TRANSNUCLEAR, INC.

E-18171
May 19, 2000

Mr. David Tiktinsky, Project Manager
Licensing Section
Spent Fuel Project Office
Office of Nuclear Material Safety and Safeguards
US Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: Model No. TN-68 Transport Package (Docket No. 71-9293, TAC No. L22899

Reference: NRC letter dated March 29, 2000 to Tara Neider, Transnuclear

Dear Mr. Tiktinsky:

Enclosed please find the responses to your questions itemized in the referenced letter. This package includes the following:

1. Responses to letter dated March 29, 2000
2. List of Revision 2 Pages
3. Description of Changes Made to Revision 2
4. Rev. 2 SAR pages

If you have any questions, please feel free to contact me.

Sincerely,

Tara Neider

Tara Neider
Vice President

Cc: Project 972 file

NMSS01 Public

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Attachment to E-18171 dated May 19, 2000
Docket 71-9293, Tac No. L22899
Responses to NRC questions dated March 29, 2000

1. Numerous RAI responses either indicate that Safety Analysis Report (SAR) page changes will be made or the responses themselves should be incorporated into the SAR. However, changes to SAR Sections 1, 3, and 5 were not provided and should be submitted.

   Revised SAR pages identified in RAI1 are included in this submittal.

2. The response to RAI 1-6-1 discusses the concept of preferential loading. However, the details of this preferential loading are not addressed. For example, the following items need to be considered:

   2.1 A detailed shielding analysis for the combination of 10 year cooled fuel and 26 year cooled fuel was not provided. Note that the shielding analysis presented for the package must demonstrate compliance with the shielding requirements of 10CFR71 and not depend only on future dose measurements at the time of transport.

   The details of this preferential shielding analysis have been included in the revised Section 5 SAR pages being submitted. The calculated dose rates meet the requirements of 10CFR71.

   2.2 The effects of non-symmetrical heat loads may invalidate the 1/12 axis symmetrical thermal model proposed by TN.

   The thermal analysis assumes all 68 assemblies are the design basis 40,000 MWD/MTU, 10 year cooled fuel. The total cask decay heat in the cask is 21.2 kw with each assembly having a maximum of 0.312 kw. This is a bounding thermal analysis that predicts maximum temperatures for the cask components. Actual cask loadings will have non-symmetrical heat loads; however, the thermal analysis performed will be bounding.

   2.3 The cladding temperature limit varies with cooldown time. The effect of multiple temperature limits was not evaluated.

   The temperature limit for the spent fuel has been revised to a single value of 380 °C (716 °F) which is not dependent of cooling time, per *PNL-4835, Johnson et. al., Technical Basic for Storage of Zircaloy-Clad Spent Fuel in Inert Gases, Pacific Northwest Laboratory, 1983.* The revised SAR pages reflect this temperature limit for any qualified spent fuel contents of the TN-68 packaging.

2.4 The operating procedures for the package do not appear to support preferential loading.

Section 7 of the SAR has been revised to address preferential loading.

3. The response to RAI 3-1-4 is in error. TN limits consideration of accessible surfaces to the impact limiters. In addition to the impact limiters, the cask body exterior surfaces need to be considered.

The response to RAI 3-1-4 addressed the impact limiters as the accessible surface because the use of a personnel barrier protects the cask body. However, the wording talked about railings limiting access and was somewhat confusing. The revised SAR pages/drawings show a wire mesh placed around the cask body that serves as a personnel barrier. This allows only the impact limiter surfaces to be accessible.

4. The response to RAI 3-6 did not address thermal degradation issues of the wood or glue. The document cited in the RAI response, NUREG/CR-0322, page 12, specifically states that the "mechanical properties of wood decrease when heated" and that "prolonged exposure to high temperature causes an irreversible decrease in properties".

As cited in the NUREG document, there is degradation of the wood structural properties at elevated temperatures. This irreversible degradation is a function of both temperature and the period of exposure. Repeated exposures to elevated temperatures result in a cumulative effect on wood properties. For example, using data and correlations provided in Mechanics of Wood and Wood Components (Bodig and Jayne, 1982) it would take a cumulative period of over 325 days of exposure to a 175 °F temperature to cause a 5% permanent degradation in structural wood properties. Exposure to a 160 °F temperature for a cumulative period of over 650 days would cause a similar 5% degradation in structural properties.

To reduce the temperature of the TN-68 impact limiter and minimize the effect of thermal degradation on the wood, a thermal shield has been installed between the bottom portion of the cask body and the rear impact limiter. The maximum wood temperature during normal transport conditions is 175 °F with the use of the thermal shield. This design change is reflected in the revised SAR pages.

Less than 10% of the wood in the TN-68 impact limiter has maximum temperatures between 160 and 175 °F. The impact limiter is subjected to full insolation and 100 °F ambient conditions during only a portion of the time of actual transport time. Hence, the effects of thermal degradation on the wood are considered to be negligible.

A resorcinol resin adhesive is used within the impact limiters. Resorcinol is classified within the Wood Handbook: Wood as an Engineering Material (U.S. Department of Agriculture, 1999) as "more resistant than wood to high temperature and chemical aging". In addition, the wood is confined by the inner and outer shells and separated by gussets. The structural analysis does not take credit for the glue within the impact limiters. Therefore, any degradation of the glue would have an insignificant effect on the performance of the impact limiters.

5. In response to RAI 3-9-3, the table on page 50 shows a temperature of 82 °F post fire for the radial neutron shield, which appears to be incorrect.

There was a typo in the table on page 50 of the response. The value should have been reported as 982 °F. Table 3-3 in the revised SAR Section 3 reports the correct value.

6. The applicant provided an alternative configuration for the OP transport cover (Item 56 on Drawing 972-71-7). This was not due to an RAI. TN should provide a summary of all other significant drawing changes.

A summary of all drawing changes for the RAI1 response and this submittal is included in the description of SAR changes provided with this submittal.

Attachment to E-18171 dated May 19, 2000
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Description of SAR Changes

The SAR changes described below have been made to address responses to RAI1 and the letter dated March 29, 2000. All revisions to the pages have been marked as Rev. 2 and by a line in the margin. This description is provided for clarity.

Chapter 1

Section 1.2.1:

- Added description of thermal shield used to minimize heat transfer to the bottom limiter. Increased overall length of packaging due to addition of thermal shield.
- Added description of personnel barrier. Removed reference to tarp.

Section 1.2.1.3:

- Material of impact limiter shells revised to stainless steel. This was revised prior to testing the impact limiters. All testing was performed on impact limiters with stainless steel shells.
- Added description of thermal shield.

Section 1.2.3:

- Added description of intact fuel assembly.
- Added reference to Table 6.2-1.
- Added description of preferential loadings.
- Added max. heat load per assembly.
- Added reference to new table 1-2, minimum cooling time required for various combinations of minimum init. Enrichment and burnup.

Drawing changes are listed for both Rev. 1 and Rev. 2.

Drawing 972-71-1. The 269.33" Ref. Dimension was changed to 271.08" Ref. To account for thermal shield.

Drawing 972-71-2. The shield ring thickness was increased to one inch. Tolerance was changed from +/-.03" to +.12"/-.25". Attachment bracket was added to the shield ring. Notes 13 and 14 were added. Drawing revision increased from Rev. 0 to Rev. 2.

Revision 1 changes were as follows:
Note 6 was modified to specify the code and standards for fabrication, examination, assembly, and testing.
Note 8 was modified to identify the containment system.

Note 9 was modified to specify the maximum allowable weight of package, maximum allowable weight of contents and secondary packaging.
Disabling bolts for impact limiter lifting lugs were added.
Nominal interference between gamma shield and containment shell was added.

Revision 2 changes are as follows:
1. The longitudinal section of the Packaging Transport Configuration was changed to 271.08". The rear impact limiter was moved out.
Items 64 and 65 were added. The tolerance increased between trunnion centerline distance. It was changed from +/-.12" to +.25"/-.12" to account for fabrication variations.
Note 12 was changed from 12.83" to 11.08" due to addition of thermal shield.

Drawing 972-71-3. The boron-10 content of the neutron absorber material and poison plates were added. The picture of the basket holddown-lifting lug was revised. Tolerance of +/-.06" was added to 6.00" dimension, Detail B. Items 62 , Hex Bolt and 63, Lock Bolt were added to the Parts List. Drawing revision went from Rev. 0 to Rev. 3.
Revision 2 changes are as follows:
1. Parts List: Item 26: The number required was 3. "Note 8" referenced.
2. Note 8 was added.
Revision 3 changes are as follows:
1. Parts List, Item 64, Thermal Shield and Item 65, Hex Hd Cap Screw were added.
2. Item 47, the quantity required for the Socket Head Cap Screw was changed from 8 to 4.

Drawing 972-71-4. Top View – Added tolerance of +/-.12" to 57.00" D.B.C. The O.P. Port Bolt orientation and cover configuration picture changed from 4 bolt holes to 3 bolt holes, 2.094" diameter. The Bolt Hole tolerance was also changed to +0.020"/-.010" from 2.094" Dia, General Tolerance. Drawing Revision increased from Rev. 0 to Rev. 2. Revision 2 change was revising O.P. Cover Picture, Top View. "See Detail Of Item 56 on Dwg. 972-71-7."

Drawing 972-71-5. Detail D: 2.00" diameter was changed to 2.56". Note 6 was also added.

Drawing 972-71-6. Dimensions and weld sizes were added to alignment key.

Drawing 972-71-7. Shield ring attachment strap and bracket were added. Shield ring thickness was increased to 1" from 0.5". Set screws and lifting lugs were deleted. Transport cover now has 3 bolt holes instead of 4 bolt holes and scallops were added. Drawing revision increased from Rev. 0 to Rev. 3. Revision 2 change was the addition of note to existing Item 56, "For Alternate Configurations." Revision 3 change was to Item 50, Tierod. The dimension changed from 152.00" to 153.75"

Drawing 972-71-8. The transport frame was changed to phantom. Drawing revision went from Rev. 0 to Rev. 2. Rev. 2 changes are as follows:

1. Side View: Dimension changed from 269.33" REF. to 271.08" REF.
2. Impact limiter was moved out.
3. Personnel Barrier and frame were added.
4. Dimension 136.75" was changed to 138.50".
5. Section A-A: Personnel Barrier and frame were added and 90"REF. dimension was added.

Drawing 972-71-9. Weld size between Item 2 to Item 5 was added in View B-B. Drawing revision went from Rev. 0 to Rev. 2. Rev. 2 changes are as follows:
In View C-C: Added 3/8" threaded holes and section N-N was called out.

Drawing 972-71-10. Parts List changed. Item 37 was added. Items 1-9, 18-21, and 25-32 were all Material ASTM A-516, GR. 70 and were changed to Material A240 Type 304. Items 22 and 36 were material ASTM A-516, GR. 70 and were changed to Material A-276 Type 304. Item 33 was Material A-194 GR. 2H, and has been changed to Material A-194, GR. 8. Section N-N was also added.

Drawing 972-71-11. 3/8" threaded holes were added to picture in View C-C. Thermal Shield Detail was also added.

Drawing 972-71-14 This new drawing was added as part of Rev. 1 of the SAR to show the exceptions to the ASME code.

Table 1-1

- Revised overall length to account for thermal shield. Revised weights to account for weight of thermal shield.

- Added new table 1-2.

Chapter 2

- Section 2.1.2.3. carbon steel changed to stainless steel for impact limiter housing.
- Table 2-6. Updated weights to include thermal shield.
- Table 2-30. Corrected typo. These stresses are not limiting.

Appendix 2.10.8

- Section 2.10.8.2. Carbon steel changed to stainless steel for impact limiter housing.

Chapter 3

- Section 3.1 revised to add description of personnel barrier. The maximum fuel cladding temperature limit has also been revised.

- Section 3.2 was revised to add thermal conductivity values for the wood and to add painting to the impact limiters.
- Section 3-4 was revised to incorporate a new model of the impact limiters (Section 3.4.1.2). Section 3-4 has also been reorganized and renumbered. Several sections have moved to provide a more orderly description of the two models.. The heat dissipation writeup (Now section 3.4.1.4) was revised to include an additional equation for the Nusselt number. The section on solar heat load has been revised to add an insolation value for flat surfaces. The maximum accessible temperatures in the shade has been revised to 115°F as a result of the new analysis performed. This section has been moved from section 3.4.1 to section 3.4.3.
- Section 3.5. Section referenced has been corrected.
- Section 3.5.1. Deleted description regarding damage to the impact limiters.
- Section 3.5.3 has been added. This describes the evaluation of crushed impact limiters.
- Section 3.5.5. The seal temperature has increased from 360°F to 362°F as a result of the new analysis.
- Section 3.6. Reference 14 has been added to support the new analysis.
- Table 3-1. Temperatures have increased slightly. A temperature value has been added for the wood in the impact limiters.
- Table 3-3. Temperatures increase by up to 2°F as a result of the new analysis.
- Figures 3-5, 3-9, 3-10, 3-11, 3-12, 3-13, 3-14 have been added to show the results of the additional analyses performed.
- Previous figures 3-8, 3-9 and 3-10 have been deleted.

Chapter 4

The containment analyses for the hypothetical thermal accident have been revised slightly to account for the increase in temperature from the thermal evaluation presented in Chapter 3.

Chapter 5

- Section 5.1 has been revised to change 20 year cooled fuel to 16 year cooled fuel.
- Section 5.33 has been added to address preferential loading.
- File 5.6.2 has been revised to account for a 1" thick ancillary shield ring. The previous submittal had a ½ inch thick ancillary shield ring and to revise the cooling time from 20 years to 16 years.
- File 5.6.3 has been added to address preferential loading.
- As a result of the revised fuel contents, Table 5.1-2, summary of dose rates has been revised.
- Table 5.2-4 has been revised to show data for 10 year cooled fuel.
- Table 5.2-5 has been revised to show data for 16 year cooling time.
- Table 5.2-6 has been added for 10 year cooled fuel.
- Table 5.2-7 has been added for 26 year cooled fuel.

- Table 5.2-8 (previous table 5.2-6) has been revised to show data for 16 year cooled fuel.
- Table 5.2-9 and 5.2-10 have been added for 10 and 26 year cooled fuel.
- Table 5.4-3 has been added.
- Figure 5.1-1 has been revised to show the increased thickness of the ancillary shield ring.
- Figure 5.3-3 has been added to show preferential loading configuration.

Chapter 7

This section has been revised to refer to Figure 5.3-3 for preferential loading.

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Docket 71-9293, Tac No. L22899
List of Included Rev. 2 Pages

Chapter 1

Pages 1-i, 1-1 through 1-8
Drawings 972-71-1 Rev. 1, 972-71-2, Rev. 2, 972-71-3 Rev. 3,972-71-7 Rev. 3, 972-71-8 Rev. 2, 972-71-9, Rev. 2, 972-71-10, Rev. 1, 972-71-11, Rev. 1,
Table 1-1/1-2
Figure 1-1/Figure 1-1 Notes

Chapter 2

Pages 2-5/2-6
Tables 2-5/2-6
Tables 2-30/2-31

Appendix 2.10.8

Pages 2.10.8-1/2.10.8-2

Chapter 3

Complete Chapter

Chapter 4

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Chapter 5

i, ii, pages 5-1 through 5-34
Table 5.1-1/5.1-2
Table 5.2-1/5.2-1a
Table 5.2-2/5.2-3
Table 5.2-4/5.2-5
Table 5.2-6/5.2-7
Table 5.2-8/5.2-9
Table 5.2-10/5.2-11
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Table 5.4-1/Table 5.4-2
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Figure 5.1-1
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Figure 5.4-2
Figure 5.4-3
Figure 5.4-4

Chapter 7

Page 7-1/7-2

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Transnuclear, Inc.

TN 68 TRANSPORT PACKAGING
SAFETY ANALYSIS REPORT

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TN 68 TRANSPORT PACKAGING

CHAPTER 1

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1. GENERAL INFORMATION

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CHAPTER 1

GENERAL INFORMATION

1.1 INTRODUCTION

This Safety Analysis Report (SAR) presents the evaluation of a Type B(U) spent fuel transport packaging developed by Transnuclear, Inc. and designated the TN-68. This SAR describes the design features and presents the safety analyses which demonstrate that the TN-68 complies with applicable requirements of 10 CFR 71(1). The format and content of this SAR follow the guidelines of Regulatory Guide 7.9(2).

The TN-68 is a dual purpose cask intended for both storage and transport. A separate SAR has been submitted to address the safety related aspects of storing spent fuel in TN-68 casks in accordance with 10 CFR 72(3).

The packaging is intended to be shipped as exclusive use. The Transport Index for nuclear criticality control for the TN-68 cask is determined to be zero (0) in accordance with 10 CFR 71.59. See Chapter 6.

Transnuclear, Inc. has a NRC approved quality assurance program (Docket Number 71-0250) which satisfies the requirements of 10 CFR 71 Subpart H.

1.2 PACKAGE DESCRIPTION

1.2.1 Packaging

The TN-68 packaging will be used to transport 68 intact BWR fuel assemblies with or without channels. Only intact fuel will be transported in the cask. Known or suspected failed fuel assemblies (rods) and fuel with cladding defects greater than pin holes and hairline cracks are not to be transported in the TN-68 packaging. In its transport configuration, the TN-68 packaging consists of the following components:

- A basket assembly which locates and supports the fuel assemblies, transfers heat to the cask body wall, and provided neutron absorption to satisfy nuclear criticality requirements.
- A containment vessel including a closure lid and seals which provides radioactive materials containment and a cavity with an inert gas atmosphere.
- A thick-walled, forged steel cask body for gamma shielding surrounding the containment vessel.
- A radial neutron shield surrounding the gamma shield which provides additional radiation shielding. The neutron shielding is enclosed in an outer steel shell.
- A set of impact limiters consisting of balsa and redwood, encased in carbon steel shells, which are attached to both ends of the containment vessel during the shipment. An aluminum spacer is also present to provide a smooth contact surface between the top impact limiter and the cask lid. A thermal shield is provided between the bottom impact limiters and the casks to minimize heat transfer to the bottom limiter. The impact limiters are held in place with the use of tie rods and attachment bolts.
- Sets of upper and lower trunnions that provide support, lifting, and rotation capability for the cask.

A personnel barrier is mounted to the transport frame to prevent unauthorized access to the cask body. The overall dimensions of the TN-68 packaging are 271.08 inches long and 144 inches in diameter with the impact limiters installed. The cask body is 197.25 inches long and 84.50 inches in diameter except at the lid which is 79.88 inches in diameter. The cask diameter including the radial neutron shield is 98.0 inches. The cask cavity is 178 inches long and 69.5 inches in diameter. The general arrangement of the TN-68 packaging is depicted in Figure 1-1. Detailed design drawings for the TN-68 packaging are provided in Appendix 1.4. The materials used to fabricate the packaging are shown in the Parts List on Drawing 972-71-3 and the materials used to fabricate the impact limiters are shown in Parts List on Drawing 972-71-10. Where more than one material has been specified for a component, the most limiting properties are used in the analyses in the subsequent chapters of this SAR.

The maximum gross weight of the loaded package is 130.0 tons including a maximum payload of 47.9 kips. Table 1-1 summarizes the dimensions and weights of the TN-68 packaging. Trunnions attached to the cask body are provided for lifting and handling operations, including rotation of the packaging between the horizontal and vertical orientations. The TN-68 packaging is loaded in the vertical configuration and transported in the horizontal orientation, on a specially designed shipping frame, with the lid end facing the direction of travel.

The maximum normal operating pressure of the TN-68 is 18.5 psig. A cask cavity pressure of 100 psig is conservatively used for the purposes of structural analyses. The spent fuel payload is shipped dry in a helium atmosphere. The heat generated by the spent fuel assemblies is rejected to the surrounding air by convection and radiation. No forced cooling or cooling fins are required.

The following sections provide a physical and functional description of each major component. Detail drawings showing dimensions of significance to the safety analyses, welding and NDE information, and a complete materials list are provided in Appendix 1.4. Reference to these drawings is made in the following physical description sections and in general, throughout this SAR. Fabrication of the TN-68 packaging is performed in accordance with these drawings.

1.2.1.1 Containment Vessel

The containment boundary consists of the inner shell and bottom plate, shell flange, lid outer plate, lid bolts, penetration cover plate and bolts and the inner metallic O-rings of the lid seal and the two lid penetrations (vent and drain). The containment vessel prevents leakage of radioactive material from the cask cavity. It also maintains an inert atmosphere (helium) in the cask cavity. Helium assists in heat removal and provides a non-reactive environment to protect fuel assemblies against fuel cladding degradation which might otherwise lead to gross rupture.

The overall containment vessel length is approximately 189 in. with a wall thickness of 1.5 in. The cylindrical cask cavity has a nominal diameter of 69.5 in. and a length of 178 in. The containment lid is 5 in. thick and is fastened to the body by 48 bolts. Double metallic O-ring seals are provided for the lid closure. To preclude air in-leakage, the cask cavity is pressurized with helium to above the atmospheric pressure.

There are two penetrations through the containment vessel which are in the lid. These penetrations are for draining and venting. Double metallic seals are utilized on these two lid penetrations.

The OP port provides access to the interspace lid seals for testing purposes. The OP transport cover is not part of the containment boundary.

The containment shell, bottom, and lid materials are SA-203, Grade E and SA-350, Grade LF3. The TN-68 containment vessel is designed, fabricated, examined and tested in accordance with the requirements of Subsection NB(4) of the ASME Code to the maximum practical extent. In addition, the design meets the requirements of Subsection WB of the ASME Section III, Division 3(5) and Regulatory Guides 7.6(6) and 7.8(7). Exceptions to the ASME Code are discussed in

Section 2.11 of Chapter 2. The construction of the containment boundary is shown on drawings 972-71-2, 3 and 4 provided in Appendix 1.3. The design of the containment boundary is discussed in Chapter 2 and the fabrication requirements (including examination and testing) of the containment boundary are discussed in Chapter 4.

1.2.1.2 Gamma and Radial Neutron Shielding

A gamma shield is provided around the walls and the bottom of the containment vessel, by an independent shell and bottom plate of carbon steel (Drawings 972-71-2, -3 and –4). The gamma shield completely surrounds the containment vessel inner shell and bottom closure. The 6.0 inch thick gamma shielding cylinder is SA-266, Class 2 and the 8.25 inch thick bottom is SA-266 Class 2 or SA-516, Grade 70.

In order to obtain a close fit between the containment vessel and the gamma shielding for heat transfer, the gamma shielding is heated prior to assembly with the containment shell. As the gamma shielding cools, a gap forms between the containment vessel flange and the gamma shielding. This gap is filled with shims as shown on Drawing 972-71-4. The shims are machined to fill the gap and act as a backing plate for the 0.50 inch weld between the containment flange and the gamma shield shell. The shims are typically less than 0.25 inches and no more than 0.50 inches thick and are made from SA-516, Grade 70 material. The shims are sized so there is no more than 0.03 inch gap between the shims and the flange or the shims and the gamma shield shell.

A 4.50 inch thick gamma shield (SA-105 or SA-516, Grade 70) is also welded to the inside of the containment lid (Drawing 972-71-4).

Neutron shielding is provided by a borated polyester resin compound surrounding the gamma shield. The resin compound is cast into long, slender aluminum containers. The containers are 6063-T5 aluminum. The total thickness of the resin and aluminum is 6.00 inches. The array of resin-filled containers is enclosed within a smooth 0.75 inch thick outer steel shell (SA-516, Grade 70) constructed of two half cylinders. In addition to serving as resin containers, the aluminum provides a conduction path for heat transfer, from the cask body to the outer shell. A pressure relief valve is mounted on top of the resin enclosure (during storage) for venting the overpressure, caused by heating of the resin and the air entrapped after fuel loading.

Noncontainment welds are inspected in accordance with the NDE acceptance criteria of ASME B&PV Code Subsection NF.

The structural analysis of the TN-68 cask body is presented in Chapter 2.

1.2.1.3 Impact Limiters

Front and rear impact limiters, shown on TN Drawings 972-71-1 and -8 through -12, form a part of the TN-68 packaging. The impact limiters are attached to each other using 13 tie rods and to the cask by 8 bolts attaching to brackets welded to the outer shell in eight locations (four bolting locations per impact limiter). The impact limiters consist of balsa wood and redwood blocks, encased in sealed stainless steel shells (Type 304) that maintain the wood in a dry atmosphere and provide wood confinement when crushed during a free drop. The impact limiters have internal radial gussets for added strength and confinement.

The impact limiters have an outside diameter of 144 inches, and an inside diameter of 85.55 inches. They extend, axially, 35.25 inches from the ends of the cask, and overlap the sides of the cask by 12.75 inches. The external surfaces of the impact limiter shells are painted.

Thirteen 1.5 inch diameter tie-rods are used to hold the impact limiters in place. The tie-rods span the length of the cask and connect to both impact limiters via mounting brackets (See Drawings 972-71-8 through 972-71-11). The impact limiters are also attached to the outer shell of the cask with 1.5 inch diameter bolts. The bolts are attached to brackets (welded to the cask outer shell) and thread into to each impact limiter. There are a total of eight bolt-bracket sets, four per impact limiter.

Each impact limiter is provided with seven fusible plugs that are designed to melt during a fire accident, thereby relieving excessive internal pressure. Each impact limiter has two lifting lugs for handling, and two support angles for holding the impact limiter in a vertical position during storage. The lifting lugs and the support angles are welded to the stainless steel shells.

An aluminum spacer is placed on the cask lid prior to mounting the impact limiters. The purpose of the aluminum spacer is to provide a smooth contact surface for the top impact limiter. The top plate of the spacer has 48 holes to allow clearance for the lid bolt heads. The lip of the spacer is designed to make up the difference between the lid and cask outer diameters so that the top impact limiter cavity mates with a surface of constant diameter (Drawing 972-71-12).

Aluminum thermal shield is added to the bottom impact limiter to reduce the impact limiter wood temperature. The details of the thermal shield are included in TN drawing no. 972-71-11.

The functional description as well as the performance analysis of the impact limiters are provided in Appendix 2.10.8.

1.2.1.4 Tiedown and Lifting Devices

Threaded holes are provided in the lid for attachment of component lifting devices. These are used as attachment points for sling systems or other lifting tools. These threaded holes are equally spaced 90° apart as shown on Drawing 972-71-4. Prior to transport, any attachments will be removed and access to these threaded holes is prevented by the presence of the top impact limiter.

Four trunnions, which form part of the cask body, are attached for lifting and rotating of the cask. Two of the trunnions are located near the top of the body, and two near the bottom. The upper trunnions are bolted to the gamma shielding and sized for single failure proof lifting. The upper trunnions are not intended to be removed during transport. The lower trunnions are welded to the gamma shield, and are used for rotating the cask between the vertical and the horizontal positions.

The top trunnions are fabricated and tested in accordance with ANSI N14.6 and are designed for single failure proof lifting.

1.2.1.5 Fuel Basket

The basket structure is designed, fabricated and inspected in accordance with ASME B&PV Code Subsection NG. Exceptions to the code are provided in Section 2.11. The basket structure consists of an assembly of stainless steel cells, joined by a proprietary fusion welding process to 1.75 in. wide stainless steel plates. Above and below the plates are slotted borated aluminum (or boron carbide/aluminum) metal matrix composite plates (neutron poison plates) which form an egg-crate structure. The poison plates provide the necessary criticality control and provide the heat conduction paths from the fuel assemblies to the cask cavity wall. This construction forms a very strong honeycomb-like structure of cell liners, which provide compartments for 68 fuel assemblies. The nominal open dimension of each cell is 6.0 in. x 6.0 in., which provides some clearance around the fuel assemblies. The overall basket length of 164 in. is less than the cask cavity length, and allows for thermal expansion and fuel assembly handling.

A shear key is welded to the inner wall of the containment vessel to prevent the basket from rotating during normal operations. Similarly, a hold down ring is installed above the basket after fuel loading is complete to prevent the basket from moving axially during transport.

1.2.2 Operational Features

There are no complex operational features associated with the TN-68 cask. The TN-68 packaging is designed to be compatible with spent fuel pool loading/unloading methods. The sequential steps to be followed for cask loading, testing, and unloading operations are provided in Chapter 7. These operations are summarized below.

Upon arrival, the empty cask is inspected. Preparation of the packaging for loading/unloading requires that the front (top) and rear (bottom) impact limiters including the tie-rods and attachment bolts are removed from the cask body, first. The cask is then rotated from the horizontal transport orientation to the vertical orientation using a crane and lift beam attached to the front trunnions. The rear trunnions pivot in the shipping frame as the cask is rotated.

The cask is brought into the spent fuel building. Access to the cask cavity and fuel basket is obtained by untorquing and removing the 48 closure lid bolts, and removing the lid using the lifting lugs provided. The cask is then lowered into the cask pit/spent fuel pool. Fuel assemblies are loaded into the 68 basket compartments.

The lid is installed and the cavity is vented and drained. The cask is lifted above the water and some of the lid bolts are installed hand tight. Venting/draining may occur while lifting the cask out of the pool. The cask is moved from the cask pit/spent fuel pool to the decontamination area. The remaining lid bolts are installed. The cask cavity is then evacuated and dried by means of a vacuum system and then back filled with helium. The lid seals and penetration cover seals are leak tested. The external surface radiation levels are checked to assure that they are within limits.

1.2.3 Contents of Packaging

The contents of the TN-68 packaging are limited to the following.

- Fuel parameters
    - Fuel is limited to 68 unconsolidated intact GE BWR fuel assemblies with zircalloy cladding. An intact fuel assembly is a spent nuclear fuel assembly without known or suspected cladding defects greater than pinhole leak or hairline cracks and which can be handled by normal means. Partial fuel assemblies that is spent fuel assemblies from which fuel rods are missing, shall not be classified as intact fuel assemblies unless dummy fuel rods are used to displace an amount of water equal to that displaced by the original rod(s).
    - Fuel may be transported with or without channels. Nominal channel thicknesses up to 0.120 inches thick are acceptable for transport.
    - Permissible fuel assembly types are listed below (fuel designs may be C, D, or S lattice)

GE Type	Designation	# of Fueled Rods	Uranium Content (MTU/assembly)
7x7	2A	49	0.1977
7x7	2, 2B	49	0.1977
7x7	3, 3A, 3B	49	0.1896
8x8	4, 4A, 4B	63	0.1880
8x8	5, 6, 6B, 7, 7B	62	0.1876
8x8	8, 8B	62	0.1885
8x8	8, 8B, 9, 9B, 10	60	0.1824
9x9	11,13	74	0.1757
10x10	12	92	0.1857

    - Fuel characteristics of each assembly type are provided in Table 6.2-1
    - Provided all the requirements listed in this section are met, the bounding fuel characteristics are:

Characteristic	Parameter
Maximum Initial lattice-average enrichment	3.7%
Minimum Initial bundle average enrichment	3.3%
Maximum assembly average burnup	40,000 MWD/MTU
Minimum cooling time	10 years[1]
Maximum Heat Load	0.313 KW/assy.

Note 1: Fuel assemblies are categorized into two types, Type I and Type II. Type I assemblies are the 40,000 MWD/MTU, 3.3% initial enrichment, 10 year cooled assemblies or equivalent, i.e. assemblies with various combinations of burnup, enrichment and cool time that provides an equivalent source term/dose rate as the bounding fuel assembly. Type I assemblies shall be placed into the interior compartments of the fuel basket as shown in Figure 5.3-3. Type II assemblies are those with various combinations of burnup, initial enrichment and cool time that provide a source term/dose rate that is less than the bounding fuel assembly. Type II assemblies may be placed in any basket fuel compartment. Type I and Type II assemblies may be mixed in any shipment such that the following conditions are met. It may be necessary to place the "colder" fuel in the peripheral basket compartments to meet the external dose rate requirements.

- The maximum contents weight shall not exceed 75.6 kips. The total weight of the BWR fuel assemblies shall not exceed 47.9 kips.
- The total decay heat of the cavity contents shall not exceed 21.2 kW.
- Measured external radiation levels shall not exceed the requirements of 10 CFR 71.47. Measured surface contamination levels shall not exceed the requirements of 10 CFR 71.87(i).
- Table 1-2 provides the minimum cooling time required for various combinations of minimum initial enrichment and burnup.

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

NO.	DATE	REVISIONS	DWN.	CHK'D.	M.D.		Q/A	PROJ.
1	[illegible]	SEE DCN 972-137	[illegible]	PS	JC			[illegible]

APPROVALS	DATE
PROJ. T.J.N.	19 MAY 99
Q/A W.R.S.	19 MAY 99
MECH. DES. P.S.	19 MAY 99
CHK'D. BY P.S.	19 MAY 99
DWN. BY. J.T.G.	18 MAY 99

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-68 PACKAGING
TRANSPORT CONFIGURATION

SAR

SCALE	SIZE	DWG. NO.	REV.
NONE	B	972-71-1	1

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

NO.	DATE	REVISIONS	DWN.	CHK'D.	M.D.		O/A	PROJ.
2	9/19/01	SEE DCN 972-138	JTG	PS	PS			
1	2/28/00	SEE DCN 972-108	J.T.G.	P.S.	P.S.		W.R.S.	T.J.N.

APPROVALS	DATE
PROJ. T.J.N.	19 MAY 98
O/A W.R.S.	19 MAY 98
MECH. DES. P.S.	19 MAY 98
CHK'D. BY P.S.	19 MAY 98
DWN. BY. J.T.G.	18 MAY 98

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-68 PACKAGING
GENERAL ARRANGEMENT

SAR

SCALE	SIZE	DWG. NO.	REV.
NONE	B	972-71-2	2

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

NO.	DATE	REVISIONS	DWN.	CHK'D	M.D.	N/T	O/A	PROJ.
3	[illegible]	SEE DCN 972-139	[illegible]	PS	JC		[illegible]	[illegible]
2	3/2/00	SEE DCN 972-125	J.T.G.	J.H.C.	P.S.		S.D.L.	T.J.N.
1	2/28/00	SEE DCN 972-109	J.T.G.	P.S.	P.S.		W.R.S.	T.J.N.

APPROVALS		DATE
PROJ.	T.J.N.	19 MAY 99
O/A	W.R.S.	19 MAY 99
MECH. DES.	P.S.	19 MAY 99
CHK'D. BY	P.S.	19 MAY 99
DWN. BY.	J.T.G.	18 MAY 99

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-68 PACKAGING
GENERAL ARRANGEMENT
PARTS LIST & DETAILS

SAR

SCALE	SIZE	DWG. NO.	REV.
NONE	B	972-71-3	3

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

NO.	DATE	REVISIONS	DWN.	CHKD	M.D.		O/A	PROJ.
3	9/13/[illegible]	SEE DCN 972-140	[illegible]	PS	JC		[illegible]	[illegible]
2	3/2/00	SEE DCN 972-127	J.T.G.	J.M.C.	P.S.		S.D.L.	T.J.N.
1	2/28/00	SEE DCN 972-112	J.T.G.	P.S.	P.S.		W.R.S.	T.J.N.

APPROVALS		DATE
PROJ.	T.J.N.	19 MAY 99
O/A	W.R.S.	19 MAY 99
MECH. DES.	P.S.	19 MAY 99
CHK'D. BY	P.S.	19 MAY 99
DWN. BY.	J.T.G.	18 MAY 99

TRANSNUCLEAR, INC.
HAWTHORNE, NY.

TN-68 PACKAGING DETAILS

SAR

SCALE	SIZE	DWG. NO.	REV.
NONE	B	972-71-7	3

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

NO.	DATE	REVISIONS	DWN.	CHK'D.	M.D.		Q/A	PROJ.
2	[illegible]	SEE DCN 972-141		PS	JC			
1	2/28/00	SEE DCN 972-113	J.T.G.	P.S.	P.S		W.R.S.	T.J.N.

APPROVALS		DATE
PROJ.	T.J.N.	19 MAY 98
Q/A	W.R.S.	19 MAY 98
MECH. DES.	P.S.	19 MAY 98
CHK'D. BY	P.S.	19 MAY 98
DWN. BY.	J.T.G.	18 MAY 99

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-68 PACKAGING
CASK ON TRANSPORT FRAME

SAR

SCALE	SIZE	DWG. NO.	REV.
NONE	B	972-71-8	2

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

NO.	DATE	REVISIONS	DWN.	CHKD.	M.O.		Q/A	PROJ.
2	[illegible]	SEE DCN 972-142	[illegible]	PS	JC		[illegible]	[illegible]
1	2/28/00	SEE DCN 972-14	J.T.G.	P.S.	P.S.		W.R.S.	T.J.N.

APPROVALS	DATE
PROJ. T.J.N.	19 MAY 99
Q/A W.R.S.	19 MAY 99
MECH. DES. P.S.	19 MAY 99
CHK'D. BY P.S.	19 MAY 99
DWN. BY J.T.G.	18 MAY 99

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-68 PACKAGING
TRANSPORT IMPACT LIMITER
ASSEMBLY

SAR

SCALE	SIZE	DWG. NO.	REV.
NONE	B	972-71-9	2

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

NO.	DATE	REVISIONS	DWN.	CHK'D.	M.O.		Q/A	PROJ.
1	5/12/00	SEE DCN 972-143	[illegible]	PS	JC		[illegible]	[illegible]

APPROVALS		DATE
PROJ.	T.J.N.	19 MAY 99
Q/A	W.R.S.	19 MAY 99
MECH. DES.	P.S.	19 MAY 99
CHK'D. BY	P.S.	19 MAY 99
DWN. BY	J.T.G.	18 MAY 99

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-68 PACKAGING
TRANSPORT IMPACT LIMITER
PARTS LIST & DETAILS

SAR

SCALE	SIZE	DWG. NO.	REV.
NONE	B	972-71-10	1

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

NO.	DATE	REVISIONS	DWN.	CHK'D.	M.D.		Q/A	PROJ.
1	[illegible]	SEE DCN 972-144		PS	JC			

APPROVALS	DATE
PROJ. T.J.N.	19 MAY 99
Q/A W.R.S.	19 MAY 99
MECH. DES. P.S.	19 MAY 99
CHK'D. BY P.S.	19 MAY 99
DWN. BY J.T.G.	18 MAY 99

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-68 PACKAGING
TRANSPORT IMPACT LIMITER
DETAILS

SAR

SCALE	SIZE	DWG. NO.	REV.
NONE	B	972-71-11	1

TABLE 1-1

NOMINAL DIMENSIONS AND WEIGHTS OF THE TN-68 PACKAGING

Overall length (with impact limiters, in)	271.08
Overall length (without impact limiters, in)	197.25
Impact Limiter Outside diameter (in)	144
Outside diameter (without impact limiters, in)	98
Cavity diameter (in)	69.5
Cavity length (in)	178
Containment shell thickness (in)	1.5
Containment vessel length (in)	184
Body wall thickness (in)	7.5
Containment Lid thickness (in)	5
Overall Lid thickness (in)	9.5
Bottom thickness (in)	9.75
Resin and aluminum box thickness (in)	6
Outer shell thickness (in)	0.75
Overall basket length (in)	164

Weight of Fuel Assemblies	47.9	kips
Loaded Weight of TN-68 Cask (without impact limiters)	227.4	kips
Weight of Impact Limiters, Aluminum Spacer, and Tie-Rods	33.0	kips
Total Loaded Weight of TN-68 Packaging (w/o shipping frame)	260.4	kips

TABLE 1-2

COOLING TIME AS A FUNCTION OF MAXIMUM BURNUP AND MINIMUM INITIAL ENRICHMENT

BWR COOLING TIMES (YEARS)

Initial Enrichment	Burnup (GWd/MTU)											
(bundle ave %w)	15	20	30	32	33	34	35	36	37	38	39	40
1.0	10	▨ 10	■	■	■	■	■	■	■	■	■	■
1.1	10	▨ **10**	■	■	■	■	■	■	■	■	■	■
1.2	10	▨ 10	■	■	■	■	■	■	■	■	■	■
1.3	10	▨ 10	■	■	■	■	■	■	■	■	■	■
1.4	10	▨ 10	■	■	■	■	■	■	■	■	■	■
1.5	10	▨ 10	▨ **10**	▨ 10	▨ **11**	▨ 11	▨ **11**	■	■	■	■	■
1.6	10	10	10	▨ 10	▨ 10	▨ 11	▨ 11	▨ 11	■	■	■	■
1.7	10	10	10	▨ 10	▨ **10**	▨ 11	▨ 11	▨ 11	▨ **12**	■	■	■
1.8	10	10	10	▨ 10	▨ 10	▨ 11	▨ 11	▨ 11	▨ **11**	▨ **12**	■	■
1.9	10	10	10	▨ 10	▨ 10	▨ 11	▨ 11	▨ 11	▨ 11	▨ 12	■	■
2.0	10	10	10	10	▨ 10	▨ **10**	▨ 11	▨ 11	▨ **11**	▨ 12	▨ **12**	■
2.1	10	10	10	10	▨ 10	▨ 10	▨ 11	▨ 11	▨ 11	▨ 12	▨ 12	▨ **12**
2.2	10	10	10	10	▨ 10	▨ 10	▨ 11	▨ 11	▨ 11	▨ 12	▨ 12	▨ 12
2.3	10	10	10	10	▨ 10	▨ 10	▨ 11	▨ 11	▨ 11	▨ **11**	▨ 12	▨ 12
2.4	10	10	10	10	10	▨ 10	▨ **10**	▨ 11	▨ 11	▨ 11	▨ 12	▨ 12
2.5	10	10	10	10	10	▨ 10	▨ 10	▨ 11	▨ 11	▨ 11	▨ 12	▨ 12
2.6	10	10	10	10	10	▨ 10	▨ 10	▨ 11	▨ 11	▨ 11	▨ 12	▨ 12
2.7	10	10	10	10	10	10	▨ 10	▨ **10**	▨ 11	▨ 11	▨ **11**	▨ 12
2.8	10	10	10	10	10	10	10	▨ 10	▨ 10	▨ 11	▨ 11	▨ 12
2.9	10	10	10	10	10	10	10	▨ 10	▨ 10	▨ 11	▨ 11	▨ 12
3.0	10	10	10	10	10	10	10	10	▨ **10**	▨ 10	▨ 11	▨ 12
3.1	10	10	10	10	10	10	10	10	▨ 10	▨ 10	▨ 11	▨ 12
3.2	10	10	10	10	10	10	10	10	10	▨ 10	▨ **10**	▨ **11**
3.3	10	10	10	10	10	10	10	10	10	10	▨ 10	▨ **10**
3.4	10	10	10	10	10	10	10	10	10	10	▨ 10	▨ 10
3.5	10	10	10	10	10	10	10	10	10	10	▨ 10	▨ 10
3.6	10	10	10	10	10	10	10	10	10	10	▨ 10	▨ 10
3.7	10	10	10	10	10	10	10	10	10	10	▨ 10	▨ 10

■ - not evaluated
▨ - Type I
☐ - Type II

Notes:

1. Total dose from gamma and neutron considered.
2. Cooling times in bold are cases actually run. Others are interpolated.

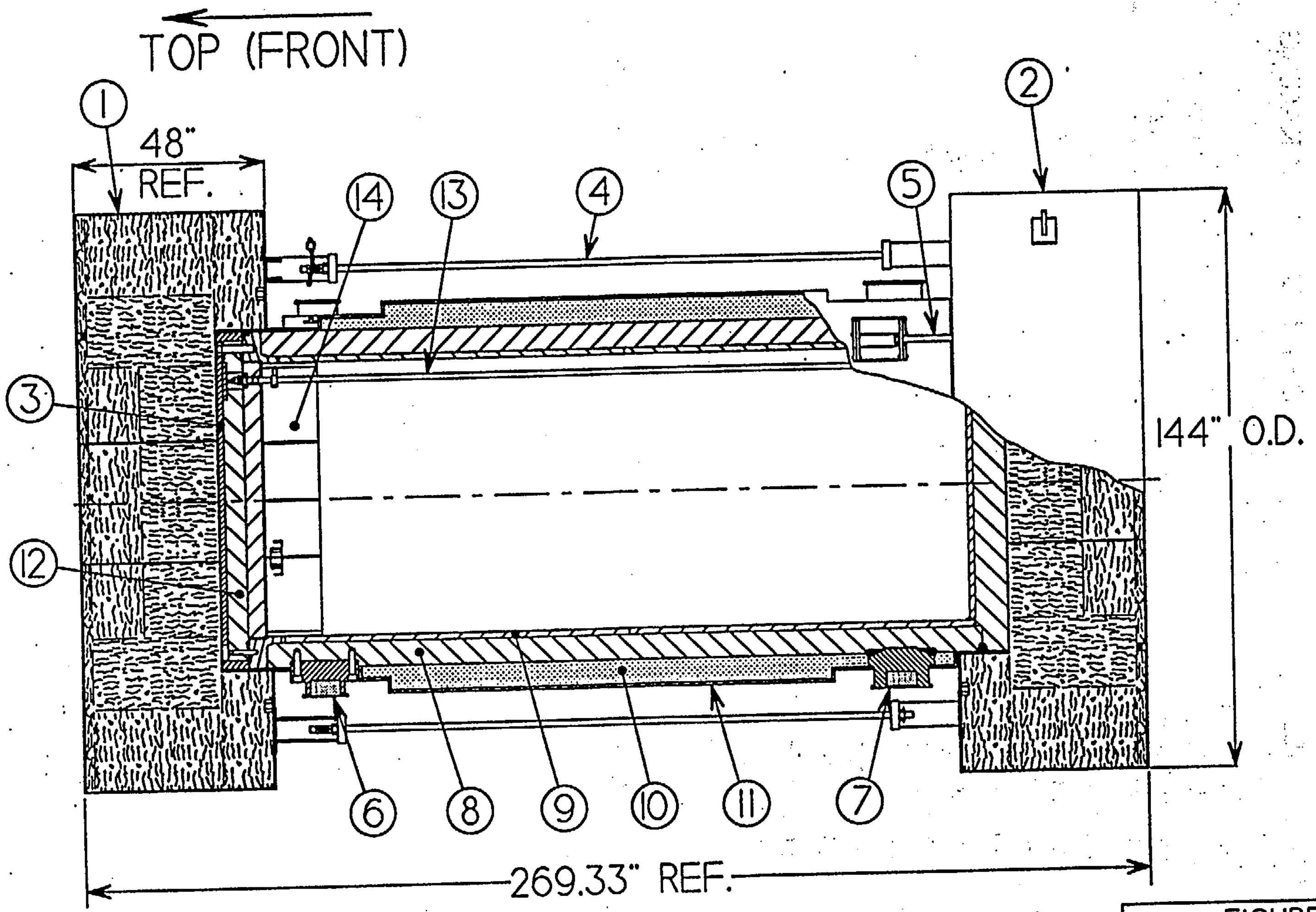

FIGURE 1-1
GENERAL ARRANGEMENT
TN-68 PACKAGING

FIGURE 1-1

GENERAL ARRANGEMENT TN-68 PACKAGING

Notes to Figure 1-1

A. Some details exaggerated for clarity.

B. Components are listed below:

1 Upper (front) impact limiter
2 Lower (rear) impact limiter
3 Aluminum Spacer
4 Impact Limiter Tie Rod
5 Impact Limiter Attachment Bolt & Bracket
6 Upper (bolted) Trunnions
7 Lower Trunnions
8 Cask Body (Gamma Shield Shell & Bottom)
9 Containment Shell (Inner Shell & Bottom)
10 Neutron Shielding
11 External Shell
12 Lid Assembly
13 Drain Tube
14 Basket Hold Down Ring

Seal welds are examined visually, or by liquid penetrant or magnetic particle methods, in accordance with Section V of the ASME Code(8). Electrodes, wire, and fluxes used for fabrication, comply with the applicable requirements of the ASME Code, Section II, Part C(9). The welding procedures, welders and weld operators are qualified in accordance with Section IX of the ASME Code(10).

The radial neutron shield, including the carbon steel enclosure, have not been designed to withstand all of the hypothetical accident loads. The shielding may degrade during the fire or due to the 40 inch drop onto the puncture bar. Therefore a bounding shielding analysis, assuming that the exterior neutron shielding is completely removed, has been performed. This analysis shows that the accident dose rates are not exceeded. These accident analyses are described in Chapter 5.

2.1.2.2 Basket

The basket is designed, fabricated and inspected in accordance with the ASME Code Subsection NG(3), to the maximum practical extent. The following exceptions are taken:

The poison and aluminum plates are not used for structural analysis. Therefore, the materials are not required to be code materials. The quality assurance requirements of NQA-1 is imposed in lieu of NCA-3800. The basket will not be code stamped. Therefore the requirements of NCA are not imposed. Fabrication and inspection surveillance is performed by the owner and design organization in lieu of an authorized nuclear inspector.

The fuel basket rail material is not a Class 1 material. It was selected for its properties. Aluminum has excellent thermal conductivity and a high strength to weight ratio provided that temperatures do not exceed 400°F.

NUREG-3854(11) and NUREG-1617(12) allow materials other than ASME Code materials to be used in the cask fabrication. ASME Code does provide the material properties for the aluminum alloy up to 400°F, and also allows the material to be used for Section III applications (Class 2 or 3) up to 400°F temperature (the maximum rail temperature is less than 310°F). The construction of the aluminum rails will meet the requirements of Section III, Subsection NG(3).

The stress limits for the basket are summarized in Table 2-5. The wall thickness of the basket fuel compartment is established to meet the heat transfer, nuclear criticality, and the structural requirements. The basket structure must provide sufficient rigidity to maintain a subcritical configuration under the applied loads. The 304 stainless steel members in the TN-68 basket are the primary structural components. The neutron poison plates are the primary heat conductors, and they also provide the necessary criticality control.

The basis for the allowable stresses for the 304 stainless steel fuel compartment box and the fusion welds is Section III, Division I, Subsection NG of the ASME Code. The primary membrane stress and primary membrane plus bending stress are limited to S_m (S_m is the code allowable stress intensity) and 1.5 S_m, respectively, at any location in the basket for normal (Design and Level A) load conditions.

The hypothetical impact accidents are evaluated as short duration, Level D conditions. The stress criteria are taken from Section III, Appendix F of the ASME Code(7). For elastic quasi-static analysis, the primary membrane stress intensity (P_m) is limited to the smaller of $2.4S_m$ or $0.7S_u$, and membrane plus bending stress intensities ($P_m + P_b$) are limited to $1.5P_m$.

The fuel compartment walls under compressive loads are also evaluated against the ASME Code rules for component supports, to ensure that buckling will not occur. The acceptance criteria (allowable buckling loads) are taken from the ASME Code, Section III, Appendix F, paragraph F-1341.4, Plastic Instability Load. The allowable buckling load is equal to 70% of the calculated plastic instability load. The buckling analyses of the aluminum rails are considered separately. See Appendix 2.10.5 for complete details of criteria for these conditions.

The basket hold down ring is set between the top of the basket assembly and inside surface of the lid assembly. The hold down ring is used to prevent the basket assembly from sliding freely in the axial direction during the normal transport conditions. The basket hold down ring is designed, fabricated and inspected in accordance with the ASME Code Subsection NF(3), to the maximum practical extent.

2.1.2.3 Impact Limiters (Front and Rear)

The TN-68 packaging is provided with impact limiters at each end of the cask body. The limiters are identical. The inside diameter of the limiter is determined by the diameter of the cask body. The length and outside diameter of the limiter are sized to limit the cask inertial loads during the 1 foot normal and 30 foot accident drop events so that the containment vessel (and the non-containment structures) meet the design criteria.

The impact limiter stainless steel cylinders, gussets, and end plates, are designed to position and confine the balsa and redwood blocks so that the impact energy is properly absorbed. The stainless steel shell is also designed to support and protect the wood blocks under normal environmental conditions (moisture, pressure, temperature, etc.).

The impact limiter and attachments are designed to withstand the applied loads and to prevent separation of the limiters from the cask during an impact. The design criteria for the impact limiters and attachments are both unique and specific. They are specified in Appendix 2.10.8.

2.1.2.4 Trunnions

The evaluation and design criteria for the lifting/tiedown trunnions are based on the requirements of 10CFR71.45. The details of the evaluation are presented in Section 2.5. Evaluation demonstrates that the front trunnions, used for lifting, have a minimum factor of safety of six against yield or ten against ultimate, whichever is most restrictive. The design and fabrication of the lifting trunnions are in accordance with the requirements of ANSI N14.6.

In the transport configuration (see TN drawing no. 971-71-8), the regulatory tie-down loads [10CFR 71.45(b)(1)] are shared by the rear trunnions and the outer surface of the cask at the front end which contacts the front saddle of the shipping frame. The evaluation provided in

Table 2-5
Basket Stress Limits

CLASSIFICATION	STRESS INTENSITY LIMIT
Normal (Level A) Conditions ⁽¹⁾	
P_m	S_m
P_l	$1.5\ S_m$
$(P_m + P_l) + P_b$	$1.5\ S_m$
$(P_m + P_l) + P_b + Q$	$3\ S_m$
$(P_m + P_l) + P_b + Q + F$	S_a
Shear Stress	$0.6\ S_m$
Hypothetical Accident (Level D) ⁽²⁾	
P_m	Smaller of $2.4\ S_m$ or $0.7\ S_u$
P_l	$1.5 \times P_m$
$(P_m + P_l) + P_b$	$1.5 \times P_m$
Shear Stress	Smaller of $0.42\ S_u$ or $2(0.6S_m)$

NOTES:

1. Classifications and stress intensity limits are as defined in ASME B&PV Code, Section III, Subsection NG.
2. Limits are in accordance with ASME B&PV Code, Section III, Appendix F.

Table 2-6
Cask Weight and Center Gravity

COMPONENT	NOMINAL WEIGHT (lbs. x 1000)
Cask Body	94.4
Bottom	15.6
Lid and Lid Bolts	12.3
Neutron Shield Aluminum Boxes	2.5
Resin	13.9
Outer Shell	11.2
Trunnions - Upper - Lower	0.8 0.9
Basket and Rails	25.9
Shield Ring	0.5
Basket Hold Down Ring	1.4
Fuel Assemblies	47.9
Overpressure Tank, Drain Tube	0.1
Cask Weight w/o Impact Limiters and Attachments	**227.4**
Impact Limiters (2)	30.6
Spacer (1) & Thermal Shield	1.4
Tie Rods (13)	1.0
Total Package Weight	**260.4**

* Center of Gravity of the package is approximately 97 inches and is measured along the axial centerline from the rear (bottom) of the cask.

Summary of weights used for Analysis:

1.	Front (Top) Trunnion Lifting (w/o impact limiters)	240,000 lbs.
2.	Rear (Bottom) Trunnion Tie-Down Analysis	271,950 lbs.
3.	Cask Body Analysis	271,950 lbs.

Table 2-30
Transport Truck Shock in Cold Environment Load Combination
(Preload + Fabrication + External Pressure + -20°F + Truck Shock)

Location		Nodal Stress Intensity (psi)
Flange	19	15121
	20	7741
Lid	21	676
	22	524
Outer Bottom Plate	23	715
	24	1127
	25	5184
	26	453
Outer Shell	27	10296*
	28	11824*
	29	3720
	30	2933
	31	3602
	32	2963
	33	3705
	34	2928
	35	2814
	36	1971
Weld	37	342
	38	1657
	39	1992

*Includes Local Stresses From Trunnion Due to Truck Shock Load
at Location 27: 3911 + 6385 = 10296
at Location 28: 3835 + 7989 = 11824

Table 2-31
Transport Rail Car Shock in Hot Environment Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + Rail Car Shock)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	6040
	2	2224
	3	5811
	4	2116
	5	7397
	6	6562
Inner Shell	7	30080*
	8	29565*
	9	17030
	10	16587
	11	17257
	12	16871
	13	17466
	14	16841
	15	18073
	16	20285
	17	11348
	18	11441

*Includes Local Stresses From Trunnion Due to Rail Car Shock Load

Linaerized stresses:

Location 7: $P_m = 15733 + 6382 = 22115$, $P_m + P_b = 15991 + 14089 = 30080$

Location 8: $P_m = 15733 + 6382 = 22115$, $P_m + P_b = 15476 + 14089 = 29565$

APPENDIX 2.10.8

STRUCTURAL ANALYSIS OF IMPACT LIMITERS

2.10.8.1 Introduction

This appendix presents the details of the structural analysis of the TN-68 impact limiters. The impact limiters are designed to absorb the kinetic energy resulting from the one (1) foot and thirty (30) foot normal and hypothetical accident free drop events specified by 10 CFR 71. Redwood and balsa wood are used as the primary energy absorption material(s) in the impact limiters. A sketch of the impact limiter is shown in Figure 2.10.8-1. A functional description of the impact limiters is given in Section 2.10.8.2. The impact limiter design criteria are described in Section 2.10.8.3.

A computer model of the TN-68 Packaging was developed to perform system dynamic analyses during impacts of 30 foot accident and 1 foot normal condition drops. The model was developed for use with the ADOC (Acceleration Due To Drop On Covers) computer code described in detail in Section 2.10.8.8 which determines the deformation of the impact limiters, the forces on the packaging and the packaging deceleration due to impact on an unyielding surface. Numerous cases were run to determine the effects of the wood properties and the initial drop angle. A description of the computer model, input data, analysis results and conclusions for the 30 foot accident condition and one foot normal condition free drops are given in Sections 2.10.8.4 and 2.10.8.5 respectively. The analysis of the impact limiter attachments is described in Section 2.10.8.6. A summary of results for all drop orientations is provided in Section 2.10.8.7. The forces and decelerations used in the cask body and basket structural analysis, presented in detail in Appendix 2.10.1 and Appendix 2.10.5, are given in Table 2.10.8-12 (loading values calculated in this appendix are increased for conservatism). Planned testing programs on the TN-68 wood filled limiters are discussed in Appendix 2.10.9. Test results to date indicate that ADOC predicts higher deceleration values, crush forces and crush depths than measured test results.

2.10.8.2 Design Description

The impact limiters absorb energy during impact events by crushing of balsa and redwood. The size, location and orientation of each wood block is selected to provide protection for the cask during all normal and hypothetical accident conditions of transport.

The top and bottom impact limiters are identical. Each has an outside diameter of 144 inches and a height of 48.00 inches. The inner and outer shells are Type 304 stainless steel joined by radial gussets of the same material. The gussets limit the stresses in the 0.25 in. thick steel outer cylinder and end plates due to pressure differentials caused by elevation and temperature changes during normal transport and provide wood confinement during impact. The metal structure positions, supports, confines and protects the wood energy absorption material. The metal structure does contribute to the energy absorbing capability of the impact limiter. However, the contribution to a side drop or oblique angles is negligible because contact starts at a single point with the unyielding surface (target) and initiates buckling of a single gusset. After the drop event is complete, relatively few gussets are buckled.

The region of the impact limiter which is backed-up by the cask body is filled with balsa wood and redwood mostly oriented with the grain direction perpendicular to the end of the cylindrical cask (see Figure 2.10.8-1). The materials and grain orientations are selected to provide acceptably low deceleration to prevent excessively high stresses in the cask during impact after the thirty foot end drop. A 2.25 inch layer of balsa wood with the grain parallel to the end of the cylindrical cask is provided on the outer face of the impact limiter to minimize decelerations after a one foot end drop.

A 12.5 inch wide ring of redwood (consisting of 12 segments or blocks of wood) is located in the sides of the pie shaped compartments which surround the end of the cylindrical surface of the cask with the grain direction oriented radially. This ring of redwood absorbs most of the kinetic energy during a side drop. Redwood was selected for this portion of the impact limiter because of its high crush strength and hence the ability of a small amount of wood to absorb a large amount of energy in a relatively short crush distance.

The corners of the pie shaped compartments are filled with redwood. A 32.25 inch section of redwood is located next to the side redwood in the outer corner. The primary function of the redwood block is energy absorption during a 30 foot corner drop.

All wood blocks used in the impact limiters are composed of individual boards glued together with a Phenol Resorcinol Adhesive or equivalent. This adhesive is selected for its superior strength and moisture resistance. The wood blocks are assembled and glued together in accordance with an approved QA procedure. Minimum properties of the adhesive are listed in Table 2.10.8-1. Ranges of shear and tensile strengths of each type of wood are also listed. The adhesive is significantly stronger than any of the wood used in the limiter in terms of shear and tensile strength. Therefore the boards or blocks of wood will not fail along the glue joints.

The other mechanical properties of the wood used in the analysis are shown in Table 2.10.8-2. The crush strength properties used cover the range of expected values for the density and moisture content specified in the procurement specification. During procurement, wood samples are tested for density, moisture content and crush strength in accordance with an approved sampling plan.

If the density, moisture content, and crush strength are not within the specified range, the wood blocks from which samples are taken would be rejected.

During the end drop, all of the wood in the central part of the impact limiter that is directly "backed-up" by the cask body will crush. The wood in the corner and side of the limiter will tend to slide around the side of the cask since it is not supported or backed-up by the body and it will not crush or absorb energy as effectively as the wood that is backed-up. During the side or oblique drop the wood backed up by the cask will crush, while the wood beyond the end of the cask body will have a tendency to slide around the end of the cask. The analyses assume that the

TN 68 TRANSPORT PACKAGING

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CHAPTER 3

THERMAL EVALUATION

3.1 Discussion

The TN-68 packaging is designed to passively reject decay heat under normal conditions of transport and hypothetical accident conditions while maintaining appropriate packaging 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 cask materials limits to ensure components perform their intended safety functions;
- Determination of temperature distributions to support the calculation of thermal stresses;
- Determination of the cask cavity gas temperature to support containment pressurization calculations;
- Determination of the maximum fuel cladding temperature.

Chapter 2 presents the principal design bases for the TN-68 packaging.

The design features of the TN-68 basket are described in Section 1.2. The basket consists of an assembly of 68 stainless steel fuel compartments with aluminum and neutron poison (borated aluminum or boron carbide / aluminum metal matrix composite) plates sandwiched between them. The compartments are joined by a fusion welding process to 1.75 in. wide stainless steel plates. Above and below the plates are slotted neutron poison plates which form an egg-crate structure. The aluminum basket rails are bolted to the basket periphery to provide a conduction path from the basket to the cavity wall. This thermal design feature of the basket allows the heat from the fuel assemblies to be conducted along the basket structure (including the neutron poison plates) to the basket rails and dissipated to the cask cavity wall.

Another thermal design feature is the conduction path created by the aluminum boxes in the neutron shielding layer described in Section 1.2. The neutron shielding is provided by a resin compound cast into long slender aluminum containers placed around the cask shell and enclosed within a smooth outer shell. By butting against the adjacent shell surfaces, the aluminum containers allow decay heat to be conducted across the neutron shield.

The design of the steel encased wooden impact limiters is described in Section 1.2. These components are considered in the thermal analysis because of their contribution as a thermal insulator. The impact limiters provide protection to the lid and bottom regions from the external heat load applied during the hypothetical thermal accident event.

A personnel barrier prevents access to the outer surfaces of the cask body. The barrier, which consists of a stainless steel mesh attached to 1 ¼" stainless steel tubing, will extend no further than the cask body centerline, and have an open area of at least 80%.

To establish the heat removal capability, several thermal design criteria are established for the TN-68. These are:

- Containment of radioactive material and gases is a major design requirement. Seal temperatures must be maintained within specified limits to satisfy the leak tight containment function during normal transport conditions. A maximum temperature limit of 536°F (280°C) is set for the Helicoflex seals (double metallic O-rings) in the containment vessel closure lid (Reference 10).
- To maintain the stability of the neutron shield resin during normal transport conditions, an allowable temperature range of -40 to 300° F (-40 to 149° C) is set for the neutron shield.
- Maximum temperatures of the containment structural components must not adversely affect the containment function.
- In accordance with 10CFR71.43(g) the maximum temperature of accessible package surfaces in the shade is limited to 185 °F (85 °C).
- A maximum fuel cladding temperature limit of 380 °C (716 °F) is set for the fuel assemblies with an inert cover gas as concluded in Reference 12.

The ambient temperature range for normal transport is –20 to 100 °F (-29 to 38 °C) per 10CFR71(b). In general, all the thermal criteria are associated with maximum temperature limits and not minimum temperatures. All materials can be subjected to the minimum environment temperature of -40 °F (-40 °C) without adverse effects as required by 10CFR71(c)(2).

The TN-68 is analyzed based on a maximum heat load of 21.2 kW from 68 fuel assemblies. The analyses consider the effect of the decay heat flux varying axially along a fuel assembly. The heat flux profile for a BWR fuel assembly with a peak power factor of 1.2 and an active length of 144 in. is used for the evaluation. The use of the minimum active length of 144 in. along with a 1.2 peaking factor typically bounds the peak heat flux for the design basis fuel. A description of the detailed analyses performed for normal transport conditions is provided in Section 3.4 and accident conditions in Section 3.5. A summary of the analysis for normal conditions is provided in Table 3-1. The thermal evaluation concludes that with this design heat load, all design criteria are satisfied.

3.2 Summary of Thermal Properties of Materials

1. BWR Fuel

Temperature °F	Thermal Conductivity Btu/hr-in-°F		Specific Heat Btu/lb-F	Density lb/in^3
	Transverse	Axial		
195.8	0.0157		0.055	0.149
200.0		0.0580		
268.4	0.0178			
365.9	0.0206			
400.0		0.0646		
463.7	0.0239			
561.8	0.0277			
600.0		0.0709		
660.3	0.0319			
758.9	0.0367			
800.0		0.0769	0.055	0.149

The effective thermal conductivity is the lowest calculated value for the BWR fuel array that may be stored in this cask and corresponds to the GE 10x10 BWR assembly with channel. The fuel conductivity analysis is presented in Appendix 3.7.1. The values for BWR fuel density and specific heat are typical values obtained from Reference 13.

2. 6061 Aluminum (used for basket rails and shims) (Reference 2)

Temperature °F	Thermal Conductivity Btu/hr-in-°F	Specific Heat Btu/lb-F	Density lb/in^3
70	8.01	0.218	0.096
100	8.08	0.219	
150	8.17	0.223	
200	8.25	0.225	
250	8.32	0.228	
300	8.38	0.230	
350	8.44	0.233	
400	8.49	0.234	0.096

3. Poison Plates

Specific Heat Btu/lb-F	Density lb/in^3
0.214	0.098

Properties are from Reference 5 for aluminum. The thermal conductivities are specified in Section 3.3 for the neutron poison plates and will be verified by test.

4. Stainless Steel Type 304/304L (used for basket plates and fuel compartment) (Reference 2)

Temperature °F	Thermal Conductivity Btu/hr-in-°F	Specific Heat Btu/lb-F	Density lb/in^3
70	0.63	0.111	0.289
100	0.73		
200	0.78	0.124	
400	0.87	0.130	
600	0.94	0.134	
800	1.02	0.140	
1000	1.10		0.289

5. SA-350, Grade LF3 Carbon St (used for cask containment shell) (Reference 2)

Temperature °F	Thermal Conductivity Btu/hr-in-°F	Specific Heat Btu/lb-F	Density lb/in^3
70	1.97	0.106	0.283
100	1.99	0.110	
200	2.03	0.118	
400	2.02	0.128	
600	1.93	0.137	
800	1.81	0.149	
1000	1.67	0.165	
1200	1.52	0.189	
1400	1.28	0.406	0.283

6. Helium (used for gaps within the cask cavity) (Reference 8)

Temperature °F	Thermal Conductivity Btu/hr-in-°F
80	0.0073
440	0.0103
620	0.0116
800	0.0129
1160	0.0152

For the transient analyses, the thermal mass is relatively small and neglected. The density and specific heat are not used.

7. SA-516 Grade 70 Carbon Steel (used for gamma shield shell, outer shell and lid)(Reference 2)

Temperature °F	Thermal Conductivity Btu/hr-in-°F	Specific Heat Btu/lb-F	Density lb/in^3
70	1.91	0.109	0.280
200	1.98	0.118	
400	1.99	0.129	
600	1.91	0.139	
800	1.80	0.152	
1000	1.68	0.169	
1200	1.52	0.206	
1400	1.29	0.184	0.280

8. Air (Reference 5)

Temperature °F	Thermal Conductivity Btu/hr-in-°F	Prandtl Number	Kinematic Viscosity (in^2/sec)
-100	0.0009	0.740	0.0118
81	0.0013	0.708	0.0261
261	0.0016	0.694	0.0409
441	0.0019	0.680	0.0588
621	0.0022	0.680	0.0796
981	0.0028	0.689	0.1275

For the transient analyses, the thermal mass is relatively small and neglected. The density and specific heat are not used.

9. Neutron Shielding (Polyester Resin) (Reference 3)

Thermal Conductivity Btu/hr-in-°F	Specific Heat Btu/lb-F	Density lb/in^3
0.0083	0.311	0.057

10. Wood

Thermal Conductivity (Btu/hr-in-°F)	
Min.	Max.
0.0019	0.0378

Thermal conductivity values bound, perpendicular and parallel to the grain, values in both References 1 and 14 for moisture contents up to 30% and specific gravities between 0.08 and 0.80. During the transient analyses the thermal mass of the wood is conservatively neglected.

The analyses use interpolated values when appropriate for intermediate temperatures where the temperature dependency of a specific parameter is deemed significant. The interpolation assumes a linear relationship between the reported values.

Thermal radiation effects at the external surfaces of the packaging are considered. The thermal analysis assumes that the cask body and impact limiter external surfaces are painted white. The emissivity of white paint varies between 0.93-0.95 and the solar absorptivity varies between 0.12-0.18 (References 5 & 11). To account for dust and dirt, the thermal analysis uses a solar absorptivity of 0.30 and an emissivity of 0.90 for the exterior surfaces in the thermal models. After a fire, the cask surface will be partially covered in soot (emissivity = 0.95, Reference 9).

3.3 Technical Specifications for Components

The cask components for which a thermal technical specification is necessary are the seals and the neutron poison plates.

The seals used in the packaging are the Helicoflex seals (double metallic O-rings). The seals will have a minimum and maximum temperature rating of -40°F and 536°F respectively.

The neutron poison plates will have the following minimum conductivity:

Temperature		Conductivity	
°C	°F	W/m-°C	Btu/hr-in-°F
20	68	120	5.78
100	212	145	6.98
250	482	150	7.22
300	571	150	7.22

3.4 Thermal Evaluation for Normal Conditions of Transport

The normal conditions of transport are used for the determination of the maximum fuel cladding temperature, TN-68 component temperatures, confinement pressure and thermal stresses. These steady state environmental conditions correspond to the maximum daily averaged ambient temperature of 100°F and the 10CFR Part 71.71(c) insolation averaged over a 24 hour period.

3.4.1 Thermal Models

The finite element models are developed using the ANSYS computer code (Reference 4). ANSYS is a comprehensive thermal, structural and fluid flow analysis package. It is a finite element analysis code capable of solving steady-state and transient thermal analysis problems in one, two or three dimensions. Heat transfer via a combination of conduction, radiation and convection can be modeled by ANSYS. The three-dimensional geometry of the cask was modeled. Solid entities were modeled by SOLID70 and SHELL57 three-dimensional thermal elements.

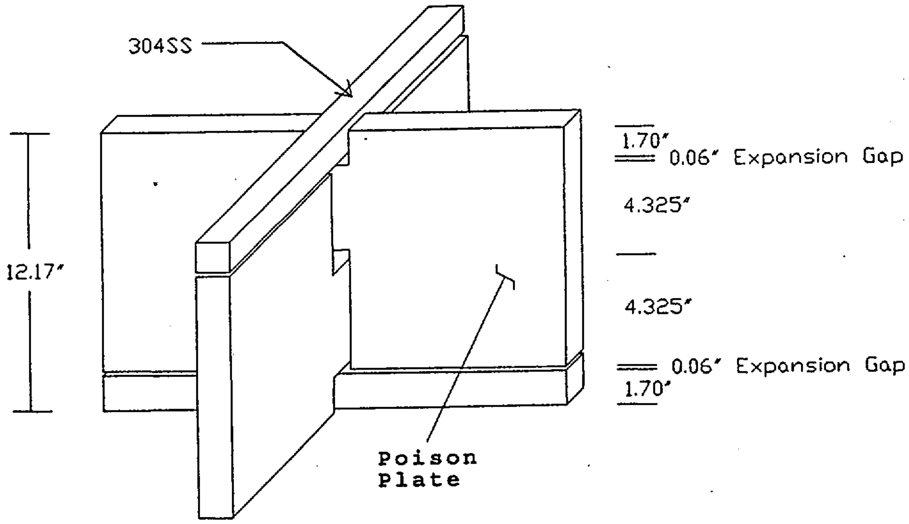
3.4.1.1 Basket Model

To determine temperatures of components within the cask body and basket during normal transport conditions a finite element model of the basket and cask is developed. The three-dimensional model represents a 90° symmetric section of the TN-68 cask with basket, and includes the geometry and material properties of the basket components, the basket rails, the cask shells, the neutron shielding (resin in aluminum containers) and the outer shell (see Figures 3-1 and 3-2). The model simulates the effective thermal properties of the fuel with a homogenized material occupying the volume within the basket where the 144 inch active length of the fuel is stored. The length of model is 160 inches, which corresponds to the neutron shield length. Adiabatic boundary conditions are assumed at the ends of the model. The inner and outer cask body shells will be assembled with an interference fit. This will assure thermal contact at the shell interface. From Reference 5, the thermal interface conductance increases with contact pressure and reduces with rougher surface finish. At a minimal contact pressure of 5 psi, Reference 5 reports a conductance of 375 Btu/hr-ft^2. For further conservatism, this interface conductance is reduced to 200 Btu/hr-ft^2 for the thermal evaluation. The neutron shielding consists of 60 long slender resin-filled aluminum containers placed between the cask body and outer steel shell. The aluminum containers are confined between the cask body and outer shell, and butt against the adjacent shells. For conservatism, an air gap of 0.01 in. at thermal equilibrium is assumed to be present between the aluminum resin boxes and the adjacent shells. Radiation across these gaps is neglected. The finite element plot of the model is shown in Figure 3-4.

The basket structure consists of an assembly of 68 stainless steel boxes (6.00 in. square) joined by a proprietary fusion welding process to 1.75 in. wide stainless steel plates. Above and below the plates are slotted poison plates (0.31 in. thick) which form an egg-crate structure (see Figure 3-3). The steel boxes are modeled as 6.15 in. square, and the poison plates are modeled as 0.30 in. thick, to conservatively bound the maximum opening and plate thickness that may be fabricated. The welded design causes the poison plates to be tightly sandwiched between adjacent box sides. The basket portion of the thermal model simulates the conduction paths provided by the poison material and stainless steel plates, the stainless steel boxes and the fuel (modeled as a homogenous material). Aluminum basket rails, bolted to the basket periphery, increase the surface area for heat dissipation while providing structural support for the basket.

Generally, good surface contact is expected between adjacent components within the basket structure. However to bound the heat conductance uncertainty between adjacent components, the following gaps at thermal equilibrium are assumed:

a. 0.01 in. gap between an aluminum/stainless steel plate and its adjacent stainless steel fuel compartment.
b. 0.125 in. total gap between the rails and the basket periphery.
c. 0.125 in. thermal equilibrium gap between the basket rails and the cask cavity wall.
d. The gaps modeled in the axial direction and the axial lengths of the basket plates are shown in the schematic below:



A 0.94 in. total width gap exists between the plates in the slots.

All heat transfer across the gaps is by gaseous conduction. Other modes of heat transfer are neglected.

Maximum Fuel Cladding Temperature

The finite element model includes a representation of the spent nuclear fuel that is based on a fuel effective conductivity model. The decay heat of the fuel with a peaking factor of 1.2 was applied directly to the fuel elements. The maximum fuel temperature reported is based on the results of the temperature distribution in the fuel region of the model. As described in Appendix 3.7.1, the homogenized fuel properties are chosen to match both the temperature drop between basket walls and fuel assembly center pin, and the effective conductivity of the fuel assemblies.

Average Cavity Gas Temperature

The cavity gas temperature is calculated using the temperatures at the hottest cross section of the cask. For simplicity and conservatism, it is assumed to be the average value of the maximum basket and cask inner shell temperatures.

3.4.1.2 Impact Limiters Model

To determine maximum wood temperatures during normal conditions of transport and the surface temperature of the impact limiters in the shade, a finite element model of the cask body and impact limiters is developed. The three-dimensional model represents a 30° symmetric section of the TN-68 cask body with impact limiters, and includes the geometry and material properties of the cask shells, the neutron shielding (resin in aluminum containers), the outer shell, cask lid, impact limiter spacer, thermal shield, and front and rear impact limiters.

The redwood and balsa within the impact limiters are modeled as a homogenized region containing bounding material properties. As per the basket model an interface conductance of 200 Btu/hr-ft^2 is used for the interference fit between the inner and outer cask body shells and a 0.010 in thermal gap at equilibrium is assumed between the resin boxes and adjacent shells.

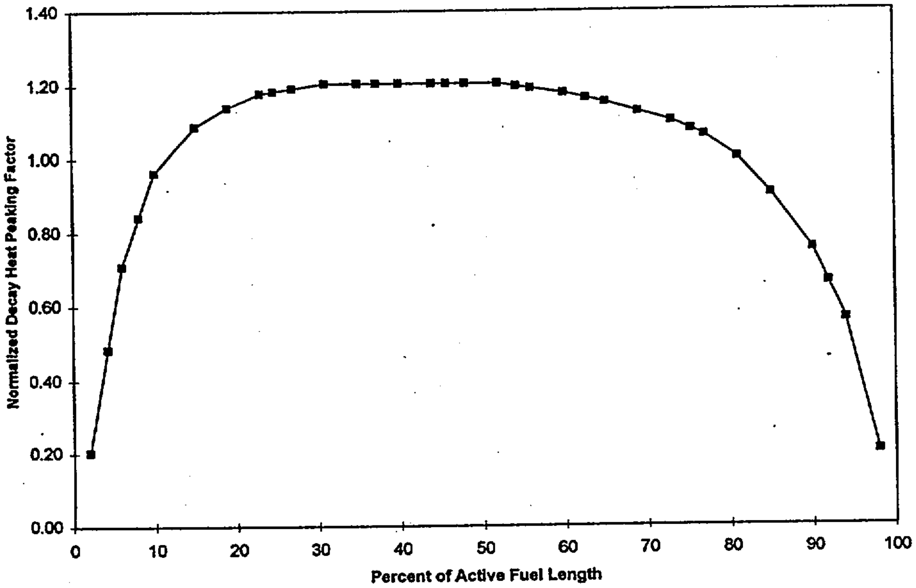
To bound the heat conductance uncertainty between adjacent packaging components the following gaps at thermal equilibrium are assumed:

a) 0.0625" axial gap between the bottom shield and the thermal shield
b) 0.0625" axial gap between the thermal shield and rear impact limiter
c) 0.2000" radial gap between the cask body and the thermal shield
d) 0.2000" radial gap between thermal shield and the rear impact limiter
e) 0.0700" radial gap between the inner shell and the cask lid
f) 0.0600" radial gap between the impact limiter spacer and the cask lid
g) 0.0625" axial gap between the impact limiter spacer and the inner shell
h) 0.0625" axial gap between the cask lid and the impact limiter spacer
i) 0.1250" axial gap between the impact limiter spacer and the front impact limiter

All heat transfer across the gaps is by gaseous conduction. Other modes of heat transfer are neglected. The finite element plot of the model is shown in Figure 3-5.

3.4.1.3 Decay Heat Load

The decay heat load corresponds to a total heat load of 21.2 kW from 68 assemblies (0.312 kW/assy.) with a peaking factor of 1.2. A typical heat flux profile for spent BWR fuel with an axial peaking factor of 1.2 was used to distribute the decay heat load in the axial direction within the active length regions of the models. This heat flux profile is shown below. Within the basket model, the decay heat load is applied as volumetric heat generation in the elements that represent the homogenized fuel. Within the impact limiters model the heat is applied as heat fluxes into the elements that model the cask cavity wall.



3.4.1.4 Heat Dissipation

Heat is dissipated from the surface of the packaging by a combination of radiation and natural convection.

Heat dissipation by natural convection from horizontal cylinders is described by the following equations for the average Nusselt number (Reference 6):

$$\overline{N}_{uL} = \overline{H}_c \frac{L}{k} = 0.13(Gr_L Pr)^{1/3} \quad \text{for } Pr\,Gr_L > 10^9 \qquad \text{(Horizontal cylinders and vertical surfaces)}$$

$$\overline{N}_{uL} = \overline{H}_c \frac{L}{k} = 0.59(Gr_L Pr)^{1/4} \quad \text{for } 10^4 < Pr\,Gr_L < 10^9 \qquad \text{(vertical surfaces)}$$

where,

Gr_L = Grashof number = $\rho^2 g\beta(T_s-T_a)L^3/\mu^2$
ρ = density, lb/ft^3
g = acceleration due to gravity, ft/sec^2
β = temperature coefficient of volume expansion, 1/R

μ = absolute viscosity, lb/ft-sec
L = characteristic length, ft
Pr = Prandtl number
H_c = natural convection coefficient

The heat transfer coefficient, H_r, for heat dissipation by radiation, is given by the equation:

$$H_r = G_{12}\left[\frac{\sigma(T_1^4 - T_2^4)}{T_1 - T_2}\right] Btu/hr - ft^2 - {}^\circ F$$

where,

G_{12} = the gray body exchange coefficient
= (surface emissivity) (view factor)
T_1 = ambient temperature, °R
T_2 = surface temperature, °R

The total heat transfer coefficient $H_t = H_r + H_c$, is applied as a boundary condition on the outer surfaces of the finite element models.

3.4.1.5 Solar Heat Load

The total insolation for a 12-hour period in a day is 1475 Btu/ft^2 for curved surfaces and 738 Btu/ft^2 for flat surfaces not transported horizontally as per 10CFR Part 71.71(c). This insolation is averaged over a 24-hr period (daily averaged value) and applied as a constant steady state value to the external surfaces of the thermal models. A solar absorptivity of 0.30 is used for the painted outer surfaces of the packaging. Daily averaging of the solar heat load is justified based on the large thermal inertia of the TN-68 transport cask.

3.4.2 Maximum Temperatures

Steady state thermal analyses are performed using the maximum decay heat load of 0.312 kW per assembly (21.2 kW total), 100°F ambient temperature and the maximum insolation. The temperature distribution within the cask body and basket is shown in Figure 3-6. The cask body temperature distribution as calculated in the basket model is shown in Figure 3-8. Details of the temperature distribution in the basket region are shown in Figure 3-7. The temperature distributions within the impact limiter wood are shown in Figure 3-9. A summary of the calculated cask component temperatures is listed in Table 3-1.

3.4.3 Maximum Accessible Surface Temperature in the Shade

The accessible surfaces of the TN-68 packaging consist of the personnel barrier and outermost vertical and radial surfaces of the impact limiters. The cask body and impact limiters model is run without insolation to determine the accessible surface temperature of the impact limiters in the shade. The maximum accessible surface temperature of the impact limiters in the shade does not exceed 115 °F.

The personnel barrier surrounds approximately one fourth of the cask body and has an open area of at least 80%. Heat transfer between the cask and barrier will be minimal due to the small radiation viewfactor between the cask and barrier. The personnel barrier rises 90 in. above the base of the transport frame and limits the accessible packaging surfaces to only the impact limiter surfaces. Accessible surfaces of the packaging remain below the design criteria of 185 °F (85 °C).

3.4.4 Minimum Temperatures

Under the minimum temperature condition of -40°F (-40°C) ambient, the resulting packaging component temperatures will approach -40°F if no credit is taken for the decay heat load. Since the package materials, including containment structures and the seals, continue to function at this temperature, the minimum temperature condition has no adverse effect on the performance of the TN-68.

Temperature distributions in a minimum ambient temperature of -40°F and no insolation are determined. Table 3-2 lists the results of the analyses.

3.4.5 Maximum Internal Pressure

The maximum internal pressure during normal conditions of transport is calculated in Chapter 4.

3.4.6 Maximum Thermal Stresses

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

3.4.7 Evaluation of Cask Performance for Normal Conditions of Transport

The thermal analysis for normal transport concludes that the TN-68 cask design meets all applicable requirements. The maximum temperatures calculated using conservative assumptions are low. The maximum temperature of any containment structural component is less than 300°F (149°C). The maximum seal temperature (234°F, 112°C) during normal transport is well below the 536°F long-term limit specified for continued seal function. The maximum neutron shield temperature is below 300°F (149°C) and no degradation of the neutron shielding is expected. The predicted maximum fuel cladding temperature is well within allowable fuel temperature limit of 716°F (380°C). The comparison of the results with the allowable ranges is tabulated below:

Component	**Temperature, °F**		
	Maximum	**Minimum**	**Allowable Range**
Seal	234	-40	-40 to 536
Neutron Shield	244	-40	-40 to 300
Fuel Cladding	490	-40	716 max.

3.5 Thermal Evaluation for Accident Conditions

The TN-68 cask is evaluated under the hypothetical accident sequence of 10CFR71.73. The front impact limiter provides protection to the TN-68 cask lid containing the lid and port seals from the thermal accident environment. However, a direct conduction path exists from the cask surfaces exposed to the accident environment to the seal. A shield ring may be placed between the front impact limiter and the neutron shield shell if required for shielding. The shield ring would provide thermal protection during the fire accident and is neglected in the model. Since maintaining the seal temperature below 536 °F is a design requirement analytical models are developed as discussed in sections 3.5.2 and 3.5.3.

3.5.1 Fire Accident Evaluation

The fire thermal evaluation is performed primarily to demonstrate the containment integrity of the TN-68. This is assured as long as the metallic lid seals remain below 536°F and the cavity pressure is less than 100 psig. A cask cross-section model and two crushed impact limiter models are used for the evaluation. The cask cross-section model represents the midsection of the cask, where the decay heat generation is at its highest. The crushed impact limiter models represent the crushed impact limiters and cask body to evaluate the performance of the seal and aluminum boxes under fire conditions.

The Sandia Report reports an average convective heat transfer coefficient of 4.5 Btu/hr-ft^2-°F for a railroad tank car fire test (Reference 7). The same parameter is utilized for the fire accident evaluation.

3.5.2 Cask Cross Section Model.

The basket finite element model developed in Section 3.4.1.1 is modified for the fire accident conditions. The cross section model is created by selecting the nodes and elements in the hottest region along with the temperature distribution. During the pre-fire and post-fire phases, convection and radiation from the external surface of this model are as in normal conditions of transport (100°F ambient). During the fire phase, a constant convective heat transfer coefficient of 4.5 Btu/hr-ft^2-°F is used. Also the 0.01 in. gaps between the neutron shield and the adjacent shells were removed to assume contact to maximize heat input into the model from the fire. As per 10CFR71.73, a 30 minute 1,475°F flame temperature with an emittance of 0.9 and a surface absorptivity of 0.8 is used during the fire accident condition. An emissivity of 0.9 and an absorptivity of unity were used for the cask external surfaces after the fire accident condition in order to bound the problem.

See Section 3.4.1 for a detailed description of the model including the method used to calculate the maximum fuel cladding temperature and the average cavity gas temperature. The decay heat load used in this analysis corresponds to a total heat load of 21.2 kW from 68 assemblies (0.312 kW/assy.) with a peaking factor of 1.2.

3.5.3 Crushed Impact Limiter Models

To demonstrate the integrity of the seals in the lid during the fire accident and that the aluminum resin boxes do not melt, the impact limiters finite element model developed in Section 3.4.1.2 is modified to reflect deformation due to a 30 foot drop. Two crushed impact limiter configurations are considered:

1) A crushed front impact limiter corresponding to a 15° drop resulting in the shortest distance between the fire ambient and the lid seals.
2) A crushed front impact limiter corresponding to a 70° drop resulting in the shortest distance between the fire ambient and the port seals.

The impact limiters are locally deformed from the 30 foot drop, but they remain firmly attached to the cask. Under exposure to the thermal accident environment the wood at the periphery of the impact limiter shell would char but not burn. Hence, the steel encased wooden impact limiters still provide protection to the lid of the cask from the external heat load applied during the hypothetical accident events.

To bound the heat conductance uncertainty between adjacent packaging components during pre and post-fire accident conditions, the same gaps at thermal equilibrium used in the impact limiters model of Section 3.4.1.2 are used for the crushed impact limiter models. The decay heat load is applied to the model in the manner described in Section 3.4.1.3. The environmental boundary conditions for the pre-fire, fire and post-fire are applied in the same manner as for the cask cross section model.

3.5.3.1 Crushed Impact Limiter Model, 15° Drop Configuration

During a 30 foot 15° drop the front impact limiter is crushed a maximum of 19 in. radially inward resulting in the shortest distance between the fire ambient and the lid seals. This crush configuration is modeled by reducing the outer 72" radius of the front impact limiter to 53". The finite element model is shown in Figure 3-10.

3.5.3.2 Crushed Impact Limiter Model, 70° Drop Configuration

During a 30 foot 70° drop the front impact limiter is crushed such that the shortest distance between the fire ambient and the port seals is 16.5". This crush configuration is modeled by reducing the overall length of the front impact limiter to 29.25". The finite element model is shown in Figure 3-11.

3.5.4 Summary of Results

Table 3-3 presents the maximum temperatures of the cask components during the fire event. The maximum temperatures calculated for the seal and the fuel cladding are 362°F and 552°F respectively. The transient average cavity gas temperature peaks at 423°F. The corresponding peak cavity pressure assuming 100% fuel failure is evaluated in Chapter 4 and is less than 100 psig. The maximum temperature distribution in the basket is shown in Figure 3-12. Figures 3-

13 and 3-14 show the temperature distributions of the crushed impact limiter models at the end of the fire.

3.5.5 Evaluation of Package Performance During Fire Accident Conditions

It is concluded that the TN-68 maintains containment during the postulated fire accident. The results of the analysis show that no melting of the aluminum resin boxes occurs. The neutron shield will off-gas during the fire event. A pressure relief valve is provided on the outer shell to prevent the pressurization of the outer shell. The shielding integrity of the neutron shielding is assumed to be lost after the fire event and the resulting accident dose rates have been evaluated in Chapter 5. The maximum seal temperature is well below the 536°F long-term limit specified for continued seal function and the fuel cladding temperature is below the limit of 716°F (380°C).

A comparison of the results with the temperature limits is tabulated below:

	Temperature, °F	
Component	**Maximum**	**Limit**
Seal	362	536
Fuel Cladding	552	716

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TABLE 3-1

COMPONENT TEMPERATURES IN THE TN-68 PACKAGE

Component	Normal Transport			Fire Accident	
	Maximum (°F)	Minimum* (°F)	Allowable Range(°F)	Peak(°F)	Allowable Range(°F)
Outer Shell	204	-40	**	1000	**
Radial Neutron Shield	244	-40	-40 to 300	N/A	N/A
Inner Shell	262	-40	**	371	**
Basket Rail	319	-40	**	390	**
Basket Plate	469	-40	**	537	**
Gamma Shell	260	-40	**	379	**
Fuel Cladding	490	-40	716 max.	555	716 max.
Impact Limiter Wood	175	-40	**	N/A	N/A
Seal	234	-40	-40 to 536	362	-40 to 536
Average Cavity Gas	366	-40	N/A	423	N/A

* Assuming no credit for decay heat and a daily average ambient temperature of -20°F
** The components perform their intended safety function within the operating range.

TABLE 3-2

TEMPERATURE DISTRIBUTION IN THE TN-68 PACKAGE (-40°F AMBIENT TEMPERATURE)

Component	Maximum Component Temperature
Outer Shell	80 °F
Aluminum Boxes	123 °F
Resin	123 °F
Gamma Shield Shell	141 °F
Inner Shell	143 °F
Basket Rails	206 °F
Fuel Cladding	388 °F
Cask Bottom Plate*	135 °F
Seal**	113 °F
Basket	362 °F

* Corresponds to maximum cavity wall temperature at the bottom end of cask body model.

** Corresponds to maximum cavity wall temperature at the top end of cask body model.

TABLE 3-3

MAXIMUM TRANSIENT TEMPERATURES DURING FIRE ACCIDENT

Component	Maximum Transient
Outer Surface	1000°F (End of Fire)
Seal	362°F (2.0 hours)
Radial Neutron Shield	982°F (0.50 hours)
Gamma Shell	379°F (1.3 hours)
Basket Rail	390°F (5.0 hours)
Inner Shell	371°F (2.3 hours)
Basket	537°F (22.1 hours)
Fuel Cladding	555°F (22.6 hours)
Average Cavity Gas	423°F (14.6 hours)

FIGURE 3-1

SCHEMATIC OF THE CASK BODY

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

FIGURE 3-2

THERMAL MODEL
RADIAL CROSS SECTION

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

FIGURE **3-3**

BASKET, PARTIAL ISOMETRIC VIEW

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

FIGURE 3-4

FINITE ELEMENT PLOT OF THE TN-68 BASKET MODEL

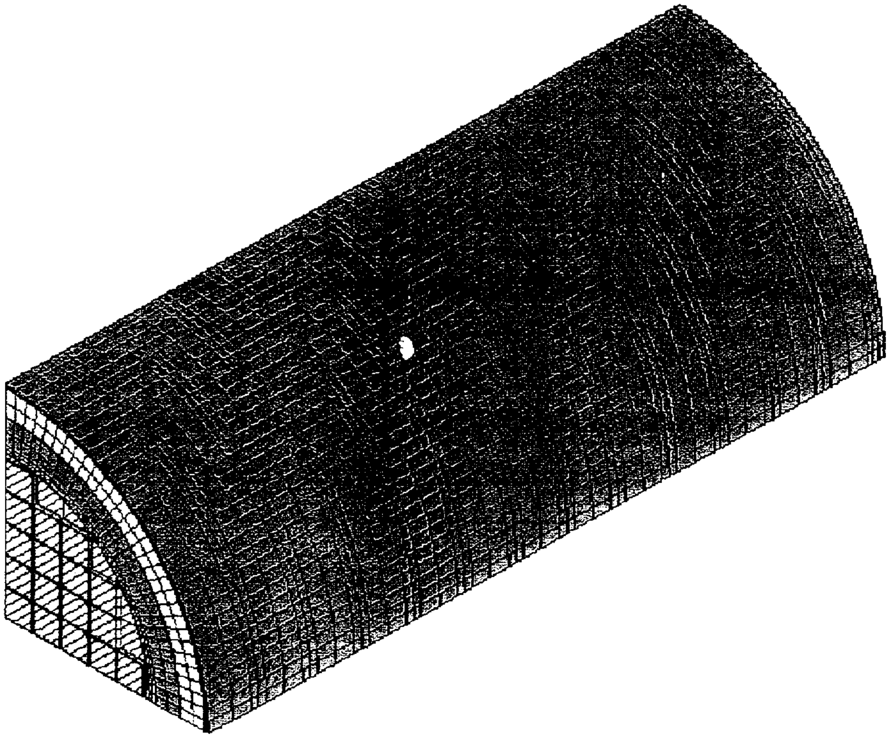
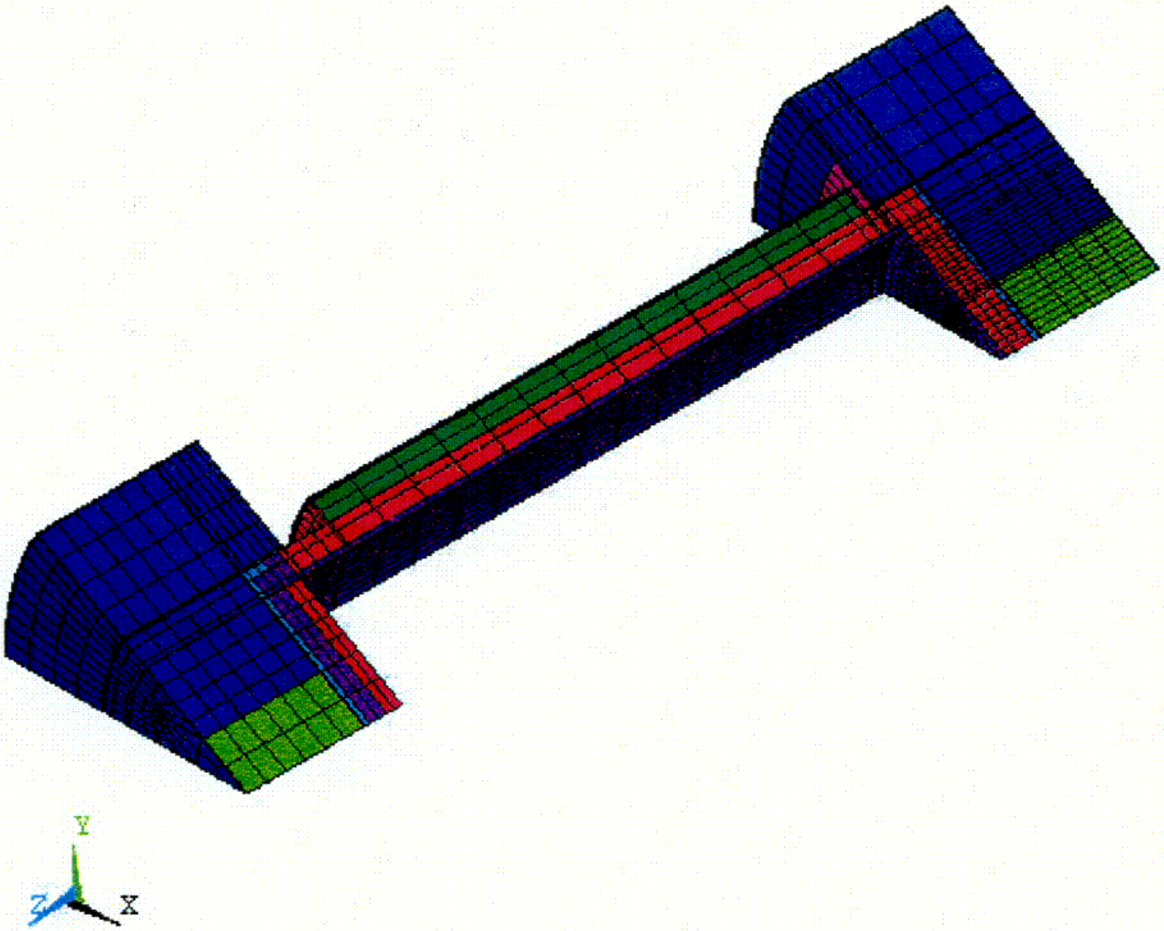


FIGURE 3-5

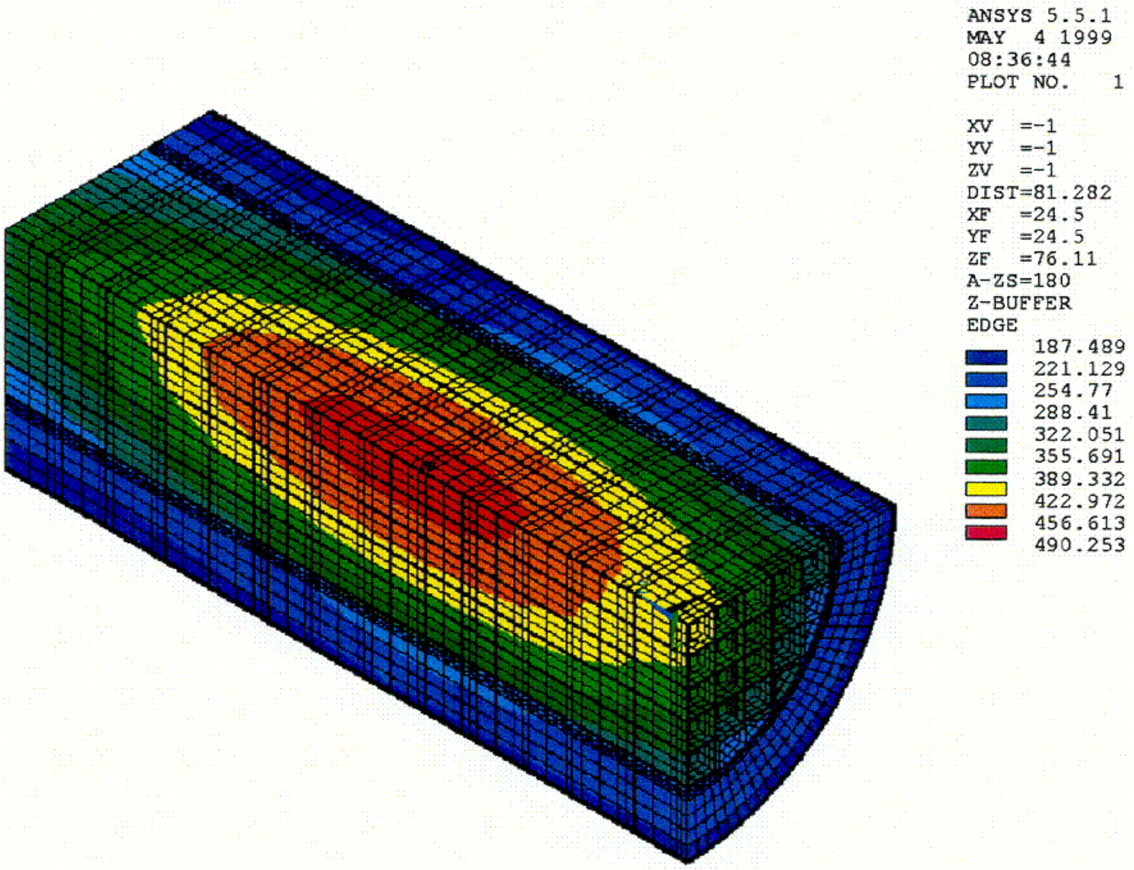
FINITE ELEMENT PLOT OF THE TN-68 IMPACT LIMITERS MODEL



C1

FIGURE 3-6

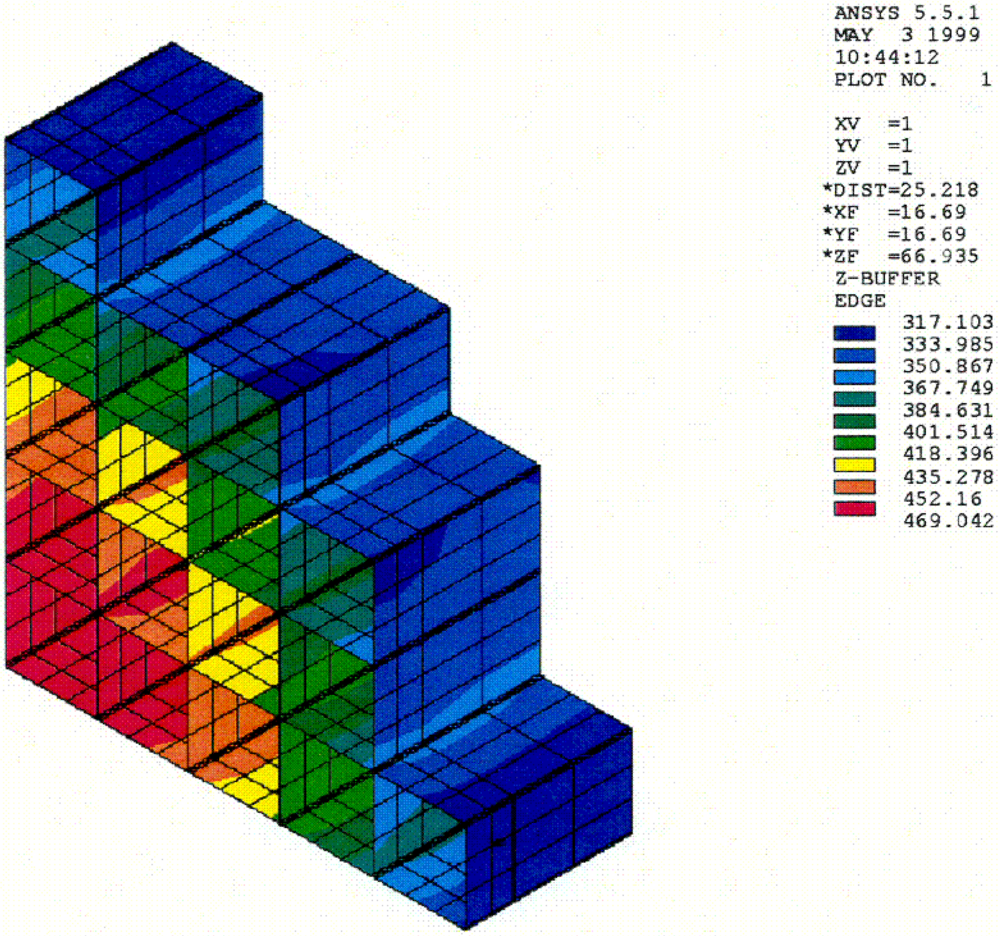
MAXIMUM TEMPERATURE DISTRIBUTION IN THE TN-68 CASK,
NORMAL CONDITIONS OF TRANSPORT



C2

FIGURE 3-7

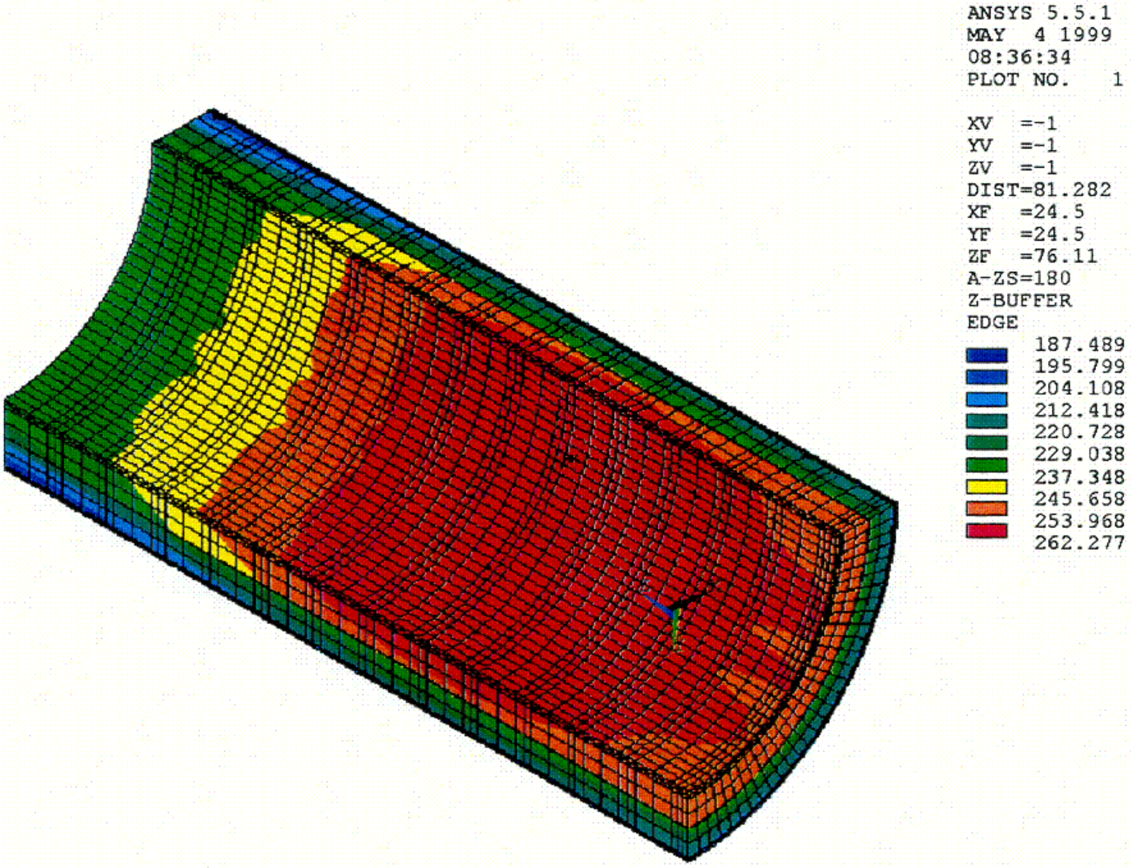
MAXIMUM TEMPERATURE DISTRIBUTION IN THE BASKET STRUCTURE, HOTTEST CROSS-SECTION



C3

FIGURE 3-8

MAXIMUM TEMPERATURE DISTRIBUTION IN THE TN-68 CASK BODY, NORMAL CONDITIONS OF TRANSPORT

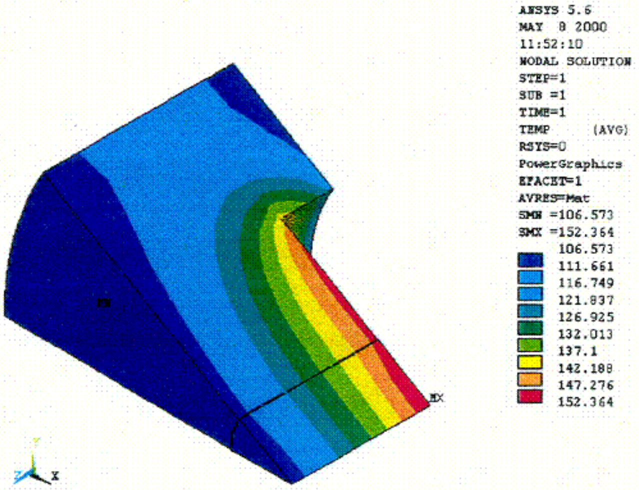


C4

FIGURE 3-9

MAXIMUM TEMPERATURE DISTRIBUTIONS IN THE IMPACT LIMITER WOOD, NORMAL CONDITIONS OF TRANSPORT

FRONT IMPACT LIMITER WOOD



REAR IMPACT LIMITER WOOD

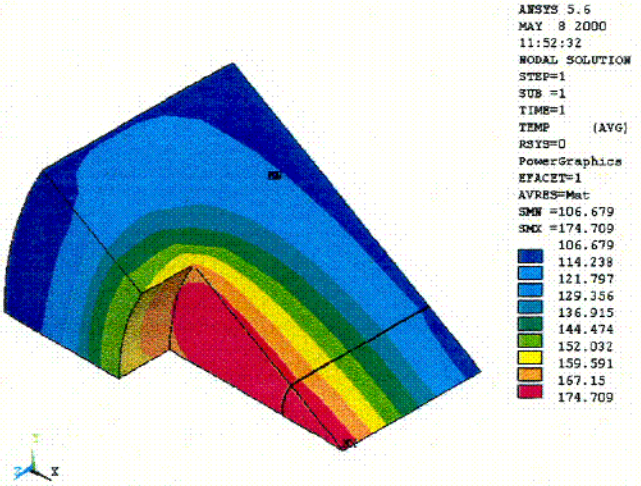
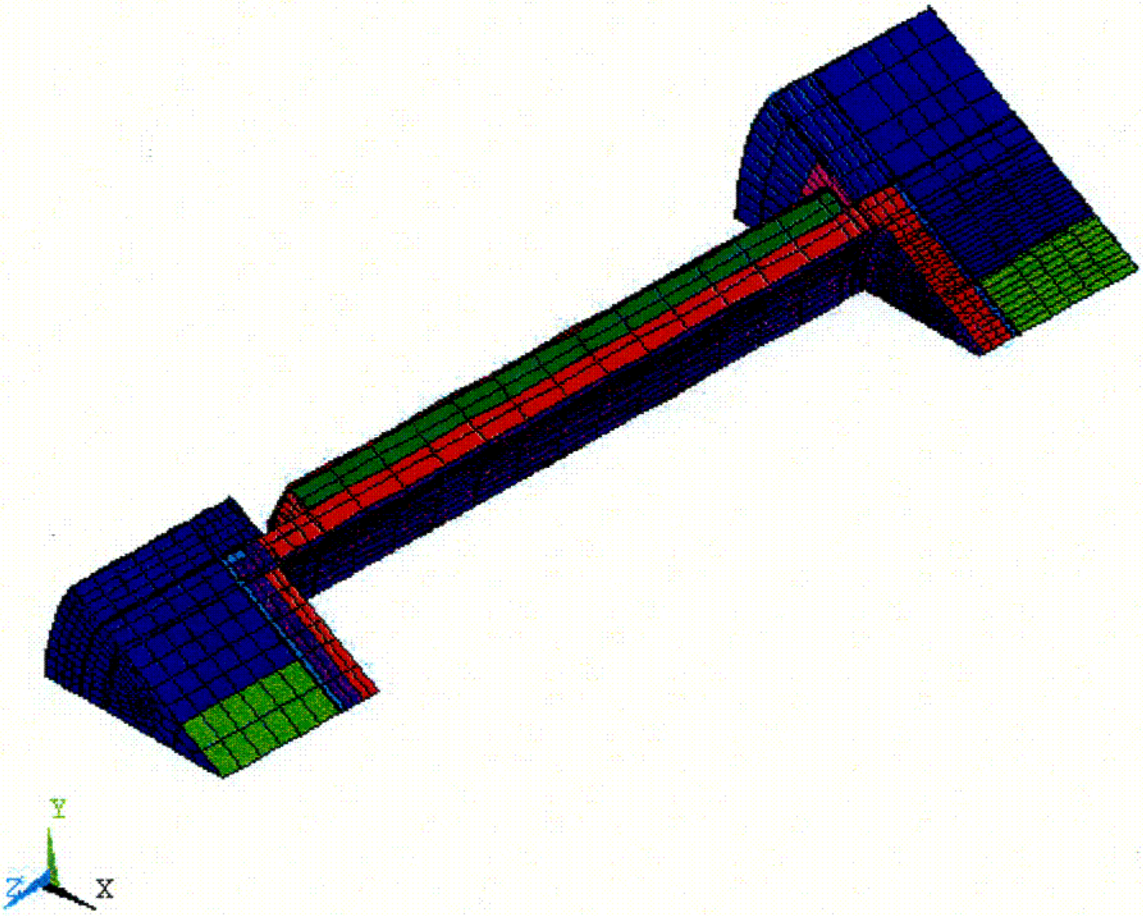


FIGURE 3-10

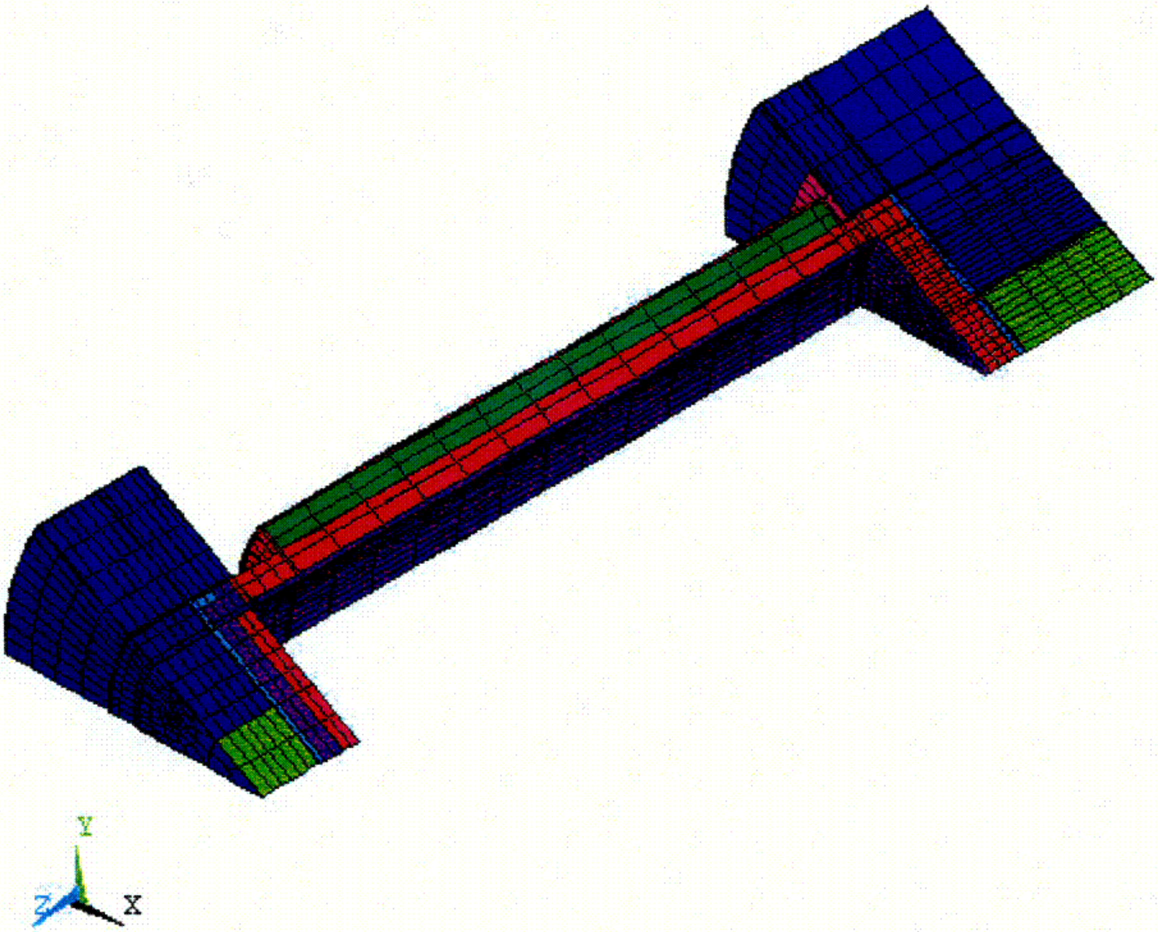
FINITE ELEMENT PLOT OF CRUSHED IMPACT LIMITER MODEL, 15° DROP CONDIGURATION



C6

FIGURE 3-11

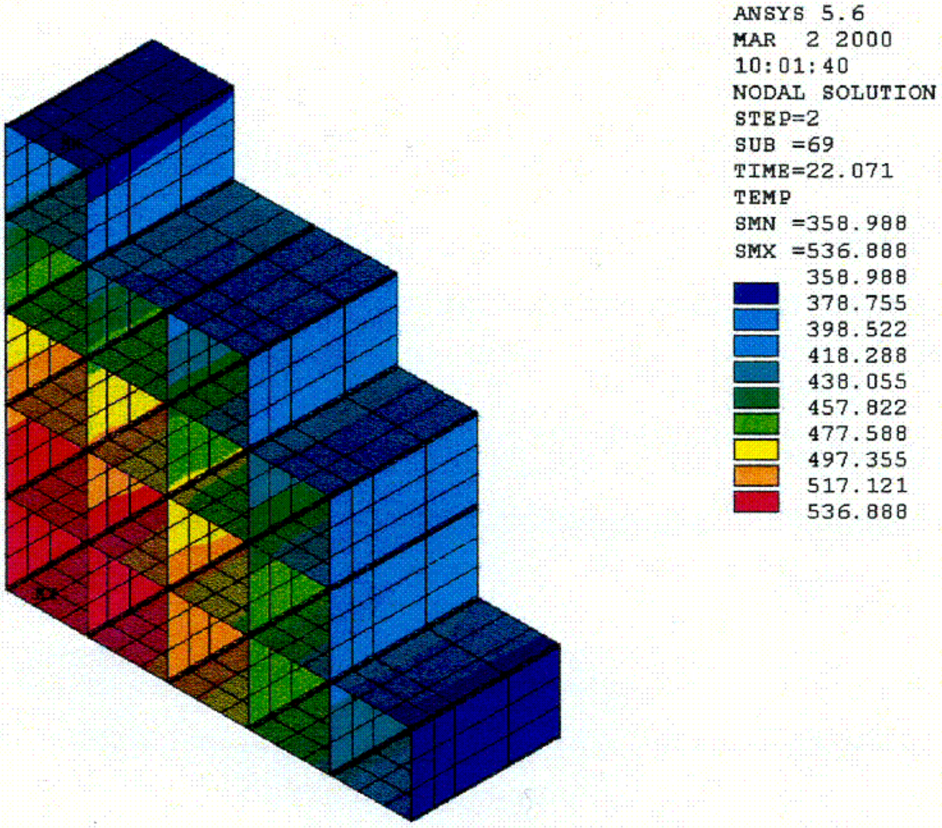
FINITE ELEMENT PLOT OF CRUSHED IMPACT LIMITER MODEL, 70° DROP CONFIGURATION



C7

FIGURE 3-12

MAXIMUM TEMPERATURE DISTRIBUTION IN THE BASKET REGION DURING THE FIRE EVENT



C8

FIGURE 3-13

TEMPERATURE DISTRIBUTION IN CRUSHED IMPACT LIMITER MODEL
AT THE END OF FIRE, 15° DROP CONFIGURATION

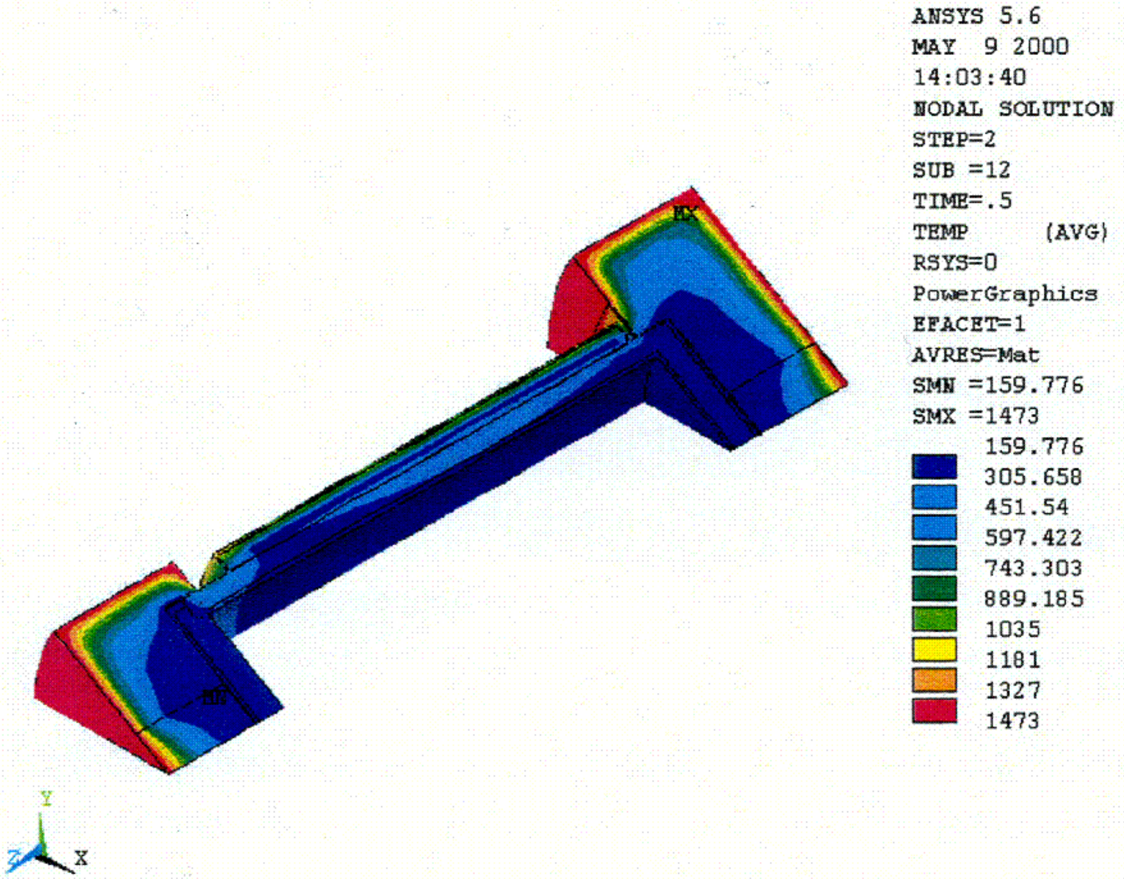
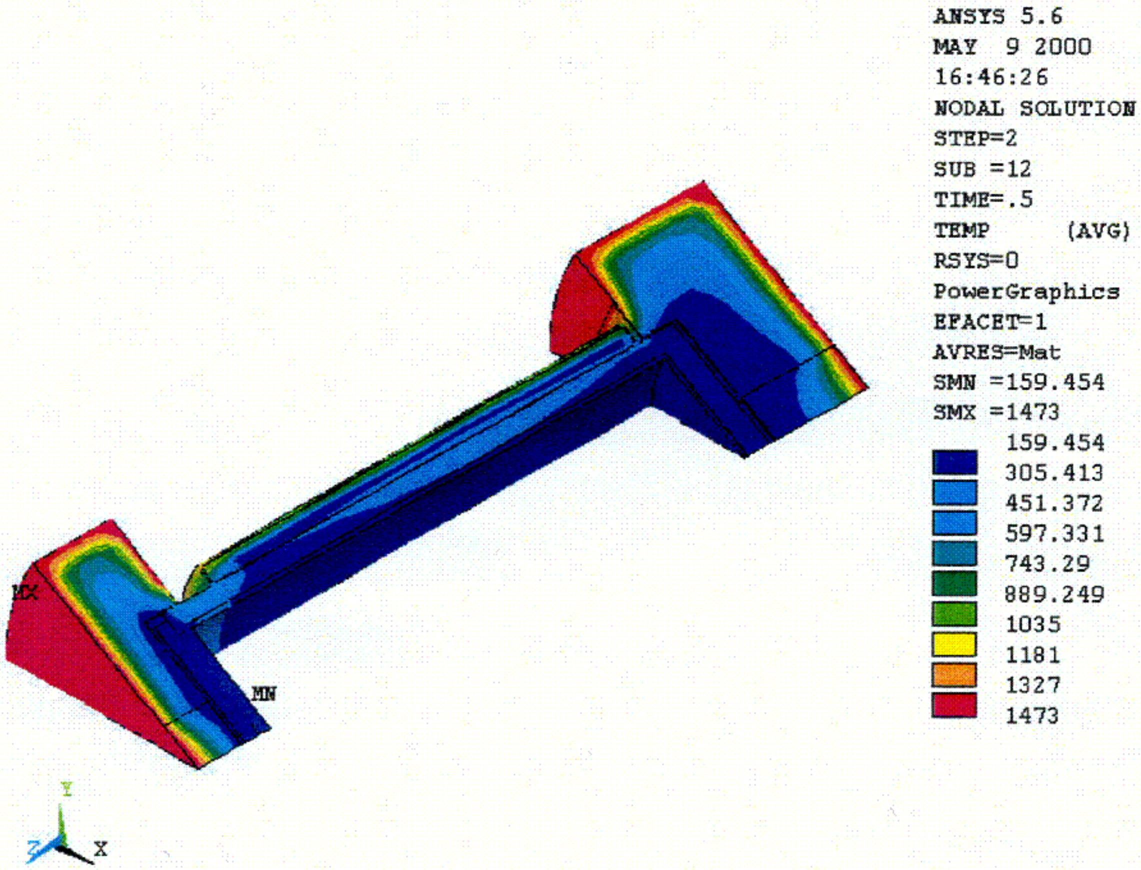


FIGURE 3-14

TEMPERATURE DISTRIBUTION IN CRUSHED IMPACT LIMITER MODEL AT THE END OF FIRE, 70° DROP CONFIGURATION



C10

4.3 CONTAINMENT REQUIREMENTS FOR HYPOTHETICAL ACCIDENT CONDITIONS

The containment requirement under hypothetical accident conditions specified by 10 CFR 71.51(a)(2). It states "there would be no escape of krypton-85 exceeding 10 A_2 in 1 week, no escape of other radioactive material exceeding a total amount A_2 in 1 week." It is assumed for purposes of the accident condition evaluation that 100% of the fuel rods fail thereby releasing all of the available fission gas in the fuel rod gas gap to the cask cavity.

Calculation of the fission gas inventory is discussed in Section 4.2.1.

4.3.1 Fission Gas Products

Similar to normal transport conditions described in Section 4.2.1, the following equations from NUREG/CR-6487 (Reference 4) are used to determine the source term available for release.

$$C_{volatiles} = \{N_A f_B A_V f_V\} / V$$
$$C_{gases} = \{N_A\, f_B\, A_F\, f_F\} / V$$
$$C_{fines} = \{N_A\, f_B\, A_F\, f_F\} / V$$
$$C_{crud} = \{f_C\, S_C\, N_R\, N_A\, S_{AR}\}$$
$$C_{total} = C_{crud} + C_{volatiles} + C_{gases} + C_{fines}$$

Table 4-1 shows the free activity available for release from the fuel rods. Table 4-2 shows the activity concentration from each of the sources available for release from inside the TN-68. The release fractions for the radionuclides are taken from NUREG/CR-6487. Under hypothetical accident conditions, the cladding of 100% of the fuel rods is assumed to fail (f_B=1.0).

4.3.2 Containment of Radioactive Material

The TN-68 is designed to meet the hypothetical accident requirements of 10 CFR 71.51. The A_2 values are calculated using the methodology of 10 CFR 71.71 and NUREG/CR-6487. The A_2 values are provided in Tables 4-3 and 4-4.

4.3.3 Containment Criterion

The allowable leak rates under hypothetical accident conditions are calculated using the methodology of NUREG/CR-6487 and previously presented in Section 4.2.3. The permissible leak rates under hypothetical accidents is 8.71E-03 cc /sec (Table 4-5). This value is converted to units of ref-cm^3 / sec by first calculating the equivalent hole size. The equations of ANSI 14.5 (also see section 4.2.1.3) are used:

$$L_u = (F_c + F_m)(P_u - P_d)(P_a/P_u) \text{ cc/sec at } T_u, P_u$$

where:

L_u = 8.71E-03 cc/sec
P_u = 4.2 atm abs

P_d = 1.0 atm abs
a = 0.5 cm
μ = 0.0269 cP
T = 423°F (= 217°C = 490 K)
M = 4 g/mol (from ANSI N14.5, Table B.1)
P_a = 2.6 atm abs

Substituting into the equations of ANSI N14.5:

$$F_c = (2.49\text{x}10^6 \times D^4)/(0.5 \times 0.0269) = 1.85\text{E+}08\ D^4$$
$$F_m = \{3.81\text{x}10^3 \times D^3 \times (490/4)^{0.5}\}\ /\ \{0.5 \times 2.6\} = 3.24\text{E+}04\ D^3$$

$$L_u = (F_c + F_m)(P_u - P_d)(P_a/P_u)$$
$$8.71\text{E-}03 = (F_c + F_m)\ (4.2 - 1.0)\ (2.6\ /\ 4.2)$$
$$F_c + F_m = 4.39\text{E-}03$$

Solving the equations above for D, yields a hole diameter of 2.17×10^{-3} cm.

This equivalent hole size, is then used to calculate the reference air rate at standard conditions. Assuming all upstream test conditions correspond to standard conditions:

$$L_u = (F_c + F_m)(P_u - P_d)(P_a/P_u) \text{ cc/sec at } T_u, P_u$$

where:

P_u = 1.0 atm abs
P_d = 0.01 atm abs
D = 2.17E-03 cm
a = 0.5 cm
μ = 0.0185 cP (from ANSI N14.5, Table B.1)
T = 298°K
M = 29.0 g/mol (from ANSI N14.5, Table B.1)
P_a = 0.505 atm abs

$$L_u = (F_c + F_m)(P_u - P_d)(P_a/P_u) \text{ cc/sec}$$

$$F_c = \{2.49\text{x}10^6 \times (2.17 \times 10^{-3})^4\}/(0.5 \times 0.0185) = 5.97\text{E-}03$$
$$F_m = \{3.81\text{x}10^3 \times (2.17 \times 10^{-3})^3 \times (298/29.0)^{0.5}\}\ /\ \{0.5 \times 0.505\} = 4.94\text{E-}04$$

$$L_{std} = (F_c + F_m)(P_u - P_d)(P_a/P_u) \text{ cc/sec}$$
$$L_{std} = (5.97\text{E-}03 + 4.94\text{E-}04)(1.0 - 0.01)(0.505\ /\ 1.0)$$
$$L_{std} = 3.22\text{E-}03 \text{ ref cm}^3\ /\ \text{s}$$

Because the reference leak rate for normal conditions is lower than that for accident conditions, the leak test criterion developed in Section 4.2.3 demonstrates that the containment criteria for both normal and accident conditions are met. The structural and thermal consequences of

TN 68 TRANSPORT PACKAGING

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CHAPTER 5

SHIELDING EVALUATION

5.1 DISCUSSION AND RESULTS

Shielding for the TN-68 cask is provided mainly by the cask body. For the neutron shielding, a borated polyester resin compound surrounds the cask body radially. Additional shielding is provided by the steel shell surrounding the resin layer and by the steel and aluminum structure of the fuel basket.

For transport, wood filled impact limiters are installed on the top and bottom of the cask and provide additional shielding for the top and bottom ends in addition to some radial shielding for the areas above and below the radial neutron shield. Figure 5.1-1 shows the configuration of shielding in the cask. Table 5.1-1 lists the compositions of the shielding materials.

The fuel assemblies acceptable for storage in the TN-68 are listed in Section 1.2.3. This listing of fuel assemblies was collapsed into seven basic designs. Using the SAS2H/ORIGEN-S modules of SCALE(1), source terms for the seven basic fuel designs are calculated. Each basic design has an initial bundle-average enrichment of 3.3 wt% and a total maximum bundle-average burnup of 40,000 MWD/MTU. The most conservative source term (of the seven basic fuel designs) is used in the subsequent shielding calculations.

Through this analysis, the GE 7x7 fuel array with a maximum bundle-average burnup of 40,000 MWD/MTU and an initial bundle-average enrichment of 3.3 wt% is identified as the most conservative fuel source. Section 5.2 describes the source specification and Section 5.4 describes the shielding analysis performed for the TN-68 cask.

Normal conditions are modeled with the TN-68 intact. This shielding calculation is performed using the Monte Carlo computer code MCNP(5). Dose rates on the side, top and bottom of the TN-68 cask are calculated for the various sources (active fuel-gamma and neutron and irradiated hardware-gamma) and summed to a total gamma and neutron dose rate.

Accident conditions assume that the neutron shield, the impact limiters and the ancillary shield ring are removed. This evaluation bounds the accident conditions since it is shown in Chapter 2 that the impact limiters and the radial neutron shield remain on the cask. Shielding calculations for accident conditions are also performed using MCNP.

The expected maximum dose rates (for normal and accident conditions) from the TN-68 cask are provided in Table 5.1-2. Although this dose rate evaluation is performed using 16 year cooled fuel, thermal (Chapter 3) and containment (Chapter 4) evaluations show that 10 year minimum cooled design basis fuel is acceptable for transport. Additionally, a dose rate analysis is provided for a preferential loading where moderate burnup, long cooled fuel assemblies are placed on the basket periphery, surrounding design basis 10 year cooled fuel in the middle of the basket.

It is therefore expected that design basis fuel cooled for a minimum of 10 years will be acceptable for transport provided they are placed in the middle basket compartments and are surrounded by "cooler" fuel assemblies such that the measured dose rates meet 10CFR71.47.

5.2 SOURCE SPECIFICATION

There are five principal sources of radiation associated with cask storage that are of concern for radiation protection:

- Primary gamma radiation from spent fuel;
- Primary neutron radiation from spent fuel (both alpha-n reactions and spontaneous fission);
- Gamma radiation from activated fuel structural materials;
- Capture gamma radiation produced by attenuation of neutrons by shielding material of the cask; and
- Neutrons produced by sub-critical fission in fuel.

The TN-68 is designed to transport GE BWR fuel types; from the GE Series 2 and 3 (7x7 fuel array), the GE Series 4 through 10 (8x8 fuel array), the current GE Series 12 (10x10 fuel array), and the current GE Series 11 and 13 (9x9 fuel array). The fuel assemblies acceptable for transport in the TN-68 are described in Section 1.2.3. This listing of fuel assemblies was collapsed into seven basic designs provided below. The various fuel assembly designs were separated according to fuel assembly array, the maximum metric tons of uranium, and the number of water rods. These three parameters are the significant contributors to the SAS2H/ORIGEN-S model. The largest uranium loading results in the largest source term at the design basis enrichment and burnup.

Fuel Array Type	Number of Fueled Rods	Number of Water Rods	Metric Tons Uranium per Assembly
7 x 7	49	0	0.1977
8 x 8	63	1	0.1880
8 x 8	62	2	0.1856
8 x 8	60	4	0.1825
8 x 8	60	1	0.1834
9 x 9	74	2	0.1766
10 x 10	92	2	0.1867

Table 5.2-1 provides additional fuel assembly design characteristics for the seven basic fuel designs. The SAS2H/ORIGEN-S modules of the SCALE code are used to generate a gamma and neutron source term for each fuel assembly design. Each basic design has an initial bundle-average enrichment of 3.3 wt% U235 and the fuel zone is irradiated at a constant specific power of 5 MW/assembly to a total bundle-average burnup of 40,000 MWD/MTU. A conservative three-cycle operating history is utilized with 30 day down time each cycle except for no down time in the last cycle.

The source terms are generated for the active fuel regions, the plenum region, and the end regions. Irradiation of the fuel assembly structural materials (including the channel, plenum, and end fittings) are included in the irradiation of the fuel zone. The fuel assembly hardware materials and masses on a per assembly basis are listed in Table 5.2-2. Table 5.2-3 provides the material composition of fuel assembly hardware materials. Cobalt impurities are included in the SAS2H model. In particular, the cobalt impurities in Inconel, Zircaloy and Stainless Steel are 0.649%, 0.001% and 0.08%, respectively.

The masses for the materials in the top end fitting, the plenum, and the bottom fitting regions are multiplied by 0.1, 0.2 and 0.15, respectively. (4) These factors are used to correct for the spatial and spectral changes of the neutron flux outside of the fuel zone. The material compositions of the fuel assembly hardware are included in the SAS2H/ORIGEN-S model on a per assembly basis.

Axial variation in the moderator density along the BWR fuel assembly was considered by including a volume averaged density for the moderator around the fuel pins. The following axial variation of temperatures and moderator densities were used to calculated the volume average moderator density for use in the BWR source term models(1):

Distance from bottom of Active Fuel Length	Average Density in Zone (g/cc)	Average Water Temp (K)
30.83	0.743	552
43.17	0.600	558
55.5	0.494	558
67.83	0.417	558
80.17	0.360	558
98.67	0.309	558
123.33	0.264	558
148	0.234	558
Assembly data –water, volume-average density	0.4234 g/cc	558 K

Gamma and neutron source terms are calculated for each of the basic fuel designs. Table 5.2-4 presents the gamma and neutron source terms for a 10 year cooling time. The 7x7 fuel assembly is the most conservative source and is utilized for the shielding analysis.

The inventory of fission gases, volatile nuclides and fines used for the containment analyses is presented in Chapter 4.

5.2.1 Axial Source Distribution

Axial source term peaking factors are determined based on typical axial burnup distributions for BWR assemblies and based upon typical axial water density distribution that occurs during core operation. Using the base SAS2H/ORIGEN-S input for the 7x7 BWR, selected as the design basis assembly above, neutron and gamma source terms are generated for axial zones as a function of burnup and moderator density. This estimates both the non-linear behavior of the neutron source with burnup and the core operating moderator density effects on the actinide isotopics (neutron source).

In-core data from an operating BWR facility forms the basis for the evaluation. The data provided the burnup and moderator density for 25 axial locations along the fuel assembly. Five assemblies located in different locations in the reactor core were utilized to generate a burnup (peaking factor) distribution for the assembly. Figure 5.2-1 represents this distribution.

For water densities, the nodal data provided was examined and 7 assemblies with the lowest densities were selected for evaluation. Of these seven, the assembly with the lowest densities was chosen. The water density data provided shows densities ranging from 0.7608 g/cc at the bottom node to 0.3607 at the top node.

The peaking factors and water densities for the 25 axial locations were collapsed into 12 axial zones and utilized in determining the source terms and axial profiles of the sources for the shielding evaluation. The top and bottom 10% of the assembly was divided into two zones each and the middle 80% divided into 8 equal zones. The peaking factors ranged from 0.2357 and 0.2410 at the bottom and top respectively, to a maximum of 1.20 just below the middle. The water densities ranged from 0.3609 at the top zone to 0.7603 at the bottom.

The burnup and water density axial distribution data was utilized to prepare a 12 axial zone fuel assembly model. Twelve SAS2H calculations were performed for the design basis fuel with the power and water density being variables for each zone. The specific power input was the product of the nominal specific power, (5 MW) and the peaking factor. The water density was that value calculated for the zone as described above. Therefore, the fuel assembly was divided into 12 zones, with each zone having a unique gamma and neutron source term, specifically calculated for the burnup and water density in that zone. This data is presented in Table 5.2-11. (Note: the axial profile data is for 10 year cooled fuel, but the profile is equally applicable for longer cooled fuel.)

5.2.2 Gamma Source

The primary gamma source spectrum for three 7x7 spent fuel assembly conditions are provided in Tables 5.2-5, 5.2-6 and 5.2-7. Tables 5.2-5 and 5.2-6 present spectra for a 7x7 assembly with an initial bundle average enrichment of 3.3wt%, maximum bundle-average burnup of 40,000 MWD/MTU and 16 and 10 year decay, respectively. Table 5.2-7 provides the gamma spectrum for a 7x7 assembly with an initial bundle average enrichment of 2.5wt%, maximum bundle-average burnup of 21,500 MWD/MTU and 26 year decay.

The gamma source spectra are presented in the 18-group structure consistent with the SCALE 27n-18γ cross section library. The conversion of the source spectra from the default ORIGEN-S energy grouping to the SCALE 27n-18γ energy grouping is performed directly through the ORIGEN-S code. The SAS2H/ORIGEN-S input file for the 7x7 fuel assembly is provided in Section 5.5.

The gamma source for the fuel assembly hardware is primarily from the activation of cobalt. This activation contributes primarily to SCALE Energy Groups 36 and 37. Based on the weight fraction of cobalt in each zone of the fuel assembly model (as adjusted by the appropriate flux ratio), the gamma source term in SCALE Energy Groups 36 and 37 are redistributed accordingly. The gamma source for the plenum region, the top fitting region and the bottom fitting region is provided in Tables 5.2-5, 5.2-6 and 5.2-7.

An axial burnup profile has been developed as discussed in Section 5.2.1 above. Table 5.2-11 provides design axial gamma peaking factors and source terms that were utilized in the MCNP shielding model.

5.2.3 Neutron Source

Tables 5.2-8, 5.2-9 and 5.2-10 provide the total neutron source spectra for the 7 x 7 fuel assembly under the irradiation/decay history described above in 5.2.2. The SAS2H/ORIGEN-S code provides the neutron spectra in the SCALE 27n-18γ energy groups. The SAS2H/ORIGEN-S input file for the 7x7 fuel assembly is provided in Section 5.5.

The neutron source is not linearly dependent with burnup, and therefore analyses were performed to determine the axial neutron source distribution (Section 5.2.1). The axial neutron source distribution as a function of burnup and water density is shown in Table 5.2-11.

5.3 MODEL SPECIFICATION

The monte carlo code MCNP is used for calculating the gamma and neutron doses immediately around the cask.

5.3.1 Description of Radial and Axial Shielding Configuration

A single geometric model was developed for MCNP. This model was used to calculate both the axial and radial dose rates. In order to determine the total dose rate around a single cask, three separate runs were performed, each with a different source; 1) primary gamma, 2) neutron and 3) hardware gamma (end fittings). A model without impact limiters was utilized for the accident condition evaluation.

Sections 5.3.1.1 and 5.3.1.2 describe the shielding model (for the vicinity immediately around the cask) developed for the TN-68 under normal, off-normal and accident conditions.

5.3.1.1 Radial and Axial Shielding Configuration under Normal Conditions of Transport

Under normal conditions, one shielding configuration is used for the TN-68 design. The model is illustrated in Figures 5.3-1 and 5.3-2. The dimensions of this shielding model correspond to the dimensions of the TN-68 design. The only exception is that the upper and lower trunnions are modeled as flush with the resin shield. (Actually the trunnions extend slightly past the resin shield.) This minor modeling change allowed the model to have surface detectors at the resin shield. This configuration actually results in slightly less shielding present in the area of the trunnions.

The axial locations of the plenum and the end fittings for the fuel assembly are taken from Reference 4; these are the same regardless of fuel assembly type.

The modeled active fuel length is 144 inches and the plenum length is 16.5 inches. The basket's peripheral layer of stainless steel and aluminum are represented by a layer of material with the equivalent thickness. The aluminum rails and shims are also included as an equivalent layer of material within the cask cavity.

Around the fuel region are two thin layers of stainless steel (0.19") and aluminum (0.31") to simulate the periphery of the basket. Also within the cask cavity is 1.21 inches equivalent aluminum to represent the aluminum rails and shims around the basket.

The basket hold down ring is also modeled inside the cask cavity. This hold down ring is 1 inch thick carbon steel with four reduced thickness (7/16 inch) sections. The cross members of the hold down ring are neglected in the model.

The impact limiters are modeled as wood surrounded by a 0.25" thick steel shell. The interior steel gussets are neglected. The wood is assumed to be redwood except for the 68" diameter plug in the end of each limiter which is modeled as balsa. An aluminum spacer utilized under the top impact limiter is included in the model. The thermal shield under the bottom impact limiter is not included in the model which is conservative since shielding material is neglected.

A 1 inch thick ancillary steel shield ring is also modeled. The shield ring rests on the radial resin shield, extending up to the top impact limiter. If the measured dose rates exceed the transportation limit, the ancillary shield ring may be utilized to lower the dose rates to acceptable limits.

The fuel region is assumed to consist of uranium dioxide. The fuel cladding and steel and aluminum basket are included in the homogenized fuel region. The fuel channels are not included in the homogenization. (However, the fuel channels are included in the source term.) The neutron poison material of the basket is also neglected. The stainless steel intermittent basket plates are assumed to be aluminum in the basket homogenization. (Aluminum has a lower density than steel and therefore will provide less self-shielding.) The fuel and basket region is modeled as a cylinder within the cask cavity.

The plenum region is assumed to consist of the cladding, plenum springs and the steel and aluminum basket. The hydrogen getters within the plenum are neglected. The basket is homogenized through the plenum region. Similarly, the bottom fitting region is homogenized with the basket. The top fitting hardware is homogenized through the same reduced cavity diameter as the other regions. The basket is not included in the homogenization of the top fitting region. The basket hold down ring is modeled in the top fitting region. The steel cross members of this ring are not included in the homogenization.

Voids are neglected within the fuel assembly. The voids within the cask cavity are modeled.

5.3.1.2 Radial and Axial Shielding Configuration under Hypothetical Accident Conditions of Transport

For accident conditions, it is conservatively assumed that the top and bottom impact limiters are gone. Also, the ancillary shield ring and the neutron shield are assumed to be removed. The model utilizes the same regional densities and shield thickness as the model for normal conditions.

5.3.2 Shield Regional Densities

For the MCNP model, four source areas, shown in Figures 5.3-1 and Figure 5.3-2 are utilized: fuel zone, plenum, upper fitting and lower fitting. The sources are uniformly homogenized over the reduced cavity diameter and the appropriate length. The fuel basket is homogenized over the source diameter and appropriate length (of the fuel zone, plenum and bottom fitting).

The radial resin and aluminum boxes are homogenized into a single composition based on the mass of each component. Measured dose rates around the TN-24P(7), the TN-40, and the TN-32 casks have shown no streaming effects around the neutron shield. This is because the neutrons will not generally travel in a direct path, but scatter, such that the majority of the neutrons will not be able to travel through the aluminum box wall for the full 6 inches of resin box thickness. The material input for the MCNP model is listed in Table 5.3-1.

5.3.3 Preferential Loading

An additional MCNP analysis was performed to provide dose rates for a TN-68 cask containing 10 year cooled design basis fuel (Type I as defined in Section 1.2.3) located in the middle of the basket, surrounded by "cooler" fuel (Type II) in the basket peripheral compartments. The MCNP model for this analysis in essentially identical to the one described in Section 5.3.1 above except, the homogenized source volume was divided into two zones; an inner cylinder surrounded by an outer annulus or ring.

The volume of the twenty four peripheral compartments, containing the cooler fuel, was calculated to be 2.394E+06 cc. The total cylindrical source volume for all 68 assemblies is:

$$V_{cylinder} = \pi r^2 h = \pi \ (83.92 \text{ cm})^2 (365.76\text{cm}) = 8.092\text{E+06 cc}$$

Therefore, the equivalent volume of the center zone containing the 10 year cooled fuel is 5.698E+06 cc and the equivalent radius for the center zone is:

$$r = \{ 5.698\text{E+06} / (365.76\pi) \}^{0.5} = 70.4 \text{ cm}$$

Thus, the cylindrical source volume was divided into two zones: a center cylindrical zone with a radius of 70.4 cm containing 44 design basis fuel assemblies (40,000 MWD/MTU, 3.3%) cooled 10 years, and a surrounding annular zone with an OD of 83.92 cm containing 24 fuel assemblies with 21,500 MWD/MTU burnup, 2.5% enrichment and cooled for 26 years. Figure 5.3-3 shows the location of the fuel assemblies in the basket. The source terms for the 10 year cooled fuel and the 26 year cooled fuel are described in Section 5.2.

Two basic MCNP runs were performed to calculate the dose rate for the preferential loading. One with the center zone as the source and the outer zone acting only as a shield and the other with the outer zone as the source. The results of the two analyses were summed to arrive at the expected dose rate for the preferentially loaded cask.

5.4 SHIELDING EVALUATION

Dose rates around the TN-68 are determined by choosing the most conservative source and using it within a three dimensional MCNP model. The MCNP dose is calculated as surface flux (F2) tallies and converted into dose rates using energy dependent dose conversion factors(6), (Tables 5.4-1and 5.4-2). The shielding evaluation accounts for subcritical neutron multiplication. The generation of secondary gamma dose due to neutron interactions in the shielding materials, principally the neutron shield resin, is neglected because the resin is surrounded by a steel shell and previous evaluations have shown the secondary gamma dose to be small fraction (< 3%) of the total calculated dose.

For the doses around the TN-68, the source is divided into four separate regions: fuel, plenum, top fitting, and bottom fitting. The model is utilized in three separate computer runs consisting of contributions from the following sources:

- Primary gamma radiation from the active fuel (axial and radial directions).
- Neutron radiation from the active fuel region (axial and radial directions).
- Gamma radiation from activated hardware within the top fitting, plenum region and bottom fitting (axial and radial directions).

The sources in the active fuel region (gamma and neutron) are uniform radially but vary axially. The sources in the structural hardware regions (plenum, top fitting, and bottom fitting) are uniform both radially and axially. The results from the individual runs are summed to provide the total gamma, neutron and total dose for the cask.

Detector surfaces were placed in several radial and axial locations in order to evaluate the dose rate around the cask body. These surfaces provide an averaged surface dose rate based on the size of the detector (surface). The surfaces are subdivided into segments in order to determine the location and magnitude of maximum dose rates. Approximately 25 cm length "detector" segments were utilized both axially and radially.

For normal conditions, the contribution of each source to each dose point is summed to calculate the total gamma and/or neutron dose for each location. Table 5.1-2 presents the maximum calculated dose at contact, at the vehicles outer edge (assumed 10 ft wide vehicle), and at 2 m from the vehicle's outer edge. The calculated neutron and gamma dose rates at the various dose points are illustrated in Figures 5.4-1 through 5.4-4.

For accident conditions, Table 5.1-2 also presents the maximum calculated doses at 1 m from the cask body.

For the preferential loading analysis, six separate MCNP runs were performed: three runs, as mentioned above, for the primary gamma, neutron and irradiated hardware sources for each of the two source zone configurations. The results of each individual run are summed to provide the total gamma, neutron and total dose for the preferential loading configuration. The calculated dose rates for the normal transport configuration, preferential loading, are presented in Table 5.4-3 at various locations around the cask. The outer ring of fuel contributes approximately 65% to 75% of the total cask surface gamma dose and as much as 10% of the total cask surface neutron dose in the central area on the side of the cask. In the top trunnion area, below the impact limiter, the irradiated hardware from the inner assemblies dominate and contribute over 90% of the total cask dose. As expected, the outer ring of fuel contributes less than 10% to the total cask dose for both gamma and neutron doses at the top and bottom surfaces of the cask/impact limiter. An accident condition was not evaluated for the preferential loading since the calculated dose rates for normal conditions were less than the dose rates reported in Table 5.1-2.

The source term evaluation was performed using SCALE 4.3, "Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation for Workstations and Personal Computers"(1) by Oak Ridge National Laboratory. The dose rate analysis was performed using MCNP, "MCNP4B2 Monte Carlo N-Particle Transport Code System"(5) by Los Alamos National Laboratory. SCALE 4.3 is implemented on a Hewlett Packard 9000/715 Workstation. MCNP is implemented on Pentium based PCs using Windows NT. These program(s) have been verified in accordance with the Transnuclear quality assurance program.

Selected input for MCNP are included in Section 5.6.

5.5 REFERENCES

1. SCALE 4.3, "Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation for Workstations and Personal Computers," CCC-545, ORNL, March 1997.

2. Croff, et al, "Revised Uranium-Plutonium Cycle PWR and BWR Models for the ORIGEN Computer Codes," ORNL/TM-6051, Oak Ridge National Laboratories, September 1978.

3. Moore and Notz, "Physical Characteristics of GE BWR Fuel Assemblies," ORNL-TM-10902, June 1989.

4. Luksic, 'Spent Fuel Assembly Hardware: Characterization and 10 CFR 61 Classification for Waste Disposal,' PNL-6906, UC-85, June 1989.

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

6. "Data for Use in Protection Against External Radiation," Publication 51, International Commission on Radiological Protection, Annals of the ICRP, 17, No. 2/3, Pergamon Press, Oxford, 1987.

7. EPRI-NP-5128, "The TN-24P PWR Spent-Fuel Storage Cask: Testing and Analyses," prepared by Pacific Northwest Laboratory, Virginia Power Company and EG&G Idaho National Engineering Laboratory, April 1987.

5.6 APPENDIX

5.6.1 SAS2H/ORIGENS Input File

```
=sas2h     parm=(halt03,skipshipdata)
7x7-49-0rv1.inp, 3.3 w/o U235, 40,000 MWD/MTU, 5-60 year cooling
27groupndf4  latticecell
uo2      1   0.95  840 92234 0.0294 92235 3.3 92236 0.0152
92238 96.6555 end
zircalloy 2   1.0      620   end
h2o       3  den=0.432  1.0  558    end
zircalloy 5   1.0      552   end
h2o       11  den=0.669  1.0  552    end
end comp
squarepitch  1.8745   1.23698  1  3  1.43002  2   1.26746  0  end
npin/assm=49  fuelength=365.76  ncycles=3  nlib/cyc=1  printlevel=10
lightel=10    inplevel=2      numzones=4  end
 500  7.4031   3  7.5091  5  7.7957  11  8.5982
power=5.00   burn=527.2   down=30    end
power=5.00   burn=527.2   down=30    end
power=5.00   burn=527.2   down=1461  end
n  0.0432    si 0.0106   ti  0.0106  cr 0.375  mn 0.0228  fe  0.854
co  0.00456   ni 0.422   sn  1.30    zr 84.9
end
=origens
0$$  a4  21  a8  26  a10  51  71  e
1$$  1  1t
cooling to 60 years and fission product gamma reordering
3$$  21  0   1   a33 -86  e
54$$  a8  1   e   t
35$$  0   t
56$$  0   8   a13 -2  5    3   e
57**  4.0 e   t
cooling to 60 years and fission product gamma re-ordering
single reactor assembly
60**  5.0   8.0   10.0   20.0   30.0   40.0   50.0    60.0
65$$  a4 1 a7 1 a10 1 a25 1 a28 1 a31 1 a46 1 a49  1  a52  1  e
61**  f.0000001
81$$  2  51  26  1  e
82$$  f6  t
fission product gamma spectra in scale 18 groups
fission product gamma spectra in scale 18 groups
fission product gamma spectra in scale 18 groups
fission product gamma spectra in scale 18 groups
fission product gamma spectra in scale 18 groups
fission product gamma spectra in scale 18 groups
fission product gamma spectra in scale 18 groups
fission product gamma spectra in scale 18 groups
56$$  f0  t
end
=origens
0$$  a4  21  a8  26  a10  51  71  e
1$$  1  1t
cooling to 60 years and actinide gamma re-ordering
3$$  21  0   1   a33 -86  e
```

```
54$$ a8 1 e t
35$$ 0 t
56$$ 0 8 a13 -2 5 3 e
57** 4.0 e t
cooling to 60 years and actinide gamma re-ordering
single reactor assembly
60** 5.0 8.0 10.0 20.0 30.0 40.0 50.0 60.0
65$$ e
61** f.0000001
81$$ 2 51 26 1 e
82$$ f5 t
actinide gamma spectra in scale 18 groups
actinide gamma spectra in scale 18 groups
actinide gamma spectra in scale 18 groups
actinide gamma spectra in scale 18 groups
actinide gamma spectra in scale 18 groups
actinide gamma spectra in scale 18 groups
actinide gamma spectra in scale 18 groups
actinide gamma spectra in scale 18 groups
56$$ f0 t
end
=origens
0$$ a4 21 a8 26 a10 51 71 e
1$$ 1 1t
cooling to 60 years and light element gamma re-ordering
3$$ 21 0 1 a33 -86 e
54$$ a8 1 e t
35$$ 0 t
56$$ 0 8 a13 -2 5 3 e
57** 4.0 e t
cooling to 60 years and light element gamma re-ordering
single reactor assembly
60** 5.0 8.0 10.0 20.0 30.0 40.0 50.0 60.0
65$$ e
61** f.0000001
81$$ 2 51 26 1 e
82$$ f4 t
light element scale group structure
light element scale group structure
light element scale group structure
light element scale group structure
light element scale group structure
light element scale group structure
light element scale group structure
light element scale group structure
56$$ f0 t
end
```

5.6.2 MCNP Neutron Model Input File

```
TransNuclear TN-68 cask:   Near-Field model; neutron source (12 zones)
c    Secondary photons not included.
c    Cask cells have IMP=1; Geometry splitting/routlette used outside
c    cask.  Volumetric F2 detectors used. TRANSPORT CONFIGURATION
c ***********************  BLOCK 1: CELL CARDS ************************
c GEOMETRY (r-z)* includes 1" ancillary shield ring between resin & top
limiter
c
c  ^ z-axis
c  .
c  | ------------------  |  tally surfaces @
c  .___________________. |     contact,
c  |    impact limiter | |     rail car surface,
c  .______________.    | |     2m from rail car
c  |-------------+--+  | |
c  .-------------+  |  | |
c  |.............|  |__| |
c  .  BASKETS    |  |+   |
c  |.............|  ||   |             VOID
c  .             |  ||   |
c  |             |  ||   |
c  .   FUEL      |  ||   |
c  O ------------|--||-----------------------------> y-axis
c  |  (12 sub    |  ||   |
c  .   regions)  |  ||   |
c  |             |  ||   |
c  .             |  ||
c  |.............|  ||
c  .  BASKET     |  |__.
c  |-------------+  |  |
c  .=---------------+  |
c  |   impact limiter  |
c  .___________________|
c  |
c                                                   M. Mason (2/00)
c
c ****** Cask cells
   1  9   -7.8212  1 -2 -21          imp:n,p=1  $ Fe cask bottom
   2  9   -7.8212  2 -13 201 -21     imp:n,p=1  $ Fe cask side
   211 9  -7.8212  -32 21 10 -160 #407 #408    imp:n,p=1  $ ancil shield ring
   3  7   -1.918   2 -5 -26          imp:n,p=1  $ bottom basket
   4  6   -1.158   7 -8 -26          imp:n,p=1  $ top plenum basket
   5  5   -0.491   8 -11 -26         imp:n,p=1  $ top fitting
   6  8   -7.92    26 -27 2 -28      imp:n,p=1  $ ss side basket
   7  10  -2.702   27 -201 2 -28     imp:n,p=1  $ Al side basket/rails
   8  0    11 -12 -26                imp:n,p=1  $ top void - part1
   9  0   (28 -12 26 -24):(19 -12 24 -201) imp:n,p=1    $ top void - part2
   10  9   -7.8212  (28 -19 24 -201)(#13 #14 #15 #16) imp:n,p=1    $ hold
down rin
   11  9   -7.8212  12 -14 -201         imp:n,p=1  $ Fe cask lid - part1
   12  9   -7.8212  13 -14 201 -29      imp:n,p=1  $ Fe cask lid - part2
   13  0   195 -25 -191 192 24 -19 28   imp:n,p=1  $ cutout in hold down ring
   14  0  -195 -25 -191 192 24 -19 28   imp:n,p=1  $ cutout in hold down ring
   15  0   196 -25  193 -194 24 -19 28  imp:n,p=1  $ cutout in hold down ring
```

```
    16  0  -196 -25  193 -194 24 -19 28  imp:n,p=1 $ cutout in hold down ring
    19  9   -7.8212  21 -23 9 -10 #400 #402 #407 #408 #409 #410
                     #411 #412           imp:n,p=1 $ top side-shld Fe shell
    20  9   -7.8212  22 -23 4 -9 #400 #402 #409 #410 #411 #412
                    #420 #422 #429 #430 #431 #432 imp:n,p=1 $ side side-shld
Fe shell
    21  9   -7.8212  21 -23 3 -4 #420 #422 imp:n,p=1 $ bot side-shld Fe shell
    22  12  -1.687   21 -22 4 -9 #400 #402 #403 #404 #405 #406 #407 #408
            #409 #410 #411 #412 #420 #422 #423 #424 #425 #426 #427 #428
            #429 #430 #431 #432         imp:n,p=1 $ side resin/Al shield
   23  0          150 -3 21 -23         imp:n,p=1 $ void under side shld
   24  0    32 -23 10 -160 #407 #408 #409 #410 #411 #412
                         imp:n,p=1              $ void above side shld - pt1
c 25  1  -0.0013    30 -23 18 -17       imp:n,p=1  $ air above side shld - pt2
c **** impact limiters  *****
c  bottom limiter
   80 9  -7.8212  (-1 155 -253):(1 -151 -253 21) imp:n,p=1 $ inside skin
   81 9  -7.8212  (153 -152 -250):(152 -151 -250 251) imp:n,p=1 $ outside
skin
   82 9  -7.8212     151 -150 -250 21      imp:n,p=1 $ outside skin
   83 14 -0.387      155 -151 -251 253     imp:n,p=1 $ redwood
   84 14 -0.387      154 -155 -251 252     imp:n,p=1 $ redwood
   85 14 -0.387      154 -155 -252         imp:n,p=1 $ redwood
   86 14 -0.387      152 -154 -251 252     imp:n,p=1 $ redwood
   87 15 -0.125      152 -154 -252         imp:n,p=1 $ balsa
c  top limiter
 90 9  -7.8212  (166 -165 -253):(161 -166 -253 21) imp:n,p=1 $ inside skin
 91 9  -7.8212  (162 -163 -250):(161 -162 -250 251) imp:n,p=1 $ outside skin
   92 9  -7.8212     160 -161 -250 21      imp:n,p=1 $ outside skin
   93 14 -0.387      161 -165 -251 253     imp:n,p=1 $ redwood
   94 14 -0.387      165 -164 -251 252     imp:n,p=1 $ redwood
   95 14 -0.387      165 -164 -252         imp:n,p=1 $ redwood
   96 14 -0.387      164 -162 -251 252     imp:n,p=1 $ redwood
   97 15 -0.125      164 -162 -252         imp:n,p=1 $ balsa
   98 10 -2.702 (14 -166 -21):(-14 13 29 -21)  imp:n,p=1 $ al spacer
c  trunnions
   400 0    195 300 -23 304 -10 #409 #411   imp:n,p=1 $ resin cutout at top
trun
   402 0   -195 -301 -23 304 -10 #410 #412  imp:n,p=1 $ resin cutout at top
trunn
   403 9   -7.8212 195 305 -300 -22 304 -9
                #407  #411                  imp:n,p=1 $ trunnion flat fe
plate
   404 9   -7.8212 -195 -306 301 -22 304 -9
               #408  #412                   imp:n,p=1 $ trunnion flat fe
plate
   405 9   -7.8212 195 305 -22 303 -304      imp:n,p=1  $ flat plate under
top tru
   406 9   -7.8212 -195 -306 -22 303 -304    imp:n,p=1  $ flat plate under
top tru
   407 9   -7.8212 307 -300 -330 #2 #411 imp:n,p=1  $ top trunnion base
   408 9   -7.8212 -308 301 -330 #2 #412 imp:n,p=1  $ top trunnion base
   409 9   -7.8212 300 -309 -331 #411  imp:n,p=1  $ top trunnion load surface
   410 9   -7.8212 -301 310 -331 #412  imp:n,p=1  $ top trunnion load surface
   411 12  -1.687  311 -309 -332       imp:n,p=1  $ top trunnion resin plug
   412 12  -1.687 -312  310 -332       imp:n,p=1  $ top trunnion resin plug
```

```
  420 0    195  320 -23 -323 3 #429 #431     imp:n,p=1 $ resin cutout at
bottom t
  422 0   -195 -321 -23 -323 3 #430 #432     imp:n,p=1 $ resin cutout at
bottom t
  423 9   -7.8212 195 324 -320 -22 -323 4 #431
                        imp:n,p=1 $ bottom trunnion flat fe plate
  424 9   -7.8212 -195 -325 321 -22 -323 4 #432
                   imp:n,p=1 $ bottom trunnion flat fe plate
  425 9   -7.8212 195 324 -22 -322 323       imp:n,p=1  $ flat plate under bot
tru
  426 9   -7.8212 -195 -325 -22 -322 323    imp:n,p=1  $ flat plate under bot
tru
  427 9   -7.8212  326 -324 -333 #2        imp:n,p=1  $ bottom trunnion base
  428 9   -7.8212 -327  325 -333 #2        imp:n,p=1  $ bottom trunnion base
  429 9   -7.8212  320 -328 -334 #431        imp:n,p=1  $ bottom trunnion load
sur
  430 9   -7.8212 -321  329 -334 #432        imp:n,p=1  $ bottom trunnion load
sur
  431 12  -1.687  311 -328 -335              imp:n,p=1  $ bottom trunnion
resin pl
  432 12  -1.687 -312  329 -335              imp:n,p=1  $ bottom trunnion
resin pl
c **** fuel regions
  40 4   -3.231   5  -39 -26            imp:n,p=1  $ FUEL region 1 (bottom)
  401 4  -3.231   39 -40 -26            imp:n,p=1  $ FUEL region 2
  41 4   -3.231   40 -41 -26            imp:n,p=1  $ FUEL region 3
  42 4   -3.231   41 -42 -26            imp:n,p=1  $ FUEL region 4
  43 4   -3.231   42 -43 -26            imp:n,p=1  $ FUEL region 5
  44 4   -3.231   43 -44 -26            imp:n,p=1  $ FUEL region 6
  45 4   -3.231   44 -45 -26            imp:n,p=1  $ FUEL region 7
  46 4   -3.231   45 -46 -26            imp:n,p=1  $ FUEL region 8
  47 4   -3.231   46 -47 -26            imp:n,p=1  $ FUEL region 9
  48 4   -3.231   47 -48 -26            imp:n,p=1  $ FUEL region 10
  481 4  -3.231   48 -49 -26            imp:n,p=1  $ FUEL region 11
  49 4   -3.231   49 -7  -26            imp:n,p=1  $ FUEL region 12 (top)
c ***** outside cells above/below cask
  140 0              170  -60 -172      imp:n,p=0  $ air beneath cask-pt2
  142 0             -153   60 -250      imp:n,p=1  $ air beneath cask-pt1
  145 0              163  -61 -250      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
c 600 2   -2.32     150 -1  23 -60      imp:n,p=1 $ concrete inner air
  601 0             150 -160  23 -62    imp:n,p=1 $ inner air (void)
  602 0             150 -160  62 -63    imp:n,p=1 $ inner air (void)
  603 0   (60 -61 250 -64):(150 -160 63 -250) imp:n,p=1 $ inner air (void)
c 604 2   -2.32     150 -1  60 -152    imp:n,p=1 $ concrete outer air
  605 0              60 -61 -172 64     imp:n,p=0    $ outer air (void)
c 606 0             17 -61  60 -152    imp:n,p=1 $ outer air (void)
c 607 0             61 -151 60 -152    imp:n,p=1 $ 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  -226.42       $ cask bottom - ground surface
  2   pz  -201.65       $ cask bottom - top of bot Fe plate
  3   pz  -192.76       $ side Fe jacket - outside lower bottom
  4   pz  -190.86       $ side Fe jacket - inside lower bottom
```

```
   5  pz  -182.88       $ top bottom basket/bottom of fuel
   7  pz   182.88       $ bottom of plenum basket/top of fuel
   8  pz   224.72       $ top of plenum basket
   9  pz   211.74       $ side Fe jacket - inside top
  10  pz   213.64       $ side Fe jacket - outside top
  11  pz   245.90       $ top of top fitting
  12  pz   250.47      $ cask top - bot of lid
  13  pz   261.90      $ cask side - top of Fe side
  14  pz   274.60      $ cask top - top of Fe
c  15  pz   284.76      $ top of polyprop on top of cask
c  16  pz   318.74      $ top Fe cover - bot surface
c  17  pz   319.38      $ top Fe cover - top surface
  18  pz   266.35       $ flange top
  19  pz   248.56       $ top hold down ring
  191 py    18.42        $ half height of hold down ring cutout
  192 py   -18.42        $ half height of hold down ring cutout
  193 px   -18.42        $ half height of hold down ring cutout
  194 px    18.42        $ half height of hold down ring cutout
  195 px     0.0         $ ambiguity surface
  196 py     0.0         $ ambiguity surface
  28  pz   214.91       $ bottom hold down ring
  150  pz  -194.04       $ top of bottom limiter
  151  pz  -194.68       $ inside skin bottom limiter
  152  pz  -314.68       $ inside skin bottom limiter
  153  pz  -315.32       $ bottom of bottom limiter
  154  pz  -275.94       $ top of balsa disk bottom limiter
  155  pz  -227.06       $ top of inside skin bottom limiter
  160  pz   246.03       $ bottom of top limiter
  161  pz   246.67       $ inside skin top limiter
  162  pz   366.67       $ inside skin  top limiter
  163  pz   367.31       $ top of top limiter
  164  pz   327.93       $ bottom of balsa disc top limiter
  165  pz   279.05       $ top of inside skin top limiter
 166  pz   278.41       $ top of Al spacer top limiter
  300  px   116.28       $ OD of top trunnion base (flat)
  301  px  -116.28       $ OD of top trunnion base (flat)
  302  py    44.37       $ half width of trunnion flat
  303  pz   171.09       $ bottom of plate under top trunnion
  304  pz   173.00       $ top of resin recess under top trunnion
  305  px   114.38       $ ID of flat plate at top trunnion
  306  px  -114.38       $ ID of flat plate at top trunnion
  307  px   102.44       $ top trunnion socket
  308  px  -102.44       $ top trunnion socket
  309  px   123.85       $ top trunnion OD ( to match body OD)
  310  px  -123.85       $ top trunnion OD ( to match body OD)
  311  px   115.34       $ ID of top trunnion resin plug
  312  px  -115.34       $ ID of top trunnion resin plug
  320  px   117.01       $ OD of bottom trunnion base (flat)
  321  px  -117.01       $ OD of bottom trunnion base (flat)
  322  pz  -111.72       $ top of plate over bottom trunnion
  323  pz  -113.62       $ bottom of resin recess over bottom trunnion
  324  px   115.10       $ ID of flat plate at bottom trunnion
  325  px  -115.10       $ ID of flat plate at bottom trunnion
  326  px   104.34       $ bottom trunnion socket
  327  px  -104.34       $ bottom trunnion socket
  328  px   123.19       $ bottom trunnion OD (to match body OD)
  329  px  -123.19       $ bottom trunnion OD  (to match body OD)
```

```
c ***** cylindrical cask surfaces
  201  cz    88.27      $ cask inner surface
  21  cz   107.32       $ cask outer surface
   22  cz   122.56       $ side Fe jacket -- inside
  23  cz   124.47       $ side Fe jacket -- outside
  24  cz    85.73       $ inside radius of hold down ring
  25  cz    87.15       $ inside radius of cutouts in ring
c 25  cz    89.22       $ top polyprop disk radius
  26  cz    83.92       $ inside radius ss basket
27  cz    84.40       $ inside radius Al backet/rails
  29  cz   101.45       $ inside radius top cover
c  30  cz   102.40       $ outside radius top cover
  32   cz  109.86       $ ancillary shield ring (1")
  250 cz   182.88       $ outside radius of impact limiter
  251 cz   182.24       $ inside radius of impact limiter
 252 cz    86.36      $ radius of balsa disk
  253 cz   107.96       $ outside radius inside skin
  330 c/x   0 213.64 21.59       $ top trunnion base
  331 c/x   0 213.64 12.38       $ top trunnion load surface
 332 c/x   0 213.64 9.65        $ top trunnion resin plug
 333 c/x   0 -156.8 21.59       $ bottom trunnion base
  334 c/x   0 -156.8 17.78       $ bottom trunnion load surface
 335 c/x   0 -156.8 9.84        $ bottom trunnion resin plug
c ***** surfaces for fuel regions
 39  pz  -164.59       $ top of fuel region 39
 40  pz  -146.30       $ top of fuel region 40
 41  pz  -109.73       $ top of fuel region 41
 42  pz  -73.15        $ top of fuel region 42
 43  pz  -36.53        $ top of fuel region 43
 44  pz  -0.0          $ top of fuel region 44
 45  pz   36.53        $ top of fuel region 45
 46  pz   73.15        $ top of fuel region 46
 47  pz   109.73       $ top of fuel region 47
 48  pz   146.30       $ top of fuel region 48
 49  pz   164.59       $ top of fuel region 49
  c ***** problem boundaries
  170  pz  -500.E2       $ bottom of air (problem boundary)
  171  pz   500.E2       $ top of air (problem boundary)
  172  cz   500.E2       $ radial air limit (problem boundary)
c ****** surfaces for detector segmentation
  60  pz  -318.0        $ bottom tally surface
  61  pz   370.0        $ top tally surface
  62  cz   125.0        $ radial tally surface  (outer shell)
  63  cz   152.0        $ radial tally surface   (rail car edge)
  64  cz   352.0        $ radial tally surface   (2 m from rail car)
  71  pz  -190.0        $ segmentation plane
  72  pz   200.0        $ segmentation plane
  81  cz    25.00       $ segmentation cylinder
  82  cz    50.00       $ segmentation cylinder
  83  cz    75.00       $ segmentation cylinder

c ***********************  BLOCK 3: DATA CARDS *************************
c
c  --- volumetric neutron source in 12 axial zones for TN-68 cask
c      7x7 fuel assemblies; 40,000 MWd/Mt average burnup; 16y cooling time
SDEF  par=1 pos 0 0 0  axs=0 0 1  rad=d1  ext=d2   erg=d3  cel=d4
 SI1  0   83.92         $ range of radius sampling: 0 to Rmax
```

```
 SP1  -21 1                $ radial distriubtion: here r^1
 SI2 -182.88 182.88        $ range of axial sampling
 SP2  -21  0               $ axial distribution: here z^0
 SI3  H   0.1   0.4     0.9     1.4     1.85    3.0     6.434   20  $ energy bins
 SP3      0.0 .03762 .1922 .1766 .1311 .2344 .2098 .01835  $ bin prob.
 SI4 L 40 401 41 42 43 44 45 46 47 48 481 49
 SP4   0.0000924 0.008421 0.08446 0.1386 0.1529 0.1578
       0.1562 0.1384 0.1071 0.05047 0.005463 0.0001396
 SB4   0.05     0.05     0.1      0.1      0.1      0.1
       0.1      0.1      0.1      0.1      0.05     0.05
c
c
c ---- Detector types and locations -- neutrons and NO secondary gammas
c -- doses on cask's radial surface (F2 segmented surface detectors)
c FM2    2.324E18       $ convert Sv/neutron to mrem/h for fuel zones
c      7.16E7 x 68 X 1.326 (NF) X 3600 X 1E5 = 2.008E18
c TF2 3j 6
FC2  Doses on outer shell averaged over subsurfaces
F2:n  62
FS2   -71 -39 -40 -41 -42 -43 -44 -45 -46 -47 -48 -49 -72 -8 -11
SD2  3.0E7 19956.97 14364.93 28722.01 28729.86 28761.28
       28690.59 28690.59 28761.28 28729.86 28722.01
        14364.93 27810.95 19415.04 16634.73 3.0E7
 FC12   Doses at the rail car edge averaged over subsurfaces.
 F12:n  63
 FS12  -71 -39 -40 -41 -42 -43 -44 -45 -46 -47 -48 -49 -72 -8 -11
 SD12  3.0E7 24267.67 17467.76 34925.96 34935.52 34973.72
         34887.76 34887.76 34973.72 34935.72 34925.96
        17467.76 33818.11 23608.69 20227.84 3.0E7
 FC22    Doses at 2 meters from rail car averaged over subsurfaces
 F22:n   64
 FS22  -152 -154 -155 -71 -39 -40 -41 -42 -43 -44 -45 -46 -47
        -48 -49 -72 -8 -11 -165 -164 -162
  SD22   1.0E8 85680.53 108106.98 81964.90 56198.82 40451.65 80881.18
          80903.30 80991.77 80792.71 80792.71 80991.77 80903.30
          80881.18 40451.65 78315.63 54672.76 46843.41
          73317.23 108106.98 85680.53 8.0E7
c
c -- doses along cask's top
 FC32 Doses at top limiter surface averaged over subsurfaces
 f32:n   61          $ surface tally
 fs32   -81 -82 -83 -29 -23 -63 -250 -64
 sd32   1963.50 5890.49 9817.48 14662.13 16338.41 23911.35
          32487.51 284185.03 7.8E7
c
c -- doses along cask's bottom
 FC42 Doses at bottom limiter surface averaged over subsurfaces
 f42:n   60          $ surface tally
 fs42   -81 -82 -83 -29 -23 -63 -250 -64
  sd42   1963.50 5890.49 9817.48 14662.13 16338.41 23911.35
        32487.51 284185.03 7.8E7
c
c mode n p
 phys:n 20.0 0.0
 cut:n j 0.0
 esplt:n 0.5 0.1  0.5 0.01  0.25 0.001
 wwp:n  5  3  5  0  0.5
```

```
c phys:p 0 1 1
 nps  4000000
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  ambient photon dose equiv. H*(10mm) Sv (from T-D1 of S&F)
c ------------------------------------------------------------------
c de24   1.000E-02 1.500E-02 2.000E-02 3.000E-02 4.000E-02 5.000E-02
c      6.000E-02 8.000E-02 1.000E-01 1.500E-01 2.000E-01 3.000E-01
c      4.000E-01 5.000E-01 6.000E-01 8.000E-01 1.000E+00 1.500E+00
c      2.000E+00 3.000E+00 4.000E+00 5.000E+00 6.000E+00 8.000E+00
c       1.000E+01
c df24   7.690E-14 8.460E-13 1.010E-12 7.850E-13 6.140E-13 5.260E-13
c      5.040E-13 5.320E-13 6.110E-13 8.900E-13 1.180E-12 1.810E-12
c      2.380E-12 2.890E-12 3.380E-12 4.290E-12 5.110E-12 6.920E-12
c      8.480E-12 1.110E-11 1.330E-11 1.540E-11 1.740E-11 2.120E-11
c       2.520E-11
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     CONCRETE: ANSI/ANS-6.4.3;   density = 2.32 g/cm^3
c               Composition by mass fraction
c    ************************************************************
m2     1001.50c  -.0056
       8016.60c  -.4983
      11023      -.0171
      12000      -.0024
      13027.50c  -.0456
      14000.50c  -.3158
      16000      -.0012
      19000.50c  -.0192
      20000.50c  -.0826
      26000.50c  -.0122
c
c    **************************************************************
```

```
c     SOIL: [Jacob, Radn. Prot. Dos. 14, 299, 1986]
c           density = 1.625 g/cm^3;  Composition by mass fraction
c    *************************************************************
m3      1001.50c  -.021
        6012.50c  -.016
       19000.50c  -.013
       26000.50c  -.011
       20000.50c  -.041
       13027.50c  -.050
       14000.50c  -.271
        8016.60c  -.577
c
c    *************************************************************
c     Fuel-Basket TN-68 Cask  (Table 5.3-1)
c          Density = 3.231 g/cm^3;  Composition by atom fraction
c    *************************************************************
m4     92238.50c  0.14291
       92235.50c  0.00494
       40000.60c  0.09981
       28000.50c  0.02423
       26000.50c  0.18629
       25055.50c  0.00545
       24000.50c  0.05470
       13027.50c  0.18597
        8016.60c  0.29570
c
c    ************************************************************
c     Top Fitting TN-68 Cask (Table 5.3-1)
c          Density = 0.491 g/cm^3;  Composition by atom fraction
c    ************************************************************
m5     26000.50c  0.50712
       28000.50c  0.06595
       25055.50c  0.01483
       24000.50c  0.14890
       40000.60c  0.26320
c
c    ************************************************************
c     Plenum/Basket TN-68 (Table 5.3-1)
c         Density = 1.158 g/cm^3;   Composition by atom fraction
c    ************************************************************
m6     26000.50c  0.34907
       28000.50c  0.04535
       40000.60c  0.17975
       25055.50c  0.01021
       24000.50c  0.10246
       13027.50c  0.31316
c
c    ************************************************************
c     Bottom/Basket TN-68 (Table 5.3-1)
c         Density = 1.918 g/cm^3;  Composition by atom fraction
c    ************************************************************
m7     26000.50c  0.48631
       28000.50c  0.06329
       25055.50c  0.01423
       24000.50c  0.14285
       13027.50c  0.23378
       40000.60c  0.05954
```

```
c
c    *************************************************************
c     Basket Periphery (SS304) TN-68 (Table 5.3-1)
c          Density = 7.92 g/cm^3;   Composition by atom fraction
c    *************************************************************
m8    26000.50c  0.68826
      25055.50c  0.02013
      24000.50c  0.20209
      28000.50c  0.08952
c
c    *************************************************************
c     Carbon Steel TN-68 (Table 5.3-1)
c          Density = 7.8212 g/cm^3;  Composition by atom fraction
c    *************************************************************
m9    26000.50c  0.95510
       6000.60c  0.04490
c
c    *************************************************************
c      Outer Basket/Rails TN-68 (Table 5.3-1)
c          Density = 2.702 g/cm^3;   Composition by atom fraction
c    *************************************************************
m10   13027.50c  1.00000
c
c    ************************************************************
c     Polypropylene Disk TN-68 (Table 5.3-1)
c        Density = 0.90 g/cm^3;   Composition by atom fraction
c    ************************************************************
m11    6012.50c .33480
       1001.50c .66520
c
c    ************************************************************
c     Resin/Aluminum Composite for TN-68 (Table 5.3-1)
c         Density = 1.687 g/cm^3;   Composition by atom fraction
c    ************************************************************
m12   13027.50c  0.10331
       6012.50c  0.24658
       8016.60c  0.21985
       1001.50c  0.42207
       5010.60c  0.00164
       5011.60c  0.00655
c
c    ************************************************************
c     Berm (Silica + water) for ISFSI Site (SAR Page 7a-5);
c         density = 1.400 g/cm^3;  Composition by atom fraction
c    ************************************************************
m13    14000.50c   0.26524
        8016.60c   0.59855
        1001.50c   0.13621
c
c    ************************************************************
c     Redwood for Impact Limiter  (Standard Composition SCALE4.4)
c         density = 0.387 g/cm^3;  Composition by atom fraction
c    ************************************************************
m14     6012.50c   0.2857
        8016.60c   0.2381
        1001.50c   0.4762
c
```

```
c    ************************************************************
c     Balsa for Impact Limiter  (Standard Composition SCALE4.4)
c         density = 0.125 g/cm^3;  Composition by atom fraction
c    ************************************************************
m15      6012.50c   0.2857
         8016.60c   0.2381
         1001.50c   0.4762
c
c  prdmp 2j 1
c  print
□
```

5.6.3 MCNP Primary Gamma Input File (Preferential Loading)

```
TransNuclear TN-68 cask: Near-field gamma doses.Source: outer fuel zone.
c    Air replaced by void. Surface F2 detectors used for doses outside cask.
c    Cask's iron shell decomposed into 10 sublayers and importances are used
c    to sweep photons through the cask sublayers. TRANSPORT CONFIGURATION
c   Medium Burnup Fuel 24 on the periphery
c ***********************  BLOCK 1: CELL CARDS ************************
c GEOMETRY (r-z)*includes 1" ancillary shield ring between resin & top
limiter
c
c  ^ z-axis
c  .
c  | ------------------  |  tally surfaces @
c  .___________________. |     contact,
c  |    impact limiter | |     rail car surface,
c  ._____________.     | |     2m from rail car
c  |-------------+--+  | |
c  .-------------+  |  | |
c  |.............|  |__| |
c  .  BASKETS    |  |+   |
c  |.............|  ||   |            VOID
c  .             |  ||   |
c  |             |  ||   |
c  .   FUEL      |  ||   |
c  O ------------|--||------------------------------> y-axis
c  |  (12 sub    |  ||   |
c  .   regions)  |  ||   |
c  |             |  ||   |
c  .             |  ||
c  |.............|  ||
c  .  BASKET     |  |__.
c  |-------------+  |  |
c  .=---------------+  |
c  |   impact limiter  |
c  .___________________|
c  |
c                                                   M. Mason (2/00)
c
c ****** Cask cells
c decomposed case bottom into 10 sublayers
 110 9   -7.8212  1 -110 -29          imp:n,p=1024 $ Fe cask bot-sublayer 1
 111 9   -7.8212  110 -109 -209       imp:n,p=512  $ Fe cask bot-sublayer 2
 112 9   -7.8212  109 -108 -208       imp:n,p=256  $ Fe cask bot-sublayer 3
 113 9   -7.8212  108 -107 -207       imp:n,p=128  $ Fe cask bot-sublayer 4
 114 9   -7.8212  107 -106 -206       imp:n,p=64   $ Fe cask bot-sublayer 5
 115 9   -7.8212  106 -105 -205       imp:n,p=32   $ Fe cask bot-sublayer 6
 116 9   -7.8212  105 -104 -204       imp:n,p=16   $ Fe cask bot-sublayer 7
 117 9   -7.8212  104 -103 -203       imp:n,p=8    $ Fe cask bot-sublayer 8
 118 9   -7.8212  103 -102 -202       imp:n,p=4    $ Fe cask bot-sublayer 9
 119 9   -7.8212  102 -2   -201       imp:n,p=2    $ Fe cask bot-sublayer 10
c decompose cask side into 10 sublayers
 201 9   -7.8212  102 -122 201 -202   imp:n,p=2    $ Fe cask side-sublayer 1
 202 9   -7.8212  103 -123 202 -203   imp:n,p=4    $ Fe cask side-sublayer 2
 203 9   -7.8212  104 -124 203 -204   imp:n,p=8    $ Fe cask side-sublayer 3
 204 9   -7.8212  105 -13  204 -205   imp:n,p=16   $ Fe cask side-sublayer 4
```

```
 205 9   -7.8212  106 -126 205 -206   imp:n,p=32   $ Fe cask side-sublayer 5
 206 9   -7.8212  107 -18  206 -207   imp:n,p=64   $ Fe cask side-sublayer 6
 207 9.  -7.8212  108 -128 207 -208   imp:n,p=128  $ Fe cask side-sublayer 7
 208 9   -7.8212  109 -129 208 -209   imp:n,p=256  $ Fe cask side-sublayer 8
 209 9   -7.8212  110 -14  209  -29   imp:n,p=512  $ Fe cask side-sublayer 9
 210 9   -7.8212  1    -18  29   -21   imp:n,p=1024 $ Fe cask side-sublayer 10
 211 9   -7.8212  -32 21 10 -160 #407 #408  imp:n,p=1024  $ ancil shield ring
c decompose cask lid into 9 sublayers
 301 9   -7.8212  12 -122 -201          imp:n,p=4    $ Fe cask lid-sublayer 1
 302 9   -7.8212 122 -123 -202          imp:n,p=8    $ Fe cask lid-sublayer 2
 303 9   -7.8212 123 -124 -203          imp:n,p=16   $ Fe cask lid-sublayer 3
 304 9   -7.8212 124  -13 -204          imp:n,p=32   $ Fe cask lid-sublayer 4
 305 9   -7.8212  13 -126 -205          imp:n,p=64   $ Fe cask lid-sublayer 5
 306 9   -7.8212 126  -18 -206          imp:n,p=128  $ Fe cask lid-sublayer 6
 307 9   -7.8212  18 -128 -207          imp:n,p=256  $ Fe cask lid-sublayer 7
 308 9   -7.8212 128 -129 -208          imp:n,p=512  $ Fe cask lid-sublayer 8
 309 9   -7.8212 129  -14 -209          imp:n,p=1024 $ Fe cask lid-sublayer 9
c  trunnions
 400 0     195 300 -23 304 -10 #409 #411     imp:n,p=1024 $ resin cutout at
top trunnion
 402 0   -195 -301 -23 304 -10 #410 #412   imp:n,p=1024 $ resin cutout at top
trunnion
 403 9   -7.8212 195 305 -300 -22 304 -9
          #407  #411                       imp:n,p=1024 $ trunnion flat fe
plate
 404 9   -7.8212 -195 -306 301 -22 304 -9
          #408  #412                       imp:n,p=1024 $ trunnion flat fe
plate
 405 9   -7.8212 195 305 -22 303 -304      imp:n,p=1024  $ flat plate under
top trunnion
 406 9   -7.8212 -195 -306 -22 303 -304    imp:n,p=1024  $ flat plate under
top trunnion
 407 9   -7.8212 307 -300 -330 #210 #411 imp:n,p=1024  $ top trunnion base
 408 9   -7.8212 -308 301 -330 #210 #412 imp:n,p=1024  $ top trunnion base
 409 9   -7.8212 300 -309 -331 #411  imp:n,p=1024  $ top trunnion load
surface
 410 9   -7.8212 -301 310 -331 #412  imp:n,p=1024  $ top trunnion load
surface
 411 12  -1.687  311 -309 -332       imp:n,p=1024  $ top trunnion resin plug
 412 12  -1.687 -312  310 -332       imp:n,p=1024  $ top trunnion resin plug
 420 0     195  320 -23 -323 3 #429 #431     imp:n,p=1024 $ resin cutout at
bottom trunnion
 422 0   -195 -321 -23 -323 3 #430 #432     imp:n,p=1024 $ resin cutout at
bottom trunnion
 423 9   -7.8212 195 324 -320 -22 -323 4 #431
                                        imp:n,p=1024 $ bottom trunnion flat
fe plate
 424 9   -7.8212 -195 -325 321 -22 -323 4 #432
                                        imp:n,p=1024 $ bottom trunnion flat
fe plate
 425 9   -7.8212 195 324 -22 -322 323      imp:n,p=1024  $ flat plate under
bot trunnion
 426 9   -7.8212 -195 -325 -22 -322 323    imp:n,p=1024  $ flat plate under
bot trunnion
 427 9   -7.8212  326 -324 -333 #210       imp:n,p=1024  $ bottom trunnion
base
```

```
 428 9   -7.8212 -327  325 -333 #210       imp:n,p=1024  $ bottom trunnion
base
 429 9   -7.8212  320 -328 -334 #431       imp:n,p=1024  $ bottom trunnion
load surface
 430 9   -7.8212 -321  329 -334 #432       imp:n,p=1024  $ bottom trunnion
load surface
 431 12  -1.687  311 -328 -335             imp:n,p=1024  $ bottom trunnion
resin plug
 432 12  -1.687 -312  329 -335             imp:n,p=1024  $ bottom trunnion
resin plug
c other cask cells
  3  7   -1.918   2 -5 -31            imp:n,p=1    $ bottom basket
503  7  -1.918    2 -5 31 -26         imp:n,p=1    $ bottom
fitting/basket(outer)
  4  6   -1.158   7 -8 -31            imp:n,p=2    $ top plenum basket
504  6  -1.158    7 -8 31 -26         imp:n,p=2    $ top plenum basket(outer)
  5  5   -0.491   8 -11 -31           imp:n,p=2    $ top fitting
  505  5  -0.491    8 -11 31 -26        imp:n,p=2    $ top fitting(outer)
  6  8   -7.92    26 -27 2 -28        imp:n,p=2    $ ss side basket
  7  10  -2.702   27 -201 2 -28       imp:n,p=2    $ Al side basket/rails
  8  0            11 -12 -26          imp:n,p=2    $ top void - part1
  9  0   (28 -12 26 -24):(19 -12 24 -201) imp:n,p=2    $ top void - part2
 10  9   -7.8212  (28 -19 24 -201)(#13 #14 #15 #16) imp:n,p=2    $ hold down
ring
 13  0   195 -25 -191 192 24 -19 28   imp:n,p=2    $ cutout in hold down ring
 14  0  -195 -25 -191 192 24 -19 28   imp:n,p=2    $ cutout in hold down ring
 15  0   196 -25  193 -194 24 -19 28  imp:n,p=2    $ cutout in hold down ring
 16  0  -196 -25  193 -194 24 -19 28  imp:n,p=2    $ cutout in hold down ring
c 13  11  -0.90    14 -15 -25          imp:n,p=1024 $ polyprop top shield
c 14  0            15 -16 -25          imp:n,p=1024 $ void under top cover -
pt1
c 15  0            14 -16 25 -29       imp:n,p=1024 $ void under top cover -
pt2
c 16  9   -7.8212  16 -17 -30          imp:n,p=1024 $ top Fe cover - top
c 17  9   -7.8212  14 -16 29 -30       imp:n,p=1024 $ top Fe cover - side
 19  9   -7.8212  21 -23 9 -10 #400 #402 #407 #408 #409 #410
          #411 #412                    imp:n,p=1024 $ top side-shld Fe shell
 20  9   -7.8212  22 -23 4 -9 #400 #402 #409 #410 #411 #412
          #420 #422 #429 #430 #431 #432   imp:n,p=1024 $ side side-shld Fe
shell
 21  9   -7.8212  21 -23 3 -4 #420 #422   imp:n,p=1024 $ bot side-shld Fe
shell
 22  12  -1.687   21 -22 4 -9 #400 #402 #403 #404 #405 #406 #407 #408
          #409 #410 #411 #412 #420 #422 #423 #424 #425 #426 #427 #428
          #429 #430 #431 #432         imp:n,p=1024 $ side resin/Al shield
 23  0           150 -3 21 -23        imp:n,p=1024 $ void under side shld
 24  0    32 -23 10 -160 #407 #408 #409 #410 #411 #412
              imp:n,p=1024 $ void above side shld - pt1
c 25  0            30 -23 18 -17       imp:n,p=1024 $ void above side shld -
pt2
c **** impact limiters  *****
c  bottom limiter
 80 9  -7.8212  (-1 155 -253):(1 -151 -253 21) imp:n,p=1024 $ inside skin
 81 9  -7.8212  (153 -152 -250):(152 -151 -250 251) imp:n,p=2048 $ outside
skin
 82 9  -7.8212     151 -150 -250 21      imp:n,p=2048 $ outside skin
 83 14 -0.387      155 -151 -251 253     imp:n,p=2048 $ redwood
```

```
 84 14 -0.387      154 -155 -251 252     imp:n,p=2048 $ redwood
 85 14 -0.387      154 -155 -252         imp:n,p=2048 $ redwood
 86 14 -0.387      152 -154 -251 252     imp:n,p=2048 $ redwood
 87 15 -0.125      152 -154 -252         imp:n,p=2048 $ balsa
c  top limiter
 90 9  -7.8212  (166 -165 -253):(161 -166 -253 21) imp:n,p=1024 $ inside skin
 91 9  -7.8212  (162 -163 -250):(161 -162 -250 251) imp:n,p=2048 $ outside
skin
 92 9  -7.8212     160 -161 -250 21      imp:n,p=2048 $ outside skin
 93 14 -0.387      161 -165 -251 253     imp:n,p=2048 $ redwood
 94 14 -0.387      165 -164 -251 252     imp:n,p=2048 $ redwood
 95 14 -0.387      165 -164 -252         imp:n,p=2048 $ redwood
 96 14 -0.387      164 -162 -251 252     imp:n,p=2048 $ redwood
 97 15 -0.125      164 -162 -252         imp:n,p=2048 $ balsa
 98 10 -2.702   (14 -166 -21):(18 -14 29 -21)  imp:n,p=1024 $ al spacer
c **** fuel regions (inner)
 40 4   -3.231   5   -39 -31          imp:n,p=1  $ FUEL region 1 (bottom)
 401 4  -3.231   39 -40 -31           imp:n,p=1  $ FUEL region 2
 41 4   -3.231   40 -41 -31           imp:n,p=1  $ FUEL region 3
 42 4   -3.231   41 -42 -31           imp:n,p=1  $ FUEL region 4
 43 4   -3.231   42 -43 -31           imp:n,p=1  $ FUEL region 5
 44 4   -3.231   43 -44 -31           imp:n,p=1  $ FUEL region 6
 45 4   -3.231   44 -45 -31           imp:n,p=1  $ FUEL region 7
 46 4   -3.231   45 -46 -31           imp:n,p=1  $ FUEL region 8
 47 4   -3.231   46 -47 -31           imp:n,p=1  $ FUEL region 9
 48 4   -3.231   47 -48 -31           imp:n,p=1  $ FUEL region 10
 481 4  -3.231   48 -49 -31           imp:n,p=1  $ FUEL region 11
 49 4   -3.231   49 -7  -31           imp:n,p=1  $ FUEL region 12 (top)
c **** fuel regions (outer)
540 4   -3.231   5   -39 31 -26       imp:n,p=2  $ FUEL region 1 (bottom)
5401 4  -3.231   39 -40 31 -26        imp:n,p=2  $ FUEL region 2
541 4   -3.231   40 -41 31 -26        imp:n,p=2  $ FUEL region 3
542 4   -3.231   41 -42 31 -26        imp:n,p=2  $ FUEL region 4
543 4   -3.231   42 -43 31 -26        imp:n,p=2  $ FUEL region 5
544 4   -3.231   43 -44 31 -26        imp:n,p=2  $ FUEL region 6
545 4   -3.231   44 -45 31 -26        imp:n,p=2  $ FUEL region 7
546 4   -3.231   45 -46 31 -26        imp:n,p=2  $ FUEL region 8
547 4   -3.231   46 -47 31 -26        imp:n,p=2  $ FUEL region 9
548 4   -3.231   47 -48 31 -26        imp:n,p=2  $ FUEL region 10
5481 4  -3.231   48 -49 31 -26        imp:n,p=2  $ FUEL region 11
549 4   -3.231   49 -7  31 -26        imp:n,p=2  $ FUEL region 12 (top)
c ***** outside cells above/below cask
 140 0            170 -60 -172        imp:n,p=0    $ air beneath cask pt 2
 142 0           -153  60 -250        imp:n,p=2048  $ air beneath cask pt 1
 145 0            163 -61  -250       imp:n,p=2048 $ air above cask-pt1
 146 0            61 -171 -172        imp:n,p=0    $ air above cask-pt2
c ***** Cells outside radial cask surface
c 600 2   -2.32    150 -1  23 -60     imp:n,p=1024 $ concrete inner air
 601 0            150 -160  23 -62    imp:n,p=1024 $ inner air (void)
 602 0            150 -160  62 -63    imp:n,p=1024 $ inner air (void)
 603 0   (60 -61 250 -64):(150 -160 63 -250) imp:n,p=2048 $ inner air (void)
c 604 2   -2.32    150 -1  60 -152    imp:n,p=1024 $ concrete outer air
  605 0             60 -61 -172 64    imp:n,p=0    $ outer air (void)
c 606 0            17 -61  60 -152    imp:n,p=1024 $ outer air (void)
c 607 0            61 -151 60 -152    imp:n,p=1024 $ 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  -226.42       $ cask bottom - ground surface
  110 pz  -223.94       $ cask bottom - top of sublayer 10
  109 pz  -221.47       $ cask bottom - top of sublayer 9
  108 pz  -219.99       $ cask bottom - top of sublayer 8
  107 pz  -216.51       $ cask bottom - top of sublayer 7
  106 pz  -214.04       $ cask bottom - top of sublayer 6
  105 pz  -211.56       $ cask bottom - top of sublayer 5
  104 pz  -209.08       $ cask bottom - top of sublayer 4
  103 pz  -206.60       $ cask bottom - top of sublayer 3
  102 pz  -204.13       $ cask bottom - top of sublayer 2
  2   pz  -201.65       $ cask bottom - top of bot Fe plate
  3   pz  -192.76       $ side Fe jacket - outside lower bottom
  4   pz  -190.86       $ side Fe jacket - inside lower bottom
  5   pz  -182.88       $ top bottom basket/bottom of fuel
  7   pz   182.88       $ bottom of plenum basket/top of fuel
  8   pz   224.72       $ top of plenum basket
  9   pz   211.74       $ side Fe jacket - inside top
  10  pz   213.64       $ side Fe jacket - outside top
  11  pz   245.90       $ top of top fitting
  12  pz   250.47       $ cask top - bot of lid
  122 pz   253.33       $ cask top - top of sublayer 1
  123 pz   256.19       $ cask top - top of sublayer 2
  124 pz   259.04       $ cask top - top of sublayer 3
  126 pz   264.44       $ cask top - top of sublayer 6
  128 pz   269.52       $ cask top - top of sublayer 8
  129 pz   272.06       $ cask top - top of sublayer 9
  14  pz   274.60       $ cask top - top of lid
  13  pz   261.90       $ cask side - top of Fe side
c  15  pz   284.76       $ top of polyprop on top of cask
c  16  pz   318.74       $ top Fe cover - bot surface
c  17  pz   319.38       $ top Fe cover - top surface
  18  pz   266.35       $ flange top
  19  pz   248.56       $ top hold down ring
  191 py    18.42       $ half height of hold down ring cutout
  192 py   -18.42       $ half height of hold down ring cutout
  193 px   -18.42       $ half height of hold down ring cutout
  194 px    18.42       $ half height of hold down ring cutout
  195 px     0.0        $ ambiguity surface
  196 py     0.0        $ ambiguity surface
  28  pz   214.91       $ bottom hold down ring
 150  pz  -194.04       $ top of bottom limiter
 151  pz  -194.68       $ inside skin bottom limiter
 152  pz  -314.68       $ inside skin bottom limiter
 153  pz  -315.32       $ bottom of bottom limiter
 154  pz  -275.94       $ top of balsa disk bottom limiter
 155  pz  -227.06       $ top of inside skin bottom limiter
 160  pz   246.03       $ bottom of top limiter
 161  pz   246.67       $ inside skin top limiter
 162  pz   366.67       $ inside skin  top limiter
 163  pz   367.31       $ top of top limiter
 164  pz   327.93       $ bottom of balsa disc top limiter
 165  pz   279.05       $ top of inside skin top limiter
 166  pz   278.41       $ top of Al spacer top limiter
 300  px   116.28       $ OD of top trunnion base (flat)
 301  px  -116.28       $ OD of top trunnion base (flat)
```

```
 302  py    44.37       $ half width of trunnion flat
 303  pz   171.09       $ bottom of plate under top trunnion
 304  pz   173.00       $ top of resin recess under top trunnion
 305  px   114.38       $ ID of flat plate at top trunnion
 306  px  -114.38       $ ID of flat plate at top trunnion
 307  px   102.44       $ top trunnion socket
 308  px  -102.44       $ top trunnion socket
 309  px   123.85       $ top trunnion OD ( to match body OD)
 310  px  -123.85       $ top trunnion OD ( to match body OD)
 311  px   115.34       $ ID of top trunnion resin plug
 312  px  -115.34       $ ID of top trunnion resin plug
 320  px   117.01       $ OD of bottom trunnion base (flat)
 321  px  -117.01       $ OD of bottomtrunnion base (flat)
 322  pz  -111.72       $ top of plate over bottom trunnion
 323  pz  -113.62       $ bottom of resin recess over bottom trunnion
 324  px   115.10       $ ID of flat plate at bottom trunnion
 325  px  -115.10       $ ID of flat plate at bottom trunnion
 326  px   104.34       $ bottom trunnion socket
 327  px  -104.34       $ bottom trunnion socket
 328  px   123.19       $ bottom trunnion OD (to match body OD)
 329  px  -123.19       $ bottom trunnion OD
c ***** cylindrical cask surfaces
  201 cz    88.27       $ cask wall - inner surface
  202 cz    89.84       $ cask wall - inner surface of sublayer 1
  203 cz    91.41       $ cask wall - inner surface of sublayer 2
  204 cz    92.98       $ cask wall - inner surface of sublayer 3
  205 cz    94.55       $ cask wall - inner surface of sublayer 4
  206 cz    96.12       $ cask wall - inner surface of sublayer 5
  207 cz    97.69       $ cask wall - inner surface of sublayer 6
  208 cz    99.26       $ cask wall - inner surface of sublayer 7
  209 cz   100.83       $ cask wall - inner surface of sublayer 8
  21  cz   107.32       $ cask outer surface
  22  cz   122.56       $ side Fe jacket -- inside
  23  cz   124.47       $ side Fe jacket -- outside
  24  cz    85.73       $ inside radius of hold down ring
  25  cz    87.15       $ inside radius of cutouts in ring
c  25  cz    89.22       $ top polyprop disk radius
  26  cz    83.92       $ inside radius ss basket
  27  cz    84.40       $ inside radius Al backet/rails
  29  cz   101.45       $ radius top lid
c  30  cz   102.40       $ outside radius top cover
  31  cz    70.40       $ inner fuel zone
  32  cz   109.86       $ ancillary shield ring (1")
  250 cz   182.88       $ outside radius of impact limiter
  251 cz   182.24       $ inside radius of impact limiter
  252 cz    86.36       $ radius of balsa disk
  253 cz   107.96       $ outside radius inside skin
  330 c/x   0 213.64 21.59        $ top trunnion base
  331 c/x   0 213.64 12.38        $ top trunnion load surface
  332 c/x   0 213.64 9.65         $ top trunnion resin plug
  333 c/x   0 -156.8 21.59        $ bottom trunnion base
  334 c/x   0 -156.8 17.78        $ bottom trunnion load surface
  335 c/x   0 -156.8 9.84         $ bottom trunnion resin plug
c ***** surfaces for fuel regions
  39  pz  -164.59       $ top of fuel region 39
  40  pz  -146.30       $ top of fuel region 40
  41  pz  -109.73       $ top of fuel region 41
```

```
  42  pz  -73.15        $ top of fuel region 42
  43  pz  -36.53        $ top of fuel region 43
  44  pz  -0.0          $ top of fuel region 44
  45  pz   36.53        $ top of fuel region 45
  46  pz   73.15        $ top of fuel region 46
  47  pz   109.73       $ top of fuel region 47
  48  pz   146.30       $ top of fuel region 48
  49  pz   164.59       $ top of fuel region 49
c ***** problem boundaries
 170  pz  -500.E2       $ bottom of air (problem boundary)
 171  pz   500.E2       $ top of air (problem boundary)
 172  cz   500.E2       $ radial air limit (problem boundary)
c ****** surfaces for detector segmentation
  60  pz  -318.0        $ bottom tally surface
  61  pz   370.0        $ top tally surface
  62  cz   125.0        $ radial tally surface  (outer shell)
  63  cz   152.0        $ radial tally surface   (rail car edge)
  64  cz   352.0        $ radial tally surface   (2 m from rail car)
  71  pz  -190.0        $ segmentation plane
  72  pz   200.0        $ segmentation plane
  81  cz    25.00       $ segmentation cylinder
  82  cz    50.00       $ segmentation cylinder
  83  cz    75.00       $ segmentation cylinder

c ***********************  BLOCK 3: DATA CARDS ***************************
c
c  -- gamma source for medium burnup fuel in TN68 -12 axial cylindrical zones
(outer ring)
c  ***  21,500 MWD/MTU 26 year cooled assume same burnup profile as design
basis fuel **
SDEF  par=2 pos= 0 0 0  axs=0 0 1  rad=d1  ext=d2   erg d6  cel=d7
SI1  70.40   83.92          $ range of radius sampling: Rin to Rout
SP1  -21 1              $ radial distriubtion: here r^1
SI2 -182.88 182.88      $ range of axial sampling
SP2  -21  0             $ axial distribution: here z^0
SI6  H   0.05 0.1 0.2 0.3 0.4 0.6 0.8 1.0 1.33 1.66       $ energy bins -
fuel
SP6      0.0  .12501  .07867  .02417  .01648  .01257      $ bin probs.  -
fuel
             .72394  .006675  .01127  .001203
SI7 L 540 5401 541 542 543 544 545 546 547 548 5481 549         $ fuel
zones
SP7   0.01178 0.03873 0.10750 0.11836 0.12 0.12      $ prob. emission per
fuel zone
      0.11912 0.11515 0.10766 0.08973 0.03165 0.01205
SB7   0.05 0.05 0.05 0.5 0.1 0.1 0.1 0.1 0.1 0.15 0.15 0.20   $ bias top
zonesc
c
c
c ---- Detector types and locations  (F2 segmented surface detectors)
c -- doses on cask's radial surface
c FM2   2.722E24       $ convert Sv/photon to mrem/h for fuel zones
c      3.177E14 x 24 X 0.9917 (NF) x 3600 X 1E5 = 2.722E24
FC2  Doses on outer shell averaged over subsurfaces
F2:p  62
FS2   -71 -39 -40 -41 -42 -43 -44 -45 -46 -47 -48 -49 -72 -8 -11
SD2  3.0E7 19956.97 14364.93 28722.01 28729.86 28761.28
```

```
       28690.59 28690.59 28761.28 28729.86 28722.01
        14364.93 27810.95 19415.04 16634.73 3.0E7
FC12   Doses at the rail car edge averaged over subsurfaces
F12:p  63
FS12  -71 -39 -40 -41 -42 -43 -44 -45 -46 -47 -48 -49 -72 -8 -11
SD12  3.0E7 24267.67 17467.76 34925.96 34935.52 34973.72
         34887.76 34887.76 34973.72 34935.72 34925.96
        17467.76 33818.11 23608.69 20227.84 3.0E7
FC22     Doses at 2 meters from rail car averaged over subsurfaces
F22:p    64
FS22  -152 -154 -155 -71 -39 -40 -41 -42 -43 -44 -45 -46 -47
        -48 -49 -72 -8 -11 -165 -164 -162
SD22    1.0E8 85680.53 108106.98 81964.90 56198.82 40451.65 80881.18
          80903.30 80991.77 80792.71 80792.71 80991.77 80903.30
          80881.18 40451.65 78315.63 54672.76 46843.41
          73317.23 108106.98 85680.53 8.0E7
c
c -- doses along cask's top
 FC32 Doses at top limiter surface averaged over subsurfaces
 f32:p   61          $ surface tally
 fs32   -81 -82 -83 -29 -23 -63 -250 -64
 sd32   1963.50 5890.49 9817.48 14662.13 16338.41 23911.35
          32487.51 284185.03 7.8E7
c
c -- doses along cask's bottom
 FC42 Doses at bottom limiter surface averaged over subsurfaces
 f42:p   60          $ surface tally
 fs42   -81 -82 -83 -29 -23 -63 -250 -64
 sd42   1963.50 5890.49 9817.48 14662.13 16338.41 23911.35
        32487.51 284185.03 7.8E7
c
c
mode p
PHYS:p 10 1 1    $ -- no bremsstrahlung, no coherent scattering
nps  200000000
c  void
c
c ----------------------------------------------------------------
c  ambient photon dose equiv. H*(10mm) Sv (from T-D1 of S&F)
c ----------------------------------------------------------------
de0     1.000E-02 1.500E-02 2.000E-02 3.000E-02 4.000E-02 5.000E-02
        6.000E-02 8.000E-02 1.000E-01 1.500E-01 2.000E-01 3.000E-01
        4.000E-01 5.000E-01 6.000E-01 8.000E-01 1.000E+00 1.500E+00
        2.000E+00 3.000E+00 4.000E+00 5.000E+00 6.000E+00 8.000E+00
        1.000E+01
df0     7.690E-14 8.460E-13 1.010E-12 7.850E-13 6.140E-13 5.260E-13
        5.040E-13 5.320E-13 6.110E-13 8.900E-13 1.180E-12 1.810E-12
        2.380E-12 2.890E-12 3.380E-12 4.290E-12 5.110E-12 6.920E-12
        8.480E-12 1.110E-11 1.330E-11 1.540E-11 1.740E-11 2.120E-11
        2.520E-11
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      -.75519
      8016      -.23179
      6000      -.00014
     18000      -.01288
c
c    ************************************************************
c     CONCRETE: ANSI/ANS-6.4.3;    density = 2.32 g/cm^3
c               Composition by mass fraction
c    ************************************************************
m2     1001      -.0056
       8016      -.4983
      11023      -.0171
      12000      -.0024
      13027      -.0456
      14000      -.3158
      16000      -.0012
      19000      -.0192
      20000      -.0826
      26000      -.0122
c
c    **************************************************************
c     SOIL: [Jacob, Radn. Prot. Dos. 14, 299, 1986]
c           density = 1.625 g/cm^3;  Composition by mass fraction
c    **************************************************************
m3     1001  -.021
       6012  -.016
      19000  -.013
      26000  -.011
      20000  -.041
      13027  -.050
      14000  -.271
       8016  -.577
c
c    **************************************************************
c     Fuel-Basket TN-68 Cask  (Table 5.3-1)
c          Density = 3.231 g/cm^3;  Composition by atom fraction
c    **************************************************************
m4    92238  0.14291
      92235  0.00494
      40000  0.09981
      28000  0.02423
      26000  0.18629
      25055  0.00545
      24000  0.05470
      13027  0.18597
       8016  0.29570
c
c    *************************************************************
c     Top Fitting TN-68 Cask (Table 5.3-1)
c          Density = 0.491 g/cm^3;  Composition by atom fraction
c    *************************************************************
m5    26000  0.50712
      28000  0.06595
      25055  0.01483
      24000  0.14890
      40000  0.26320
c
```

```
c     ***************************************************************
c      Plenum/Basket TN-68 (Table 5.3-1)
c          Density = 1.158 g/cm^3;   Composition by atom fraction
c     ***************************************************************
m6     26000  0.34907
       28000  0.04535
       40000  0.17975
       25055  0.01021
       24000  0.10246
       13027  0.31316
c
c     ***************************************************************
c      Bottom/Basket TN-68 (Table 5.3-1)
c          Density = 1.918 g/cm^3;  Composition by atom fraction
c     ***************************************************************
m7     26000  0.48631
       28000  0.06329
       25055  0.01423
       24000  0.14285
       13027  0.23378
       40000  0.05954
c
c     ***************************************************************
c      Basket Periphery (SS304) TN-68 (Table 5.3-1)
c           Density = 7.92 g/cm^3;   Composition by atom fraction
c     ***************************************************************
m8     26000  0.68826
       25055  0.02013
       24000  0.20209
       28000  0.08952
c
c     ***************************************************************
c      Carbon Steel TN-68 (Table 5.3-1)
c           Density = 7.8212 g/cm^3;  Composition by atom fraction
c     ***************************************************************
m9     26000  0.95510
        6000  0.04490
c
c     ***************************************************************
c       Outer Basket/Rails TN-68 (Table 5.3-1)
c           Density = 2.702 g/cm^3;   Composition by atom fraction
c     ***************************************************************
m10    13027  1.00000
c
c     ***************************************************************
c      Polypropylene Disk TN-68 (Table 5.3-1)
c         Density = 0.90 g/cm^3;   Composition by atom fraction
c     ***************************************************************
m11     6012 .33480
        1001 .66520
c
c     ***************************************************************
c      Resin/Aluminum Composite for TN-68 (Table 5.3-1)
c          Density = 1.687 g/cm^3;   Composition by atom fraction
c     ***************************************************************
m12    13027  0.10331
        6012  0.24658
```

```
       8016  0.21985
       1001  0.42207
       5010  0.00164
       5011  0.00655
c
c    **************************************************************
c     Berm (Silica + water) for ISFSI Site (SAR Page 7a-5);
c         density = 1.400 g/cm^3;  Composition by atom fraction
c    **************************************************************
m13    14000   0.26524
        8016   0.59855
        1001   0.13621
c
c    **************************************************************
c     Redwood for Impact Limiter  (Standard Composition SCALE4.4)
c         density = 0.387 g/cm^3;  Composition by atom fraction
c    **************************************************************
m14     6012   0.2857
        8016   0.2381
        1001   0.4762
c
c    **************************************************************
c     Balsa for Impact Limiter  (Standard Composition SCALE4.4)
c         density = 0.125 g/cm^3;  Composition by atom fraction
c    **************************************************************
m15     6012   0.2857
        8016   0.2381
        1001   0.4762
c
c  prdmp 2j 1
c  print
□
```

TABLE 5.1-1

TN-68 CASK SHIELD MATERIALS

Component	Material	Density (g/cm^3)	Thickness (inches)
Cask Body Wall	Carbon Steel	7.82	7.50
Lid	Carbon Steel	7.82	9.50
Bottom	Carbon Steel	7.82	9.75
Resin [a]	Polyester Resin Styrene Aluminum Hydrate Zinc Borate	1.58	6.00
Aluminum Box	Aluminum	2.7	0.12
Outer Shell	Carbon Steel	7.82	0.75
Basket [b]	Stainless Steel (Inserts)	7.92	0.19
	Stainless Steel (Strips)	7.92	0.31
	Aluminum	2.7	0.31
	Neutron Poison Material [c]		
Impact Limiter	Carbon Steel	7.82	0.25
	Redwood	0.387	19.25[d]
	Balsa Wood	0.125	15.25[d]
Basket Hold Down Ring	Carbon Steel	7.82	1.0
Ancillary Shield Ring	Carbon Steel	7.82	0.5

Notes:

[a] The neutron shielding is borated polyester resin compound with a density of 1.58 g/cc. The four major constituents are listed in the table.

[b] The stainless steel inserts of the basket are 0.19 inches thick. The remaining portion of the basket consists of 10.4-inch sections containing neutron poison material intermittent with 4-inch stainless steel sections. See Chapter 3 for the basket design.

[c] This is modeled as aluminum for shielding purposes (see Chapter 6 for details).

[d] Thickness of wood is variable.

TABLE 5.1-2

SUMMARY OF DOSE RATES
(Exclusive Use)

Normal Conditions[1]	Package Surface mSv/h (mrem/h)			Vehicle Edge mSv/h (mrem/h)			2 Meter from Vehicle mSv/h (mrem/h)		
Radiation	Top	Side	Bottom	Top	Side	Bottom	Top	Side	Bottom
Gamma	0.12 (12)	1.04 (104)	0.088 (8.8)	-	0.56(56)	-	-	0.090 (9.0)	-
Neutron	0.001 (0.1)	0.18 (18)	0.004 (0.4)	-	0.080 (8.0)	-	-	0.010 (1.0)	-
Total	0.12 (12)	1.22 (122)	0.092 (9.2)	-	0.64 (64)	-	-	0.100 (10)	-
Limit	10 (1000)	10 (1000)	10 (1000)		2 (200)			0.1 (10)	

Hypothetical Accident Conditions[2]	1 Meter from Package Surface mSv/h (mrem/h)		
Radiation	Top	Side	Bottom
Gamma	0.86 (86)	0.78 (78)	0.40 (40)
Neutron	0.12 (12)	2.47 (247)	0.35 (35)
Total	0.98 (98)	3.25 (325)	0.75 (75)
Limit	10 (1000)	10 (1000)	10 (1000)

(1) Doses from normal conditions are calculated with the optional ancillary shield ring in place.

(2) The ancillary shield ring, the neutron shield, and the impact limiters are removed

TABLE 5.2-1

BWR FUEL ASSEMBLY DESIGN CHARACTERISTICS

Transnuclear, ID	7 x 7 - 49/0	8 x 8 - 63/1	8 x 8 - 62/2	8 x 8 - 60/4	8 x 8 - 60/1	9 x 9 - 74/2	10x10- 92/2
GE Designations	GE2 GE3	GE4	GE-5 GE-Pres GE-Barrier GE8 Type I	GE8 Type II	GE9 GE10	GE11 GE13	GE12
Max Length (in)[a]	176.2	176.2	176.2	176.2	176.2	176.2	176.2
Max Width (in)[a]	5.44	5.44	5.44	5.44	5.44	5.44	5.44
Rod Pitch (in)	0.738	0.640	0.640	0.640	0.640	0.566	0.510
No of Fueled Rods	49	63	62	60	60	66 full 8 partial	78 full 14 partial
Maximum Active Fuel Length (in)	144	146	150	150	150	146" full 90" partial	150" full 93" partial
Fuel Rod OD (in)	0.563	0.493	0.483	0.483	0.483	0.440	0.404
Clad Thickness (in)	0.032	0.034	0.032	0.032	0.032	0.028	0.026
Fuel Pellet OD (in)	0.487	0.416	0.410	0.410	0.411	0.376	0.345
No of Water Rods	0	1	2	4	1	2	2
Water Rod OD (in)	---	0.493	0.591	2 @ 0.591 2 @ 0.483	1.340	0.980	0.980
Water Rod ID (in)	---	0.425	0.531	2 @ 0.531 2 @ 0.419	1.260	0.920	0.920
Maximum MTU/assembly[b]	0.1977	0.1880	0.1886	0.1825	0.1834	0.1766	0.1867
Minimum Plenum Volume (in^3)	2.066	1.595	1.273	1.273	1.291	1.184	0.995
Fill Gas	He	He	He	He	He	He	He
Maximum Initial Rod Pressurization (psig)	10	10	80	80	80	155	155

[a] Unirradiated length and width.

[b] The maximum MTU/assembly is calculated based on the theoretical density. The calculated value is higher than the actual.

TABLE 5.2-1a

BWR FUEL ASSEMBLY DESIGN CHARACTERISTICS
(continued)

Transnuclear, ID	7 x 7 - 49/0	8 x 8 - 63/1	8 x 8 - 62/2	8 x 8 - 60/4	8 x 8 - 60/1	9 x 9 - 74/2	10x10- 92/2
GE Designations	GE2 GE3	GE4	GE-5 GE-Pres GE-Barrier GE8 Type I	GE8 Type II	GE9 GE10	GE11 GE13	GE12
Max Length (in)[a]	176.2	176.2	176.2	176.2	176.2	176.2	176.2
Plenum Length (in)	16.47	14.47	10.47	10.47	10.47	14.47	10.47
Top Fitting Length (in)	8.34	8.34	8.34	8.34	8.34	8.34	8.34
Bottom Fitting Length (in)	7.39	7.39	7.39	7.39	7.39	7.39	7.39

TABLE 5.2-2

BWR FUEL ASSEMBLY HARDWARE CHARACTERISTICS

Item	Material	Average Mass (kg/assembly)
Fuel Zone		
Cladding	Zircaloy	49.2
Spacers	Zircaloy	1.95
Spacer Springs	Inconel	0.36
Fuel-Gas Plenum Zone		
Cladding	Zircaloy	4.89
Springs	Stainless Steel	1.05
Top End Fitting Zone		
Upper Tie Plate	Stainless Steel	2.08
Lock Tab Washers & Nuts	Stainless Steel	0.05
Expansion Springs	Inconel	0.43
End Plugs	Zircaloy	1.26
Bottom End Fitting Zone		
Finger Springs	Inconel	0.05
End Plugs	Zircaloy	1.26
Lower Tie Plate	Stainless Steel	4.70
Channel		
Channel Sleeve	Zircaloy	37.1
Channel Spacer & Rivet[a]	Stainless Steel	0.13
Channel Fastener[a]		
Guard	Stainless Steel	0.46
Spring & Bolt	Inconel	0.13
Total		105.1

[a] The channel spacer, rivet and fastener are located at top end fitting zone.

TABLE 5.2-3

MATERIAL COMPOSITIONS FOR FUEL ASSEMBLY HARDWARE MATERIALS

Material[a]	Element	Weight %
Zircaloy	Zirconium	98.225
	Tin	1.5
	Chromium	0.1
	Nitrogen	0.05
	Cobalt	0.001
Stainless Steel (SS304)	Iron	69.5
	Chromium	19.0
	Nickel	9.5
	Manganese	1.92
	Cobalt	0.08
Inconel	Nickel	73
	Chromium	15
	Iron	7
	Titanium	2.5
	Silicon	1.85
	Cobalt	0.649

[a] Material compositions are taken from the SCALE Standard Composition Library, however, cobalt impurities are taken from Reference 2.

TABLE 5.2-4

BWR FUEL ASSEMBLY SOURCE (with CHANNELS) BUNDLE AVERAGE ENRICHMENT 3.3 wt% U235, 40,000 MWD/MTU, 10 YEAR COOLING TIME

Total Gamma Source (γ/sec/assembly)

TN Design ID	Total
7x7-49-0	1.38E15
8x8-63-1	1.32E15
8x8-62-2	1.30E15
8x8-60-4	1.28E15
8x8-60-1	1.29E15
9x9-74-2	1.24E15
10x10-92-2	1.31E15

Total (α,n) plus Spontaneous Fission Neutron Source (n/sec/assembly)

TN Design ID	Total
7x7-49-0	8.98E07
8x8-63-1	8.21E07
8x8-62-2	7.89E07
8x8-60-4	8.06E07
8x8-60-1	8.05E07
9x9-74-2	6.92E07
10x10-92-2	7.22E07

TABLE 5.2-5
PRIMARY GAMMA SOURCE SPECTRUM
SCALE 18 GROUP STRUCTURE
GENERAL ELECTRIC 7x7, BUNDLE AVERAGE ENRICHMENT 3.3wt% U235, 40,000 MWD/MTU, AND 16 YEAR COOLING TIME WITH CHANNELS

			γ/sec/assembly		
Scale Group	Energy Interval, MeV	Active Fuel Zone	Plenum Zone[a]	Top Fitting Zone[a]	Bottom Fitting Zone[a]
28	8.00E+00 to1.00E+01	4.03E+04			
29	6.50E+00 to 8.00E+00	1.90E+05			
30	5.00E+00 to 6.50E+00	9.67E+05			
31	4.00E+00 to 5.00E+00	2.41E+06			
32	3.00E+00 to 4.00E+00	9.12E+06			
33	2.50E+00 to 3.00E+00	2.33E+08			
34	2.00E+00 to 2.50E+00	1.67E+09			
35	1.66E+00 to 2.00E+00	3.02E+10			
36	1.33E+00 to 1.66E+00	2.10E+12	5.694E+10	1.808E+11	1.922E+11
37	1.00E+00 to 1.33E+00	2.03E+13	2.016E+11	6.402E+11	6.805E+11
38	8.00E-01 to 1.00E+00	1.28E+13			
39	6.00E-01 to 8.00E-01	5.38E+14			
40	4.00E-01 to 6.00E-01	1.62E+13			
41	3.00E-01 to 4.00E-01	1.15E+13			
42	2.00E-01 to 3.00E-01	1.82E+13			
43	1.00E-01 to 2.00E-01	6.24E+13			
44	5.00E-02 to 1.00E-01	8.57E+13			
45	1.00E-02 to 5.00E-02	2.99E+14			

[a] Cobalt-60 is the gamma source of significance in the fuel assembly hardware.

TABLE 5.2-6
PRIMARY GAMMA SOURCE SPECTRUM
SCALE 18 GROUP STRUCTURE
GENERAL ELECTRIC 7x7, BUNDLE AVERAGE ENRICHMENT 3.3wt% U235, 40,000 MWD/MTU, AND 10 YEAR COOLING TIME
WITH CHANNELS

		γ/sec/assembly			
Scale Group	Energy Interval, MeV	Active Fuel Zone	Plenum Zone[a]	Top Fitting Zone[a]	Bottom Fitting Zone[a]
28	8.00E+00 to1.00E+01	5.043E+04			
29	6.50E+00 to 8.00E+00	2.375E+05			
30	5.00E+00 to 6.50E+00	1.211E+06			
31	4.00E+00 to 5.00E+00	3.018E+06			
32	3.00E+00 to 4.00E+00	1.268E+08			
33	2.50E+00 to 3.00E+00	1.136E+09			
34	2.00E+00 to 2.50E+00	1.589E+10			
35	1.66E+00 to 2.00E+00	4.586E+10			
36	1.33E+00 to 1.66E+00	4.982E+12	1.254E+11	3.981E+11	4.231E+11
37	1.00E+00 to 1.33E+00	3.563E+13	4.440E+11	1.410E+12	1.498E+12
38	8.00E-01 to 1.00E+00	3.593E+13			
39	6.00E-01 to 8.00E-01	6.627E+14			
40	4.00E-01 to 6.00E-01	5.862E+13			
41	3.00E-01 to 4.00E-01	1.378E+13			
42	2.00E-01 to 3.00E-01	2.240E+13			
43	1.00E-01 to 2.00E-01	8.007E+13			
44	5.00E-02 to 1.00E-01	1.023E+14			
45	1.00E-02 to 5.00E-02	2.678E+14			

[a] Cobalt-60 is the gamma source of significance in the fuel assembly hardware.

TABLE 5.2-7
PRIMARY GAMMA SOURCE SPECTRUM
SCALE 18 GROUP STRUCTURE
GENERAL ELECTRIC 7x7, BUNDLE AVERAGE ENRICHMENT 2.5wt% U235, 21,500 MWD/MTU, AND 26 YEAR COOLING TIME
WITH CHANNELS

		γ/sec/assembly			
Scale Group	Energy Interval, MeV	Active Fuel Zone	Plenum Zone[a]	Top Fitting Zone[a]	Bottom Fitting Zone[a]
28	8.00E+00 to1.00E+01	3.210E+03			
29	6.50E+00 to 8.00E+00	1.513E+04			
30	5.00E+00 to 6.50E+00	7.726E+04			
31	4.00E+00 to 5.00E+00	1.928E+05			
32	3.00E+00 to 4.00E+00	5.738E+05			
33	2.50E+00 to 3.00E+00	5.129E+07			
34	2.00E+00 to 2.50E+00	6.841E+08			
35	1.66E+00 to 2.00E+00	1.345E+10			
36	1.33E+00 to 1.66E+00	3.821E+11	1.027E+10	3.275E+10	3.473E+10
37	1.00E+00 to 1.33E+00	3.581E+12	3.638E+10	1.160E+11	1.230E+11
38	8.00E-01 to 1.00E+00	2.121E+12			
39	6.00E-01 to 8.00E-01	2.300E+14			
40	4.00E-01 to 6.00E-01	3.993E+12			
41	3.00E-01 to 4.00E-01	5.237E+12			
42	2.00E-01 to 3.00E-01	7.680E+12			
43	1.00E-01 to 2.00E-01	2.499E+13			
44	5.00E-02 to 1.00E-01	3.971E+13			
45	1.00E-02 to 5.00E-02	1.300E+14			

[a] Cobalt-60 is the gamma source of significance in the fuel assembly hardware.

TABLE 5.2-8
NEUTRON SOURCE DISTRIBUTION
GENERAL ELECTRIC 7x7,
BUNDLE AVERAGE ENRICHMENT 3.3wt% U-235,
40,000 MWD/MTU, AND 16 YEAR COOLING TIME
WITH CHANNELS
TOTAL (α,n PLUS SPONTANEOUS FISSION) NEUTRON SOURCE
SCALE STRUCTURE USING SPECTRA FOR URANIUM DIOXIDE

Scale Group	Energy Interval, MeV	n/sec/assembly
1	6.43E+00 to 2.00E+01	1.31E+06
2	3.00E+00 to 6.43E+00	1.50E+07
3	1.85E+00 to 3.00E+00	1.68E+07
4	1.40E+00 to 1.85E+00	9.38E+06
5	9.00E-01 to 1.40E+00	1.26E+07
6	4.00E-01 to 9.00E-01	1.38E+07
7	1.00E-01 to 4.00E-01	2.69E+06
	Total	7.16E+07

TABLE 5.2-9
NEUTRON SOURCE DISTRIBUTION
GENERAL ELECTRIC 7x7, BUNDLE AVERAGE ENRICHMENT 3.3wt% U-235, 40,000 MWD/MTU, AND 10 YEAR COOLING TIME WITH CHANNELS
TOTAL (α,n PLUS SPONTANEOUS FISSION) NEUTRON SOURCE SCALE STRUCTURE USING SPECTRA FOR URANIUM DIOXIDE

Scale Group	Energy Interval, MeV	n/sec/assembly
1	6.43E+00 to 2.00E+01	1.65E+06
2	3.00E+00 to 6.43E+00	1.88E+07
3	1.85E+00 to 3.00E+00	2.09E+07
4	1.40E+00 to 1.85E+00	1.18E+07
5	9.00E-01 to 1.40E+00	1.59E+07
6	4.00E-01 to 9.00E-01	1.73E+07
7	1.00E-01 to 4.00E-01	3.39E+06
	Total	8.98E+07

TABLE 5.2-10
NEUTRON SOURCE DISTRIBUTION
GENERAL ELECTRIC 7x7, BUNDLE AVERAGE ENRICHMENT 2.5wt% U-235, 21,500 MWD/MTU, AND 26 YEAR COOLING TIME WITH CHANNELS
TOTAL (α,n PLUS SPONTANEOUS FISSION) NEUTRON SOURCE SCALE STRUCTURE USING SPECTRA FOR URANIUM DIOXIDE

Scale Group	Energy Interval, MeV	n/sec/assembly
1	6.43E+00 to 2.00E+01	1.03E+05
2	3.00E+00 to 6.43E+00	1.29E+06
3	1.85E+00 to 3.00E+00	1.61E+06
4	1.40E+00 to 1.85E+00	8.15E+05
5	9.00E-01 to 1.40E+00	1.04E+06
6	4.00E-01 to 9.00E-01	1.10E+06
7	1.00E-01 to 4.00E-01	2.14E+05
	Total	6.16E+06

TABLE 5.2-11

SOURCE TERM SUMMARY

SAS2H Source Terms
Summary
Neutron and Gamma Source As a Function of Burnup, Water Density and Active Core Height

7x7 Fuel Assembly	40,000 MWd/MtU Average Burnup	10 Years	Cool Time
Power (MW) 5	Cycle Length (days) 527.2		

Output File Name	Zone	Frac Core Height	Peaking Factor	Burnup (MWd/MtU)	SAS2H Power (MW)	Water Density (g/cc)	Neutron Source (n/s)	Neutron Peaking Factor	Gamma Source (g/s)	Gamma Peaking Factor
7x7-9-36.output	12	0.95-1.0	0.2410	9640	1.205	0.3609	1.661E+04	0.0028	1.574E+13	0.2303
7x7-25-36.output	11	0.90-0.95	0.6330	25320	3.165	0.3631	6.500E+05	0.1093	4.275E+13	0.6255
7x7-36-37.output	10	0.8-0.9	0.8973	35891	4.486	0.3701	6.005E+06	0.5047	1.238E+14	0.9053
7x7-43-39.output	9	0.7-0.8	1.0766	43065	5.383	0.3861	1.274E+07	1.0707	1.499E+14	1.0964
7x7-46-41.output	8	0.6-0.7	1.1515	46061	5.758	0.4118	1.647E+07	1.3842	1.535E+14	1.1227
7x7-47-43.output	7	0.5-0.6	1.1912	47649	5.956	0.4375	1.859E+07	1.5624	1.663E+14	1.2164
7x7-48-47.output	6	0.4-0.5	1.2000	48000	6.000	0.4708	1.877E+07	1.5775	1.674E+14	1.2244
7x7-48-53.output	5	0.3-0.4	1.2000	48000	6.000	0.5251	1.819E+07	1.5288	1.671E+14	1.2223
7x7-47-59.output	4	0.2-0.3	1.1836	47345	5.918	0.5945	1.649E+07	1.3859	1.644E+14	1.2027
7x7-43-70.output	3	0.1-0.2	1.0750	43001	5.375	0.7008	1.005E+07	0.8447	1.484E+14	1.0854
7x7-31-75.output	2	0.05-0.1	0.7746	30985	3.873	0.7541	1.002E+06	0.1683	5.245E+13	0.7674
7x7-9-76.output	1	0.0-0.05	0.2357	9426	1.178	0.7603	1.100E+04	0.0018	1.542E+13	0.2256
Average/Total			0.9917	39670	4.959	0.5016	1.190E+08	1.0000	1.367E+15	1.0000
Uniform Case		0.0-1.0	1	40000	5	0.432	8.976E+07		1.382E+15	
Ratio to Non-Uniform Case							1.326		0.989	

TABLE 5.3-1

MATERIALS INPUT FOR MCNP

Zone	Material	Density (g/cc)	Element/Nuclide	Library Identifier	Atomic Number Density (atoms/barn-cm)
Fuel/Basket	UO_2	1.855	U-235	92235	1.405E-04
			U-238	92238	4.065E-03
			O	8016	8.411E-03
	Zircaloy	0.430	Zr	40302	2.839E-03
	SS304	0.707	Cr	24304	1.556E-03
			Mn	25055	1.550E-04
			Fe	26304	5.299E-03
			Ni	28304	6.892E-04
	Aluminum	0.239	Al	13027	5.290E-03
Plenum/Basket	Zircaloy	0.359	Zr	40302	2.370E-03
	SS304	0.614	Cr	24304	1.351E-03
			Mn	25055	1.346E-04
			Fe	26304	4.602E-03
			Ni	28304	5.985E-04
	Aluminum	0.185	Al	13027	4.129E-03
Top Fitting	Zircaloy	0.182	Zr	40302	1.202E-03
	SS304	0.309	Cr	24304	6.800E-04
			Mn	25055	6.774E-05
			Fe	26304	2.316E-03
			Ni	28304	3.012E-04
Bottom Fitting/Basket	Zircaloy	0.205	Zr	40302	1.353E-03
	SS304	1.475	Cr	24304	3.246E-03
			Mn	25055	3.234E-04
			Fe	26304	1.105E-02
			Ni	28304	1.438E-03
	Aluminum	0.238	Al	13027	5.312E-03
Basket Periphery	SS304	7.92	Cr	24304	1.743E-02
			Mn	25055	1.736E-03
			Fe	26304	5.936E-02
			Ni	28304	7.721E-03
Basket Periphery/Shim/Rails	Aluminum	2.702	Al	13027	6.031E-02
Cask Body/shield ring impact limiter skin	Carbon Steel	7.8212	Fe	26000	8.350E-02
			C	6012	3.925E-03
Resin/Aluminum	Resin (1.58 g/cc) & Al (2.702 g/cc)	1.687	O	8016	2.245E-02
			Al	13027	1.055E-02
			C	6012	2.518E-02
			H	1001	4.310E-02
			B-10	5010	1.662E-04
			B-11	5011	6.692E-04

TABLE 5.3-1 (continued)

MATERIALS INPUT FOR MCNP

Zone	Material	Density (g/cc)	Element/Nuclide	Identifier	Atomic Number Density (atoms/barn-cm)
Impact Limiter	Balsa Wood	0.125	C	6012	2.787E-03
			O	8016	2.323E-03
			H	1001	4.646E-03
Impact Limiter	Redwood	0.387	C	6012	8.630E-03
			O	8016	7.192E-03
			H	1001	1.438E-02

TABLE 5.4-1

RESPONSE FUNCTIONS FOR GAMMA

Photon Energy (MeV)	Response (10^{-12} Sv cm^2)
0.01	0.0769
0.015	0.846
0.02	1.01
0.03	0.785
0.04	0.614
0.05	0.526
0.06	0.504
0.08	0.532
0.10	0.611
0.15	0.890
0.20	1.18
0.30	1.81
0.40	2.38
0.50	2.89
0.60	3.38
0.80	4.29
1.0	5.11
1.5	6.92
2.0	8.48
3.0	11.1
4.0	13.3
5.0	15.4
6.0	17.4
8.0	21.2
10.0	25.2

TABLE 5.4-2

RESPONSE FUNCTIONS FOR NEUTRON

Neutron Energy (MeV)	Response (10^{-12} Sv cm^2)
2.5E-8	8.0
1.0E-7	10.4
1.0E-6	11.2
1.0E-5	9.2
1.0E-4	7.1
1.0E-3	6.2
1.0E-2	8.6
2.0E-2	14.6
5.0E-2	35.0
1.0E-1	69.0
2.0E-1	126
5.0E-1	258
1.0	340
1.5	362
2.0	352
3.0	380
4.0	409
5.0	378
6.0	383
7.0	403
8.0	417
10.0	446
14.0	520
17.0	610
20.0	650

TABLE 5.4-3

DOSE RATES FOR PREFERENTIAL LOADING
(44 design basis assemblies, 10 year cooling + 24 21.5GWD/MTU, 26 year cooling)

Axial Interval (cm)*	Cask Surface			Rail Car Edge			2 M from Surface		
	gamma	neutron	total	gamma	neutron	total	gamma	neutron	total
-314.68									
-275.94							0.8	0.1	**0.9**
-227.06							1.2	0.3	**1.5**
-190							1.9	0.4	**2.3**
-164.59	9.7	3.8	**14**	7.5	2.8	**10**	2.6	0.5	**3.1**
-146.3	9.0	5.0	**14**	7.8	3.0	**11**	2.7	0.6	**3.3**
-109.73	14.0	4.7	**19**	10	2.9	**13**	3.0	0.5	**3.5**
-73.15	13.9	2.4	**16**	11	2.1	**13**	3.7	0.6	**4.3**
-36.53	14.6	2.9	**18**	11	2.3	**13**	3.9	0.7	**4.6**
0	14.6	2.9	**18**	11	2.0	**13**	4.3	0.7	**5.0**
36.53	14.6	3.3	**18**	11	2.2	**14**	4.4	0.6	**5.1**
73.15	14.6	2.4	**17**	11	1.6	**13**	4.9	0.7	**5.6**
109.73	12.3	2.1	**14**	9.7	1.5	**11**	5.2	0.7	**5.8**
146.3	10.9	1.4	**12**	8.4	1.2	**9.6**	6.1	0.7	**6.7**
164.59	8.4	0.6	**8.9**	8.7	1.1	**9.7**	7.0	0.7	**7.7**
200	9.8	1.1	**11**	14	1.7	**15**	7.9	0.8	**8.7**
224.72	51.5	8.0	**59**	48	5.3	**53**	8.2	0.7	**8.9**
245.9	135	15.4	**151**	72	6.7	**79**	8.2	0.7	**8.9**
279.05							5.9	0.5	**6.4**
327.93							2.6	0.3	**2.9**
366.67									

Top Limiter Surface				Bottom Limiter Surface			
radius (cm)	gamma	neutron	**total**	radius (cm)	gamma	neutron	**total**
25	21	0.2	**21**	25	16	0.3	**17**
50	18	0.1	**18**	50	15	0.4	**15**
75	13	0.2	**13**	75	10	0.2	**10**
101.45	7.1	0.0	**7.1**	101.45	5.5	0.1	**5.6**
124.47	2.6	0.0	**2.6**	124.47	1.8	0.0	**1.9**
152	1.1	0.0	**1.1**	152	0.6	0.0	**0.6**
182.88	0.5	0.0	**0.5**	182.88	0.2	0.0	**0.2**
352	0.9	0.1	**0.9**	352	0.4	0.1	**0.5**

* - See Figures 5.3-1 and 5.3-2 for locations

FIGURE WITHHELD AS
SENSITIVE UNCLASSIFIED
INFORMATION

FIGURE 5.1-1
CASK SHIELDING
CONFIGURATION

REV. 2 5/00

FIGURE 5.2-1

AXIAL BURNUP PROFILE FOR DESIGN BASIS FUEL

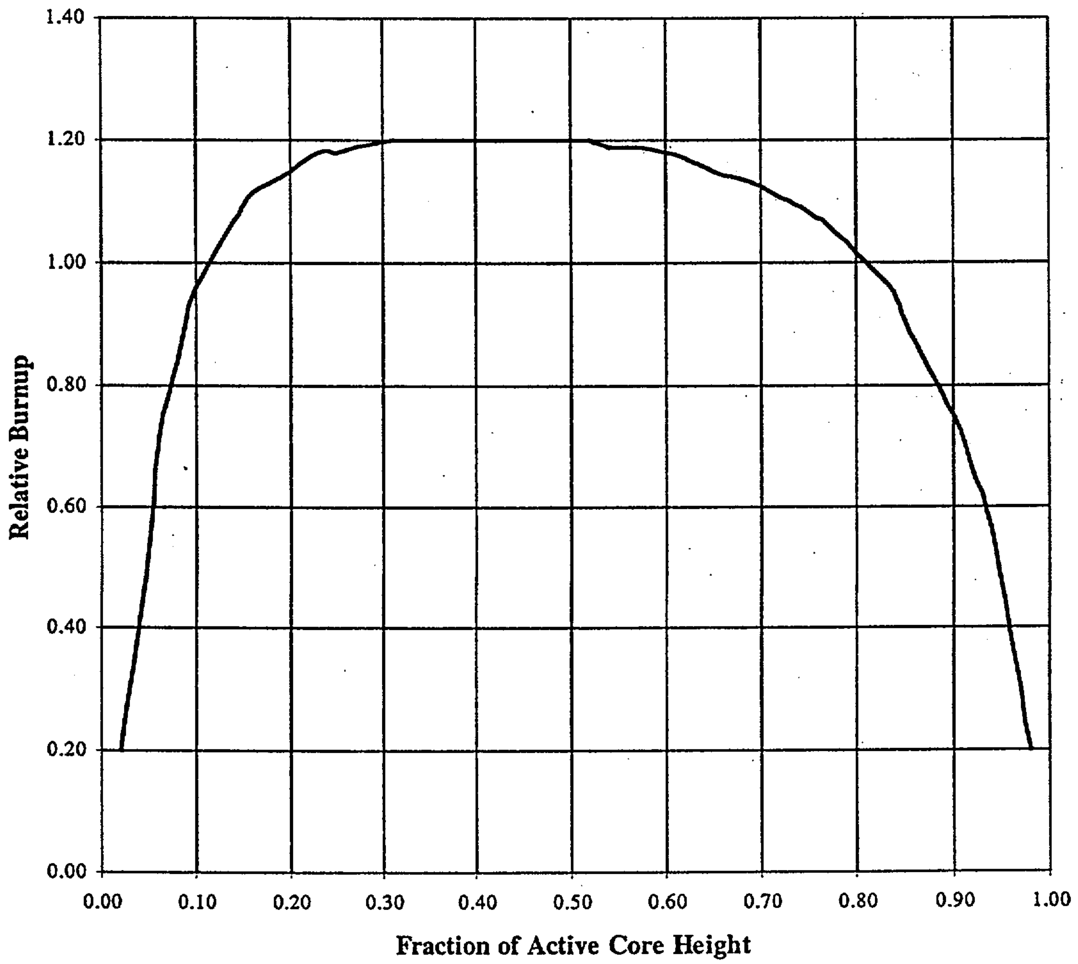
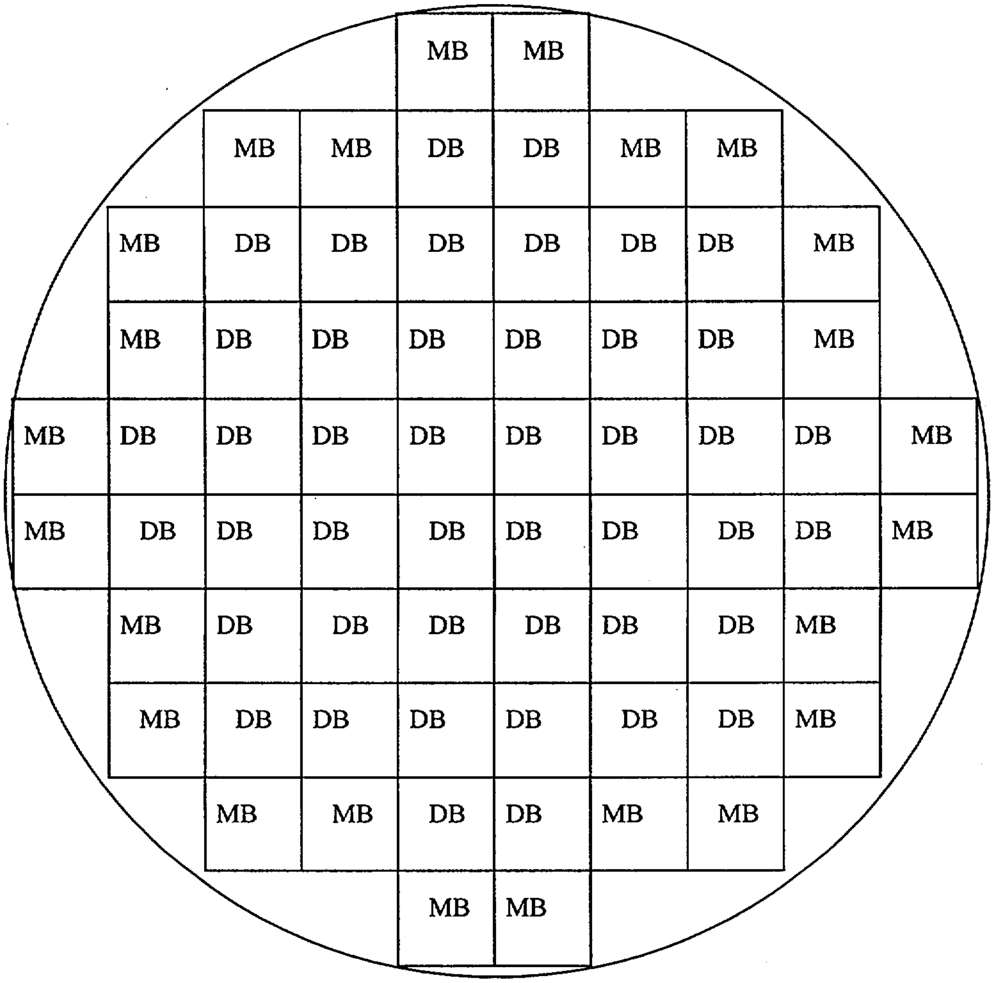


FIGURE 5.3-3

PREFERENTIAL LOADING CONFIGURATION



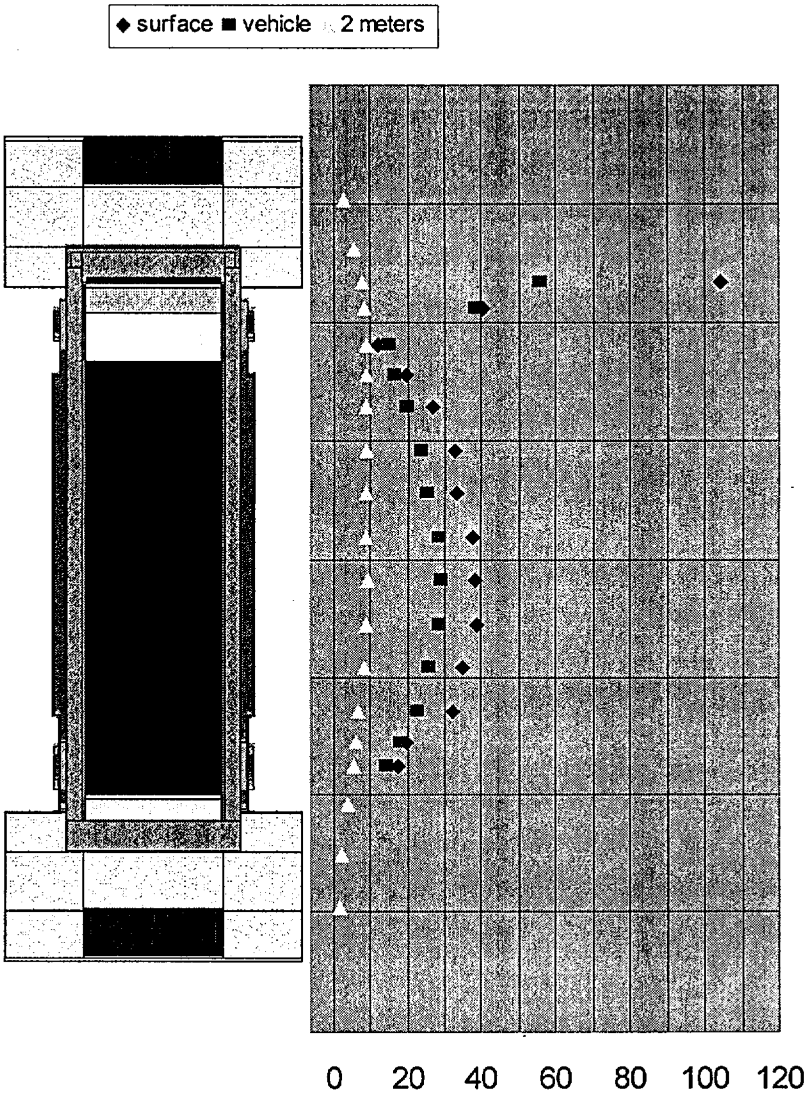
				MB	MB				
		MB	MB	DB	DB	MB	MB		
	MB	DB	DB	DB	DB	DB	DB	MB	
	MB	DB	DB	DB	DB	DB	DB	MB	
MB	DB	DB	DB	DB	DB	DB	DB	DB	MB
MB	DB	DB	DB	DB	DB	DB	DB	DB	MB
	MB	DB	DB	DB	DB	DB	DB	MB	
	MB	DB	DB	DB	DB	DB	DB	MB	
		MB	MB	DB	DB	MB	MB		
				MB	MB				

DB – 40 GWD/MTU, 3.3%, 10 year cooled (Type I)

MB – 21.5 GWD/MTU, 2.5%, 26 year cooled (Type II)

FIGURE 5.4-1

TN-68 RADIAL GAMMA DOSE RATE PROFILE



MREM/HR

FIGURE 5.4-2

TN-68 RADIAL NEUTRON DOSE RATE PROFILE

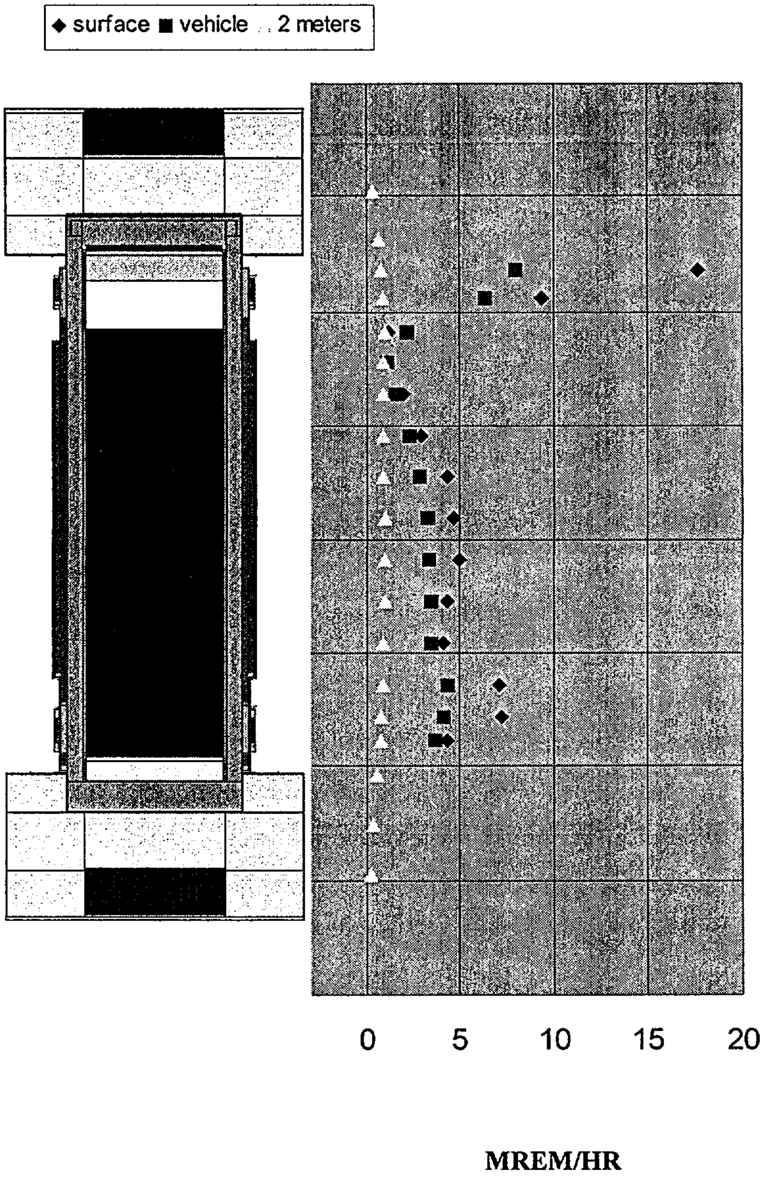


FIGURE 5.4-3

TN-68 GAMMA DOSE RATE IMPACT LIMITER SURFACE

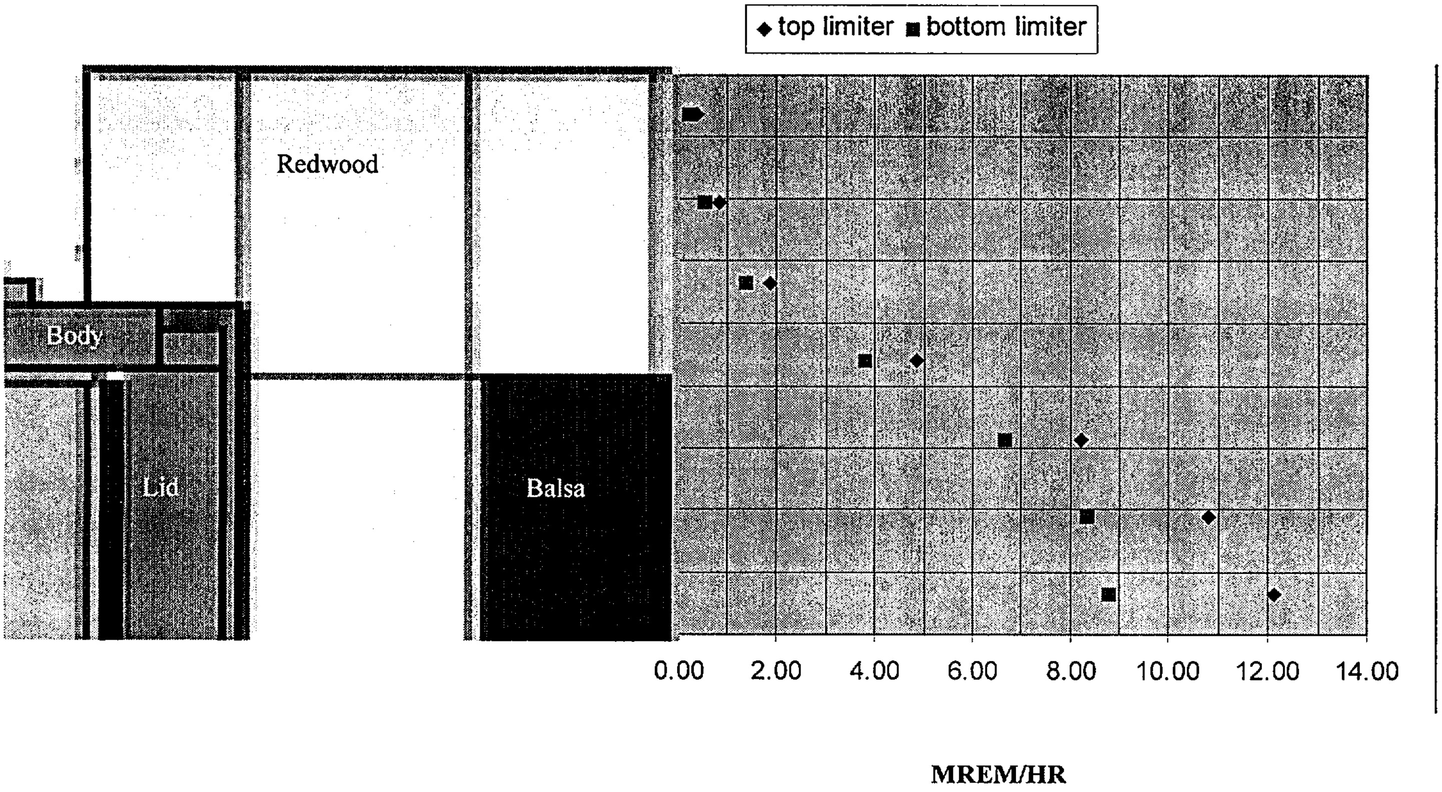
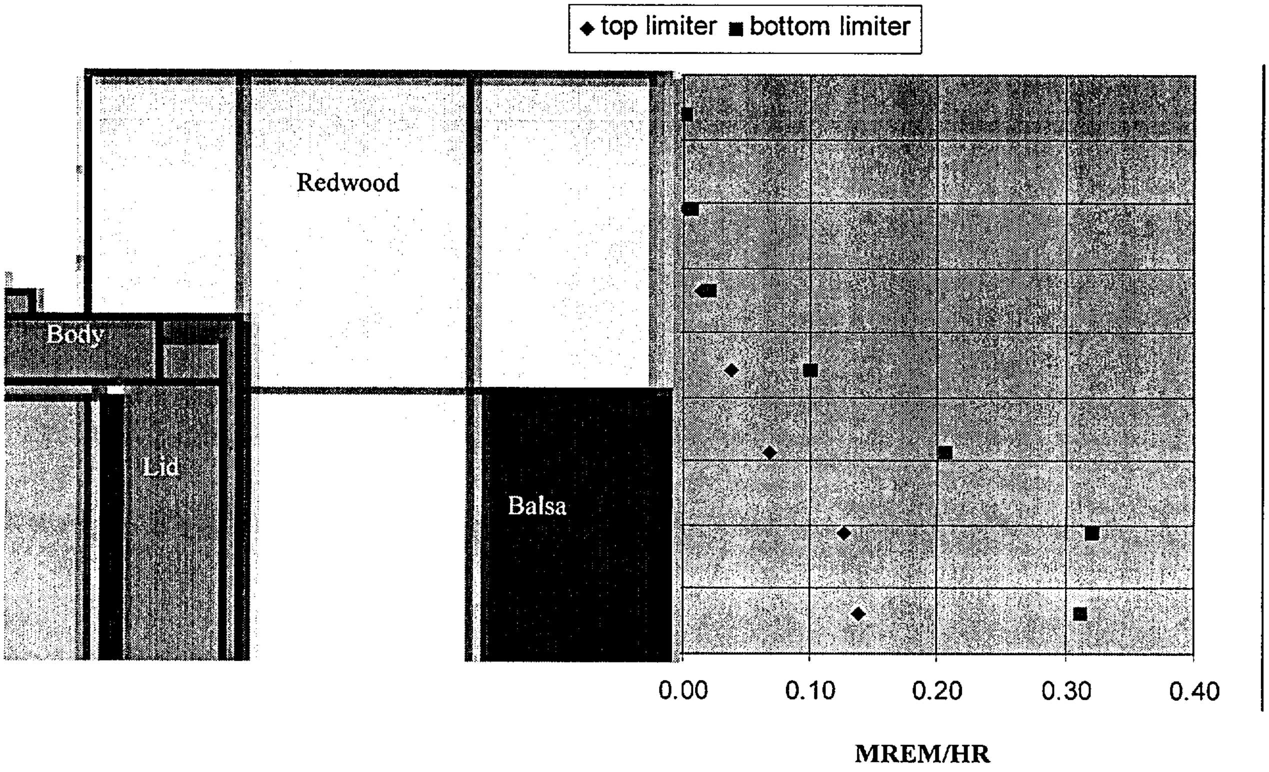


FIGURE 5.4-4

TN-68 NEUTRON DOSE RATE IMPACT LIMITER SURFACE



CHAPTER 7

OPERATING PROCEDURES

This chapter contains TN-68 loading and unloading procedures that are intended to show the general approach to cask operational activities. A separate Operations Manual (OM) will be prepared for the TN-68 to describe the operational steps in greater detail. The OM, along with the information in this chapter, will be used to prepare the site-specific procedures that will address the particular operational considerations related to the cask. The operations required to convert the cask from its storage configuration to its transport configuration are also described in here.

7.1 PACKAGE LOADING

7.1.1 Preparation for Loading

7.1.1.1 Upon arrival of the empty packaging, on its transport vehicle (rail or heavy haul trailer) and shipping frame, perform a receipt inspection to check for any damages or irregularities. Verify that the records for the packaging are complete and accurate.

7.1.1.2 Remove the security device, the impact limiter attachment bolts, tie-rods, and the associated hardware, as necessary.

7.1.1.3 Remove the front and the rear impact limiters, as well as the front spacer and the ancillary shield ring, using a suitable crane and a two-legged sling or an equivalent.

7.1.1.4 Remove the tie-down strap and trunnion support block caps.

7.1.1.5 Clean the external surfaces of the cask, if necessary, to get rid of the road dirt.

7.1.1.6 Attach the lift beam to the cask handling crane hook, and engage the lift beam to the two upper (top) trunnions.

7.1.1.7 Rotate the cask slowly from the horizontal to the vertical position.

7.1.1.8 Lift the cask from the transport/shipping frame and place it in the cask preparation area.

7.1.1.9 Disengage the lift beam from the cask

7.1.1.10 Remove the neutron shield pressure relief valve and install the plug in the neutron shield vent hole.

7.1.1.11 Remove the lid bolts and the lid.

7.1.1.12 Replace the lid seal using the retaining screws, and inspect the lid sealing surface. Check for defects in the seal contact areas that may prevent a proper seal. (This step may be performed at any time prior to installing the lid on the loaded cask).

7.1.1.13 Replace the seals in the vent, drain and transport covers, and inspect the sealing surfaces. Check for defects in the seal contact areas that may prevent a proper sealing. (This step may be performed at any time prior to installing covers on the loaded cask).

7.1.1.14 Visually inspect the lid bolts and the bolt hole threads to ensure that they do not have any laps, seams, cracks or damaged threads.

7.1.1.15 Remove the hold down ring from the cask cavity.

7.1.1.16 Verify that the basket is installed in the cask, with no evident signs of damage to either. Verify that there is no foreign material in the cask.

7.1.1.17 Move the cask to the cask loading area using the lift beam attached to the top trunnions.

7.1.2 Loading

Note: The term 'cask loading pool' is used to describe the area where the cask is to be loaded.

7.1.2.1 Lower the cask into the cask loading pool, while rinsing the exterior of the cask with demineralized water and filling the interior with demineralized or pool water.

7.1.2.2 Disengage the lift beam and move it aside.

7.1.2.3 Load the pre-selected spent fuel assemblies into the basket compartments. Procedures shall be developed to ensure that the fuel loaded into the cask meets the fuel specifications in chapter 1.2.3 of the SAR.

7.1.2.4 Verify the identity of the fuel assemblies loaded into the cask, and document the location of each fuel assembly on the cask loading report. Note: Type I fuel assemblies shall be loaded in the center compartments as shown in Figure 5.3-3.

7.1.2.5 At least one lid penetration (drain or vent port) must be completely open (both cover and quick-disconnect fitting removed) prior to the installation of the lid. Using the lift beam and the lid lifting slings, lower the lid placing it on the cask body flange over the two alignment pins.

7.1.2.6 Engage the lift beam on the upper (top) trunnions, and lift the cask so that the top of the cask is above the water surface in the pool, and install some of the lid bolts. The lid bolts should be hand tight.

Note: Throughout this procedure, all bolt threads are to be coated with Nuclear Grade Neolube or equivalent.