)
100	8.7
150	9.0
200	9.3
250	9.6
300	9.8
350	10.1
400	10.4

An emissivity of 0.30 is used for all stainless steel surfaces. (Reference 2).

2. Dry Air

Temperature (°F)	Conductivity[(3)] (W/m-K)	Conductivity (Btu/hr-in-°F)
68	0.0251	0.001208
104	0.0265	0.001276
140	0.0279	0.001343
176	0.0293	0.001411
212	0.0307	0.001478
392	0.0370	0.001781

3.3 Technical Specification of Components

The only component for which a thermal specification is necessary is the seal(s). The seals used in the Oak Ridge Container and the TN-FSV Packaging Configuration 2 are butyl o-rings which have a recommended temperature range of –75 °F to 250 °F.

3.4 Thermal Evaluation for Normal Conditions of Transport

3.4.1 Thermal Models

The thermal evaluation of the Oak Ridge Container is performed using the ANSYS[4] computer program. ANSYS is a large scale, general purpose finite element computer code which can be used for steady state or transient thermal analyses.

TN-FSV Cask Body Temperature

The temperature distributions within the TN-FSV cask body with a heat load of 360W for normal and accident conditions are found in the TN-FSV SAR. The temperature distribution was determined via the creation of an axisymmetric model within ANSYS that includes the cask body, lid, bottom, and the thermal shield. The decay heat load was applied to the model as a constant heat flux on the inner surface of the cask body over an axial length of 187.32 in. (1.92 watts/in.).

The largest heat load for any possible loading configuration of the TN-FSV cask with the Oak Ridge Container is 120 watts which is well below the 360 watts evaluated in the TN-FSV SAR. The largest heat load evaluated for any cross section of the packaging corresponding to the Oak Ridge canister axial length of 34.75 in. is 55 watts. This corresponds to 1.58 watts/in. which is well below the average heat load of 1.92 watts/in. used in obtaining the TN-FSV cask body temperatures. The temperature distributions within the cask body found in the TN-FSV SAR are bounding.

3.4.1.1 Oak Ridge Container Cross Section Model

Using ANSYS, a 2-D finite element model of the Oak Ridge Container was created to determine the maximum temperature difference from the cask inner surface to the ORC. The model includes only the fuel compartments, ORC shell, poison enclosures and the air gap between the cask inner shell and the Oak Ridge Container. The outermost nodes of the finite element model, which model the innermost surface of the TN-FSV cask body, are assigned a 167°F isothermal boundary condition corresponding to the bounding maximum cask body inner shell temperature reported in the TN-FSV SAR. The support discs, tie rods, and poison plates are not modeled but will have temperatures that will not exceed the maximum fuel compartment temperature.

The model includes heat transfer via both radiation and conduction.

The fill gas and stainless steel components 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 3-1. The dimensions and materials in the finite element model are shown in Figure 3-2.

The ORC has the capacity to carry up to 20 Oak Ridge canisters, 5 Peach Bottom fuel assemblies, or a combination of the two. The basket accommodates a maximum heat generation of 120 watts per shipment with a maximum of 35 watts for a single canister. In addition, administrative controls prevent any given cross-section of the ORC, with an axial length of the Oak Ridge canister, from having a heat load exceeding 55W.

The bounding case of loading with 20 Oak Ridge SNF canisters is considered. Fifty-five watts of the fuel load is dissipated from one Oak Ridge canister axial length within the packaging. Thirty-five watts of this heat load, corresponding to the maximum heat load for a single canister, is applied as a heat flux on the inner surface of one of the fuel compartments. The remaining 20W is applied evenly as a heat flux on the inner surface of one adjacent fuel compartment. The remaining 65W of the total 120W heat load may be distributed amongst the remaining canisters at any location in the ORC with the only restriction being at the lid end of the payload where the heat load per canister is 7W.

The axial length of an Oak Ridge SNF canister is 34.75 in. The decay heat per unit axial length of the hottest axial level is:

$$Q' = 55 \text{ watts}/ 34.75 \text{ in.} = 1.58 \text{ watts/in}$$

$$Q' = 1.58 \text{ watts/in.} \times (1 \text{ Btu/hr} / 0.293 \text{ W}) = 5.40 \text{ Btu/hr-in}$$

The heat fluxes were adjusted until the reaction solution of the model was equal to the decay heat per unit length of the hottest axial level, 5.40 Btu/hr-in. The applied boundary conditions for the worst case loading are shown in Figure 3-3. The temperature distribution of the cross section model for the worst case loading is shown in Figure 3-4. The results of the analysis are presented in Section 3.4.2.

Oak Ridge Canister Temperature

Using the maximum fuel compartment temperature from the finite element model, the Oak Ridge canister temperature is determined using the following assumptions:

- The SNF canister is centered radially within the Oak Ridge Container fuel compartment having the maximum fuel compartment temperature.
- The SNF canister has the bounding maximum heat load of 35 watts.
- The fill gas is air.

Heat transfer across an annulus via radiation and conduction is given by:

$$Q = Q_{cond} + Q_{rad} = \frac{2\pi kL(T_{can} - T_{fc})}{\ln(d_o/d_i)} + \frac{\sigma A(T_{can}^{\ 4} - T_{fc}^{\ 4})}{\frac{1}{\varepsilon_1} + \frac{1-\varepsilon_2}{\varepsilon_2}\left(\frac{d_i}{d_o}\right)}$$

Q = decay heat = 35 watts x (3.4123 Btu/hr/watt) = 119.4 Btu/hr
d_o = inner diameter of fuel compartment = 5.295 in.
d_i = outer canister diameter = 4.75 in.
L = fuel canister length = 34.75 in.
T_{can} = fuel canister temperature
T_{fc} = fuel compartment temperature
k = air conductivity at T_{fc}
σ = Stefan-Boltzman Constant = 1.1903E-11 Btu/hr-in.^{2}-°F
$A = \pi d_i L$ = 518.6 in.^{2}
$\varepsilon_1 = \varepsilon_2 = 0.30$ (Reference 2)

The fuel canister temperature, T_{fc}, is determined such that the total heat transfer across the annulus equals the bounding maximum canister heat load of 35 watts.

Average Cavity Gas Temperatures

The average cavity gas temperatures are determined by modifying the heat flux boundary conditions of the ORC cross-section finite element model. The maximum heat load of 120 watts for an Oak Ridge Container is applied evenly over the inner surfaces of the 188 in. long fuel compartments. The applied boundary conditions and the temperature distribution for this case are shown in Figure 3-5 and Figure 3-6.

To conservatively calculate the maximum cavity gas pressure in the Oak Ridge Container, the average cavity gas is assumed to be the maximum fuel compartment temperature. The average cavity gas within the TN-FSV cask body is assumed to be the average of the maximum ORC wall and cask body temperatures.

3.4.1.2 Oak Ridge Container Seal Region Model

A finite element model was created to determine the steady-state temperature difference between the cask inner surface in the region of the seals and the seal within the Oak Ridge Container. This temperature difference is used to bound the maximum seal temperatures during normal and accident transport conditions.

Using ANSYS, a 3-D finite element model of a one fifth section of the Oak Ridge Container lid was created to determine the maximum temperature difference from the cask inner surface in the seal region to the seals within the ORC. The model includes only the lid, uppermost portion of the ORC, and air gap, gap between the cask inner shell and the ORC. Figure 3-7 and Figure 3-8 show the dimensions and materials of this finite element model.

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 167 °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. 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 39°F temperature difference from the model periphery.

The average cavity gas temperatures in the ORC and the cask cavity are 183°F and 171°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 183°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 39°F lower than the maximum wall temperature. 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 261°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 261°F and 249°F for the ORC and the cask cavity respectively.

3.6 References

1) ASME Code, Section II, Part D, 1998.

2) COBRA-SFS: A Thermal-Hydraulic Analysis Computer Code, Vol. III, Validation Assessments, PNL-6049, 1986.

3) Kreith, et. al., Principles of Heat Transfer, 4th Edition, 1986.

4) ANSYS Computer Code and User's Manuals, Volumes 1-4, Rev. 5.5.

5) Parker Seals, Parker O-Ring Handbook, 1992.

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	167	200
ORC Seals	39	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	7	174	279
Oak Ridge Container, Support Discs, Tie Rods, And Poison Plates	16	183	324
Fuel Compartment	16	271	349
Average Gas Temperature within Oak Ridge Container	N/A	183	261
Average Gas Temperature within TN-FSV Cask Cavity	N/A	171	249

Figure 3-1 Oak Ridge Container Cross Section Finite Element Model

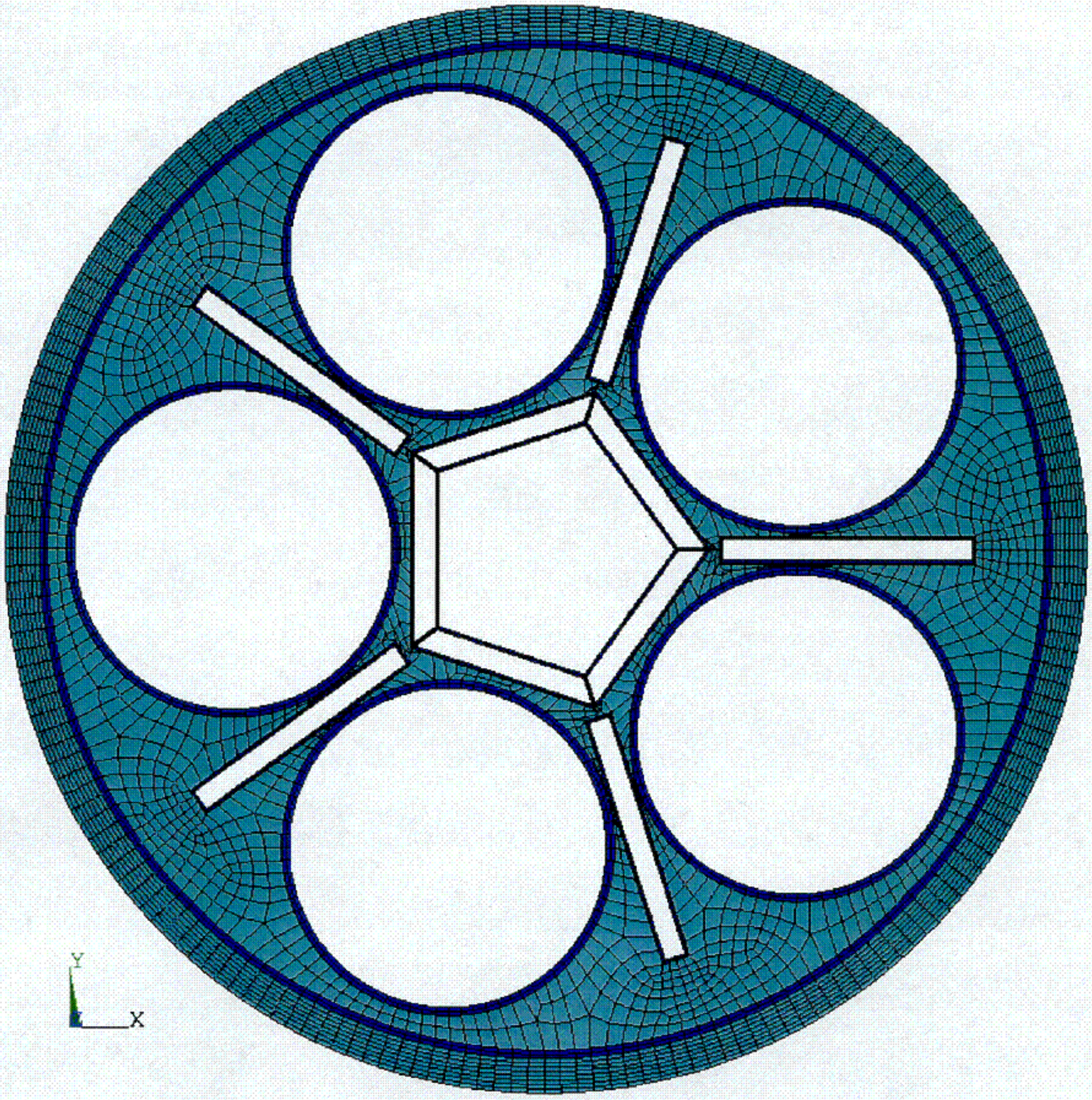

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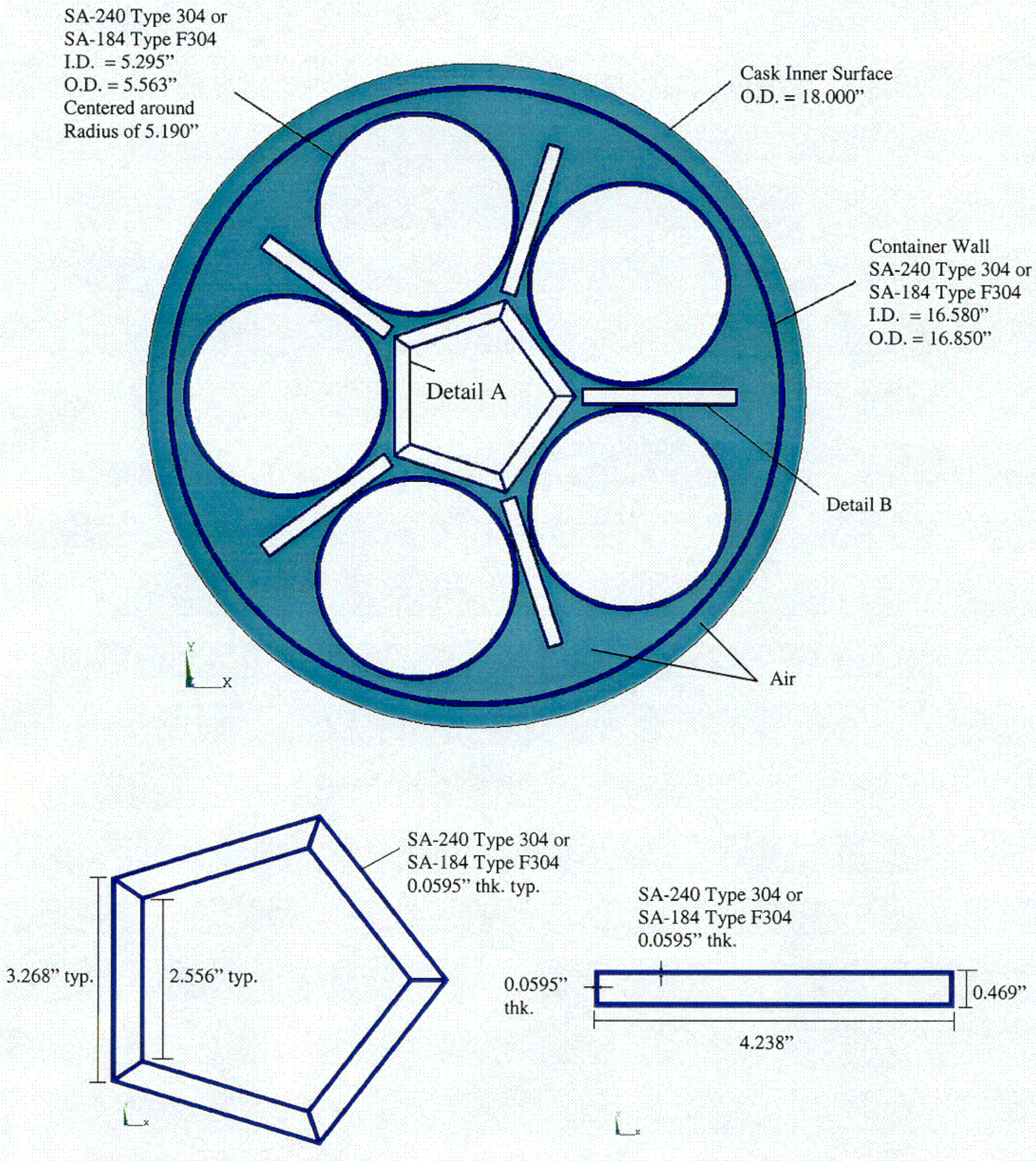
Figure 3-2 Oak Ridge Container Cross Section, Model Dimensions



Detail A

Detail B

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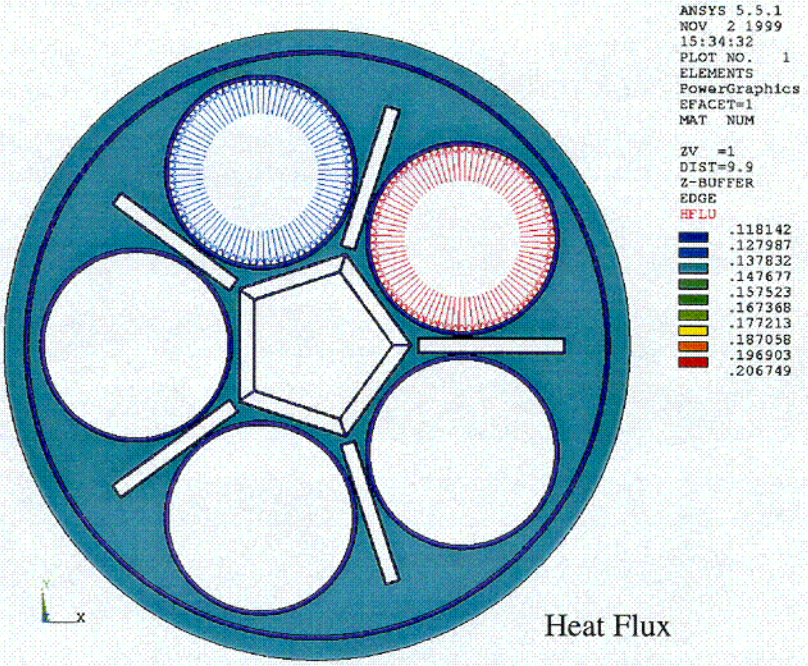
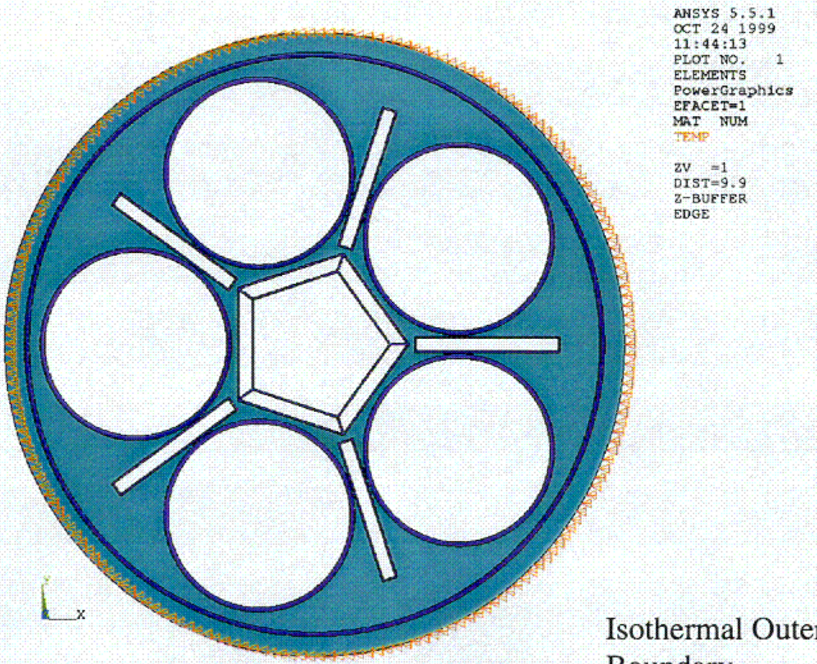
Figure 3-3 Oak Ridge Container Cross Section Boundary Condition Application for Worst Case Loading



Heat Flux



Isothermal Outer Boundary

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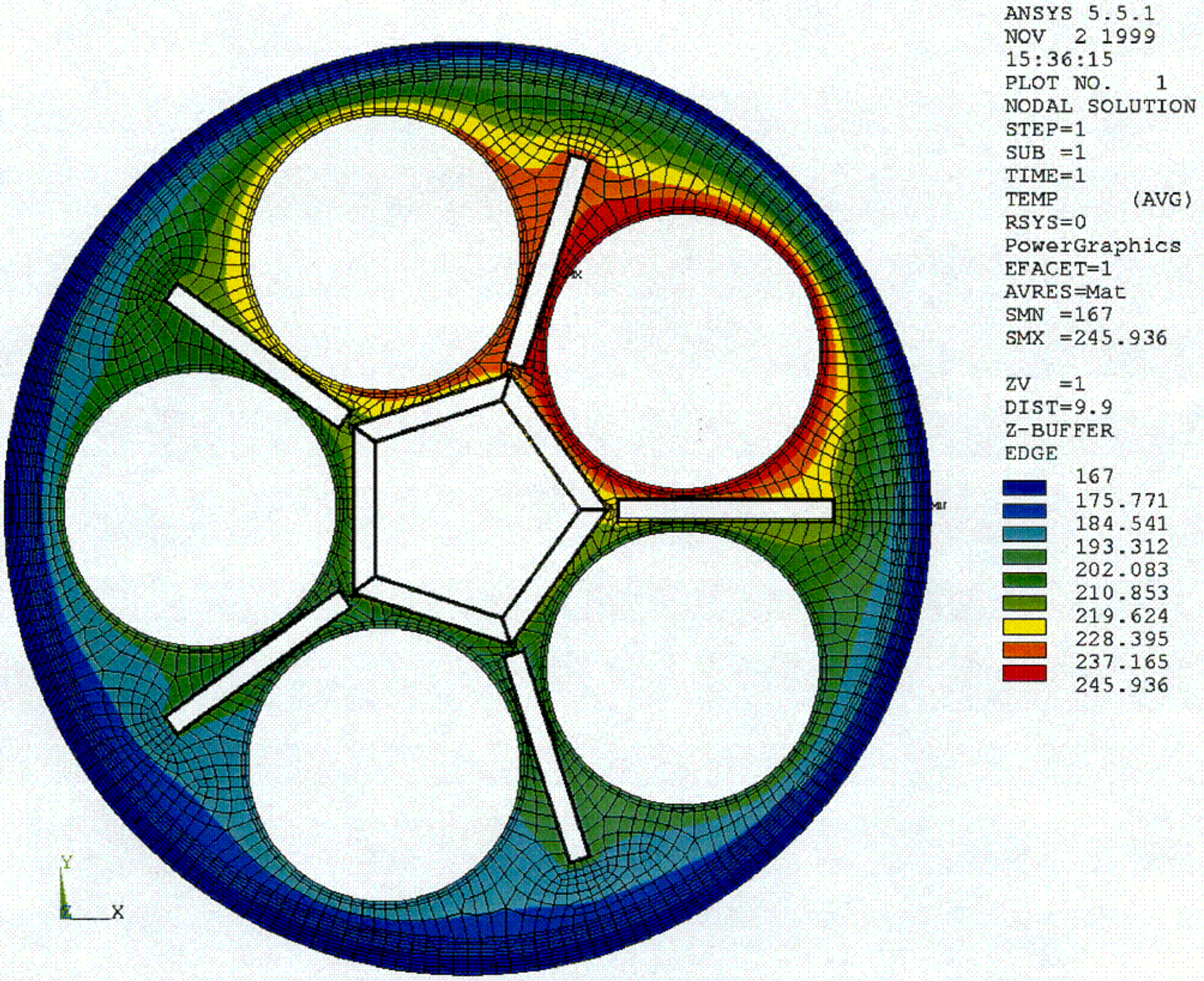
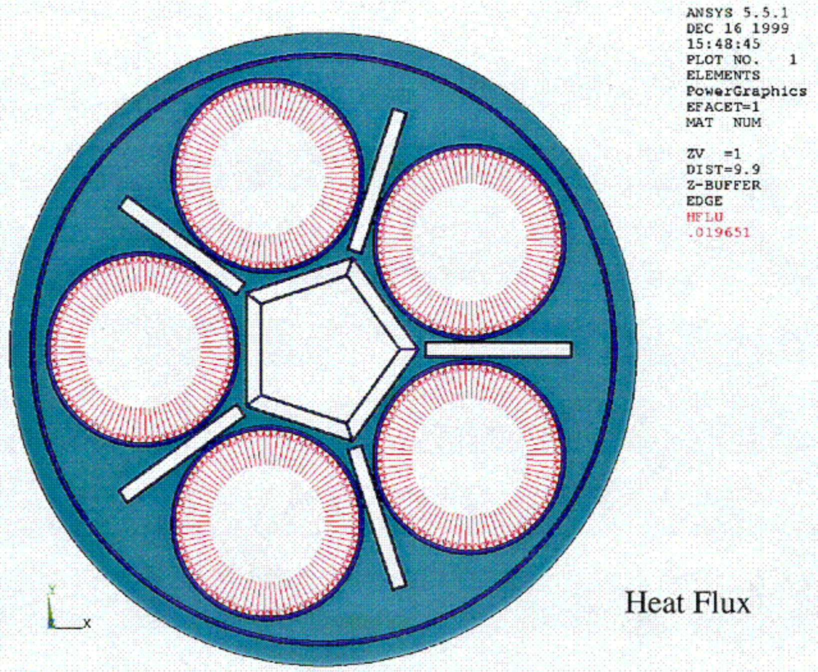
Figure 3-4 Oak Ridge Container Cross Section Temperature Distribution, Worst Case Loading

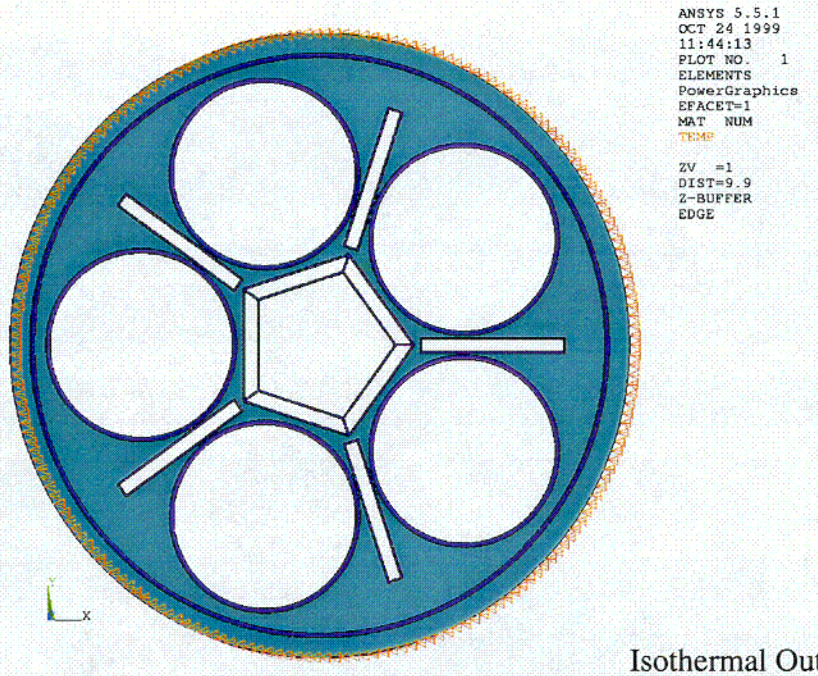


C08

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



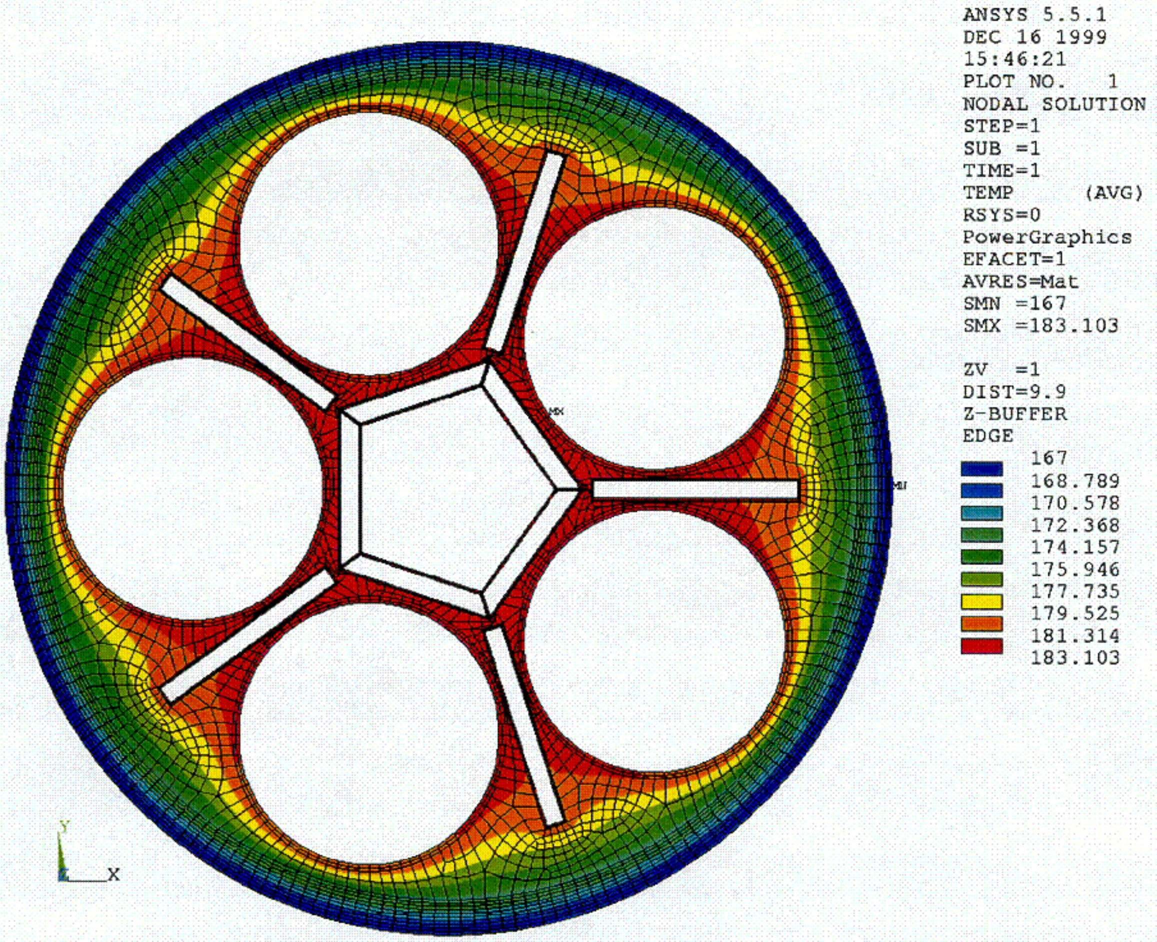
Heat Flux



Isothermal Outer Boundary

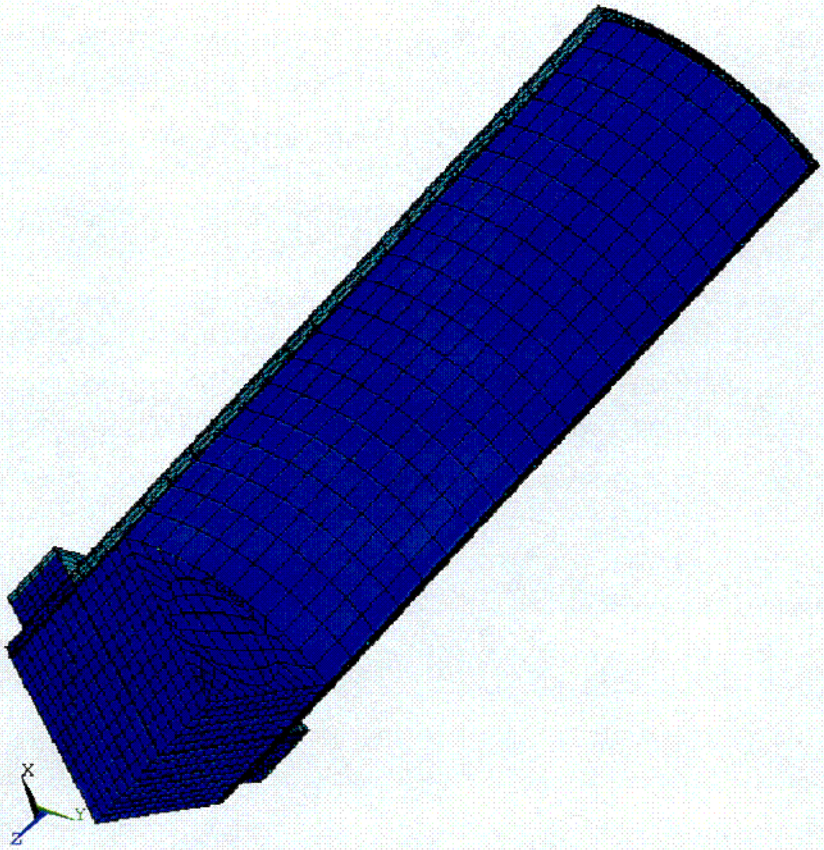
C09

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



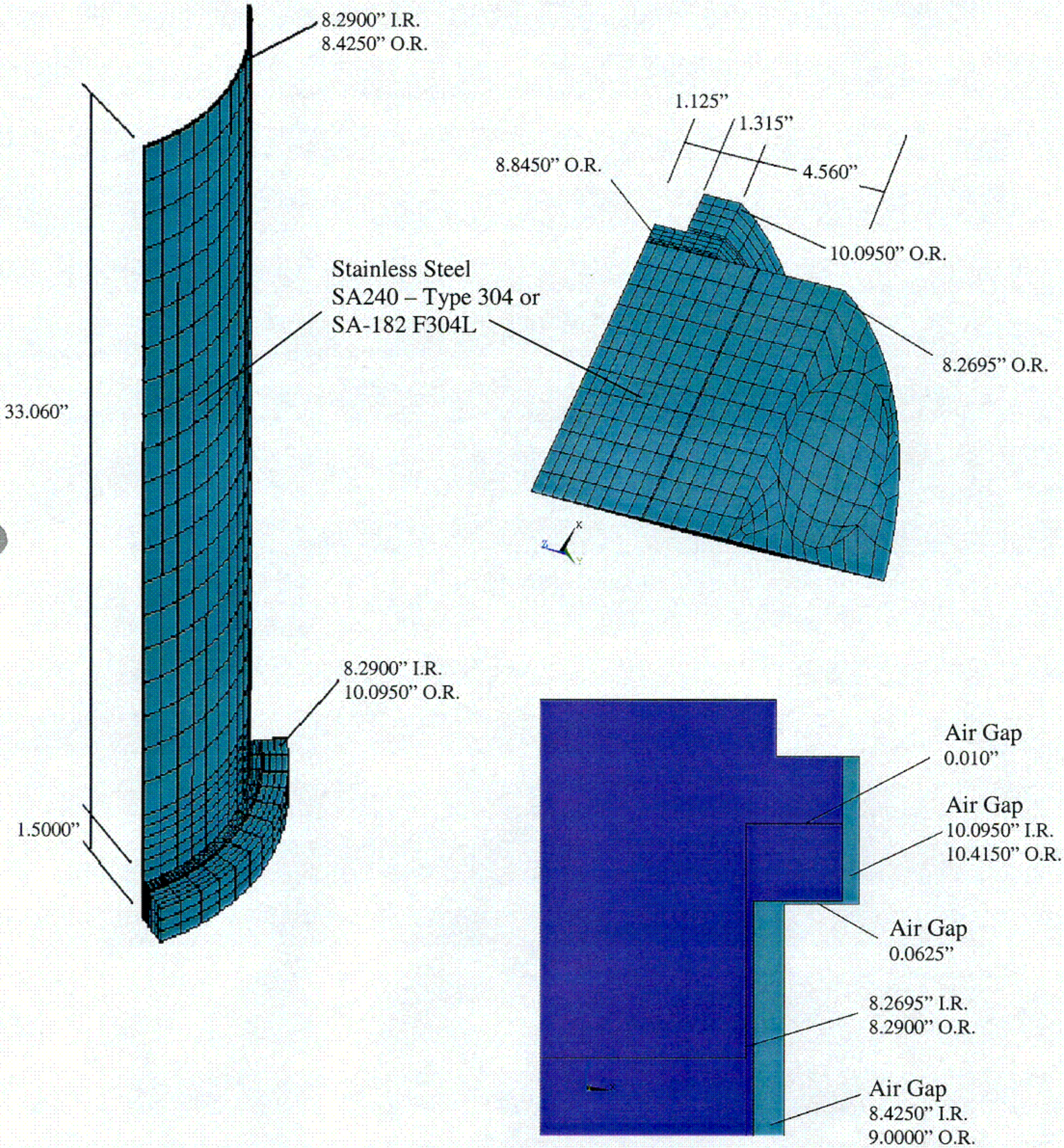
C10

Figure 3-7 Oak Ridge Container Seal Region Finite Element Model



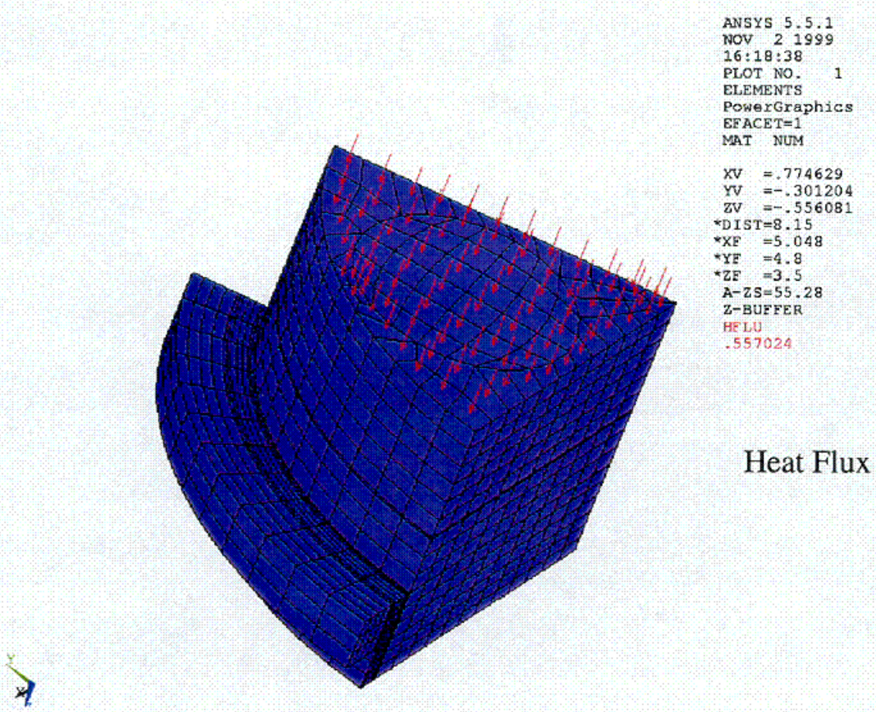
C11

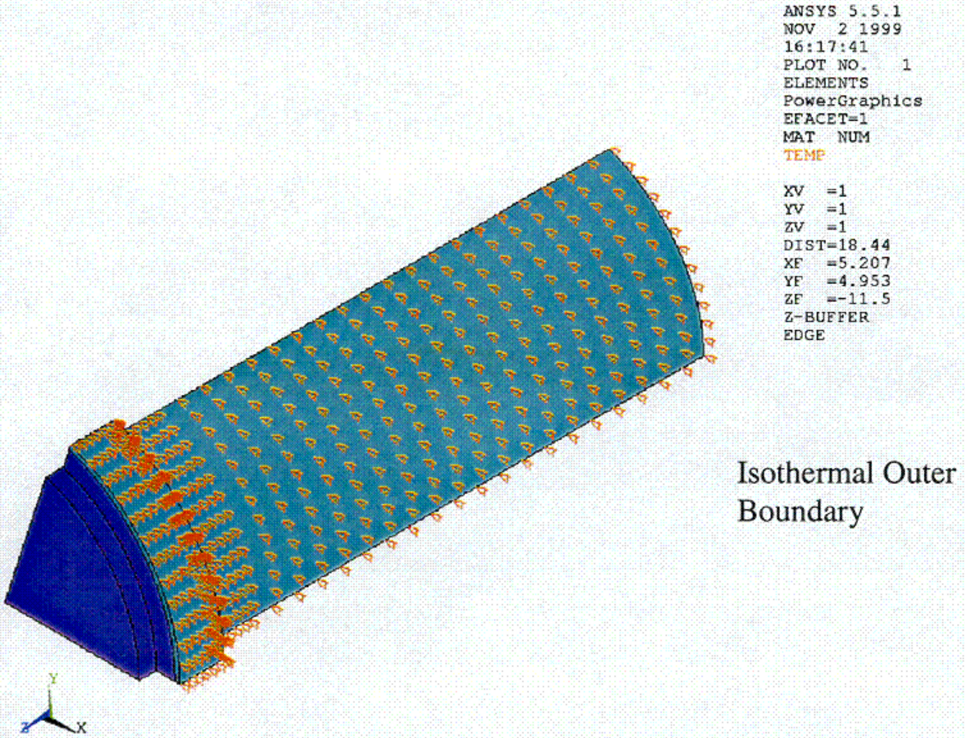
Figure 3-8 Oak Ridge Container Seal Region Model, Dimensions and Materials



C12

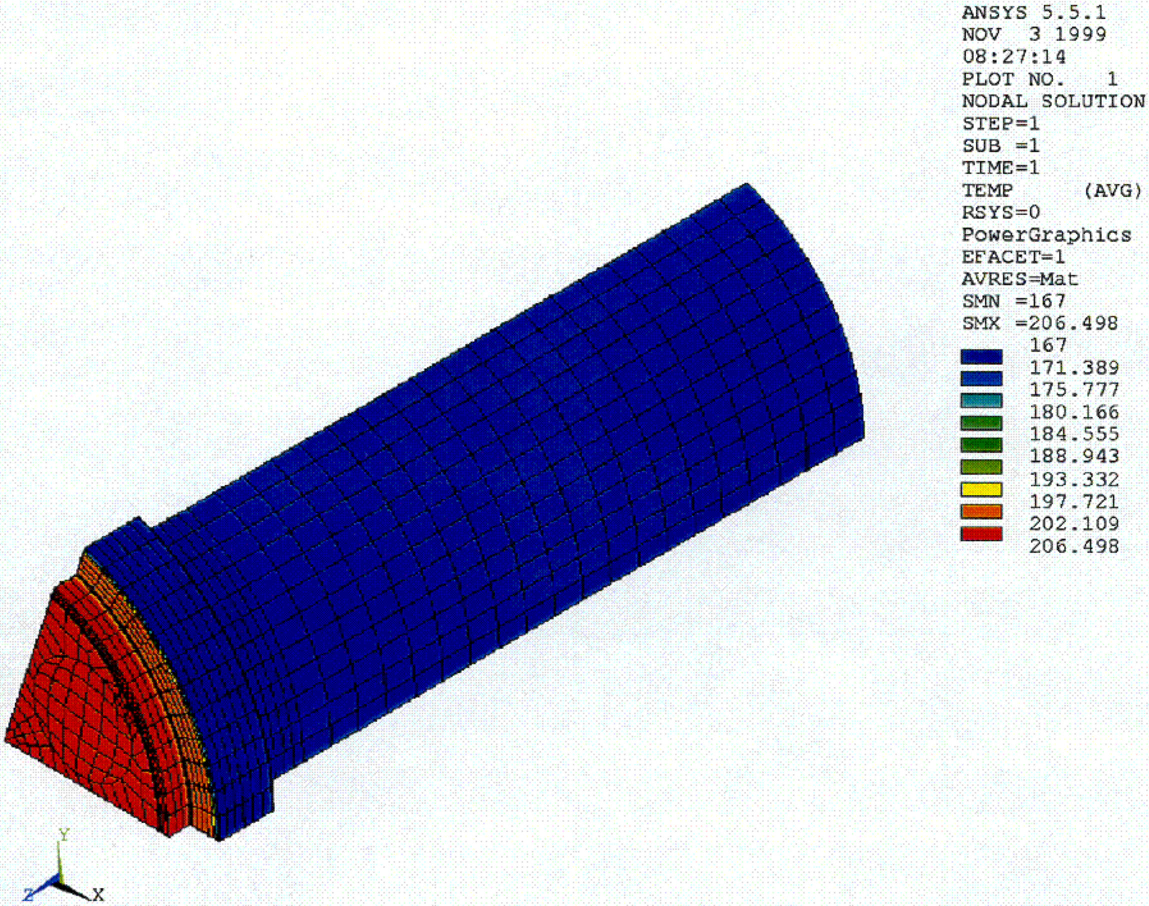
Figure 3-9 Oak Ridge Container Seal Region Boundary Condition Application





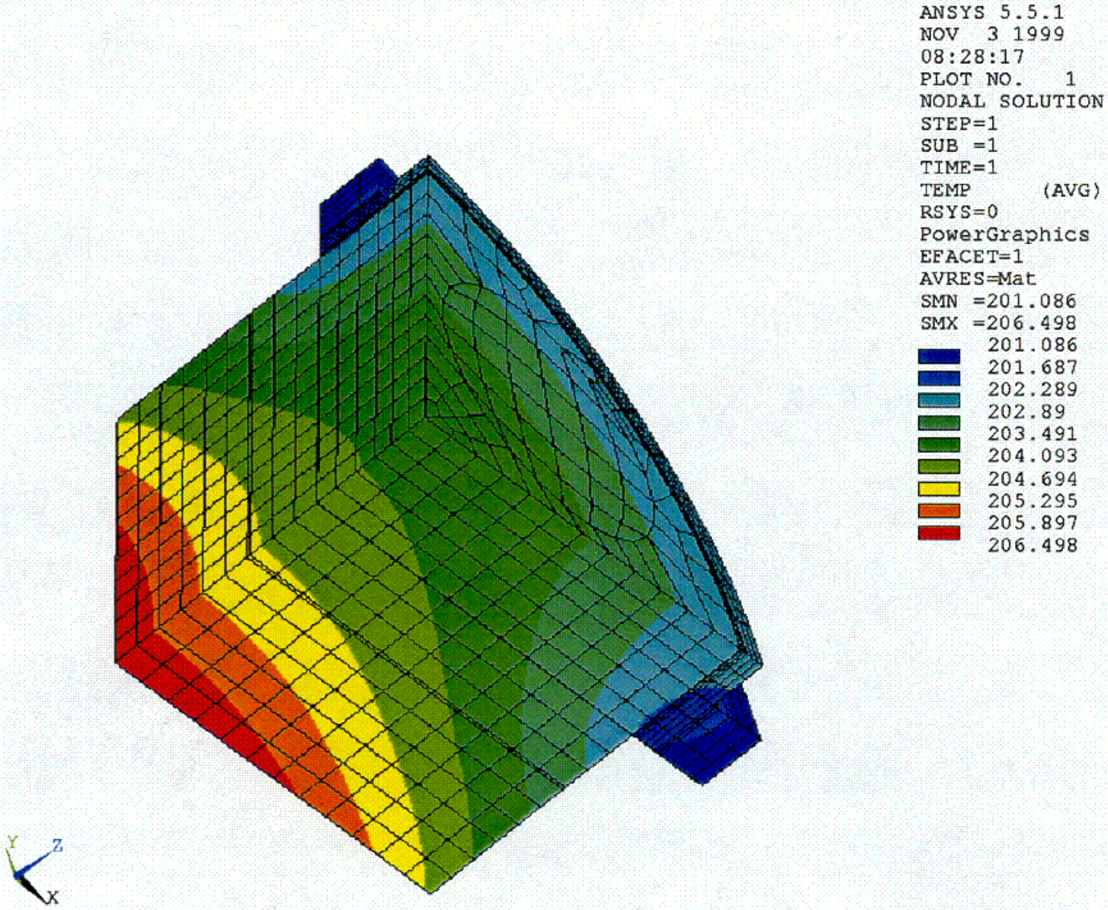
C13

Figure 3-10 Oak Ridge Container Seal Region Model, Temperature Distribution



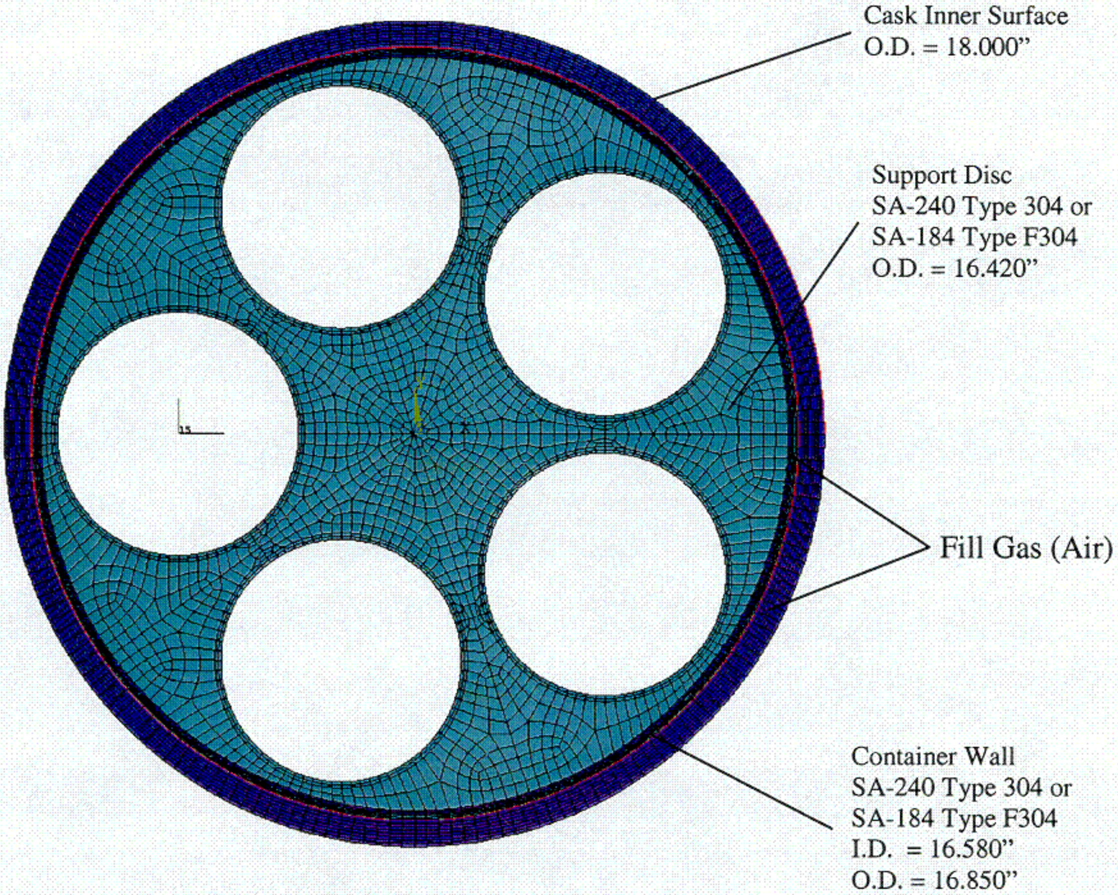
C14

Figure 3-11 Oak Ridge Container Seal Region Model, Temperature Distribution (Container Lid)



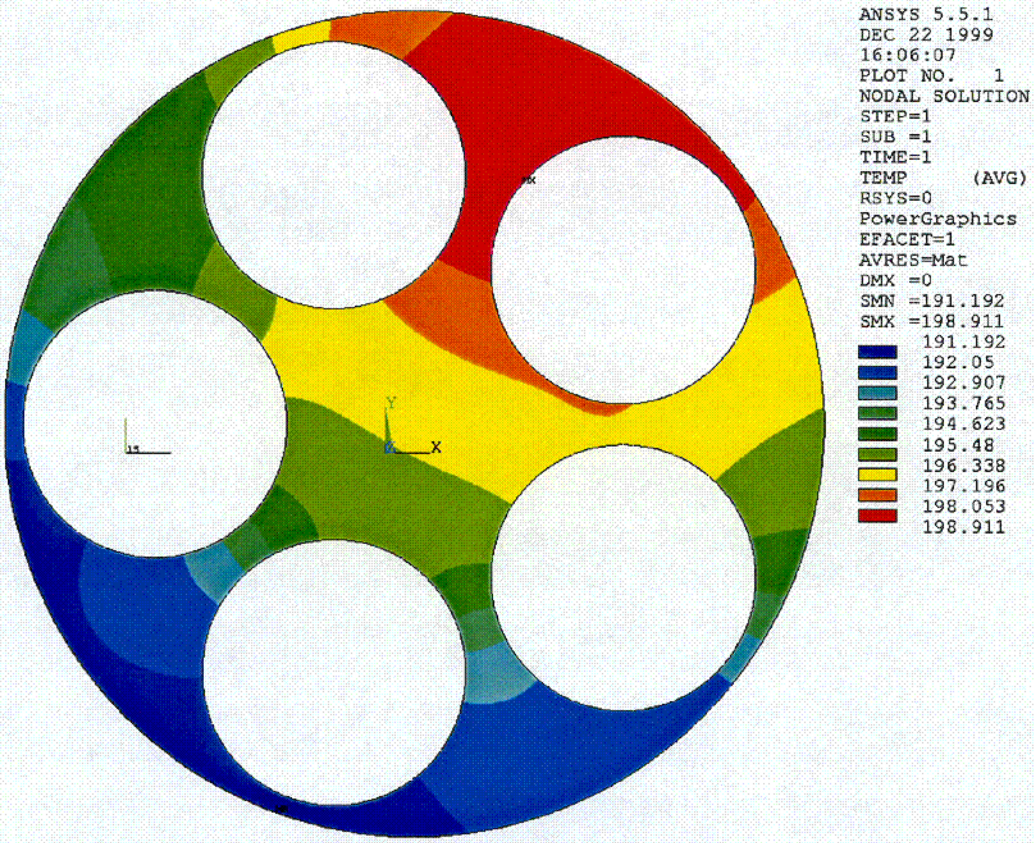
C15

Figure 3-12 Support Disc Thermal Gradient Model, Finite Element Model



C16

Figure 3-13 Support Disc Thermal Gradient Model, Temperature Distribution



C17

4.0 CONTAINMENT

The TN-FSV package with the Oak Ridge Container consists of two containment boundaries, i.e., a primary containment boundary provided by the TN-FSV cask and a secondary containment boundary provided by the Oak Ridge Container.

The description of the TN-FSV cask containment features and its containment requirements during normal and accident conditions of transport for the Fort St. Vrain container payload (Configuration 1) is presented in detail in the TN-FSV SAR, Chapter 4.0. For the Oak Ridge SNF payload, (Configuration 2), a design modification is made to the leakage requirement for the TN-FSV cask containment boundary (the primary containment boundary). This change 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 permit leak testing of the primary containment boundary of the package to the revised leakage requirement, the material for the elastomer seals of the cask has been changed from silicone to butyl. The applicable SAR drawings for the TN–FSV packaging have been revised to incorporate this design modification. The revised drawings are provided in Appendix 1.3. The revised seal material is the same as that used for the Oak Ridge Container seals. The properties of this seal material are evaluated in the appropriate sections to demonstrate that the containment function provided by the seals is maintained during normal conditions of transport and accident conditions.

The secondary containment boundary is provided by the Oak Ridge Container and is designed to satisfy the regulatory requirement specified in 10CFR71.63(b). A detailed description of the containment boundary and its requirements during normal and accident conditions are discussed below.

4.1 Containment Boundary

The containment boundary of the Oak Ridge Container consists of the ORC shell and bottom closure, shell flange, lid, lid bolts, vent port cover and bolts, the inner lid elastomer seal and the inner vent port cover elastomer seal. The containment boundary is shown in Figure 4-1. The construction of the containment boundary is shown on drawings 3044-70-2 and –6 provided in Chapter 1.0. The containment vessel provides a leak-tight boundary around the ORC cavity, and prevents the leakage of radioactive material from the ORC.

4.1.1 Containment Vessel

The containment vessel consists of: a shell which is a welded cylinder with an integrally-welded bottom closure; a welded flange forging; a bolted lid with bolts; and a vent port cover with bolts. The overall containment vessel length is 198 inch with a wall thickness of 10 gage (0.135 inch). The cylindrical cavity has a diameter of 16.58 inch and a length of 190 inch.

The materials for the containment shell, bottom closure, shell flange and lid are 300 series stainless steel.

The ORC design, fabrication and testing are performed under Transnuclear's Quality Assurance Program which conforms to the criteria in Subpart H of 10CFR71.

The materials of construction meet the requirements of Section III, Subsection WB-2000 and Section II, material specifications or the corresponding ASTM Specifications. The containment vessel is designed to the ASME Code, Section III, Subsection WB, Article 3200. The containment vessel is fabricated and examined in accordance with WB-2500, WB-4000 and WB-5000. Also, weld materials conform to WB-2400 and the material specification requirements of Section II, Part C of ASME B&PV.

It is the intent to follow Section III, Subsection WB of the Code as closely as possible for design and construction of the containment vessel. The ORC may, however, be fabricated by other than N-stamp holders and materials may be supplied by other than ASME Certificate Holders. Thus, the requirements of NCA are not imposed. TN's quality assurance requirements, which are based on 10CFR71 Subpart H and NQA-1 are imposed in lieu of the requirements of NCA-3850. This SAR is prepared in place of the ASME design and stress reports. Surveillance is performed by Transnuclear and DOE personnel rather than by an Authorized Nuclear Inspector (ANI).

The materials of the Oak Ridge Container will not result in any significant chemical, galvanic, or other reaction as discussed in Chapter 2.

4.1.2 Containment Penetrations

There is one penetration through the containment boundary, i.e., the vent port through the lid. This penetration is provided with a quick-connect coupling for ease of operation. Containment is provided by a 0.75 inch thick, 4.31 inch diameter blind flange with four 0.25 inch bolts and two elastomer o-rings.

The vent port cover (blind flange) is fabricated from 300 series stainless steel.

4.1.3 Seals and Welds

The following seals form part of the containment boundary:

- the inner butyl o-ring on the lid
- the inner butyl o-ring on the vent port cover

Both containment boundary seals are face-mounted in dovetail grooves on the lid and vent port cover. The volume of the grooves is designed to allow sufficient room so the mating metal surfaces can be brought into contact by the bolts, thereby ensuring uniform seal deformation. All surfaces in contact with the seals are machined to a 63 microinch (maximum) R_a surface finish or better.

Both seals are protected from damage during the normal transport and hypothetical thermal accident by the TN-FSV packaging which fully encloses the Oak Ridge Container. Seal temperatures are maintained within the allowable operating range during normal transport and accident conditions as demonstrated in Chapter 3.0.

The lid and the vent port cover are provided with two concentric o-rings with access to the annular space between them provided for leak testing. The outer o-rings are not considered part of the containment boundary.

The following welds are part of the containment:
- the longitudinal and circumferential (if applicable) weld(s) of the shell
- the circumferential welds between the bottom and the shell
- the circumferential weld between the flange and the shell

All welding is performed in accordance with the requirements of the ASME Boiler and Pressure Vessel Code Section III, Subsection WB-4400. Non-destructive examination includes radiographic and liquid dye penetrant methods using the acceptance standard of ASME Section III, Subsection WB-5000.

4.1.4 Closure

The closure devices consist of the lid, the vent port cover, and their associated o-rings and bolts. Bolt installation torque values are selected to achieve compression of the o-rings resulting in metal-to-metal contact between the lid or cover and the corresponding mating surface. Torque values are listed on drawing 3044-70-1 provided in Chapter 1.0. As demonstrated in Chapter 2.0, hypothetical accidents will not result in yielding of any closure bolts, ensuring that the same degree of sealing is provided under both normal and accident conditions.

The lid is closed by twelve 0.50-13UNC-2A x 2.75 in. bolts equally spaced on a 19.07 in. diameter bolt circle. The vent port cover is closed by four 0.25 in. diameter bolts.

4.2 Requirements for Normal Conditions of Transport

4.2.1 Containment of Radioactive Material

The spent fuel contents of the Oak Ridge Container consist of sectioned rods, HTGR compacts, and KEMA microspheres in the Oak Ridge canisters or Peach Bottom gas-cooled reactor elements (in aluminum canisters). The contents do not contain significant amounts of the following potential sources of releasable gases into the containment:

- fill gas from the SNF rods
- fission product gases released from the SNF
- saturated vapor from the SNF material including absorbed water vapor
- helium from the α-decay of the SNF contents
- hydrogen and other gases from radiolysis or chemical reactions
- hydrogen and other gases from the dehydration, or decomposition of SNF material

A more extensive description of the contents and the canisters is provided in Section 1.2.3 of this SAR addendum.

Although Appendix 2.11.7 demonstrates that the Oak Ridge canisters confine the fissile materials for criticality control, no credit is taken for the containment of the isotopic materials inside the canisters, and all activity is assumed to be releasable into the Oak Ridge Container. Any material released from the canisters will be contained inside the ORC containment boundary.

The requirements for normal conditions of transport are:

(a) no loss or dispersal of radioactive contents as demonstrated to a sensitivity of 10^{-6} A_2 per hour (10 CFR 71.51), and
(b) no loss or dispersal of plutonium from the inner ORC as demonstrated to a sensitivity of 10^{-6} A_2 per hour (10 CFR 71.63).

These requirements are met by demonstrating that the Oak Ridge Container is leak-tight for normal conditions of transport (see structural and thermal evaluations in Chapter 2.0 and Chapter 3.0 respectively).

4.2.2 Pressurization of Containment Vessel

The Oak Ridge Container and the TN-FSV cask cavity will be evacuated and filled with dry air at the end of loading. The operational procedure guidelines for conducting these activities are provided in Chapter 7.0. The mechanism contributing to containment pressurization is ideal gas heating only. Organic materials are excluded from the contents of the canisters to be loaded in the TN-FSV basket. Radiolysis from the residual water vapor in the canisters is negligible and there will be no flammable gas hazard.

Assuming the canisters and the ORC are closed at 70°F and 1 atm abs., the maximum normal operating pressure (MNOP) is calculated from the ideal gas law.

The average gas temperature in the ORC under normal conditions is 183°F (Section 3.3). The pressure of the gas in the cavity is (643/530)(14.7) = 17.8 psia = 3.1 psig. The MNOP is therefore 3.1 psig.

The average cavity gas temperature in the TN-FSV cask cavity under normal conditions is 171°F (Section 3.3). The pressure of the cavity gas is (631/530)(14.7) = 17.5 psia = 2.8 psig.

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.

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 N14.5-1977, 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 5×10^{-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.

4.3.3 Containment Criterion

The leak test requirements for accident conditions are the same as those listed in Section 4.2.3 for normal conditions of transport.

4.4 Special Requirements

None required.

4.5 References

1. Leakage Tests on Packages for Shipment, American National Standards Institute, ANSI N14.5-1997.

Figure 4-1 Oak Ridge Container Containment Boundary Components

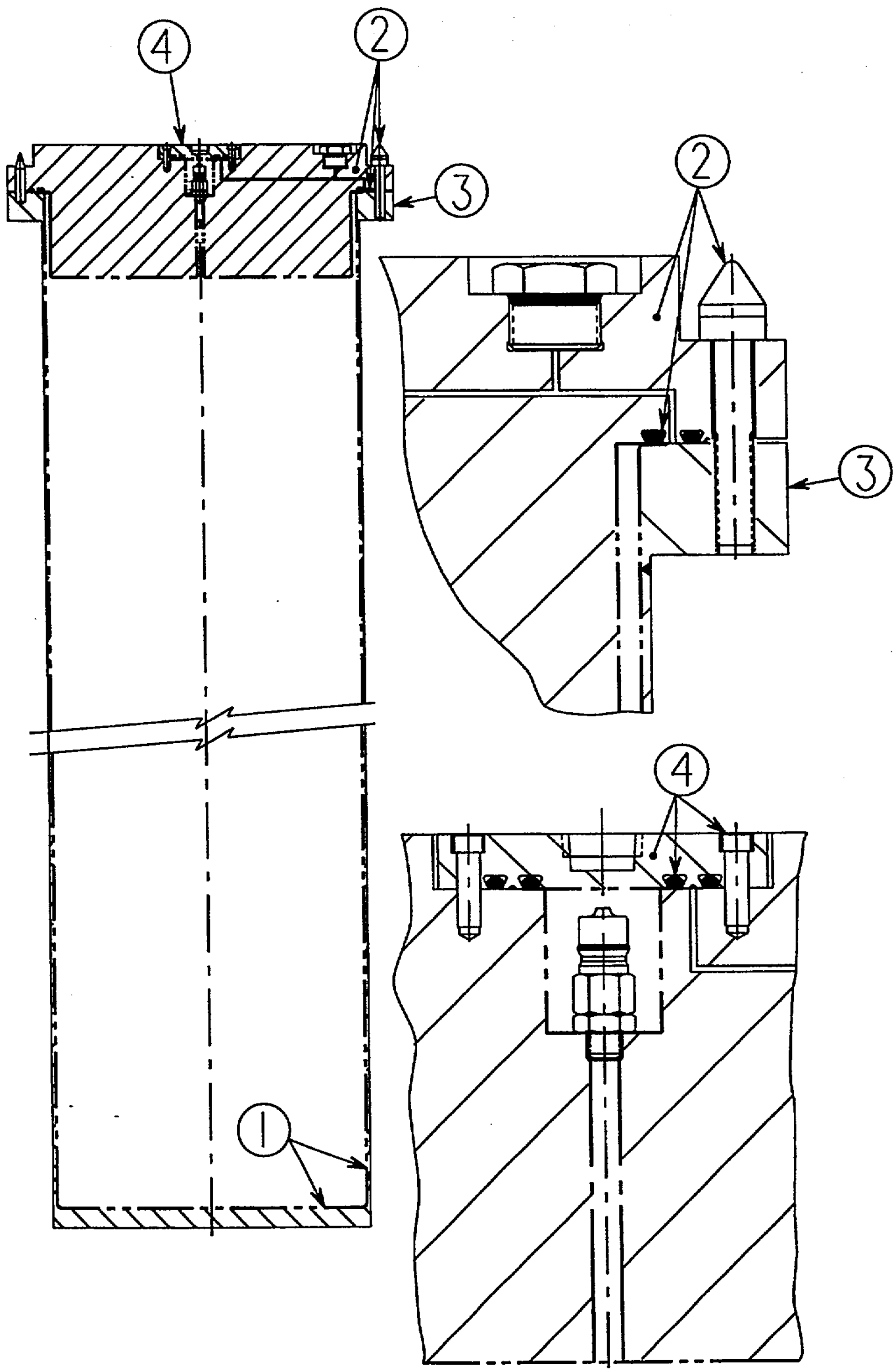


Figure 4-1 Oak Ridge Container Containment Boundary Components
(continued)

Notes:

- Drawing not to scale. Features exaggerated for clarity.
- Dashed line (— - - — - - — - - — - -) indicates containment boundary.
- Containment boundary components are listed below:

1. ORC shell with bottom closure
2. Lid, lid bolts & inner o-ring
3. Bolting flange
4. Vent port cover, bolts & inner o-ring

5.0 SHIELDING EVALUATION

5.1 Discussion and Results

An evaluation of the shielding performance of the Oak Ridge Container (ORC) in the TN-FSV cask is performed to demonstrate compliance with the dose rate limits of 10CFR71.47 for normal conditions and 10CFR71.51(a)(2) for accident conditions. A detailed description of the shielding characteristics of the TN-FSV packaging is provided in Chapter 5.0 of the SAR.

The shielding design feature of the TN-FSV cask is the cask body consisting of an inner shell of stainless steel, surrounded by lead and an outer shell of stainless steel. The lid and the bottom of the cask provide shielding in the axial direction. The impact limiters, which consist of wood in stainless steel cases, provide additional axial shielding. The thermal shield, which is a stainless steel shell surrounding the cask body, provides additional radial shielding. The stainless steel Oak Ridge Container shell and the fuel compartments provide additional radial shielding. In the axial direction, the stainless steel Container lid and bottom provide shielding. Shielding credit is also taken for the stainless steel fuel compartment bottom.

The Oak Ridge canister provides only a modest amount of shielding since the thickness of shell and closure plates is not intended to shield the SNF materials in the canisters (i.e., remote handling of canisters is required). The variety of SNF materials that may be in the Oak Ridge canisters requires that the amounts of gamma- and neutron-emitting radionuclides present be limited to ensure that transport limits on dose rates outside of the TN-FSV cask will not be exceeded. This is achieved by controlling the materials placed in each canister (e.g., restricting activated metal that would be a large Co-60 source) and by estimating the curies present in the contents using records of the burnup and cooling history for the materials.

Using these curie estimates for the Oak Ridge canisters, the dose rates for a representative load of canisters in the Oak Ridge Container and TN-FSV cask are calculated in Appendix 5.6.1. The results from this calculation are presented in Table 5-1. The expected dose rates are well below (less than one-half of) the nearest limit (i.e., <5 mrem/hr at 2 meters from the edge of the vehicle in comparison to the limit of 10 mrem/hr at this location for normal conditions of transport). At other locations and for accident conditions, the expected dose rates are smaller fractions of the limits.

In addition to this calculation of the estimated dose rates outside of the loaded TN-FSV cask, after loading and closure of an Oak Ridge canister, a check is made of each loaded canister to ensure that the surface radiation level is less than the amount which will result in acceptable dose rates once loaded into the Oak Ridge Container and TN-FSV cask. This provides a preliminary check to ensure that after the canisters are loaded into the cask, the radiation levels for the loaded cask will meet the applicable regulatory requirements.

While the surface dose rate checks do not replace the required pre-shipment radiation surveys to confirm compliance with the values in the regulations, these measurements do help to maintain radiation exposures to workers as low as reasonably achievable (ALARA) by preventing unnecessary radiation exposures to workers from having to unload and then reload a cask.

The highest surface dose rate that is acceptable during the "screening" measurement of each loaded canister was determined by a series of calculations described in Section 5.4. The 1-D SAS1 module of SCALE 4.4[(1)] was used to obtain the source term for 20 Oak Ridge canisters that would result in gamma dose rates for the loaded TN-FSV cask that just meets the 10CFR71 dose rate limits. The 1-D SAS1 module was also used to obtain the source term for the 20 canisters that would result in neutron dose rates for the TN-FSV cask that just meets the 10CFR71 dose rate limits. For each type of radiation, the dose rates at the side, top, and bottom of the TN-FSV cask were evaluated at the surface of the cask, at the surface of the impact limiter, and at a distance of 2 meters from the edge of the vehicle.

The source term for the set of 20 loaded Oak Ridge canisters was then used to determine the source term for an individual canister which would just meet the 10CFR71 dose rate limits once loaded into the TN-FSV cask. The SAS1 calculations thus provide a source term for a canister that would ensure a loaded cask would not exceed the regulatory dose rate limits of 200 mrem/hr at the surface and 10 mrem/hr at 2 meters. However, because the dose rate is directly proportional to the source, the source terms in the radial and in the two axial directions were obtained independently. From the results obtained for the three different directions (side, top, and bottom of the cask) and for the two different locations (surface and at 2 meters), the most restrictive of the source term and location combinations was identified. The radial source term at 2 meters is most restrictive and the values obtained for the other combinations of directions and location were not used further.

Since the SAS1 calculations were performed assuming that the gamma dose and the neutron dose could each be the maximum allowable, the results of the SAS1 calculations provide the most restrictive gamma source term and also provide the most restrictive neutron source term. Since the regulatory limit is for total dose rate (gamma plus neutron), the total amount of each type of radiation that would just meet the limit was also determined.

The SAS4 module (3-D Monte Carlo) of SCALE 4.4 was used with these two most restrictive source terms, as determined from the SAS1 calculations, to calculate the surface dose rates for an Oak Ridge canister for both gamma rays and neutrons. Based on the SAS4 results, if only gamma sources would be present in an Oak Ridge canister, then the radial dose rate at the surface of the canister could be as high as 1.95E+06 mrem/hr and a loaded TN-FSV cask with 20 such canisters would not exceed any regulatory dose rate limit. Similarly, if only neutron sources would be present in an Oak Ridge canister, then the radial dose rate at the surface of the canister could be as high as 4.47E+02 mrem/hr and a loaded TN-FSV cask with 20 such canisters would not exceed any regulatory dose rate limit. Since materials emitting both types of materials are in the Oak Ridge canisters, the following equation is used to ensure that each Oak Ridge canister will be acceptable for transport in the TN-FSV cask.

The equation is the sum of the fractions rule using a value of 0.95 rather than 1.0 for additional conservatism.

Dose rate at the canister surface (radial direction):

$$\frac{\text{measured gamma dose rate (mrem/hr)}}{1.95\text{E}+06} + \frac{\text{measured neutron dose rate (mrem/hr)}}{447} < 0.95$$

The dose rates for the Oak Ridge canisters measured to date are shown in Table 1-3. Beta/gamma and neutron dose rates in the radial direction were measured for the canisters at the middle and near the top and bottom of the active fuel region. All measured canisters meet the dose rate values established by the screening equation shown above. Since the values for most canisters are significantly less than the screening value, the Oak Ridge Container when loaded with 20 Oak Ridge canisters will be well below the regulatory limits.

5.2 Source Specification

Because of the variety of contents in the Oak Ridge canisters, the specific source terms were not fully quantified. The variety of contents and lack of precise records on the irradiation of many of these sources made source calculations difficult at best. Therefore, the content of the samples was measured and representative source terms were generated and are reported in Appendix. 5.6.1.

The sources assumed in the prediction of screening dose rates for canister loading are discussed in this section. The same sources are used for the determination of canister loadings which produce the regulatory limiting dose rates for the TN-FSV cask. For the purposes of these predictions only representative spectra are needed. Due to the importance of the gamma ray contribution to the doses, a conservative spectrum was used for the photon calculations, while a representative spectrum was used for the neutron sources.

The gamma and neutron source in the SAS1 model is normalized to 1 particle/cc-s and used to back calculate the magnitude of the source based on meeting the 10CFR71 dose rate limits of 200 mrem/hr at the packaging surface and 10 mrem/hr at 2 meters from the packaging.

5.2.1 Gamma Source

For this evaluation, the gamma source is assumed to be mono-energetic at 1.25 MeV (Co-60). This should be generally conservative since for spent fuel decayed at least 5 years, the majority of the gamma dose comes from energies between 0.8 MeV and 1.5 MeV. The gamma spectra for the representative ORC loading in Appendix 5.6.1 shows that the majority of the source effecting dose rates is in the 0.6 to 0.8 MeV range. The source is placed into SCALE energy group 37 which has an average energy of 1.165 MeV. To compensate for the small, non-conservative difference in energy between the average energy group and the Co energy, the SAS1 results are multiplied by the ratio of 1.25/1.165.

5.2.2 Neutron Source

For the neutron spectra, the spectrum for ^{244}Cm is used in the 27 neutron energy group breakdown. Shown below is a typical Cm spectra for an LWR fuel assembly with 15 years decay. The neutron spectra for the representative ORC loading in Appendix 5.6.1 shows the spectra to be very similar to that given below.

Neutron Spectrum

Group No.	Energy (MeV)	Fraction
1	6.43 – 20.0	1.841E-02
2	3.00 – 6.43	2.099E-01
3	1.85 – 3.00	2.333E-01
4	1.40 – 1.85	1.310E-01
5	0.90 – 1.40	1.769E-01
6	0.40 –0.90	1.928E-01
7	0.10 – 0.40	3.773E-02

5.3 Model Specification

The models used are for the normal conditions of transport. This is because the components of the TN-FSV cask which are not an integral part of the cask 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 of the TN-FSV SAR.

5.3.1 Description of Radial and Axial Shielding Configuration

The one-dimensional SAS1 shielding analysis uses an infinite cylinder for the radial model and an infinite slab (disc) for the axial model. The TN-FSV cask diameter is used for a buckling correction in the axial models to account for a finite cask dimension. The radial model uses the minimum lead thickness determined from the tolerances on the inner and outer stainless steel shells. Two canister lengths plus a spacer (~85 in.) are modeled axially with a reflected boundary condition. The TN-FSV cask with the Oak Ridge Container is included in the radial and axial models.

The following dimensions are assumed for the Oak Ridge canister:

Outer diameter:	4.75 in.
Length:	34.75 in.
Wall thickness:	0.120 in.
Top closure plate:	0.38 in.
Bottom closure plate:	0.25 in.

Dimensions for the Oak Ridge Container are:

Container:	16.85 OD x 190.0 in.
Wall thickness:	0.135 in.
Bottom closure:	1.00 in. thick
Lid	7.00 in. thick
Fuel compartment:	5.563 OD x 189.88 in.
Wall thickness:	0.134 in.
Bottom	2.00 in. thick

Dimensions for the TN-FSV cask are consistent with Chapter 5.0 of the TN-FSV SAR.

The loading configuration (see Section 1.2.3) selected for the shielding evaluation is the four (4) Oak Ridge canisters per fuel compartment or twenty canisters per Container arrangement. The acceptable contact gamma and neutron doses rates calculated for this arrangement will be bounding when applied to the other loading arrangement because the Peach Bottom assembly has a very low gamma and neutron source in comparison to the Oak Ridge canister.

The following assumptions are made for the 1-D SAS1 model representing a 20 canister payload:

- A conservative value of only 200g of heavy metal was assumed per canister, although most canisters contain many times that mass of heavy metal.
- U-238 was selected to be the heavy metal (self-shielding).

The fuel compartment wall thickness was modeled discretely rather than being homogenized into the cavity source. Therefore, for the radial model, 20 canisters each with 200g of U-238 were homogenized into a volumetric annular source of 190.0" length and an outside diameter of 16.31" (container ID of 16.58 - fuel compartment wall 2*0.134). The inside diameter was the sum of the support tube OD (4") and the poison plate thickness (0.305"), 4.610". No other ORC hardware was included in the radial model. Also, the interspace between the Container and the TN-FSV cask cavity wall is modeled as a void with no shielding credit for the aluminum spacer in this gap.

Drawings in Appendix 1.4, and Figures 1-5 and 1-6 describe the Oak Ridge Container in detail and show the loading configuration in the TN-FSV cask. The shield layers and thickness used in the model are listed in Table 5-2. The SAS1 shielding models are shown in Figures 5-1 and 5-2 for the ORC in the cask. Figure 5-3 shows the Oak Ridge canister used for the SAS4 analysis.

5.3.2 Shield Regional Densities

The densities of SS304 and Uranium in the homogenized source are calculated for the SAS1 radial and axial models as follows:

Radial Model:

Source Volume = π $(8.155^2 - 2.305^2)$ x 190.0 x 2.54^3 = 5.987E5 cc

SS304 in canisters = π $(2.375^2 - 2.255^2)$ x 34.75 x 0.29 = 17.59 lbs/canister

SS304 for 20 canisters = 20 x 17.59 lb x 454 kg/lb = 159.7 kg/ORC

ρ_{ss304} = 1.597E5/5.978E5 = 0.267 g/cc

Uranium: $\rho_{U\text{-}238}$ = 200 x 20/5.987E5 = 0.0067 g/cc

Axial Model:

For the axial model (both top and bottom), an assumption is made that only the closest two rows of canisters contribute to the external doses and a reflected model of this is utilized. Included into the homogenized source volume are the axial flux spacers between the two layers of canisters, the canister top of the lower canister, and the bottom of the upper canister. Also as in the radial model, 200 g of U-238 are assumed in each canister.

Source volume: π x 8.155^2 x (34.75+34.5+16) x 2.54^3 = 2.919E5 cc

Spacers (5 in. OD x 1.7 in. thick): π x 2.5^2 x 1.7 x 5 x 0.29 x 454 = 2.197E4 g

Canister bottom (4.75 in. OD x 0.25 in. thick):
π x 2.375^2 x 0.25 x 0.29 x 454 x 5 = 2.916E3 g

Canister top (4.75 in. OD x 0.38 in. thick)
π x 2.375^2 x 0.38 x 0.29 x 454 x 5 = 4.433E3 g

SS304: ρ_{ss304} = (2.197E4 + 7.349E3)/2.919E5 = 0.1004 g/cc

Uranium: $\rho_{U\text{-}238}$ = 200 x 10/2.919E5 = 0.0068 g/cc

The steel components of the ORC and the TN-FSV cask are modeled as Type 304 stainless steel. The lead is modeled at 11.18 g/cc, 98.5% of the theoretical density to account for minor volume shrinkage after pouring. The wood in the impact limiters is modeled as balsa at 0.125 g/cc, with the chemical composition taken from the SCALE Standard Material Composition Library. These values used for the TN-FSV cask components are consistent with that reported in Chapter 5.0, Section 5.3.2 of the TN-FSV SAR.

The shielding model densities are summarized in Table 5-3.

5.4 Shielding Evaluation

The shielding evaluation is performed by calculating the dose rates at the top, bottom and radial directions so that the TN-FSV package meets the 10CFR71 dose rates during normal conditions of transport, i.e., 200 mrem/hr at the package surface and 10 mrem/hr at 2 meters from the accessible surface of the package. Dose rates under hypothetical accident conditions are normally less restrictive than normal conditions.

The evaluation performed is on the TN-FSV package containing 20 Oak Ridge canisters in the Oak Ridge Container. The SAS1 code is utilized to determine the dose rate at the surface and at 2 meters from the surface, in both the axial and radial directions, for unit gamma and neutron sources.

From the SAS1 results, a source term is obtained based on the 10CFR71 allowable dose rates, 200 mrem/hr at the surface and 10 mrem/hr at 2 meters for the accessible surface of the package. The source terms are obtained independently, assuming the gamma dose and neutron dose could each be the maximum allowable. The column headed *mrem/hr/p/cc-s* in Table 5-4 shows the dose rate results from the SAS1 for the unit sources. The next column in the table is simply the dose rate limit at the cask surface and 2 meters divided by the calculated dose rate per unit source per cc. This provides the allowable gamma and neutron source per cc for the various configurations. The next column takes the most restrictive volumetric source, at 2 meters, multiples it by the source volume to provide the allowable source in photons or neutrons per sec for the ORC. The last column in Table 5-4 shows the allowable source per canister by dividing the radial ORC source by 20 canisters and the top and bottom ORC sources by 10 canisters. As can be seen, the radial source at 2 meters is the most restrictive.

An additional SAS1 run was made for the neutron dose, substituting U-235 for the U-238 to investigate subcritical multiplication. The neutron dose rate results from the U-235 case was not significantly different (<1% greater) than the U-238 case results shown in Table 5-4.

A single Oak Ridge canister model is evaluated using the Monte Carlo computer code SAS4. The simple model is shown in Figure 5-3. The homogenized source density is 0.022 g/cc ^{238}U. The SAS4 calculated canister surface dose rate for a unit source is shown in the first column in Table 5-5. Using the most restrictive canister source term determined in Table 5-4, (radial), the second column in Table 5-5 shows the calculated radial dose rate on the canister. The values shown in this last column are those used for the "screening" equations shown in section 5.1.

Sample input files for the SAS1 and SAS4 calculations are included in the Appendix 5.6.2.

5.4.1 Radial Analysis

A cylindrical model is used for the radial calculations. The evaluation is based on meeting the 10CFR71 dose rate of 200 mrem/hr at the surface, and 10 mrem/hr at two meters from the vehicle edge. The vehicle width used for the analysis is 8 feet consistent with that used in the SAR, Section 5.4.1.

5.4.2 Axial Analysis

A reflected disk model with buckling correction for the finite cask outside diameter is used for the axial calculation.

5.5 References

1. SCALE-4.4, Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation for Workstations and Personal Computers, CCC-545, ORNL.

2. MCNP4B2, "Monte Carlo N-Particle Transport Code System.", Los Alamos National Laboratory, CCC-660, RSIC

3. Shultis, J.K. and R.E. Faw, *Radiation Shielding*, Prentice-Hall, Upper Saddle River, New Jersey, 1996.

Table 5-1 Summary of Dose Rates for Reference Oak Ridge Container (Exclusive Use)

Normal Conditions	Package Surface mSv/h (mrem/h)			Impact Limiter Surface mSv/h (mrem/h)			2 Meter from Vehicle mSv/h (mrem/h)		
Radiation	Top	Side	Bottom	Top	Side	Bottom	Top	Side	Bottom
Gamma	0.018 (1.8)	0.63 (63)	0.009 (0.9)	0.018 (1.8)	0.150 (15)	0.009 (0.9)	-	0.022 (2.2)	-
Neutron	0.003 (0.3)	1.02 (102)	0.001 (0.1)	0.003 (0.3)	0.200 (20)	0.001 (0.1)	-	0.027 (2.7)	-
Total	0.021 (2.1)	1.65 (165)	0.010 (1.0)	0.021 (2.1)	0.350 (35)	0.010 (1.0)	-	0.049 (4.9)	-
Limit	2 (200)	2 (200)	2 (200)	2 (200)	2 (200)	2 (200)		0.1 (10)	

Hypothetical Accident Conditions	1 Meter from Package Surface* mSv/h (mrem/h)		
Radiation	Top	Side	Bottom
Gamma	< 0.019 (1.9)	< 0.150 (15)	< 0.01 (1.0)
Neutron	< 0.003 (0.3)	< 0.200 (20)	< 0.001 (0.1)
Total	< 0.022 (2.2)	< 0.350 (35)	< 0.011 (1.1)
Limit	10 (1000)	10 (1000)	10 (1000)

* - Dose rates calculated on impact limiter surface

Table 5-2 Shielding Configurations

Radial		Axial, Top		Axial, Bottom	
0.13 inch steel	(1)	0.38 inch steel	(13)	0.25 inch steel	(13)
0.13 inch steel	(3)	7.00 inch steel	(4)	1.00 inch steel	(5)
1.12 inch steel	(6)	0.56 inch Al	(10)	2.00 inch steel	(2)
3.38 inch lead	(7)	2.5 inch steel	(10)	5.5 inch steel	(11)
1.50 inch steel	(8)	0.25 inch steel	(12)	0.25 inch steel	(12)
0.25 inch steel	(9)	19.37 inch balsa	(12)	19.37 inch balsa	(12)
		0.19 inch steel	(12)	0.19 inch steel	(12)

(1) Fuel compartment tube
(2) Fuel compartment bottom
(3) Oak Ridge Container shell
(4) Oak Ridge Container lid
(5) Oak Ridge Container bottom
(6) TN-FSV cask inner shell
(7) TN-FSV cask minimum lead thickness
(8) TN-FSV cask outer shell
(9) TN-FSV cask thermal shield
(10) TN-FSV cask lid/Al. spacer
(11) TN-FSV cask bottom
(12) TN-FSV cask impact limiter
(13) Oak Ridge canister top/bottom

Table 5-3 Source and Shield Material Densities

ZONE	MATERIAL	DENSITY	
		g/cc	atoms/b.cm
Source:			
Radial	U-238	0.0067	1.695E-5
SS304		0.267	
	Iron (69.5)		1.969E-3
	Nickel (9.5)		2.602E-4
	Chromium (19)		5.875E-4
	Manganese (2)		5.853E-5
Axial	U-238	0.0068	1.720E-5
SS304		0.1004	
	Iron (69.5)		7.403E-4
	Nickel (9.5)		9.787E-5
	Chromium (19)		2.209E-4
	Manganese (2)		2.201E-5
Lead	Lead	11.18	3.247E-2
Balsa Wood	Hydrogen (6)	0.125	4.646E-3
	Carbon (44)		2.787E-3
	Oxygen (50)		2.323E-3
304SS	Iron (69.5)	7.94	5.854E-2
	Nickel (9.5)		7.740E-3
	Chromium (19)		1.747E-2
	Manganese (2)		1.741E-3
Aluminum	Aluminum	2.70	6.031E-2

Table 5-4 SAS1 Analyses Results

(1-D SAS1) Oak Ridge Container in the TN-FSV Cask

source volume (cc)		(mrem/hr/p/cc-s)			Source (p/cc-s)		Source (p/s)	Source (p/s/canister)
		surface	1 meter	2 meter	surface	2 meter	(2 meter)	
			gamma					
5.99E+05	Radial	1.59E-06	3.83E-07	1.45E-07	1.26E+08	6.91E+07	4.14E+13	**2.07E+12**
2.92E+05	Top	1.79E-07	5.36E-08	1.64E-08	1.12E+09	6.11E+08	1.78E+14	1.78E+13
2.92E+05	Bottom	8.56E-07	2.49E-07	7.52E-08	2.34E+08	1.33E+08	3.88E+13	3.88E+12
			neutron					
5.99E+05	Radial	6.28E-01	1.27E-01	4.10E-02	3.19E+02	2.44E+02	1.46E+08	**7.31E+06**
2.92E+05	Top	1.05E-02	1.82E-03	5.22E-04	1.91E+04	1.91E+04	5.59E+09	5.59E+08
2.92E+05	Bottom	2.30E-02	3.94E-03	1.12E-03	8.68E+03	8.89E+03	2.60E+09	2.60E+08
				Dose Limit =	200	10		

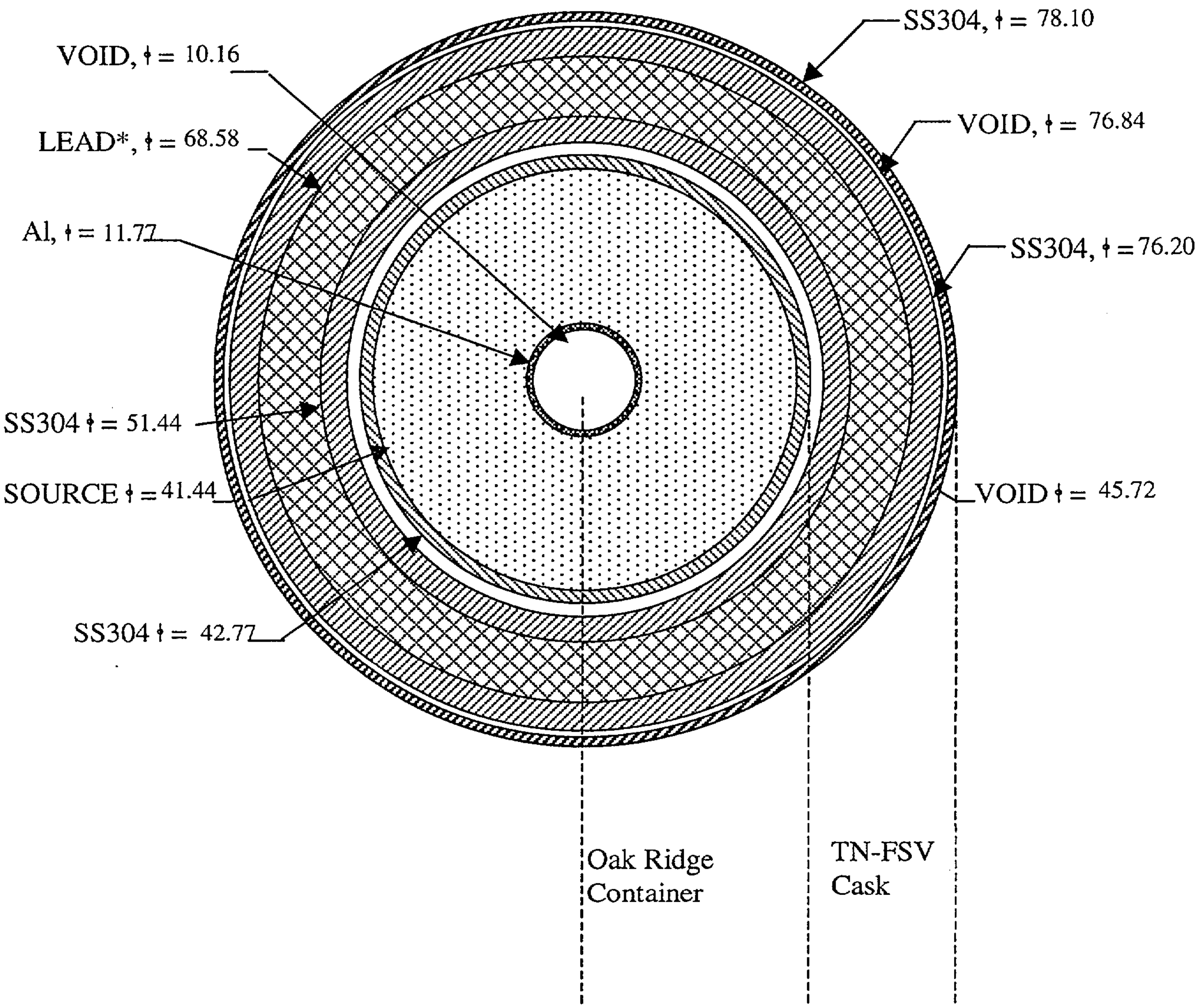
Table 5-5 SAS4 Analysis Results

Dose Rates on Canister Surface from SAS4 (Monte Carlo)

	Gamma	Neutron	Gamma[1]	Neutron[1]
	(mrem/hr/p/s)		(mrem/hr)	
Radial	9.41E-07	6.11E-05	1.95E+06	4.47E+02

1- based on most restrictive source term determined in Table 5-4 above.

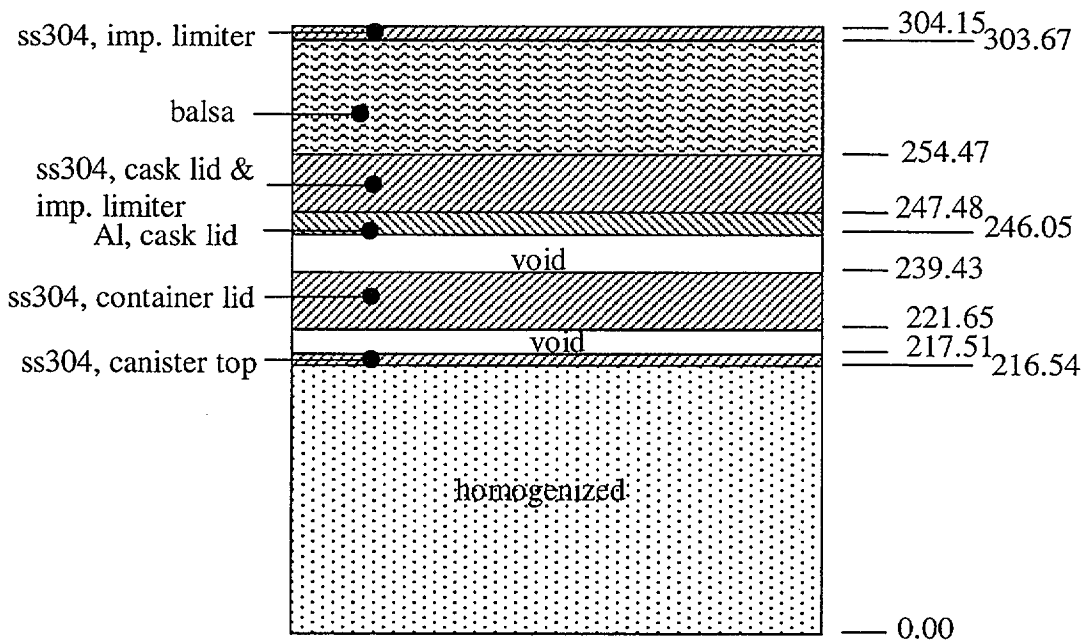
Figure 5-1 Shielding Model – Radial



All dimensions are in cm.
*Minimum lead thickness = 3.38 in.

Figure 5-2 Shielding Models, Axial

Top



Bottom

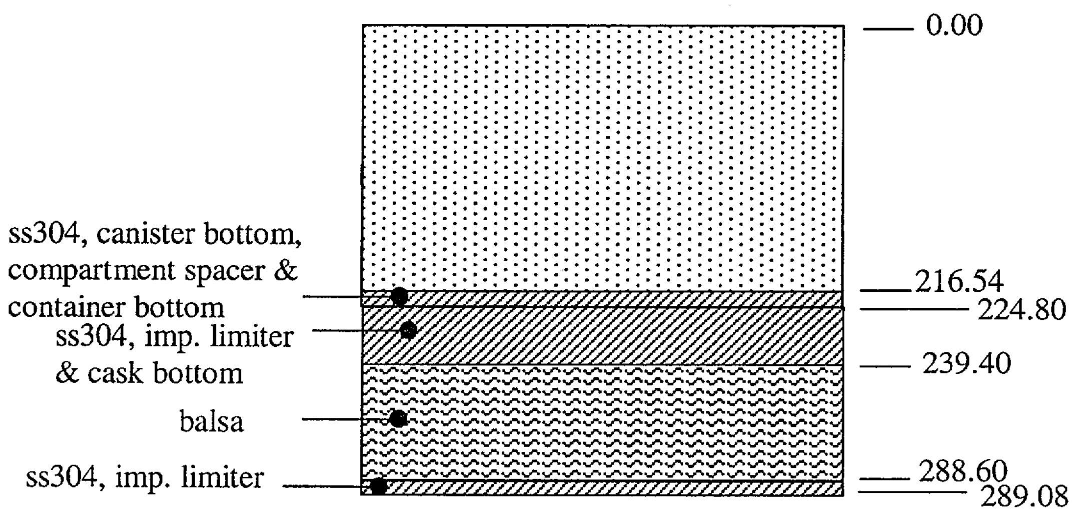
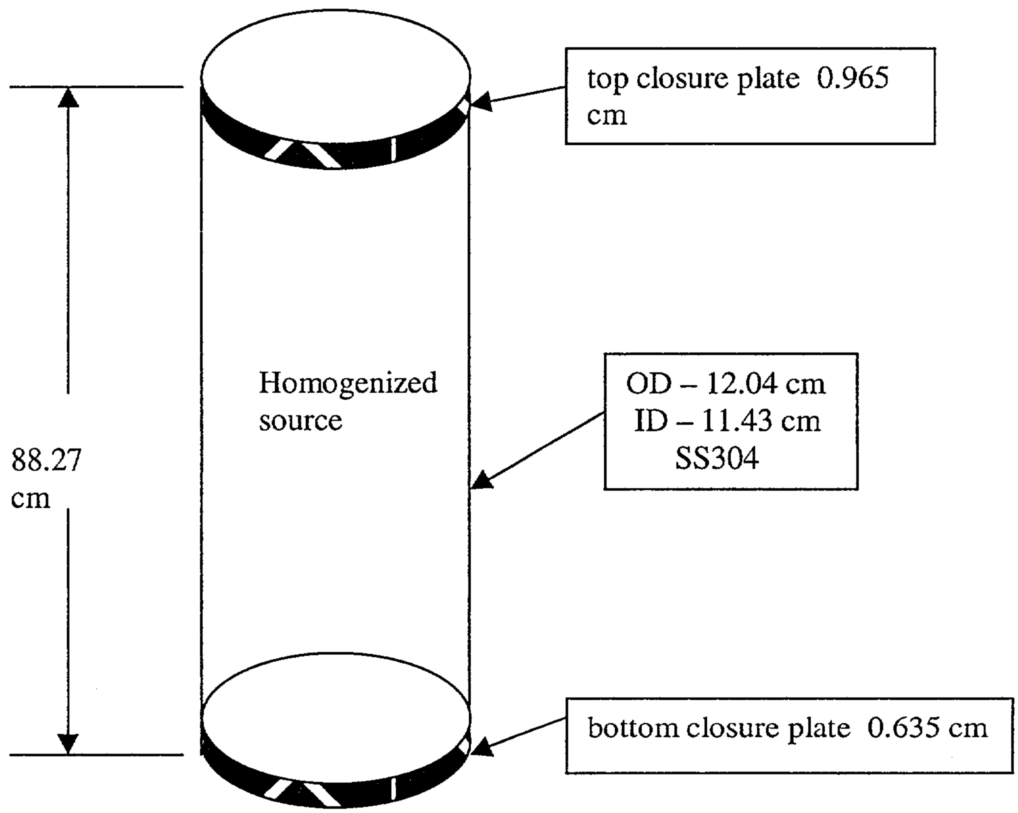


Figure 5-3 Oak Ridge Canister Model



5.6 Appendix

5.6.1 Dose Rates for Representative Loading of Oak Ridge Container

5.6.1.1 Discussion and Results

Dose rates around the TN-FSV packaging containing the Oak Ridge Container (ORC) are determined for a representative loading of the ORC. The computer code MCNP[2] is utilized to calculate the dose rates. Dose rates are calculated at the package surface, at the impact limiter surface or projected plane, and at two meters from the trailer edge.

Based on the information presented in Table 1-3 for the Oak Ridge canister contents, and the projected loading arrangements that meet all applicable constraints for the ORC, three canisters are chosen to be representative of the major fuel types (high temperature gas cooled reactor, light water reactor, and fast reactor) and the associated source terms for the planned shipments. The representative case evaluated assumes that twenty canisters are loaded into the ORC, five canisters in a layer with four layers in the ORC. Each canister layer is separated by a flux trap spacer. The first or bottom layer is assumed to be five canisters represented by the contents of canister CAN-GSF-213, which contains fast reactor fuel materials. The second and third layers are represented by the contents of canister CAN-GSF-196 which contains light water reactor fuel materials. The second layer is assumed to contain one canister that is represented by one-half the contents of canister CAN-GSF-196 and four canisters that are represented by one-quarter of the contents of canister CAN-GSF-196. The third layer is assumed to contain one canister CAN-GSF-196 and four canisters that are represented by one-half the contents of canister CAN-GSF-196. The fourth or top layer is assumed to contain five canisters represented by the contents of canister CAN-GSF-182, which contains high temperature gas cooled reactor fuel material. The total activity in this representative loading is 36,760 curies, which is about 110% of the maximum anticipated radionuclide inventory in any of the five planned shipments.

The canisters are homogenized into annular sources for the MCNP model. Each layer of source is separated by a flux trap spacer. A separate MCNP model is utilized to calculate the gamma and neutron dose rates around the TN-FSV package. For the accident conditions, Appendix 2.11-8 of this Addendum shows that a lead slump of approximately 1.9" occurs. An accident condition MCNP model with a 2" void at the top and bottom of the lead column is utilized to calculate dose rates under the accident condition.

The calculated dose rates for the TN-FSV packaging containing the ORC with a representative canister loading are presented in Table 5-1. The results of the accident condition dose rate calculation show no significant change in the dose rates around the middle of the package; however, the dose rates on the OD of the top and bottom impact limiters increase from 1 to 3 mrem/hr for normal conditions to around 20 mrem/hr due to the lead slump.

5.6.1.2 Source Specification

Three different canisters are chosen from Table 1-3 to be used as sources for the representative case. The canisters selected are GSF-213, GSF-196 and GSF-182. The fully loaded curie content of each canister was used to generate a gamma and neutron spectrum, 18 and 27 groups respectively, using the SCALE ORIGEN-S computer code. The gamma and neutron spectrum are shown in the tables below for 20 years of decay. This is a conservative decay for the Oak Ridge canisters, since much of the fuel is closer to 30 years out of the reactor. Note, only twelve gamma groups and seven neutron groups have significant contribution to the dose rate and are included in the analysis.

Oak Ridge Canisters
Gamma Spectrum

	Energy (MeV)			GSF-182 γ/s/can	GSF-182 fraction	GSF-196 γ/s/can	GSF-196 fraction	GSF-213 γ/s/can	GSF-213 fraction
1	1.00E-02	to	5.00E-02	2.10E+12	0.28314	2.43E+13	0.28351	4.01E+11	0.28524
2	5.00E-02	to	1.00E-01	6.09E+11	0.08213	7.09E+12	0.08386	1.67E+11	0.11882
3	1.00E-01	to	2.00E-01	4.25E+11	0.05733	4.92E+12	0.05726	7.67E+10	0.05461
4	2.00E-01	to	3.00E-01	1.25E+11	0.01687	1.45E+12	0.01686	2.27E+10	0.01615
5	3.00E-01	to	4.00E-01	8.09E+10	0.01091	9.36E+11	0.01092	1.46E+10	0.01042
6	4.00E-01	to	6.00E-01	8.20E+10	0.01107	9.53E+11	0.01106	1.47E+10	0.01049
7	6.00E-01	to	8.00E-01	3.82E+12	0.51496	4.41E+13	0.51309	6.77E+11	0.48182
8	8.00E-01	to	1.00E+00	6.88E+10	0.00928	8.02E+11	0.00922	1.24E+10	0.00881
9	1.00E+00	to	1.33E+00	9.98E+10	0.01347	1.16E+12	0.01336	1.80E+10	0.01283
10	1.33E+00	to	1.66E+00	6.13E+09	0.00083	7.14E+10	0.00082	1.10E+09	0.00079
11	1.66E+00	to	2.00E+00	2.11E+08	0.00003	2.44E+09	0.00003	3.81E+07	0.00003
12	2.00E+00	to	2.50E+00	1.05E+07	0.00000	1.21E+08	0.00000	1.90E+06	0.00000
			total	7.41E+12	1.0000	8.57E+13	1.0000	1.40E+12	1.0000

Oak Ridge Canisters
Neutron Spectrum

	Energy (MeV)			GSF-182 n/s/can	GSF-182 fraction	GSF-196 n/s/can	GSF-196 fraction	GSF-213 n/s/can	GSF-213 fraction
1	6.43E+00	-	2.00E+01	1.10E+04	0.01835	1.27E+05	0.01832	2.05E+03	0.01729
2	3.00E+00	-	6.43E+00	1.25E+05	0.20951	1.46E+06	0.20985	2.50E+04	0.21033
3	1.85E+00	-	3.00E+00	1.40E+05	0.23448	1.63E+06	0.23477	2.99E+04	0.25201
4	1.40E+00	-	1.85E+00	7.82E+04	0.13112	9.10E+05	0.13107	1.56E+04	0.13160
5	9.00E-01	-	1.40E+00	1.05E+05	0.17666	1.23E+06	0.17643	2.03E+04	0.17084
6	4.00E-01	-	9.00E-01	1.15E+05	0.19225	1.33E+06	0.19199	2.17E+04	0.18229
7	1.00E-01	-	4.00E-01	2.25E+04	0.03763	2.61E+05	0.03758	4.23E+03	0.03564
			total	5.97E+05	1.0000	6.94E+06	1.0000	1.19E+05	1.0000

Gamma Source

	Canister ID	# of Canisters*	γ/s/Canister	total γ/s
Layer 1	GSF-213	5	1.40E+12	7.00E+12
Layer 2	GSF-196	1.5	8.57E+13	1.29E+14
Layer 3	GSF-196	3	8.57E+13	2.57E+14
Layer 4	GSF-182	5	7.41E+12	3.70E+13
				4.30E+14

* - equivalent fully loaded Canisters

Neutron Source

	Canister ID	# of Canisters*	n/s/Canister	total n/s
Layer 1	GSF-213	5	1.19E+05	5.95E+05
Layer 2	GSF-196	1.5	6.94E+06	1.04E+07
Layer 3	GSF-196	3	6.94E+06	2.08E+07
Layer 4	GSF-182	5	5.97E+05	2.98E+06
				3.48E+07

* - equivalent fully loaded canisters

5.6.1.3 Model Specification

Model Description

The 3-dimensional MCNP model for the TN-FSV cask is based on information and dimensions given in the SAR. The internal steel gussets in the impact limiters are ignored and the wood is all assumed to be balsa wood. The upper trunnion pockets are modeled as cylindrical holes rather than the completed actual geometry. As in Chapter 5 of the SAR, the lead is modeled at a reduced density and at the minimum dimension. For the Configuration 2, Oak Ridge Container, the aluminum spacer at the bottom of the cask is not utilized and the aluminum spacer that separates the ORC from the cask cavity wall is neglected. The aluminum spacer attached to the cask lid is modeled.

The Oak Ridge canisters are stacked four high in the Oak Ridge Container with each layer containing 5 canisters. The 5 Oak Ridge canisters are homogenized into a cylindrical (annular) source with an outside radius equal to the ORC radius (8.425") minus the fuel compartment wall (0.134") and minus the ORC wall (0.135") which equals 8.156" (20.71) and an inside radius of 2.30" (5.85) (see Section 5.3.1). The homogenized canister source length (each layer) is equal to the canister liner length of 29.75" (75.56). Only the SS canister wall and the appropriate mass of heavy metal (U-238) are homogenized into the source. The bottom of the homogenized source is the same as the canister bottom 0.25" (.635) of SS and the top is also the same as the canister top, 0.38" (0.96) of SS, (see canister drawing in Section 1.4). Each layer of source is separated by a flux trap spacer 16" (40.64) high with a top and bottom SS plate of 0.80" (2.03) and 0.70" (1.78), respectively. The homogenized source is surrounded by a SS wall equal to the thickness of a fuel compartment wall plus the ORC wall, 0.269" (0.68).

The first (bottom) source layer sits on a layer of SS which represents the fuel compartment bottom, 2" (5.08) plus the ORC bottom, 1" (2.54). The ORC lid and flange area are modeled explicitly. The aluminum/poison components are neglected in the model.

An analog model of the TN-FSV cask for neutron dose is used (i.e., each cask component was modeled by a single MCNP cell.) However, for the gamma-ray doses it is necessary to subdivide the cask body into multiple cell sub-layers with increasing photon importances for the outer layers in order to bias photon transport to the outside of the cask.

In particular, sub-layers for the cask body are used. The top and bottom half of the simpler neutron model with the Oak Ridge Container are shown in Figures 5.6-1 and 5.6-2.

Source and Shielding Regional Densities

The four different source layers have been defined and discussed previously in this Appendix. The source densities are determined based on the following volume.

The source volume (one layer) = $\pi\ (20.71^2 - 5.85^2) \times 29.75 \times 2.54 = 9.370\text{E+4}$ cc

	Can ID	*HM/Can (grams)	Tube 1 (# Cans)	Tube 2 (# Cans)	Tube 3 (# Cans)	Tube 4 (# Cans)	Tube 5 (# Cans)	Total (# Cans)	Density (g/cc)
Layer 4 (top)	GSF-182	1,000	1	1	1	1	1	5	0.0534
Layer 3	GSF-196	10,000	1	1/2**	1/2	1/2	1/2	3	0.3202
Layer 2	GSF-196	10,000	1/2	1/4	1/4	1/4	1/4	1 1/2	0.1601
Layer 1	GSF-213	200	1	1	1	1	1	5	0.0107

* - From Table 1-3, GSF-213 = 254g HM , GSF-182 = 1,341g HM, GSF-196 = 14,856g HM , HM assumed to be ^{238}U
** - Partially loaded canisters; total curies and mass of HM adjusted by this fraction

The 1/8"stainless steel walls of the five canisters are homogenized into each source layer. The mass of the stainless steel is:

$$\pi/4\ (4.75^2 - 4.5^2) \times 0.29 \times 5 = 78.35 \text{ lbs}$$

and the homogenized density is:

$$78.35 \times 454/9.370\text{E+4} = 0.3796 \text{ g/cc}$$

The material compositions are based on the SCALE Standard Composition Library. The elemental and/or isotopic compositions of the materials utilized in the MCNP model are shown in Table 5.6-1.

5.6.1.4 Shielding Evaluation

The fluence-to-dose conversion factors incorporated into the MCNP TN-FSV cask models are those for the ambient dose equivalent (the dose equivalent at 10-cm depth in the ICRP spherical phantom illuminated by a plane-parallel beam of radiation incident on the sphere). They are from Ref 3 in Chapter 5 and are shown in Table 5.6-2.

Since MCNP yields results normalized to one source particle, it is necessary to convert the MCNP calculated dose d (Sv/particle) to an appropriate dose rate, here taken as D (mrem/h). This is accomplished with

$$D(\text{mrem/h}) = d\ (\text{Sv/particle}) \times S_i\ (\text{particles/s}) \times 10^5(\text{mrem/Sv}) \times 3600(\text{s/h}),$$

where S_i (particles/s) is the total particle emission rate for the ith source region.

From section 5.6.1.2, the Gamma Source table, the total photon emitted by the canisters in the four layers is 4.30E+14 /sec.

Thus D (mrem/h) = 4.30E14 x 3600 x 10^5 = 1.547E23 x d (S v/photon)

From section 5.6.1.2, the Neutron Source table, the total neutron emitted by the canisters in the four layers is 3.48E+07 n/sec.

Thus D_n(mrem/h) = 3.481E7 x 3600 x 10^5 = 1.253E16 x d_n(Sv/neutron)

Annular detector surfaces are formed by segmenting the tally planes into approximately 30 cm high surfaces. The tally planes were located at the cask surface, r = 39.05 cm, at the OD plane of the impact limiter, r = 99 cm, and at two meters from the vehicle edge, r = 322 cm. Axially, doses are determined at the impact limiter surface. The MCNP F2 surface tally is used to obtain the flux. The surface segment areas are calculated and input into MCNP to obtain proper particle flux at the detector surfaces. The MCNP output, D (Sv /particle), is converted into dose rate, mrem/hr, using the factors determined above.

Two separate MCNP models were evaluated, a gamma source, and a neutron source.

The accident condition was also evaluated with MCNP. Appendix 2.11.8 shows that a lead slump of 1.9" occurs in the cask during the accident conditions. Accident conditions dose rates were evaluated in MCNP, modeling a 2" lead slump (void) at the top and bottom of the lead, gamma shield. The MCNP accident model is the same as the normal model in all other aspects. Dose rates at the impact limiter surface or the plane of the surface were determined.

The distribution of calculated dose rates around the TN-FSV cask are depicted in Figures 5.6-3 and 5.6-4. Maximum calculated dose rates are reported in Table 5-1.

The MCNP input file for the neutron dose rate of the TN-FSV with the ORC is included in Appendix 5.6.2.

Table 5.6-1 Composition of materials used in the MCNP models.

(Shown are the elemental (or nuclide) atomic fraction w_i of each component)

Element & w_i	Element & w_i	Element & w_i	Element & w_i	Element & w_i
Stainless Steel: ρ = 7.92 g/cc				
Fe 0.67138	Mn 0.01996	Cr 0.20037	Ni 0.08876	Si 0.01952
Gamma Shield (Lead): ρ = 11.18 g/cc (partial density)				
Pb 1.00				
Carbon Steel: ρ = 7.8212 g/cc				
Fe 0.95510	^{12}C 0.04490			
Aluminum: ρ = 2.702 g/cc				
Al 1.00				
Balsa Wood: ρ=0.125 g/cc				
^{1}H 0.4762	^{16}O 0.2381	C 0.2857		
ORC Representative Source (Layer 1 GSF-213): ρ =0.3903 g/cc				
^{238}U 0.00644	Fe 0.66706	Mn 0.01983	Cr 0.19908	Ni 0.08819
Si 0.01940				
ORC Representative Source (Layer 2 GSF-196): ρ =0.5397 g/cc				
^{238}U 0.08855	Fe 0.61193	Mn 0.01819	Cr 0.18263	Ni 0.08090
Si 0.01780				
ORC Representative Source (Layer 3 GSF-196): ρ =0.6998 g/cc				
^{238}U 0.16270	Fe 0.56215	Mn 0.01671	Cr 0.16777	Ni 0.07432
Si 0.01635				
ORC Representative Source (Layer 4 GSF-182): ρ =0.4330 g/cc				
^{238}U 0.03137	Fe 0.65032	Mn 0.01934	Cr 0.19409	Ni 0.08598
Si 0.01891				
FSV Homogenized Source:				
C 1.00				
FSV Canister Depleted Uranium: ρ =19.05 g/cc				
^{238}U 0.99727	^{235}U 0.00273			

Table 5.6-2 Response functions (fluence-to-dose conversion factors)

Photon energy (MeV)	Response Function (10^{-12} Sv cm^2)	Neutron energy (MeV)	Response Function (10^{-12} Sv cm^2)
0.01	0.0769	2.5×10^{-8}	8.0
0.015	0.846	1.0×10^{-7}	10.4
0.02	1.01	1.0×10^{-6}	11.2
0.03	0.785	1.0×10^{-5}	9.2
0.04	0.614	1.0×10^{-4}	7.1
0.05	0.526	1.0×10^{-3}	6.2
0.06	0.504	1.0×10^{-2}	8.6
0.08	0.532	2.0×10^{-2}	14.6
0.10	0.611	5.0×10^{-2}	35.0
0.15	0.890	1.0×10^{-1}	69.0
0.20	1.18	2.0×10^{-1}	126
0.30	1.81	5.0×10^{-1}	258
0.40	2.38	1.0	340
0.50	2.89	1.5	362
0.60	3.38	2.0	352
0.80	4.29	3.0	380
1.0	5.11	4.0	409
1.5	6.92	5.0	378
2.0	8.48	6.0	383
3.0	11.1	7.0	403
4.0	13.3	8.0	417
5.0	15.4	10.0	446
6.0	17.4	14.0	520
8.0	21.2	17.0	610
10.0	25.2	20.0	650

Source: Reference 3

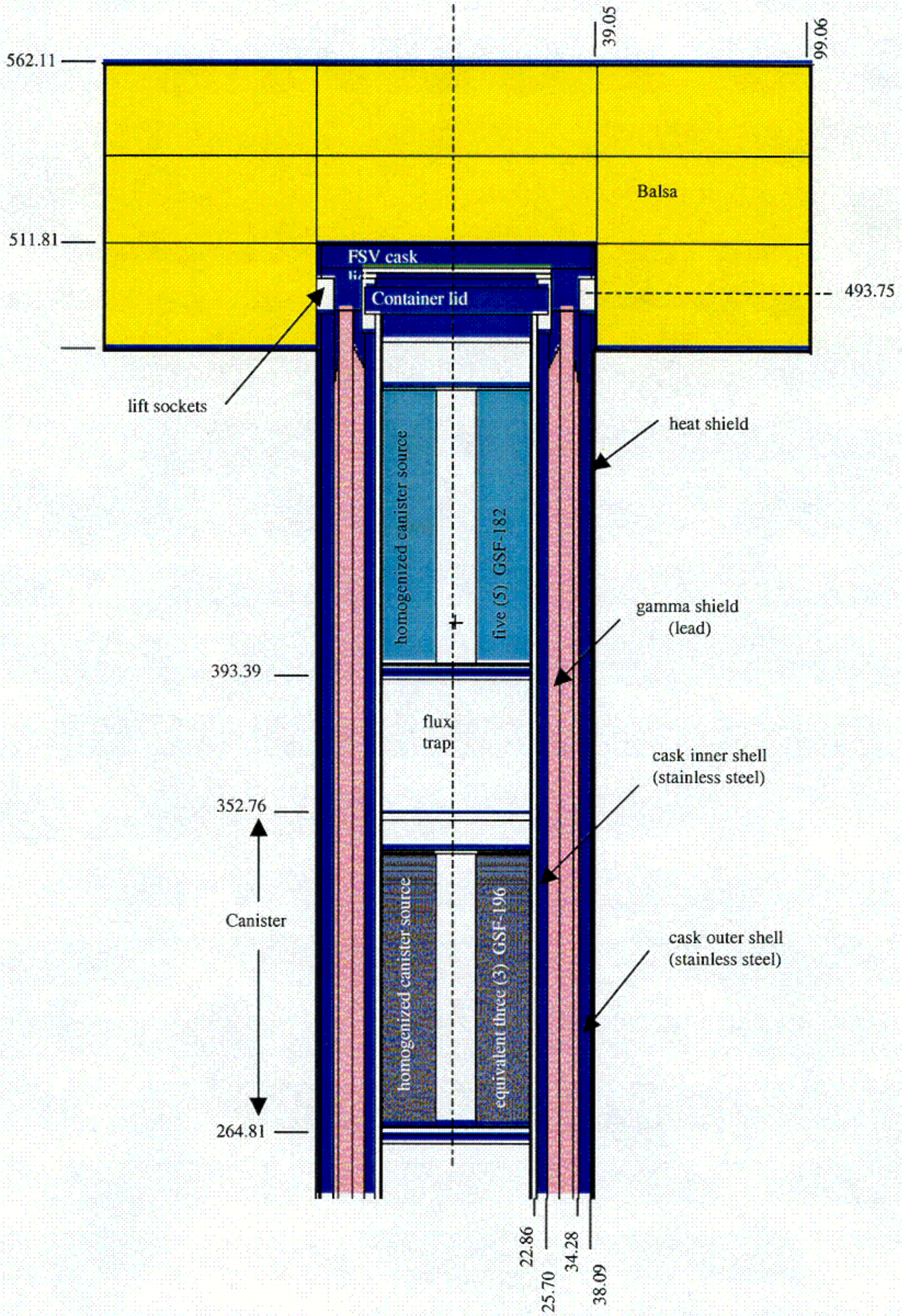


FIGURE 5.6-1. MCNP TOP HALF MODEL VIEW THROUGH LIFTING SOCKETS

C18

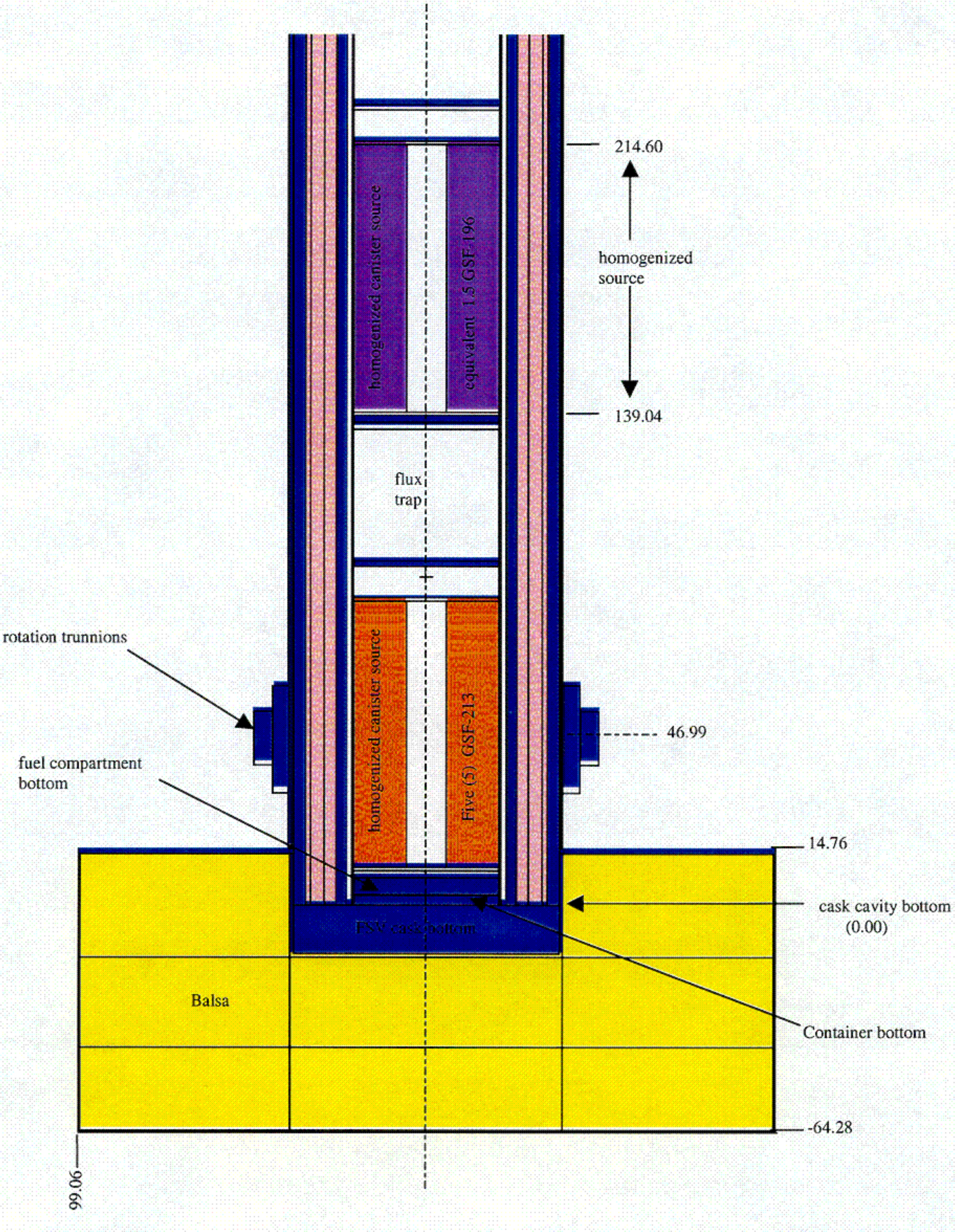


FIGURE 5.6-2. MCNP BOTTOM HALF MODEL VIEW THROUGH TRUNNIONS

C19

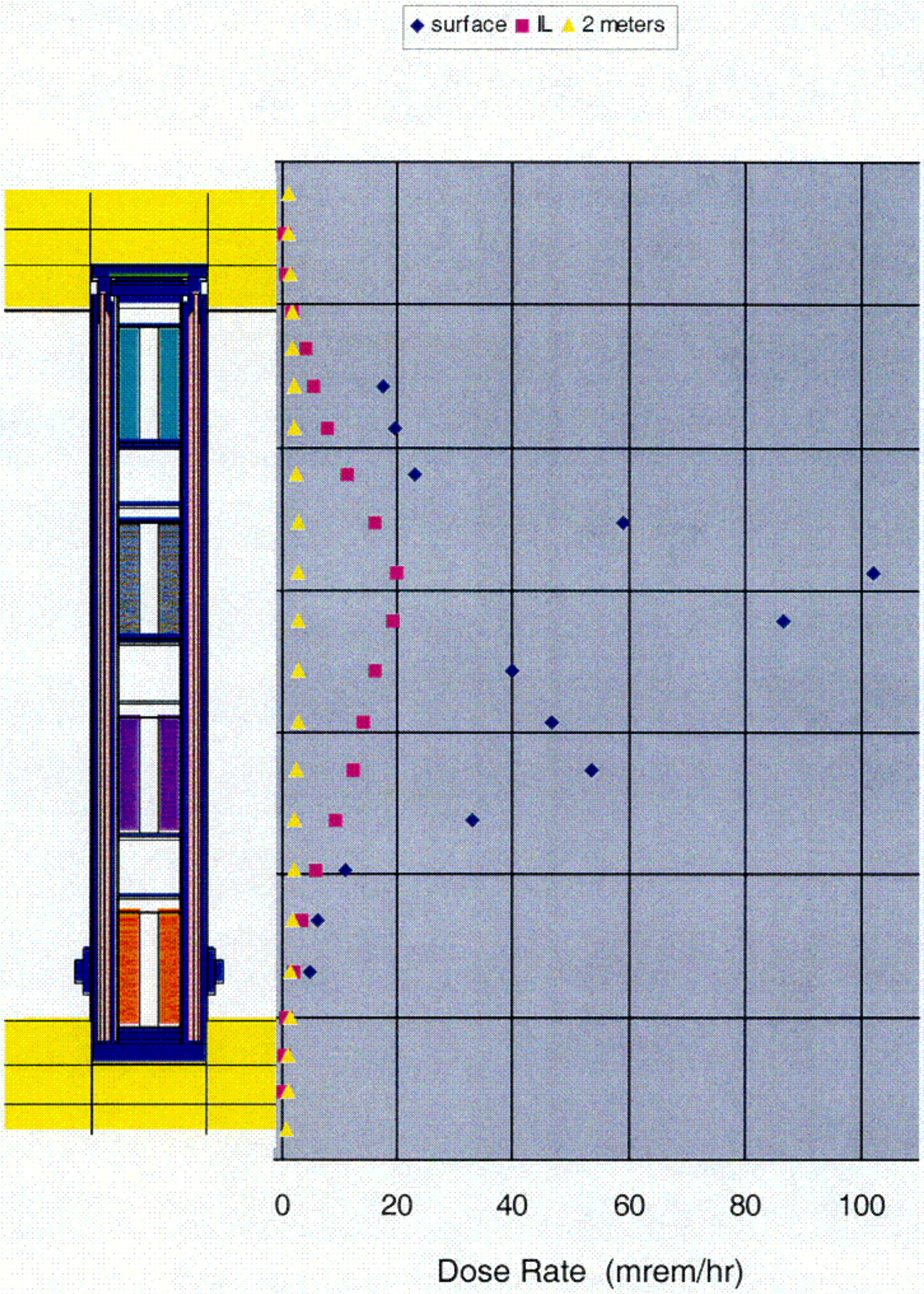


FIGURE 5.6-3 TN-FSV NEUTRON DOSE RATE AXIAL DISTRIBUTION

C20

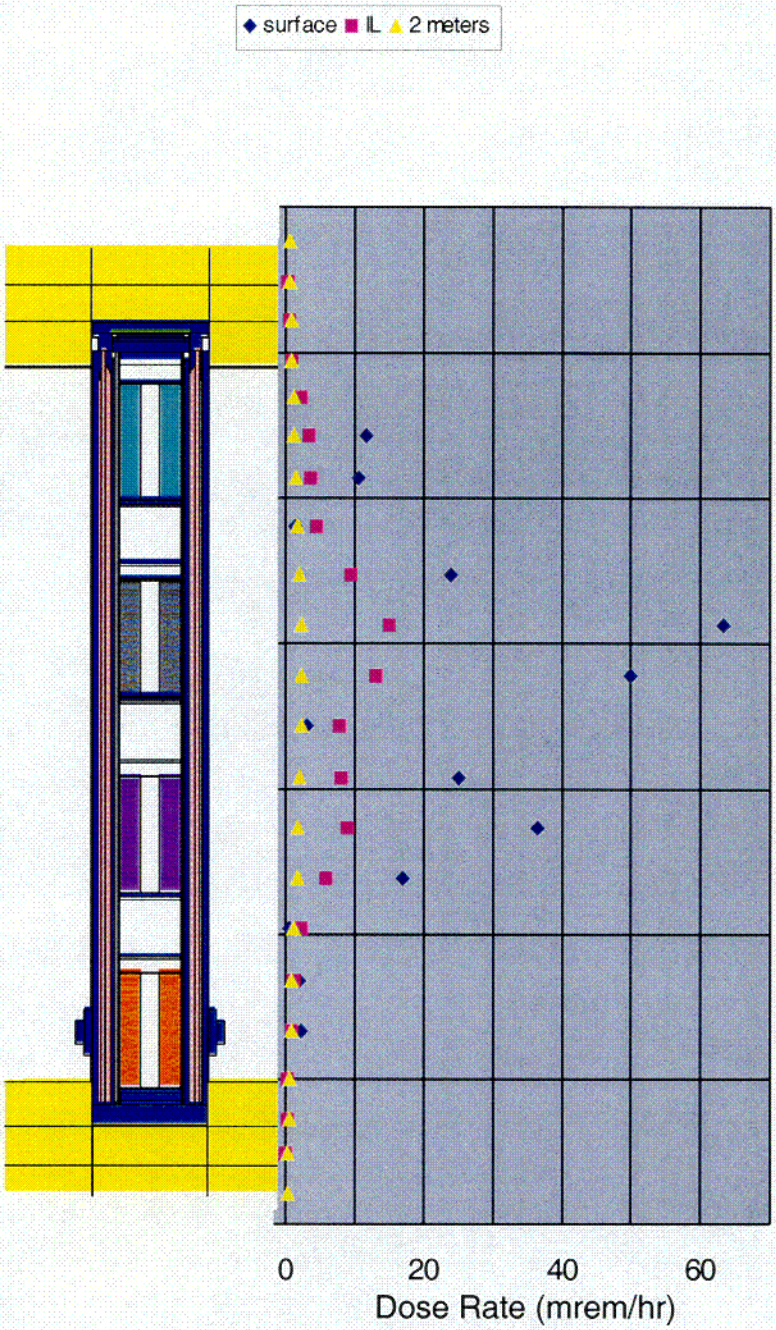


FIGURE 5.6-4 TN-FSV GAMMA DOSE RATE AXIAL DISTRIBUTION

C21

5.6.2 Appendix

Sample SAS1, SAS4 and MCNP Input Files

```
=SAS1
TN-FSV cask with ORNL Container and canisters
27N-18COUPLE   INFHOMMEDIUM
U-238         1    den=0.0067  END
SS304         1    den=0.2670    END
CARBONSTEEL  2  1.0  END
SS304        3   1.0   END
PB            4  0.985  END
AL         5  1.0  END
BALSA      6  1.0  END
U-238         7    den=0.0068  END
SS304         7    den=0.1004    END
END COMP
END

TN-FSV CASK RADIAL GAMMA Co60 20 ORNL canisters
CYLINDRICAL
0    5.08  1  0
5    5.855 1  0
1   20.7  30   -1  0  0.0  0.  1.0
3   21.385 3  0
0   22.86  3  0
3   25.72  6  0
4   34.29 18  0
3   38.10  8  0
0   38.42  1  0
3   39.05  2  0
 END ZONE
' multiply dose by 1.25/1.165 for Co60 correction
    36Z 1.0  8Z
NDETEC=3
READ XSDOSE
484.0
 39.1 242.  139.1 242.  322.0 242.
END

TN-FSV Cask TOP GAMMA Co60 top 2 layers of ORNL canisters
DISC       REFLECTED
7   216.54  70  -1  0  0.0  0.  1.00
3   217.51   2  0
0   221.65   1  0
3   239.43  35  0
0   246.05   1  0
5   247.48   4  0
3   254.47   14  0
6   303.67  20  0
3   304.15   1  0
END ZONE
    36Z 1.00  8Z
NDETEC=3  DY=78.2  DZ=78.2
READ XSDOSE
```

```
39.1
 0.  0.1  0. 100.  0. 200.
END

TN-FSV Cask BOTTOM GAMMA Co60 bottom 2 layers of ORNL canisters
' add 2.0" to container spacer
DISC        REFLECTED
7   216.54  60  -1  0  0.0  0.  1.00
3   224.80   15  0
3   239.40  30  0
6   288.60  15  0
3   289.08   1  0
END ZONE
    36Z 1.00  8Z
NDETEC=3  DY=78.2  DZ=78.2
READ XSDOSE
39.1
 0.  0.1  0. 100.  0. 200.
END
LAST
TN-FSV Cask BOTTOM GAMMA Co60 bottom 2 layers of ORNL canisters
' No impact limiter
DISC        REFLECTED
7   216.54   60  -1  0  0.0  0.  1.00
3   224.80   15  0
3   239.40  30  0
END ZONE
    36Z 1.00  8Z
NDETEC=3  DY=78.2  DZ=78.2
READ XSDOSE
39.1
 0.  0.1  0. 100.  0. 200.
END



=sas4
TN-FSV cask with ORNL Container - Canister evaluation
27n-18couple infhommedium
u-238         1  den=0.022  end
ss304         2  1.0  end
end comp
idr=0 ity=2 izm=2 isn=8 mhw=0 frd=5.728  end
5.728  6.033   end
1      2     end
xend
tim=3000  nst=1000   nit=150  nmt=8000 sfa=1.00
igo=4  isp=0  isd=2  end
soe  36z   1.00  8z  end
sxy 1  -5.728  5.728  -5.728  5.728  0.0  43.498  5.729 43.498
       6.033  44.133  end
'---------------------------------------------
'   surface detectors
'---------------------------------------------
sdl  6.033  36.033   end
sdr  0. 43.498  0. 43.498 end
```

```
sds   4 1   4 1   end
gend
ORNL canister- primary gamma  radial
  0  0  1  20
rcc   1  0.   0.   -43.498  0.   0.   86.996    5.728
rcc   2  0.   0.   -44.133  0.   0.   88.266    6.033
rcc   3  0.   0.   -144.133  0.   0.  288.266   106.033
rcc   4  0.   0.   -244.133  0.   0.  488.266   206.033
rcc   5  0.   0.   -344.133  0.   0.  688.266   306.033
rcc   6  0.   0. -2044.133  0.   0.  4088.266  2006.033
rcc   7  0.   0. -2144.133  0.   0.  4288.266  2106.033
rcc   8  0.   0.   -144.133  0.   0.   288.266    36.033

   end
  ful      1
  can      2    -1
  de1      8    -2
  de2      3    -8
  de3      4    -3
  de4      5    -4
  inv      6    -5
  exv      7    -6
    end
  2R1  2  1  2  1  2  1
  8R0
   1     2  1000 1000 1000 1000 1000 0
   0
end

=sas4
TN-FSV cask with ORNL Container - Canister evaluation
27n-18couple infhommedium
u-238          1  den=0.022   end
ss304          2  1.0  end
end comp
idr=1 ity=1 izm=2 isn=8 mhw=0 frd=5.728   end
43.181  44.133   end
1       2      end
xend
tim=3000  nst=200   nit=500  nmt=8000 sfa=1.00
igo=4  isp=0  isd=2  end
soe  1.841-2 2.099-1 2.333-1 1.310-1 1.769-1 1.928-1 3.773-2
    20z  end
sxy 1  -5.728  5.728  -5.728  5.728  0.0  43.181  5.729 43.181
       6.033  44.133  end
'--------------------------------------------
'   surface detectors
'--------------------------------------------
sdl  44.133  74.5   end
sdr  0. 6.033  0. 6.033 end
sds  1 1  1 1  end
gend
ORNL canister- primary neutron  axial  top
0  0  1  20
rcc   1  0.   0.  -43.181  0.   0.   86.362    5.728
rcc   2  0.   0.  -44.133  0.   0.   88.266    6.033
rcc   3  0.   0.  -144.133  0.   0.  288.266   106.033
```

```
rcc   4  0.   0.   -244.133  0.   0.   488.266    206.033
rcc   5  0.   0.   -344.133  0.   0.   688.266    306.033
rcc   6  0.   0. -2044.133  0.   0.   4088.266   2006.033
rcc   7  0.   0. -2144.133  0.   0.   4288.266   2106.033
rcc   8  0.   0.   -74.5      0.   0.    149.00     36.033   end
 ful      1
 can      2   -1
 de1      8   -2
 de2      3   -8
 de3      4   -3
 de4      5   -4
 inv      6   -5
 exv      7   -6
   end
 2R1 2 1 2 1 2 1
 8R0
  1     2  1000 1000 1000 1000 1000 0
  0
end
```

MCNP INPUT FILE FOR NEUTRON DOSE RATE

```
TransNuclear TN-FSV cask:   Near-Field model
c
c    This model calculates doses for fuel neutrons with ORNL Container
c    Homogenized ORNL canisters and fuel compartments REPRESENTATIVE CASE
c    GFS-196:10 Kg HM/can/ GSF-182:1 Kg HM/can/ GSF-213: 200 g/can
c ***********************  BLOCK 1: CELL CARDS ***********************
c GEOMETRY (r-z)
c
c  ^ z-axis
c  .
c  | ------------------   |  tally surfaces @
c  .____________________. |     contact,
c  |    impact limiter  | |     1m and
c  .______________.     | |     2m from surface IL
c  |-------------+--+   | |     for the radial (side)
c  .-------------+   |  | |
c  |             |   |__| |
c  .             |   |+   |
c  |             |   ||   |            VOID
c  .             |   ||   |
c  |             |   ||   |
c  .   FUEL      |   ||   |
c  O ------------|--||----------------------------> y-axis
c  | CANISTER(s) |   ||   |
c  .             |   ||   |
c  |             |   ||   |
c  .             |   ||
c  |             |   ||
c  .             |   |__.
c  |-------------+   |  |
c  .=---------------+   |
c  |   impact limiter   |
c  .____________________|
c  |
c                            M Mason 5/01
c
c ****** Cask cells
  1  4   -7.92    1   -2 -260    imp:n,p=1  $ SS cask bottom
 10  4   -7.92   12  -14 -260    imp:n,p=1     $ SS cask lid
 20  4   -7.92    2 -330   25  -21    imp:n,p=1   $ SS inner shell
 30  8  -11.18    2  332   21 -374  imp:n,p=1     $ Pb gamma shield pt 1
330  4  -7.92  -15 -332   21 -374 #67 imp:n,p=1   $ SS above Pb pt 1
 33  8  -11.18    2  -15  374 -382    imp:n,p=1  $ Pb gamma shield pt 2
 36  8  -11.18 (2  -17  382 -22):(17 -22 382 -333) imp:n,p=1 $ Pb gamma shld pt 3
```

```
361  4   -7.92    17   -15   382 -22 #36   imp:n,p=1     $ SS above Pb pt 3
 40 4   -7.92      2   -15    22 -260 #100 #101  imp:n,p=1  $ SS outer shell
 43 4   -7.92    15   -12    23 -260 #100 #101  imp:n,p=1  $ SS flange above Pb
 44 0           167 -166  260 -251   imp:n,p=1          $ air gap thermal shield
 45 4   -7.92   167 -166  251 -201   imp:n,p=1         $ SS shell over thermal gap
 46 4   -7.92 166 -14   260 -201 #100 #101  imp:n,p=1   $ SS  cask flange area
 47 0   150 -167  260 -201   imp:n,p=1  $ air between heat shld and bot limit
 50 6   -2.70    11   -12   -23          imp:n,p=1      $ Al spacer under cask lid
c ****************  ORNL Container  ****************
   51  0           451  -11  -23      imp:n,p=1  $ void above Container lid
   52  4  -7.92      2 -400  -32      imp:n,p=1  $ Container bottom
   53  4  -7.92 400 -401 -32          imp:n,p=1  $ fuel compartment bottom
  200  0   401 -410 -32               imp:n,p=1  $ bottom of lower canister ****
  201  4  -7.92 410 -411 -32 #202     imp:n,p=1  $ canister ss bottom
  202  0   411 -412 -30               imp:n,p=1  $ center void
  203 11  -0.3903 411 -412 -32 #202  imp:n,p=1  $ bottom layer of fuel GSF-182
  204  4  -7.92 412 -413 -32 #202     imp:n,p=1  $ canister ss top
  205  0   413 -414 -32               imp:n,p=1  $ top of canister  **********
  210  4  -7.92 414 -415 -32          imp:n,p=1  $ flux trap bottom plate
  211  0   415 -416 -32               imp:n,p=1  $ flux trap void
  212  4  -7.92 416 -417 -32          imp:n,p=1  $ flux trap top plate
  220  0   417 -420 -32               imp:n,p=1  $ bottom of 2nd canister *****
  221  4  -7.92 420 -421 -32 #222     imp:n,p=1  $ canister ss bottom
  222  0   421 -422 -30               imp:n,p=1  $ center void
  223  2  -0.5397 421 -422 -32 #222 imp:n,p=1  $ 2nd layer of fuel GSF-196
  224  4  -7.92 422 -423 -32 #222     imp:n,p=1  $ canister ss top
  225  0   423 -424 -32               imp:n,p=1  $ top of canister*******
  230  4  -7.92 424 -425 -32          imp:n,p=1  $ flux trap bottom plate
  231  0   425 -426 -32               imp:n,p=1  $ flux trap void
  232  4  -7.92 426 -427 -32          imp:n,p=1  $ flux trap top plate
  240  0   427 -430 -32               imp:n,p=1  $ bottom of 3rd canister *****
  241  4  -7.92 430 -431 -32 #242     imp:n,p=1  $ canister ss bottom
  242  0   431 -432 -30               imp:n,p=1  $ center void
  243 12  -0.6998 431 -432 -32 #242  imp:n,p=1  $ 3rd layer of fuel GSF-196
  244  4  -7.92 432 -433 -32 #242     imp:n,p=1  $ canister ss top
  245  0   433 -434 -32               imp:n,p=1  $ top of canister*******
  250  4  -7.92 434 -435 -32          imp:n,p=1  $ flux trap bottom plate
  251  0   435 -436 -32               imp:n,p=1  $ flux trap void
  252  4  -7.92 436 -437 -32          imp:n,p=1  $ flux trap top plate
  260  0   437 -440 -32               imp:n,p=1  $ bottom of top canister *****
  261  4  -7.92 440 -441 -32 #262     imp:n,p=1  $ canister ss bottom
  262  0   441 -442 -30               imp:n,p=1  $ center void
  263 10  -0.433 441 -442 -32 #262  imp:n,p=1  $ top layer of fuel Forecast
  264  4  -7.92 442 -443 -32 #262     imp:n,p=1  $ canister ss top
  265  0   443 -450 -32               imp:n,p=1  $ top of canister*******
  266  4  -7.92 450 -452 -32          imp:n,p=1  $ Container lid bottom
  270  4  -7.92 452 -453 -24          imp:n,p=1 $ Container lid flange
  274  4  -7.92 453 -451 -26          imp:n,p=1 $ Container lid top
  280  4  -7.92     2 -452 32 -33     imp:n,p=1  $ Container wall
 c 51  0            20  -11  -23          imp:n,p=25000 $ void above DU plug
 c 52 9  -19.05  19  -320  -27          imp:n,p=25000 $ FSV DU canister top plug
 c 53 9  -19.05  320 -321  -27          imp:n,p=25000 $ FSV DU canister top plug
 c 54 9  -19.05  321 -322  -27          imp:n,p=25000 $ FSV DU canister top plug
 c 55 9  -19.05  322 -323  -27          imp:n,p=25000 $ FSV DU canister top plug
 c 56 9  -19.05  323 -324  -27          imp:n,p=25000 $ FSV DU canister top plug
 c 57 9  -19.05  324 -325  -27          imp:n,p=25000 $ FSV DU canister top plug
 c 58 9  -19.05  325 -326  -27          imp:n,p=25000 $ FSV DU canister top plug
 c 59 9  -19.05  326 -327  -27          imp:n,p=25000 $ FSV DU canister top plug
 c 60 9  -19.05  327 -328  -27          imp:n,p=25000 $ FSV DU canister top plug
 c 61 9  -19.05  328 -329  -27          imp:n,p=25000 $ FSV DU canister top plug
 c 62 9  -19.05  329  -20  -27          imp:n,p=25000 $ FSV DU canister top plug
 c 63  5  -7.82      8 -319  -27        imp:n,p=25000 $ FSV canister top CS plate
 c 64  5  -7.82    319  -19  -27        imp:n,p=25000 $ FSV canister top CS plate
 c 65  0         7    -8  -28       imp:n,p=25000 $ void above FSV canister fuel
 c 66  5  -7.82    330  -20  27   -29   imp:n,p=64    $ CS in FSV top flange
 c 67  0        330  -20   29  -23   imp:n,p=64     $ void around FSV top flange
  67  0 (330 -451 24 -23):(453 -451 26 -23):(330 -452 25 -24) imp:n,p=1 $ void around Cont
flange
 c 70  3 -1.54      5   -45   -28   imp:n,p=1  $ homogenized fuel in FSV canister
 c 71  3 -1.54     45   -46   -28   imp:n,p=1  $ homogenized fuel in FSV canister
 c 72  3 -1.54     46   -47   -28   imp:n,p=1  $ homogenized fuel in FSV canister
```

```
 c 73  3 -1.54     47   -7  -28  imp:n,p=1  $ homogenized fuel in FSV canister
 c 75  5 -7.82      5   -8   28  -27   imp:n,p=2  $ FSV CS canister shell
 c 76  0  18 -330   27  -25   imp:n,p=2  $ void between FSV canister and cask
  76   0  2 -452   33  -25  imp:n,p=1    $ void between ORNL Container and cask
 c 77  5 -7.82    308   -5  -27      imp:n,p=2  $ FSV canister bottom CS plate
 c 78  5 -7.82     18 -308  -27      imp:n,p=4  $ FSV canister bottom CS plate
 c 79  6 -2.70      2  -18  -25      imp:n,p=8  $ FSV canister bottom Al plate
c ****** trunnion blocks and pockets********
 100  0          -331 -201   347  imp:n,p=1  $ top right trunnion pocket
 101  0          -331 -201  -348  imp:n,p=1  $ top left trunnion pocket
 102  4 -7.92  195 -335 -344  260 #44 #45  imp:n,p=1  $ bot R trunnion block
 103  4 -7.92 -195 -335  345  260 #44 #45  imp:n,p=1  $ bot L trunnion block
 104  4 -7.92  195 -334 -341  344     imp:n,p=1  $ bot R trunnion shoulder
 105  4 -7.92 -195 -334  342 -345     imp:n,p=1  $ bot L trunnion shoulder
c **** impact limiters  *****
c  bottom limiter
  80 4  -7.92    (156   -1 -255):(  1 -150 -255 260) imp:n,p=1 $ inside skn
  81 4  -7.92 (153 -152 -253):(151 -150  255 -253)  imp:n,p=1 $ outside skn
  82 4  -7.92    153 -150 -250 253      imp:n,p=1          $ outside skin
  83 7  -0.125   156 -151 -253 255  imp:n,p=1  $ balsa
  84 7  -0.125   154 -156 -253 255  imp:n,p=1  $ balsa
  85 7 -0.125   154 -156 -255       imp:n,p=1  $ balsa
  86 7 -0.125   152 -154 -253 255   imp:n,p=1  $ balsa
  87 7 -0.125   152 -154 -255       imp:n,p=1  $ balsa
c  top limiter
  90 4  -7.92    ( 14 -165 -254):(161  -14 -254 201) imp:n,p=1 $ inside skn
  91 4  -7.92 (162 -163 -253):(161 -160  254 -253)  imp:n,p=1 $ outside skn
  92 4  -7.92    161 -163 -250 253   imp:n,p=1               $ outside skn
  93 7 -0.125   160 -165 -253 254   imp:n,p=1 $ balsa
  94 7 -0.125   165 -164 -253 254   imp:n,p=1 $ balsa
  95 7 -0.125   165 -164 -254       imp:n,p=1 $ balsa
  96 7 -0.125   164 -162 -253 254   imp:n,p=1 $ balsa
  97 7 -0.125   164 -162 -254       imp:n,p=1 $ balsa
c ***** outside cells above/below cask
   140 0            170  -60 -172       imp:n,p=0     $ air beneath cask-pt2
   142 0           -153   60  -64       imp:n,p=1  $ air beneath cask-pt1
   145 0            163  -61  -64       imp:n,p=1 $ air above cask-pt1
   146 0             61 -171 -172       imp:n,p=0     $ air above cask-pt2
c ***** Cells outside radial cask surface
   601 0   150 -161  201 -250 #102 #103 #104 #105  imp:n,p=1 $  air (void)
   602 0   153 -163  250  -65            imp:n,p=1 $ outer air (void)
   603 0   153 -163   65  -64            imp:n,p=1 $ outer air (void)
c  606 0            60 -61 65 -64      imp:n,p=150000 $ inner air (void)
   605 0    60 -61 -172 64               imp:n,p=0     $ outer air (void)
   190 0     -170:171:172                imp:n,p=0     $ problem boundary

c ***********************  BLOCK 2: SURFACE CARDS ***********************
c **** Horizontal cask planes
  1   pz  -13.97        $ cask bottom - ground surface 5.5"
 301  pz  -12.2         $ cask bottom split
 302  pz  -10.5         $ cask bottom split
 303  pz   -8.7         $ cask bottom split
 304  pz   -7.0         $ cask bottom split
 305  pz   -5.2         $ cask bottom split
 306  pz   -3.5         $ cask bottom split
 307  pz   -1.7         $ cask bottom split
  2   pz    0.00        $ bottom of cask cavity
  5   pz   11.91        $ top of CS FSV canister bottom 2.00"
 308  pz    9.4         $ CS FSV canister bottom split
  7   pz  487.70        $ top of fuel in FSV canister
  8   pz  488.59        $ top of void in FSV canister 0.35"
 11   pz  504.04        $ top of void above FSV DU plug 0.55"
 12   pz  505.46        $ top of  Al spacer under FSV cask lid 0.56"
 14   pz  511.81        $ cask top - top of Fe lid**  2.50"
 314  pz  507.0         $ cask lid split
 315  pz  508.6         $ cask lid split
 316  pz  510.2         $ cask lid split
 15   pz  493.75        $ top of lead GS
 16   pz  484.81        $ top of GS, slice inside cone
 216  pz  477.37        $ bottom of  slice inside cone
 17   pz  473.71        $ top of GS, slice outside cone
```

```
 18  pz    6.83      $ top of bottom Al spacer  2.69"
318  pz    3.4      $ Al spacer split
 19  pz  491.76      $ top  of CS FSV canister top  1.25"
319  pz  490.2       $ CS FSV canister top split
 20  pz  502.88      $ top of DU plug FSC canister  4.38"
320  pz  493.0       $ DU plug split
321  pz  494.1       $ DU plug split
322  pz  495.2       $ DU plug split
323  pz  496.3       $ DU plug split
324  pz  497.3       $ DU plug split
325  pz  498.3       $ DU plug split
326  pz  499.3       $ DU plug split
327  pz  500.3       $ DU plug split
328  pz  501.2       $ DU plug split
329  pz  502.1       $ DU plug split
330  pz  487.38      $ shelf at cask top (26.45 radius)
150  pz   14.76      $ top of bottom limiter
151  pz   14.28      $ inside skin bottom limiter
152  pz  -63.80      $ inside skin bottom limiter
153  pz  -64.28      $ bottom of bottom limiter
154  pz  -40.0       $ balsa split bottom limiter
156  pz  -14.60      $ Inside skin BL
160  pz   483.07     $ inside skin top limiter
161  pz   482.59     $ bottom of top limiter
162  pz   561.63     $ inside skin  top limiter
163  pz   562.11     $ top of top limiter
164  pz   536.7      $ balsa split top limiter
165  pz   512.44     $ top of inside skin top limiter
166  pz   482.90     $ top of heat shield
167  pz    15.87     $ bottom of heat shield
341  px    49.34     $ trunnion shoulder
342  px   -49.34     $ trunnion shoulder
344  px    43.62     $ Trunion block
345  px   -43.62     $ Trunion block
347  px    34.30     $ Trunnion pocket depth
348  px   -34.30     $ Trunnion pocket depth
195  px    0.0       $ ambiguity surface
196  pz   493.75     $ centerline of top trunnion pocket
197  pz    46.99     $ centerline of bottom trunnions
c *****  surfaces for ORNL Container  ***********************
400  pz     2.54     $ ORNL Container bottom
401  pz     7.62     $ ORNL fuel compartment bottom
410  pz     9.83     $ bottom of canister bottom
411  pz    10.46     $ bottom of homogenized fuel bottom layer
412  pz    86.02     $ top of homogenized fuel bottom layer
413  pz    86.98     $ top of canister top bottom layer
414  pz    95.56     $ bottom of flux trap bottom 1st to 2nd layer
415  pz    97.34     $ top of flux trap bottom 1st to 2nd layer
416  pz   134.17     $ bottom of flux trap top 1st to 2nd layer
417  pz   136.20     $ top of flux trap top 1st to 2nd layer
420  pz   138.41     $ bottom of canister bottom
421  pz   139.04     $ bottom of homogenized fuel 2nd layer
422  pz   214.60     $ top of homogenized fuel 2nd layer
423  pz   215.56     $ top of canister top 2nd layer
424  pz   224.17     $ bottom of flux trap bottom 2st to 3rd layer
425  pz   225.95     $ top of flux trap bottom 2st to 3rd layer
426  pz   262.78     $ bottom of flux trap top 2st to 3rd layer
427  pz   264.81     $ top of flux trap top 2st to 3rd layer
430  pz   267.02     $ bottom of canister bottom
431  pz   267.66     $ bottom of homogenized fuel 3rd layer
432  pz   343.22     $ top of homogenized fuel 3rd layer
433  pz   344.18     $ top of canister top 3rd layer
434  pz   352.76     $ bottom of flux trap bottom 3rd to 4th layer
435  pz   354.54     $ top of flux trap bottom 3rd to 4th layer
436  pz   391.36     $ bottom of flux trap top 3rd to 4th layer
437  pz   393.39     $ top of flux trap top 3rd to 4th layer
440  pz   395.61     $ bottom of canister bottom
441  pz   396.24     $ bottom of homogenized fuel 4th layer
442  pz   471.80     $ top of homogenized fuel 4th layer
443  pz   472.76     $ top of canister top 4th layer
450  pz   484.99     $ bottom of ORNL Container lid
```

```
 451  pz    502.77        $ top of ORNL Container lid 7.00"
 452  pz    492.7         $ bottom of Container flange
 453  pz    499.91        $ top of lid flange
 454  pz    486.9         $ Container lid split
 455  pz    488.8         $ Container lid split
 456  pz    490.7         $ Container lid split
 457  pz    494.5         $ Container lid split
 458  pz    496.3         $ Container lid split
 459  pz    498.1         $ Container lid split
 460  pz    501.3         $ Container lid split
c ***** cylindrical cask surfaces
  25  cz    22.86         $ cask inner surface cavity wall
 371  cz    24.3          $ split of inner surface
  21  cz    25.70         $ outside inner shell inside gamma shield  1.12"
 372  cz    26.9          $ gamma shield split
 373  cz    28.1          $ gamma shield split
 374  cz    29.27         $ gamma shield SPLIT
 380  cz    30.4          $ gamma sheild split
 381  cz    31.6          $ gamma sheild split
 382  cz    32.78         $ gamma sheild SPLIT
 383  cz    33.5          $ gamma sheild split
  22  cz    34.28         $ outside gamma shield inside outer shell 3.38"(min)
  23  cz    26.45         $ top al spacer outside
 375  cz    35.5          $ split of outer shell
 376  cz    36.8          $ split of outer shell
 251  cz    38.42         $ heat shield air gap  0.13"
 260  cz    38.09         $ outside outer shell  **  1.50"
 202  cz     6.20         $ hole radius in botom al spacer
 201  cz    39.05         $ outside of SS heat shield  0.25"
  27  cz    22.38         $ outside radius of FSV canister
  28  cz    21.12         $ inside radius of FSV canister
  29  cz    25.97         $ outside radius of top steel FSV canister
c *****  ORNL Container Surfaces  ********************
  24  cz    25.64         $ lid flange OR
  26  cz    22.47         $ lid top OR
  30  cz     5.85         $ inside void region (annulus)
  31  cz    20.40         $ flux trap spacer IR (homogenized representation)
  32  cz    20.71         $ homogenized source OR
  33  cz    21.39         $ fuel compartment+Container wall OR
c **************************************************
 250  cz    99.06         $ outside radius of impact limiter
 253  cz    98.58         $ outside radius inside skin
 254  cz    39.53         $ inside skin top limiter
 255  cz    38.57         $ inside skin bottom limiter
 335  c/x   0 46.99 15.24  $ bottom trunnion block
 331  c/x   0 497.75 5.08  $ top trunnion pocket
 334  c/x   0 46.99 7.62   $ bottom trunnion shoulder
c ****** cone surfaces ****************
 332  kz    423.76  0.2299 1 $ tapering of lead inside
 333  kz    682.34  0.0270 -1 $ tapering of lead outside
c ***** problem boundaries
  170  pz   -400.E2        $ bottom of air (problem boundary)
  171  pz    800.E2        $ top of air (problem boundary)
  172  cz    500.E2        $ radial air limit (problem boundary)
c ****** surfaces for detector segmentation
  60  pz   -265.0          $ bottom tally surface 2m from IL
  61  pz    762.0          $ top tally surface  2m from IL
c  62  cz    125.0         $ radial tally surface  (outer shell)
  63  cz    122.0          $ radial tally surface   (trailer edge)
  64  cz    322.0          $ radial tally surface   (2 m from trailer edge )
  65  cz    199.0          $ radial tally surface (1m from cask)
  70  pz    50.0          $ segmentation plane
  71  pz    121.0         $ segmentation plane
  72  pz    156.0         $ segmentation plane
  73  pz    191.0         $ segmentation plane
  74  pz    295.0         $ segmentation plane
  75  pz    330.0         $ segmentation plane
  76  pz    365.0         $ segmentation plane
  77  pz    431.0         $ segmentation plane
  78  pz    456.0         $ segmentation plane
  79  pz    592.0         $ segmentation plane
```

```
  80  pz   -94.0         $ segmentation plane
  81  cz    20.00        $ segmentation cylinder
  82  cz    40.00        $ segmentation cylinder
  83  cz    75.00        $ segmentation cylinder

c **********************  BLOCK 3: DATA CARDS ***************************
c Representative Case with layer 1(bottom) = 5 GSF-213, layer 2 = equiv 1.5 cans
c GSF-196,layer 3 = equiv 3 cans GSF-196 & layer 4 (top) = 5 cans GSF-182
c  - 4 cylindrical (annular) sources in cells 203,223,243& 263 for ORNL canisters
c GSF-182 (203 on bottom)) GSF-196 (223 & 243)  Forecast (263 on top)
SDEF par=1 CEL=d1 POS=FCEL d2  AXS=0 0 1  RAD=d9  EXT d10  ERG=FCEL d15
c -- define cells for each source
SI1 L  203 223 243 263              $ cell: bottom layer to top canisters
SP1    0.0170 0.2991 0.5982 .0857   $ relative source strengths
c -- set POS for each source
DS2 S 3 4 5 6            $ based on cell choosen, set distribution for POS
SI3 L 0 0  48.24         $ center for spatially sampling of source 1 (bot can
SP3 1                    $ prob. distn for src 1 center
SI4 L 0 0 176.82         $ center for spatially sampling of source 2 (2nd can)
SP4 1                    $ prob. distn for src 2 center
SI5 L 0 0 305.44         $ center for spatially sampling of source 3 (3rd can)
SP5 1                    $ prob. distn for src 3 center
SI6 L 0 0 434.02         $ center for spatially sampling of source 4 (top can)
SP6 1                    $ prob. distn for src 4 center
c -- set RAD for each source (must completely include cells 203,223,243,263)
SI9  5.85 20.71          $ radial sampling limits for all 4 sources
SP9 -21 1                $ radial sampling weight for all 4 sources
c -- set EXT for each source (must completely include cells 203,223,243,263)
SI10 L  -37.78  37.78    $ axial sampling limits for 4 sources
SP10  -21  0             $ axial sampling weight for 4 sources
c -- neutron energy spectrum:   for all four sources
DS15  S 16 17 18 19      $ distns for energy sampling four sources
SI16 0.1   0.4     0.9    1.4    1.85    3.0     6.434  20  $ energy bins
SP16  0   .03763 .19225 .17666 .13112 .23448 .20951 .01835  $ bin probs. GSF-182
SI17 0.1   0.4     0.9    1.4    1.85    3.0     6.434  20  $ energy bins
SP17  0   .03758 .19199 .17643 .13107 .23477 .20985 .01832  $ bin probs. GSF-196
SI18 0.1   0.4     0.9    1.4    1.85    3.0     6.434  20  $ energy bins
SP18  0   .03758 .19199 .17643 .13107 .23477 .20985 .01832  $ bin probs. GSF-196
SI19 0.1   0.4     0.9    1.4    1.85    3.0     6.434  20  $ energy bins
SP19  0   .03564 .18229 .17084 .13160 .25201 .21033 .01729  $ bin probs. Forecast
c
c
c ---- Detector types and locations -- primary neutron
c -- doses on and away from cask's surface (F2 segmented surface detectors)
c FM2    2.332E25       $ convert Sv/neutron to mrem/h for fuel zones
c      1.071E15 x 61 X 0.9917 (NF) X 3600 X 1E5 = 2.332E25
c TF2 3j 6
 FC2  Radial doses at contact averaged over subsurfaces (between IL)
 F2:n  201
 FS2   -150 -70 -412 -71 -72 -73 -424 -426 -74 -75 -76 -441
         -77 -78 -161
 SD2   3.0E7 8646.43 8837.81 8582.64 8587.54 8587.54 8138.54
       9473.29 7905.45 8587.54 8587.54 7665.0 8528.66
       6133.96 6524.08 3.0E7
 FC12    Radial doses at IL plane averaged over subsurfaces
 F12:n   250
 FS12  -153 -154 -156 -150 -70 -412 -71 -72 -73 -424 -426
       -74 -75 -76 -441 -77 -78 -161 -314 -164 -163
 SD12    1.0E8 15112.17 15809.27 18274.03 21933.81 22419.29
         21771.98 21784.43 21784.43 20645.42 24031.34 20054.13
         21784.43 21784.43 19444.16 21635.05 15560.31 16549.94
         15193.08 18485.65 15815.50 8.0E7
 FC22    Radial doses at 2 meters from trailer averaged over subsurfaces
 F22:n   64
 FS22    -80 -153 -154 -156 -150 -70 -412 -71 -72 -73 -424 -426
         -74 -75 -76 -441 -77 -78 -161 -314 -164 -163 -79
 SD22    1.0E8 60129.08 49122.95 51388.92 59400.73 71297.06
         72875.15 70771.03 70811.5 70811.5 67109.07 78115.2
         65187.04 70811.5 70811.5 63204.32 70325.93 50579.64
         53796.51 49385.96 60088.61 51409.15 60473.02 8.0E7
c
```

```
FC52  Radial doses at FSV cavity wall (between IL)
 F52:n  25
 FS52   -150 -70 -412 -71 -72 -73 -424 -426 -74 -75 -76
 SD52   3.0E7 4217.08 5061.65 5024.3 5027.18 5027.18
        4764.33 5545.69 4627.88 5027.18 5027.18 3.0E7
c
c -- doses along cask's top limiter
 FC32 Doses at top limiter surface averaged over subsurfaces
 f32:n   163          $ surface tally
 fs32   -81 -82 -83 -250 -63
 sd32   1256.64 3769.91 12644.91 13156.62 15931.38 7.8E7
c
c -- doses along cask's bottom limiter
 FC42 Doses at bottom limiter surface averaged over subsurfaces
 f42:n   153          $ surface tally
 fs42   -81 -82 -83 -250  -63
 sd42   1256.64 3769.91 12644.91 13156.62 15931.38 7.8E7
c
c print 110
c mode p
 phys:n 20.0 0.0
 cut:n j 0.0
c phys:p 0 1 1
 esplt:n 0.5 0.1 0.5 0.01 0.25 0.001
 wwp:n 5 3 5 0 0.5
 nps  30000000
c  void
c
c ------------------------------------------------------------------
c  ambient neutron dose equiv. H*(10mm) Sv (from T-D3 of S&F)
c ------------------------------------------------------------------
de0    2.500E-08 1.000E-07 1.000E-06 1.000E-05 1.000E-04 1.000E-03
       1.000E-02 2.000E-02 5.000E-02 1.000E-01 2.000E-01 5.000E-01
       1.000E+00 1.500E+00 2.000E+00 3.000E+00 4.000E+00 5.000E+00
       6.000E+00 7.000E+00 8.000E+00 1.000E+01 1.400E+01 1.700E+01
       2.000E+01
df0    8.000E-12 1.040E-11 1.120E-11 9.200E-12 7.100E-12 6.200E-12
       8.600E-12 1.460E-11 3.500E-11 6.900E-11 1.260E-10 2.580E-10
       3.400E-10 3.620E-10 3.520E-10 3.800E-10 4.090E-10 3.780E-10
       3.830E-10 4.030E-10 4.170E-10 4.460E-10 5.200E-10 6.100E-10
       6.500E-10
c -------------------------------------------------------------------c
c    ***** MATERIAL CARDS
c    ************************************************************
c     AIR: ANSI/ANS-6.4.3, Dry air;  density = 0.0012 g/cm^3
c          Composition by mass fraction
c    *************************************************************
m1    7014.50c  -.75519
      8016.60c  -.23179
      6000.60c  -.00014
     18000.35c  -.01288
c
c
c    **************************************************************
c     Homogenized OR Canister Source layer 2 GSF-196 eqv 15 kg u238
c          Density = 0.5397 g/cm^3;  Composition by atom fraction
c    **************************************************************
m2    92238.50c  0.08855
      28000.50c  0.08090
      26000.50c  0.61193
      25055.50c  0.01819
      24000.50c  0.18263
      14000.50c  0.01780
c
c    *************************************************************
c     Carbon Source FSV Container TN-FSV SAR Table 5-6
c          Density = 1.54 g/cm^3;  Composition by atom fraction
c    *************************************************************
m3     6000.60c  1.00
c
c    **************************************************************
```

```
c       SS304 TN-FSV SAR Table 5-6
c           Density = 7.92 g/cm^3;   Composition by atom fraction
c     ***************************************************************
m4     26000.50c  0.67138
       25055.50c  0.01996
       24000.50c  0.20037
       28000.50c  0.08876
       14000.50c  0.01952
c
c     ***************************************************************
c      Carbon Steel TN-FSV SAR Table 5-6
c           Density = 7.8212 g/cm^3;  Composition by atom fraction
c     ***************************************************************
m5     26000.50c  0.95510
        6000.50c  0.04490
c
c     ***************************************************************
c       Aluminum  TN-FSV SAR Table 5-6
c           Density = 2.702 g/cm^3;   Composition by atom fraction
c     ***************************************************************
m6     13027.50c   1.00000
c
c
c     **************************************************************
c      Balsa for Impact Limiter  (Standard Composition SCALE4.4/TN-FSV SAR Table 5-6)
c          density = 0.125 g/cm^3;  Composition by atom fraction
c     **************************************************************
m7        6000.60c   0.28571
          8016.60c   0.23810
          1001.50c   0.47619
c      **************************************************************
c      Lead for Gamma Shield  (Standard Composition SCALE4.4/TN-FSV SAR Table 5-6)
c          reduced density = 11.18 g/cm^3;  Composition by atom fraction
c     **************************************************************
m8      82000.50c   1.0
c      **************************************************************
c      Depleted Uranium for FSV Canister Plug  (TN-FSV SAR Table 5-6)
c          density = 19.05 g/cm^3;  Composition by atom fraction
c     **************************************************************
m9      92238.50c   0.99727
        92235.50c   0.00273
c     ***************************************************************
c      Homogenized OR Canister Source layer 4 GSF-182  5 kg u238
c           Density = 0.4330 g/cm^3;  Composition by atom fraction
c     ***************************************************************
m10    92238.50c  0.03137
       28000.50c  0.08598
       26000.50c  0.65032
       25055.50c  0.01934
       24000.50c  0.19409
       14000.50c  0.01891
c
c     ***************************************************************
c      Homogenized OR Canister Source layer 1 GSF-213  1 kg u238
c           Density = 0.3903 g/cm^3;  Composition by atom fraction
c     ***************************************************************
m11    92238.50c  0.00644
       28000.50c  0.08819
       26000.50c  0.66706
       25055.50c  0.01983
       24000.50c  0.19908
       14000.50c  0.01940
c
c     ***************************************************************
c      Homogenized OR Canister Source layer 3 GSF-196  30 kg u238
c           Density = 0.6998 g/cm^3;  Composition by atom fraction
c     ***************************************************************
m12    92238.50c  0.16270
       28000.50c  0.07432
       26000.50c  0.56215
       25055.50c  0.01671
```

```
      24000.50c  0.16777
      14000.50c  0.01635

c
c  prdmp 2j 1
c  print
□
```