NUHOMS® -MP197 TRANSPORT PACKAGING

CHAPTER 5

TABLE OF CONTENTS

Page

5. SHIELDING EVALUATION

5.1 Discussion and Results 5-1

5.2 Source Specification 5-2
5.2.1 Axial Source Distribution 5-4
5.2.2 Gamma Source 5-4
5.2.3 Neutron Source 5-5

5.3 Model Specification 5-6
5.3.1 Description of Radial and Axial Shielding Configuration 5-6
5.3.2 Shield Regional Densities 5-7

5.4 Shielding Evaluation 5-8

5.5 References 5-10

5.6 Appendix 5-11
5.6.1 SAS2H/ORIGENS Input File 5-11
5.6.2 MCNP Neutron Model Input File 5-13
5.6.3 MCNP Primary Gamma Input File (Preferential Loading) 5-21

LIST OF TABLES

5.1-1 NUHOMS® MP-197/61B Shield Materials
5.1-2 Summary of Dose Rates
5.2-1 BWR Fuel Assembly Design Characteristics
5.2-2 BWR Fuel Assembly Hardware Characteristics
5.2-3 Material Compositions For Fuel Assembly Hardware Materials
5.2-4 BWR Fuel Assembly Source (With Channels) Bundle Average Enrichment 3.3 Wt% U235, 40,000 MWD/MTU, 10 Year Cooling Time
5.2-5 Primary Gamma Source Spectrum Scale 18 Group Structure General Electric 7x7, Bundle Average Enrichment 2.65wt% U235, 35,000 MWD/MTU, And 12 Year Cooling Time With Channels
5.2-6 Neutron Source Distribution, General Electric 7x7, Bundle Average Enrichment 2.65wt% U235, 35,000 MWD/MTU, And 12 Year Cooling Time With Channels, Total (α,n Plus Spontaneous Fission)

LIST OF TABLES (continued)

5.2-7 Source Term Summary
5.3-1 Materials Input For MCNP
5.4-1 Response Functions For Gamma
5.4-2 Response Functions For Neutron

LIST OF FIGURES

5.1-1 NUHOMS®-MP197 Cask Shielding Configuration
5.2-1 Axial Burnup Profile For Design Basis Fuel
5.3-1 MCNP Top Half Model
5.3-2 MCNP Bottom Half Model
5.4-1 NUHOMS®-MP197 Radial Gamma Dose Rate Profile
5.4-2 NUHOMS®-MP197 Radial Neutron Dose Rate Profile
5.4-3 NUHOMS®-MP197 Gamma Dose Rate Impact Limiter Surface
5.4-4 NUHOMS®-MP197 Neutron Dose Rate Impact Limiter Surface

CHAPTER 5

SHIELDING EVALUATION

5.1 DISCUSSION AND RESULTS

Shielding for the NUHOMS®-MP197 cask is provided mainly by the cask body. Gamma-ray shielding is provided mainly by the lead and stainless steel shells that comprise the cask wall. For the neutron shielding, a borated polyester resin compound surrounds the cask body radially. Gamma shielding in the cask ends is provided mainly by the steel top and bottom assemblies of the NUHOMS® -61BT DSC.

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 NUHOMS®-MP197 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 group 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/configuration is used in the subsequent shielding calculations.

Through this analysis, the GE 7x7 fuel array is identified as the most conservative source/configuration, due mainly to the mass of uranium. Additional SAS2H/ORIGENS analyses are performed for four different fuel burnup/enrichment groups using the bounding 7x7 fuel assembly. Through these analyses, the Group 2 source was identified as having the bounding gamma and neutron source. Section 5.2 describes the source specification and Section 5.4 describes the shielding analysis performed for the NUHOMS®-MP197 cask containing the 61BT canister.

Normal conditions are modeled with the NUHOMS®-MP197 intact. This shielding calculation is performed using the Monte Carlo computer code MCNP [5]. Dose rates on the side, top and bottom of the MP197 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, and shield shell are removed. A gap(s) is also modeled in the lead shield to account for lead slump in the accident. Shielding calculations for accident conditions are also performed using MCNP.

The expected maximum dose rates (for normal and accident conditions) from the MP197 cask are provided in Table 5.1-2. These dose rates are calculated for a NUHOMS®-MP197 cask containing the 61BT DSC filled with Group 2 fuel assemblies cooled for 12 years.

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 NUHOMS®-MP197 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 MP197 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 [2].

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 four groups. 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/configuration and is utilized to determine the bounding source terms for the NUHOMS®-MP197 shielding analysis.

As shown in Section 1.2.3, four different groups of fuel assembly parameters are chosen as representative of the fuel to be transported in the MP197. SAS2H/ORIGEN-S analyses are performed for each of these four groups of fuel assemblies and the bounding source term identified and chosen for the shielding analysis. The Group 2 fuel assembly (lattice enrichment 2.65 wt% and 35,000 MWD/MTU burnup) with a cooling time of 12 years is selected as the bounding source for the shielding analysis.

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 5.2-7. (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 the Group 2 fuel assembly is provided in Tables 5.2-5,. Table 5.2-5 present spectra for a 7x7 assembly with an initial bundle average enrichment of 2.65wt%, maximum bundle-average burnup of 35,000 MWD/MTU and 12 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 Group 2 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.

An axial burnup profile has been developed as discussed in Section 5.2.1 above. Table 5.2-7 provides design axial gamma peaking factors and source terms that were utilized in the MCNP shielding model.

5.2.3 Neutron Source

Tables 5.2-6 provides the total neutron source spectra for the Group 2 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 5.2-7.

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).

Sections 5.3.1.1 and 5.3.1.2 describe the shielding model (for the vicinity immediately around the cask) developed for the NUHOMS®-MP197 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 NUHOMS®-MP197 design. The model is illustrated in Figures 5.3-1 and 5.3-2 for the transport configuration of the MP197. The dimensions of this shielding model correspond to the dimensions of the MP197 design. The metal trunnions are replaced with the trunnion plugs. The impact limiter wood is assumed to all be balsa. The hold down ring was not included in the model. A 0.06" radial air gap is assumed at the lead (gamma shield) and outer shell interface to account for possible lead shrinkage during fabrication.

The axial locations of the plenum and the end fittings for the fuel assembly are taken from Reference 3; 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 stainless steel rails are included as an equivalent layer of material (0.44") within the canister.

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 balsa. The thermal shield under the bottom impact limiter is not included in the model, this is conservative since shielding material is neglected.

The fuel region is assumed to consist of uranium dioxide. The fuel cladding and one half of the steel and aluminum basket mass are included in the homogenized fuel region for the radial model. Only 20% of the basket mass is included in the axial model. The fuel channels are not included in the homogenization. (However, the fuel channels are included in the source term.) The fuel and basket region are modeled as a cylinder within the DSC. The actual DSC ID is reduced by the 0.44" equivalent steel rail layer so that the homogenized source region is modeled with a reduced diameter of 65.37".

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. One-half of the basket mass in this region is homogenized through the plenum region for the radial model, 20% for the axial model.

Similarly, the bottom fitting region is homogenized with one-half the basket for the radial model and 20% for the axial model. Because the basket does not extend above the top fitting, the homogenized top fitting hardware does not contain any basket mass.

The key-way at the bottom of the cask that interfaces the cask to the transporter is included in the model. The key-way is assumed to be filled with the steel "key" on the transporter since the cask in normal transport mode is modeled. 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 assumed the neutron shield and shield shell are removed. The accident model also includes a 3.5" air gap at the top and bottom of the lead shield to account for the lead slump calculated in Chapter 2. 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 canister diameter (65.37") and the appropriate length. One-half of the fuel basket mass is homogenized over the source diameter and appropriate length (of the fuel zone, plenum and bottom fitting) for the radial model and 20% is homogenized into the axial model.

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.

5.4 SHIELDING EVALUATION

Dose rates around the MP-197 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 contact dose.

For the doses around the NUHOMS®-MP197, 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.

The source term evaluation was performed using SCALE 4.4, "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 4.4 and MCNP are 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 4.4, "Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation for Workstations and Personal Computers," CCC-545, ORNL, NUREG/CR-0200, September 1998.

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.inp, 2.65 w/o U235, 35,000 MWD/MTU, 8-60 year cooling
27groupndf4   latticecell
uo2        1    0.95  840 92234 0.0294 92235 2.65 92236 0.0152
92238 97.3055 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=5  end
 3  1.0E-10  500  7.4031   3  7.5091  5  7.7957  11  8.5982
power=5.00    burn=461.3    down=30    end
power=5.00    burn=461.3    down=30    end
power=5.00    burn=461.3    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 18 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 18 years and fission product gamma re-ordering
single reactor assembly
60**  8.0   9.0  10.0   11.0  12.0   14.0   16.0  18.0
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 18 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 18 years and actinide gamma re-ordering
single reactor assembly
60**  8.0   9.0  10.0   11.0  12.0   14.0   16.0  18.0
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 18 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 18 years and light element gamma re-ordering
single reactor assembly
60**  8.0   9.0  10.0   11.0  12.0   14.0   16.0  18.0
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 NU-61B cask:   Near-Field model
c
c    This model calculates doses for neutrons
c
c ***********************  BLOCK 1: CELL CARDS ***********************
c GEOMETRY (r-z)
c
c   ^ z-axis
c   .
c   | -----------------  |   tally surfaces @
c   ._________________.  |      contact,
c   |    impact limiter | |      1m and
c   .___________.       | |      2m from surface IL
c   |------------+--+   | |      for the radial (side)
c   .------------+   |  | |      and 1 cm from the top and
c   |............|   |__| |      bottom of the ILs axially
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 4/01
c
c ****** Cask cells
  1  8   -7.92  1 -2 -260 #35   imp:n,p=1  $ Fe cask bottom
  2  8   -7.92  2 -12 25 -21 imp:n,p=1  $ Inner shell
  3  7   -1.284   18 -5 -28       imp:n,p=1  $ bottom basket
  4  6   -0.790   7 -8 -28        imp:n,p=1  $ top plenum basket
  5  5   -0.446   8 -11 -28       imp:n,p=1  $ top fitting
  8  1  -0.0013  11 -19 -28       imp:n,p=1  $ Void between top and canister
  9  1  -0.0013  20 -12 -27  imp:n,p=1  $ Void between canister and lid
  10  8   -7.92 2 -18 -27          imp:n,p=1  $ bottom of canister
  11  8   -7.92  12 -14 -260        imp:n,p=1  $ Fe cask lid - part1
  12  8   -7.92 19 -20 -27  imp:n,p=1  $ top of canister
  25  8   -7.92  18 -19 28 -27   imp:n,p=1   $ The canister
  26  1  -0.0013  2 -12 27 -25  imp:n,p=1  $ Void between canister and inner
shell
  27  16   -11.34   333 -12 21 -222 332 -17 2  imp:n,p=1  $ Gamma shield
 627  1  -0.0013  333 -12 -22 222  332 -17  2   imp:n,p=1  $ gap at gamma
shield
  16  8   -7.92  21 2 -12 -22 #27 #627 imp:n,p=1  $ Gamma shield CS
```

```
  28  8    -7.92  2 -12 22 -260  imp:n,p=1 $ Outer shell
c  29  12  -1.687  149 -166 260 -202 #37 #38 #39 #99 #240 #241 #242 #243
c            #260 #261 #262 #263 imp:n,p=1 $ neutron shield
  29  12  -1.687  198 -199 260 -202 #37 #38 #39 #99 #260 #261
                  #262 #263 #265 #266 #267 #268 #244 imp:n,p=1  $ neutron
shield
  36  8    -7.92  149 -166 202 -201 #265 #266 #267 #268 imp:n,p=1 $ SS Skin
over NS
   6  8    -7.92  (-166 199 260 -202)#37 #38 :
                  (149 -198 260 -202) #39 #99  imp:n,p=1  $ top & bot ss plate
on NS
  30  0    150 -149 -201 260          imp:n,p=1 $ void space between BL & NS
  31  0    161 -14 260 -251           imp:n,p=1 $ void btw side of TL and csk
  32  0    155 -150 260 -251          imp:n,p=1 $ void btw side of BL and csk
  33  0    155 -1 -260                imp:n,p=1 $ void btw csk bottom and BL
  34  0    166 -161 260 -201          imp:n,p=1 $ void btw top of NS and TL
  35  0    167 -2 -255                imp:n,p=1 $ canister plug
c ****** trunnion blocks with trunnion plugs ********
  37  8    -7.92 (195 -344 345 -166 196 -341 260)#260 :
             (195 -330 260 -341 -196) #260 imp:n,p=1 $ TR trun block
 260  17   -0.90 195  -336 260 -341  imp:n,p=1        $ PP trunnion plug
 265  8    -7.92  -334 -300 341  imp:n,p=1          $ Fe trunnion plug
  38  8    -7.92  (-195 -344 345 -166 196 342 260)#261:
            (-195 -330 260 342 -196) #261 imp:n,p=1 $ TL trun block
 261  17   -0.90  -195 -336 260  342  imp:n,p=1      $ PP trunnion plug
 266  8    -7.92  -334 301 -342  imp:n,p=1         $ Fe trunnion plug
  39  8    -7.92 (195 -344 345 149 -197 -341 260)#262 :
             (195 -331 260 -341 197) #262 imp:n,p=1 $ BR trun block
 262  17   -0.90  195 -337 260 -341  imp:n,p=1      $ PP trunnion plug
 267  8    -7.92  -335 -300 341  imp:n,p=1         $ Fe trunnion plug
  99  8    -7.92 (-195 -344 345 149 -197 342 260)#263:
            (-195 -331 260 342 197) #263 imp:n,p=1  $ BL trun block
 263  17   -0.90  -195 -337 260  342  imp:n,p=1      $ PP trunnion plug
 268  8    -7.92  -335 301 -342  imp:n,p=1         $ Fe trunnion plug
c ******* transport key/pad on cask under-side
 244  8    -7.92   (-348 -349 351 -352 -202 256):(-353 -354 355 -356 260 -256)
                      imp:n,p=1 $ key plus pad on body
c **** impact limiters  *****
c  bottom limiter
   80 8  -7.92    (156 -155 -254):(155 -151 -254 251) imp:n,p=1 $ inside skin
   81 8  -7.92    (153 -152 -250):(152 -151 -250 253) imp:n,p=1 $ outside
skin
   82 8  -7.92     151 -150 -250 251      imp:n,p=1 $ outside skin
   83 15 -0.125      156 -151 -253 254     imp:n,p=1 $ balsa instead of
redwood
   84 15 -0.125      154 -156 -253 252     imp:n,p=1 $ balsa instead of
redwood
   85 15 -0.125      154 -156 -252         imp:n,p=1 $ balsa instead of
redwood
   86 15 -0.125      152 -154 -253 252     imp:n,p=1 $ balsa instead of
redwood
   87 15 -0.125      152 -154 -252         imp:n,p=1 $ balsa
c  top limiter
   90 8  -7.92    (14 -165 -254):(160 -14 -254 251) imp:n,p=1 $ inside steel
   91 8  -7.92    (162 -163 -250):(160 -162 -250 253) imp:n,p=1 $ outside
steel
   92 8  -7.92      -160 161 -250 251      imp:n,p=1 $ outside steel
```

```
  93 15 -0.125      160 -165 -253 254     imp:n,p=1 $ balsa instead of
redwood
  94 15 -0.125      165 -164 -253 252     imp:n,p=1 $ balsa instead of
redwood
  95 15 -0.125      165 -164 -252         imp:n,p=1 $ balsa instead of
redwood
  96 15 -0.125      164 -162 -253 252     imp:n,p=1 $ balsa instead of
redwood
  97 15 -0.125      164 -162 -252         imp:n,p=1 $ balsa
c **** fuel regions
  40 4   -2.511   5  -39 -28          imp:n,p=1  $ FUEL region 1 (bottom)
  401 4  -2.511   39 -40 -28          imp:n,p=1  $ FUEL region 2
  41 4   -2.511   40 -41 -28          imp:n,p=1  $ FUEL region 3
  42 4   -2.511   41 -42 -28          imp:n,p=1  $ FUEL region 4
  43 4   -2.511   42 -43 -28          imp:n,p=1  $ FUEL region 5
  44 4   -2.511   43 -44 -28          imp:n,p=1  $ FUEL region 6
  45 4   -2.511   44 -45 -28          imp:n,p=1  $ FUEL region 7
  46 4   -2.511   45 -46 -28          imp:n,p=1  $ FUEL region 8
  47 4   -2.511   46 -47 -28          imp:n,p=1  $ FUEL region 9
  48 4   -2.511   47 -48 -28          imp:n,p=1  $ FUEL region 10
  481 4  -2.511   48 -49 -28          imp:n,p=1  $ FUEL region 11
  49 4   -2.511   49 -7  -28          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
  601 0    #265 #266 #267 #268 150 -161  201 -62  imp:n,p=1 $ inner air
(void)
  602 0            150 -161  62 -63   imp:n,p=1 $ inner air (void)
  603 0   (60 -61 250 -65):(150 -161 63 -250) imp:n,p=1 $ inner air (void)
  606 0            60 -61 65 -64      imp:n,p=1 $ inner air (void)
  605 0             60 -61 -172 64    imp:n,p=0    $ outer air (void)
  190 0           -170:171:172        imp:n,p=0    $ problem boundary

c ***********************  BLOCK 2: SURFACE CARDS ***********************
c **** Horizontal cask planes
  1   pz  -237.26       $ cask bottom - ground surface
  2   pz  -220.75      $ top of csk bottom, canister 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
  11  pz   245.90       $ top of top fitting
  12  pz   279.65       $ cask top - bot of lid
  14  pz   291.08       $ cask top - top of Fe
c  17  pz   268.89       $ top of GS, slice cone
  17  pz   270.74       $ top of GS, slice cone
  18  pz   -201.65      $ top of canister bottom
  19  pz   253.77       $ bottom of canister top
  20  pz   276.43       $ top of canister
  31  pz   244.00       $ top of alum, bot of void
  148 pz   -178.155     $ Al/Void Bndry btw BL and NS
  149  pz  -176.30      $ bottom of neutron shield
  150  pz  -177.58      $ top of bottom limiter
  151  pz  -178.22      $ inside skin bottom limiter
  152  pz  -331.24      $ inside skin bottom limiter
```

```
   153   pz   -331.88       $ bottom of bottom limiter
   154   pz   -275.94       $ top of balsa disk bottom limiter
   155   pz   -241.71       $ top of inside skin bottom limiter
   156   pz   -242.34       $ Inside skin BL
   160   pz    227.64       $ inside skin top limiter
   161   pz    227.01       $ bottom of top limiter
   162   pz    380.68       $ inside skin  top limiter
   163   pz    381.25       $ top of top limiter
   164   pz    327.98       $ bottom of balsa disc top limiter
   165   pz    291.72       $ top of inside skin top limiter
   166   pz    226.30       $ top of neutron shield
   167   pz    -229.64      $ bottom of canidter plug
   300   px    118.12       $ outside of trunion plug
   301   px    -118.12      $ outside of trunion plug
   340   pz    166.823      $ flat trun cutout
   341   px    109.86       $ trunnion block
   342   px    -109.86      $ trunnion block
   343   pz    -120.573     $ flat trun cutout
   344   py     34.29       $ Trunion block
   345   py    -34.29       $ Trunion block
   348   p     -3.014893 1.0 0. 0.    $ keyway surface
   349   p      3.014893 1.0 0. 0.    $ keyway syrface
   351   pz    9.80         $ bottom of key
   352   pz    40.44        $ top of key
   353   p    -2.050304 1.0 0. 0.     $ key pad surface
   354   p     2.050304 1.0 0. 0.     $ key pad surface
   355   pz    -20.52       $ bottom of key pad
   356   pz    70.92        $ top of key pad
   195   px     0.0         $ ambiguity surface
   196   pz     183.08      $ centerline of top trunnions
   197   pz    -133.12      $ centerline of bottom trunnions
   198   pz    -172.49      $ Inside steel plate on NS
   199   pz     222.49      $ Inside steel plate on NS
c ***** cylindrical cask surfaces
   25    cz    86.36       $ cask inner surface outside of void (see 27)
   21    cz    89.535      $ outside inner shell inside gamma sheild
   22    cz    97.79       $ outside gamma sheild inside outer shell
   222   cz    97.64       $ lead gap at outer shell interface
   251   cz    105.41      $ Inside radius IL
   260   cz    104.15      $ inside NS
   202   cz    115.72      $ outside of neutron sheild
   201   cz    116.20      $ outside of SS Skin
   27    cz    85.41       $ outside radius of canister
   28    cz    83.02       $ inside radius of canister outside fuel rad
   250   cz    155.00      $ outside radius of impact limiter
   252   cz    96.50       $ radius of balsa disk
   253   cz    154.4       $ outside radius inside skin
   254   cz    106.04      $ inside skin
   256   cz    107.96      $ outside of key pad (1.5" thk)
   255   cz    12.7        $ canister plug
   330   c/x   0 183.08 34.29  $ trunnion block
   331   c/x   0 -133.12 34.29  $ trunnion block
   334   c/x   0 183.08 31.75  $ trunnion plug Fe
   335   c/x   0 -133.12 31.75  $ trunnion plug Fe
   336   c/x   0 183.08 21.59  $ trunnion plug PP
   337   c/x   0 -133.12 21.59  $ trunnion plug PP
c ****** cone surfaces *****************
```

```
c  332  kz   -127.39  0.0566  $ tapering of STS
c 333  kz   173.68  0.0566  $ tapering of STS
  332  kz   -118.64  0.0566  $ tapering of STS
  333  kz    168.63  0.0566  $ tapering of STS
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  -334.095       $ bottom tally surface
  61  pz   382.31       $ top tally surface
  62  cz   125.0       $ radial tally surface  (outer shell)
  63  cz   152.0       $ radial tally surface   (rail car edge)
  64  cz   355.00       $ radial tally surface   (2 m from IL)
  65  cz   215.72      $ radial tally surface (1m from cask)
  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
  29  cz    101.45     $ segmentation cylinder
  23  cz    124.47     $ segmentation cylinder
  350 cz    182.88     $ segmentation cylinder

c ***********************  BLOCK 3: DATA CARDS ***************************
c
c
c  --- volumetric neutron source in 12 axial zones for TN-61 cask
c      7x7 fuel assemblies; 35,000 MWd/Mt design basis; 12y 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 .03776 .1929 .1769 .1310 .2331 .2098 .01842  $ 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    2.043E18      $ convert Sv/neutron to mrem/h for fuel zones
c      7.016E7 x 61 X 1.326 (NF) X 3600 X 1E5 = 2.043E18
c TF2 3j 6
FC2  Doses at contact averaged over subsurfaces
F2:n  201
FS2   -71 -39 -40 -41 -42 -43 -44 -45 -46 -47 -48 -49 -72 -8 -11
SD2  3.0E7 18552.00 13353.64 26699.98 26707.28 26736.49
       26670.78 26670.78 26736.49 26707.28 26699.98
        13353.64 25853.06 18048.22 15463.65 3.0E7
c FC12   Doses at the rail car edge averaged over subsurfaces
c F12:n  63
c FS12  -71 -39 -40 -41 -42 -43 -44 -45 -46 -47 -48 -49 -72 -8 -11
c SD12  3.0E7 24267.67 17467.76 34925.96 34935.52 34973.72
c         34887.76 34887.76 34973.72 34935.72 34925.96
c        17467.76 33818.11 23608.69 20227.84 3.0E7
FC12    Doses at 1 meters from cask averaged over subsurfaces
F12:n   65
FS12  -152 -154 -155 -71 -39 -40 -41 -42 -43 -44 -45 -46 -47
       -48 -49 -72 -8 -11 -165 -164 -162
SD12   1.0E8 76825.71 43985.79 72757.22 34517.57 24845.59 49677.59
          49691.17 49745.51 49623.25 49623.25 49745.51 49691.17
          49677.59 24845.59 48101.82 33580.26 28771.43
          59648.43 51783.15 71697.65 8.0E7
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 126147.67 72224.59 119467.23 56677.79 40796.41 81570.51
          81592.81 81682.04 81481.29 81481.29 81682.04 81592.81
          81570.51 40796.41 78983.09 55138.72 47242.64
          97942.61 85027.83 117727.41 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 -350 -64
sd32   1963.50 5890.49 9817.48 14662.13 16338.41 23911.35
        32487.51 290848.35 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 -350 -64
sd42   1963.50 5890.49 9817.48 14662.13 16338.41 23911.35
       32487.51 290848.35 7.8E7
c
c mode n p
 phys:n 20.0 0.0
 cut:n j 0.0
c phys:p 0 1 1
 esplt:n 0.5 0.1 0.5 0.01 0.25 0.001
 wwp:n 5 3 5 0 0.5
 nps  20000000
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    **************************************************************
c     Fuel-Basket Nu-61b Cask
c          Density = 2.511 g/cm^3;  Composition by atom fraction
c    **************************************************************
m4    92238.50c  0.19053
      92235.50c  0.00773
      40000.60c  0.13149
      28000.50c  0.01470
      26000.50c  0.11116
      25055.50c  0.00331
      24000.50c  0.03318
      13027.50c  0.11140
       8016.60c  0.39652
c
c    *************************************************************
c     Top Fitting NU-61b Cask
c          Density = 0.446 g/cm^3;  Composition by atom fraction
c    *************************************************************
m5    26000.50c  0.50879
      28000.50c  0.06722
      25055.50c  0.01512
```

```
        24000.50c  0.15180
        40000.60c  0.25707
c
c      ************************************************************
c       Plenum/Basket Nu-61b Cask
c           Density = 0.790 g/cm^3;   Composition by atom fraction
c      ************************************************************
m6      26000.50c  0.32657
        28000.50c  0.04318
        40000.60c  0.25966
        25055.50c  0.00971
        24000.50c  0.09746
        13027.50c  0.26343
c
c      ************************************************************
c       Bottom/Basket Nu-61b
c           Density = 1.284 g/cm^3;  Composition by atom fraction
c      ************************************************************
m7      26000.50c  0.51974
        28000.50c  0.06872
        25055.50c  0.01545
        24000.50c  0.15512
        13027.50c  0.15415
        40000.60c  0.08682
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       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
```

```
        5011.60c  0.00655
c
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     Lead for Gamma Shield  (Standard Composition SCALE4.4)
c         density = 11.34 g/cm^3;  Composition by atom fraction
c    ***********************************************************
m16      82000.50c   1.0
c
c
c    ***********************************************************
c     Polypropylene Disk TN-68 (Table 5.3-1)
c        Density = 0.90 g/cm^3;   Composition by atom fraction
c    ***********************************************************
m17     6012 .33480
        1001 .66520
c
c  prdmp 2j 1
c  print
□
```

5.6.3 MCNP Primary Gamma Input File

```
TransNuclear NU-61B cask:   Near-Field model
c
c    This model calculates doses for fuel gammas
c    at the side of the cask
c
c ***********************  BLOCK 1: CELL CARDS ***********************
c GEOMETRY (r-z)
c
c  ^ z-axis
c  .
c  | ------------------   |  tally surfaces @
c  .___________________.  |     contact,
c  |    impact limiter |  |     1m and
c  .______________.    |  |     2m from surface IL
c  |-------------+--+  |  |     for the radial (side)
c  .-------------+  |  |  |
c  |.............|  |__|  |
c  .  BASKETS    |  |+    |
c  |.............|  ||    |           VOID
c  .             |  ||    |
c  |             |  ||    |
c  .   FUEL      |  ||    |
c  O ------------|--||------------------------------> y-axis
c  |  (12 sub    |  ||    |
c  .   regions)  |  ||    |
c  |             |  ||    |
```

```
c  |.............|  ||
c  .  BASKET     |  |__.
c  |-------------+  |  |
c  .=---------------+  |
c  |   impact limiter  |
c  .___________________|
c  |
c                          M Mason 4/01
c
c ****** Cask cells
  1  8    -7.92   1 -2 -260 #35    imp:n,p=1   $ Fe cask bottom
  2  8    -7.92   2 -12 25 -371 imp:n,p=20   $ Inner shell
  65 8    -7.92   2 -12 371 -21 imp:n,p=45   $ Inner shell
  3  7    -1.284   18 -5 -28        imp:n,p=1  $ bottom basket
  4  6    -0.790   7 -8 -28         imp:n,p=1  $ top plenum basket
  5  5    -0.446   8 -11 -28        imp:n,p=1  $ top fitting
  8  1   -0.0013  11 -19 -28        imp:n,p=1  $ Void between top and canister
  9  1   -0.0013  20 -12 -27   imp:n,p=2  $ Void between canister and lid
  10  8   -7.92 2 -18 -27           imp:n,p=2  $ bottom of canister
  11  8   -7.92  12 -14 -260          imp:n,p=2  $ Fe cask lid - part1
  12  8   -7.92 19 -20 -27   imp:n,p=2  $ top of canister
  25  8   -7.92  18 -19 28 -370    imp:n,p=2    $ The canister
  66  8   -7.92  18 -19 370 -27    imp:n,p=4    $ The canister
  26  1  -0.0013  2 -12 27 -25  imp:n,p=8  $ Void between canister and inner
shell
  27  16   -11.34   333 -12 21 -372 332 -17 2  imp:n,p=100  $ Gamma shield
  64  16   -11.34   333 -12 372 -373 332 -17 2  imp:n,p=250  $ Gamma shield
  63  16   -11.34   333 -12 373 -374 332 -17 2  imp:n,p=600  $ Gamma shield
  62  16   -11.34   2 -17 374 -222 imp:n,p=1500  $ Gamma shield
 662  1    -0.0013  2 -17 222 -22 imp:n,p=1500  $ Gamma Shield gap (.06")
  16  8   -7.92  21 2 -12 -22 #27 #64 #63 #62 #662 imp:n,p=250  $ Gamma
shield CS
  28  8   -7.92  2 -12 22 -375  imp:n,p=4000 $ Outer shell
  67  8   -7.92  2 -12 375 -376  imp:n,p=10000 $ Outer shell
  68  8   -7.92  2 -12 376 -260  imp:n,p=25000 $ Outer shell
c  29  12  -1.687  149 -166 260 -202 #37 #38 #39 #99 #240 #241 #242 #243
c            #260 #261 #262 #263 imp:n,p=60000 $ neutron shield
  29  12  -1.687  198 -199 260 -202 #37 #38 #39 #99 #260 #261
                 #262 #263 #265 #266 #267 #268 #244 imp:n,p=6E4  $ neutron
shield
  36  8  -7.92 149 -166 202 -201 #265 #266 #267 #268 imp:n,p=150000 $ SS Skin
over NS
   6  8   -7.92  (-166 199 260 -202)#37 #38 :
                 (149 -198 260 -202) #39 #99  imp:n,p=1.5E5  $ top & bot ss
plate on NS
  30  0    150 -149 -201 260         imp:n,p=25000 $ void space between BL &
NS
  31  0    161 -14 260 -251          imp:n,p=25000 $ void btw side of TL and
csk
  32  0    155 -150 260 -251         imp:n,p=25000 $ void btw side of BL and
csk
  33  0    155 -1 -260               imp:n,p=25000 $ void btw csk bottom and
BL
  34  0    166 -161 260 -201         imp:n,p=25000 $ void btw top of NS and
TL
  35  0    167 -2 -255               imp:n,p=2 $ canister plug
  c ****** trunnion blocks with trunnion plugs ********
```

```
 c ****** trunnion blocks with trunnion plugs ********
 37  8   -7.92 (195 -344 345 -166 196 -341 260)#260 :
            (195 -330 260 -341 -196) #260 imp:n,p=1.5E5  $ TR trun block
260  17   -0.90 195  -336 260 -341  imp:n,p=1.5E5       $ PP trunnion plug
265  8   -7.92  -334 -300 341  imp:n,p=1.5E5            $ Fe trunnion plug
 38  8   -7.92  (-195 -344 345 -166 196 342 260)#261:
            (-195 -330 260 342 -196) #261 imp:n,p=1.5E5  $ TL trun block
261  17   -0.90  -195 -336 260  342  imp:n,p=1.5E5      $ PP trunnion plug
266  8   -7.92  -334 301 -342  imp:n,p=1.5E5            $ Fe trunnion plug
 39  8   -7.92 (195 -344 345 149 -197 -341 260)#262 :
            (195 -331 260 -341 197) #262 imp:n,p=1.5E5   $ BR trun block
262  17   -0.90  195 -337 260 -341  imp:n,p=1.5E5       $ PP trunnion plug
267  8   -7.92  -335 -300 341  imp:n,p=1.5E5            $ Fe trunnion plug
 99  8   -7.92 (-195 -344 345 149 -197 342 260)#263:
            (-195 -331 260 342 197) #263 imp:n,p=1.5E5   $ BL trun block
263  17   -0.90  -195 -337 260  342  imp:n,p=1.5E5      $ PP trunnion plug
268  8   -7.92  -335 301 -342  imp:n,p=1.5E5            $ Fe trunnion plug
c ******* transport key/pad on cask under-side
 244  8   -7.92   (-348 -349 351 -352 -202 256):(-353 -354 355 -356 260 -256)
                      imp:n,p=6E4 $ key plus pad on body
c **** impact limiters  *****
c  bottom limiter
   80 8  -7.92   (156 -155 -254):(155 -151 -254 251) imp:n,p=25000 $ inside
skn
   81 8  -7.92   (153 -152 -250):(152 -151 -250 253) imp:n,p=25000 $ outside
skn
   82 8  -7.92       151 -150 -250 251      imp:n,p=25000 $ outside skin
   83 15 -0.125      156 -151 -253 254  imp:n,p=25000 $ balsa instead of
redwood
   84 15 -0.125      154 -156 -253 252   imp:n,p=10000 $ balsa instead of
redwood
   85 15 -0.125      154 -156 -252       imp:n,p=500 $ balsa instead of
redwood
   86 15 -0.125      152 -154 -253 252   imp:n,p=1000 $ balsa instead of
redwood
   87 15 -0.125      152 -154 -252         imp:n,p=1 $ balsa
c  top limiter
   90 8  -7.92   (14 -165 -254):(161 -14 -254 251) imp:n,p=25000 $ inside skn
   91 8  -7.92   (162 -163 -250):(161 -162 -250 253) imp:n,p=25000 $ outside
skn
   92 8  -7.92       160 -161 -250 251      imp:n,p=1 $ outside skin
   93 15 -0.125      161 -165 -253 254  imp:n,p=25000 $ balsa instead of
redwood
   94 15 -0.125      165 -164 -253 252  imp:n,p=10000 $ balsa instead of
redwood
   95 15 -0.125      165 -164 -252       imp:n,p=20 $ balsa instead of
redwood
   96 15 -0.125      164 -162 -253 252   imp:n,p=5000 $ balsa instead of
redwood
   97 15 -0.125      164 -162 -252         imp:n,p=1 $ balsa
c   98  0             161 -14 260 -251      imp:n,p=25000 $ space btw lid and
TL
c   98 10 -2.702 (14 -166 -21):(-14 13 29 -21)  imp:n,p=1 $ al spacer
c **** fuel regions
  40 4   -2.511   5  -39 -28          imp:n,p=1  $ FUEL region 1 (bottom)
  401 4  -2.511   39 -40 -28          imp:n,p=1  $ FUEL region 2
  41 4   -2.511   40 -41 -28          imp:n,p=1  $ FUEL region 3
```

```
  42 4   -2.511   41 -42 -28           imp:n,p=1  $ FUEL region 4
  43 4   -2.511   42 -43 -28           imp:n,p=1  $ FUEL region 5
  44 4   -2.511   43 -44 -28           imp:n,p=1  $ FUEL region 6
  45 4   -2.511   44 -45 -28           imp:n,p=1  $ FUEL region 7
  46 4   -2.511   45 -46 -28           imp:n,p=1  $ FUEL region 8
  47 4   -2.511   46 -47 -28           imp:n,p=1  $ FUEL region 9
  48 4   -2.511   47 -48 -28           imp:n,p=1  $ FUEL region 10
  481 4  -2.511   48 -49 -28           imp:n,p=1  $ FUEL region 11
  49 4   -2.511   49 -7  -28           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
  601 0   #265 #266 #267 #268 150 -161  201 -62  imp:n,p=150000 $ inner air
(void)
  602 0            150 -161  62 -63    imp:n,p=150000 $ inner air (void)
  603 0 (60 -61 250 -65):(150 -161 63 -250) imp:n,p=150000 $ inner air (void)
  606 0            60 -61 65 -64     imp:n,p=150000 $ inner air (void)
  605 0             60 -61 -172 64     imp:n,p=0    $ outer air (void)
  190 0           -170:171:172         imp:n,p=0    $ problem boundary

c ***********************  BLOCK 2: SURFACE CARDS ***********************
c **** Horizontal cask planes
  1   pz  -237.26       $ cask bottom - ground surface
  2   pz  -220.75      $ top of csk bottom, canister 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
  11  pz   245.90       $ top of top fitting
  12  pz   279.65       $ cask top - bot of lid
  14  pz   291.08       $ cask top - top of Fe
c  17  pz   268.89       $ top of GS, slice cone
  17  pz   270.74       $ top of GS, slice cone
  18  pz   -201.65      $ top of canister bottom
  19  pz   253.77       $ bottom of canister top
  20  pz   276.43       $ top of canister
  31  pz   244.00       $ top of alum, bot of void
  148 pz   -178.155     $ Al/Void Bndry btw BL and NS
  149  pz  -176.30      $ bottom of neutron shield
  150  pz  -177.58      $ top of bottom limiter
  151  pz  -178.22      $ inside skin bottom limiter
  152  pz  -331.24      $ inside skin bottom limiter
  153  pz  -331.88      $ bottom of bottom limiter
  154  pz  -275.94      $ top of balsa disk bottom limiter
  155  pz  -241.71      $ top of inside skin bottom limiter
  156  pz  -242.34      $ Inside skin BL
  160  pz   227.64      $ inside skin top limiter
  161  pz   227.01      $ bottom of top limiter
  162  pz   380.68      $ inside skin  top limiter
  163  pz   381.25      $ top of top limiter
  164  pz   327.98      $ bottom of balsa disc top limiter
  165  pz   291.72      $ top of inside skin top limiter
  166  pz   226.30      $ top of neutron shield
  167  pz   -229.64     $ bottom of canidter plug
  300  px   118.12      $ outside of trunion plug
```

```
  301  px   -118.12     $ outside of trunion plug
  340  pz   166.823     $ flat trun cutout
  341  px   109.86      $ trunnion block
  342  px   -109.86     $ trunnion block
  343  pz   -120.573    $ flat trun cutout
  344  py    34.29      $ Trunion block
  345  py   -34.29      $ Trunion block
  348  p    -3.014893 1.0 0. 0.   $ keyway surface
  349  p     3.014893 1.0 0. 0.   $ keyway syrface
  351  pz   9.80        $ bottom of key
  352  pz   40.44       $ top of key
  353  p   -2.050304 1.0 0. 0.    $ key pad surface
  354  p    2.050304 1.0 0. 0.    $ key pad surface
  355  pz   -20.52      $ bottom of key pad
  356  pz   70.92       $ top of key pad
  195  px    0.0        $ ambiguity surface
  196  pz    183.08     $ centerline of top trunnions
  197  pz   -133.12     $ centerline of bottom trunnions
  198  pz   -172.49     $ Inside steel plate on NS
  199  pz    222.49     $ Inside steel plate on NS
c ***** cylindrical cask surfaces
  25   cz   86.36      $ cask inner surface outside of void (see 27)
  371  cz   88.0       $ split of inner surface
  21   cz   89.535     $ outside inner shell inside gamma sheild
  372  cz   92.1       $ gamma shield split
  373  cz   94.2       $ gamma shield split
  374  cz   96.0       $ gamma shield split
  22   cz   97.79      $ outside gamma sheild inside outer shell
  222  cz   97.64      $ lead gap at outer shell interface
  375  cz   100.5       $ split of outer shell
  376  cz   103.0      $ split of outer shell
  251  cz   105.41     $ Inside radius BL
  260  cz   104.15    $ inside NS
  202  cz   115.72     $ outside of neutron sheild
  201  cz   116.20     $ outside of SS Skin
  27   cz   85.41      $ outside radius of canister
  28   cz   83.02      $ inside radius of canister outside fuel rad
  370  cz   83.75      $ Split canister
  250  cz   155.00     $ outside radius of impact limiter
  252  cz   96.5      $ radius of balsa disk
  253  cz   154.4      $ outside radius inside skin
  254  cz   106.04     $ inside skin
  255  cz   12.7       $ canister plug
  256  cz   107.96     $ outside of key pad (1.5" thk)
  330  c/x  0 183.08 34.29  $ trunnion block
  331  c/x  0 -133.12 34.29  $ trunnion block
  334  c/x  0 183.08 31.75  $ trunnion plug Fe
  335  c/x  0 -133.12 31.75  $ trunnion plug Fe
  336  c/x  0 183.08 21.59  $ trunnion plug PP
  337  c/x  0 -133.12 21.59  $ trunnion plug PP
c ****** cone surfaces *****************
  332  kz   -118.64  0.0566  $ tapering of STS
  333  kz    168.63  0.0566  $ tapering of STS
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  -334.095        $ bottom tally surface
  61  pz   382.31        $ top tally surface
  62  cz   125.0        $ radial tally surface  (outer shell)
  63  cz   152.0        $ radial tally surface   (rail car edge)
  64  cz   355.00        $ radial tally surface   (2 m from IL)
  65  cz   215.72       $ radial tally surface (1m from cask)
  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
  29  cz    101.45      $ segmentation cylinder
  23  cz    124.47      $ segmentation cylinder
  350 cz    182.88      $ segmentation cylinder

c ***********************  BLOCK 3: DATA CARDS ***************************
c
c
c  --- gamma-ray source for fuel in TN61  12 yr cooled-- 12 axial cylindrical
zones (inner)
c      7x7 fuel assemblies; 35,000 MWd/Mt design basis; 12y cooling time
SDEF  par=2 pos= 0 0 0  axs=0 0 1  rad=d1  ext=d2   erg d6  cel=d7
 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
SI6  H   0.01 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  .2709  .0759  .0534  .0159  .0104  .0280        $ bin probs.
- fuel
              .5111  .0151  .0165  .0028
SI7 L 40 401 41 42 43 44 45 46 47 48 481 49         $ 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
c SB4   0.05      0.05      0.1       0.1       0.1       0.1
c       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    2.332E25      $ convert Sv/neutron to mrem/h for fuel zones
c      1.071E15 x 61 X 0.9917 (NF) X 3600 X 1E5 = 2.332E25
c TF2 3j 6
```

```
FC2  Doses at contact averaged over subsurfaces
F2:p  201
FS2   -71 -39 -40 -41 -42 -43 -44 -45 -46 -47 -48 -49 -72 -8 -11
SD2  3.0E7 18552.00 13353.64 26699.98 26707.28 26736.49
      26670.78 26670.78 26736.49 26707.28 26699.98
       13353.64 25853.06 18048.22 15463.65 3.0E7
FC12    Doses at 1 meters from cask averaged over subsurfaces
F12:p   65
FS12  -152 -154 -155 -71 -39 -40 -41 -42 -43 -44 -45 -46 -47
      -48 -49 -72 -8 -11 -165 -164 -162
SD12   1.0E8 76825.71 43985.79 72757.22 34517.57 24845.59 49677.59
          49691.17 49745.51 49623.25 49623.25 49745.51 49691.17
          49677.59 24845.59 48101.82 33580.26 28771.43
          59648.43 51783.15 71697.65 8.0E7
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 126147.67 72224.59 119467.23 56677.79 40796.41 81570.51
          81592.81 81682.04 81481.29 81481.29 81682.04 81592.81
          81570.51 40796.41 78983.09 55138.72 47242.64
          97942.61 85027.83 117727.41 8.0E7
c
c
 mode p
 phys:p 20.0 0.0
c cut:n j 0.0
c phys:p 0 1 1
c esplt:n 0.5 0.1 0.5 0.01 0.25 0.001
c wwp:n 5 3 5 0 0.5
 nps  300000000
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    ***** 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      Fuel-Basket Nu-61b Cask
c           Density = 2.511 g/cm^3;  Composition by atom fraction
c     *************************************************************
m4     92238  0.19053
       92235  0.00773
       40000  0.13149
       28000  0.01470
       26000  0.11116
       25055  0.00331
       24000  0.03318
       13027  0.11140
        8016  0.39652
c
c     ************************************************************
c      Top Fitting NU-61b Cask
c           Density = 0.446 g/cm^3;  Composition by atom fraction
c     ************************************************************
m5     26000  0.50879
       28000  0.06722
       25055  0.01512
       24000  0.15180
       40000  0.25707
c
c     ************************************************************
c      Plenum/Basket Nu-61b Cask
c          Density = 0.790 g/cm^3;   Composition by atom fraction
c     ************************************************************
m6     26000  0.32657
       28000  0.04318
       40000  0.25966
       25055  0.00971
       24000  0.09746
       13027  0.26343
c
c     ************************************************************
c      Bottom/Basket Nu-61b
c          Density = 1.284 g/cm^3;  Composition by atom fraction
c     ************************************************************
m7     26000  0.51974
       28000  0.06872
       25055  0.01545
       24000  0.15512
       13027  0.15415
       40000  0.08682
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      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     ************************************************************
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      Lead for Gamma Shield  (Standard Composition SCALE4.4)
c          density = 11.34 g/cm^3;  Composition by atom fraction
c     ************************************************************
m16      82000   1.0
c
c
c     ************************************************************
c      Polypropylene Disk TN-68 (Table 5.3-1)
c         Density = 0.90 g/cm^3;   Composition by atom fraction
c     ************************************************************
m17     6012 .33480
        1001 .66520
c
c  prdmp 2j 1
c  print
```

TABLE 5.1-1

NUHOMS® MP-197/61BT SHIELD MATERIALS

Component	Material	Density (g/cm^3)	Thickness (inches)
Cask Body Wall	Stainless Steel Lead	7.92 11.34	3.75 3.25
Cask Lid	Stainless Steel	7.92	4.50
Cask Bottom	Stainless Steel	7.92	6.50
Resin [a]	Polyester Resin Styrene Aluminum Hydrate Zinc Borate	1.58	4.56
Aluminum Box [a]	Aluminum	2.7	0.12
Outer Shell	Stainless Steel	7.92	0.19
Basket [b]	Stainless Steel Aluminum Neutron Poison Material [b]	7.92 2.7	Homogenized into source region
Rails	Stainless Steel	7.92	0.44"
Impact Limiter	Stainless Steel Redwood Balsa Wood	7.92 0.387 0.125	0.25 19.25[c] 15.25[c]
Canister Wall	Stainless Steel	7.92	0.5"
Canister Lids	Stainless Steel	7.92	8.92"
Canister Bottom	Stainless Steel	7.92	7.5"

a The neutron shielding is borated polyester resin compound with a density of 1.58 g/cc. and is homogenized with the aluminum box to a combined thickness of 4.56".

b This is modeled as plain aluminum for shielding purposes .

c Thickness of wood is variable, redwood modeled as balsa.

TABLE 5.1-2

SUMMARY OF DOSE RATES
(Exclusive Use)

Normal Conditions	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	0.011 (1.1)	0.13 (13)	0.014 (1.4)	-	0.054 (5.4)	-	-	0.029 (2.9)	-
Neutron	0.009 (0.9)	1.25 (125)[1]	0.023 (2.3)	-	0.170 (17.0)	-	-	0.071 (7.1)	-
Total	0.020 (2.0)	1.38(137)	0.037 (3.7)	-	0.22 (22)	-	-	0.1 (10)	-
Limit	10 (1000)	10 (1000)	10 (1000)		2 (200)			0.1 (10)	

Hypothetical Accident Conditions	1 Meter from Package Surface mSv/h (mrem/h)		
Radiation	Top	Side	Bottom
Gamma	< 0.008 (0.8)	0.15 (15)	< 0.011 (1.1)
Neutron	< 0.009 (0.9)	4.25 (425)	< 0.020 (2.0)
Total	< 0.017 (1.7)	4.41 (440)	< 0.031 (3.1)
Limit	10 (1000)	10 (1000)	10 (1000)

(1) Dose around key-way on cask

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 5.2-1

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[c]	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 2.65wt% U235,
35,000 MWD/MTU, AND 12 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	4.07E+04			
29	6.50E+00 to 8.00E+00	1.92E+05			
30	5.00E+00 to 6.50E+00	9.78E+05			
31	4.00E+00 to 5.00E+00	2.44E+06			
32	3.00E+00 to 4.00E+00	3.76E+07			
33	2.50E+00 to 3.00E+00	4.03E+08			
34	2.00E+00 to 2.50E+00	4.44E+09			
35	1.66E+00 to 2.00E+00	3.04E+10			
36	1.33E+00 to 1.66E+00	2.90E+12	9.54E+10	3.03E+11	3.22E+11
37	1.00E+00 to 1.33E+00	1.72E+13	3.38E+11	1.07E+12	1.14E+12
38	8.00E-01 to 1.00E+00	1.57E+13			
39	6.00E-01 to 8.00E-01	5.32E+14			
40	4.00E-01 to 6.00E-01	2.92E+13			
41	3.00E-01 to 4.00E-01	1.09E+13			
42	2.00E-01 to 3.00E-01	1.65E+13			
43	1.00E-01 to 2.00E-01	5.55E+13			
44	5.00E-02 to 1.00E-01	7.90E+13			
45	1.00E-02 to 5.00E-02	2.82E+14			
	Total	1.04E+15	4.33E+11	1.38E+12	1.46E+12

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

TABLE 5.2-6
NEUTRON SOURCE DISTRIBUTION
GENERAL ELECTRIC 7x7,
BUNDLE AVERAGE ENRICHMENT 2.65wt% U-235,
35,000 MWD/MTU, AND 12 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	1.36E+06
2	3.00E+00 to 6.43E+00	1.55E+07
3	1.85E+00 to 3.00E+00	1.72E+07
4	1.40E+00 to 1.85E+00	9.67E+06
5	9.00E-01 to 1.40E+00	1.31E+07
6	4.00E-01 to 9.00E-01	1.42E+07
7	1.00E-01 to 4.00E-01	2.79E+06
	Total	7.38E+07

TABLE 5.2-7

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	1.727	U-235	92235	1.502E-04
			U-238	92238	3.703E-03
			O	8016	7.706E-03
	Zircaloy	0.394	Zr	40302	2.556E-03
	SS304	0.293	Cr	24304	6.448E-04
			Mn	25055	6.424E-05
			Fe	26304	2.160E-03
			Ni	28304	2.856E-04
	Aluminum	0.097	Al	13027	2.165E-03
Plenum/Basket*	Zircaloy	0.329	Zr	40302	2.134E-03
	SS304	0.364	Cr	24304	8.010E-04
			Mn	25055	7.980E-05
			Fe	26304	2.684E-03
			Ni	28304	3.548E-04
	Aluminum	0.097	Al	13027	2.165E-03
Top Fitting/Basket	Zircaloy	0.163	Zr	40302	1.056E-03
	SS304	0.283	Cr	24304	6.237E-04
			Mn	25055	6.214E-05
			Fe	26304	2.901E-03
			Ni	28304	2.762E-04
Bottom Fitting/Basket*	Zircaloy	0.188	Zr	40302	2.179E-03
	SS304	0.999	Cr	24304	2.170E-04
			Mn	25055	7.300E-03
			Fe	26304	9.651E-04
			Ni	28304	1.219E-03
	Aluminum	0.0.097	Al	13027	2.165E-03
Basket Periphery (rails)	SS304	7.92	Cr	24304	1.743E-02
			Mn	25055	1.736E-03
			Fe	26304	5.936E-02
			Ni	28304	7.721E-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
(gamma shield)	Lead	11.34	Pb	82000	3.296E-02
Impact Limiter	Balsa Wood	0.125	C	6012	2.787E-03
			O	8016	2.323E-03
			H	1001	4.646E-03

* - One-half of basket mass in the region for radial, 20% for axial (data not shown)

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

FIGURE 5.1-1

NUHOMS®-MP197 CASK SHIELDING CONFIGURATION

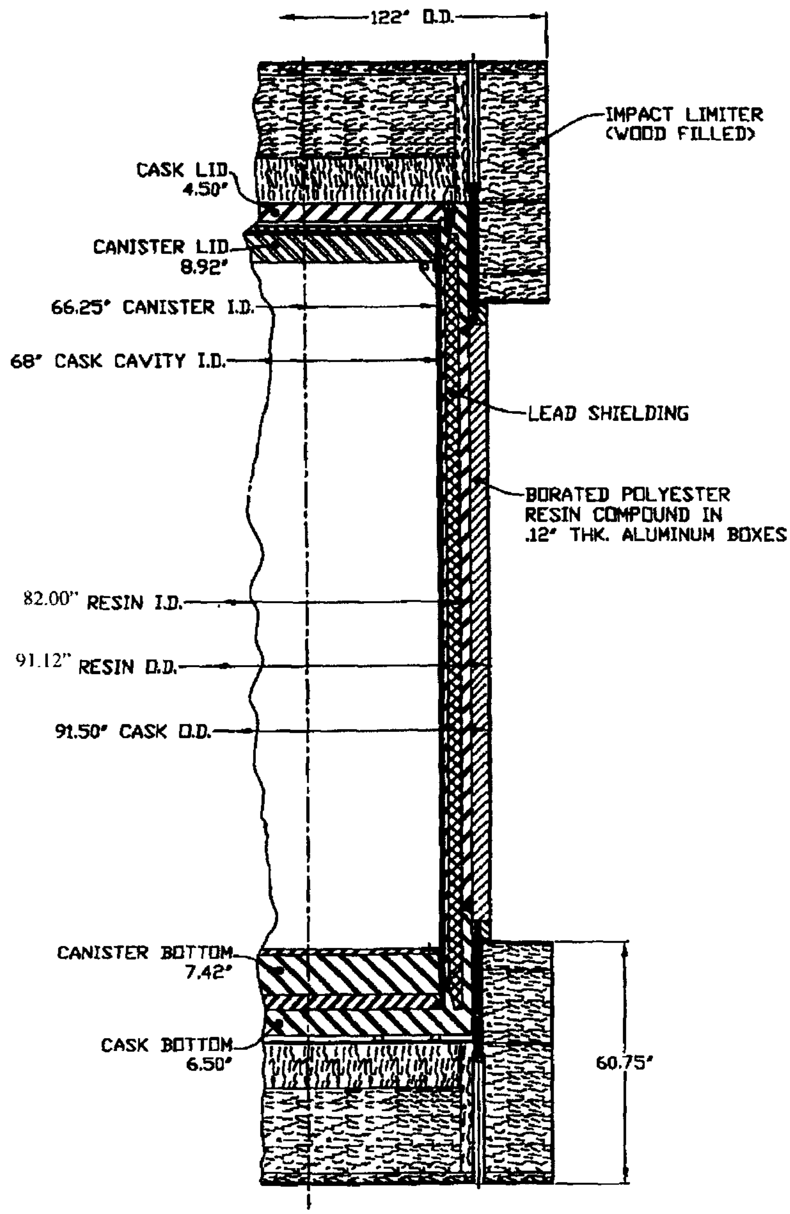


FIGURE 5.2-1

AXIAL BURNUP PROFILE FOR DESIGN BASIS FUEL

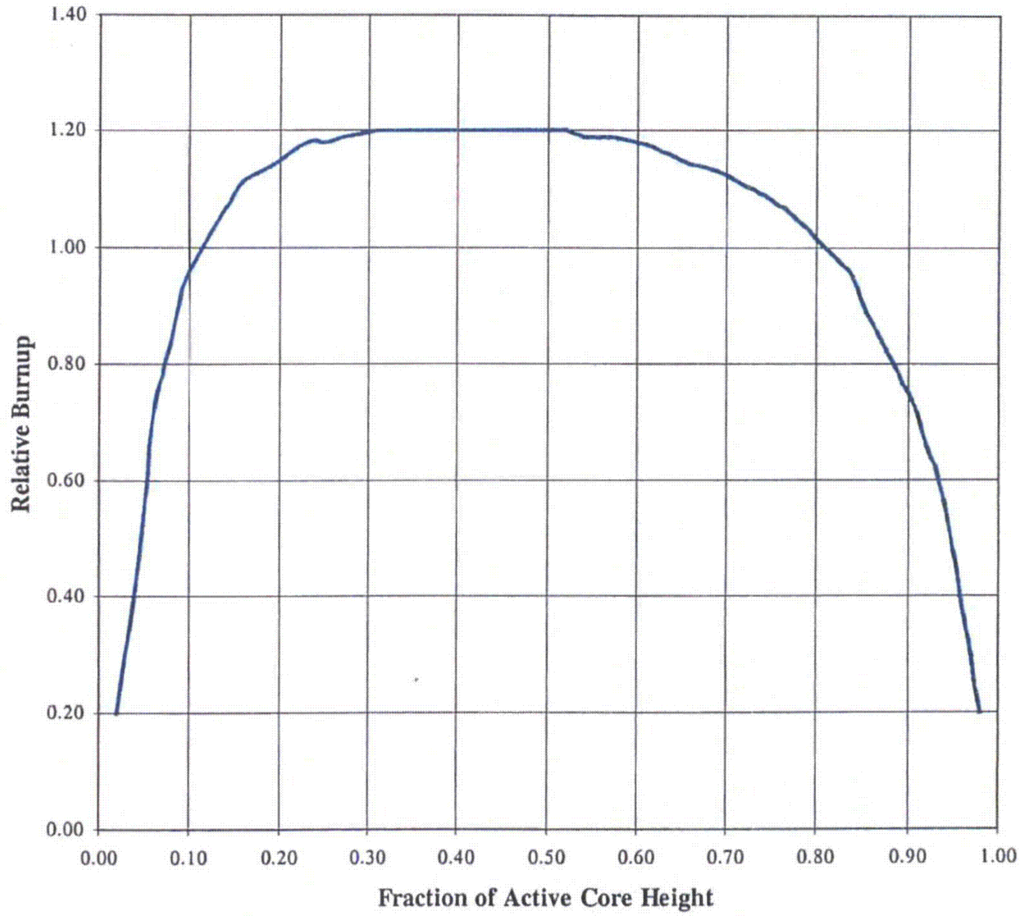
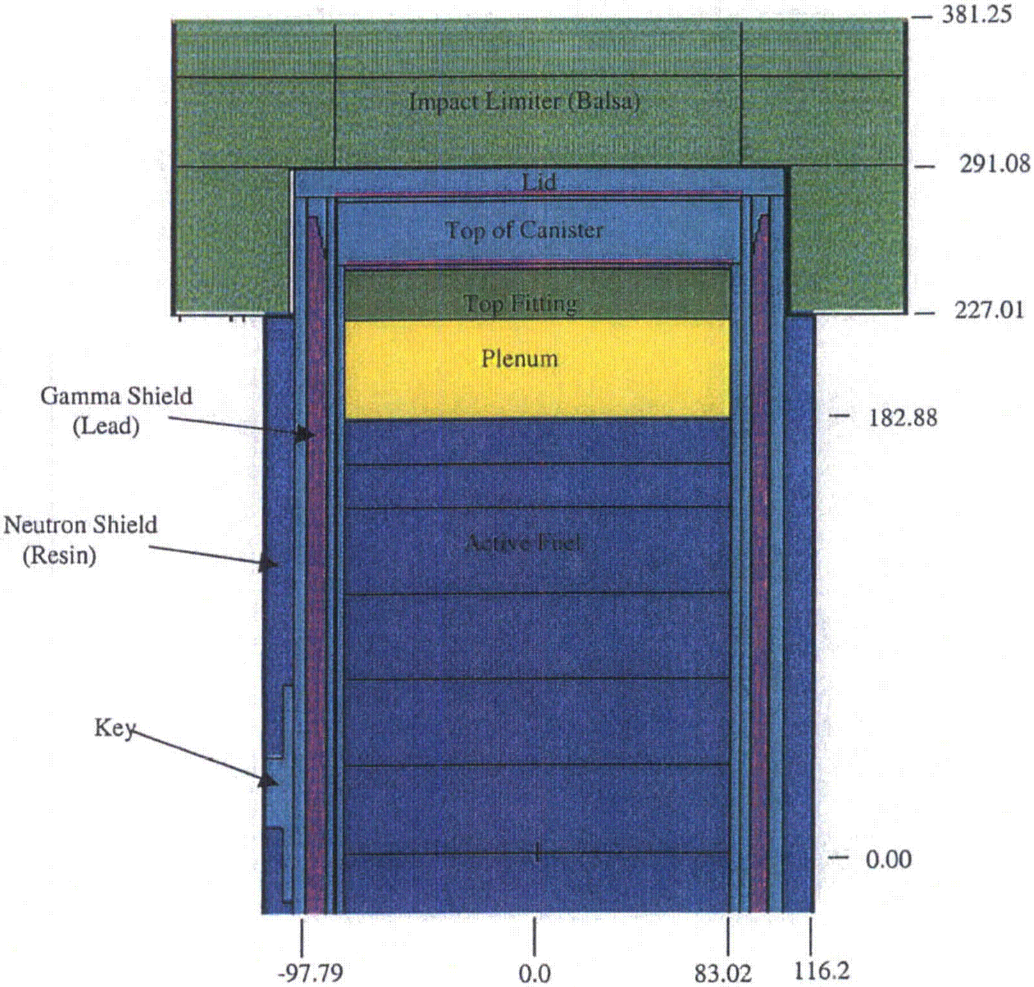


FIGURE 5.3-1

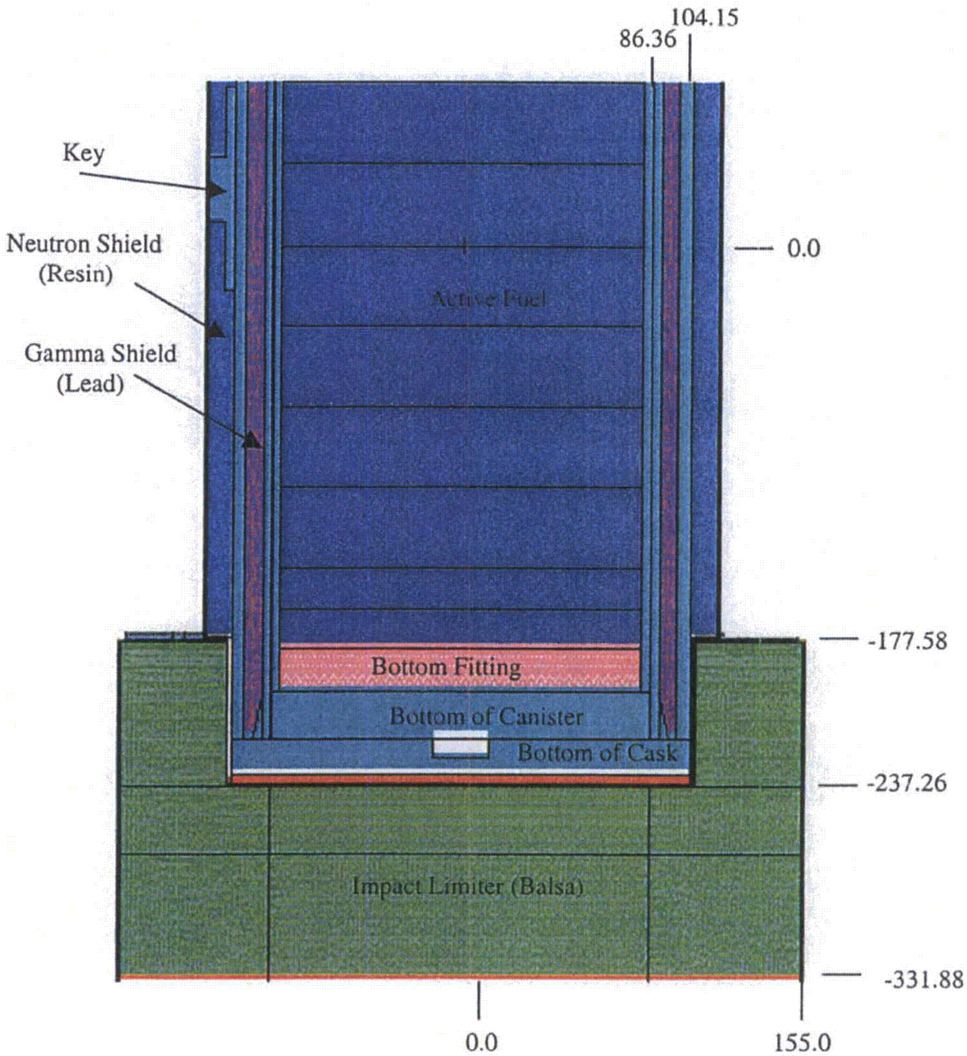
MCNP TOP HALF MODEL



All dimensions in cm.

FIGURE 5.3-2

MCNP BOTTOM HALF MODEL



All dimensions in cm.

FIGURE 5.4-1
NUHOMS®-MP197 RADIAL GAMMA DOSE RATE PROFILE

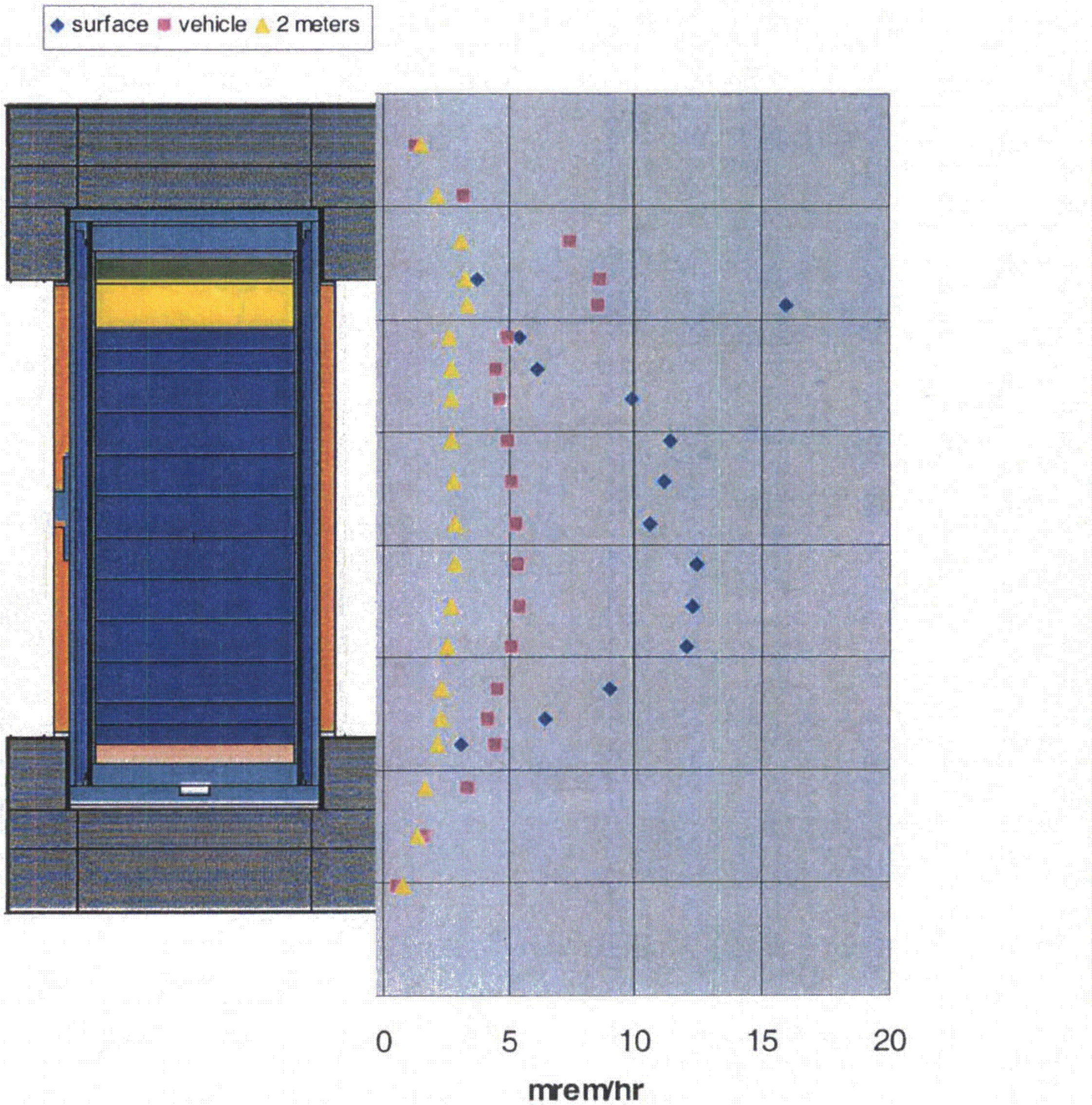


FIGURE 5.4-2

NUHOMS®-MP197 RADIAL NEUTRON DOSE RATE PROFILE

FIGURE 5.4-3

NUHOMS®-MP197 GAMMA DOSE RATE
IMPACT LIMITER SURFACE

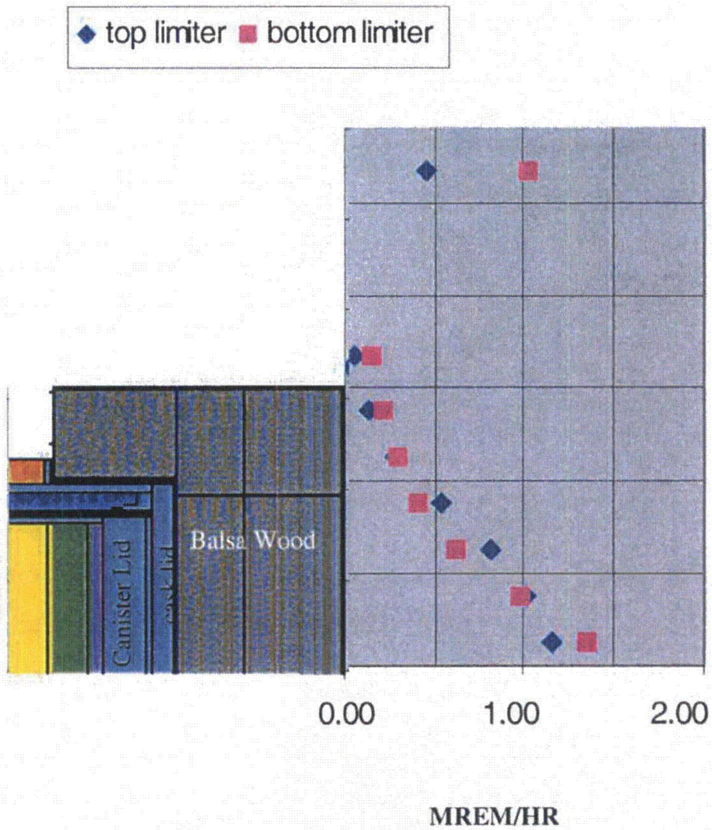
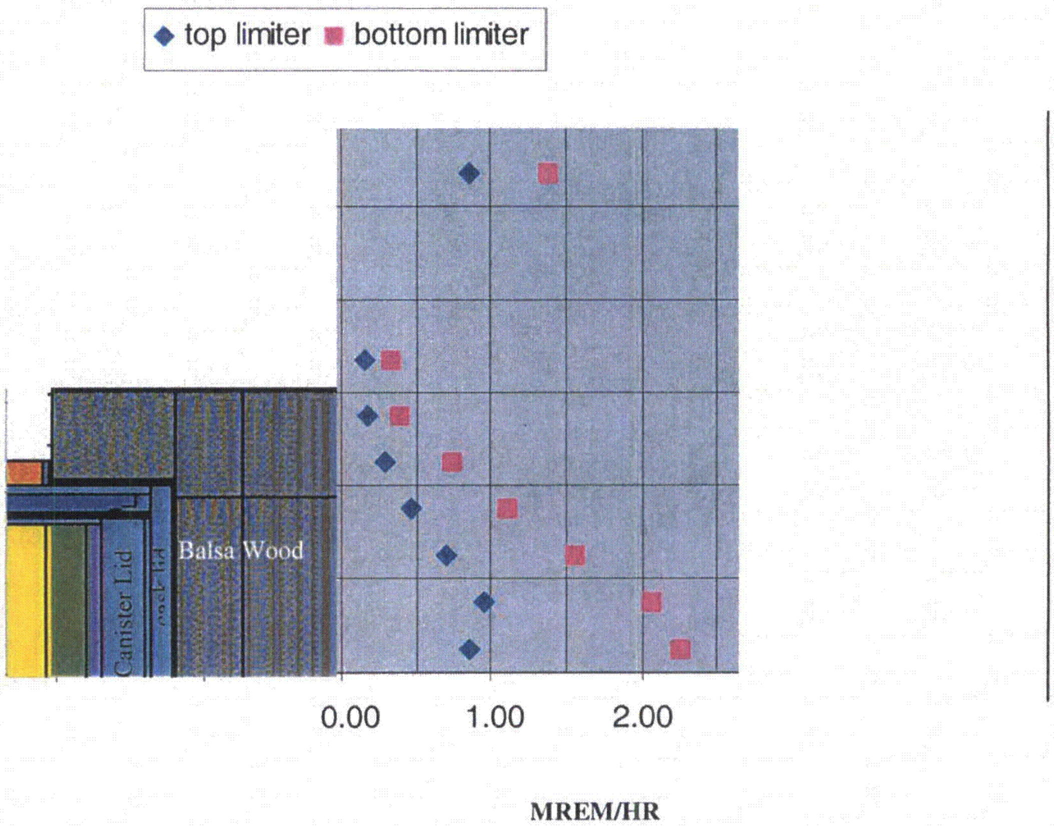


FIGURE 5.4-4
NUHOMS®-MP197 NEUTRON DOSE RATE
IMPACT LIMITER SURFACE



CHAPTER 6

TABLE OF CONTENTS

Page

6 CRITICALITY EVALUATION

6.1 Design 6-1
6.1.1 Discussion and Results 6-1

6.2 Package Fuel Loading 6-1

6.3 Model Specification 6-2
6.3.1 Description of Calculational Model 6-2
6.3.2 Package Regional Densities 6-3

6.4 Criticality Calculation 6-3
6.4.1 Calculational Method 6-4
6.4.2 Fuel Loading Optimization 6-6
6.4.3 Criticality Results (Infinite Array) 6-9
6.4.4 Criticality Results (Single Cask) 6-9

6.5 Criticality Benchmark Experiments 6-10
6.5.1 Benchmark Experiments and Applicability 6-10
6.5.2 Results of the Benchmark Calculations 6-11

CHAPTER 6

CRITICALITY EVALUATION

6.1 Design

The design criteria for the NUHOMS®-61BT Dry Shielded Canister (DSC) to be transported in the NUHOMS®-MP197 transport package require that the package remain subcritical under normal conditions of transport (NCT) and hypothetical accident conditions (HAC) as defined in 10CFR Part 71.

The NUHOMS®-61BT System's criticality safety is ensured by both fixed neutron absorbers and favorable geometry. Burnup credit is not taken in this criticality evaluation. The fixed neutron absorber may be one of several different types of borated metallic plates. The materials description, acceptance testing, and the boron 10 credit allowed for the various fixed absorber materials are included in Chapter 8.

No credit is taken for moderator exclusion by the DSC.

6.1.1 Discussion and Results

Figure 6-1 shows the cross section of the NUHOMS®-61BT DSC. The analysis presented herein is performed for a NUHOMS®-61BT DSC in a the MP-197 transportation cask. The cask consists of an inner stainless steel shell, and lead gamma shield, a stainless steel structural shell and a hydrogenous neutron shield. The NUHOMS®-MP197 configuration is shown to be subcritical under NCT and HAC.

The calculations determine k_{eff} with the CSAS25 control module of SCALE-4.4 [6.1] for various configurations and initial enrichments, including all uncertainties to assure criticality safety under all credible conditions.

The results of the evaluation demonstrate that the maximum k_{eff} - including statistical uncertainty - is less than the Upper Subcritical Limit (USL) determined from a statistical analysis of benchmark criticality experiments. The statistical analysis procedure includes a confidence band with an administrative safety margin of 0.05.

6.2 Package Fuel Loading

The NUHOMS®-MP-197 is capable of transporting intact BWR fuel assemblies with or without fuel channels. The maximum lattice-averaged enrichment of the fuel depends on the boron content in the fixed poison plates in the basket, as shown in Table 6-1. The fuel assemblies considered as authorized contents are listed in Table 6-2.

Table 6-3 lists the fuel parameters for the standard BWR fuel assemblies. The design basis fuel chosen for the NUHOMS®-MP197 Packaging criticality analysis is the GE 10×10 fuel assembly because it is the most reactive fuel assembly of the authorized contents, as demonstrated in the appendix to this chapter.

An infinite array of packages with optimal internal and interspersed moderation is evaluated to demonstrate compliance with 10CFR71.59(a)(1) and 10CFR71.59(a)(2). For 10CFR71.55(b), the effect of external reflection for a single cask is evaluated by modeling the confinement boundary (canister) surrounded by full density water. The variation in external reflection is provided by progressively modeling the various cask shells surrounding the canister, in separate calculations, surrounded by full density water. Because an infinite array of packages is used to evaluate both NCT and HAC, the *criticality safety* index *(CSI)* for *nuclear* criticality *control* is zero.

6.3 Model Specification

The following subsections describe the physical models and materials of the NUHOMS®-MP197 packaging used for input to the CSAS25 module of SCALE-4.4 [6.1] to perform the criticality evaluation.

6.3.1 Description of Calculational Model

The cask and the DSC were explicitly modeled using the appropriate geometry options in KENO V.a of the CSAS25 module in SCALE-4.4.

Two models were developed. The first model is a full-active fuel height model and full-radial cross section of the DSC alone with water boundary conditions on the ends and reflective boundary conditions on the sides. The model does not include the gaps between the poison plates. This model is more fully described in Section 6.6.2. This model is only used to determine the most reactive fuel assembly/channel combination and to justify use of the lattice average enrichment for the intact fuel analysis. The second model is a full-active fuel height model and full radial cross section of the cask and DSC with reflective boundary conditions on all sides. This model includes the worst case gaps between the poison plates and the basket internals modeled at minimum material conditions. This model includes the GE12 10×10-fuel assembly only because this assembly type is determined to be the most reactive fuel assembly type of the authorized contents. The GE12 10×10-fuel assembly is modeled as a 10×10 array comprising 92 fuel rods, including fuel, gap and cladding and two large water holes. The fuel cladding OD is also reduced by 0.010 inches in the final models to conservatively bound fuel manufacturing tolerances.

Figure 6-2 is a sketch of each KENO V.a unit showing all materials and dimensions for each unit and an annotated cross section map showing the assembled geometry units in the radial direction of the model. The assembly-to-assembly pitch is a variable in the model with the fuel assemblies modeled in the center of the fuel cells and pushed towards the center and away from the center of the basket. The poison plates are modeled with minimum plate thickness, width and length. The maximum gap between the plates is modeled in the worst case orientation to maximize the amount of "uncovered" fuel. The gaps between the poison plates are due to the need to provide space for thermal expansion of the poison plates relative to the stainless steel parts of the basket and to allow for fabrication tolerances in the basket. In addition, the NUHOMS®-61BT DSC design allows the poison plates to be fabricated in sections, rather than one continuous piece. In the axial direction, all gaps are modeled at the maximum width. Table 6-4 provides the axial position of the assembled KENO V.a geometry units. Figure 6-3 shows the second model in the bounding configuration.

An infinite array of damaged packages in a rectangular lattice is modeled by the use of mirror reflection on all six sides of a cuboid surrounding the package model (the second model described above). Neither the neutron shield nor the impact limiters are modeled, which reduces the pitch between packages in the array.

6.3.2 Package Regional Densities

The Oak Ridge National Laboratory (ORNL) SCALE code package [6.1] contains a standard material data library for common elements, compounds, and mixtures. All the materials used for the cask and DSC analysis are available in this data library. The neutron shield material in the MP197 is modeled as water and the neutron shield skin is not modeled.

Table 6-5 provides a complete list of all the relevant materials used for the criticality evaluation. The B-10 areal density specified for manufacturing of the poison plates will be larger than the areal density used in the calculations (and listed in this table), in order the satisfy the 75% or 90% B10 credit allowance as specified in Chapter 8. The cask neutron shield material is conservatively modeled as water. The actual neutron shield hydrogen atom density is lower than that of water; therefore, replacing the neutron shield with water is slightly conservative.

6.4 Criticality Calculation

This section describes the models used for the criticality analysis. The analyses were performed with the CSAS25 module of the SCALE system. A series of calculations were performed to determine the most reactive fuel and configuration. The most reactive fuel, as demonstrated by the analyses, is the GE12 10×10 assembly. The most reactive credible configuration is an infinite array of flooded casks with minimum assembly-to-assembly pitch and the poison plate gaps located near the center of the basket and at the centerline of the active fuel region.

6.4.1 Calculational Method

6.4.1.1 Computer Codes

The CSAS25 control module of SCALE-4.4 [6.1] was used to calculate the effective multiplication factor (k_{eff}) of the fuel in the cask. The CSAS25 control module allows simplified data input to the functional modules BONAMI-S, NITAWL-S, and KENO V.a. These modules process the required cross sections and calculate the k_{eff} of the system. BONAMI-S performs resonance self-shielding calculations for nuclides that have Bondarenko data associated with their cross sections. NITAWL-S applies a Nordheim resonance self-shielding correction to nuclides having resonance parameters. Finally, KENO V.a calculates the k_{eff} of a three-dimensional system. A sufficiently large number of neutron histories are run so that the standard deviation is below 0.0020 for all calculations.

6.4.1.2 Physical and Nuclear Data

The physical and nuclear data required for the criticality analysis include the fuel assembly data and cross-section data as described below.

The criticality analysis used the 44-group cross-section library built into the SCALE system. ORNL used ENDF/B-V data to develop this broad-group library specifically for criticality analysis of a wide variety of thermal systems.

6.4.1.3 Bases and Assumptions

The analytical results reported in chapter 2 demonstrate that the cask containment boundary and DSC basket structure do not experience any significant distortion under hypothetical accident conditions. Therefore, for both normal and hypothetical accident conditions the cask geometry is identical except for the neutron shield and skin. As discussed above, the neutron shield and skin are conservatively modeled as water.

The cask was modeled with KENO V.a using the available geometry input. This option allows a model to be constructed that uses regular geometric shapes to define the material boundaries. The following conservative assumptions were also incorporated into the criticality calculations:

1. Omission of grid plates, spacers, and hardware in the fuel assembly.
2. No burnable poisons accounted for in the fuel.
3. Water density at optimum internal and external moderator density.
4. Unirradiated fuel – no credit taken for fissile depletion due to burnup or fission product poisoning.

5. Where fuel pins have variable axial enrichment, the average is calculated for each axial zone (lattice), and the lattice with the highest average enrichment is used to characterize the entire bundle for criticality purposes. The average enrichment is defined as the simple arithmetic average of pin enrichments:

$$E_{avg} = \sum_{i=1,n} E_i \Big/ n$$

Where E_i is the enrichment of pin i, and n is the number of fuel pins in the lattice. There is no averaging of the axial enrichment variation in this evaluation; "bundle average" enrichments, which are an average enrichment over the entire fuel bundle, including natural uranium blankets, are not used to qualify fuel for criticality purposes.

The lattice average fuel enrichment is modeled as uniform everywhere throughout the assembly. Natural Uranium blankets and axial or radial enrichment zones are modeled as enriched uranium.

6. All fuel rods are assumed to be filled with 100% moderator in the pellet/cladding gap.

7. Only the active fuel length of each assembly type is explicitly modeled. The presence of the plenum materials, end fittings, channel material above and below the active fuel reduce the k_{eff} of the system, therefore; these regions are modeled as water or the reflective boundary conditions. For the cases with reflective boundary conditions, the model is effectively infinitely long.

8. It is assumed that for all Hypothetical Accident Conditions (HAC) cases the neutron shield and stainless steel skin of the cask are stripped away and replaced with moderator.

9. The least material condition (LMC) is assumed for the fuel clad OD, fuel compartment, poison plates and wrappers. This minimizes neutron absorption in the steel sheets and poison plates.

10. The maximum allowed gap between the poison plates in the worst case position is explicitly modeled to maximize k_{eff}.

11. The active fuel region is conservatively assumed to start level with the bottom of the poison plates.

12. Temperature at 20 °C (293 K).

13. Used 95% theoretical density for fuel although this assumption conservatively increases the total fuel content in the model.

6.4.1.4 Determination of k_{eff}.

The criticality calculations were performed with the CSAS25 control module in SCALE-4.4. The Monte Carlo calculations performed with CSAS25 (KENO V.a) used a flat neutron starting distribution. The total number of histories traced for each calculation was approximately 500,000. This number of histories was sufficient to converge the source and produce standard deviations of less than 0.2% in k_{eff}. The maximum k_{eff} for the calculation was determined with the following formula:

$$k_{eff} = k_{KENO} + 2\sigma_{KENO.}$$

6.4.2 Fuel Loading Optimization

A. Determination of the Most Reactive Fuel Lattice

All fuel lattices, with and without channels, listed in Table 6-3 are evaluated to determine the most reactive fuel assembly type. The lattices are analyzed with water in the fuel pellet cladding annulus and are centered in the fuel compartments. Each lattice is also analyzed with a 0.065, 0.080 and 0.120 inch thick channel to determine the most reactive configuration. The results show that the reactivity change due to the fuel channels is within the statistical uncertainty of the KENO V.a calculations. Finally, this model is used for three cases that demonstrate that the use of lattice average enrichment is conservative for intact fuel. One case each for the GE2 (7x7 Array), GE5 (8x8 Array) and the GE9 (8x8 Array). Figure 6-5 provides a lattice map of the three assemblies evaluated including the enrichment modeled for each fuel pin. The following results are extracted from Table 6-6.

Lattice Average Compared to Variable Enrichment Models

Assembly Version	Lattice Average Case k_{eff}	Explicit Variable Enrichment Case k_{eff}
GE2 (7x7 Array)	0.9061	0.8971
GE5 (8x8 Array)	0.9031	0.8973
GE9 (8x8 Array)	0.9069	0.9034

For this analysis, only the DSC is modeled. The DSC is modeled over the active fuel height of the fuel with water reflectors at the ends (z) and reflective boundary conditions outside the DSC (infinite array in the x-y directions) The DSC model for this evaluation differs from the actual design in the following ways:

- the boron 10 areal density specified for manufacturing the poison plates will be greater than that used in the model, as described in Chapter 8,
- no gaps between poison plates are modeled,
- the stainless steel basket rails, which hold the basket together, are modeled as water.

In all other respects, the model is the same as that described in Sections 6.3.1 and 6.3.2. The sole purpose of this model is to determine the *relative* reactivity of different fuel lattices in a configuration similar to the actual DSC.

A typical input file is included in Section 6.6.3. The results of these calculations are listed in Table 6-6. The most reactive fuel lattice evaluated for the DSC design is the GE generation 12 lattice, 10×10 array, without a fuel channel.

B. Determination of the Most Reactive Configuration

The fuel-loading configuration of the DSC/cask affects the reactivity of the package. Several series of analyses determined the most reactive configuration for the DSC/cask.

For this analysis, the DSC/cask is modeled. The DSC/cask is modeled over the active fuel height of the fuel with reflective boundary conditions on all sides of the model, this represents and infinite array in the x-y direction of DSC/casks that are infinite in length. The DSC/cask model for this evaluation differs from the actual design in the following ways:

- the boron 10 areal density specified for manufacturing the poison plates will be greater than that used in the model, as described in Chapter 8,
- maximum gaps between poison plates are modeled in their worst case configuration,
- the stainless steel basket rails, which hold the basket together, are modeled as water.

The models are fully described in Section 6.3.1. The purpose of these models is to determine the most reactive configuration for intact fuel assemblies. A typical input file is included in Section 6.6.3.

The first series of analyses determined the most reactive fuel assembly-to-assembly pitch. The maximum lattice average fuel enrichment (4.4 wt. % U-235) and a poison plate boron-10 areal density of 0.036 g/cm^2 are used in the model. The results in Table 6-7 show the most reactive configuration occurs with minimum assembly-to-assembly pitch. The model is similar to the model shown in Table 6-4 and Figure 6-2 except that the nominal fuel cell size, nominal poison sheet thickness, fuel clad OD are used and the assemblies are moved within the fuel compartment to vary the assembly-to-assembly pitch.

The second set of analysis evaluates the effect of canister shell thickness on the system reactivity. The model starts with the most reactive assembly-to-assembly pitch (minimum pitch) case above and the canister shell thickness is varied from 0.49 to 0.55 inches. As demonstrated by the results the variation of shell thickness within the tolerance range is statistically insignificant. The nominal shell thickness is used throughout the rest of the analysis except that one additional case is added for the most reactive canister configuration (minimum poison plate thickness and minimum fuel cell size) to demonstrate that the slightly higher result for the maximum shell thickness is indeed a result of the statistics of the calculation.

The third set of analysis evaluates the effect of poison plate thickness on the system reactivity. The model starts with the most reactive assembly-to-assembly pitch (minimum pitch) case above and the poison plate thickness is modeled at 0.3 inches (minimum). The poison plate B-10 volume density is increased from 0.046 to 0.04724 g B10/cm^3 to maintain the areal density of 36 mg B10/cm^2 for the reduced plate thickness. Based on the results of this evaluation the balance of the calculations will use the minimum poison plate thickness because it represents a more reactive condition.

The fourth set of analysis evaluates the sensitivity of the system reactivity on fuel cladding OD. The model starts with the minimum poison plate case above and the fuel cladding OD is varied from 0.404 to 0.394 inches. Based on the results of this analysis, it is conservative to model the GE12 10x10 assembly cladding as 0.010 inches less than that reported in Table 6-3 for the balance of this evaluation.

The fifth set of analysis evaluates the effect of fuel cell size on the system reactivity. The model starts with the most reactive fuel clad OD case above and the canister fuel cell width is varied from 5.8 to 6.1 inches. The results show that the most reactive configuration is with the minimum fuel cell size. One additional run is made to verify that the canister maximum shell thickness does not increase reactivity. The balance of this evaluation will use the minimum cell size because it represents the most reactive configuration.

The sixth set of analyses evaluates the effect of internal moderator density on reactivity. The model starts with the most fuel cell width (minimum fuel cell width) case above. The internal moderator is varied from 100 to 0 percent full density. The results in Table 6-7 confirm that the most reactive condition occurs at full internal moderator density.

The seventh set of analyses evaluates the effect of external moderator density on reactivity. The model uses the most reactive case with internal moderator (full density) density and the external internal moderator is varied from 100 to 0 percent full density. The results in Table 6-7 show that the system reactivity is not affected by external moderator density. The variation in the results is due entirely to the statistical uncertainties in Keno V.a. Nonetheless, the apparent maximum value of k_{eff}, which occurs at 70% external moderator density, is the value reported for the damaged package array.

Finally, minimum boron 10 areal density in the poison plate as a function of lattice average initial enrichment is evaluated. These models represent the most reactive intact fuel assembly (GE12, 10x10) with a minimum assembly-to-assembly pitch, nominal shell thickness, minimum poison plate thickness, minimum fuel clad OD, minimum fuel cell width with full internal and external moderator density. The initial lattice average fuel enrichment is varied as well as the boron-10 density in the poison plates. These cases are used to specify a minimum boron-10 areal density as a function of maximum lattice average assembly enrichment. The results are reported in Table 6-7.

6.4.3 Criticality Results (Infinite Array)

Table 6-8 lists the results that bound all normal and hypothetical accident conditions. These criticality calculations were performed with CSAS25 of SCALE-4.4. For each case, the result includes (1) the KENO-calculated k_{KENO}; (2) the one sigma uncertainty σ_{KENO}; and (3) the final k_{eff}, which is equal to $k_{KENO} + 2\sigma_{KENO}$. Table 6-8 lists the poison plate boron-10 areal density used in the calculations as a function of the initial lattice average enrichment for the fuel assemblies.

The criterion for subcriticality is that

$$k_{KENO} + 2\sigma_{KENO} < USL,$$

where USL is the upper subcritical limit established by an analysis of benchmark criticality experiments. From Section 6.5, the minimum USL over the parameter range (in this case, pitch) is 0.9414. From Table 6-8 for the most reactive case,

$$k_{KENO} + 2\sigma_{KENO} = 0.9365 + 2\ (0.0011) = 0.9387 < 0.9414.$$

6.4.4 Criticality Results (Single Cask)

The criticality evaluations for a single cask are shown in the following table. The single cask models KENO are based on the most reactive infinite array case shown in Table 6-8. Separate KENO models are generated based on progressively modeling the various cask shells around the canister. A total of four single cask models are analyzed based on water reflection after 1) canister, 2) inner steel shell, 3) lead shell and 4) outer steel shell.

Single Cask Calculation Results

Description	$K_{eff} \pm \sigma$	$K_{eff} \pm 2\sigma$
Most reactive infinite array case from Table 6-8 - Reference model (full density external moderator)	0.9349 ± 0.0011	0.9371
Single cask, based on Reference model, with water reflector around Canister	0.9345 ± 0.0012	0.9369
Single cask, based on Reference model, with water reflector around the inner steel shell of Cask	0.9330 ± 0.0012	0.9354
Single cask, based on Reference model, with water reflector around the lead shell of Cask	0.9349 ± 0.0011	0.9371
Single cask, based on Reference model, with water reflector around the outer steel shell of Cask	0.9346 ± 0.0011	0.9368

The results of the criticality calculations based on indicate single cask models are bounded by the infinite array results.

6.5 Critical Benchmark Experiments

The criticality safety analysis of the NUHOMS®-MP197 System used the CSAS25 module of the SCALE system of codes.

The analysis presented herein uses the fresh fuel assumption for criticality analysis. The analysis employed the 44-group ENDF/B-V cross-section library because it has a small bias, as determined by the 125 benchmark calculations described in reference [6.2]. The upper USL-1 was determined using the results of these 125 benchmark calculations.

The benchmark problems used to perform this verification are representative of benchmark arrays of commercial light water reactor (LWR) fuels with the following characteristics:

(1) water moderation

(2) boron neutron absorbers

(3) unirradiated light water reactor type fuel (no fission products or "burnup credit") near room temperature (vs. reactor operating temperature)

(4) close reflection

(5) Uranium Oxide

The 125 uranium oxide experiments were chosen to model a wide range of uranium enrichments, fuel pin pitches, assembly separation, concentration of soluble boron and control elements in order to test the codes ability to accurately calculate k_{eff}. These experiments are discussed in detail in reference [6.2]. The file-input names referred to in the following sub-sections are identical to those used in [6.2].

6.5.1 Benchmark Experiments and Applicability

A summary of all of the pertinent parameters for each experiment is included in Table 6-9 along with the results of each run. The best correlation is observed for fuel assembly separation distance with a correlation of 0.65. All other parameters show much lower correlation ratios indicating no real correlation. All parameters were evaluated for trends and to determine the most conservative USL.

The USL is calculated in accordance to NUREG/CR-6361 [6.3]. USL Method 1 (USL-1) applies a statistical calculation of the bias and its uncertainty plus an administrative margin (0.05) to the linear fit of results of the experimental benchmark data. The basis for the administrative margin is from reference [6.4]. Results from the USL evaluation are presented in Table 6-10.

The criticality evaluation used the same cross section set, fuel materials and similar material/geometry options that were used in the 125 benchmark calculations as shown in Table 6-9. The modeling techniques and the applicable parameters listed in Table 6-11 for the actual criticality evaluations fall within the range of those addressed by the benchmarks in Table 6-9.

6.5.2 Results of the Benchmark Calculations

The results from the comparisons of physical parameters of each of the fuel assembly types to the applicable USL value are presented in Table 6-11. The minimum value of the USL was determined to be 0.9414 based on comparisons to the limiting assembly parameters as shown in Table 6-11.

APPENDIX 6.6

TABLE OF CONTENTS

		Page
6.6	APPENDIX	6.6-1
6.6.1	References	6.6-1
6.6.2	Most Reactive Fuel Analysis	6.6-1
6.6.3	Example CSAS25 Input Decks	6.6-2

LIST OF TABLES

6-1 Minimum B-10 Content in the Neutron Poison Plates
6-2 Authorized Contents for MP-197 Packaging
6-3 Parameters for BWR Assemblies
6-4 Axial Layout of the KENO V.a Model of MP-197
6-5 Material Property Data
6-6 Most Reactive Fuel Type
6-7 Most Reactive Configuration
6-8 Criticality Results
6-9 Benchmarking Results
6-10 USL-1 Results
6-11 USL Determination for Criticality Analysis

LIST OF FIGURES

6-1 NUHOMS®-61BT DSC Axial Cross Section
6-2 KENO V.a Units and Radial Cross Sections of the Model
6-3 KENO V.a Model Cross Section – Bounding Case
6-4 Fuel Assembly Layouts
6-5 Variable Enrichment Fuel Assembly Layouts

6.6 Appendix

6.6.1 References

6.1 Oak Ridge National Laboratory, RSIC Computer Code Collection, "SCALE: A Modular Code System for Performing Standardized Computer Analysis for Licensing Evaluations for Workstations and Personal Computers," NUREG/CR-0200, Revision 6, ORNL/NUREG/CSD-2/V2/R6.

6.2 Transnuclear West Calculation No. SCE-01.0602, "Verification and Validation Document: SCALE 4.4 PC; CSAS25 For Uranium Oxide and Uranium Plutonium Mixed Oxide (MOX) Fuel," Revision 0.

6.3 U.S. Nuclear Regulatory Commission, "Criticality Benchmark Guide for Light-Water-Reactor fuel in Transportation and Storage Packages," NUREG/CR-6361, Published March 1997, ORNL-TM-13211.

6.4 U.S. Nuclear Regulatory Commission, "Standard Review Plan for Dry Cask Storage Systems," NUREG-1536, Published January 1997.

6.6.2 Most Reactive Fuel Analysis

The models used to determine the most reactive fuel are not based on the models used to perform the rest of the analysis. These models are simplified models of the basket and DSC only. Each model represents a different fuel assembly type or condition, such as fuel with fuel channels or variable pin enrichment. Each Unit in the KENO V.a model has a length equal to the active fuel height of the assembly modeled (See Table 6-3) with water boundary conditions on the ends and reflective boundary conditions on the sides.

Figure 6-4 is a graphical depiction of the fuel assembly layout for each assembly type, including a map of the variable enrichment case. A representative input is included below. The example input is for the GE5 fuel type with a variable rod enrichment. The fuel assembly pin by pin layouts for the variable enrichment cases are shown in Figure 6-5.

6.6.3 Example CSAS25 Input Decks

6.6.3.1 Most Reactive Fuel Analysis, GE5 8x8

```
=csas25
```

```
61B Confirmatory Fuel Enrichment Analysis with GE5 8x8,
Jack Boshoven 12/28/00
44groupndf5 latticecell
uo2     1 0.95 293 92235 2.33 92238 97.67 end
zirc2   2 1.0  293 end
h2o     3 1.0  293 end
carbonsteel 4 1.0 293 end
ss304   5 1.0  293 end
h2o     6 1.0  293 end
h2o     7 1.0  293 end
b-10    8 den=0.046 1.0 293 end
al      8 0.9  293 end
uo2     9 0.95 293 92235 3.01 92238 96.99 end
uo2    10 0.95 293 92235 3.57 92238 96.43 end
uo2    11 0.95 293 92235 4.85 92238 95.15 end
end comp
squarepitch 1.6256  1.0414 11 3 1.22682 2 1.06426 6 end
more data res=9  cylinder 0.5207 dan(9)=0.18804820
          res=10 cylinder 0.5207 dan(10)=0.18804820
          res=1  cylinder 0.5207 dan(1)=0.18804820
end more data
Keno Title Card
read param
gen=500 npg=1000 nsk=5 nub=yes run=yes plt=yes
end param
read geom
unit 1     com='Fuel Rod w/2.33 wt%'
cylinder  1   1  0.5207       381.00        0.0
cylinder  6   1  0.53213      381.00        0.0
cylinder  2   1  0.61341      381.00        0.0
cuboid    3   1  4p0.8128     381.00        0.0
unit 2     com='GE 8x8 Center Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9629     381.00        0.0
cuboid    8   1  4p8.3566     381.00        0.0
unit 3     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9629     381.00        0.0
cuboid    8   1  7.9629 -8.3566 2p8.3566      381.00
0.0
unit 4     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9629     381.00        0.0
```

```
cuboid    8   1  8.3566 -7.9629 2p8.3566       381.00
0.0
unit 5     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9629      381.00          0.0
cuboid    8   1  4p8.3566      381.00          0.0
unit 6     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9629      381.00          0.0
cuboid    8   1  8.3566 -7.9629 2p8.3566       381.00
0.0
unit 7     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9629      381.00          0.0
cuboid    8   1  7.9629 -8.3566 2p8.3566       381.00
0.0
unit 8     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9629      381.00          0.0
cuboid    8   1  4p8.3566      381.00          0.0
unit 9     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9629      381.00          0.0
cuboid    8   1  2p8.3566        7.9629 -8.3566 381.00
0.0
unit 10    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9629      381.00          0.0
cuboid    8   1  7.9629 -8.3566 7.9629 -8.3566 381.00
0.0
unit 11    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9629      381.00          0.0
cuboid    8   1  8.3566 -7.9629 7.9629 -8.3566 381.00
0.0
unit 12    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9629      381.00          0.0
cuboid    8   1  4p8.3566      381.00          0.0
```

```
unit 13    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  2p8.3566 8.3566 -7.9629        381.00
0.0
unit 14    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 8.3566 -7.9629 381.00
0.0
unit 15    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 2p8.3566        381.00
0.0
unit 16    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 8.3566 -7.9629 381.00
0.0
unit 17    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 2p8.3566        381.00
0.0
unit 18    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 8.3566 -7.9629 381.00
0.0
unit 19    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  2p8.3566 8.3566 -7.9629        381.00
0.0
unit 20    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
```

```
cuboid    8   1  7.9629 -8.3566 8.3566 -7.9629 381.00
0.0
unit 21    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62          381.00          0.0
cuboid    5   1  4p7.9629        381.00          0.0
cuboid    8   1  8.3566 -7.9629 2p8.3566          381.00
0.0
unit 22    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62          381.00          0.0
cuboid    5   1  4p7.9629        381.00          0.0
cuboid    8   1  4p8.3566        381.00          0.0
unit 23    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62          381.00          0.0
cuboid    5   1  4p7.9629        381.00          0.0
cuboid    8   1  7.9629 -8.3566 2p8.3566          381.00
0.0
unit 24    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62          381.00          0.0
cuboid    5   1  4p7.9629        381.00          0.0
cuboid    8   1  8.3566 -7.9629 7.9629 -8.3566 381.00
0.0
unit 25    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62          381.00          0.0
cuboid    5   1  4p7.9629        381.00          0.0
cuboid    8   1  2p8.3566          7.9629 -8.3566 381.00
0.0
unit 26    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62          381.00          0.0
cuboid    5   1  4p7.9629        381.00          0.0
cuboid    8   1  7.9629 -8.3566 7.9629 -8.3566 381.00
0.0
unit 27    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62          381.00          0.0
cuboid    5   1  4p7.9629        381.00          0.0
cuboid    8   1  8.3566 -7.9629 8.3566 -7.9629 381.00
0.0
unit 28    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62          381.00          0.0
cuboid    5   1  4p7.9629        381.00          0.0
```

```
cuboid    8   1  2p8.3566 8.3566 -7.9629       381.00
0.0
unit 29    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00         0.0
cuboid    5   1  4p7.9629      381.00         0.0
cuboid    8   1  7.9629 -8.3566 8.3566 -7.9629 381.00
0.0
unit 30    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00         0.0
cuboid    5   1  4p7.9629      381.00         0.0
cuboid    8   1  8.3566 -7.9629 7.9629 -8.3566 381.00
0.0
unit 31    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00         0.0
cuboid    5   1  4p7.9629      381.00         0.0
cuboid    8   1  2p8.3566        7.9629 -8.3566 381.00
0.0
unit 32    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00         0.0
cuboid    5   1  4p7.9629      381.00         0.0
cuboid    8   1  7.9629 -8.3566 7.9629 -8.3566 381.00
0.0
unit 33    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00         0.0
cuboid    5   1  4p7.9629      381.00         0.0
cuboid    8   1  8.3566 -7.9629 8.3566 -7.9629 381.00
0.0
unit 34    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00         0.0
cuboid    5   1  4p7.9629      381.00         0.0
cuboid    8   1  2p8.3566 8.3566 -7.9629       381.00
0.0
unit 35    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00         0.0
cuboid    5   1  4p7.9629      381.00         0.0
cuboid    8   1  7.9629 -8.3566 8.3566 -7.9629 381.00
0.0
unit 36    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00         0.0
```

```
cuboid    5   1  4p7.9629      381.00         0.0
cuboid    8   1  8.3566 -7.9629 7.9629 -8.3566 381.00
0.0
unit 37    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00         0.0
cuboid    5   1  4p7.9629      381.00         0.0
cuboid    8   1  2p8.3566        7.9629 -8.3566 381.00
0.0
unit 38    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00         0.0
cuboid    5   1  4p7.9629      381.00         0.0
cuboid    8   1  7.9629 -8.3566 7.9629 -8.3566 381.00
0.0
unit 39   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00         0.0
cuboid    5   1  4p7.9248      381.00         0.0
cuboid    8   1  8.3185 -7.9248 8.3185 -7.9248 381.00
0.0
unit 40  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00         0.0
cuboid    5   1  4p7.9248      381.00         0.0
cuboid    8   1  7.9248 -8.3185 8.3185 -7.9248 381.00
0.0
unit 41  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00         0.0
cuboid    5   1  4p7.9248      381.00         0.0
cuboid    8   1  8.3185 -7.9248 7.9248 -8.3185 381.00
0.0
unit 42  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00         0.0
cuboid    5   1  4p7.9248      381.00         0.0
cuboid    8   1  7.9248 -8.3185 7.9248 -8.3185 381.00
0.0
unit 43   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00         0.0
cuboid    5   1  4p7.9248      381.00         0.0
cuboid    8   1  8.3185 -7.9248 8.3185 -7.9248 381.00
0.0
unit 44  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
```

```
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  7.9248 -8.3185 8.3185 -7.9248 381.00
0.0
unit 45  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  8.3185 -7.9248 7.9248 -8.3185 381.00
0.0
unit 46  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  7.9248 -8.3185 7.9248 -8.3185 381.00
0.0
unit 47   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  8.3185 -7.9248 8.3185 -7.9248 381.00
0.0
unit 48  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  7.9248 -8.3185 8.3185 -7.9248 381.00
0.0
unit 49  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  8.3185 -7.9248 7.9248 -8.3185 381.00
0.0
unit 50  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  7.9248 -8.3185 7.9248 -8.3185 381.00
0.0
unit 51   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  8.3185 -7.9248 8.3185 -7.9248 381.00
0.0
unit 52  com='GE 8x8 Assembly'
```

```
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9248      381.00        0.0
cuboid    8   1  7.9248 -8.3185 8.3185 -7.9248 381.00
0.0
unit 53  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9248      381.00        0.0
cuboid    8   1  8.3185 -7.9248 7.9248 -8.3185 381.00
0.0
unit 54  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9248      381.00        0.0
cuboid    8   1  7.9248 -8.3185 7.9248 -8.3185 381.00
0.0
unit 55  com='center 9x9 array'
array 2 -24.6761 -24.6761 0.0
cuboid    5   1  4p24.9428     381.00        0.0
cuboid    8   1  4p25.7302     381.00        0.0
unit 56  com='right 9x9 array'
array 3 -24.6761 -24.6761 0.0
cuboid    5   1  4p24.9428     381.00        0.0
unit 57  com='top 9x9 array'
array 4 -24.6761 -24.6761 0.0
cuboid    5   1  4p24.9428     381.00        0.0
unit 58  com='left 9x9 array'
array 5 -24.6761 -24.6761 0.0
cuboid    5   1  4p24.9428     381.00        0.0
unit 59  com='bottom 9x9 array'
array 6 -24.6761 -24.6761 0.0
cuboid    5   1  4p24.9428     381.00        0.0
unit 60  com='upper right 2x2 array'
array 7 -16.2433 -16.2433 0.0
cuboid    5   1  4p16.51       381.00        0.0
unit 61  com='upper left 2x2 array'
array 8 -16.2433 -16.2433 0.0
cuboid    5   1  4p16.51       381.00        0.0
unit 62  com='lower right 2x2 array'
array 9 -16.2433 -16.2433 0.0
cuboid    5   1  4p16.51       381.00        0.0
unit 63  com='lower right 2x2 array'
array 10 -16.2433 -16.2433 0.0
cuboid    5   1  4p16.51       381.00        0.0
unit 64  com='0.31" poison plate'
cuboid    8   1  2p16.51 2p0.3937 381.00     0.0
```

```
unit 65  com='0.31" poison plate'
cuboid    8   1  2p0.3937 2p16.51 381.00    0.0
unit 66  com='water hole'
cylinder  3  1  0.67437   381.00    0.0
cylinder  2  1  0.75057   381.00    0.0
cuboid    3  1  4P0.8128  381.00    0.0
unit 67    com='Fuel Rod w/3.01 wt%'
cylinder  9   1  0.5207       381.00        0.0
cylinder  6   1  0.53213      381.00        0.0
cylinder  2   1  0.61341      381.00        0.0
cuboid    3   1  4p0.8128     381.00        0.0
unit 68    com='Fuel Rod w/3.57 wt%'
cylinder 10   1  0.5207       381.00        0.0
cylinder  6   1  0.53213      381.00        0.0
cylinder  2   1  0.61341      381.00        0.0
cuboid    3   1  4p0.8128     381.00        0.0
unit 69    com='Fuel Rod w/4.85 wt%'
cylinder 11   1  0.5207       381.00        0.0
cylinder  6   1  0.53213      381.00        0.0
cylinder  2   1  0.61341      381.00        0.0
cuboid    3   1  4p0.8128     381.00        0.0
global unit 70
cylinder  3   1  84.757       381.00        0.0
    hole 55   0.0       0.0      0.0
    hole 56   50.673    0.0      0.0
    hole 57   0.0       50.673   0.0
    hole 58  -50.673    0.0      0.0
    hole 59   0.0      -50.673   0.0
    hole 60   42.2404   42.2404 0.0
    hole 61  -42.2404   42.2404 0.0
    hole 62  -42.2404 -42.2404 0.0
    hole 63   42.2404 -42.2404 0.0
    hole 64   42.2404   25.3366 0.0
    hole 64  -42.2404   25.3366 0.0
    hole 64  -42.2404 -25.3366 0.0
    hole 64   42.2404 -25.3366 0.0
    hole 65   25.3366   42.2404 0.0
    hole 65  -25.3366   42.2404 0.0
    hole 65  -25.3366 -42.2404 0.0
    hole 65   25.3366 -42.2404 0.0
cylinder  5   1  86.027       381.00        0.0
cuboid    7   1  4p86.03      381.00        0.0
end geom
read array
   com='GE 8x8 fuel assembly slice, sd, fuel regions'
   ara=1      nux=8      nuy=8      nuz=1
   fill
```

```
    67 68 68 68 68 68 67  1
    68 69 69 69 69 69 68 67
    69 69 69 69 69 69 69 68
    69 69 69 66 69 69 69 68
    69 69 69 69 66 69 69 68
    69 69 69 69 69 69 69 68
    69 69 69 69 69 69 69 68
    68 69 69 69 69 69 68 67
end fill
com='Center 9x9 Array of Fuel'
ara=2       nux=3       nuy=3       nuz=1
fill
     18 19 20
      6  2  3
     11  9 10
end fill
com='Right 9x9 Array of Fuel'
ara=3       nux=3       nuy=3       nuz=1
fill
     27 28 29
      4  5  3
     30 31 32
end fill
com='Top 9x9 Array of Fuel'
ara=4       nux=3       nuy=3       nuz=1
fill
     16 13 14
     17 12 15
     11  9 10
end fill
com='Left 9x9 Array of Fuel'
ara=5       nux=3       nuy=3       nuz=1
fill
     33 34 35
      6  8  7
     36 37 38
end fill
com='Bottom 9x9 Array of Fuel'
ara=6       nux=3       nuy=3       nuz=1
fill
     18 19 20
     21 22 23
     24 25 26
end fill
com='Upper Right 2x2 Array of Fuel'
ara=7       nux=2       nuy=2       nuz=1
fill
```

```
        39 40
        41 42
   end fill
   com='Upper Left 2x2 Array of Fuel'
   ara=8      nux=2      nuy=2      nuz=1
   fill
        43 44
        45 46
   end fill
   com='Lower Left 2x2 Array of Fuel'
   ara=9      nux=2      nuy=2      nuz=1
   fill
        47 48
        49 50
   end fill
   com='Lower Right 2x2 Array of Fuel'
   ara=10     nux=2      nuy=2      nuz=1
   fill
        51 52
        53 54
   end fill
end array
read bounds
   xyf=specular
   zfc=water
end bounds
read plot
   ttl='cask material plot  - plan view'
   pic=mat
   nch=' fzmcsblxg'
   xul=-87   yul=87    zul=200
   xlr=87    ylr=-87   zlr=200
   uax=1.0    vdn=-1.0
   nax=650
end plot
end data
end
```

6.6.3.2 <u>Bounding Case, Infinite Array Damaged Package</u>

```
=csas25
```

```
61B w/GE 10x10, including 0.125" gaps, assemblies in
Jack Boshoven 1/6/01
44groupndf5 latticecell
uo2    1 0.95 293 92235 4.4 92238 95.6 end
zirc2  2 1.0  293 end
h2o    3 1.0  293 end
carbonsteel 4 1.0 293 end
ss304  5 1.0  293 end
h2o    6 1.0  293 end
h2o    7 0.7  293 end
b-10   8 den=0.04724 1.0 293 end
al     8 0.9  293 end
pb     9 1.0  293 end
end comp
squarepitch 1.2954 0.87630 1 3 1.00076 2 0.89408 6 end
Assemblies pushed to center; clad OD 0.394"; minimum
fuel cell width
read param
gen=500 npg=1000 nsk=5 nub=yes run=yes plt=no
end param
read geom
unit 1     com='Fuel Rod'
cylinder  1   1  0.43815      0.635          0.0
cylinder  6   1  0.44704      0.635          0.0
cylinder  2   1  0.50038      0.635          0.0
cuboid    3   1  4p0.6477     0.635          0.0
unit 2     com='GE 10x10 center center 3x3 Assembly'
array 1 -6.47700 -6.47700 0.0
cuboid    3   1  4p7.366      0.635          0.0
cuboid    5   1  4p7.6327     0.635          0.0
unit 3     com='GE 10x10 shift left center 3x3 Assembly'
array 1 -7.366   -6.47700 0.0
cuboid    3   1  4p7.366      0.635          0.0
cuboid    5   1  4p7.6327     0.635          0.0
unit 4     com='GE 10x10 shift right center 3x3
Assembly'
array 1 -5.58810 -6.47700 0.0
cuboid    3   1  4p7.366      0.635          0.0
cuboid    5   1  4p7.6327     0.635          0.0
unit 5     com='GE 10x10 shift center down 3x3 Assembly'
array 1 -6.47700 -7.366   0.0
cuboid    3   1  4p7.366      0.635          0.0
cuboid    5   1  4p7.6327     0.635          0.0
unit 6     com='GE 10x10 shift center up 3x3 Assembly'
array 1 -6.47700 -5.58810 0.0
cuboid    3   1  4p7.366      0.635          0.0
cuboid    5   1  4p7.6327     0.635          0.0
```

```
unit 7      com='GE 10x10 shift left down 3x3 Assembly'
array 1 -7.366   -7.366   0.0
cuboid    3   1  4p7.366      0.635          0.0
cuboid    5   1  4p7.6327     0.635          0.0
unit 8      com='GE 10x10 shift right down 3x3 Assembly'
array 1 -5.58810 -7.366   0.0
cuboid    3   1  4p7.366      0.635          0.0
cuboid    5   1  4p7.6327     0.635          0.0
unit 9      com='GE 10x10 shift right up 3x3 Assembly'
array 1 -5.58810 -5.58810 0.0
cuboid    3   1  4p7.366      0.635          0.0
cuboid    5   1  4p7.6327     0.635          0.0
unit 10     com='GE 10x10 shift left up 3x3 Assembly'
array 1 -7.366   -5.58810 0.0
cuboid    3   1  4p7.366      0.635          0.0
cuboid    5   1  4p7.6327     0.635          0.0
unit 11     com='GE 10x10 shift left down 2x2 Assembly'
array 1 -7.366   -7.366   0.0
cuboid    3   1  4p7.366      0.635          0.0
cuboid    5   1  4p7.5946     0.635          0.0
unit 12     com='GE 10x10 shift right down 2x2 Assembly'
array 1 -5.58810 -7.366   0.0
cuboid    3   1  4p7.366      0.635          0.0
cuboid    5   1  4p7.5946     0.635          0.0
unit 13     com='GE 10x10 shift right up 2x2 Assembly'
array 1 -5.58810 -5.58810 0.0
cuboid    3   1  4p7.366      0.635          0.0
cuboid    5   1  4p7.5946     0.635          0.0
unit 14     com='GE 10x10 shift left up 2x2 Assembly'
array 1 -7.366   -5.58810 0.0
cuboid    3   1  4p7.366      0.635          0.0
cuboid    5   1  4p7.5946     0.635          0.0
unit 15     com='horizontal left gap poison 3x3'
cuboid    0   1  0.3175   0.0  2p0.3810  0.635     0.0
cuboid    8   1 15.2654   0.0  2p0.3810  0.635     0.0
unit 16     com='horizontal gap  3x3'
cuboid    0   1 15.2654   0.0  2p0.3810  0.635     0.0
unit 17     com='horizontal left and right gap poison
3x3'
cuboid    0   1  0.15875 0.0  2p0.3810  0.635     0.0
cuboid    8   1 15.09395 0.0  2p0.3810  0.635     0.0
cuboid    0   1 15.2654   0.0  2p0.3810  0.635     0.0
unit 18     com='horizontal right gap poison 3x3'
cuboid    8   1 14.9479   0.0  2p0.3810  0.635     0.0
cuboid    0   1 15.2654   0.0  2p0.3810  0.635     0.0
unit 19     com='horizontal left gap poison 2'
cuboid    0   1  0.3175   0.0  2p0.3810  0.635     0.0
```

```
cuboid    8   1 15.1892  0.0  2p0.3810  0.635     0.0
unit 20   com='horizontal gap  3x3'
cuboid    0   1 15.1892  0.0  2p0.3810  0.635     0.0
unit 21    com='horizontal right gap poison 2x2'
cuboid    8   1 14.8717  0.0  2p0.3810  0.635     0.0
cuboid    0   1 15.1892  0.0  2p0.3810  0.635     0.0
unit 22    com='vertical top gap poison 3x3'
cuboid    8   1 2p0.3810  14.9479  0.0  0.635     0.0
cuboid    0   1 2p0.3810  15.2654  0.0  0.635     0.0
unit 23    com='vertical gap  3x3'
cuboid    0   1 2p0.3810  15.2654  0.0  0.635     0.0
unit 24    com='vertical bottom gap poison 3x3'
cuboid    0   1 2p0.3810   0.3175  0.0  0.635     0.0
cuboid    8   1 2p0.3810  15.2654  0.0  0.635     0.0
unit 25    com='horizontal center gap poison 3x3'
cuboid    0   1 2p0.3175  2p0.3810      0.635     0.0
cuboid    8   1 2p23.6601 2p0.3810      0.635     0.0
unit 26    com='horizontal gap  3x3'
cuboid    0   1 2p23.6601 2p0.3810      0.635     0.0
unit 27    com='vertical center gap poison 3x3'
cuboid    0   1 2p0.3810  2p0.3175      0.635     0.0
cuboid    8   1 2p0.3810  2p23.6601     0.635     0.0
unit 28    com='vertical gap  3x3'
cuboid    0   1 2p0.3810  2p23.6601     0.635     0.0
unit 29    com='vertical bottom gap poison 2x2'
cuboid    0   1 2p0.3810  0.3175   0.0  0.635     0.0
cuboid    8   1 2p0.3810 15.41145  0.0  0.635     0.0
cuboid    0   1 2p0.3810 16.04645  0.0  0.635     0.0
cuboid    8   1 2p0.3810 31.1404   0.0  0.635     0.0
unit 30   com='vertical gap  2x2'
cuboid    0   1 2p0.3810 31.1404   0.0  0.635     0.0
unit 31   com='vertical top gap poison 2x2'
cuboid    8   1 2p0.3810 15.09395  0.0  0.635     0.0
cuboid    0   1 2p0.3810 15.72895  0.0  0.635     0.0
cuboid    8   1 2p0.3810 30.8229   0.0  0.635     0.0
cuboid    0   1 2p0.3810 31.1404   0.0  0.635     0.0
unit 32   com='Upper Right 2x2 w/poison'
array 2   -7.5946 -15.5702 0.0
unit 33   com='Upper Left 2x2 w/poison'
array 3   -7.5946 -15.5702 0.0
unit 34   com='Upper Right 2x2 w/poison'
array 4   -7.5946 -15.5702 0.0
unit 35   com='Uppwe Left 2x2 w/poison'
array 5   -7.5946 -15.5702 0.0
unit 36   com='3x3 with poison'
array 6   -7.6327 -23.6601 0.0
unit 37   com='3x3 with poison'
```

```
array 7   -7.6327 -23.6601 0.0
unit 38   com='3x3 with poison'
array 8   -7.6327 -23.6601 0.0
unit 39   com='3x3 with poison'
array 9   -7.6327 -23.6601 0.0
unit 40   com='3x3 with poison'
array 10  -7.6327 -23.6601 0.0
unit 41   com='Center 3x3 fuel with poison'
array 11 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635          0.0
unit 42   com='Right 3x3 fuel with poison'
array 12 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635          0.0
unit 43   com='Top 3x3 fuel with poison'
array 13 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635          0.0
unit 44   com='Left 3x3 fuel with poison'
array 14 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635          0.0
unit 45   com='Bottom 3x3 fuel with poison'
array 15 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635          0.0
unit 46   com='Upper Right 2x2 fuel with poison'
array 16 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635          0.0
unit 47   com='Upper Left 2x2 fuel with poison'
array 17 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635          0.0
unit 48   com='Lower Left 2x2 fuel with poison'
array 18 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635          0.0
unit 49   com='Lower Right 2x2 fuel with poison'
array 19 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635          0.0
unit 50   com='vertical poison between 3x3 compartments'
cuboid    8   1 2p0.3810  2p23.69185  0.635     0.0
cuboid    0   1 2p0.3810  2p23.8506    0.635     0.0
unit 51   com='vertical poison between 3x3 compartments,
gap'
cuboid    0   1 2p0.3810  2p23.8506    0.635     0.0
unit 52   com='center horizontal strip of 3x3 arrays'
array 20 -72.3138 -23.8506 0.0
unit 53   com='center horizontal strip of poison'
cuboid    8   1 2p56.2102 2p0.3810    0.635     0.0
unit 54   com='center horizontal strip of poison, gap'
cuboid    0   1 2p56.2102 2p0.3810    0.635     0.0
unit 55   com='top vertical strip of poison'
```

```
cuboid     8    1 2p0.3810  15.7607 -15.4432 0.635     0.0
cuboid     0    1 2p0.3810 2p15.7607 0.635     0.0
unit 56    com='top vertical strip of poison gap'
cuboid     0    1 2p0.3810 2p15.7607 0.635     0.0
unit 57    com='top vertical strip of poison'
cuboid     8    1 2p0.3810  15.4432 -15.7607 0.635     0.0
cuboid     0    1 2p0.3810 2p15.7607 0.635     0.0
unit 58    com='poison everywhere'
cylinder   3    1  84.1375       0.635         0.0
    hole 52    0.0        0.0      0.0
    hole 53    0.0       24.2316   0.0
    hole 53    0.0      -24.2316   0.0
    hole 43    0.0       48.4633   0.0
    hole 45    0.0      -48.4633   0.0
    hole 55  24.2316    40.3734   0.0
    hole 55 -24.2316    40.3734   0.0
    hole 57  24.2316   -40.3734   0.0
    hole 57 -24.2316   -40.3734   0.0
    hole 46  40.3734    40.3734   0.0
    hole 47 -40.3734    40.3734   0.0
    hole 48 -40.3734   -40.3734   0.0
    hole 49  40.3734   -40.3734   0.0
cylinder   5    1  85.4075       0.635         0.0
cylinder   3    1  86.36         0.635         0.0
cylinder   5    1  89.535        0.635         0.0
cylinder   9    1  97.79         0.635         0.0
cylinder   5    1 104.14         0.635         0.0
cuboid     7    1 4p104.15       0.635         0.0
unit 59    com='poison inside, gap outside'
cylinder   3    1  84.1375       0.635         0.0
    hole 60    0.0        0.0      0.0
    hole 54    0.0       24.2316   0.0
    hole 54    0.0      -24.2316   0.0
    hole 43    0.0       48.4633   0.0
    hole 45    0.0      -48.4633   0.0
    hole 56  24.2316    40.3734   0.0
    hole 56 -24.2316    40.3734   0.0
    hole 56  24.2316   -40.3734   0.0
    hole 56 -24.2316   -40.3734   0.0
    hole 46  40.3734    40.3734   0.0
    hole 47 -40.3734    40.3734   0.0
    hole 48 -40.3734   -40.3734   0.0
    hole 49  40.3734   -40.3734   0.0
cylinder   5    1  85.4075       0.635         0.0
cylinder   3    1  86.36         0.635         0.0
cylinder   5    1  89.535        0.635         0.0
cylinder   9    1  97.79         0.635         0.0
```

```
cylinder  5   1 104.14        0.635         0.0
cuboid    7   1 4p104.15      0.635         0.0
unit 60   com='center horizontal strip of 3x3 arrays
with gap'
array 22 -72.3138 -23.8506 0.0
unit 61   com='Upper Right 2x2 w/o poison'
array 23  -7.5946 -15.5702 0.0
unit 62   com='Upper Left 2x2 w/o poison'
array 24  -7.5946 -15.5702 0.0
unit 63   com='Upper Right 2x2 w/o poison'
array 25  -7.5946 -15.5702 0.0
unit 64   com='Uppwe Left 2x2 w/o poison'
array 26  -7.5946 -15.5702 0.0
unit 65   com='3x3 with out poison'
array 27  -7.6327 -23.6601 0.0
unit 66   com='3x3 with out poison'
array 28  -7.6327 -23.6601 0.0
unit 67   com='3x3 with out poison'
array 29  -7.6327 -23.6601 0.0
unit 68   com='3x3 with out poison'
array 30  -7.6327 -23.6601 0.0
unit 69   com='3x3 with out poison'
array 31  -7.6327 -23.6601 0.0
unit 70   com='Center 3x3 fuel with out poison'
array 32 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 71   com='Right 3x3 fuel with out poison'
array 33 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 72   com='Top 3x3 fuel with out poison'
array 34 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 73   com='Left 3x3 fuel with out poison'
array 35 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 74   com='Bottom 3x3 fuel with out poison'
array 36 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 75   com='Upper Right 2x2 fuel with out poison'
array 37 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635         0.0
unit 76   com='Upper Left 2x2 fuel with out poison'
array 38 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635         0.0
unit 77   com='Lower Left 2x2 fuel with out poison'
array 39 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635         0.0
```

```
unit 78   com='Lower Right 2x2 fuel with out poison'
array 40 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607      0.635          0.0
unit 79   com='gap inside, gap outside'
cylinder  3   1  84.1375       0.635          0.0
    hole 80   0.0        0.0       0.0
    hole 54   0.0       24.2316   0.0
    hole 54   0.0      -24.2316   0.0
    hole 72   0.0       48.4633   0.0
    hole 74   0.0      -48.4633   0.0
    hole 56  24.2316   40.3734   0.0
    hole 56 -24.2316   40.3734   0.0
    hole 56  24.2316  -40.3734   0.0
    hole 56 -24.2316  -40.3734   0.0
    hole 75  40.3734   40.3734   0.0
    hole 76 -40.3734   40.3734   0.0
    hole 77 -40.3734  -40.3734   0.0
    hole 78  40.3734  -40.3734   0.0
cylinder  5   1  85.4075       0.635          0.0
cylinder  3   1  86.36         0.635          0.0
cylinder  5   1  89.535        0.635          0.0
cylinder  9   1  97.79         0.635          0.0
cylinder  5   1 104.14         0.635          0.0
cuboid    7   1 4p104.15       0.635          0.0
unit 80   com='center horizontal strip of 3x3 arrays
with all gaps'
array 41 -72.3138 -23.8506 0.0
unit 81  com='water hole'
cuboid    3  1  4P0.6477       0.635          0.0
global unit 82
array 21 -85.41   -85.41  0.0
end geom
read array
   com='GE 10x10 fuel assembly slice, sd, fuel regions'
   ara=1      nux=10     nuy=10     nuz=1
   fill
        1  1  1  1  1  1  1  1  1  1
        1  1  1  1  1  1  1  1  1  1
        1  1  1  1  1  1  1  1  1  1
        1  1  1 81 81  1  1  1  1  1
        1  1  1 81 81  1  1  1  1  1
        1  1  1  1  1 81 81  1  1  1
        1  1  1  1  1 81 81  1  1  1
        1  1  1  1  1  1  1  1  1  1
        1  1  1  1  1  1  1  1  1  1
        1  1  1  1  1  1  1  1  1  1
   end fill
```

```
com='Upper Right 2x2 Array of Fuel w/poison'
ara=2      nux=1      nuy=3      nuz=1
fill
     11
     19
     11
end fill
com='Upper Left 2x2 Array of Fuel w/poison'
ara=3      nux=1      nuy=3      nuz=1
fill
     12
     21
     12
end fill
com='Lower Left 2x2 Array of Fuel w/poison'
ara=4      nux=1      nuy=3      nuz=1
fill
     13
     21
     13
end fill
com='Lower Left 2x2 Array of Fuel w/poison'
ara=5      nux=1      nuy=3      nuz=1
fill
     14
     19
     14
end fill
com='3x3 Array of Fuel w/poison'
ara=6      nux=1      nuy=5      nuz=1
fill
      9
     18
      4
     18
      8
end fill
com='3x3 Array of Fuel w/poison'
ara=7      nux=1      nuy=5      nuz=1
fill
      6
     17
      2
     17
      5
end fill
com='3x3 Array of Fuel w/poison'
```

```
ara=8       nux=1       nuy=5       nuz=1
fill
     10
     15
      3
     15
      7
end fill
com='3x3 Array of Fuel w/poison'
ara=9       nux=5       nuy=1       nuz=1
fill
      9  22   6  22  10
end fill
com='3x3 Array of Fuel w/poison'
ara=10      nux=5       nuy=1       nuz=1
fill
      8  24   5  24   7
end fill
com='Center 3x3 Array of Fuel w/poison'
ara=11      nux=5       nuy=1       nuz=1
fill
     36  27  37  27  38
end fill
com='Right 3x3 Array of Fuel w/poison'
ara=12      nux=5       nuy=1       nuz=1
fill
     38  27  38  27  38
end fill
com='Top 3x3 Array of Fuel w/poison'
ara=13      nux=1       nuy=5       nuz=1
fill
     40
     25
     40
     25
     40
end fill
com='Left 3x3 Array of Fuel w/poison'
ara=14      nux=5       nuy=1       nuz=1
fill
     36  27  36  27  36
end fill
com='Bottom 3x3 Array of Fuel w/poison'
ara=15      nux=1       nuy=5       nuz=1
fill
     39
     25
```

```
        39
        25
        39
   end fill
   com='Upper Right 2x2 Array of Fuel w/poison'
   ara=16     nux=3      nuy=1      nuz=1
   fill
        32  29  32
   end fill
   com='Upper Left 2x2 Array of Fuel w/poison'
   ara=17     nux=3      nuy=1      nuz=1
   fill
        33  29  33
   end fill
   com='Lower Left 2x2 Array of Fuel w/poison'
   ara=18     nux=3      nuy=1      nuz=1
   fill
        34  31  34
   end fill
   com='Lower Right 2x2 Array of Fuel w/poison'
   ara=19     nux=3      nuy=1      nuz=1
   fill
        35  31  35
   end fill
   com='Center row of 3x3 arrays of Fuel w/poison'
   ara=20    nux=5      nuy=1      nuz=1
   fill
        44  50  41  50  42
   end fill
   com='Axail Cask'
   ara=21    nux=1      nuy=1      nuz=576
   fill
        58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
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        59
   end fill
   com='Center row of 3x3 arrays of Fuel w/poison'
   ara=22    nux=5      nuy=1      nuz=1
   fill
        44  51  41  51  42
   end fill
   com='Upper Right 2x2 Array of Fuel w/o poison'
   ara=23     nux=1      nuy=3      nuz=1
   fill
        11
        20
        11
   end fill
   com='Upper Left 2x2 Array of Fuel w/o poison'
   ara=24     nux=1      nuy=3      nuz=1
   fill
        12
        20
        12
   end fill
   com='Lower Left 2x2 Array of Fuel w/o poison'
   ara=25     nux=1      nuy=3      nuz=1
   fill
        13
        20
        13
   end fill
   com='Lower Left 2x2 Array of Fuel w/o poison'
   ara=26     nux=1      nuy=3      nuz=1
   fill
        14
        20
        14
   end fill
   com='3x3 Array of Fuel w/o poison'
   ara=27     nux=1      nuy=5      nuz=1
   fill
         9
        16
```

```
        4
       16
        8
end fill
com='3x3 Array of Fuel w/o poison'
ara=28     nux=1      nuy=5      nuz=1
fill
        6
       16
        2
       16
        5
end fill
com='3x3 Array of Fuel w/o poison'
ara=29     nux=1      nuy=5      nuz=1
fill
       10
       16
        3
       16
        7
end fill
com='3x3 Array of Fuel w/o poison'
ara=30     nux=5      nuy=1      nuz=1
fill
        9  23   6  23  10
end fill
com='3x3 Array of Fuel w/o poison'
ara=31     nux=5      nuy=1      nuz=1
fill
        8  23   5  23   7
end fill
com='Center 3x3 Array of Fuel w/o poison'
ara=32     nux=5      nuy=1      nuz=1
fill
       65  28  66  28  67
end fill
com='Right 3x3 Array of Fuel w/o poison'
ara=33     nux=5      nuy=1      nuz=1
fill
       67  28  67  28  67
end fill
com='Top 3x3 Array of Fuel w/o poison'
ara=34     nux=1      nuy=5      nuz=1
fill
       69
       26
```

```
        69
        26
        69
    end fill
    com='Left 3x3 Array of Fuel w/o poison'
    ara=35      nux=5       nuy=1       nuz=1
    fill
        65  28  65  28  65
    end fill
    com='Bottom 3x3 Array of Fuel w/o poison'
    ara=36      nux=1       nuy=5       nuz=1
    fill
        68
        26
        68
        26
        68
    end fill
    com='Upper Right 2x2 Array of Fuel w/o poison'
    ara=37      nux=3       nuy=1       nuz=1
    fill
        61  30  61
    end fill
    com='Upper Left 2x2 Array of Fuel w/o poison'
    ara=38      nux=3       nuy=1       nuz=1
    fill
        62  30  62
    end fill
    com='Lower Left 2x2 Array of Fuel w/o poison'
    ara=39      nux=3       nuy=1       nuz=1
    fill
        63  30  63
    end fill
    com='Lower Right 2x2 Array of Fuel w/o poison'
    ara=40      nux=3       nuy=1       nuz=1
    fill
        64  30  64
    end fill
    com='Center row of 3x3 arrays of Fuel w/o poison'
    ara=41     nux=5       nuy=1       nuz=1
    fill
        73  51  70  51  71
    end fill
end array
read bounds
    xyf=specular
    zfc=specular
```

```
end bounds
read plot
   ttl='cask material plot  - plan view all poison'
   pic=mat
   nch=' fzmcsblxg'
   xul=-105  yul=105   zul=20
   xlr=105   ylr=-105  zlr=20
   uax=1.0    vdn=-1.0
   nax=650
end plot
end data
end
```

6.6.3.2 Evaluation of Varied Pin Enrichment

```
GE5 (8x8 Array) ) Input file:
=csas25
61B Confirmatory Fuel Enrichment Analysis with GE5 8x8, Jack
Boshoven 12/28/00
44groupndf5 latticecell
uo2     1 0.95 293 92235 2.33 92238 97.67 end
zirc2   2 1.0  293 end
h2o     3 1.0  293 end
carbonsteel 4 1.0 293 end
ss304   5 1.0  293 end
h2o     6 1.0  293 end
h2o     7 1.0  293 end
b-10    8 den=0.046 1.0 293 end
al      8 0.9  293 end
uo2     9 0.95 293 92235 3.01 92238 96.99 end
uo2    10 0.95 293 92235 3.57 92238 96.43 end
uo2    11 0.95 293 92235 4.85 92238 95.15 end
end comp
squarepitch 1.6256  1.0414 11 3 1.22682 2 1.06426 6 end
more data res=9  cylinder 0.5207 dan(9)=0.18804820
          res=10 cylinder 0.5207 dan(10)=0.18804820
          res=1  cylinder 0.5207 dan(1)=0.18804820
end more data
Keno Title Card
read param
gen=500 npg=1000 nsk=5 nub=yes run=yes plt=yes
end param
read geom
unit 1     com='Fuel Rod w/2.33 wt%'
cylinder  1   1  0.5207      381.00       0.0
cylinder  6   1  0.53213     381.00       0.0
cylinder  2   1  0.61341     381.00       0.0
cuboid    3   1  4p0.8128    381.00       0.0
unit 2     com='GE 8x8 Center Assembly'
```

```
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  4p8.3566      381.00        0.0
unit 3      com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 2p8.3566      381.00        0.0
unit 4      com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 2p8.3566      381.00        0.0
unit 5      com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  4p8.3566      381.00        0.0
unit 6      com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 2p8.3566      381.00        0.0
unit 7      com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 2p8.3566      381.00        0.0
unit 8      com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  4p8.3566      381.00        0.0
unit 9      com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  2p8.3566        7.9629 -8.3566 381.00        0.0
unit 10     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 7.9629 -8.3566 381.00        0.0
unit 11     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 7.9629 -8.3566 381.00        0.0
unit 12     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  4p8.3566      381.00        0.0
```

```
unit 13    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  2p8.3566 8.3566 -7.9629        381.00        0.0
unit 14    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 8.3566 -7.9629 381.00        0.0
unit 15    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 2p8.3566        381.00        0.0
unit 16    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 8.3566 -7.9629 381.00        0.0
unit 17    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 2p8.3566        381.00        0.0
unit 18    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 8.3566 -7.9629 381.00        0.0
unit 19    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  2p8.3566 8.3566 -7.9629        381.00        0.0
unit 20    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 8.3566 -7.9629 381.00        0.0
unit 21    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 2p8.3566        381.00        0.0
unit 22    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  4p8.3566      381.00        0.0
unit 23    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
```

```
cuboid    8   1  7.9629 -8.3566 2p8.3566        381.00           0.0
unit 24    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 7.9629 -8.3566 381.00        0.0
unit 25    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  2p8.3566        7.9629 -8.3566 381.00        0.0
unit 26    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 7.9629 -8.3566 381.00        0.0
unit 27    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 8.3566 -7.9629 381.00        0.0
unit 28    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  2p8.3566 8.3566 -7.9629        381.00        0.0
unit 29    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 8.3566 -7.9629 381.00        0.0
unit 30    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 7.9629 -8.3566 381.00        0.0
unit 31    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  2p8.3566        7.9629 -8.3566 381.00        0.0
unit 32    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 7.9629 -8.3566 381.00        0.0
unit 33    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 8.3566 -7.9629 381.00        0.0
unit 34    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
```

```
cuboid    5   1  4p7.9629     381.00         0.0
cuboid    8   1  2p8.3566 8.3566 -7.9629       381.00          0.0
unit 35    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00         0.0
cuboid    5   1  4p7.9629     381.00         0.0
cuboid    8   1  7.9629 -8.3566 8.3566 -7.9629 381.00          0.0
unit 36    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00         0.0
cuboid    5   1  4p7.9629     381.00         0.0
cuboid    8   1  8.3566 -7.9629 7.9629 -8.3566 381.00          0.0
unit 37    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00         0.0
cuboid    5   1  4p7.9629     381.00         0.0
cuboid    8   1  2p8.3566       7.9629 -8.3566 381.00          0.0
unit 38    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00         0.0
cuboid    5   1  4p7.9629     381.00         0.0
cuboid    8   1  7.9629 -8.3566 7.9629 -8.3566 381.00          0.0
unit 39   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00         0.0
cuboid    5   1  4p7.9248     381.00         0.0
cuboid    8   1  8.3185 -7.9248 8.3185 -7.9248 381.00          0.0
unit 40  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00         0.0
cuboid    5   1  4p7.9248     381.00         0.0
cuboid    8   1  7.9248 -8.3185 8.3185 -7.9248 381.00          0.0
unit 41  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00         0.0
cuboid    5   1  4p7.9248     381.00         0.0
cuboid    8   1  8.3185 -7.9248 7.9248 -8.3185 381.00          0.0
unit 42  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00         0.0
cuboid    5   1  4p7.9248     381.00         0.0
cuboid    8   1  7.9248 -8.3185 7.9248 -8.3185 381.00          0.0
unit 43   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00         0.0
cuboid    5   1  4p7.9248     381.00         0.0
cuboid    8   1  8.3185 -7.9248 8.3185 -7.9248 381.00          0.0
unit 44  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00         0.0
cuboid    5   1  4p7.9248     381.00         0.0
cuboid    8   1  7.9248 -8.3185 8.3185 -7.9248 381.00          0.0
unit 45  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
```

```
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9248       381.00        0.0
cuboid    8   1  8.3185 -7.9248 7.9248 -8.3185 381.00        0.0
unit 46  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9248       381.00        0.0
cuboid    8   1  7.9248 -8.3185 7.9248 -8.3185 381.00        0.0
unit 47   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9248       381.00        0.0
cuboid    8   1  8.3185 -7.9248 8.3185 -7.9248 381.00        0.0
unit 48  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9248       381.00        0.0
cuboid    8   1  7.9248 -8.3185 8.3185 -7.9248 381.00        0.0
unit 49  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9248       381.00        0.0
cuboid    8   1  8.3185 -7.9248 7.9248 -8.3185 381.00        0.0
unit 50  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9248       381.00        0.0
cuboid    8   1  7.9248 -8.3185 7.9248 -8.3185 381.00        0.0
unit 51   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9248       381.00        0.0
cuboid    8   1  8.3185 -7.9248 8.3185 -7.9248 381.00        0.0
unit 52  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9248       381.00        0.0
cuboid    8   1  7.9248 -8.3185 8.3185 -7.9248 381.00        0.0
unit 53  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9248       381.00        0.0
cuboid    8   1  8.3185 -7.9248 7.9248 -8.3185 381.00        0.0
unit 54  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9248       381.00        0.0
cuboid    8   1  7.9248 -8.3185 7.9248 -8.3185 381.00        0.0
unit 55  com='center 9x9 array'
array 2 -24.6761 -24.6761 0.0
cuboid    5   1  4p24.9428      381.00        0.0
cuboid    8   1  4p25.7302      381.00        0.0
unit 56  com='right 9x9 array'
array 3 -24.6761 -24.6761 0.0
```

```
cuboid     5   1  4p24.9428     381.00          0.0
unit 57  com='top 9x9 array'
array 4 -24.6761 -24.6761 0.0
cuboid     5   1  4p24.9428     381.00          0.0
unit 58  com='left 9x9 array'
array 5 -24.6761 -24.6761 0.0
cuboid     5   1  4p24.9428     381.00          0.0
unit 59  com='bottom 9x9 array'
array 6 -24.6761 -24.6761 0.0
cuboid     5   1  4p24.9428     381.00          0.0
unit 60  com='upper right 2x2 array'
array 7 -16.2433 -16.2433 0.0
cuboid     5   1  4p16.51       381.00          0.0
unit 61  com='upper left 2x2 array'
array 8 -16.2433 -16.2433 0.0
cuboid     5   1  4p16.51       381.00          0.0
unit 62  com='lower right 2x2 array'
array 9 -16.2433 -16.2433 0.0
cuboid     5   1  4p16.51       381.00          0.0
unit 63  com='lower right 2x2 array'
array 10 -16.2433 -16.2433 0.0
cuboid     5   1  4p16.51       381.00          0.0
unit 64  com='0.31" poison plate'
cuboid     8   1  2p16.51 2p0.3937 381.00       0.0
unit 65  com='0.31" poison plate'
cuboid     8   1  2p0.3937 2p16.51 381.00       0.0
unit 66  com='water hole'
cylinder  3  1  0.67437    381.00    0.0
cylinder  2  1  0.75057    381.00    0.0
cuboid    3  1  4P0.8128   381.00    0.0
unit 67    com='Fuel Rod w/3.01 wt%'
cylinder  9   1  0.5207        381.00          0.0
cylinder  6   1  0.53213       381.00          0.0
cylinder  2   1  0.61341       381.00          0.0
cuboid    3   1  4p0.8128      381.00          0.0
unit 68    com='Fuel Rod w/3.57 wt%'
cylinder 10   1  0.5207        381.00          0.0
cylinder  6   1  0.53213       381.00          0.0
cylinder  2   1  0.61341       381.00          0.0
cuboid    3   1  4p0.8128      381.00          0.0
unit 69    com='Fuel Rod w/4.85 wt%'
cylinder 11   1  0.5207        381.00          0.0
cylinder  6   1  0.53213       381.00          0.0
cylinder  2   1  0.61341       381.00          0.0
cuboid    3   1  4p0.8128      381.00          0.0
global unit 70
cylinder  3   1  84.757        381.00          0.0
    hole 55   0.0        0.0      0.0
    hole 56   50.673     0.0      0.0
    hole 57   0.0        50.673   0.0
    hole 58  -50.673     0.0      0.0
    hole 59   0.0       -50.673   0.0
    hole 60   42.2404   42.2404 0.0
    hole 61  -42.2404   42.2404 0.0
```

```
    hole 62  -42.2404 -42.2404 0.0
    hole 63   42.2404 -42.2404 0.0
    hole 64   42.2404  25.3366 0.0
    hole 64  -42.2404  25.3366 0.0
    hole 64  -42.2404 -25.3366 0.0
    hole 64   42.2404 -25.3366 0.0
    hole 65   25.3366  42.2404 0.0
    hole 65  -25.3366  42.2404 0.0
    hole 65  -25.3366 -42.2404 0.0
    hole 65   25.3366 -42.2404 0.0
cylinder  5   1  86.027       381.00        0.0
cuboid    7   1  4p86.03      381.00        0.0
end geom
read array
   com='GE 8x8 fuel assembly slice, sd, fuel regions'
   ara=1      nux=8      nuy=8      nuz=1
   fill
       67 68 68 68 68 68 67  1
       68 69 69 69 69 69 68 67
       69 69 69 69 69 69 69 68
       69 69 69 66 69 69 69 68
       69 69 69 69 66 69 69 68
       69 69 69 69 69 69 69 68
       69 69 69 69 69 69 69 68
       68 69 69 69 69 69 68 67
   end fill
   com='Center 9x9 Array of Fuel'
   ara=2      nux=3      nuy=3      nuz=1
   fill
        18 19 20
         6  2  3
        11  9 10
   end fill
   com='Right 9x9 Array of Fuel'
   ara=3      nux=3      nuy=3      nuz=1
   fill
        27 28 29
         4  5  3
        30 31 32
   end fill
   com='Top 9x9 Array of Fuel'
   ara=4      nux=3      nuy=3      nuz=1
   fill
        16 13 14
        17 12 15
        11  9 10
   end fill
   com='Left 9x9 Array of Fuel'
   ara=5      nux=3      nuy=3      nuz=1
   fill
        33 34 35
         6  8  7
        36 37 38
   end fill
```

```
    com='Bottom 9x9 Array of Fuel'
    ara=6       nux=3       nuy=3       nuz=1
    fill
         18 19 20
         21 22 23
         24 25 26
    end fill
    com='Upper Right 2x2 Array of Fuel'
    ara=7       nux=2       nuy=2       nuz=1
    fill
         39 40
         41 42
    end fill
    com='Upper Left 2x2 Array of Fuel'
    ara=8       nux=2       nuy=2       nuz=1
    fill
         43 44
         45 46
    end fill
    com='Lower Left 2x2 Array of Fuel'
    ara=9       nux=2       nuy=2       nuz=1
    fill
         47 48
         49 50
    end fill
    com='Lower Right 2x2 Array of Fuel'
    ara=10      nux=2       nuy=2       nuz=1
    fill
         51 52
         53 54
    end fill
end array
read bounds
   xyf=specular
   zfc=water
end bounds
read plot
   ttl='cask material plot  - plan view'
   pic=mat
   nch=' fzmcsblxg'
   xul=-87   yul=87    zul=200
   xlr=87    ylr=-87   zlr=200
   uax=1.0    vdn=-1.0
   nax=650
end plot
end data
end
```

Table 6-1
Minimum B-10 Content in the Neutron Poison Plates

NUHOMS®-61BT DSC Type	Maximum Lattice Averaged Enrichment (wt % U235)	B10 Areal Density in Calculations (mg B10/cm^2)
A	3.7	19
B	4.1	29
C	4.4	36

Table 6-2
Authorized Contents for MP-197 Packaging

Assembly Type[1]	Array
General Electric 7x7 /GE2	7x7
General Electric 7x7 /GE3	7x7
General Electric 8x8 /GE4	8x8
General Electric 8x8 /GE5	8x8
General Electric 8x8 /GE-Pres	8x8
General Electric 8x8 /GE-Barrier	8x8
General Electric 8x8 /GE8 Type I	8x8
General Electric 8x8 /GE8 Type II	8x8
General Electric 8x8 /GE9	8x8
General Electric 8x8 /GE10	8x8
General Electric 9x9 /GE11	9x9
General Electric 9x9 /GE13	9x9
General Electric 10x10/GE12	10x10

(1) Reload fuel from other manufactures with the same parameters as those listed in Table 6-3 are also considered as authorized contents.

Table 6-3
Parameters for BWR Assemblies

Manufacturer[(1)]	Array	Version	Active Fuel Length (in)	Number Fuel Rods per Assembly	Pitch (in)	Fuel Pellet OD (in)
GE	7x7	GE2	144	49	0.738	0.487
GE	7x7	GE3	144	49	0.738	0.487
GE	8x8	GE4	146	63	0.640	0.416
GE	8x8	GE5	150	62	0.640	0.410
GE	8x8	GE-Pres	150	62	0.640	0.410
GE	8x8	GE-Barrier	150	62	0.640	0.410
GE	8x8	GE8 Type I	150	62	0.640	0.410
GE	8x8	GE8 Type II	150	60	0.640	0.410
GE	8x8	GE9	150	60	0.640	0.411
GE	8x8	GE10	150	60	0.640	0.411
GE	9x9	GE11	146-Full 90-Partial	66-Full 8-Partial	0.566	0.376
GE	9x9	GE13	146-Full 90-Partial	66-Full 8-Partial	0.566	0.376
GE	10x10	GE12	150-Full 93-Partial	78-Full 14-Partial	0.510	0.345

Manufacturer [(1)]	Array	Version	Clad Thickness (in)	Clad OD (in)	Water Rod OD (in)	Water Rod ID (in)
GE	7x7	GE2	0.032	0.563	NA	NA
GE	7x7	GE3	0.032	0.563	NA	NA
GE	8x8	GE4	0.034	0.493	0.591	0.531
GE	8x8	GE5	0.032	0.483	0.591	0.531
GE	8x8	GE-Pres	0.032	0.483	0.591	0.531
GE	8x8	GE-Barrier	0.032	0.483	0.591	0.531
GE	8x8	GE8 Type I	0.032	0.483	0.591	0.531
GE	8x8	GE8 Type II	0.032	0.483	2@0.591 2@0.483	2@0.531 2@0.419
GE	8x8	GE9	0.032	0.483	1.34	1.26
GE	8x8	GE10	0.032	0.483	1.34	1.26
GE	9x9	GE11	0.028	0.440	0.98	0.92
GE	9x9	GE13	0.028	0.440	0.98	0.92
GE	10x10	GE12	0.026	0.404	0.98	0.92

(1) Reload fuel from other manufacturers with these parameters are also acceptable

Table 6-4
Axial Layout of the KENO V.a Model of MP-197

Number of Times Unit is Repeated	Unit Number	Description (Reflective Boundary Conditions on All Sides)
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
3	79	0.75 inches of Fuel w/out poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
365.76	Total Length of Model, cm	
144	Total Length of Model, cm	

Table 6-5
Material Property Data

Material	Density g/cm^3	Element	Weight %	Atom Density (atoms/b-cm)
UO_2 (Enrichment - 4.4 wt%)	10.41	U-235	3.88	1.0347E-03
		U-238	84.26	2.2197E-02
		O	11.86	4.6464E-02
UO_2 (Enrichment - 4.1 wt%)	10.41	U-235	3.61	9.6415E-04
		U-238	84.53	2.2267E-02
		O	11.86	4.6462E-02
UO_2 (Enrichment - 3.7 wt%)	10.41	U-235	3.26	8.7010E-04
		U-238	84.88	2.2360E-02
		O	11.86	4.6460E-02
Zircaloy-2	6.56	Zr	98.250	4.2550E-02
		Sn	1.450	4.8254E-04
		Fe	0.135	9.5501E-05
		Cr	0.100	7.5978E-05
		Ni	0.055	3.7023E-05
		Hf	0.010	2.2133E-06
Water	0.9982	H	11.1	6.6769E-02
		O	88.9	3.3385E-02
Carbon Steel	7.8212	Fe	99	8.3498E-02
		C	1	3.9250E-03
Stainless Steel (SS304)	7.94	C	0.080	3.1877E-04
		Si	1.000	1.7025E-03
		P	0.045	6.9468E-05
		Cr	19.000	1.7473E-02
		Mn	2.000	1.7407E-03
		Fe	68.375	5.8545E-02
		Ni	9.500	7.7402E-03
Lead	11.344	Pb	100	3.2969E-02
Aluminum - Boron Poison Plate (0.036 g/cm^2 B-10)	2.479	B-10	1.906	2.8412E-03
		Al	98.094	5.4276E-02
Aluminum - Boron Poison Plate (0.029 g/cm^2 B-10)	2.470	B-10	1.531	2.2734E-03
		Al	98.469	5.4276E-02
Aluminum - Boron Poison Plate (0.019 g/cm^2 B-10)	2.457	B-10	1.010	1.4916E-03
		Al	98.990	5.4276E-02

Table 6-6
Most Reactive Fuel Type

Manufacturer	Array	Version	k_{KENO}	1σ	k_{eff}
GE	7x7	GE2, GE3	0.9037	0.0012	0.9061
GE	7x7 0.120 channel	GE2, GE3	0.9033	0.0015	0.9063
GE	7x7 0.080 channel	GE2, GE3	0.9028	0.0012	0.9052
GE	7x7 0.065 channel	GE2, GE3	0.9043	0.0013	0.9069
GE	8x8	GE4	0.8951	0.0013	0.8977
GE	8x8 0.120 channel	GE4	0.8927	0.0013	0.8953
GE	8x8 0.080 channel	GE4	0.8930	0.0013	0.8956
GE	8x8 0.065 channel	GE4	0.8940	0.0012	0.8964
GE	8x8	GE5 GE-Pres GE-Barrier GE8 Type I GE8 Type II	0.9009	0.0011	0.9031
GE	8x8 0.120 channel	GE5	0.9015	0.0012	0.9039
GE	8x8 0.080 channel	GE5	0.9027	0.0013	0.9053
GE	8x8 0.065 channel	GE5	0.9012	0.0011	0.9034
GE	8x8	GE8 Type II	0.9020	0.0012	0.9044
GE	8x8 0.120 channel	GE8 Type II	0.9054	0.0014	0.9082
GE	8x8 0.080 channel	GE8 Type II	0.9043	0.0014	0.9071
GE	8x8 0.065 channel	GE8 Type II	0.9023	0.0013	0.9049
GE	8x8	GE9, GE10	0.9043	0.0013	0.9069
GE	8x8 0.120 channel	GE9, GE10	0.9062	0.0013	0.9088
GE	8x8 0.080 channel	GE9, GE10	0.9054	0.0011	0.9076
GE	8x8 0.065 channel	GE9, GE10	0.9052	0.0014	0.9080
GE	9x9	GE11, GE13	0.9042	0.0014	0.9070
GE	9x9 0.120 channel	GE11, GE13	0.9025	0.0014	0.9053
GE	9x9 0.080 channel	GE11, GE13	0.9066	0.0012	0.9090
GE	9x9 0.065 channel	GE11, GE13	0.9040	0.0013	0.9066
GE	10x10	GE12	0.9095	0.0013	0.9121
GE	10x10 0.120 channel	GE12	0.9094	0.0010	0.9114
GE	10x10 0.080 channel	GE12	0.9092	0.0013	0.9118
GE	10x10 0.065 channel	GE12	0.9076	0.0011	0.9098
GE	7x7 w/variable enrichment	GE2, GE3	0.8947	0.0012	0.8971
GE	8x8 w/variable enrichment	GE5	0.8951	0.0011	0.8973
GE	8x8 w/variable enrichment	GE9	0.9008	0.0013	0.9034

Table 6-7
Most Reactive Configuration

Model Description	k_{KENO}	1σ	k_{eff}
Assembly-to-Assembly Pitch Evaluation			
Maximum Assembly-to-Assembly Pitch	0.8710	0.0013	0.8736
Assemblies Centered in Sleeves	0.9110	0.0012	0.9134
Minimum Assembly-to-Assembly Pitch	0.9110	0.0014	0.9138
Canister Shell Variation Evaluation			
Minimum Shell Thickness	0.9125	0.0012	0.9149
Nominal Shell Thickness	0.9110	0.0014	0.9138
Maximum Shell Thickness	0.9141	0.0011	0.9163
Poison Thickness Evaluation			
Nominal PoisonThickness (0.31 inches)	0.9110	0.0014	0.9138
Minimum Poison Thickness (0.3 inches)	0.9163	0.0012	0.9187
Fuel Cladding O.D. Evaluation			
Fuel Clad OD = 0.404 inches	0.9163	0.0012	0.9187
Fuel Clad OD = 0.402 inches	0.9157	0.0010	0.9177
Fuel Cald OD = 0.400 inches	0.9183	0.0011	0.9205
Fuel Clad OD = 0.398 inches	0.9201	0.0013	0.9227
Fuel Clad OD = 0.396 inches	0.9222	0.0012	0.9246
Fuel Clad OD = 0.394 inches	0.9229	0.0012	0.9253
Fuel Cell Width Evaluation			
Maximum Fuel Cell Width	0.9194	0.0011	0.9216
Nominal Fuel Cell Width	0.9229	0.0012	0.9253
Minimum Fuel Cell Width	0.9349	0.0011	0.9371
Minimum Fuel Cell Width with Maximum Shell Thickness	0.9326	0.0014	0.9354
Internal Moderator Density Evaluation			
Internal Moderator at 100% TD	0.9349	0.0011	0.9371
Internal Moderator at 90% TD	0.9079	0.0013	0.9105
Internal Moderator at 80% TD	0.8772	0.0013	0.8798
Internal Moderator at 70% TD	0.8401	0.0012	0.8425
Internal Moderator at 60% TD	0.7980	0.0010	0.8000
Internal Moderator at 50% TD	0.7466	0.0010	0.7486
Internal Moderator at 40% TD	0.6862	0.0010	0.6882
Internal Moderator at 30% TD	0.6236	0.0008	0.6252
Internal Moderator at 20% TD	0.5628	0.0010	0.5648
Internal Moderator at 10% TD	0.5078	0.0006	0.5090
Internal Moderator at 0% TD	0.4364	0.0004	0.4372
External Moderator Density Evaluation			
External Moderator at 100% TD	0.9349	0.0011	0.9371
External Moderator at 90% TD	0.9340	0.0011	0.9362
External Moderator at 80% TD	0.9324	0.0012	0.9348
External Moderator at 70% TD	0.9365	0.0011	0.9387
External Moderator at 60% TD	0.9363	0.0011	0.9385
External Moderator at 50% TD	0.9336	0.0011	0.9358
External Moderator at 40% TD	0.9345	0.0011	0.9367
External Moderator at 30% TD	0.9332	0.0013	0.9358
External Moderator at 20% TD	0.9332	0.0012	0.9356
External Moderator at 10% TD	0.9321	0.0013	0.9347
External Moderator at 0% TD	0.9321	0.0012	0.9345
Minimum Boron-10 Loading as a Function of Maximum Lattice Average Enrichment			
4.4 wt% U-235; 0.040 g/cm^2 B-10	0.9349	0.0011	0.9371
4.1 wt% U-235; 0.032 g/cm^2 B-10	0.9336	0.0011	0.9358
3.7 wt% U-235; 0.021 g/cm^2 B-10	0.9343	0.0013	0.9369

Table 6-8
Criticality Results

Model Description	k_{KENO}	1σ	k_{eff}
Infinite array of damaged packages per 10CFR Part 71.59 (a) (2) 4.4 wt% U-235; 0.040 g/cm^2 B-10 100% internal, 70% external water density	0.9365	0.0011	0.9387
Minimum Boron-10 Loading as a Function of Maximum Lattice Average Enrichment (same model as above, but external water at 100% density)			
4.4 wt% U-235; 0.040 g/cm^2 B-10	0.9349	0.0011	0.9371
4.1 wt% U-235; 0.032 g/cm^2 B-10	0.9336	0.0011	0.9358
3.7 wt% U-235; 0.021 g/cm^2 B-10	0.9343	0.0013	0.9369

Table 6-9
Benchmarking Results

Run ID	U Enrich. Wt%	Pu Enrich. Wt%	Pitch (cm)	H_2O/fuel volume	Separation of assemblies (cm)	AEG	k_{eff}	1σ
B1645SO1	2.46		1.41	1.015		32.8194	0.9967	0.0009
B1645SO2	2.46		1.41	1.015		32.7584	1.0002	0.0011
BW1231B1	4.02		1.511	1.139		31.1427	0.9966	0.0012
BW1231B2	4.02		1.511	1.139		29.8854	0.9972	0.0009
BW1273M	2.46		1.511	1.376		32.2106	0.9965	0.0009
BW1484A1	2.46		1.636	1.841	1.636	34.5304	0.9962	0.0010
BW1484A2	2.46		1.636	1.841	4.908	35.1629	0.9931	0.0010
BW1484B1	2.46		1.636	1.841		33.9421	0.9979	0.0010
BW1484B2	2.46		1.636	1.841	1.636	34.5820	0.9955	0.0012
BW1484B3	2.46		1.636	1.841	4.908	35.2609	0.9969	0.0011
BW1484C1	2.46		1.636	1.841	1.636	34.6463	0.9931	0.0011
BW1484C2	2.46		1.636	1.841	4.908	35.2422	0.9939	0.0012
BW1484S1	2.46		1.636	1.841	1.636	34.5105	1.0001	0.0010
BW1484S2	2.46		1.636	1.841	1.636	34.5569	0.9992	0.0010
BW1484SL	2.46		1.636	1.841	6.544	35.4151	0.9935	0.0011
BW1645S1	2.46		1.209	0.383	1.778	30.1040	0.9990	0.0010
BW1645S2	2.46		1.209	0.383	1.778	29.9961	1.0037	0.0011
BW1810A	2.46		1.636	1.841		33.9465	0.9984	0.0008
BW1810B	2.46		1.636	1.841		33.9631	0.9984	0.0009
BW1810C	2.46		1.636	1.841		33.1569	0.9992	0.0010
BW1810D	2.46		1.636	1.841		33.0821	0.9985	0.0013
BW1810E	2.46		1.636	1.841		33.1600	0.9988	0.0009
BW1810F	2.46		1.636	1.841		33.9556	1.0031	0.0011
BW1810G	2.46		1.636	1.841		32.9409	0.9973	0.0011
BW1810H	2.46		1.636	1.841		32.9420	0.9972	0.0011
BW1810I	2.46		1.636	1.841		33.9655	1.0037	0.0009
BW1810J	2.46		1.636	1.841		33.1403	0.9983	0.0011
DSN399-1	4.74		1.6	3.807	1.8	33.9520	1.0036	0.0015
DSN399-2	4.74		1.6	3.807	5.8	34.4207	0.9989	0.0016
DSN399-3	4.74		1.6	3.807		35.3140	1.0024	0.0015
DSN399-4	4.74		1.6	3.807		35.3784	0.9977	0.0013
EPRU65	2.35		1.562	1.196		33.9106	0.9960	0.0011
EPRU65B	2.35		1.562	1.196		33.4013	0.9993	0.0012
EPRU75	2.35		1.905	2.408		35.8671	0.9958	0.0010
EPRU75B	2.35		1.905	2.408		35.3043	0.9996	0.0010
EPRU87	2.35		2.21	3.687		36.6129	1.0007	0.0011
EPRU87B	2.35		2.21	3.687		36.3499	1.0007	0.0011
NSE71SQ	4.74		1.26	1.823		33.7610	0.9979	0.0012
NSE71W1	4.74		1.26	1.823		34.0129	0.9988	0.0013
NSE71W2	4.74		1.26	1.823		36.3037	0.9957	0.0010
P2438BA	2.35		2.032	2.918	5.05	36.2277	0.9979	0.0013
P2438SLG	2.35		2.032	2.918	8.39	36.2889	0.9986	0.0012
P2438SS	2.35		2.032	2.918	6.88	36.2705	0.9974	0.0011
P2438ZR	2.35		2.032	2.918	8.79	36.2840	0.9987	0.0010
P2615BA	4.31		2.54	3.883	6.72	35.7286	1.0019	0.0014
P2615SS	4.31		2.54	3.883	8.58	35.7495	0.9952	0.0015
P2615ZR	4.31		2.54	3.883	10.92	35.7700	0.9977	0.0014
P2827L1	2.35		2.032	2.918	13.27	36.2526	1.0057	0.0011
P2827L2	2.35		2.032	2.918	11.25	36.2908	0.9999	0.0012

Table 6-9
Benchmarking Results, continued

Run ID	U Enrich. Wt%	Pu Enrich. Wt%	Pitch (cm)	H_2O/fuel volume	Separation of assemblies (cm)	AEG	k_{eff}	1σ
P2827L3	4.31		2.54	3.883	20.78	35.6766	1.0092	0.0012
P2827L4	4.31		2.54	3.883	19.04	35.7131	1.0073	0.0012
P2827SLG	2.35		2.032	2.918	8.31	36.3037	0.9957	0.0010
P3314BA	4.31		1.892	1.6	2.83	33.1881	0.9988	0.0012
P3314BC	4.31		1.892	1.6	2.83	33.2284	0.9992	0.0012
P3314BF1	4.31		1.892	1.6	2.83	33.2505	1.0037	0.0013
P3314BF2	4.31		1.892	1.6	2.83	33.2184	1.0009	0.0013
P3314BS1	2.35		1.684	1.6	3.86	34.8594	0.9956	0.0013
P3314BS2	2.35		1.684	1.6	3.46	34.8356	0.9949	0.0010
P3314BS3	4.31		1.892	1.6	7.23	33.4247	0.9970	0.0013
P3314BS4	4.31		1.892	1.6	6.63	33.4162	0.9998	0.0012
P3314SLG	4.31		1.892	1.6	2.83	34.0198	0.9974	0.0012
P3314SS1	4.31		1.892	1.6	2.83	33.9601	0.9999	0.0012
P3314SS2	4.31		1.892	1.6	2.83	33.7755	1.0022	0.0012
P3314SS3	4.31		1.892	1.6	2.83	33.8904	0.9992	0.0013
P3314SS4	4.31		1.892	1.6	2.83	33.7625	0.9958	0.0011
P3314SS5	2.35		1.684	1.6	7.8	34.9531	0.9949	0.0013
P3314SS6	4.31		1.892	1.6	10.52	33.5333	1.0020	0.0011
P3314W1	4.31		1.892	1.6		34.3994	1.0024	0.0013
P3314W2	2.35		1.684	1.6		35.2167	0.9969	0.0011
P3314ZR	4.31		1.892	1.6	2.83	33.9954	0.9971	0.0013
P3602BB	4.31		1.892	1.6	8.3	33.3221	1.0029	0.0013
P3602BS1	2.35		1.684	1.6	4.8	34.7750	1.0027	0.0012
P3602BS2	4.31		1.892	1.6	9.83	33.3679	1.0039	0.0012
P3602N11	2.35		1.684	1.6	8.98	34.7438	1.0023	0.0012
P3602N12	2.35		1.684	1.6	9.58	34.8391	1.0030	0.0012
P3602N13	2.35		1.684	1.6	9.66	34.9337	1.0013	0.0012
P3602N14	2.35		1.684	1.6	8.54	35.0282	0.9974	0.0013
P3602N21	2.35		2.032	2.918	11.2	36.2821	0.9987	0.0011
P3602N22	2.35		2.032	2.918	10.36	36.1896	1.0025	0.0011
P3602N31	4.31		1.892	1.6	14.87	33.2094	1.0057	0.0013
P3602N32	4.31		1.892	1.6	15.74	33.3067	1.0093	0.0012
P3602N33	4.31		1.892	1.6	15.87	33.4174	1.0107	0.0012
P3602N34	4.31		1.892	1.6	15.84	33.4683	1.0045	0.0013
P3602N35	4.31		1.892	1.6	15.45	33.5186	1.0013	0.0012
P3602N36	4.31		1.892	1.6	13.82	33.5855	1.0004	0.0014
P3602N41	4.31		2.54	3.883	12.89	35.5276	1.0109	0.0013
P3602N42	4.31		2.54	3.883	14.12	35.6695	1.0071	0.0014
P3602N43	4.31		2.54	3.883	12.44	35.7542	1.0053	0.0015
P3602SS1	2.35		1.684	1.6	8.28	34.8701	1.0025	0.0013
P3602SS2	4.31		1.892	1.6	13.75	33.4202	1.0035	0.0012
P3926L1	2.35		1.684	1.6	10.06	34.8519	1.0000	0.0011
P3926L2	2.35		1.684	1.6	10.11	34.9324	1.0017	0.0011
P3926L3	2.35		1.684	1.6	8.5	35.0641	0.9949	0.0012
P3926L4	4.31		1.892	1.6	17.74	33.3243	1.0074	0.0014
P3926L5	4.31		1.892	1.6	18.18	33.4074	1.0057	0.0013
P3926L6	4.31		1.892	1.6	17.43	33.5246	1.0046	0.0013
P3926SL1	2.35		1.684	1.6	6.59	33.4737	0.9995	0.0012
P3926SL2	4.31		1.892	1.6	12.79	33.5776	1.0007	0.0012

Table 6-9
Benchmarking Results, continued

Run ID	U Enrich. Wt%	Pu Enrich. Wt%	Pitch (cm)	H_2O/fuel volume	Separation of assemblies (cm)	AEG	k_{eff}	1σ
P4267B1	4.31		1.8901	1.59		31.8075	0.9990	0.0010
P4267B2	4.31		0.89	1.59		31.5323	1.0033	0.0010
P4267B3	4.31		1.715	1.09		30.9905	1.0050	0.0011
P4267B4	4.31		1.715	1.09		30.5061	0.9996	0.0011
P4267B5	4.31		1.715	1.09		30.1011	1.0004	0.0011
P4267SL1	4.31		1.89	1.59		33.4737	0.9995	0.0012
P4267SL2	4.31		1.715	1.09		31.9460	0.9988	0.0016
P62FT231	4.31		1.891	1.6	5.19	32.9196	1.0012	0.0013
P71F14F3	4.31		1.891	1.6	5.19	32.8237	1.0009	0.0014
P71F14V3	4.31		1.891	1.6	5.19	32.8597	0.9972	0.0014
P71F14V5	4.31		1.891	1.6	5.19	32.8609	0.9993	0.0013
P71F214R	4.31		1.891	1.6	5.19	32.8778	0.9969	0.0012
PAT80L1	4.74		1.6	3.807	4.9	35.0253	1.0012	0.0012
PAT80L2	4.74		1.6	3.807	4.9	35.1136	0.9993	0.0015
PAT80SS1	4.74		1.6	3.807	4.9	35.0045	0.9988	0.0013
PAT80SS2	4.74		1.6	3.807	4.9	35.1072	0.9960	0.0013
W3269A	5.7		1.422	1.93		33.1480	0.9988	0.0012
W3269B1	3.7		1.105	1.432		32.4055	0.9961	0.0011
W3269B2	3.7		1.105	1.432		32.3921	0.9963	0.0011
W3269B3	3.7		1.105	1.432		32.2363	0.9944	0.0011
W3269C	2.72		1.524	1.494		33.7727	0.9989	0.0012
W3269SL1	2.72		1.524	1.494		33.3850	0.9981	0.0014
W3269SL2	5.7		1.422	1.93		33.0910	1.0005	0.0013
W3269W1	2.72		1.524	1.494		33.5114	0.9966	0.0014
W3269W2	5.7		1.422	1.93		33.1680	1.0014	0.0014
W3385SL1	5.74		1.422	1.932		33.2387	1.0009	0.0012
W3385SL2	5.74		2.012	5.067		35.8818	0.9997	0.0013
EPRI70UN	0.71	2	1.778	1.2		31.6775	0.9983	0.0012
EPRI70B	0.71	2	1.778	1.2		30.9021	1.0009	0.0012
EPRI87UN	0.71	2	2.2098	2.53		33.3230	1.0096	0.0011
EPRI87B	0.71	2	2.2098	2.53		31.6775	0.9983	0.0012
EPRI99UN	0.71	2	2.5146	3.64		35.1817	1.0063	0.0011
EPRI99B	0.71	2	2.5146	3.64		34.4098	1.0095	0.0011
SAXTON52	0.71	6.6	1.3208	1.68		30.2980	1.0020	0.0014
SAXTON56	0.71	6.6	1.4224	2.16		31.4724	1.0010	0.0014
SAXTON56B	0.71	6.6	1.4224	2.16		31.0038	0.9994	0.0013
SAXTN735	0.71	6.6	1.8669	4.7		34.1848	1.0007	0.0016
SATN792	0.71	6.6	2.01168	5.67		34.6401	1.0026	0.0013
SAXTN104	0.71	6.6	2.6416	10.75		35.8333	1.0054	0.0014
Correlation	0.31	-0.26	0.43	0.25	0.65	-0.01	N/A	N/A

Table 6-10
USL-1 Results

Parameter	Range of applicability	USL-1
U Enrichment (wt. % U-235)	2.4 2.8 3.3 3.8 – 5.7	0.9424 0.9430 0.9435 0.9438
Pu Enrichment (wt. % Pu)	2.0 – 6.6	0.9417
Fuel Rod Pitch (cm)	0.89 1.1 1.4 1.6 1.9 – 2.6	0.9396 0.9408 0.9421 0.9433 0.9439
Water/Fuel Volume Ratio	0.38 1.9 3.3 – 11	0.9414 0.9425 0.9426
Assembly Separation (cm)	1.6 4.4 7.1 9.8 – 21	0.9410 0.9425 0.9440 0.9441
Average Energy Group Causing Fission (AEG)	30 – 37	0.9433

Table 6-11
USL Determination for Criticality Analysis

Parameter	Value from Limiting Analysis	Bounding USL-1
U Enrichment (wt% U-235)	3.7 - 4.4	0.9438
Fuel Rod Pitch (cm)	1.875	0.9433
Water/Fuel Ratio	1.6	**0.9414**
Assembly Separation (cm)	16.56	0.9441
Average Energy Group Causing Fission (AEG)	~33	0.9433

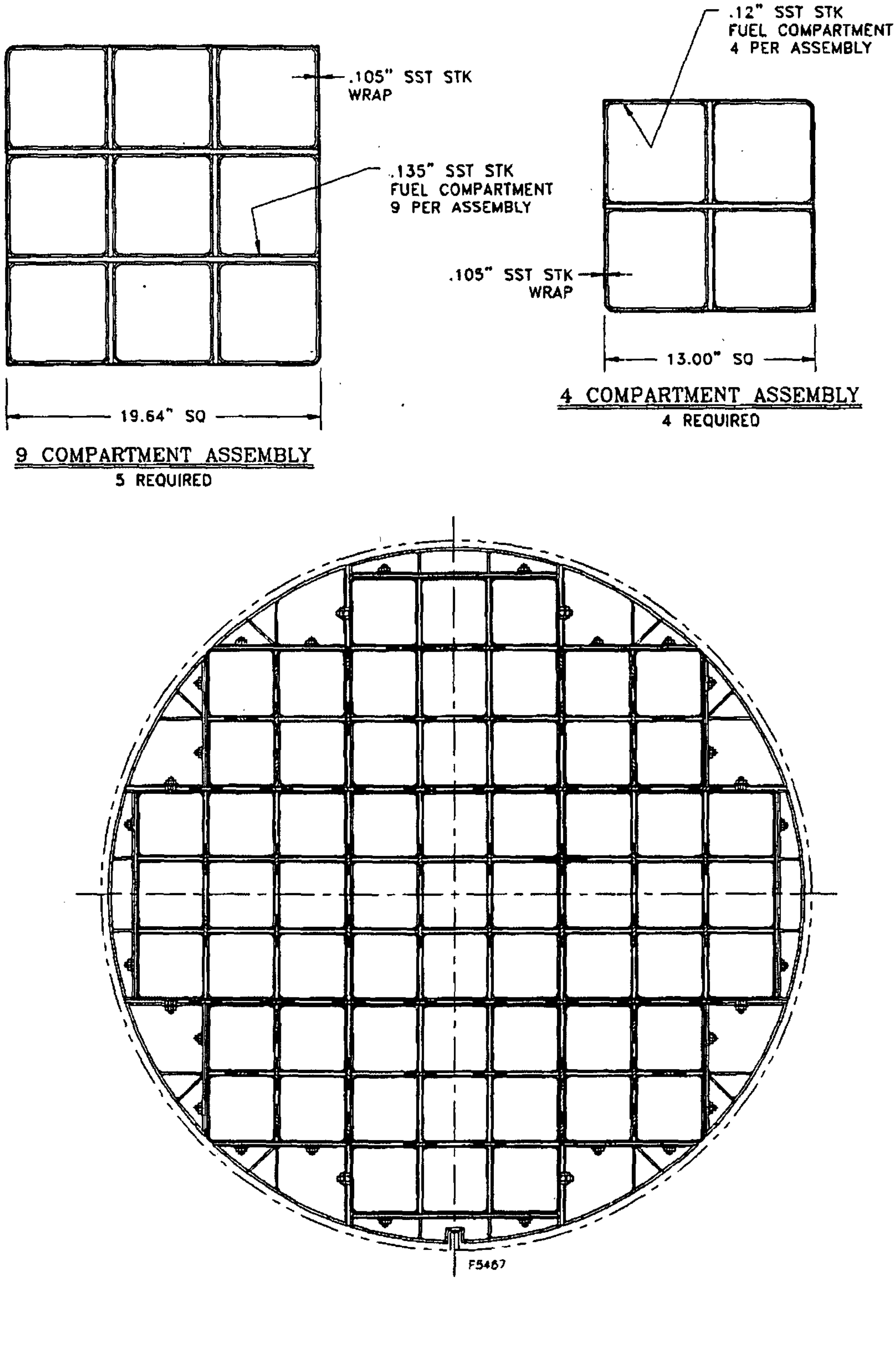
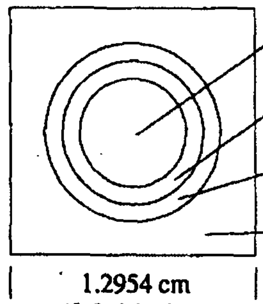
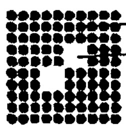


Figure 6-1 NUHOMS®-61BT DSC Axial Cross Section

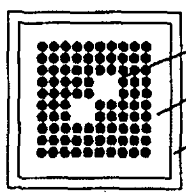
Unit 1 GE 10x10 Fuel Rod



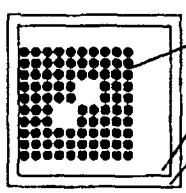
Array 1 GE 10x10 Fuel Assembly made up by a 10x10 array of Units 1 (fuel) and 81 (Water Holes)



Unit 2 GE 10x10 Fuel Assembly Centered in a Fuel Compartment for a 3x3 Compartment



Unit 3 GE 10x10 Fuel Assembly Shifted to the Left in a Fuel Compartment for a 3x3 Compartment



Unit 4 GE 10x10 Fuel Assembly Shifted to the Right in a Fuel Compartment for a 3x3 Compartment

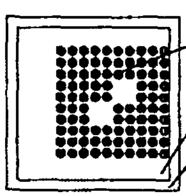
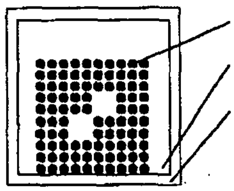


Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model

PART 1 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 5 GE 10x10 Fuel Assembly Shifted Down in a Fuel Compartment for a 3x3 Compartment

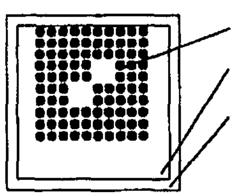


Fuel Assembly; Array 1 inside Fuel Compartment

Water in Fuel Compartment; 14.732 cm (5.80 inches) square; Material 3, water

Fuel Compartment; 15.2654 cm (6.01 inches) square (0.105 in. thick); Material 5, Stainless Steel

Unit 6 GE 10x10 Fuel Assembly Shifted Up in a Fuel Compartment for a 3x3 Compartment

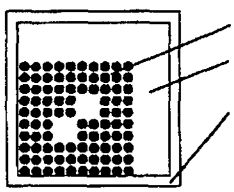


Fuel Assembly; Array 1 inside Fuel Compartment

Water in Fuel Compartment; 14.732 cm (5.80 inches) square; Material 3, water

Fuel Compartment; 15.2654 cm (6.01 inches) square (0.105 in. thick); Material 5, Stainless Steel

Unit 7 GE 10x10 Fuel Assembly Shifted to the Lower Left in a Fuel Compartment for a 3x3 Compartment

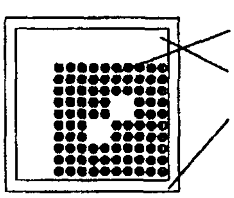


Fuel Assembly; Array 1 inside Fuel Compartment

Water in Fuel Compartment; 14.732 cm (5.80 inches) square; Material 3, water

Fuel Compartment; 15.2654 cm (6.01 inches) square (0.105 in. thick); Material 5, Stainless Steel

Unit 8 GE 10x10 Fuel Assembly Shifted to the Lower Right in a Fuel Compartment for a 3x3 Compartment

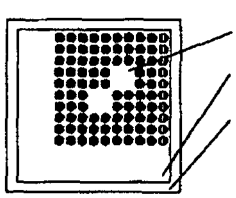


Fuel Assembly; Array 1 inside Fuel Compartment

Water in Fuel Compartment; 14.732 cm (5.80 inches) square; Material 3, water

Fuel Compartment; 15.2654 cm (6.01 inches) square (0.105 in. thick); Material 5, Stainless Steel

Unit 9 GE 10x10 Fuel Assembly Shifted to the Upper Right in a Fuel Compartment for a 3x3 Compartment



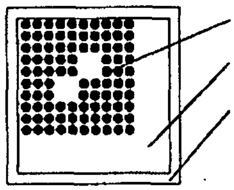
Fuel Assembly; Array 1 inside Fuel Compartment

Water in Fuel Compartment; 14.732 cm (5.80 inches) square; Material 3, water

Fuel Compartment; 15.2654 cm (6.01 inches) square (0.105 in. thick); Material 5, Stainless Steel

Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 2 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 10 GE 10x10 Fuel Assembly Shifted to the Upper Left in a Fuel Compartment for a 3x3 Compartment

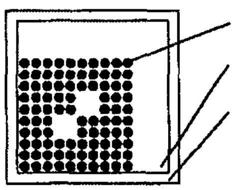


Fuel Assembly; Array 1 inside Fuel Compartment

Water in Fuel Compartment; 14.732 cm (5.80 inches) square; Material 3, water

Fuel Compartment; 15.2654 cm (6.01 inches) square (0.105 in. thick);
Material 5, Stainless Steel

Unit 11 GE 10x10 Fuel Assembly Shifted to the Lower Left in a Fuel Compartment for a 2x2 Compartment

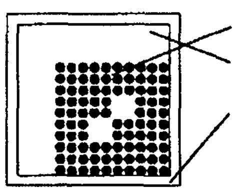


Fuel Assembly; Array 1 inside Fuel Compartment

Water in Fuel Compartment; 14.732 cm (5.80 inches) square; Material 3, water

Fuel Compartment; 15.1892 cm (5.98 inches) square (0.090 in. thick);
Material 5, Stainless Steel

Unit 12 GE 10x10 Fuel Assembly Shifted to the Lower Right in a Fuel Compartment for a 2x2 Compartment

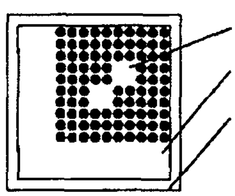


Fuel Assembly; Array 1 inside Fuel Compartment

Water in Fuel Compartment; 14.732 cm (5.80 inches) square; Material 3, water

Fuel Compartment; 15.1892 cm (5.98 inches) square (0.090 in. thick);
Material 5, Stainless Steel

Unit 13 GE 10x10 Fuel Assembly Shifted to the Upper Right in a Fuel Compartment for a 2x2 Compartment

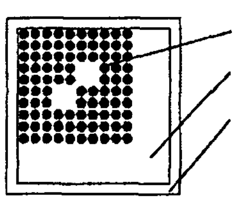


Fuel Assembly; Array 1 inside Fuel Compartment

Water in Fuel Compartment; 14.732 cm (5.80 inches) square; Material 3, water

Fuel Compartment; 15.1892 cm (5.98 inches) square (0.090 in. thick);
Material 5, Stainless Steel

Unit 14 GE 10x10 Fuel Assembly Shifted to the Upper Left in a Fuel Compartment for a 2x2 Compartment



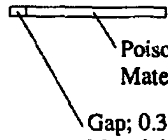
Fuel Assembly; Array 1 inside Fuel Compartment

Water in Fuel Compartment; 14.732 cm (5.80 inches) square; Material 3, water

Fuel Compartment; 15.1892 cm (5.98 inches) square (0.090 in. thick);
Material 5, Stainless Steel

Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 3 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

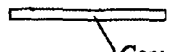
Unit 15 Poison Plate with Gap for a 3x3 Compartment



Poison Plate; 14.9479 x 0.762 cm (5.885 x 0.30 inches);
Material 8, Borated Aluminum

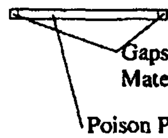
Gap; 0.3175 x 0.762 cm (0.125 x 0.30 inches);
Material 0, Void

Unit 16 Gap for a 3x3 Compartment



Gap; 15.2654 x 0.762 cm (6.01 x 0.30 inches);
Material 0, Void

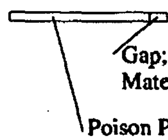
Unit 17 Poison Plate with Gap for a 3x3 Compartment



Gaps; 0.15875 x 0.762 cm (0.0625 x 0.30 inches);
Material 0, Void

Poison Plate; 14.9479 x 0.762 cm (5.885 x 0.30 inches);
Material 8, Borated Aluminum

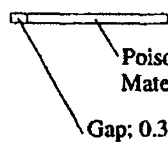
Unit 18 Poison Plate with Gap for a 3x3 Compartment



Gap; 0.3175 x 0.762 cm (0.125 x 0.30 inches);
Material 0, Void

Poison Plate; 14.9479 x 0.762 cm (5.885 x 0.30 inches);
Material 8, Borated Aluminum

Unit 19 Poison Plate with Gap for a 2x2 Compartment



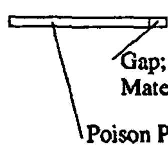
Poison Plate; 14.8717 x 0.762 cm (5.855 x 0.30 inches);
Material 8, Borated Aluminum

Gap; 0.3175 x 0.762 cm (0.125 x 0.30 inches);
Material 0, Void

Unit 20 Gap for a 2x2 Compartment

Gap; 15.1892 x 0.762 cm (5.98 x 0.30 inches);
Material 0, Void

Unit 21 Poison Plate with Gap for a 2x2 Compartment

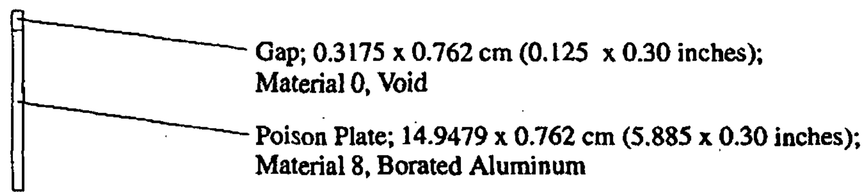


Gap; 0.3175 x 0.762 cm (0.125 x 0.30 inches);
Material 0, Void

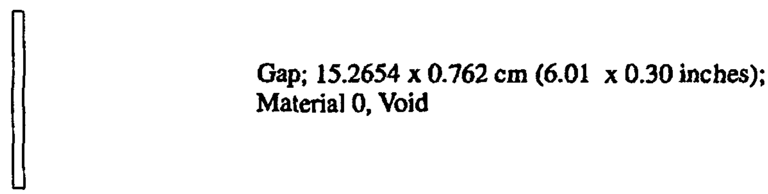
Poison Plate; 14.8717 x 0.762 cm (5.855 x 0.30 inches);
Material 8, Borated Aluminum

Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 4 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

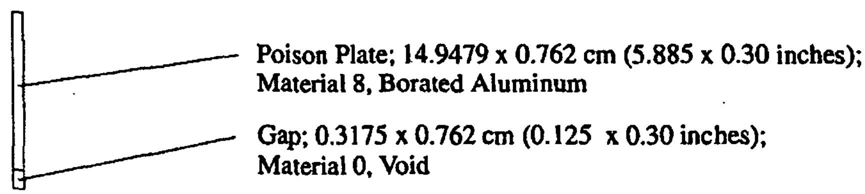
Unit 22 Poison Plate with Gap for a 3x3 Compartment



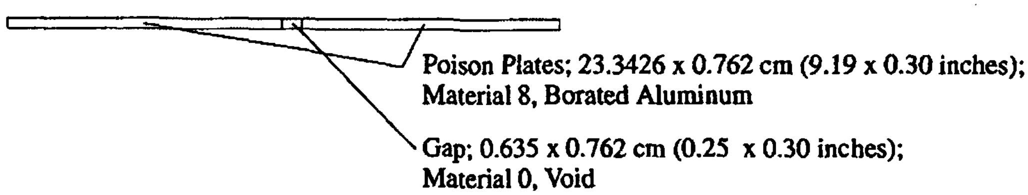
Unit 23 Gap for a 3x3 Compartment



Unit 24 Poison Plate with Gap for a 3x3 Compartment



Unit 25 Poison Plates with Gap for a 3x3 Compartment



Unit 26 Long Gap for a 3x3 Compartment

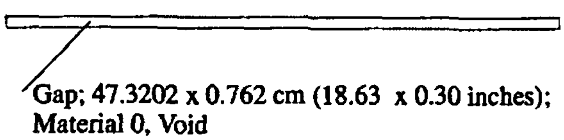
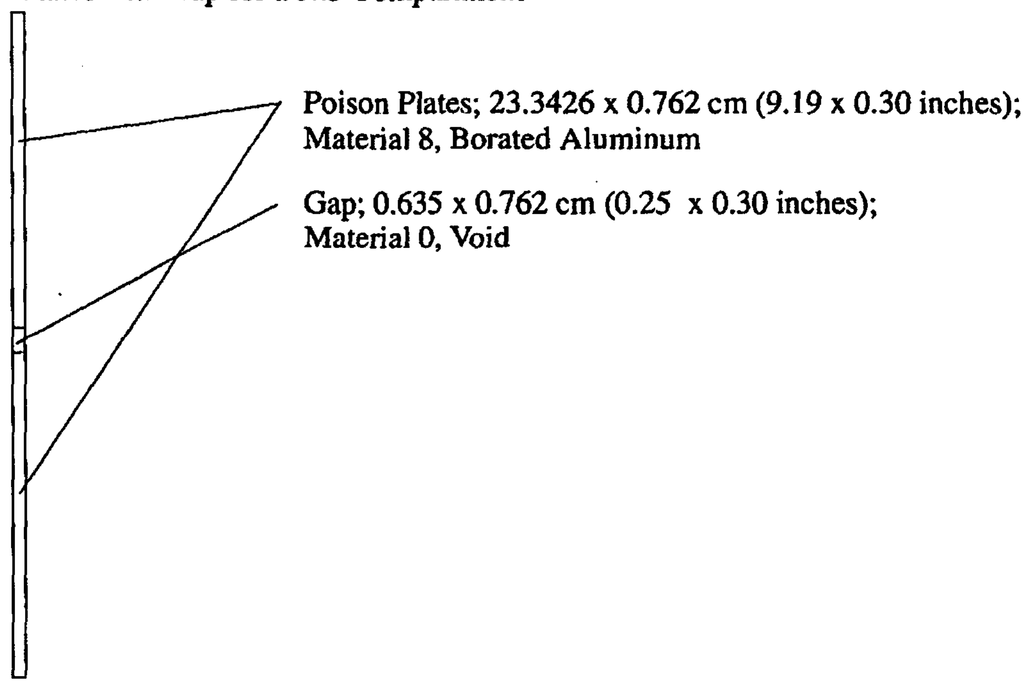


Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 5 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 27 Poison Plates with Gap for a 3x3 Compartment



Unit 28 Long Gap for a 3x3 Compartment

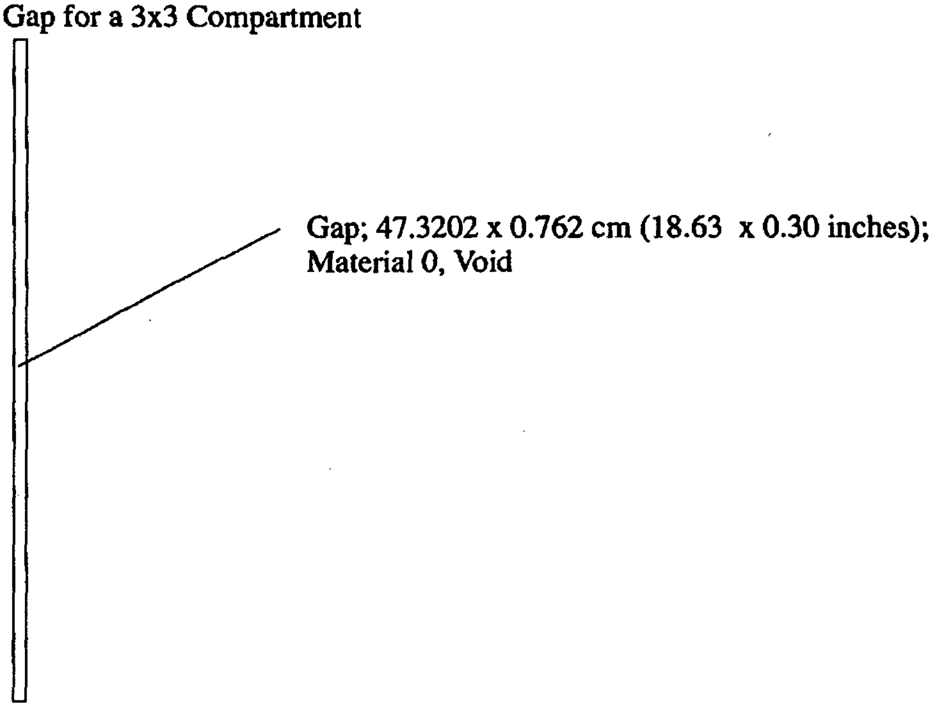
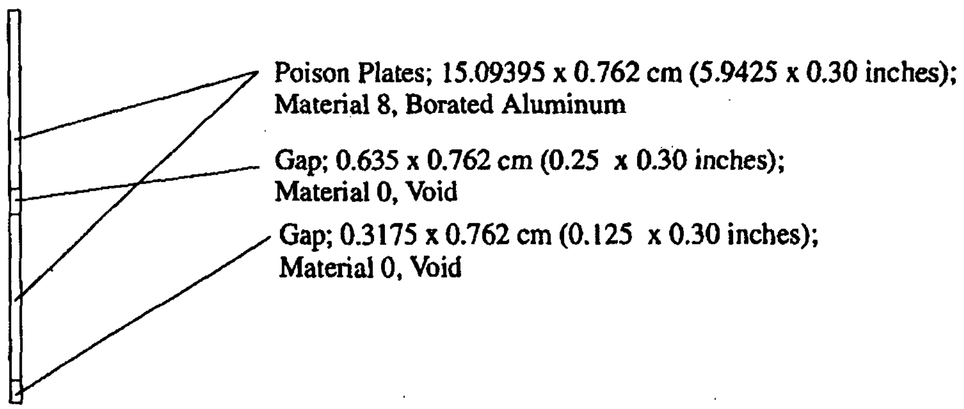
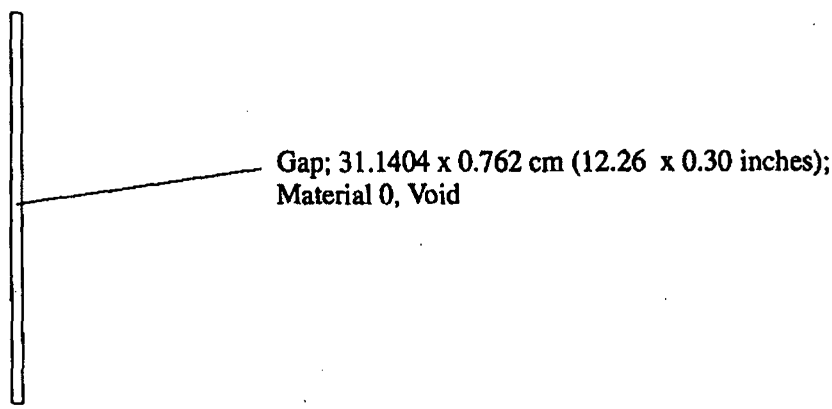


Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 6 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 29 Poison Plates with Gap for a 2x2 Compartment



Unit 30 Gap for a 2x2 Compartment



Unit 31 Poison Plates with Gap for a 2x2 Compartment

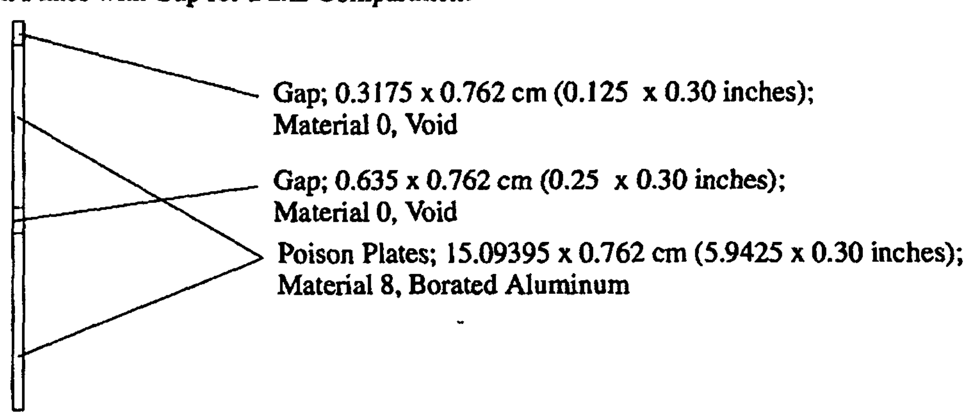
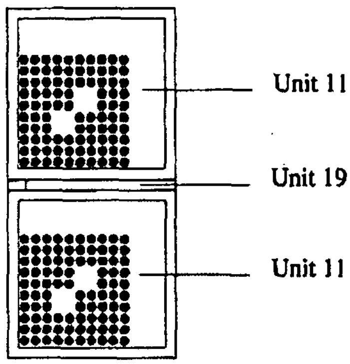
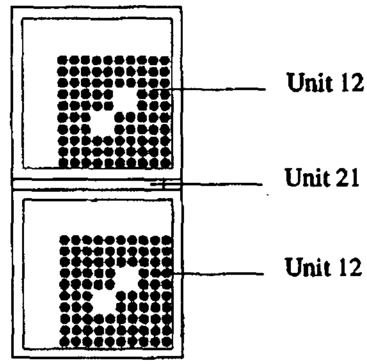


Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 7 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

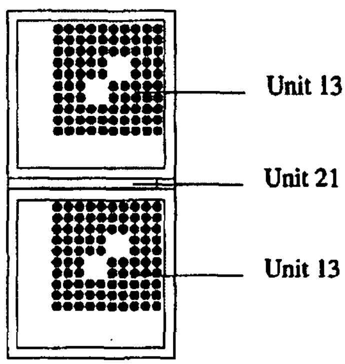
Unit 32, Array 2 - 2x2 with Poison



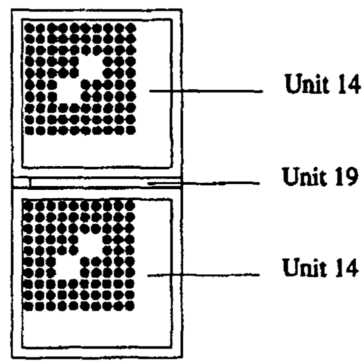
Unit 33, Array 3 - 2x2 with Poison



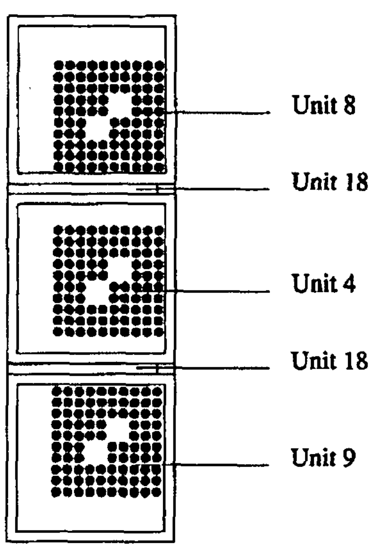
Unit 34, Array 4 - 2x2 with Poison



Unit 35, Array 5 - 2x2 with Poison



Unit 36, Array 6 - 3x3 with Poison



Unit 37, Array 7 - 3x3 with Poison

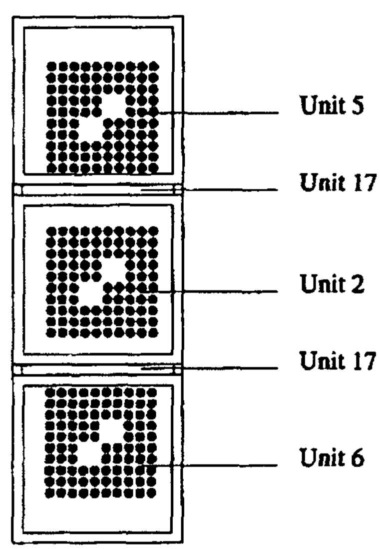
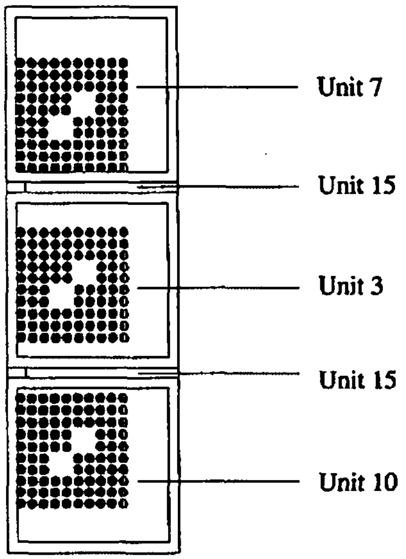
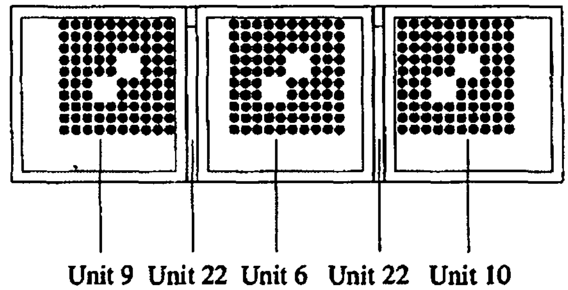


Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 8 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

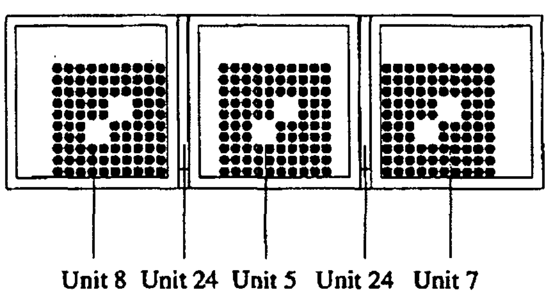
Unit 38, Array 8 - 3x3 with Poison



Unit 39, Array 9 - 3x3 with Poison



Unit 40, Array 10 - 3x3 with Poison



Unit 41, Array 11 - 3x3 with Poison

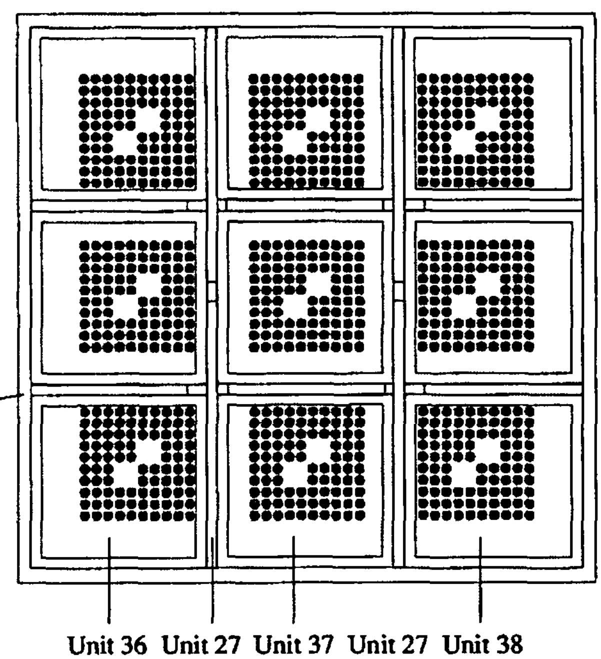


Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 9 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

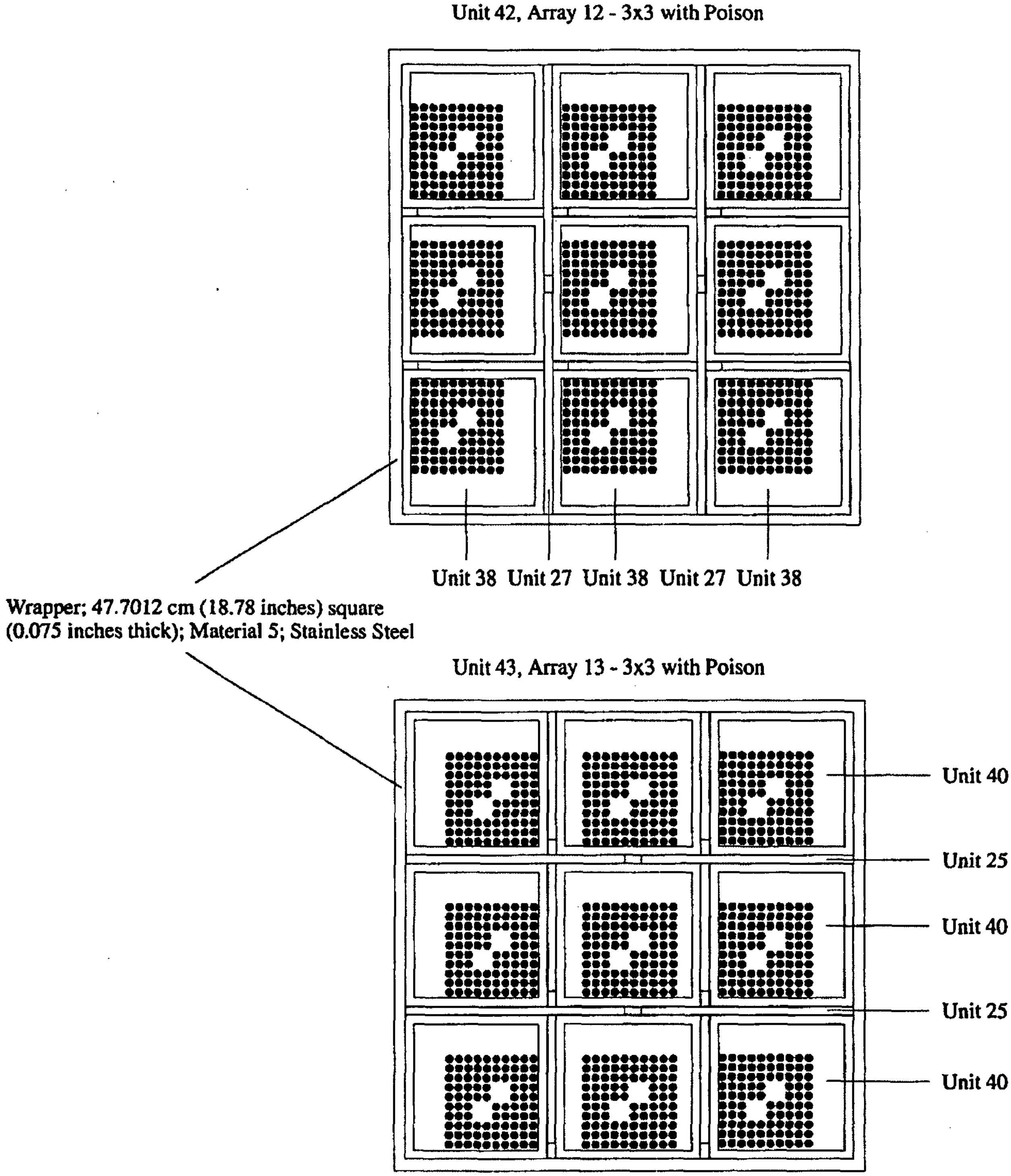


Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 10 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

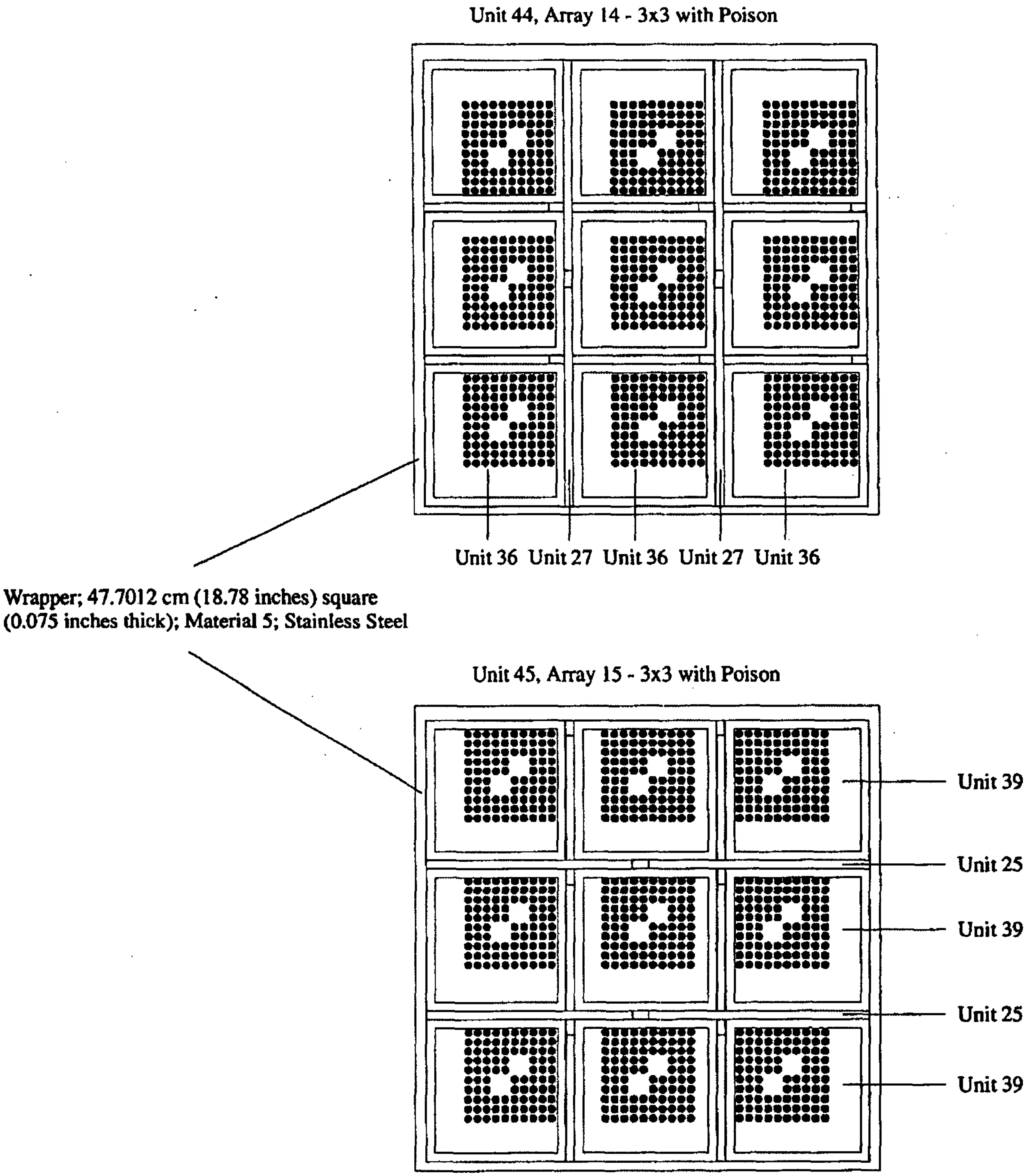


Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 11 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

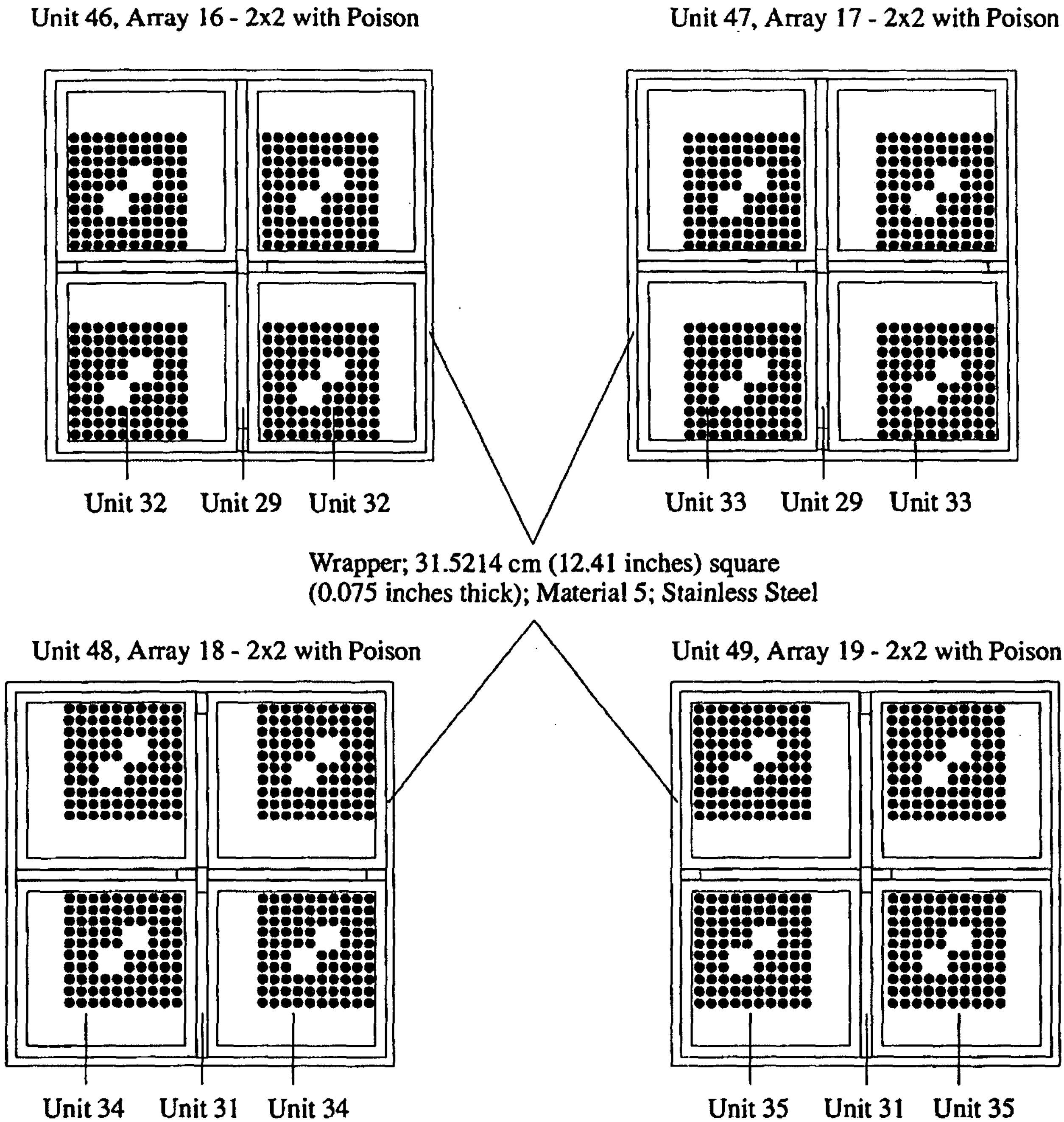
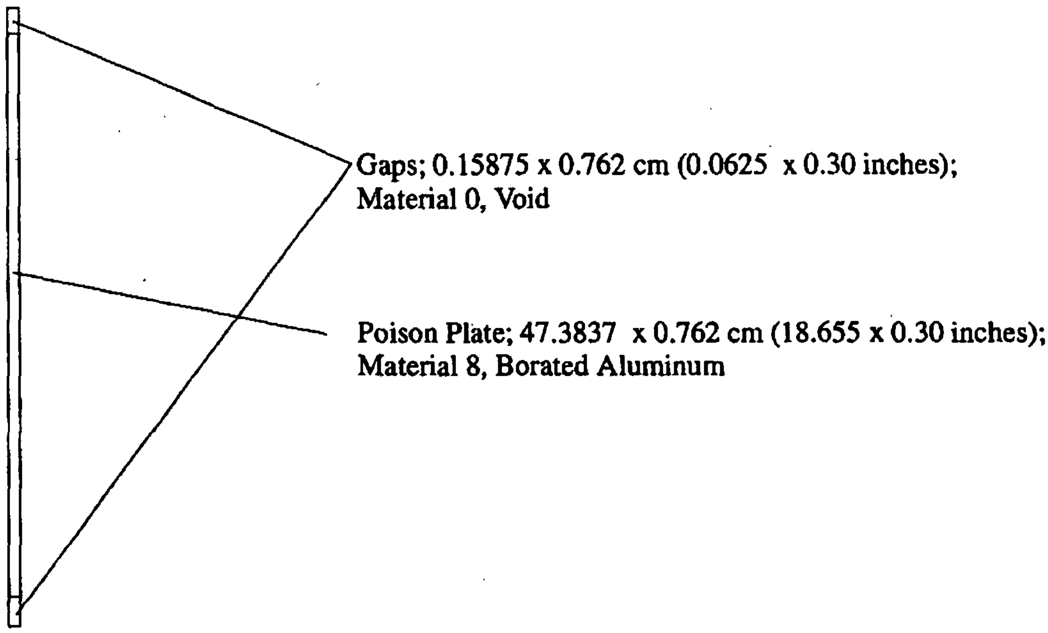


Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 12 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 50, Poison Plates for 3x3 with Gaps - Outside



Unit 51, Short Gap for 3x3 - Outside

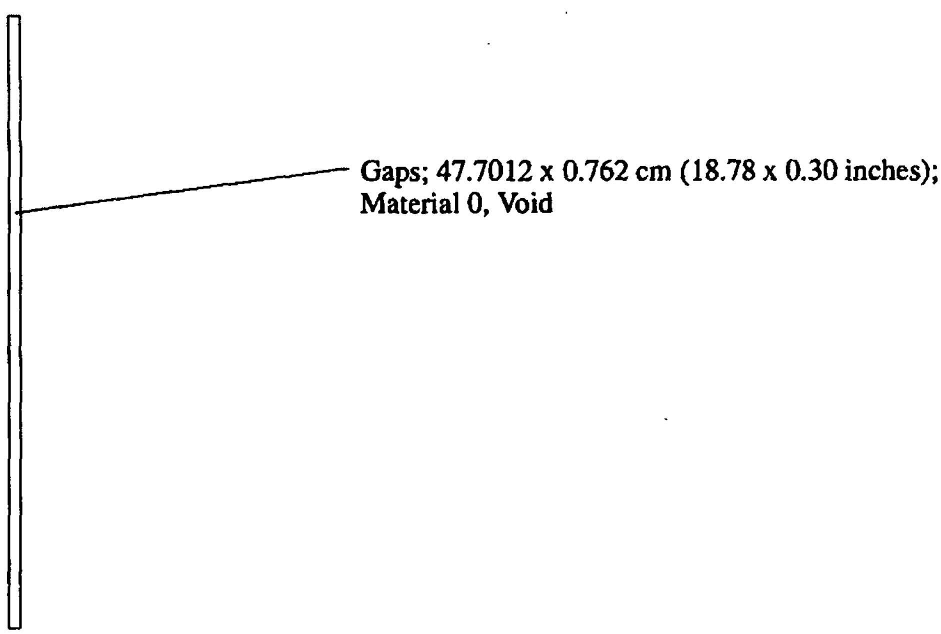
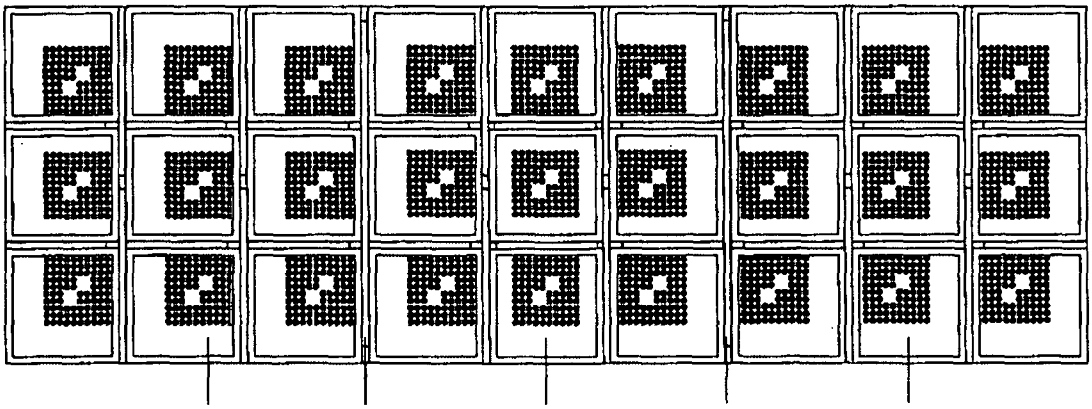


Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 13 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 52, Array 20 - Row of 3x3 Compartments with Poison



Unit 53 Long Horizontal Poison Plates

Poison Plate; 112.4204 x 0.762 cm (44.26 x 0.30 inches);
Material 8, Borated Aluminum

Unit 54 Long Horizontal Gaps

Gap; 112.4204 x 0.762 cm (44.26 x 0.30 inches);
Material 0, Void

Unit 55 Poison Plates with Gap

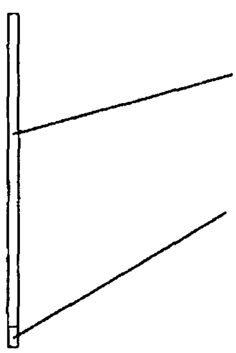
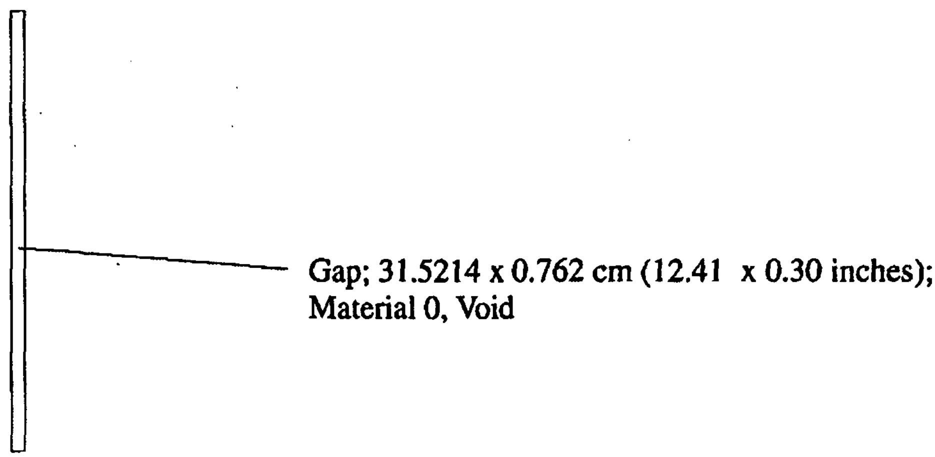


Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 14 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 56 Gap



Unit 57 Poison Plates with Gap

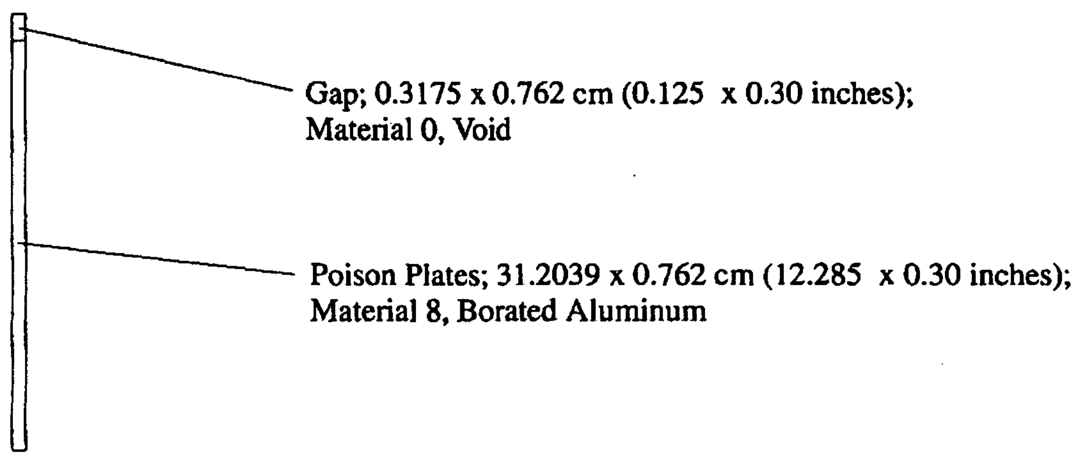


Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 15 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 58 DSC/Cask Layer with Poison

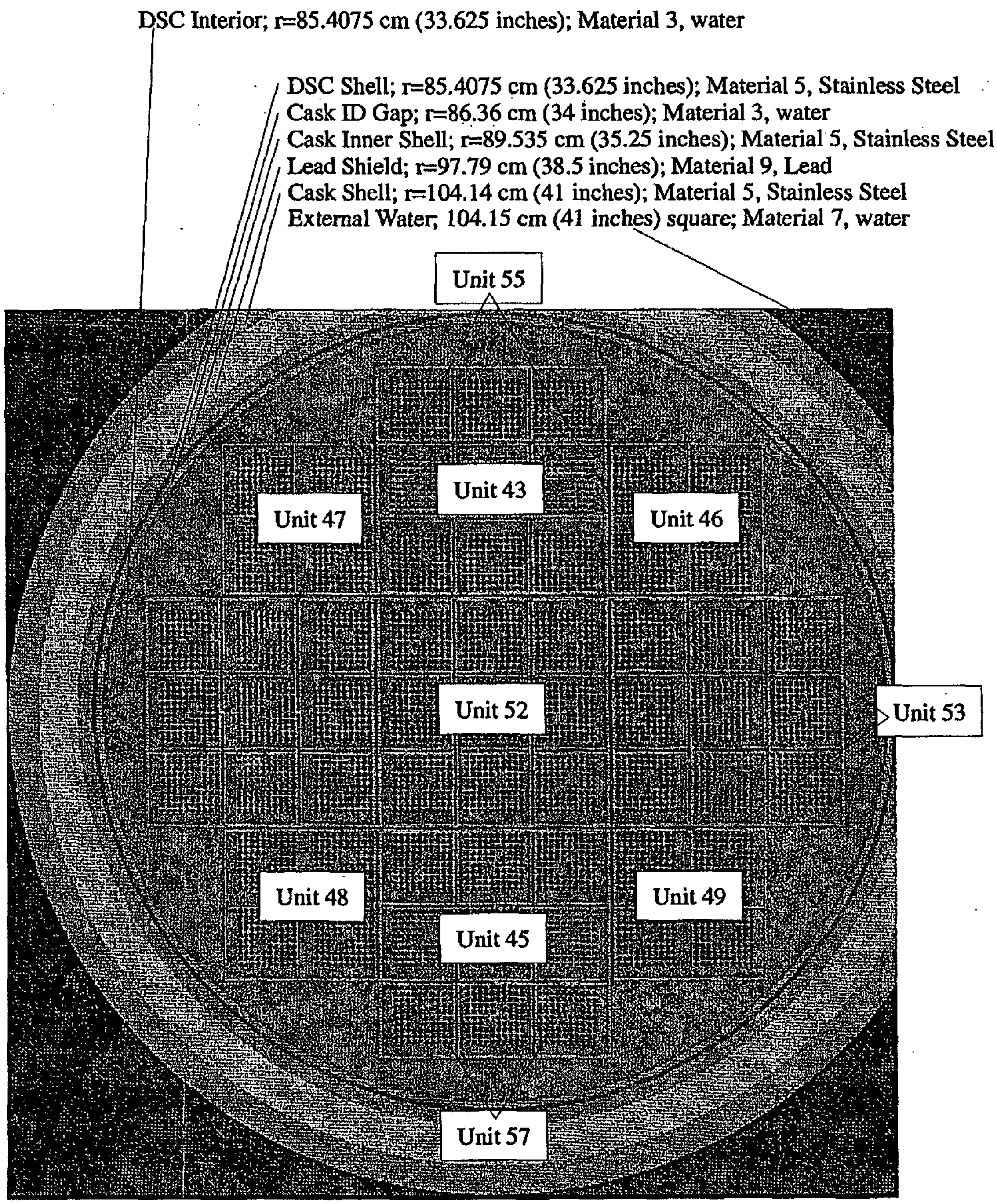


Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 16 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 59 models the portion of the DSC that has poison in side the 3x3 and 2x2 compartments, but no poison between the compartments. Therefore, Unit 59 is identical to Unit 58 except: Unit 52 is replaced with Unit 60,

Unit 53 is replaced with Unit 54,
Units 55 and 57 are replaced with Unit 56

Unit 60, (Array 22) is identical to Unit 52 except that Unit 50 is replaced with Unit 51 as compared to Array 20.

Unit 61, (Array 23) is identical to Unit 32 except that Unit 19 is replaced with Unit 20 as compared to Array 2.

Unit 62, (Array 24) is identical to Unit 33 except that Unit 21 is replaced with Unit 20 as compared to Array 3.

Unit 63, (Array 25) is identical to Unit 34 except that Unit 21 is replaced with Unit 20 as compared to Array 4.

Unit 64, (Array 26) is identical to Unit 35 except that Unit 19 is replaced with Unit 20 as compared to Array 5.

Unit 65, (Array 27) is identical to Unit 36 except that Unit 18 is replaced with Unit 16 as compared to Array 6.

Unit 66, (Array 28) is identical to Unit 37 except that Unit 17 is replaced with Unit 16 as compared to Array 7.

Unit 67, (Array 29) is identical to Unit 38 except that Unit 15 is replaced with Unit 16 as compared to Array 8.

Unit 68, (Array 30) is identical to Unit 39 except that Unit 22 is replaced with Unit 23 as compared to Array 9.

Unit 69, (Array 31) is identical to Unit 40 except that Unit 24 is replaced with Unit 23 as compared to Array 10.

Unit 70, (Array 32) is identical to Unit 41 except that Unit 27 is replaced with Unit 28 as compared to Array 11.

Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 17 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 71, (Array 33) is identical to Unit 42 except that Unit 27 is replaced with Unit 28 as compared to Array 12.

Unit 72, (Array 34) is identical to Unit 43 except that Unit 25 is replaced with Unit 26 as compared to Array 13.

Unit 73, (Array 35) is identical to Unit 44 except that Unit 27 is replaced with Unit 28 as compared to Array 14.

Unit 74, (Array 36) is identical to Unit 45 except that Unit 25 is replaced with Unit 26 as compared to Array 15.

Unit 75, (Array 37) is identical to Unit 46 except that
Unit 32 is replaced with Unit 61 and
Unit 29 is replaced with Unit 30 as compared to Array 16.

Unit 76, (Array 38) is identical to Unit 47 except that
Unit 33 is replaced with Unit 62 and
Unit 29 is replaced with Unit 30 as compared to Array 17.

Unit 77, (Array 39) is identical to Unit 48 except that
Unit 34 is replaced with Unit 63 and
Unit 31 is replaced with Unit 30 as compared to Array 18.

Unit 78, (Array 40) is identical to Unit 49 except that
Unit 35 is replaced with Unit 64 and
Unit 31 is replaced with Unit 30 as compared to Array 19.

Unit 79, models the portion of the DSC that has no inside the compartments, and no poison between the compartments. Therefore, Unit 79 is identical to Unit 59 except:

Unit 60 is replaced with Unit 80,
Unit 43 is replaced with Unit 72,
Unit 43 is replaced with Unit 74,
Unit 45 is replaced with Unit 74,
Unit 46 is replaced with Unit 75,
Unit 47 is replaced with Unit 76,
Unit 48 is replaced with Unit 77, and
Unit 49 is replaced with Unit 78.

Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 18 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 80, (Array 41) is identical to Unit 60 except that:
Unit 44 is replaced with Unit 73,
Unit 41 is replaced with Unit 70, and
Unit 42 is replaced with Unit 71 as compared to Array 22.

Unit 81 GE 10x10 Water "Hole" in Fuel

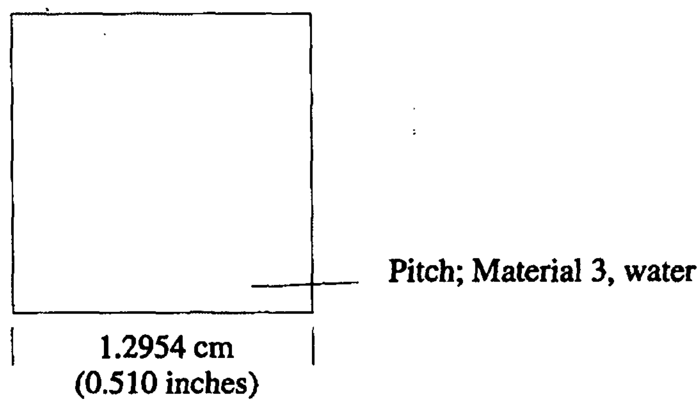


Figure 6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 19 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

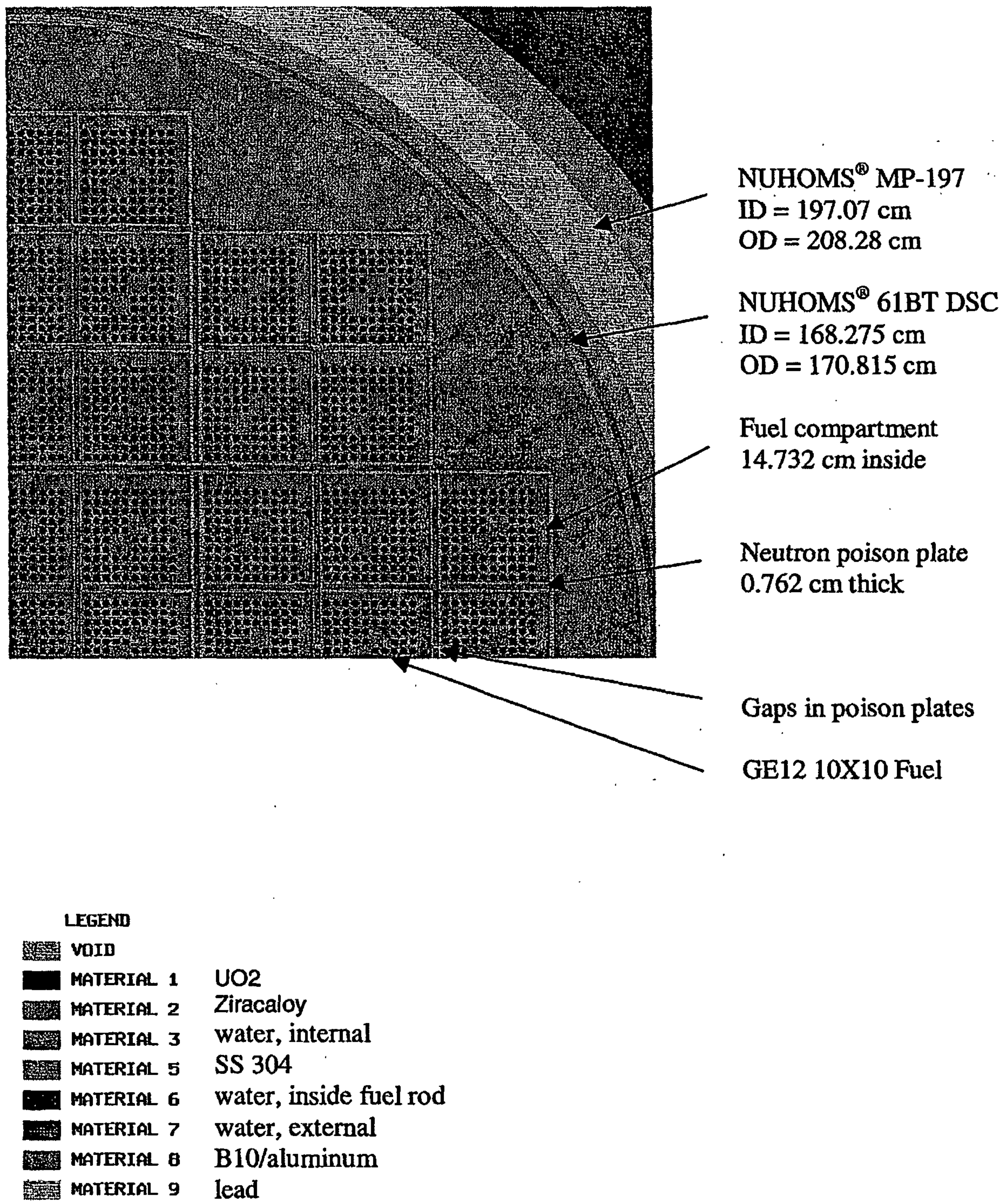


Figure 6-3
KENO V.a Model Cross Section – Bounding Case

1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1

GE2 - 7x7 Array
1 = Fuel Rod

1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	66	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1

GE4 - 8x8 Array
1 = Fuel Rod
66 = Water Rod

1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	66	1	1	1	1
1	1	1	1	66	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1

GE5 - 8x8 Array
1 = Fuel Rod
66 = Water Rod

1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	67	66	1	1	1
1	1	1	66	67	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1

GE8 - 8x8 Array
1 = Fuel Rod
66 = Water Rod 1
67 = Water Rod 2

1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	66	66	1	1	1
1	1	1	66	66	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1

GE9 - 8x8 Array
1 = Fuel Rod
66 = Water Hole

1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	66	66	1	1	1	1
1	1	1	66	66	66	1	1	1
1	1	1	1	66	66	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1

GE11 - 9x9 Array
1 = Fuel Rod
66 = Water Hole

1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	66	66	1	1	1	1	1
1	1	1	66	66	1	1	1	1	1
1	1	1	1	1	66	66	1	1	1
1	1	1	1	1	66	66	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1

GE12 - 10x10 Array
1 = Fuel Rod
66 = Water Hole

Figure 6-4
Fuel Assembly Layouts

68	67	67	67	68	68	69
67	1	1	1	1	67	68
1	1	1	1	1	1	68
1	1	1	1	1	1	67
1	1	1	1	1	1	67
67	1	1	1	1	1	67
67	67	1	1	1	67	68

GE2 - 7x7 Array
(Case GE2var)
1 = Fuel Rod w/ 5.15 wt%
67 = Fuel Rod w/3.41 wt%
68 = Fuel Rod w/2.97 wt%
69 = Fuel Rod w/2.34 wt%

67	68	68	68	68	68	67	1
68	69	69	69	69	69	68	67
69	69	69	69	69	69	69	68
69	69	69	w	69	69	69	68
69	69	69	69	w	69	69	68
69	69	69	69	69	69	69	68
69	69	69	69	69	69	69	68
68	69	69	69	69	69	68	67

GE5 - 8x8 Array
(Case GE5var)
1 = Fuel Rod w/ 2.33 wt%
67 = Fuel Rod w/3.01 wt%
68 = Fuel Rod w/3.57 wt%
69 = Fuel Rod w/4.85 wt%
w = Water Rod

71	70	69	69	69	68	74	1
69	72	70	72	72	71	69	74
72	69	72	72	72	72	71	68
72	72	73	w	w	72	72	69
72	69	72	w	w	72	72	69
72	72	72	72	73	72	70	69
69	69	72	69	72	69	72	70
71	69	72	72	72	72	69	71

GE9 - 8x8 Array
(Case GE9var)
1 = Fuel Rod w/ 2.02 wt%
68 = Fuel Rod w/4.03 wt%
69 = Fuel Rod w/4.29 wt%
70= Fuel Rod w/ 3.78 wt%
71 = Fuel Rod w/3.03 wt%
72 = Fuel Rod w/4.98 wt%
73 = Fuel Rod w/4.54 wt%
74 = Fuel Rod w/3.28 wt%
w = Water Rod

Figure 6-5
Variable Enrichment Fuel Assembly Layouts

NUHOMS®-MP197 TRANSPORT PACKAGING

CHAPTER 7

TABLE OF CONTENTS

Page

7. OPERATING PROCEDURES 7-1

7.1 Procedures for Loading the Package 7-1
7.1.1 Preparation of the NUHOMS®-MP197 Cask for Use 7-1
7.1.2 Wet Loading the NUHOMS®-MP197 Cask and 61BT DSC 7-3
7.1.3 Loading the DSC into the Cask from an HSM 7-10
7.1.4 Preparing the Cask for Transportation 7-11
7.1.5 Placing the Cask onto the Railcar 7-11
7.1.6 Glossary 7-12

7.2 Procedures for Unloading the Cask 7-14
7.2.1 Receipt of the Loaded NUHOMS®-MP197 Cask 7-14
7.2.2 Unloading the NUHOMS®-MP197 Cask to a Staging Module 7-15
7.2.3 Unloading the NUHOMS®-MP197 Cask to a Fuel Pool 7-16
7.2.4 Unloading the NUHOMS®-MP197 Cask to a Dry Cell 7-18

7.3 Preparation of an Empty Cask for Transport 7-19

7.4 Leakage rate Testing of the containment Boundary 7-20

7.5 References 7-24

LIST OF FIGURES

7-1 Torquing Pattern
7-2 Assembly Verification Leak Test Flow Chart

CHAPTER 7
OPERATING PROCEDURES

This chapter contains NUHOMS®-MP197 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 NUHOMS®-MP197 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.

7.1 Procedures for Loading the Package

The NUHOMS®-MP197 Cask will be used to transport fuel off-site. This mode of use requires (1) preparation of the cask for use; (2) verification that the fuel assemblies to be loaded meet the criteria set forth in this document; and (3) installation of a DSC and fuel assemblies into the cask.

Offsite transport involves (1) preparation of the cask for transport; (2) assembly verification leakage-rate testing of the package containment boundary; (3) placement of the cask onto a transportation vehicle; and (4) installation of the impact limiters.

During shipment, the packaging contains up to 61BWR spent fuel assemblies in the NUHOMS®-61BT DSC. Procedures are provided in this section for transport of (1) the cask/DSC directly from the spent plant fuel pool and (2) transport of a NUHOMS®-61BT DSC after storage in a NUHOMS® Horizontal Storage Module (HSM). A glossary of terms used in this section is provided in Section 7.1.6.

7.1.1 Preparation of the NUHOMS®-MP197 Cask for Use

Procedures for preparing the cask for use after receipt at the site are provided in this section.

a. Remove the impact limiter attachment bolts from each impact limiter and remove the impact limiters from the cask. Wash the cask and impact limiters to remove mud dirt & grime and touch-up paint as required.

b. Anytime prior to removing the lid, sample the cask cavity atmosphere through the vent port. Flush the cask interior gases to the site radwaste systems if necessary.

c. Remove the personnel barrier(s) from the transport frame.

d. Remove the transportation skid tie down straps.

e. Take contamination smears on the outside surfaces of the cask. If necessary, decontaminate the cask until smearable contamination is at an acceptable level.

f. Inspect the cask hardware (including vent/drain/test port plugs) for damage which may have occurred during transportation. Repair or replace as required.

g. Install the front and rear trunnions. Lubricate, install and preload the trunnion bolts and torque them to 250 ft-lbs in the first pass and to 520 - 540 ft-lbs in the final pass following the torquing sequence shown in Figure 7-1.

h. Place suitable slings around the cask front and rear trunnions, lift cask and place on the onsite transfer trailer.

i. Remove the slings from the cask.

j. Install the onsite transfer trailer trunnion block covers.

7.1.2 Wet Loading the NUHOMS®-MP197 Cask and 61BT DSC

The procedure for wet loading the cask and 61BT DSC is summarized in this section. This procedure is intended to describe the type and quality of work performed to load and seal a DSC. *Site specific conditions and requirements may require the use of different equipment and ordering of steps other than those described below to accomplish the same objectives or acceptance criteria which must be met to ensure the integrity of the package.* The NUHOMS®-MP197 Cask is designed to transport one NUHOMS-61BT DSC containing 61 BWR fuel assemblies. All fuel assembly locations are to be loaded with design basis fuel assemblies. Verification that the burnup, enrichment, and cooling time of the assemblies are all within acceptable ranges will be performed by site personnel, prior to shipment, as discussed below. All basket compartments must be filled with a fuel assembly or a dummy fuel assembly as specified in the C of C.

7.1.2.1 Preparation of the Transport Cask and DSC

a. Verify the basket type A, B, or C, by inspecting the last digit of the serial number on the grapple ring at the bottom of the DSC.

b. Verify that the fuel assemblies to be placed in the DSC meet the maximum burnup, maximum initial enrichment, minimum cooling time, and maximum decay heat limits for fuel assemblies as specified in Section 1.2.3 of this document and the C of C. The enrichment limit must correspond to the basket type verified in step "a".

c. Using a suitable prime mover, position the cask and onsite transfer trailer below the plant crane.

d. Remove the onsite transfer trailer trunnion block covers.

e. Engage the cask front trunnions with the lifting yoke using the plant crane, rotate the cask to a vertical orientation, lift the cask from the onsite transfer trailer, and place the cask in the plant decon area.

f. Place scaffolding around the cask so that the top closure lid and surface of the cask are easily accessible to personnel.

g. Remove the top closure lid and examine the cask cavity for any physical damage and ready the cask for service.

h. Examine the DSC for any physical damage which might have occurred since the receipt inspection was performed. The DSC is to be cleaned and any loose debris removed.

i. Using a crane, lower the DSC into the cask cavity by the internal lifting lugs and rotate the DSC to match the cask and DSC alignment marks.

j. Fill the cask-DSC annulus with clean, demineralized water. Place the inflatable seal into the upper cask liner recess and seal the cask-DSC annulus by pressurizing the seal with compressed air.

k. Fill the DSC cavity with water from the fuel pool or an equivalent source. For BWR fuel, demineralized water may be used.

   Note: A Cask/DSC annulus pressurization tank filled with clean demineralized water is connected to the top vent port of the cask via a hose to provide a positive head above the level of water in the Cask/DSC annulus. This is an optional arrangement, which provides additional assurance that contaminated water from the fuel pool will not enter the Cask/DSC annulus, provided the positive head is maintained at all times.

l. Position the cask lifting yoke and engage the cask lifting trunnions.

m. Visually inspect the yoke lifting hooks to insure that they are properly positioned and engaged on the cask lifting trunnions.

n. Move the scaffolding away from the cask as necessary.

o. Lift the cask just far enough to allow the weight of the cask to be distributed onto the yoke lifting hooks. Reinspect the lifting hooks to insure that they are properly positioned on the cask trunnions.

p. Optionally, secure a sheet of suitable material to the bottom of the transport cask to minimize the potential for ground-in contamination. This may also be done prior to initial placement of the cask in the decon area.

q. Prior to the cask being lifted into the fuel pool, the water level in the pool should be adjusted as necessary to accommodate the Cask/DSC volume. If the water placed in the DSC cavity was obtained from the fuel pool, a level adjustment may not be necessary.

7.1.2.2 DSC Fuel Loading

a. Lift the Cask/DSC and position it over the cask loading area of the spent fuel pool in accordance with the plant's 10CFR50 cask handling procedures.

b. Lower the cask into the fuel pool until the bottom of the cask is at the height of the fuel pool surface. As the cask is lowered into the pool, spray the exterior surface of the cask with clean water.

c. Place the cask in the location of the fuel pool designated as the cask loading area.

d. Disengage the lifting yoke from the cask lifting trunnions and move the yoke clear of the cask. Spray the lifting yoke with clean water if it is raised out of the fuel pool.

e. Move a candidate fuel assembly from a fuel rack in accordance with the plant's 10CFR50 fuel handling procedures.

f. Prior to insertion of a spent fuel assembly into the DSC, the identity of the assembly is to be verified by two individuals using an underwater video camera or other means. Read and record the fuel assembly identification number from the fuel assembly and check this identification number against the DSC loading plan which indicates which fuel assemblies are acceptable for transport.

g. Position the fuel assembly for insertion into the selected DSC storage cell and load the fuel assembly. Repeat Steps e through g for each SFA loaded into the DSC. After the DSC has been fully loaded, check and record the identity and location of each fuel assembly in the DSC.

h. After all the SFAs have been placed into the DSC and their identities verified, install the hold down ring and the top shield plug into the DSC.

i. Visually verify that the top shield plug is properly seated in the DSC.

j. Position the lifting yoke with the cask trunnions and verify that it is properly engaged.

k. Raise the transport cask to the pool surface. Prior to raising the top of the cask above the water surface, stop vertical movement.

l. Inspect the top shield plug to verify that it is properly seated onto the DSC. If not, lower the cask and reposition the top shield plug. Repeat Steps k and l as necessary.

m. Continue to raise the cask from the pool and spray the exposed portion of the cask with clean water until the top region of the cask is accessible.

n. Drain any excess water from the top of the DSC shield plug back to the fuel pool.

o. Check the radiation levels at the center of the top shield plug and around the perimeter of the cask.

p. As required for crane load limitations, drain water from the DSC by pumping at the siphon port.

q. Lift the cask from the fuel pool. As the cask is raised from the pool, continue to spray the cask with clean water.

r. Move the transport cask with loaded DSC to the cask decon area.

s. Water removed at step "p" may be replaced with spent fuel pool water or equivalent.

7.1.2.3 DSC Drying and Backfilling

a. Check the radiation levels along the perimeter of the cask. The cask exterior surface should be decontaminated as required. Temporary shielding may be installed as necessary to minimize personnel exposure.

b. Place scaffolding around the cask so that any point on the surface of the cask is easily accessible to personnel.

c. Disengage the rigging cables from the top shield plug and remove the eyebolts. Disengage the lifting yoke from the trunnions and position it clear of the cask.

d. Decontaminate the exposed surfaces of the DSC shell perimeter and remove the inflatable cask/DSC annulus seal.

e. Connect the cask drain line to the cask, open the cask cavity drain port and allow water from the annulus to drain out until the water level is approximately twelve inches below the top edge of the DSC shell. Take swipes around the outer surface of the DSC shell and check for smearable contamination as required.

f. Drain as required such that the net amount drained by steps 7.1.2.2 "p" and "s" and this step is approximately 1100 gallons.

g. Place the inner top cover plate onto the DSC. Verify proper fit-up of the inner top cover plate with the DSC shell.

h. Check radiation levels along surface of the inner top cover plate. Temporary shielding may be installed as necessary to minimize personnel exposure.

i. CAUTION: Connect a hydrogen monitor to the vent port to allow continuous monitoring of the hydrogen atmosphere in the DSC cavity during welding of the inner cover plate.

j. Cover the cask/DSC annulus to prevent debris and weld splatter from entering the annulus.

k. Weld the inner top cover plate to the DSC shell.

    CAUTION: Continuously monitor the hydrogen concentration in the DSC cavity using the arrangement described in step "i" during the inner top cover plate cutting/welding operations. Verify that the measured hydrogen concentration does not exceed a safety limit of 2.4%. If this limit is exceeded, stop all welding operations and purge the DSC cavity with helium (or any other inert medium) via the vent or the siphon port to reduce the hydrogen concentration safely below the 2.4% limit.

l. Perform dye penetrant weld examination of the inner top cover plate weld.

m. Place the strongback so that it sits on the inner top cover plate and is oriented such that:

    - the DSC siphon and vent ports are accessible
    - the strongback stud holes line up with the cask lid bolt holes.

n. Lubricate the studs and, using a crossing pattern, adjust the strongback studs to snug tight ensuring approximately even pressure on the cover plate.

o. Install temporary shielding to minimize personnel exposure throughout the subsequent welding operations as required.

p. Engage the compressed air, nitrogen or helium supply and open the valve on the vent port and allow compressed gas to force the water from the DSC cavity through the siphon port. Note: a pressure regulator set to a maximum of 20 psig must be installed on the compressed gas supply.

q. Once the water stops flowing from the DSC, close the DSC siphon port and disengage the gas source.

r. Connect either the vent port or the siphon port or both to the intake of the vacuum drying system (VDS). Vent the discharge side of the VDS to the plant's radioactive waste system, spent fuel pool, or other appropriate system. Connect the VDS to a helium source.

s. Open the valve on the suction side of the pump, start the VDS and draw a vacuum on the DSC cavity. The cavity pressure should be reduced in steps of approximately 100 mm Hg, 50 mm Hg, 25 mm Hg, 15 mm Hg, 10 mm Hg, 5 mm Hg, and 3 mm Hg. After pumping down to each level, the pump is valved off and the cavity pressure monitored. The cavity pressure will rise as water and other volatiles in the cavity evaporate. When the cavity pressure stabilizes, the pump is valved in to complete the vacuum drying process. It may be necessary to repeat some steps, depending on the rate and extent of the pressure increase. Vacuum drying is complete when the pressure stabilizes for a minimum of 30 minutes at 3 mm Hg or less.

t. Open the valve to either or both ports and allow helium to flow into the DSC cavity.

u. Pressurize the DSC with helium to about 24 psia not to exceed 34 psia (10 – 20 psig).

v. Helium leak test the inner top cover plate weld for leakage to a sensitivity of 1 x 10^{-5} ref cm^3/sec. (This is a preliminary test, for information only; the final leak test is performed at 7.1.2.4 step "d".)

w. If a leak is found, repair the weld, repressurize the DSC and repeat the helium leak test.

x. Once no leaks are detected, depressurize the DSC cavity by releasing the helium through the VDS to the plant's spent fuel pool, radioactive waste system, or other appropriate system.

y. Re-evacuate the DSC cavity . Vacuum drying is complete when the pressure stabilizes for a minimum of 30 minutes at 3 mm Hg or less.

z. Open the valve to either or both ports and allow helium to flow into the DSC cavity to pressurize the DSC to about 17.2 psia (2.5 psig).

aa. Close the valves on the helium source.

bb. Remove the strongback, decontaminate as necessary, and store.

7.1.2.4 DSC Sealing Operations

a. Disconnect the VDS from the DSC. Seal weld the prefabricated plugs over the vent and siphon ports and perform a dye penetrant weld examination.

b. Place the outer top cover plate onto the DSC. Verify proper fit up of the outer top cover plate with the DSC shell.

c. Tack weld the outer top cover plate to the DSC shell. Place the outer top cover plate weld root pass.

d. Helium leak test the inner top cover plate and vent/siphon port plate welds using the leak test port in the outer top cover plate with an acceptance criterion of 1×10^{-7} ref cm^3/sec.

e. If a leak is found, remove the outer cover plate root pass, the vent and siphon port plugs and repair the inner cover plate welds. Then install the strongback and repeat procedure steps from section 7.1.2.3 step "t".

f. Perform dye penetrant examination of the root pass weld. Weld out the outer top cover plate to the DSC shell and perform dye penetrant examination on the weld surface.

g. Seal weld the prefabricated plug over the outer cover plate test port and perform dye penetrant weld examinations.

h. Remove the cask drain port screw and drain the Cask/DSC annulus.

i. Install the drain port screw and tighten it to 65 ft-lbs. Install and tighten the drain port plug.

j. Install the cask lid. Lubricate, install and preload the lid bolts and torque them to 200 ft-lbs. Follow the torquing sequence shown in Figure 7-1. Repeat the torquing process following the sequence of Figure 7-1. Torque to 600 ft-lbs in second pass, 1000 ft-lbs in third pass and between 1440 and 1510 ft-lbs in the final pass. A circular pattern of torquing may be used, to eliminate further bolt movement.

k. Evacuate the cavity between the cask and the DSC, backfill with helium and perform the assembly verification leakage rate testing as specified in Section 7.4. This test must be performed within 12 months prior to the shipment.

l. Verify that the cask surface removable contamination levels meet the requirements of 49 CFR 173.443 [2] and 10 CFR 71.87 [3].

7.1.2.5 Transport Cask Downending

a. Re-attach the transport cask lifting yoke to the crane hook, as necessary. Ready the transport trailer and cask support skid for service.

b. Move the scaffolding away from the cask as necessary. Engage the lifting yoke and lift the cask over the cask support skid on the transport trailer.

c. The transport trailer should be positioned so that cask support skid is accessible to the crane with the trailer supported on the vertical jacks.

d. Position the cask rear trunnions onto the transfer trailer support skid pillow blocks.

e. Move the crane forward while simultaneously lowering the cask until the cask front trunnions are just above the support skid upper trunnion pillow blocks. For plants with limited space or crane travel, such that the downending cannot be completed with the trailer stationary, alternate procedures may be developed.

f. Inspect the positioning of the cask to insure that the cask and trunnion pillow blocks are properly aligned.

g. Lower the cask onto the skid until the weight of the cask is distributed to the trunnion pillow blocks.

h. Inspect the trunnions to insure that they are properly seated onto the skid and install the trunnion tower closure plates.

7.1.3 Loading the DSC into the Cask from an HSM

The procedure for loading a DSC into the cask from a NUHOMS® Horizontal Storage Module (HSM) is summarized in this section. Depending on the most recent use of the cask, several of the initial steps listed below may not be necessary.

a. Using a suitable prime mover, bring the onsite transfer trailer (and cask) to the ISFSI site and back the trailer in front of the module face.

b. Remove the ram closure plate and the lid.

c. Install the ram trunnion support assembly.

d. Remove the HSM door and the DSC seismic restraint assembly from the HSM.

e. Use the trailer skid positioning system and optical surveying transits to align and dock the cask with the HSM.

f. Install the cask/HSM restraints.

g. Install and align the hydraulic ram cylinder in the ram trunnion support assembly.

h. Extend the ram hydraulic cylinder until the grapple contacts the DSC bottom cover.

i. Engage the DSC grapple ring with the ram grapple.

j. Retract the ram hydraulic cylinder until the DSC is fully seated in the cask.

k. Disengage the grapple from the DSC.

l. Remove the hydraulic ram and ram trunnion support assembly from the cask.

m. Install the cask ram closure plate with new o-rings. Lubricate, install and preload the ram closure bolts and torque them to 65 ft-lbs in the first pass and to 100 – 125 ft-lbs in the final pass follow the torquing sequence shown in Figure 7-1.

n. Remove the cask/HSM restraints.

o. Using the skid positioning system, move the cask to the transfer position and secure the onsite support skid to the onsite transfer trailer.

p. Verify that the lid O-ring seals are new. Discard any seals that have previously been installed in the cask.

q. If necessary, apply vacuum grease to the seals and the adjoining sealing surfaces on the cask lid.

r. Install the cask lid. Lubricate, install and preload the lid bolts and torque them to 200 ft-lbs. Follow the torquing sequence shown in Figure 7-1. Repeat the torquing process following the sequence of Figure 7-1. Torque to 600 ft-lbs in second pass, 1000 ft-lbs in third pass and between 1440 and 1510 ft-lbs in the final pass. A circular pattern of torquing may be used, to eliminate further bolt movement.

s. Prepare the cask for transportation in accordance with the procedure described in Section 7.1.4.

7.1.4 Preparing the Cask for Transportation

Once a loaded DSC has been placed inside the NUHOMS®-MP197 Cask, the following tasks are performed to prepare the cask for transportation. The cask is assumed to be seated horizontally in the onsite support skid.

a. Verify that the fuel assemblies meet the burnup, initial enrichment, cooling time, and decay heat criteria set forth in Section 1.2.3 and the C of C.

b. Verify that the cask surface removable contamination levels meet the requirements of 49 CFR 173.443 [2] and 10 CFR 71.87 [3].

c. Perform the assembly verification leakage rate testing specified in Section 7.4. This test must be performed within 12 months prior to the shipment. This test includes drawing a vacuum in the cavity between the cask and DSC, which ensures that any water has been removed.

7.1.5 Placing the Cask onto the Railcar

The procedure for placement of the cask on the railcar.

a. Using a suitable prime mover, bring the cask and onsite transfer trailer to the transportation railcar.

b. Remove the onsite transfer trailer trunnion block covers.

c. Install suitable slings around the cask front and rear trunnions.

d. Lift the cask from the onsite transfer trailer.

e. Place the cask onto the railcar transportation skid.

f. Remove the lifting slings from the cask.

g. Remove the cask front and rear trunnions and install the trunnion plugs.

g1. Verify that the cask surface removable contamination levels meet the requirements of 49 CFR 173.443 [2] and 10 CFR 71.87 [3].

h. Install the skid tie down strap.

i. Install the front and rear impact limiters onto the cask. Lubricate the attachment bolts with Nuclear Grade Neolube or equivalent and torque to 100 ft-lbs, diametrically in the first pass, and between 140 – 160 ft-lbs in the final pass.

j. Inspect the personnel barrier(s) to assure there are no holes or gaps in the material. Repair/replace as required and install on the transport frame.

k. Install the cask tamperproof device.

l. Perform a final radiation survey to assure the cask radiation levels do not exceed 49 CFR 173.441 [2] and 49 CFR 173.47 [3].

m. Verify that the temperature on all accessible surfaces is <185°F.

n. Prepare the final shipping documentation and release the loaded cask for shipment.

Note: The procedure outlined above may also be used to transfer the cask directly from the fuel pool to a rail car, without using the transfer trailer, should appropriate facilities be available for such a transfer. The procedures outlined in Section 7.1.5 would also be applicable to such a scenario.

7.1.6 Glossary

The following terms, used in the above procedures, are defined below.

a.	Horizontal Storage Module (HSM):	Concrete shielded structure used for onsite storage of DSCs.
b.	Onsite Transfer Trailer:	A hydraulically supported trailer used for onsite movements of the cask.

c.	Onsite Support Skid:	Skid present on the onsite transfer trailer used to support the cask during onsite movements.
d.	Cask/DSC Annulus Seal:	Pneumatic seal placed between the cask and DSC during operations in the fuel pool.
e.	Cask Lifting Yoke:	Passive, open hook lifting yoke used for vertical lifts of the cask.
f.	Ram Trunnion Support Assembly:	Frame attached to the cask bottom which provides an anchor for the hydraulic ram during DSC insertion and retrieval.
g.	Skid Positioning System:	Hydraulically operated alignment system that provides the interface between the onsite transfer trailer and the onsite support skid.
h.	Hydraulic Ram:	Hydraulic cylinder used to insert/withdraw DSCs to/from HSMs.
i.	Cask/HSM Restraints:	Provides the load path between the cask and HSM during DSC transfer operations.

7.2 Procedures for Unloading the Cask

Unloading the NUHOMS®-MP197 Cask after transport involves removing the cask from the railcar and removing the canister from the cask. The cask is designed to allow the canister to be unloaded from the cask into a NUHOMS® staging module, or hot cell, and provisions exist to allow wet unloading into a fuel pool. The necessary procedures for these tasks are essentially the reverse of those described in Section 7.1.

7.2.1 Receipt of the Loaded NUHOMS®-MP197 Cask

Procedures for receiving the loaded cask after shipment are described in this section. Procedures for receiving an empty cask are provided in Section 7.1.1.

a. Verify that the tamperproof device is intact.

b. Remove the tamperproof device.

c. Remove the impact limiter attachment bolts from each impact limiter and remove the impact limiters from the cask.

d. Remove the transportation skid tie down strap.

e. Take contamination smears on the outside surfaces of the cask. If necessary, decontaminate the cask until smearable contamination is at an acceptable level.

d. Install the front and rear trunnions. Lubricate, install and preload the trunnion bolts and torque them to 250 ft-lbs in the first pass and to 520 - 540 ft-lbs in the final pass follow the torquing sequence shown in Figure 7-1.

f. Place suitable slings around the cask front and rear trunnions.

g. Using a suitable crane, lift the cask from the railcar. Place cask onto the onsite transfer trailer. Remove the slings from the cask.

h. Install the onsite support skid pillow block covers.

i. Transfer the cask to a staging module, fuel pool, or dry cell and unload using the procedures described in the following sections.

7.2.2 Unloading the NUHOMS®-MP197 Cask to a Staging Module

The procedure for unloading a DSC from the cask into an HSM is summarized in this section. This procedure is typical of NUHOMS® ISFSIs and some of the steps listed below may be performed in a different order.

a. Position the onsite transfer trailer in front of the module face.

b. Sample the cask cavity atmosphere through the vent port. Flush the cask interior gases to the site radwaste systems if necessary.

c. Remove the cask ram closure plate. Discard the ram closure seals.

d. Install the ram trunnion support assembly.

e. Remove the HSM door.

f. Use the skid positioning system and optical surveying transits to align the cask with the HSM.

g. Remove the cask lid. Discard the lid seals.

h. Dock the cask with the HSM and install the cask/HSM restraints.

i. Install and align the hydraulic ram cylinder in the ram trunnion support assembly.

j. Extend the ram hydraulic cylinder until the grapple contacts the DSC bottom cover.

k. Engage the DSC grapple ring with the ram grapple.

l. Extend the ram hydraulic cylinder until the DSC is fully inserted in the HSM.

m. Disengage the grapple from the DSC.

n. Remove the hydraulic ram from the cask.

o. Remove the cask from the HSM.

p. Install the HSM door and DSC seismic restraint.

q. Move the onsite transfer trailer and cask to a low-dose maintenance area.

r. Inspect the cask hardware (including vent/drain/test port plugs) for damage that may have occurred during transportation. Repair or replace as necessary.

7.2.3 Unloading the NUHOMS®-MP197 Cask to a Fuel Pool

The procedure for unloading the cask and DSC into a fuel pool is summarized in this section. This procedure is intended to describe the type and quality of work performed to unload a DSC. *Site specific conditions and requirements may require the use of different equipment and ordering of steps other than those described below to accomplish the same objectives or acceptance criteria which must be met to ensure the integrity of the package.*

a. Tow the onsite transfer trailer to the fuel receiving area.

b. Remove the onsite support skid pillow block covers.

c. Using the cask lifting yoke, engage the front trunnions, rotate the cask to a vertical orientation, lift the cask from the onsite support skid, and place the cask in the decon pit.

d. Sample the cask cavity atmosphere through the vent port. Flush the cask interior gases to the site radwaste systems if necessary.

e. Remove the bolts from the cask lid and lift the lid from the cask.

f. Remove and discard the cask lid seals.

g. Locate the DSC siphon and vent ports using the indications on the DSC outer top cover plate.

h. Drill a hole in the DSC outer top cover plate and remove the siphon closure plug to expose the siphon port quick connect.

i. Drill a hole in the DSC outer top cover plate and remove the vent closure plug to expose the vent port quick connect.

j. Sample the DSC cavity atmosphere. If necessary, flush the DSC cavity gases to the site radwaste systems.

k. Fill the DSC with fuel pool or equivalent water through the siphon port with the vent port open and routed to the plant's off-gas system or other appropriate system.

l. Install a debris shield over the cask/DSC annulus.

m. Use plasma arc-gouging, a mechanical cutting system, or other suitable means remove the closure weld from the outer top cover plate.

CAUTION: Monitor the hydrogen concentration in the DSC cavity during this step to ensure that it does not exceed 2.4%.

n. Remove the DSC outer top cover plate.

o. Remove the closure weld from the DSC inner top cover plate.

p. Remove the DSC inner top cover plate.

q. Fill the cask/DSC annulus with demineralized water and install the cask/DSC annulus seal.

r. Remove excess material on the DSC inside shell surface which will interfere with top shield plug removal.

s. Clean the cask surface of dirt and debris that may have accumulated during transportation or weld removal.

t. Engage the cask lifting yoke to the front trunnions and install the shield plug cables between the yoke and the DSC top shield plug.

u. Lower the cask into the fuel pool.

v. Disengage the lifting yoke from the cask trunnions and remove the top shield plug.

w. Remove the fuel assemblies from the DSC.

x. Engage the lifting yoke to the cask front trunnions, remove the cask from the pool, and place it in the decon area.

y. Remove the water from the DSC cavity and DSC/Cask annulus.

z. Remove the DSC from the cask and handle in accordance with low-level waste procedures.

aa. Decontaminate the cask inner and outer surfaces as necessary.

bb. Inspect the cask hardware for damage that may have occurred during transportation. Repair or replace as necessary.

7.2.4 Unloading the NUHOMS®-MP197 Cask to a Dry Cell

The procedure for handling a DSC in a dry cell is highly dependent on the design of the dry cell and on the intended future use of the DSC. The procedure described below is intended to show the type of operations that will be performed and is not intended to be limiting.

a. Tow the onsite transfer trailer to the hot cell area.

b. Remove the onsite support skid pillow block covers.

c. Using the cask lifting yoke, engage the front trunnions, rotate the cask to a vertical orientation, lift the cask from the onsite support skid, and place the cask in the appropriate handling area.

d. Sample the cask cavity atmosphere through the vent port. Flush the cask interior gases to the site radwaste systems if necessary.

e. Remove the bolts from the cask lid and lift the lid from the cask.

f. Remove and discard the cask lid seals.

g. Transfer the cask into the hot cell using suitable handling equipment.

h. Remove the DSC from the cask and handle according to appropriate procedures.

i. Remove the cask from the hot cell.

j. Decontaminate the cask inner and outer surfaces as necessary.

k. Inspect the cask hardware for damage that may have occurred during transportation. Repair or replace as necessary.

7.3 Preparation of an Empty Cask for Transport

Previously used and empty NUHOMS®-MP197 casks shall be prepared for transport per the requirements of 49 CFR 173.427 [2].

7.4 Leakage Rate Testing of the Containment Boundary

The procedure for leak testing the cask containment boundary prior to shipment is given in this section. Assembly verification leak testing shall conform to the requirements of Section 6.5 and Section A3.5 of ANSI N14.5-1997, "American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment [1]". The order in which the leak tests of the various seals are performed may vary. If more than one leak detector is available then more than one seal may be tested at a time. Assembly verification leak test flow chart is presented in Figure 7-2. Personnel performing the leak testing activities shall be specifically trained in leak testing.

a. Remove the cask vent port plug.

b. Install the cask port tool in the cask vent port. (The port tool is designed to replace the vent/drain and test port plugs and provide a means for loosening the vent/drain and test port screw in a controlled volume. This volume can be isolated from the cask volume by an externally accessible valve to ensure personnel protection during cask venting operations.)

c. Turn the cask port tool handle to open the cask vent port.

d. Attach a suitable vacuum pump to the cask port tool.

e. Reduce the cask cavity pressure to below 1.0 psia.

f. Attach a source of helium to the cask port tool.

g. Fill the cask cavity with helium to pressure of 3.5 psig.

h. Close the vent port screw by turning the cask port tool handle. Tighten the vent port screw to 65 ft-lbs.

i. Remove the helium saturated cask port tool and install a clean (helium free) cask port tool.

j. Connect a mass spectrometer leak detector capable of detecting a leak of 5×10^{-8} ref cm^3/sec to the cask port tool.

k. Evacuate the vent port until the vacuum is sufficient to operate the leak detection equipment per the manufacturer's recommendations.

l. Perform the leak test. If the leakage rate is greater than 1×10^{-7} ref cm^3/sec repair or replace the vent port screw and/or seal as required and retest.

Note: Upon removing the vent port screw, it will be necessary to reduce the cask cavity pressure below 1.0 psia and refill with helium through the vent port.

m. Remove the leak detection equipment from the cask vent port.

n. Remove the cask port tool from the vent port and replace the vent port plug.

o. Remove the top test port plug.

p. Install the cask port tool in the top test port.

q. Turn the cask port tool handle to open the top test port screw.

r. Connect the vacuum pump to the cask port tool.

s. Connect the leak detector to the cask port tool.

t. Evacuate the top test port until the vacuum is sufficient to operate the leak detection equipment per the manufacturer's recommendations. Perform a pressure rise leak test to confirm leakage past the outer seal is less than 7×10^{-3} ref cm^3/sec .

u. Perform the helium leak test. If the leakage rate is greater than 1×10^{-7} ref cm^3/sec repair or replace the cask top lid O-ring seals as required and retest.

Note: Upon removing and reinstalling the cask top closure, it will be necessary to reduce the cask cavity pressure below 1.0 psia and refill with helium through the vent port. The vent port assembly verification test must also be retested as described above.

v. Remove the leak detection equipment from the top test port.

w. Tighten the top test port screw to 65 ft-lbs. Remove the cask port tool from the top test port and replace the top test port plug.

x. Remove the cask drain port plug.

y. Install the cask port tool in the cask drain port.

z. Turn the cask port tool handle to verify that the cask drain port is closed.

aa. Connect the vacuum pump to the cask port tool.

bb. Connect the leak detector to the cask port tool.

cc. Evacuate the drain port until the vacuum is sufficient to operate the leak detection equipment per the manufacturer's recommendations.

dd. Perform the leak test. If the leakage rate is greater than 1×10^{-7} ref cm^3/sec repair or replace the drain port screw and/or seal as required and retest.

Note: Upon removing the drain port screw, it will be necessary to reduce the cask cavity pressure below 1.0 psia and refill with helium through the vent port. The vent port assembly verification test must also be retested as described above.

ee. Remove the leak detection equipment from the drain port.

ff. Tighten the drain port screw to 65 ft-lbs. Remove the cask port tool from the cask drain port and replace the drain port plug.

gg. Remove the bottom test port plug.

hh. Install the cask port tool in the bottom test port.

ii. Turn the cask port tool handle to open the bottom test port screw.

jj. Connect the vacuum pump to the cask port tool.

kk. Connect the leak detector to the cask port tool.

ll. Evacuate the bottom test port until the vacuum is sufficient to operate the leak detection equipment per the manufacturer's recommendations. Perform a pressure rise leak test to confirm leakage past the outer seal is less than 7×10^{-3} ref cm^3/sec.

mm. Perform the helium leak test. If the leakage rate is greater than 1×10^{-7} ref cm^3/sec repair or replace the cask ram closure O-ring seals as required and retest.

Note: Upon removing the cask ram closure, it will be necessary to reduce the cask cavity pressure below 1.0 psia and refill with helium through the vent port. The vent port assembly verification test must also be retested as described above.

nn. Remove the leak detection equipment from the bottom test port.

oo. Tighten the bottom test port screw to 65 ft-lbs. Remove the cask port tool from the bottom test port and replace the bottom test port plug.

This concludes the assembly verification leak test procedure.

7.5 References

1. ANSI N14.5-1997, "American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment," American National Standards Institute, Inc., New York

2. Title 49, Code of Federal Regulations, Part 173 (49 CFR 173), "Shippers - General Requirements for Shipments and Packaging."

3. Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), "Packaging and Transportation of Radioactive Material."

Figure 7-1
Torquing Patterns

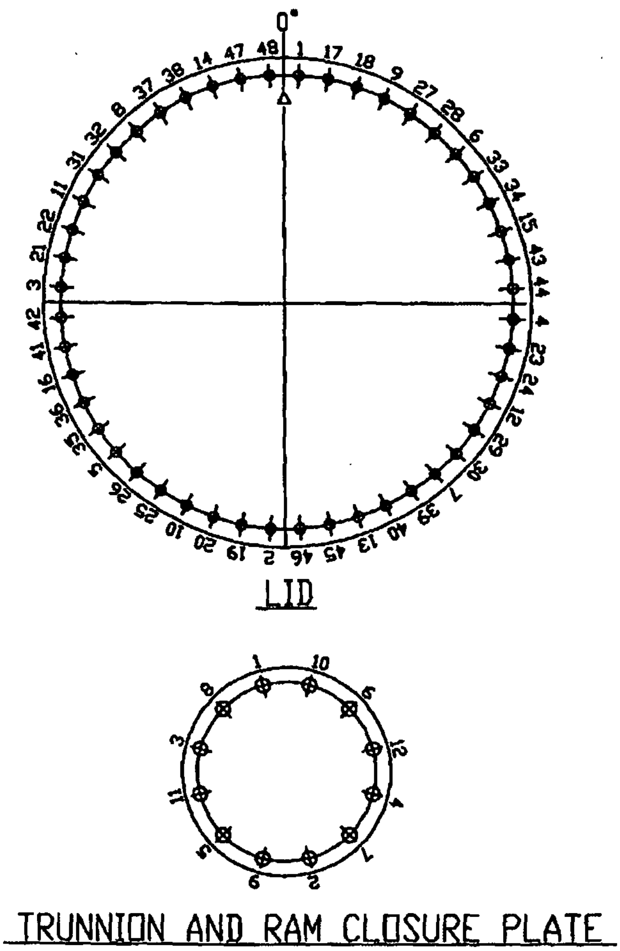
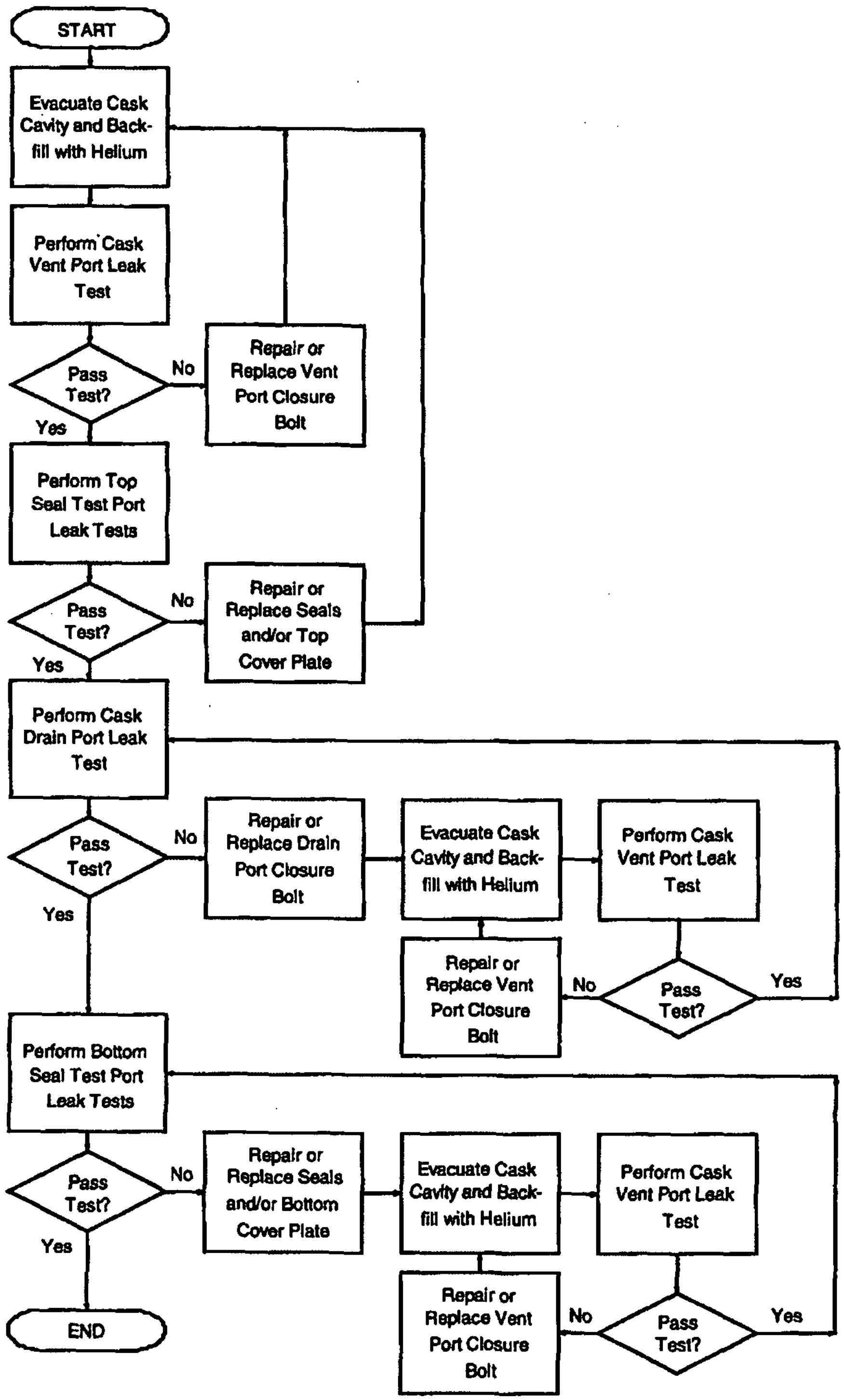


Figure 7-2
Assembly Verification Leak Test Flow Chart



NUHOMS®-MP197 TRANSPORT PACKAGING

CHAPTER 8

TABLE OF CONTENTS

Page

8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Acceptance Tests 8-1
8.1.1 Visual Inspection 8-1
8.1.2 Structural and Pressure Tests 8-1
8.1.3 Leak Tests 8-2
8.1.4 Component Tests 8-3
8.1.5 Shielding Tests 8-4
8.1.6 Neutron Absorber Tests 8-6

8.2 Maintenance Program 8-12
8.2.1 Structural and Pressure Tests 8-12
8.2.2 Leak Tests 8-12
8.2.3 Subsystem Maintenance 8-13
8.2.4 Valves, Rupture Discs, and Gaskets on Containment Vessel 8-13
8.2.5 Shielding 8-13
8.2.6 Thermal 8-13

8.3 References 8-14

LIST OF TABLES

8-1 Specified Boron 10 Content

CHAPTER 8

ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Acceptance Tests

The following reviews, inspections, and tests shall be performed on the NUHOMS®-MP197 packaging prior to initial transport. Many of these tests will be performed at the Fabricator's facility prior to delivery of the Cask/DSC to the utility for use. Tests will be performed in accordance with written procedures.

8.1.1 Visual Inspection

Visual inspections are performed at the Fabricator's facility to ensure that the packaging conforms to the drawings and specifications. The visual Inspections Include:

A. Cleanliness Inspections
B. Visual Weld Inspections as Required by ASME Code
C. Inspection of Sealing Surface Finish
D. Dimensional Inspections for Conformance with Chapter 1 Drawings

8.1.2 Structural and Pressure Tests

The structural analyses performed on the packaging are presented in Chapter 2. To ensure that the packaging can perform its design function, the structural materials are chemically and physically tested to confirm that the required properties are met. All welding is performed using qualified processes and qualified personnel, according to the ASME Boiler and the Pressure Vessel Code(1). Base materials and welds are examined in accordance with the ASME Boiler and Pressure Vessel code requirements. NDE requirements for welds are specified on the drawings provided in Chapter 1. All NDE is performed in accordance with written procedures. The inspection personnel are qualified in accordance with SNT-TC-1A(2).

The NUHOMS®-MP197 containment welds, and the NUHOMS®-61BT DSC (canister) are designed, fabricated, tested and inspected, in accordance with ASME B&PV Code Subsection NB. The NUHOMS®-61BT fuel basket is designed, fabricated, and inspected in accordance with the ASME B&PV Code Subsection NG. Exceptions to the code are described in Chapter 2, Section 2.11. Welds of the noncontainment structure are inspected as per the NDE acceptance criteria of ASME B&PV Code, Subsection NF.

The impact limiter attachment bolt material shall be Charpy tested to show absorbed energy is at least 20 ft-lb at -20°F.

8.1.2.1 Pressure Tests

A pressure test is performed on the NUHOMS®-MP197 packaging assembly (with or without the DSC in place) at a pressure of 62.5 psig. This is well above 1.5 times the maximum normal operating pressure of 5.4 psig (Chapter 4). The test pressure is held for a minimum of 10 minutes. The test is performed in accordance with ASME B&PV Code, Section III, Subsection NB, Paragraph NB-6200 or NB-6300. All visible joints/surfaces are visually examined for possible leakage after application of the pressure.

In addition, a bubble leak test is performed on the resin enclosure. The purpose of this test is to identify any potential leak passages in the enclosure welds.

8.1.2.2 Load Tests

Two sets of trunnions are provided for the NUHOMS®-MP197 transport package lifting. One set of trunnions has double shoulders (non-single failure proof). The other set of trunnions has a single shoulder (single failure proof). Only one set of trunnions is used depending on site and transfer operation requirements. The trunnions are fabricated and tested in accordance with ANSI N14.6 [3]. A load test of three times the design lift load (for single failure proof trunnions) or 1 ½ times the design lift load (for non-single failure proof trunnions) is applied to the trunnions for a period of ten minutes, to ensure that the trunnions can perform satisfactorily.

A force equal to 1.5 times the impact limiter weight will be applied to the hoist rings of each limiter for a period of ten (10) minutes. At the conclusion of the test, the impact limiter hoist rings will be visually examined for defects and permanent deformations.

8.1.3 Leak Tests

8.1.3.1 NUHOMS®-MP197 Cask

Leakage tests are performed on the containment boundary prior to first use, typically at the Fabricator's facility. The fabrication verification leak test can be separated into the following five tests: 1) cask leakage integrity, 2) cask vent port closure bolt seal integrity, 3) cask drain port closure bolt seal integrity, 4) cask top closure (lid) seal integrity, and 5) ram closure plate seal integrity. These tests are usually performed using the helium mass spectrometer method. Alternative methods are acceptable, provided that the required sensitivity is achieved. The leak test is performed in accordance with ANSI N14.5 [4]. The personnel performing the leakage test are qualified in accordance with SNT-TC-1A [2].

Testing the Cask Leakage Integrity

Prior to lead pour and final machining of the inner shell, the cylindrical portion of the containment boundary including the bottom end closure will be leak tested in accordance with the requirements of ANSI N14.5, using temporary closures and seals for the ram and top closure plates. Because the inner shell will not be accessible for leak testing after lead is poured, leak testing will be performed during the fabrication process, as permitted by ANSI N 14.5 Table 1. As one means of performing this test, the interior of the cask cavity may be flooded with a helium atmosphere while vacuum is drawn on the lead cavity to determine the leak rate. If a leak is discovered the source will be determined, repaired and the shells retested to ensure that the measured leak rate is less than $1x10^{-7}$ ref cm^3/s.

The test will be performed in conjunction with the non-destructive examination of the inner shell welds in accordance with ASME BPVC, Section III, Subsection NB, a PT examination of every weld layer in the shell to top forging closure weld, and a PT examination of all final machined weld surfaces of the inner shell per the ASME Code.

Fabrication Leak Test

The fabrication leak tests include the following:

- Testing the Cask Vent Port Closure seal Integrity
- Testing the Cask Drain Port Closure seal Integrity
- Testing the Cask top Closure Plate (Lid) seal Integrity
- Testing the Cask Ram Closure seal Integrity

The tests will be performed as described in Section 7.4, in accordance with the ANSI N 14.5. The acceptance criterion is each component must be individually leaktight, that is, the leak rate must be less than $1x10^{-7}$ ref-cc/s.

8.1.3.2 NUHOMS®-61BT DSC

The NUHOMS®-61BT DSC containment is leak tested to verify it is leaktight in accordance with ANSI N14.5.

The leak tests are typically performed using the helium mass spectrometer method. Alternative methods are acceptable, provided that the required sensitivity is achieved.

8.1.4 Components Tests

8.1.4.1 Valves, Rupture Discs, and Fluid Transport Devices

There are no valves or couplings in the NUHOMS®-MP197 packaging.

8.1.4.2 Gaskets

The lid and all the other containment penetrations are sealed using double elastomer seals. The inner seal forms part of the containment boundary. Leak testing of the seals is described in section 8.1.3.

8.1.4.3 Impact Limiter Leakage Test

The following test will be performed, after all the seal welds are completed on the impact limiter, to verify that the impact limiter wood has been protected from any moisture exchange with the environment.

Pressurize each impact limiter container to a pressure of approximately 3 psig. Test all the weld seams and surfaces for leakage using a soap bubble test.

8.1.4.4 Functional Tests

The following functional tests will be performed prior to first use of the cask. Generally these tests will be performed at the fabrication facility.

a. Installation and removal of the lid, penetration covers, and other fittings will be observed. Each component will be checked for difficulties in installation and removal. After removal, each component will be visually examined for damage. Any defects will be corrected prior to acceptance of the cask.

b. After installation of the fuel basket into the DSC, each basket compartment will be checked by gauge to demonstrate that the fuel assemblies will fit in the basket.

8.1.5 Shielding Tests

Chapter 5 presents the analyses performed to ensure that the NUHOM®-MP197 package shielding integrity is adequate.

8.1.5.1 Neutron Shield Tests

The radial neutron shield is protected from damage or loss by the aluminum and steel enclosure. The neutron shield material is a proprietary, borated, reinforced polymer.

The primary function of the resin is to shield against neutrons, which is performed primarily by the hydrogen content in the resin. The sole function of the boron is to suppress n-γ reactions with hydrogen. The resin also provides some gamma shielding, which is a function of the overall resin density, and is not sensitive to composition.

The shielding performance of the resin can be verified adequately by chemical analysis and verification of density. Uniformity is assured by installation process control.

The following are acceptance values for density and chemical composition for the resin. The values used in the shielding calculations of Chapter 5 are included for comparison.

Chapter 5 values		Acceptance Testing Values		
Element	Nominal wt %	Element	wt %	acceptance range (wt %)
H	5.05	H	5.05	-10 / +20
B	1.05	B	1.05	± 20

The minimum resin density in acceptance testing is 1.547 g/cm^3. Resin composition or density test results which fall outside of this range will be evaluated to ensure that the shielding regulatory dose limits are not exceeded.

Density testing will be performed on every mixed batch of resin. Chemical analysis will be made on the first batch mixed with a given set of components, and thereafter whenever a new lot of one of the major components is introduced. Major components are aluminum oxide, zinc borate and the polyester resin, which combined make up 92% of the resin by weight.

Qualification tests of the personnel and procedure used for mixing and pouring the polyester resin used for radial neutron shielding are performed. Qualification testing includes verification that the chemical composition and density are achieved, and that the process is performed in such a manner as to prevent voids.

Tests are performed at loading to ensure that the radiation dose limits are not exceeded for each cask.

8.1.5.2 Gamma Shield Test

The NUHOMS®-MP-197 cask body poured lead shielding integrity will be confirmed via gamma scanning prior to installation of the neutron shield.

The outer cask surface is gridded and a chart is made to reflect the gridded surface. The gamma scan will be performed using a detector with a detection area enveloping the grid minimum area (e.g., for a 6" × 6" grid, the detector will encompass a 6" × 6" square). The acceptance criterion is determined by utilizing a test block made up from minimum thickness less 5% for the lead and steel sheets. The source is placed behind the test block assembly and the dose rate is measured. The dose rate measured on this test block is then used as the maximum acceptable reading for the inspected cask.

The source/detector distance used in the inspection shall be the same as that used in establishing the minimum dose rate in the mockup. Dose rates for minimum cask shell thickness shall be at least three times the background dose rate.

8.1.6 Neutron Absorber Tests

Functional Requirements of Poison Plates

The poison plates only serve as a neutron absorber for criticality control and as a heat conduction path; the NUHOMS®-MP197 safety analyses do not rely upon their mechanical strength. The basket structural components surround the plates on all sides. The radiation and temperature environment in the cask is not sufficiently severe to damage the aluminum matrix that retains the boron-containing particles. To assure performance of the plates' Important-to-Safety function, the only critical variables that need to be verified are thermal conductivity and B10 areal density as discussed in the following paragraphs.

Thermal Conductivity Testing

The poison plate material will be qualification tested to verify that the thermal conductivity equals or exceeds the values listed in Section 3.3. Acceptance testing of the material in production may be done at only one temperature in that range to verify that the conductivity equals or exceeds the corresponding value in Section 3.3.

Testing may be by ASTM E1225 [5], ASTM E1461 [6], or equivalent method. Acceptance testing shall be performed on specimens removed from coupons adjacent to the final plates.

B10 Areal Density Testing

There are three types of NUHOMS®-61BT DSC baskets (Type A, B, and C), each identical with the exception of the minimum B10 content in the poison plates, as described in Chapter 1. Only one type of poison plate is used in a specific NUHOMS®-61BT DSC, based on the maximum enrichment of the fuel that will be placed in the NUHOMS®-61BT DSC. There are three acceptable poison materials, Boral®, Borated Aluminum and Boron Carbide/Aluminum Metal Matrix Composite (MMC). All materials shall be subject to thermal conductivity, dimensional, and visual acceptance testing. The B10 areal density and uniformity of the poison plates shall be verified using approved procedures as follows.

A. Borated Aluminum Using Enriched Boron, 90% B10 Credit

Material Description

The poison consists of borated aluminum containing boron which is isotopically enriched to 95 wt. % B10. Because of the negligibly low solubility of boron in solid aluminum, the boron appears entirely as discrete second phase particles of AlB_2 in the aluminum matrix. The matrix is limited to any 1000 series aluminum, aluminum alloy 6063, or aluminum alloy 6351 so that no boron-containing phases other than AlB_2 are formed. Titanium may also be added to form TiB_2 particles, which are finer. The effect on the properties of the matrix aluminum alloy are those typically associated with a uniform fine (1-10 micron) dispersion of an inert equiaxed second phase.

The cast ingot may be rolled, extruded, or both to the final plate dimensions.

The minimum boron 10 areal density for the three DSC types is given in Table 8-1 in the 90% credit column. As an example of the correspondence between areal density and the weight percent of boron in the alloy, 2.1 wt. % boron converts to slightly more than 40 mg B10/cm^2 as follows: (2.69 g BAl/cm^3)(2.1 wt. % B)(95 wt. % B10)(0.305 inch)(2.54 cm/inch) = 0.0416 g B10/cm^2. If thinner poison sheets are paired with aluminum sheets (see drawing NUH-61B-1065), the boron content is proportionately higher, up to that needed to maintain the minimum required B10 areal density.

Test Coupons

The poison plates are manufactured in a variety of sizes. Coupons will be removed between every other plate or at the end of the plate so that there is at least one coupon contiguous with each plate. Coupons will generally be the full width of the plate. Thermal conductivity coupons may be removed from the full width coupon. The minimum dimension of the coupon shall be as required for acceptance test specimens; 1 to 2 inches is generally adequate.

Acceptance Testing, Neutronic

Boron-10 areal density will be verified by neutron transmission testing of the coupons. The transmission through the coupons is compared with transmission through calibrated standards composed of a homogeneous boron compound without other significant poisons, for example zirconium diboride or titanium diboride. These standards are paired with aluminum shims sized to match the scattering by aluminum in the poison plates. Uniform but non-homogeneous materials such as metal matrix composites may be used for standards, provided that testing shows them to be equivalent to a homogeneous standard. The effective boron-10 content of each coupon, minus 3σ based on the number of neutrons counted for that coupon, must be greater than or equal to the minimum specified, for the DSC type A, B, or C, using the 90% credit column in Table 8-1.

The area of the collimated neutron beam used for neutron transmission testing is approximately 1 cm^2.

In the event that a coupon fails the neutron transmission measurement, the associated plate is rejected. As an alternate basis for accepting that plate, four additional measurements may be made at separate locations on the plate itself, or on coupons cut from the four corners of the plate. For each of the additional measurements, the value of areal density less 3σ based on the number of neutrons counted must be greater than or equal to the specified minimum in order to accept the plate.

If any of those four fails, the plate associated with the measurements will be rejected, but the average of the five measurements made is used as a datum in the statistical analysis of the lot (see below).

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

For every lot, initial sampling of coupons for neutron transmission measurements and radiography/radioscopy shall be 100%, which shall be considered normal sampling. Rejection of a given coupon shall result in rejection of its associated plate.

Reduced sampling (50%) may be introduced based upon acceptance of all coupons in the first 25% randomly sampled from the lot. A rejection during reduced inspection will require a return to 100% inspection of the lot. A lot is defined as all the plates produced from a single ingot.

A statistical analysis of the neutron transmission results for each lot shall be used to demonstrate that applying the one-sided tolerance factors for a 95% probability / 95% confidence level results in a minimum areal density greater than or equal to the minimum specified. The analysis shall be based on full data set for the lot, except that any data from materials which are rejected based on physical examination of the materials are not to be used in the statistical analysis. For example, a rejection based on dimensional or surface finish inspection is ground for excluding the datum associated with that plate. Failure of this statistical analysis shall result in rejection of the entire lot. Individual pieces in that lot may be accepted based on the determination of an alternate minimum thickness as follows.

All areal densities determined by neutron transmission for that lot may be converted to volume density by dividing by the thickness of the corresponding coupon. The one sided lower tolerance limit of volume density with 95% probability and 95% confidence may then be determined. Finally, the minimum specified value of B10 areal density may be divided by the 95/95 lower tolerance limit of B10 volume density to arrive at a minimum plate thickness. Then, all plates which have any location (other than local pits) thinner than this minimum shall be rejected, and those equal to or thicker may be accepted.

B. Boralyn®, Metamic® or equivalent Metal Matrix Composites, 90% B10 credit

<u>Material Description</u>

The poison plates consist of a composite of aluminum with boron carbide particulate reinforcement. The material is formed into a billet by powder metallurgical processes and either extruded, rolled, or both to final dimensions. The finished product has near-theoretical density and metallurgical bonding of the aluminum matrix particles. It is "uniform" blend of powder particles from face to face, i.e.; it is not a "sandwich" panel.

The specified minimum boron 10 areal density, depending on the NUHOMS®-61BT DSC Type, is given in Table 8-1 in the 90% credit column. As an example of the relation between boron 10 areal density and volume % boron carbide, 15 volume % boron carbide corresponds to slightly more than 40 mg $B10/cm^2$ as follows: $0.15(2.52\ g/cm^3\ B_4C)(0.782\ gB/gB_4C)(0.185\ g\ B10/gB)(0.305\ in)(2.54\ cm/in) = 0.0424\ g\ B10/cm^2$.

The process specifications for the material shall be subject to qualification testing to demonstrate that the process results in a material that:

- has a uniform distribution of boron carbide particles in an aluminum alloy with few or none of the following: voids, oxide-coated aluminum particles, B_4C fracturing, or B_4C/aluminum reaction products,
- meets the requirements for B10 areal density and thermal conductivity, and
- will be capable of performing its Important-to-Safety functions under the thermal and radiological environment of the NUHOMS®-61BT DSC over its 40-year lifetime.

The production of plates for use in the NUHOMS®-61BT DSC is consistent with the process used to produce the qualification test material. Processing changes may be incorporated into the production process, only if they are reviewed and approved by the holder of an NRC-approved QA plan who is supervising fabrication. The basis for acceptance shall be that the changes do not have an adverse effect on either the microstructure or the uniformity of the boron carbide distribution, because these are the characteristics that determine the durability and neutron absorption effectiveness of the material. The evaluation may consist of an engineering review, or it may consist of additional testing. In general, changes in key billet forming variables such as the temperature or pressure would require testing, while changes in mechanical processing variables, such as extrusion speed, would not have to be evaluated. Increasing the boron carbide content would require testing, while decreasing it would not.

Typical processing consists of:

- blending of boron carbide powder with aluminum alloy powder,
- billet formed by vacuum hot pressing (Boralyn® process) or by cold isostatic pressing followed by vacuum sintering (Metamic® process),
- billet extruded to intermediate or to final size,
- hot roll, cold roll and flatten as required, and
- anneal (optional)

Test Coupons

Test coupon removal will be the same as that for borated aluminum, as described in Section 8.1.6A.

Acceptance Testing, B10 Density

Acceptance testing will be the same as that for borated aluminum, as described in Section 8.1.6A.

C. Justification for Use of 90% Boron 10 Credit in Borated Aluminum and Metal Matrix Composites

According to NUREG/CR-5661 [7]

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

Furthermore

"A percentage of poison material greater than 75% may be considered in the analysis only if comprehensive tests, capable of verifying the presence *and uniformity* of the poison, are implemented."

The calculations in Chapter 6 use boron areal densities that are 90% of the minimum values specified here for these materials. This is justified by the following considerations.

a) The coupons for neutronic inspection are removed adjacent to the finished plates. As such, they are taken from locations that are representative of the finished product.

b) Neutron radiography/radioscopy of coupons will detect macroscopic non-uniformities in the B10 distribution such as could be introduced by the fabrication process.

c) Neutron transmission measures effective B10 content directly. The term "effective" is used here because if there are any of the effects noted in NUREG/CR-5661, the neutron transmission technique will measure not the physical B10 areal density, but a lower value. Thus, this technique by its nature screens out the microscopic non-uniformities which have been the source of the recommended 75% credit for B10 in criticality evaluations.

d) The use of neutron transmission and radiography/radioscopy satisfies the "and uniformity" requirement emphasized in NUREG/CR-5661 on both the microscopic and macroscopic scales.

e) Statistical analysis of the neutron transmission results will verify with 95% confidence and 95% certainty that the boron 10 areal density is 100% or more of the minimum specified value at any location in the lot.

f) The recommendations of NUREG/CR-5661 are based upon testing of a poison with boron carbide particles averaging 85 microns. The boride particles in these materials are finer: borated aluminum approximately 5-10 microns and metal matrix composites 1-25 microns. For a given degree of uniformity, fine particles will be less subject to neutron streaming than coarse particles.

g) Because the material reviewed in the NUREG was a sandwich panel, the thickness of the boron carbide-containing center could not be directly verified by thickness measurement. The alloy and MMC specified here are uniform throughout their thickness.

D. Boral®, 75% B10 Credit

Material Description, Boral®

Boral® consists of a core of mechanically bonded aluminum and boron carbide powders sandwiched between two outer layers of aluminum 1100, which is mechanically bonded to the core. The boron carbide particles average approximately 85 microns in diameter. The sheet is formed by filling an aluminum 1100 box with the boron carbide/aluminum powder mixture, and then hot-rolling the box. The walls of the box form the cladding, while the powder mixture forms the core of the Boral®. Additional information on the fabrication, specification, and performance of Boral® may be found in references [8]and [9].

Acceptance Testing, Neutronic

Boral® will be procured in accordance with AAR Manufacturing Inc.'s Standard Specification for Boral® Composite Sheet [8]. In accordance with Section 7.3 of that specification, B 10 areal density will be verified by chemical analysis or by neutron attenuation testing, using a sampling plan that will verify that the coupon meets the specified minimum values of with 95% probability at the 95% confidence level.

Boral® has been used in dry storage, wet storage, and research reactor control blades for over 25 years. Because the standard 75% credit is being used for boron 10, it is not necessary to impose requirements in addition to those in the manufacturer's standard specification.

8.2 Maintenance Program

8.2.1 Structural and Pressure Tests

Within 14 months prior to any lift of a NUHOMS®-MP197 transport package, the lifting (top) trunnions shall be subject to either of the following:

1. A test load equal to 300% of the maximum service load per ANSI N14.6 [3], paragraph 7.3.1(a) for single failure proof trunnions or a test load equal to 150% of the maximum service load per ANSI N14.6, paragraph 7.3.1(b) for non-single failure proof trunnions. After sustaining the test load for a period of not less than 10 minutes, critical areas shall be subjected to visual inspection for defects, and all components shall be inspected for permanent deformation.

2. Dimensional testing, visual inspection and nondestructive examination of critical areas of the trunnions including the bearing surfaces in accordance with Paragraph 6.3.1 of ANSI N14.6. The examination will be performed for subsequent shipments.

8.2.2 Leak Tests

The following containment boundary components shall be subject to periodic maintenance, and preshipment leak testing in accordance with ANSI N14.5:

Vent Port
Drain Port
Top Closure Plate
Ram Port

Test	Frequency	Acceptance Criteria	Typical Method (ANSI N14.5 TABLE A-1)
Periodic	within 12 months Prior to shipment	Each component individually $\leq 1\times10^{-7}$ ref cm³/s	(He) A.5.3 A.5.4
Pre-shipment	Before each shipment, after the contents are loaded and the package is closed	No detected leakage, sensitivity of 10^{-3} ref cm³/s or better	A.5.1 A.5.2 A.5.8 A.5.9
Maintenance	After maintenance repair or replacement of containment by components. Including inner seals	Each component individually $\leq 1\times10^{-7}$ ref cm³/s	(He) A.5.3 A.5.4

No leak tests are required prior to shipment of an empty NUHOMS®-MP197 packaging.

8.2.3 Subsystem Maintenance

8.2.3.1 Fasteners

The lid bolts, ram cover bolts, vent plug, drain plug, and test plugs shall be inspected after each use, and annually, for deformed or stripped threads. Damaged parts shall be evaluated for continued use and replace as required.

8.2.3.2 Impact Limiters

A visual examination of the impact limiters before each shipment will be performed to ensure that the impact limiters have not been degraded between leak test intervals. If there is no evidence of weld cracking or other damage which could result in water in-leakage, the wood will not be degraded. If there is visual damage, the impact limiter will be removed from service, repaired, if possible, and inspected for degradation of the wood. Impact limiters will be leak tested once every five years to ensure that water has not entered the impact limiters. If the leak test indicates that the impact limiters have a leak, a humidity test will be performed to verify that there is no free water in the impact limiters.

8.2.4 Valves, Rupture Discs, and Gaskets on Containment Vessel

If a ram cover or the lid is removed, the seals are replaced prior to spent fuel transport. The seals will be leak tested after retorquing the bolts in accordance with Section 7.4.

The elastomer seals may be reused for transport of an empty NUHOMS®-MP197 packaging.

There are no valves or rupture discs on the NUHOMS®-MP197 packaging containment.

8.2.5 Shielding

There are no periodic tests or inspections required for the NUHOMS®-MP197 shielding. Radiation surveys will be performed on the package exterior to ensure that the limits specified in 10 CFR 71.47 are met prior to each shipment.

8.2.6 Thermal

There are no periodic tests or inspections required for the NUHOMS®-MP197 package heat transfer components.

8.3 References

1. ASME Boiler and Pressure Vessel Code, Section III, 1998 Edition including 1999 addenda.
2. SNT-TC-1A, "American Society for Nondestructive Testing, Personnel Qualification and Certification in Nondestructive Testing," 1992.
3. ANSI N14.6-1993, "American National Standard for Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds or More for Nuclear Materials," New York
4. ANSI N14.5-1997, "American National Standard for Leakage Tests on Packages for Shipment of Radioactive Materials"
5. ASTM E1225, "Thermal Conductivity of Solids by Means of the Guarded-Comparative-Longitudinal Heat Flow Technique."
6. ASTM E1461, "Thermal Diffusivity of Solids by the Flash Method."
7. NUREG/CR-5661, "Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages," 1997.
8. AAR Advanced Structures, "Boral®, The Proven Neutron Absorber".
9. AAR Advanced Structures, Boral® Product Performance Report 624.

Table 8-1
Specified Boron 10 Content

NUHOMS-61BT® DSC Type	Chapter 6 Analysis B10 Areal Density (g/cm^2)	Specified Minimum B10 Areal Density (g/cm^2)	
		90% B10 Credit Materials (note 1)	75% B10 Credit Materials (note 2)
A	0.019	0.021	0.025
B	0.029	0.032	0.038
C	0.036	0.040	0.048

Notes:
1. Borated aluminum, Boralyn®, Metamic®, or equivalent metal matrix composites
2. Boral®

Master Table of Contents

Chapter A.1

A.1.1 Introduction A.1-1
A.1.2 Package Description A.1-2
A.1.2.1 Packaging A.1-2
A.1.2.2 Operational Features A.1-6
A.1.2.3 Contents of Packaging A.1-6
A.1.3 References A.1-8
A.1.4 Appendices A.1.8

Appendix A.1.4.1

A.1.4.1.1 NUHOMS®-24PT4 DSC Description A.1.4.1-1
A.1.4.1.2 NUHOMS®-24PT4 Fuel Basket A.1.4.1-1
A.1.4.1.3 NUHOMS®-24PT4 DSC Contents A.1.4.1-2
A.1.4.1.4 References A.1.4.1-4

Appendix A.1.4.2

A.1.4.2.1 NUHOMS®-32PT DSC Description A.1.4.2-1
A.1.4.2.2 NUHOMS®-32PT Fuel Basket A.1.4.2-1
A.1.4.2.3 NUHOMS®-32PT DSC Contents A.1.4.2-2
A.1.4.2.4 References A.1.4.2-2

Appendix A.1.4.3

A.1.4.3.1 NUHOMS®-24PTH DSC Description A.1.4.3-1
A.1.4.3.2 NUHOMS®-24PTH DSC Fuel Basket A.1.4.3-1
A.1.4.3.3 NUHOMS®-24PTH DSC Contents A.1.4.3-2
A.1.4.3.4 References A.1.4.3-3

Appendix A.1.4.4

A.1.4.4.1 NUHOMS®-32PTH DSC Description A.1.4.4-1
A.1.4.4.2 NUHOMS®-32PTH DSC Fuel Basket A.1.4.4-1
A.1.4.4.3 NUHOMS®-32PTH DSC Contents A.1.4.4-2
A.1.4.4.4 References A.1.4.4-3

Appendix A.1.4.5

A.1.4.5.1 NUHOMS®-32PTH1 DSC Description A.1.4.5-1
A.1.4.5.2 NUHOMS®-32PTH1 DSC Fuel Basket A.1.4.5-1
A.1.4.5.3 NUHOMS®-32PTH1 DSC Contents A.1.4.5-2
A.1.4.5.4 References A.1.4.5-3

Appendix A.1.4.6

A.1.4.6.1 NUHOMS®-37PTH DSC Description A.1.4.6-1
A.1.4.6.2 NUHOMS®-37PTH DSC Fuel Basket A.1.4.6-1
A.1.4.6.3 NUHOMS®-37PTH DSC Contents A.1.4.6-2
A.1.4.6.4 References A.1.4.6-3

Appendix A.1.4.7

A.1.4.7.1 NUHOMS®-61BT DSC Description A.1.4.7-1
A.1.4.7.2 NUHOMS®-61BT Fuel Basket A.1.4.7-1
A.1.4.7.3 NUHOMS®-61BT DSC Contents A.1.4.7-2
A.1.4.7.4 References A.1.4.7-2

Appendix A.1.4.8

A.1.4.8.1 NUHOMS®-61BTH DSC Description A.1.4.8-1
A.1.4.8.2 NUHOMS®-61BTH DSC Fuel Basket A.1.4.8-1
A.1.4.8.3 NUHOMS®-61BTH DSC Contents A.1.4.8-2
A.1.4.8.4 References A.1.4.8-3

Appendix A.1.4.9

A.1.4.9.1 NUHOMS®-69BTH DSC Description A.1.4.9-1
A.1.4.9.2 NUHOMS®-69BTH Fuel Basket A.1.4.9-1
A.1.4.9.3 NUHOMS®-69BTH DSC Contents A.1.4.9-2
A.1.4.9.4 References A.1.4.9-2

Appendix A.1.4.9A

A.1.4.9A.1 RWC Description A.1.4.9A-1
A.1.4.9A.2 RWC Inner Liner A.1.4.9A-2
A.1.4.9A.3 RWC Contents A.1.4.9A-2
A.1.4.9A.4 References A.1.4.9A-4

Appendix A.1.4.10

A.1.4.10.1 NUHOMS®-MP197HB Drawings A.1.4.10-7
A.1.4.10.2 NUHOMS® 24PT4 DSC Drawings A.1.4.10-24
A.1.4.10.3 NUHOMS® 32PT DSC Drawings A.1.4.10-42
A.1.4.10.4 NUHOMS® 24PTH DSC Drawings A.1.4.10-77
A.1.4.10.5 NUHOMS® 32PTH DSC Drawings A.1.4.10-*113*
A.1.4.10.6 NUHOMS® 32PTH1 DSC Drawings A.1.4.10-*159*
A.1.4.10.7 NUHOMS® 37PTH DSC Drawings A.1.4.10-*194*
A.1.4.10.8 NUHOMS® 61BT DSC Drawings A.1.4.10-229
A.1.4.10.9 NUHOMS® 61BTH DSC Drawings A.1.4.10-244
A.1.4.10.10 NUHOMS® 69BTH DSC Drawings A.1.4.10-274
A.1.4.10.11 Radioactive Waste Canister Drawings A.1.4.10-308

Chapter A.2

A.2.1 Structural Design A.2-1
A.2.1.1 Discussion A.2-1
A.2.1.2 Design Criteria A.2-4
A.2.1.3 Weights and Centers of Gravity A.2-8
A.2.1.4 Identification of Codes and Standards for Package Design A.2-9
A.2.2 Materials A.2-9
A.2.2.1 Material Properties and Specifications A.2-9
A.2.2.2 Chemical, Galvanic, or Other Reactions A.2-9
A.2.2.3 Effects of Radiation on Materials A.2-14
A.2.3 Fabrication and Examination A.2-15
A.2.3.1 Fabrication A.2-15
A.2.3.2 Examination A.2-15
A.2.4 General Requirements for All Packages A.2-15
A.2.4.1 Minimum Package Size A.2-15
A.2.4.2 Tamper-Indicating Feature A.2-15
A.2.4.3 Positive Closure A.2-15
A.2.5 Lifting and Tie-down Standards for All Packages A.2-16
A.2.5.1 Lifting Devices A.2-16
A.2.5.2 Tie-Down Devices A.2-17
A.2.6 Normal Conditions of Transport A.2-19
A.2.6.1 Heat A.2-20
A.2.6.2 Cold A.2-22
A.2.6.3 Reduced External Pressure A.2-22
A.2.6.4 Increased External Pressure A.2-23
A.2.6.5 Shock and Vibration A.2-23
A.2.6.6 Water Spray A.2-25
A.2.6.7 Free Drop A.2-25
A.2.6.8 Corner Drop A.2-26
A.2.6.9 Compression A.2-26
A.2.6.10 Penetration A.2-26
A.2.6.11 Fabrication Stresses A.2-26
A.2.6.12 Lid Bolt and Ram Access Cover Plate Bolts A.2-26
A.2.6.13 Fatigue Analysis of the Containment Boundary A.2-27
A.2.6.14 Summary of Normal Condition Cask Body Structural Analysis A.2-28
A.2.6.15 Structural Evaluation of the Basket/Canister Shell under Normal Condition Loads A.2-28
A.2.7 Hypothetical Accident Conditions A.2-30
A.2.7.1 Free Drop A.2-30
A.2.7.2 Crush A.2-34
A.2.7.3 Puncture A.2-34
A.2.7.4 Thermal A.2-35
A.2.7.5 Immersion–Fissile Material A.2-35
A.2.7.6 Immersion–All Packages A.2-36
A.2.7.7 Deep Water Immersion Test A.2-36
A.2.7.8 Summary of Damage A.2-36
A.2.8 Accident Conditions for Air Transport of Plutonium A.2-37
A.2.9 Accident Conditions for Fissile Material Packages for Air Transport A.2-37
A.2.10 Special Form A.2-37

A.2.11 Fuel Rods ... A.2-37
A.2.12 References ... A.2-38
A.2.13 Appendices ... A.2-49

Appendix A.2.13.1

A.2.13.1.1 Introduction ... A.2.13.1-1
A.2.13.1.2 Description of the MP197HB Cask ... A.2.13.1-1
A.2.13.1.3 Boundary Conditions ... A.2.13.1-9
A.2.13.1.4 Load Cases and Load Combinations ... A.2.13.1-9
A.2.13.1.5 NCT Loads Structural Evaluations ... A.2.13.1-12
A.2.13.1.6 HAC Loads Structural Evaluations ... A.2.13.1-15
A.2.13.1.7 NCT Stress Evaluation ... A.2.13.1-19
A.2.13.1.8 HAC Stress Evaluation ... A.2.13.1-21
A.2.13.1.9 Elastic Analysis of MP197HB Cask Body Due to HAC Loads ... A.2.13.1-22
A.2.13.1.10 Method of Interpretation/Obtaining the Stress Results From ANSYS Model ... A.2.13.1-23
A.2.13.1.11 Summary of MP197HB Cask Body Structural Evaluations ... A.2.13.1-26
A.2.13.1.12 References ... A.2.13.1-27

Appendix A.2.13.2

A.2.13.2.1 Purpose ... A.2.13.2-1
A.2.13.2.2 Lid Bolt Load Calculations ... A.2.13.2-2
A.2.13.2.2.1 Bolt Preload ... A.2.13.2-2
A.2.13.2.2.2 Gasket Seating Load ... A.2.13.2-3
A.2.13.2.2.3 Internal Pressure Load ... A.2.13.2-3
A.2.13.2.2.4 Temperature Load ... A.2.13.2-4
A.2.13.2.2.5 Impact Load ... A.2.13.2-4
A.2.13.2.2.6 Puncture Load ... A.2.13.2-5
A.2.13.2.2.7 External Pressure Load of 290 psig ... A.2.13.2-5
A.2.13.2.3 Lid Bolt Load Combinations ... A.2.13.2-6
A.2.13.2.3.1 Additional Prying Bolt Force ... A.2.13.2-6
A.2.13.2.3.2 Bending Moment Bolt Force ... A.2.13.2-8
A.2.13.2.4 Bolt Stress Calculations ... A.2.13.2-8
A.2.13.2.4.1 Average Tensile Stress ... A.2.13.2-8
A.2.13.2.4.2 Bending Stress ... A.2.13.2-9
A.2.13.2.4.3 Shear Stress ... A.2.13.2-10
A.2.13.2.4.4 Maximum Combined Stress Intensity ... A.2.13.2-10
A.2.13.2.4.5 Stress Ratios ... A.2.13.2-10
A.2.13.2.4.6 Bearing Stress Under Bolt Head ... A.2.13.2-11
A.2.13.2.5 Results ... A.2.13.2-11
A.2.13.2.6 Lid Bolt Fatigue Analysis ... A.2.13.2-11
A.2.13.2.6.1 Vibration/Shock ... A.2.13.2-12
A.2.13.2.6.2 Damage Factor Calculation ... A.2.13.2-12
A.2.13.2.7 Lid Seal Contact Evaluation ... A.2.13.2-13
A.2.13.2.7.1 Assumptions ... A.2.13.2-13
A.2.13.2.7.2 Analysis ... A.2.13.2-13
A.2.13.2.7.3 Results ... A.2.13.2-14
A.2.13.2.8 Minimum Engagement Length for Bolt and Flange ... A.2.13.2-14
A.2.13.2.9 Ram Closure Plate Bolts Analysis ... A.2.13.2-16
A.2.13.2.9.1 Bolt Load Calculations ... A.2.13.2-17
A.2.13.2.9.2 Load Combinations ... A.2.13.2-21

A.2.13.2.9.3 Bolt Stress Calculations A.2.13.2-23
A.2.13.2.9.4 Bearing Stress Under Bolt Head A.2.13.2-25
A.2.13.2.9.5 Results A.2.13.2-25
A.2.13.2.9.6 Minimum Engagement Length for Bolt and Flange A.2.13.2-25
A.2.13.2.10 Conclusions A.2.13.2-27
A.2.13.2.11 References A.2.13.2-28

Appendix A.2.13.3

A.2.13.3.1 Introduction A.2.13.3-1
A.2.13.3.2 Finite Element Model A.2.13.3-1
A.2.13.3.3 Material Properties A.2.13.3-4
A.2.13.3.4 Loading and Boundary Conditions A.2.13.3-4
A.2.13.3.5 FEA Results A.2.13.3-5
A.2.13.3.6 Conclusions A.2.13.3-6
A.2.13.3.7 References A.2.13.3-7

Appendix A.2.13.4

A.2.13.4.1 Introduction A.2.13.4-1
A.2.13.4.2 Description A.2.13.4-1
A.2.13.4.3 Materials Properties and Stress Criteria A.2.13.4-1
A.2.13.4.4 Finite Element Model Description A.2.13.4-1
A.2.13.4.5 Applied Loads A.2.13.4-2
A.2.13.4.6 Analysis Results A.2.13.4-3
A.2.13.4.7 References A.2.13.4-5

Appendix A.2.13.5

A.2.13.5.1 Purpose A.2.13.5-1
A.2.13.5.1.1 Lifting Devices A.2.13.5-1
A.2.13.5.1.2 Tie-Down Devices A.2.13.5-1
A.2.13.5.2 Trunnions Analysis A.2.13.5-2
A.2.13.5.2.1 Double Shoulder Trunnions A.2.13.5-2
A.2.13.5.2.2 Single Shoulder Trunnions A.2.13.5-8
A.2.13.5.2.3 Shear Key Bearing Block Assembly A.2.13.5-12
A.2.13.5.3 Results A.2.13.5-15
A.2.13.5.3.1 Double Shoulder Trunnions A.2.13.5-15
A.2.13.5.3.2 Single Shoulder Trunnions A.2.13.5-16
A.2.13.5.3.3 Shear key assembly A.2.13.5-16
A.2.13.5.4 Conclusions A.2.13.5-16
A.2.13.5.4.1 Trunnion assembly A.2.13.5-16
A.2.13.5.4.2 Shear key assembly A.2.13.5-16
A.2.13.5.5 References A.2.13.5-17

Appendix A.2.13.6

A.2.13.6.1 Purpose A.2.13.6-1
A.2.13.6.2 Assumptions A.2.13.6-1
A.2.13.6.3 Calculations A.2.13.6-2
A.2.13.6.3.1 Bolt Preload A.2.13.6-2
A.2.13.6.3.2 Leak test A.2.13.6-2
A.2.13.6.3.3 Pressure Fluctuations A.2.13.6-2
A.2.13.6.3.4 Temperature Fluctuations A.2.13.6-3
A.2.13.6.3.5 Vibration A.2.13.6-3
A.2.13.6.3.6 Shock A.2.13.6-3
A.2.13.6.3.7 1-foot Normal Condition Drop A.2.13.6-4
A.2.13.6.3.8 Transport Cask Fatigue Evaluation–Usage Factor Calculation A.2.13.6-4
A.2.13.6.4 Conclusions A.2.13.6-4
A.2.13.6.5 References A.2.13.6-5

Appendix A.2.13.7

A.2.13.7.1 Introduction A.2.13.7-1
A.2.13.7.2 Dynamic Load Factors and Maximum Drop Accelerations A.2.13.7-5
A.2.13.7.3 Canister Structural Analysis A.2.13.7-7
A.2.13.7.4 Stress Analysis Results A.2.13.7-16
A.2.13.7.4.1 Group 1 DSC Stress Analysis Results A.2.13.7-17
A.2.13.7.4.2 Group 2 DSC Stress Analysis Results A.2.13.7-25
A.2.13.7.4.3 Group 3 DSC Stress Analysis Results A.2.13.7-31
A.2.13.7.4.4 Group 4 DSC Stress Analysis Results A.2.13.7-37
A.2.13.7.5 Limit Analysis A.2.13.7-46
A.2.13.7.6 References A.2.13.7-49

Appendix A.2.13.8

A.2.13.8.1 Introduction A.2.13.8-1
A.2.13.8.2 Approach A.2.13.8-1
A.2.13.8.2.1 Normal Condition of Transport (NCT) Analysis A.2.13.8-1
A.2.13.8.2.2 Hypothetical Accident Condition (HAC) Analysis A.2.13.8-2
A.2.13.8.3 Loading A.2.13.8-2
A.2.13.8.4 Design Criteria A.2.13.8-3
A.2.13.8.5 NUH61BT/NUH61BTH Baskets A.2.13.8-4
A.2.13.8.5.1 Basket Side Drop A.2.13.8-4
A.2.13.8.5.2 Basket End Drop A.2.13.8-9
A.2.13.8.6 NUH69BTH Basket A.2.13.8-9
A.2.13.8.6.1 Basket Side Drop A.2.13.8-9
A.2.13.8.6.2 Basket End Drop A.2.13.8-11
A.2.13.8.7 NUH24PTH A.2.13.8-12
A.2.13.8.7.1 Basket Side Drop A.2.13.8-12
A.2.13.8.7.2 Basket End Drop A.2.13.8-15
A.2.13.8.7.3 Fusion Welds A.2.13.8-15
A.2.13.8.8 NUH32PT Basket A.2.13.8-16
A.2.13.8.8.1 Basket Side Drop A.2.13.8-16
A.2.13.8.8.2 Basket End Drop A.2.13.8-18
A.2.13.8.9 NUH32PTH and 32PTH Type 1/NUH32PTH1 Type 1 and Type 2 Baskets A.2.13.8-19

A.2.13.8.9.1 Basket Side Drop A.2.13.8-19
A.2.13.8.9.2 Basket End Drop A.2.13.8-23
A.2.13.8.9.3 Fusion Welds A.2.13.8-24
A.2.13.8.10 NUH37PTH Basket A.2.13.8-25
A.2.13.8.10.1 Basket Side Drop A.2.13.8-25
A.2.13.8.10.2 Basket End Drop A.2.13.8-27
A.2.13.8.11 NUH24PT4 Basket A.2.13.8-28
A.2.13.8.11.1 Basket Side Drop A.2.13.8-28
A.2.13.8.11.2 Guide Sleeve Assemblies A.2.13.8-30
A.2.13.8.11.3 Support Rod Assemblies A.2.13.8-31
A.2.13.8.12 Basket Deformation for Criticality A.2.13.8-32
A.2.13.8.13 References A.2.13.8-33

Appendix A.2.13.9

A.2.13.9.1 Introduction A.2.13.9-1
A.2.13.9.2 Natural Frequencies during End Drop A.2.13.9-2
A.2.13.9.3 Natural Frequencies during Side Drop A.2.13.9-5
A.2.13.9.4 Dynamic Load Factor Calculations A.2.13.9-7
A.2.13.9.5 References A.2.13.9-8

Appendix A.2.13.10

A.2.13.10.1 Purpose A.2.13.10-1
A.2.13.10.2 Radial Thermal Expansion A.2.13.10-3
A.2.13.10.3 Axial Thermal Expansion A.2.13.10-5
A.2.13.10.4 Results and Conclusions A.2.13.10-9
A.2.13.10.5 Reference A.2.13.10-10

Appendix A.2.13.11

A.2.13.11.1 Material Properties A.2.13.11-1
A.2.13.11.2 Side Drop Analysis A.2.13.11-4
A.2.13.11.2.1 BWR Fuel Assemblies Analysis A.2.13.11-4
A.2.13.11.2.2 PWR Fuel Assemblies Analysis A.2.13.11-7
A.2.13.11.3 End Drop Analysis A.2.13.11-8
A.2.13.11.4 *Effect of the Radial Hydrides on the Mechanical Properties* A.2.13.11-*14*
A.2.13.11.5 References A.2.13.11-21

Appendix A.2.13.12

A.2.13.12.1 Introduction A.2.13.12-1
A.2.13.12.2 NUHOMS®-MP197 Transport Package 1/3 Scale Impact Limiter Drop Testing A.2.13.12-1
A.2.13.12.3 MP197 1/3 Scale LS-DYNA Benchmark Analysis A.2.13.12-2
A.2.13.12.4 1/3 Scale Impact Limiter Benchmark Analysis Results A.2.13.12-6
A.2.13.12.5 MP197HB Full Scale Transport Package LS-DYNA Impact Analysis A.2.13.12-8
A.2.13.12.6 Analysis Results A.2.13.12-13
A.2.13.12.7 Additional Analysis Results for Slap Down Drop Analyses A.2.13.12-13
A.2.13.12.8 End Drop Analysis Based on -40 °F Wood Properties A.2.13.12-14
A.2.13.12.9 Sensitivity Studies of MP197HB Impact Limiter Analysis A.2.13.12-14
A.2.13.12.10 Baseline g Loads for Structural Evaluations A.2.13.12-18
A.2.13.12.11 Impact Limiter Bolt Evaluation A.2.13.12-19

A.2.13.12.12 References A.2.13.12-27

Appendix A.2.13.13

A.2.13.13.1 Introduction A.2.13.13-1
A.2.13.13.2 References A.2.13.13-2

Appendix A.2.13.14

A.2.13.14.1 Finite Element Model A.2.13.14-2
A.2.13.14.2 Boundary and Initial Conditions A.2.13.14-5
A.2.13.14.3 Results A.2.13.14-6
A.2.13.14.4 Conclusion A.2.13.14-7
A.2.13.14.5 References A.2.13.14-8

Chapter A.3

A.3.1 Description of Thermal Design....A.3-2
A.3.1.1 Design Features....A.3-3
A.3.1.2 Content's Decay Heat....A.3-6
A.3.1.3 Summary Tables of Temperatures....A.3-7
A.3.1.4 Summary Tables of Maximum Pressures....A.3-8
A.3.2 Material Properties and Component Specifications....A.3-9
A.3.2.1 Material Properties....A.3-9
A.3.2.2 Component Specifications....A.3-28
A.3.3 Thermal Evaluation under Normal Conditions of Transport....A.3-30
A.3.3.1 Thermal Models....A.3-30
A.3.3.2 Heat and Cold....A.3-67
A.3.3.3 Maximum Normal Operating Pressure....A.3-69
A.3.3.4 Thermal Evaluation for Loading/Unloading Operations....A.3-79
A.3.4 Thermal Evaluation under Hypothetical Accident Conditions....A.3-81
A.3.4.1 Initial Conditions....A.3-81
A.3.4.2 Fire Test Conditions....A.3-82
A.3.4.3 Maximum Temperatures and Pressure....A.3-90
A.3.4.4 Maximum Thermal Stresses....A.3-92
A.3.4.5 Accident Conditions for Fissile Material Packages for Air Transport....A.3-92
A.3.5 References....A.3-93
A.3.6 Appendices....A.3-96
A.3.6.1 Macros for Heat Transfer Coefficient....A.3-97
A.3.6.2 Mesh Sensitivity....A.3-103
A.3.6.3 Justification for Bounding Temperature Profiles....A.3-104
A.3.6.4 Acceptance Criteria for Coating Damages for MP197HB TC....A.3-105
A.3.6.5 Effective Thermal Properties of the Fuel Assemblies....A.3-113
A.3.6.6 Thermal Analysis of 24PTHF and 61BTHF DSCs in MP197HB TC....A.3-120
A.3.6.7 Justification of Hot Gaps....A.3-127
A.3.6.8 Sensitivity Study for Effects of Fire Emissivity....A.3-139
A.3.6.9 Sensitivity Study for Effects of High Burnup Damaged Fuel Assemblies....A.3-139c
A.3.6.10 Sensitivity Analysis for HAC using Coupled Model....A.3-139d

Chapter A.4

A.4.1 Description of Containment System....A.4-1
A.4.1.1 Containment Boundary....A.4-1
A.4.2 Containment under Normal Conditions of Transport (Type B Packages)....A.4-3
A.4.2.1 Containment of Radioactive Material....A.4-3
A.4.2.2 Pressurization of Containment Vessel....A.4-3
A.4.2.3 Containment Criteria....A.4-4
A.4.3 Containment under Hypothetical Accident Conditions (Type B Packages)....A.4-4
A.4.3.1 Fission Gas Products....A.4-4
A.4.3.2 Containment of Radioactive Material....A.4-4
A.4.3.3 Containment Criterion....A.4-4
A.4.4 Special Requirements....A.4-4
A.4.5 References....A.4-5

Chapter A.5

A.5.1		Discussion and Results	A.5-1
	A.5.1.1	NUHOMS® DSC Contents	A.5-1
	A.5.1.2	Irradiated/Contaminated Waste	A.5-4*b*
A.5.2		Source Specification	A.5-4*c*
	A.5.2.1	Axial Source Distribution	A.5-7
	A.5.2.2	Gamma Source	A.5-7a
	A.5.2.3	Neutron Source	A.5-10
A.5.3		Model Specification	A.5-12
	A.5.3.1	Description of Radial and Axial Shielding Configuration	A.5-12
	A.5.3.2	Shield Regional Densities	A.5-15
	A.5.3.3	Source Selection for Bounding Shielding Evaluation	A.5-15
	A.5.3.4	Physics Specification	A.5-16
	A.5.3.5	Tallies	A.5-17
A.5.4		Shielding Evaluation	A.5-19
	A.5.4.1	Used Fuel in DSCs	A.5-19
	A.5.4.2	Irradiated/Contaminated Waste	A.5-22
A.5.5		Fuel Qualification	A.5-23
	A.5.5.1	Generation of Response Functions Used for Fuel Qualification for Transportation and Transportation FQTs	A.5-24
	A.5.5.2	Transportation FQTs for Assemblies Containing Control Components	A.5-26
	A.5.5.3	Transportation FQTs for Assemblies with Damaged or Reconstituted Rods	A.5-27
	A.5.5.4	Decay Heat Restrictions	A.5-27
	A.5.5.5	Methodology for Alteration of Minimum Cooling Times in Transportation FQTs	A.5-31
	A.5.5.6	Shielding Sensitivity Calculations	A.5-33
	A.5.5.7	*Uncertainty Evaluations for Source Terms and Shielding*	*A.5-34a*
A.5.6		References	A.5-34*d*
A.5.7		Input File Listing	A.5-35
	A.5.7.1	Sample SAS2H/ORIGEN-S Input File	A.5-36
	A.5.7.2	Annotated MCNP Input Deck Utilizing Neutron Radiation Source for NCT Bounding Shielding Evaluation	A.5-39
	A.5.7.3	MCNP Input Deck Utilizing Primary Gamma Radiation Source for HAC Bounding Shielding Evaluation	A.5-73
A.5.8		*VYAL-B Mixing and Installation*	*A.5-105a*

Chapter A.6

A.6.1 Description of Criticality Design A.6-1
A.6.1.1 Design Features A.6-1
A.6.1.2 Criticality Safety Index A.6-1
A.6.1.3 Summary of Criticality Evaluations A.6-2
A.6.2 Contents, Calculational Models and Criticality Calculations A.6-2
A.6.2.1 Fresh Fuel Methodology A.6-2
A.6.2.2 Burn-Up Credit Methodology A.6-3
A.6.2.3 Model Specification for Burnup Credit A.6-5
A.6.2.4 SAS2H Modeling of Spent Fuel Assemblies A.6-5
A.6.2.5 SAS2H Calculations A.6-10
A.6.2.6 Determination of Most Reactive Fuel A.6-12a
A.6.2.7 Criticality Sensitivity Calculations A.6-12b

A.6.3 Benchmark Evaluations and Applicable Biases A.6-13
A.6.3.1 Fresh Fuel Benchmark A.6-13
A.6.3.2 Burnup Credit Benchmarks A.6-13
A.6.3.3 Horizontal Burnup Bias A.6-24
A.6.3.4 Fuel Assembly Burnup Assignment and Reactivity Margins A.6-26
A.6.4 References A.6-30
A.6.4.1 Listing of SAS2H Input Files A.6-32
A.6.5 Appendices A.6-39

Appendix A.6.5.1

A.6.5.1.1 Discussion and Results A.6.5.1-1
A.6.5.1.2 Package Fuel Loading A.6.5.1-3
A.6.5.1.3 Model Specification A.6.5.1-4
A.6.5.1.3.1 Description of the 61BT DSC Calculational Model A.6.5.1-4
A.6.5.1.3.2 Description of the 61BTH DSC Calculational Model A.6.5.1-5
A.6.5.1.3.3 Package Regional Densities A.6.5.1-7
A.6.5.1.4 Criticality Calculations A.6.5.1-8
A.6.5.1.4.1 NUHOMS®-61BT and NUHOMS®-61BTH DSC Calculational Methods A.6.5.1-9
A.6.5.1.4.2 61BT DSC Fuel Loading Optimization A.6.5.1-11
A.6.5.1.4.3 61BTH DSC Fuel Loading Optimization A.6.5.1-15
A.6.5.1.5 Criticality Results A.6.5.1-26
A.6.5.1.6 Critical Benchmark Experiments A.6.5.1-27
A.6.5.1.7 References A.6.5.1-28
A.6.5.1.7.1 Input File Listing A.6.5.1-30
A.6.5.1.7.2 Input Listing for 4 Failed, 12 Damaged, and 45 Intact Fuel Assemblies ... A.6.5.1-43

Appendix A.6.5.2

A.6.5.2.1 Discussion and Results A.6.5.2-1
A.6.5.2.2 Package Fuel Loading A.6.5.2-2
A.6.5.2.3 Model Specification A.6.5.2-3
A.6.5.2.3.1 Description of the Calculational Models A.6.5.2-3
A.6.5.2.3.2 Package Regional Densities A.6.5.2-5
A.6.5.2.4 Criticality Calculations A.6.5.2-6

A.6.5.2.4.1 Calculational Method A.6.5.2-7
A.6.5.2.4.2 Fuel Loading Optimization A.6.5.2-10
A.6.5.2.4.3 Criticality Results A.6.5.2-18
A.6.5.2.5 Critical Benchmark Experiments A.6.5.2-19
A.6.5.2.5.1 Benchmark Experiments and Applicability A.6.5.2-19
A.6.5.2.6 References A.6.5.2-21
A.6.5.2.7 Input File Listing A.6.5.2-22
A.6.5.2.7.1 CSAS25 Input Deck for Design Basis Intact Fuel Assembly Case A.6.5.2-22
A.6.5.2.7.2 CSAS25 Input Decks for Design Basis Damaged Fuel Assembly Case A.6.5.2-32

Appendix A.6.5.3

A.6.5.3.1 Discussion and Results A.6.5.3-1
A.6.5.3.2 Package Fuel Loading A.6.5.3-3
A.6.5.3.3 Model Specification A.6.5.3-4
A.6.5.3.3.1 Description of the Calculational Models A.6.5.3-4
A.6.5.3.3.2 Neutron Absorber Material Efficacy A.6.5.3-8
A.6.5.3.4 Criticality Calculations A.6.5.3-9
A.6.5.3.4.1 Calculational Method A.6.5.3-9
A.6.5.3.4.2 Fuel Loading Optimization A.6.5.3-9
A.6.5.3.4.3 Criticality Results A.6.5.3-17
A.6.5.3.5 Summary And Conclusions A.6.5.3-20
A.6.5.3.5.1 Summary of 24PT4-DSC Limits with Normal ^{10}B Loading of 0.025 g/cm^2 .... A.6.5.3-20
A.6.5.3.5.2 Summary of 24PT4-DSC Limits with High ^{10}B Loading of 0.068 g/cm^2 .... A.6.5.3-20
A.6.5.3.6 Critical Benchmark Experiments A.6.5.3-22
A.6.5.3.7 References A.6.5.3-23
A.6.5.3.8 Input File Listing A.6.5.3-24
A.6.5.3.8.1 Input File for Intact Fuel A.6.5.3-24
A.6.5.3.8.2 Input File for Damaged Fuel A.6.5.3-24n

Appendix A.6.5.4

A.6.5.4.1 Discussion and Results A.6.5.4-1
A.6.5.4.2 Package Fuel Loading A.6.5.4-3
A.6.5.4.3 Model specification A.6.5.4-4
A.6.5.4.3.1 Description of the Calculational Models A.6.5.4-4
A.6.5.4.3.2 Package Regional Densities A.6.5.4-6
A.6.5.4.4 Criticality Calculations A.6.5.4-6
A.6.5.4.4.1 Calculational Method A.6.5.4-6
A.6.5.4.4.2 Fuel Loading Optimization A.6.5.4-9
A.6.5.4.5 Criticality Results A.6.5.4-15
A.6.5.4.6 References A.6.5.4-17
A.6.5.4.7 Input File Listing A.6.5.4-18
A.6.5.4.7.1 CSAS25 Input Deck for *WE 17x17* Intact Fuel Assembly Case A.6.5.4-18
A.6.5.4.7.2 CSAS25 Input Deck for Design Basis WE 17x17 Damaged Fuel Assembly Case A.6.5.4-32a

Appendix A.6.5.5

A.6.5.5.1 Discussion and Results A.6.5.5-1
A.6.5.5.2 Package Fuel Loading A.6.5.5-3
A.6.5.5.3 Model Specification A.6.5.5-4
A.6.5.5.3.1 Description of the Calculational Models A.6.5.5-4
A.6.5.5.3.2 Package Regional Densities A.6.5.5-6
A.6.5.5.4 Criticality Calculations A.6.5.5-6
A.6.5.5.4.1 Calculational Method A.6.5.5-6
A.6.5.5.4.2 Fuel Loading Optimization A.6.5.5-9
A.6.5.5.4.3 Criticality Results A.6.5.5-16
A.6.5.5.5 References A.6.5.5-17
A.6.5.5.6 Input File Listing A.6.5.5-18
A.6.5.5.6.1 CSAS25 Input Deck for *WE 14x14 Damaged* Fuel Assembly Case A.6.5.5-18
A.6.5.5.6.2 CSAS25 Input Deck for WE 14x14 Damaged Fuel Assembly Case A.6.5.5-34b

Appendix A.6.5.6

A.6.5.6.1 Discussion and Results A.6.5.6-1
A.6.5.6.2 Package Fuel Loading A.6.5.6-4
A.6.5.6.3 Model specification A.6.5.6-5
A.6.5.6.3.1 Description of the Calculational Models A.6.5.6-5
A.6.5.6.3.2 Package Regional Densities A.6.5.6-6
A.6.5.6.4 Criticality Calculations A.6.5.6-6
A.6.5.6.4.1 Calculational Method A.6.5.6-7
A.6.5.6.4.2 Fuel Loading Optimization A.6.5.6-9
A.6.5.6.4.3 Criticality Results A.6.5.6-13
A.6.5.6.5 References A.6.5.6-14
A.6.5.6.6 Input File Listing A.6.5.6-15
A.6.5.6.6.1 CSAS25 Input Deck for *WE 17x17* Intact Fuel Assembly Case A.6.5.6-15

Appendix A.6.5.7

A.6.5.7.1 Discussion and Results A.6.5.7-1
A.6.5.7.2 Package Fuel Loading A.6.5.7-3
A.6.5.7.3 Model specification A.6.5.7-4
A.6.5.7.3.1 Description of the Calculational Models A.6.5.7-4
A.6.5.7.3.2 Package Regional Densities A.6.5.7-5
A.6.5.7.4 Criticality Calculations A.6.5.7-6
A.6.5.7.4.1 Calculational Method A.6.5.7-6
A.6.5.7.4.2 Fuel Loading Optimization A.6.5.7-9
A.6.5.7.4.3 Criticality Results A.6.5.7-14
A.6.5.7.5 References A.6.5.7-16
A.6.5.7.6 Input File Listing A.6.5.7-17
A.6.5.7.6.1 CSAS25 Input Deck for *WE 14x14* Intact Fuel Assembly Case A.6.5.7-17
A.6.5.7.6.2 CSAS25 Input Deck for WE 14x14 Damaged Fuel Assembly Case A.6.5.7-28

Chapter A.7

A.7.1 NUHOMS®-MP197HB Package Loading A.7-1
A.7.1.1 NUHOMS®-MP197HB Cask Preparation for Loading A.7-1a
A.7.1.2 NUHOMS®-MP197HB Cask Wet Loading A.7-3
A.7.1.3 NUHOMS®-MP197HB Cask Dry Loading (Transferring a Loaded DSC or RWC from an Overpack into an MP197HB Cask) A.7-7
A.7.1.4 NUHOMS®-MP197HB Cask Preparation for Transport A.7-9
A.7.2 NUHOMS®-MP197HB Package Unloading A.7-10
A.7.2.1 Receipt of Loaded NUHOMS®-MP197HB Package from Carrier A.7-10
A.7.2.2 Removal of Contents from NUHOMS®-MP197HB Cask A.7-11
A.7.3 Preparation of Empty Package for Transport A.7-14
A.7.4 Other Operations A.7-14
A.7.4.1 Leakage Testing of the Containment Boundary A.7-14
A.7.5 References A.7-17
A.7.6 Glossary A.7-18
A.7.7 Appendices A.7-19

Appendix A.7.7.1

A.7.7.1.1 NUHOMS®-24PT4 DSC Fuel Loading A.7.7.1-1
A.7.7.1.2 NUHOMS®-24PT4 DSC Drying and Backfilling A.7.7.1-2
A.7.7.1.3 NUHOMS®-24PT4 DSC Sealing Operations A.7.7.1-5
A.7.7.1.4 Unloading the NUHOMS®-24PT4 DSC to a Fuel Pool A.7.7.1-5
A.7.7.1.5 References A.7.7.1-8

Appendix A.7.7.2

A.7.7.2.1 NUHOMS®-32PT DSC Fuel Loading A.7.7.2-1
A.7.7.2.2 NUHOMS®-32PT DSC Drying and Backfilling A.7.7.2-3
A.7.7.2.3 NUHOMS®-32PT DSC Sealing Operations A.7.7.2-5
A.7.7.2.4 Unloading a NUHOMS®-32PT DSC to a Fuel Pool A.7.7.2-6
A.7.7.2.5 References A.7.7.2-8

Appendix A.7.7.3

A.7.7.3.1 NUHOMS®-24PTH DSC Fuel Loading A.7.7.3-1
A.7.7.3.2 NUHOMS®-24PTH DSC Drying and Backfilling A.7.7.3-3
A.7.7.3.3 NUHOMS®-24PTH DSC Sealing Operations A.7.7.3-5
A.7.7.3.4 Unloading the NUHOMS®- 24PTH DSC to a Fuel Pool A.7.7.3-6
A.7.7.3.5 References A.7.7.3-9

Appendix A.7.7.4

A.7.7.4.1 NUHOMS®-32PTH DSC Fuel Loading A.7.7.4-1
A.7.7.4.2 NUHOMS®-32PTH DSC Drying and Backfilling A.7.7.4-3
A.7.7.4.3 NUHOMS®-32PTH DSC Sealing Operations A.7.7.4-5
A.7.7.4.4 Unloading a NUHOMS®-32PTH DSC to a Fuel Pool A.7.7.4-6
A.7.7.4.5 References A.7.7.4-9

Appendix A.7.7.5

A.7.7.5.1 NUHOMS®-32PTH1 DSC Fuel Loading A.7.7.5-1
A.7.7.5.2 NUHOMS®-32PTH1 DSC Drying and Backfilling A.7.7.5-3
A.7.7.5.3 NUHOMS®-32PTH1 DSC Sealing Operations A.7.7.5-6
A.7.7.5.4 Unloading a NUHOMS®-32PTH1 DSC to a Fuel Pool A.7.7.5-6
A.7.7.5.5 References A.7.7.5-9

Appendix A.7.7.6

A.7.7.6.1 NUHOMS®-37PTH DSC Fuel Loading A.7.7.6-1
A.7.7.6.2 NUHOMS®-37PTH DSC Drying and Backfilling A.7.7.6-3
A.7.7.6.3 NUHOMS®-37PTH DSC Sealing Operations A.7.7.6-5
A.7.7.6.4 Unloading a NUHOMS®-37PTH DSC to a Fuel Pool A.7.7.6-6
A.7.7.6.5 References A.7.7.6-9

Appendix A.7.7.7

A.7.7.7.1 NUHOMS®-61BT DSC Fuel Loading A.7.7.7-1
A.7.7.7.2 NUHOMS®-61BT DSC Drying and Backfilling A.7.7.7-2
A.7.7.7.3 NUHOMS®-61BT DSC Sealing Operations A.7.7.7-5
A.7.7.7.4 Unloading the NUHOMS®-61BT DSC to a Fuel Pool A.7.7.7-6
A.7.7.7.5 References A.7.7.7-8

Appendix A.7.7.8

A.7.7.8.1 NUHOMS®-61BTH DSC Fuel Loading A.7.7.8-1
A.7.7.8.2 NUHOMS®-61BTH DSC Drying and Backfilling A.7.7.8-2
A.7.7.8.3 NUHOMS®-61BTH DSC Sealing Operations A.7.7.8-5
A.7.7.8.4 Unloading a NUHOMS®-61BTH DSC to a Fuel Pool A.7.7.8-6
A.7.7.8.5 References A.7.7.8-9

Appendix A.7.7.9

A.7.7.9.1 NUHOMS®-69BTH DSC Fuel Loading A.7.7.9-1
A.7.7.9.2 NUHOMS®-69BTH DSC Drying and Backfilling A.7.7.9-2
A.7.7.9.3 NUHOMS®-69BTH DSC Sealing Operations A.7.7.9-5
A.7.7.9.4 Unloading a NUHOMS®-69BTH DSC to a Fuel Pool A.7.7.9-6
A.7.7.9.5 References A.7.7.9-8

Appendix A.7.7.10

A.7.7.10.1 Wet Loading of the RWC A.7.7.10-1
A.7.7.10.2 RWC Drying and Backfilling A.7.7.10-2
A.7.7.10.3 RWC Sealing Operations A.7.7.10-3

Chapter A.8

A.8.1	Acceptance Tests	A.8-1
A.8.1.1	Visual Inspection and Measurements	A.8-1
A.8.1.2	Weld Examinations	A.8-1
A.8.1.3	Structural and Pressure Tests	A.8-2
A.8.1.4	Containment Boundary Leakage Tests	A.8-2
A.8.1.5	MP187HB Cask Component and Material Tests	A.8-3
A.8.1.6	Shielding Tests	A.8-4
A.8.1.7	Neutron Absorber Tests	A.8-*6*
A.8.1.8	Thermal Tests	A.8-*14*
A.8.2	Maintenance Program	A.8-*15*
A.8.2.1	Structural and Pressure Tests	A.8-*15*
A.8.2.2	Leakage Tests	A.8-*15*
A.8.2.3	Component and Material Tests	A.8-*16*
A.8.2.4	*Periodic* Thermal Tests	A.8-*17*
A.8.2.5	Miscellaneous Tests	A.8-*17*
A.8.3	References	A.8-*18*

Chapter A.1
General Information

TABLE OF CONTENTS

A.1.1 Introduction A.1-1
A.1.2 Package Description A.1-2
A.1.2.1 Packaging A.1-2
A.1.2.2 Operational Features A.1-6
A.1.2.3 Contents A.1-6
A.1.3 References A.1-8
A.1.4 Appendices A.1-8

LIST OF TABLES

A.1-1 Nominal Dimensions and Weights of the NUHOMS®-MP197HB Packaging A.1-9
A.1-2 *DSC* Configuration *in the NUHOMS®-MP197HB Package* A.1-10

LIST OF FIGURES

A.1-1 General Arrangement of the NUHOMS®-MP197HB Packaging A.1-11

Chapter A.1
General Information

NOTE: References in this Chapter are shown as [1], [2], etc. and refer to the reference list in Section A.1.3.

A.1.1 Introduction

This Appendix A to the Safety Analysis Report (SAR) for the NUHOMS®-MP197 Transport Cask presents the evaluation of a modified version of the *NUHOMS®* MP197. This modified version is a Type B(U) spent fuel transport packaging developed by Transnuclear, Inc. and designated as Model Number NUHOMS®-MP197HB packaging. Appendix A of this SAR describes the design features and presents the safety analyses which demonstrate that the NUHOMS®-MP197HB packaging complies with applicable requirements of 10 CFR 71 [1]. The format and content of Appendix A follow the guidelines of Regulatory Guide 7.9 [2].

The NUHOMS®-MP197HB packaging consists of the NUHOMS®-MP197HB Transport Cask, which is utilized for the off-site transport of one of several NUHOMS® Dry Shielded Canisters (DSCs) or a secondary container with dry irradiated and/or contaminated non-fuel bearing solid materials in accordance with 10 CFR 71 [1]. The packaging is intended to be shipped as exclusive use. The criticality safety index (CSI) for nuclear criticality control for the packaging when transporting fuel is determined to be zero (0) in accordance with 10 CFR 71.59 *[1]*. See Chapter A.6 for details of this determination.

Transnuclear, Inc. has an NRC approved quality assurance program (Docket Number 71-0250) which satisfies the requirements of 10 CFR 71 Subpart H [1].

A.1.2 Package Description

A.1.2.1 Packaging

The NUHOMS®-MP197HB packaging can be used to transport several types of Boiling Water Reactor (BWR) fuel assemblies with or without fuel channels or Pressurized Water Reactor (PWR) fuel assemblies with or without control components. The fuel assemblies are contained in a single NUHOMS® DSC. In addition the NUHOMS®-MP197HB packaging can be used to transport a secondary container with dry irradiated and/or contaminated non-fuel bearing solid materials. The NUHOMS®-MP197HB packaging is designed for a maximum heat load of 32 kW depending on the NUHOMS® DSC being transported and cask configuration. The fuels that may be transported in the NUHOMS®-MP197HB packaging are presented in Section A.1.2.3. The dry irradiated and/or contaminated non-fuel bearing solid materials that may be transported in the NUHOMS®-MP197HB packaging are also presented in Section A.1.2.3.

The NUHOMS®-MP197HB packaging is shown in Figure A.1-1 and consists of the following components:

- A NUHOMS®-MP197HB transport cask consists of a containment boundary, structural shell, gamma shielding material, and solid neutron shield. The containment boundary consists of a cylindrical shell, bottom plate with a ram access penetration, cask body flange, bottom and top cover plates (lids) with associated seals and bolts, and vent and drain port closure bolts and seals. The transport cask cavity also contains an inert gas atmosphere.

- Because there are two different Outside Diameters (ODs) for the DSCs and secondary containers, an aluminum inner sleeve is used for smaller diameter DSCs and secondary containers. The inner sleeve is designed with slots to accommodate the existing rails inside the cask and to provide rails inside the sleeve on which the smaller diameter DSCs or secondary containers slide during horizontal loading or unloading of the cask.

- To accept the varying lengths of the DSCs and secondary containers, stainless steel or aluminum spacers are provided to limit axial movement of the payload.

- *For a* NUHOMS®-69BTH *DSC* with heat load greater than 26 kW, removable external fins are provided as an option for the cask. *The use of these fins is optional.* The aluminum fins, if used, are attached to an outer aluminum sleeve which is fabricated in two halves which are bolted together around the cask between the impact limiters.

- Sets of removable front and rear trunnions which are bolted to the outer shell of the cask provide support, lifting, and rotation capability for the NUHOMS®-MP197HB cask.

- Impact limiters consisting of balsa and redwood encased in stainless steel shells are attached to each end of the NUHOMS®-MP197HB cask during shipment. A thermal shield is provided between each impact limiter and the cask to minimize heat transfer to the impact limiters. Each impact limiter is held in place by twelve (12) attachment bolts.

- A personnel barrier is mounted to the transport frame to prevent unauthorized access to the cask body.

- There are nine DSC designs authorized for transport in the NUHOMS®-MP197HB packaging. All of the DSCs consist of a cylindrical shell, and top and bottom shielded closure assemblies. Details for each DSC type are provided in Appendices A.1.4.1 through A.1.4.9. After loading, each DSC is vacuum dried and back-filled with an inert gas. Each DSC includes a fuel basket assembly, located inside the DSC. The basket assembly locates and supports the fuel assemblies, transfers heat to the DSC wall, and provides neutron absorption to satisfy nuclear criticality requirements. For some DSC designs, a basket hold down ring is installed on top of the basket, after fuel loading, to prevent axial motion of the basket within the DSC.

- The dry irradiated and/or contaminated non-fuel bearing solid materials are contained in a secondary container (Radioactive Waste *Canister* (RWC)). The safety analysis of this configuration takes no credit for the containment provided by the *RWC*.

A.1.2.1.1 NUHOMS®-MP197HB Transport Cask

The cask is fabricated primarily of nickel-alloy steel (NAS). Other materials include the cast lead shielding between the containment boundary inner shell and the structural shell, the O-ring seals, the borated resin neutron shield and the carbon steel closure bolts. Socket headed cap screws (bolts) are used to secure the lid to the cask body and the ram access closure plate to the bottom of the cask. The body of the cask consists of a 1.25 inch thick, 70.50 inch inside diameter NAS inner (containment) shell and a 2.75 inch thick, 84.50 inch outside diameter NAS structural shell which sandwich the 3.00 inch thick cast lead shielding material.

The overall dimensions of the NUHOMS®-MP197HB packaging are 271.25 inches long and 126.00 inches in diameter with both impact limiters installed. The transport cask body is 210.25 inches long and 84.50 inches in diameter. The cask diameter including the radial neutron shield is 97.75 inches or 104.25 inches with the fins. The *minimum length of* cask cavity is 199.25 inches and 70.50 inches in diameter without the sleeve or 68 inches with the sleeve. Detailed design drawings for the NUHOMS®-MP197HB packaging are provided in Appendix A.1.4.10, Section A.1.4.10.1. The materials used to fabricate the packaging are shown in the Parts List on Drawing MP197HB-71-1002. Where more than one material has been specified for a component, the most limiting properties are used in the analyses in the subsequent sections of this appendix to the SAR.

The maximum gross weight of the loaded package is 152.0 tons including a maximum payload of 56.0 tons. Table A.1-1 summarizes the dimensions and weights of the NUHOMS®-MP197HB packaging components. 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 NUHOMS®-MP197HB packaging is transported in the horizontal orientation, on a specially designed shipping frame, with the lid end facing the direction of travel.

DSCs with a spent fuel payload are shipped dry in a helium atmosphere. Both the transport cask cavity and the DSC cavity are filled with helium. The heat generated by the spent fuel assemblies is rejected to the environment by conduction, convection and radiation. No forced cooling is required.

RWCs with dry irradiated and/or contaminated non-fuel bearing solid materials are shipped dry in an air, nitrogen or inert gas environment. When a wet load procedure (i.e., in-pool) is followed for cask loading, the *RWC* and cask cavities are drained and dried in order to ensure that free liquids do not remain in the package during transport. The heat generated by the contents of the *RWC* is rejected to the environment by conduction, convection and radiation. No forced cooling is required.

A. Containment Vessel

The cask containment boundary consists of the inner shell, a 6.50 inch thick bottom plate with a 28.88 inch diameter, 2.50 inch thick ram access closure plate, a cask body flange, a 4.50 inch thick lid with lid bolts, vent and drain port closures and bolts, and O-ring seals for each of the penetrations. A 70.50 inch diameter, 199.25 inch long cavity is provided.

The containment vessel prevents leakage of radioactive material from the cask cavity. It also maintains an inert atmosphere (helium) in the cask cavity. Helium *within the DSCs* assists in heat removal and provides a non-reactive environment to protect fuel assemblies against fuel cladding degradation. To preclude air in-leakage, the cask cavity is pressurized with helium to above atmospheric pressure.

The inner containment shell is SA-203, Grade E, and the bottom and top flange materials are SA-350-LF3. The lid is constructed from SA-350-LF3 or SA-203, Grade E. The NUHOMS®-MP197HB packaging containment vessel is designed, fabricated, examined and tested in accordance with the requirements of Subsection NB [3] of the ASME Code to the maximum practical extent. In addition, the design meets the requirements of Regulatory Guides 7.6 [5] and 7.8 [6]. *Alternatives* to the ASME Code are discussed in Chapter A.2, Appendix A.2.13.13. The construction of the containment boundary is shown in Drawings MP197HB-71-1002, -1003, -1004, -1005 and -1006 provided in Appendix A.1.4.10, Section A.1.4.10.1. The design of the containment boundary is discussed in Chapter A.2 and the fabrication requirements (including examination and testing) of the containment boundary are discussed in Chapter A.4.

B. Gamma and Radial Neutron Shielding

The lead and steel shells of the transport cask provide shielding between the fuel and the exterior surface of the package for the attenuation of gamma radiation (Drawings MP197HB-71-1002, -1003, -1004, -1005 and -1006).

Neutron shielding is provided by a borated resin compound surrounding the outer shell. The resin compound is cast into long, slender aluminum containers. The containers are constructed from 6063-T651 aluminum. The total thickness of the resin and aluminum is 6.25 inches. The array of resin-filled containers is enclosed within a 0.375 inch thick outer steel shell (coated SA-516-70). In addition to serving as resin containers, the aluminum provide a heat conduction path from the cask body to the neutron shield shell.

Noncontainment welds are inspected in accordance with the NDE acceptance criteria of ASME B&PV Code Subsection NF [8].

The structural analysis of the NUHOMS®-MP197HB cask body is presented in Chapter A.2.

A.1.2.1.2 Tiedown and Lifting Devices

There are four trunnion sockets on the cask; two front trunnion sockets, and two rear trunnion sockets. They accommodate removable trunnions for handling, lifting, and rotating the cask. These trunnion sockets are attached to the structural shell. Two types of trunnions are provided for the NUHOMS®-MP197HB transport package lifting. One type of trunnion has a double shoulder (non-single failure proof). The other type of trunnion has a single shoulder (single failure proof). The front (lifting) set of trunnions could be either type, depending on site and transfer operation requirements. The rear set of trunnions *may also be of either* type. The trunnions are fabricated and tested in accordance with ANSI N14.6 [7]. During transport, four trunnion plugs, containing neutron shielding material, are bolted to the four trunnion sockets.

When the cask is in the horizontal position, a shear key receptacle on the bottom of the cask reacts the longitudinal tiedown loads. The shear key receptacle is welded to the structural shell and protrudes through the neutron shield. During transport the receptacle interfaces with the shear block attached to the transport skid.

A.1.2.1.3 Impact Limiters

The front and rear impact limiters, shown in Drawings MP197HB-71-1001, -1002, -1003, -1008, and -1009, absorb energy during impact events by crushing balsa and redwood. The two impact limiters are identical. Each has an outside diameter of 126 inches and a height of 58 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 stainless steel outer cylinder and end plates due to pressure differentials caused by elevation and temperature changes during normal transport. The metal structure locates, supports, confines, and protects the wood energy absorption material.

Each impact limiter is attached to the NUHOMS®-MP197HB cask by twelve (12) attachment bolts. The attachment bolts are designed to keep the impact limiters attached to the cask body during all normal conditions of transport and hypothetical accident conditions.

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 three hoist rings for handling, and two support angles for supporting the impact limiter in a vertical position during storage. The hoist rings are threaded into the impact limiter shell, while the support angles are welded to the shell. Prior to transport, the impact limiter hoist rings are removed and replaced with bolts.

An aluminum thermal shield is added to each impact limiter to reduce the impact limiter wood temperature. The details of the thermal shield are included in Drawing MP197HB-71-1002, -1003 and -1009.

The functional description as well as the performance analysis of the impact limiters is provided in Chapter A.2, Appendix A.2.13.12. The description and results of the impact limiter dynamic testing program are also provided in that Appendix.

Packaging markings are specified on Drawing MP197HB-71-1007.

A.1.2.2 Operational Features

The NUHOMS®-MP197HB package is not considered to be operationally complex and is designed to be compatible with spent fuel pool loading/unloading methods. All operational features are readily apparent from inspection of the General Arrangement Drawings provided in Appendix A.1.4.10, Section A.1.4.10.1. The sequential steps to be followed for cask loading, testing, and unloading operations are provided in Chapter A.7.

A.1.2.3 Contents

A.1.2.3.1 NUHOMS® DSCs

As noted above, there are nine DSC designs authorized for transport in the NUHOMS®-MP197HB packaging. Details for each DSC type are provided in Appendices A.1.4.1 through A.1.4.9. The maximum weight of the payload (DSC including the fuel) is limited to 56.0 tons.

Table A.1-2 lists each DSC type authorized for transport along with the required sleeves, spacers and a recommendation regarding fins to be used on the cask. In addition, the table lists the SAR appendix where the payload details can be found for each DSC. *Loaded DSCs that are currently in storage, or DSCs which will be transported directly from the spent fuel pool, will only be shipped if the gaps between the fuel assemblies and the inner surfaces of the ends of the cavity meet the gaps specified in Appendix A.2.13.14, Table A.2.13.14-2.*

A.1.2.3.2 *Radioactive Waste Canister*

The NUHOMS®-MP197HB packaging is also licensed to transport a RWC. The RWC is designed to carry dry irradiated and/or contaminated non-fuel-bearing solid materials. Details of the RWC are provided in Appendix A.1.4.9A.

A.1.3 References

1. 10 CFR 71, Packaging and Transportation of Radioactive Material.

2. USNRC Regulatory Guide 7.9, "Standard Format and Content of Part 71 Applications for Approval of Packages for Radioactive Material," Rev. 2, March 2005.

3. American Society of Mechanical Engineers, ASME Boiler And Pressure Vessel Code, Section III, Division 1 - Subsection NB, 2004 edition including 2006 Addenda.

4. Not Used.

5. USNRC Regulatory Guide 7.6, "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessel," Rev. 1, March 1978.

6. USNRC Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Cask," Rev. 1, March 1989.

7. ANSI N14.6-1993, "American National Standard For Radioactive Materials-Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 Kg) or More," American National Standards Institute, Inc., New York, New York.

8. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Subsection NF, 2004 edition including 2006 *Addenda*.

A.1.4 Appendices

A.1.4.1 NUHOMS®-24PT4 DSC
A.1.4.2 NUHOMS®-32PT DSC
A.1.4.3 NUHOMS®-24PTH DSC
A.1.4.4 NUHOMS®-32PTH DSC
A.1.4.5 NUHOMS®-32PTH1 DSC
A.1.4.6 NUHOMS®-37PTH DSC
A.1.4.7 NUHOMS®-61BT DSC
A.1.4.8 NUHOMS®-61BTH DSC
A.1.4.9 NUHOMS®-69BTH DSC
A.1.4.9A Radioactive Waste Canister
A.1.4.10 Drawings of Transport Packaging, DSCs, *and RWC*.

Table A.1-1
Nominal Dimensions and Weights of the NUHOMS®-MP197HB Packaging

Nominal Dimensions (in.)	
NUHOMS®-MP197HB packaging overall length with impact limiters and thermal shield	271.25
NUHOMS®-MP197HB packaging overall length without impact limiters and thermal shield	210.25
NUHOMS®-MP197HB cask impact limiter outside diameter	126.00
NUHOMS®-MP197HB cask outside diameter (w/o impact limiters and fins)	97.75
NUHOMS®-MP197HB cask outside diameter with fins (w/o impact limiters)	104.25
NUHOMS®-MP197HB cask cavity inner diameter	70.50
NUHOMS®-MP197HB cask cavity length (minimum)	199.25
NUHOMS®-MP197HB cask inner shell radial thickness	1.25
NUHOMS®-MP197HB cask lead gamma shield radial thickness	3.00
NUHOMS®-MP197HB cask body outer shell	2.75
NUHOMS®-MP197HB cask lid thickness	4.50
NUHOMS®-MP197HB cask bottom thickness	6.50
NUHOMS®-MP197HB cask resin and aluminum box thickness	6.25
Nominal Weights (lb x 1000)	
Weight of Contents *(maximum)*	112.0
Empty weight of NUHOMS®-MP197HB Packaging without lid or impact limiters	157.5
Cask lid	6.0
Outer sleeve with fins	3.1
Weight of impact limiters, thermal shield, and attachments	25.0
Total loaded weight of NUHOMS-MP197HB® Packaging (without transport skid)	303.6

Table A.1-2
DSC* Configuration *in the NUHOMS®-MP197HB Package

DSC Type	Sub Type	Bottom Spacer Required	Sleeve Required	Fins Recommended	Detailed Contents Description in Appendix
NUHOMS®-24PT4	–	Yes	Yes	No	A.1.4.1
NUHOMS®-32PT	S-100	Yes	Yes	No	A.1.4.2
	S-125	Yes	Yes	No	
	L-100	Yes	Yes	No	
	L-125	Yes	Yes	No	
NUHOMS®-24PTH	-S	Yes	Yes	No	A.1.4.3
	-L	Yes	Yes	No	
	-S-LC	Yes	Yes	No	
NUHOMS®-32PTH	–	Yes	No	No	A.1.4.4
	Type 1	Yes	No	No	
NUHOMS®-32PTH1	-S	Yes	No	No	A.1.4.5
	-M	Yes	No	No	
	-L	No	No	No	
NUHOMS®-37PTH	-S	Yes	No	No	A.1.4.6
	-M	Yes	No	No	
NUHOMS®-61BT	–	Yes	Yes	No	A.1.4.7
NUHOMS®-61BTH	*Type 1*	Yes	Yes	No	A.1.4.8
	Type 2				
NUHOMS®-69BTH	–	Yes	No	*Optional*(1)	A.1.4.9

(1) For Heat Loads Greater than 26kW

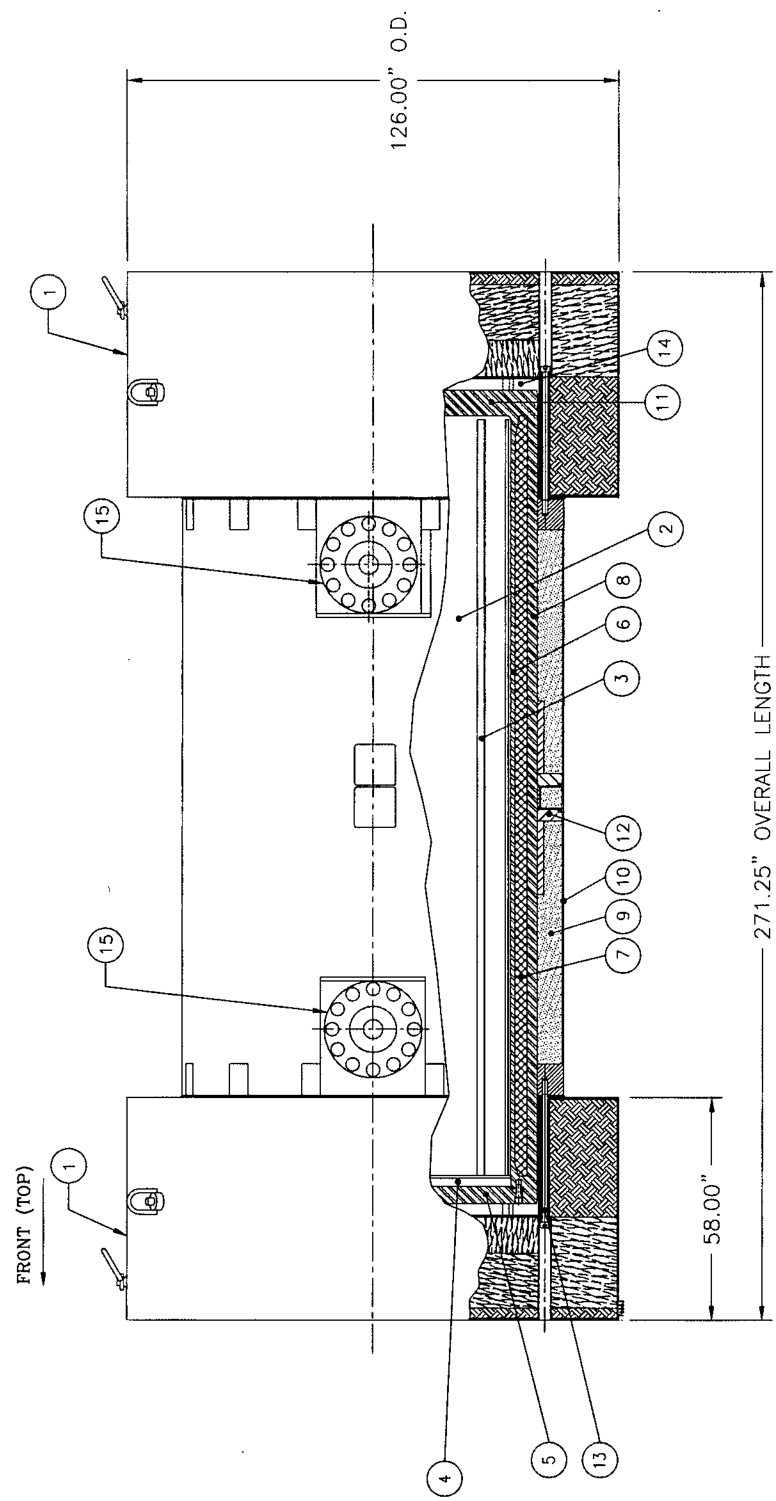


Figure A.1-1
General Arrangement of the NUHOMS®-MP197HB Packaging

Notes to Figure A.1-1

A. Some details exaggerated for clarity.

B. Components are listed below:

1 Impact Limiter
2 *Transport Cask Cavity*
3 *Transport Cask Slide Rail*
4 Hold Down Ring (if required)
5 Transport Cask Lid
6 Transport Cask Inner Shell
7 Transport Cask Gamma (Lead) Shield
8 Transport Cask Outer Shell
9 Transport Cask Neutron (Resin) Shield
10 Transport Cask Shield Shell
11 Transport Cask Bottom
12 Transport Cask Bearing Block
13 Impact Limiter Attachment Bolt
14 Thermal Shield
15 Trunnion

Appendix A.1.4.1
NUHOMS®-24PT4 DSC

TABLE OF CONTENTS

A.1.4.1.1 NUHOMS®-24PT4 DSC Description A.1.4.1-1
A.1.4.1.2 NUHOMS®-24PT4 Fuel Basket A.1.4.1-1
A.1.4.1.3 NUHOMS®-24PT4 DSC Contents A.1.4.1-2
A.1.4.1.4 References A.1.4.1-4

LIST OF TABLES

Table A.1.4.1-1 PWR Fuel Specification of Intact Fuel to be Transported in the 24PT4 DSC A.1.4.1-5
Table A.1.4.1-2 PWR Fuel Specifications of Damaged Fuel to be Transported in the 24PT4 DSC A.1.4.1-6
Table A.1.4.1-3 PWR Fuel Assembly Design Characteristics A.1.4.1-7
Table A.1.4.1-4 Maximum Fuel Enrichment v/s Neutron Poison Requirements for the 24PT4 DSC A.1.4.1-8
Table A.1.4.1-5 PWR Fuel Qualification Table for the 24PT4 DSC A.1.4.1-9
Table A.1.4.1-6 PWR Assembly Decay Heat for Heat Load Configurations A.1.4.1-10

LIST OF FIGURES

Figure A.1.4.1-1 Location of Failed Fuel Cans Inside the 24PT4 DSC A.1.4.1-11
Figure A.1.4.1-2 Heat Load Configuration No. 1 for the 24PT4 DSC A.1.4.1-12
Figure A.1.4.1-3 Heat Load Configuration No. 2 for the 24PT4 DSC A.1.4.1-13
Figure A.1.4.1-4 Heat Load Configuration No. 3 for the 24PT4 DSC A.1.4.1-14

Appendix A.1.4.1
NUHOMS®-24PT4 DSC

NOTE: References in this Appendix are shown as [1], [2], etc. and refer to the reference list in Section A.1.4.1.4.

A.1.4.1.1 NUHOMS®-24PT4 DSC Description

The NUHOMS®-24PT4 DSC consists of a DSC shell assembly and a basket assembly. The shell assembly consists of a cylindrical shell, the inner cover plates of the top and bottom shield plug assemblies and top and bottom outer top cover plates. *The DSC shell assembly is designed, fabricated and inspected in accordance with ASME B&PV Code Subsection NB [1]. Alternatives to the code are provided in Chapter A.2, Appendix A.2.13.13.* The *maximum* length and the outer diameter of the 24PT4 DSC are *approximately* 196.3 inches and 67.*2* inches, respectively. The 24PT4 DSC assembly and details are shown in the drawings in Section A.1.4.10.2 of Appendix A.1.4.10. The shell assembly is a high integrity stainless steel welded pressure vessel that provides confinement of radioactive materials, encapsulates the fuel in an inert atmosphere (the canister is back-filled with helium before being seal welded closed), and provides biological shielding (in the axial direction). The 24PT4 DSC has double redundant seal welds that join the shell and the top and bottom cover plate assemblies to seal the canister. The bottom end assembly welds are made during fabrication of the 24PT4 DSC. The top end closure welds are made after fuel loading. Both top plug penetrations (siphon and vent ports) are redundantly sealed after the 24PT4 DSC drying operations are complete.

The canister is designed to contain the fuel basket and fuel assemblies, and is completely supported by the transport cask. Under normal transport conditions, the canister rests on four canister rails, attached to the inside surface of the aluminum inner sleeve of the transport cask.

A.1.4.1.2 NUHOMS®-24PT4 Fuel Basket

The basket structure is designed, fabricated and inspected in accordance with ASME B&PV Code Subsection NG[1]. Alternatives to the code are provided in Chapter A.2, Appendix A.2.13.13. The details of the 24PT4 fuel basket are shown in the drawings in Section A.1.4.10.2 of Appendix A.1.4.10. The 24PT4 basket is designed to accommodate 24 intact and/or damaged PWR fuel assemblies. The 24PT4 can hold up to 12 damaged fuel assemblies in specially designed Failed Fuel Cans with the balance being loaded with intact fuel. The basket structure consists of circular spacer discs which provide radial support to the guidesleeves and fuel assemblies. Poison plates are placed around the guidesleeves for criticality control.

The guidesleeves are open at each end. Therefore, longitudinal fuel assembly/failed fuel loads are applied directly to the canister/cask body and not the basket structure. The fuel assemblies are laterally supported by the guidetubes/failed fuel can in the circular spacer discs and the canister shell. The guidesleeves are laterally supported by the circular spacer discs and the canister shell. The spacer discs establish and maintain basket orientation. Axial support for the basket assembly is provided by four support rods.

*S*hear key*s*, welded to the inner wall of the 24PT4 DSC, mate with notch*es* in *top and bottom* spacer discs to prevent the basket from rotating during normal operations.

The poison plates are constructed of Boral®, and provide the necessary criticality control.

A.1.4.1.3 NUHOMS®-24PT4 DSC Contents

The spent fuel to be transported in the NUHOMS® 24PT4 DSC consists of intact (including reconstituted) Westinghouse-CENP 16x16 (CE 16x16) and/or damaged CE 16x16 fuel assemblies with Zircaloy or ZIRLO™ cladding and UO_2 or $(U,Er)O_2$ or $(U,Gd)O_2$ fuel pellets. Assemblies are with or without Integral Fuel Burnable Absorber (IFBA) rods or integral burnable poison rods.

Each 24PT4 DSC can accommodate a maximum of 12 damaged fuel assemblies, with the remaining assemblies intact.

Reconstituted assemblies containing up to eight replacement stainless steel rods in place of damaged fuel rods (these rods must displace an amount of water equal to or greater than that displaced by the original fuel rods in the active fuel region of the fuel assembly) or replacement Zircaloy clad uranium rods (any number per assembly) are acceptable for storage in the 24PT4 DSC as either intact or damaged assemblies.

Damaged fuel may include assemblies with known or suspected cladding defects greater than pinhole leaks or hairline cracks or an assembly with partial and/or missing rods (i.e., extra water holes). Damaged fuel assemblies shall be encapsulated in individual Failed Fuel Cans in locations as shown in Figure A.1.4.1-1.

Fuel debris and damaged fuel rods that have been removed from a damaged fuel assembly and placed in a Rod Storage Basket are also considered as damaged fuel. A Rod Storage Basket is a 9x9 array of tubes in a lattice that has approximately the same dimensions as a standard fuel assembly. Rod storage baskets may also include IFBA and integral burnable poison rods. Loose fuel debris not contained in a Rod Storage Basket may also be placed in a Failed Fuel Can provided the size of the debris is larger than the Failed Fuel Can screen mesh opening. Fuel debris may be associated with any type of UO_2 fuel provided that the maximum uranium content and initial enrichment limits are met.

The specifications and design characteristics of intact and/or damaged CE 16x16 fuel assemblies acceptable for storage in the 24PT4 DSC are shown in Table A.1.4.1-1, Table A.1.4.1-2, and Table A.1.4.1-3. The fuel to be transported in the 24PT4 DSC is limited to a maximum initial enrichment of 4.85 wt. % ^{235}U. The maximum allowable assembly average burnup is given as a function of initial fuel enrichment but does not exceed 60,000 MWd/MTU. The minimum cooling time is 7 years.

A 24PT4 DSC containing less than 24 fuel assemblies may contain dummy fuel assemblies in fuel assembly slots, or empty slots. The dummy fuel assemblies are unirradiated, stainless steel encased structures that approximate the weight and center of gravity of a fuel assembly.

The 24PT4 DSC may transport PWR assemblies in any one of the three alternate configurations shown in Figure A.1.4.1-2 through Figure A.1.4.1-4 with a maximum heat load of 1.26 kW per assembly and a maximum heat load of 24 kW per DSC. Table A.1.4.1-5 defines the minimum required cooling time (in years) after reactor discharge based on the fuel assembly burnup and initial fuel enrichment. This table ensures that the fuel assembly contribution to the radiation source term is bounded by that analyzed in Chapter A.5.

As shown in Table A.1.4.1-4, two different 24PT4 DSC basket configurations are utilized. These configurations differ in the boron loading in the Boral® plates. The minimum areal Boron-10 (^{10}B) concentrations for the standard (Type A basket) and high (Type B basket) loadings are 0.025 and 0.068 g/cm^2, respectively. Fuel to be transported in the Type A basket is limited to an initial ^{235}U enrichment of 4.1 wt.%. Fuel to be transported in the Type B basket is limited to an initial ^{235}U enrichment of 4.85 wt.%.

Also shown in Table A.1.4.1-4 are the maximum fuel enrichment versus neutron poison requirements for 24PT4 DSC utilized to transport damaged fuel. These are as follows:

- Up to four damaged fuel assemblies may be transported in a 24PT4 DSC of either ^{10}B loading without impact upon the maximum allowed ^{235}U enrichment and without the use of any poison rodlets. For this configuration, the damaged assemblies are transported in Failed Fuel Cans located at the 45, 135, 225 and 315 degree azimuth locations (Zone A of Figure A.1.4.1-1).
- Five to 12 damaged fuel assemblies may be transported in a 24PT4 DSC of either ^{10}B loading without the use of poison rodlets if the maximum allowed ^{235}U enrichment is reduced for the damaged assemblies. The intact assembly enrichment limits remain at their nominal values of 4.1 and 4.85 wt. % for the standard and high ^{10}B loadings, respectively. Damaged fuel to be transported in the standard ^{10}B loading 24PT4 DSC is limited to an initial ^{235}U enrichment of 3.7 wt. %, and damaged fuel to be transported in the high ^{10}B loading 24PT4 DSC is limited to an initial ^{235}U enrichment of 4.1 wt. %. For this configuration, the damaged assemblies are transported in Failed Fuel Cans located in Zones A and B of Figure A.1.4.1-1.
- Five to 12 damaged fuel assemblies may be transported in a 24PT4 DSC of either ^{10}B loading without impact upon the maximum allowed ^{235}U enrichment if poison rodlets are utilized. For the Type A basket, a single poison rodlet is inserted into the center guide tube of each intact fuel assembly located in Zone C of Figure A.1.4.1-1. For the Type B basket, a poison rodlet is inserted into each of the five guide tubes in each intact fuel assembly located in Zone C of Figure A.1.4.1-1. For this configuration, the damaged assemblies are transported in Failed Fuel Cans located in Zones A and B of Figure A.1.4.1-1.

The poison rodlets consist of B_4C (pellets or powder) encased in a 0.75" nominal OD stainless steel tube with a wall thickness of 0.035". The minimum linear B_4C content is 0.70 g/cm with sufficient length to cover the active fuel length.

Fuel assembly poison rods installed within the guide tubes for criticality control in the spent fuel pool racks may be transported with any intact fuel assembly or damaged fuel assemblies as long as the total assembly weight is less than that specified in Table A.1.4.1-1.

Each poison rodlet may include a lifting mechanism to allow insertion into the selected fuel assembly guide tube.

A.1.4.1.4 References

1. American Society of Mechanical Engineers, ASME Boiler And Pressure Vessel Code, Section III, Division 1 - Subsections NB, NG and NF, 1992 with Addenda through 1994 with Code Cases N-499-1.

Table A.1.4.1-1
PWR Fuel Specification of Intact Fuel to be Transported in the 24PT4 DSC

Fuel Design:	Intact CE 16x16 PWR fuel assembly or equivalent reload fuel that is enveloped by the fuel assembly design characteristics as listed in Table A.1.4.1-3 and the following requirements:
Fuel Damage:	Fuel with known or suspected cladding damage in excess of pinhole leaks or hairline cracks or an assembly with partial and/or missing rods is not authorized to be transported as "intact PWR Fuel."
Physical Parameters[1]	
Unirradiated Length (in)	176.8
Cross Section (in)	8.290
Assembly Weight (lbs)	1500[2] [3]
Max. U Content (kg)	455.5
No. of Assemblies per DSC	≤ 24 intact assemblies
Fuel Cladding	Zircaloy-4 or ZIRLO™
Reconstituted Fuel Assemblies	Damaged fuel rods replaced by either stainless rods (up to 8 rods per assembly) or Zircaloy clad uranium rods (any number of rods per assembly).
Nuclear and Radiological Parameters	
Maximum Initial ^{235}U Enrichment (wt %)	Per Table A.1.4.1-4 and Figure A.1.4.1-1
Fuel Assembly Average Burnup and Minimum Cooling Time[4]	Per Table A.1.4.1-5 and decay heat restrictions below
Decay Heat[4]	Per Figures A.1.4.1-2, A.1.4.1-3 or A.1.4.1-4

Notes:

(1) Nominal values shown unless stated otherwise.
(2) Does not include weight of Poison Rodlets (25 lbs each) installed in accordance with Table A.1.4.1-4.
(3) Includes the weight of fuel assembly Poison Rods installed for 10CFR50 criticality control in spent fuel pool racks.
(4) Minimum cooling time is the longer of that given in Table A.1.4.1-5 for a given burnup and enrichment of a fuel assembly and that calculated via the decay heat equation based on the restrictions provided in Figures A.1.4.1-2, A.1.4.1-3 or A.1.4.1-4.

Table A.1.4.1-2
PWR Fuel Specifications of Damaged Fuel to be Transported in the 24PT4 DSC

Fuel Design	Damaged CE 16x16 PWR fuel assembly or equivalent reload fuel that is enveloped by the fuel assembly design characteristics as listed in Table A.1.4.1-3 and the following requirements:
Fuel Damage	Damaged fuel may include assemblies with known or suspected cladding defects greater than pinhole leaks or hairline cracks or an assembly with partial and/or missing rods (i.e., extra water holes). Damaged fuel assemblies shall be encapsulated in individual Failed Fuel Cans and placed in Zones A and/or B as shown in Figure A.1.4.1-1. Fuel debris and damaged fuel rods that have been removed from a damaged fuel assembly and placed in a Rod Storage Basket are also considered as damaged fuel. Loose fuel debris, not contained in a Rod Storage Basket may also be placed in a Failed Fuel Can for storage, provided the size of the debris is larger than the Failed Fuel Can screen mesh opening. Fuel debris may be associated with any type of UO_2 fuel provided that the maximum uranium content and initial enrichment limits are met.
Physical Parameters[1]	
Unirradiated Length (in)	176.8
Cross Section (in)	8.290
Assembly Weight (lbs)	1500[2] [3]
Max. U Content (kg)	455.5
No. of Assemblies per DSC	≤ 12 damaged assemblies, balance intact.
Fuel Cladding	Zircaloy-4 or ZIRLO™
Reconstituted Fuel Assemblies	Damaged fuel rods replaced by either stainless rods (up to 8 rods per assembly) or Zircaloy clad uranium rods (any number of rods per assembly).
Nuclear and Radiological Parameters	
Maximum Initial ^{235}U Enrichment (wt %)	Per Table A.1.4.1-4 and Figure A.1.4.1-1
Fuel Assembly Average Burnup and Minimum Cooling Time[4] [5]	Per Table A.1.4.1-5 and decay heat restrictions below
Decay Heat[4]	Per Figures A.1.4.1-2, A.1.4.1-3 or A.1.4.1-4

Notes:
(1) Nominal values shown unless stated otherwise.
(2) Does not include weight of Poison Rodlets (25 lbs each) installed in accordance with Table A.1.4.1-4.
(3) Includes the weight of fuel assembly Poison Rods installed for 10CFR50 criticality control in spent fuel pool racks.
(4) Minimum cooling time is the longer of that given in Table A.1.4.1-5 for a given burnup and enrichment of a fuel assembly and that calculated via the decay heat equation based on the restrictions provided in Figures A.1.4.1-2, A.1.4.1-3 or A.1.4.1-4.
(5) An additional cooling time of 8 years is required for damaged fuel assemblies in addition to that obtained from Table A.1.4.1-5, when 5 or more damaged fuel assemblies are loaded.

Table A.1.4.1-3
PWR Fuel Assembly Design Characteristics

Assembly Class	CE 16x16
Parameters[1]	
Assembly Length	See Table A.1.4.1-1or A.1.4.1-2
Max. Initial ^{235}U Enrichment (wt%)	4.85
Fissile Material	UO_2, or (U, Er)O_2, or (U, Gd)O_2
Number of Rods	236
Fuel Rod Pitch (in)	0.506
Fuel Rod O.D. (in)	0.382
Clad Thickness (in)	0.025
Nominal Pellet O.D., (in)	0.3255[2]
Number of Guide/Instrument Tubes	5

Notes:

(1) Nominal values shown unless stated otherwise.

(2) Bounds pellets with a nominal OD of 0.325".

Table A.1.4.1-4
Maximum Fuel Enrichment v/s Neutron Poison Requirements for the 24PT4 DSC

Storage Configuration	Maximum No. of Damaged Fuel Assemblies[(1)]	Maximum ^{235}U Fuel Enrichment (wt %)	DSC Basket, Minimum BORAL® Areal Density (gm/cm^2)	Minimum No. of Poison Rodlets Required[(2)]
All Intact Fuel Assemblies	0	4.1	.025 (Type A Basket)	0
	0	4.85	.068 (Type B Basket)	0
Combination of Damaged and Intact Fuel Assemblies	4	4.1	.025 (Type A Basket)	0
	4	4.85	.068 (Type B Basket)	0
	12	3.7 (damaged) 4.1 (intact)	.025 (Type A Basket)	0
	12	4.1 (damaged) 4.85 (intact)	.068 (Type B Basket)	0
	12	4.1	.025 (Type A Basket)	1[(2)] (Located in center guide tube of each intact assembly)
	12	4.85	.068 (Type B Basket)	5[(2)] (Located in all five guide tubes of each intact assembly)

Notes:

(1) See Figure A.1.4.1-1 for location of damaged fuel assemblies within the 24PT4 DSC (Zones A and/or B only).

(2) Poison rodlets are only required for a specific DSC configuration with a payload of 5-12 damaged assemblies in combination with maximum fuel enrichment levels as shown. The poison rodlets are to be located within the guide tubes of the Zone C intact assemblies as shown in Figure A.1.4.1-1.

Table A.1.4.1-5
PWR Fuel Qualification Table for the 24PT4 DSC
(Minimum required years of cooling time after reactor core discharge)

BU (GWd/ MTU)	Initial Enrichment																														
	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8
10	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
15	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
20	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
25	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
28	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
30	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
32	7.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
34	8.5	8.5	8.0	7.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
36	10.5	10.0	9.5	9.0	8.5	8.0	7.5	7.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
38											7.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
39											8.0	7.5	7.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
40											8.5	8.5	8.0	7.5	7.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
41											9.5	9.0	8.5	8.0	8.0	7.5	7.5	7.5	7.5	7.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
42											10.0	9.5	9.0	9.0	8.5	8.0	8.0	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.0
43																8.5	8.5	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.5	7.5	7.5	7.5
44																9.5	9.0	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.0	8.0	8.0	8.0	8.0
45																					9.0	9.0	9.0	9.0	9.0	9.0	8.5	8.5	8.5	8.5	8.5
48																					11.0	11.0	11.0	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
51																					13.0	13.0	13.0	13.0	13.0	13.0	13.0	12.5	12.5	12.5	12.5
54																					16.0	15.0	14.5	14.0	13.5	13.0	13.0	12.5	12.5	12.5	12.5
57																					19.0	18.5	18.0	17.0	16.5	16.0	15.5	15.0	14.5	14.0	13.5
60																					23.0	22.0	21.5	20.5	20.0	19.5	18.5	18.0	17.5	17.0	16.5

Notes:

- BU = Assembly average burnup.
- Use burnup and enrichment to lookup minimum cooling time in years. Licensee is responsible for ensuring that uncertainties in fuel enrichment and burnup conservatively applied in determination of actual values for these two parameters.
- For reconstituted fuel assemblies with irradiated stainless steel rods, increase the cooling time by 1 year for fuel assemblies in the 12 peripheral locations of the canister with cooling times less than 10 years. For fuel assemblies with cooling times greater than 10 years or in the center of the basket, no adjustment is required.
- Round burnup UP to next higher entry, round enrichments DOWN to next lower entry.
- Fuel with an initial enrichment either less than 1.8 or greater than 4.85 wt.% U-235 is unacceptable for transport.
- Fuel with a burnup greater than 60 GWd/MTU is unacceptable for transport.
- Fuel with a burnup less than 10 GWd/MTU is acceptable for transport after 7-years cooling.
- Example: An assembly with an initial enrichment of 4.85 wt. % U-235 and a burnup of 41.5 GWd/MTU is acceptable for transport after a 7.0-year cooling time as defined by 4.8 wt. % U-235 (rounding down) and 42 GWd/MTU (rounding up) on the qualification table (other considerations not withstanding).
- *When loading five or more damaged fuel assemblies per DSC, an additional cooling time of 8 years is required for only damaged fuel assemblies.*

Table A.1.4.1-6
PWR Assembly Decay Heat for Heat Load Configurations

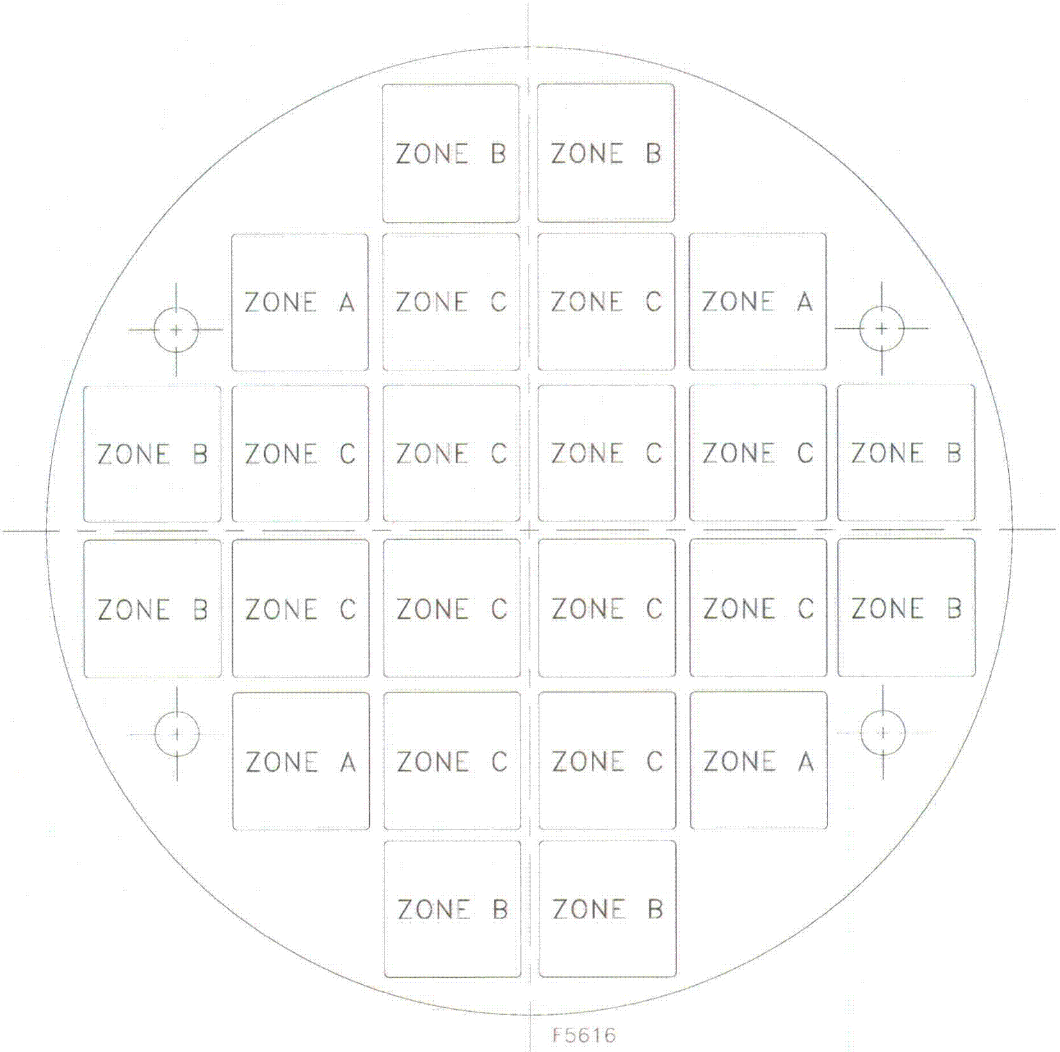
The Decay Heat (DH) in watts is expressed as:

$$F1 = -44.8 + 41.6*X1 - 37.1*X2 + 0.611*X1^2 - 6.80*X1*X2 + 24.0*X2^2$$
$$DH = F1*Exp(\{[1-(1.8/X3)]* -0.575\}*[(X3-4.5)^{0.169}]*[(X2/X1)^{-0.147}]) + 20$$

where,

F1 Intermediate Function
X1 Assembly Burnup in GWD/MTU
X2 Initial Enrichment in wt. % U-235
X3 Cooling Time in Years (minimum 7 years)

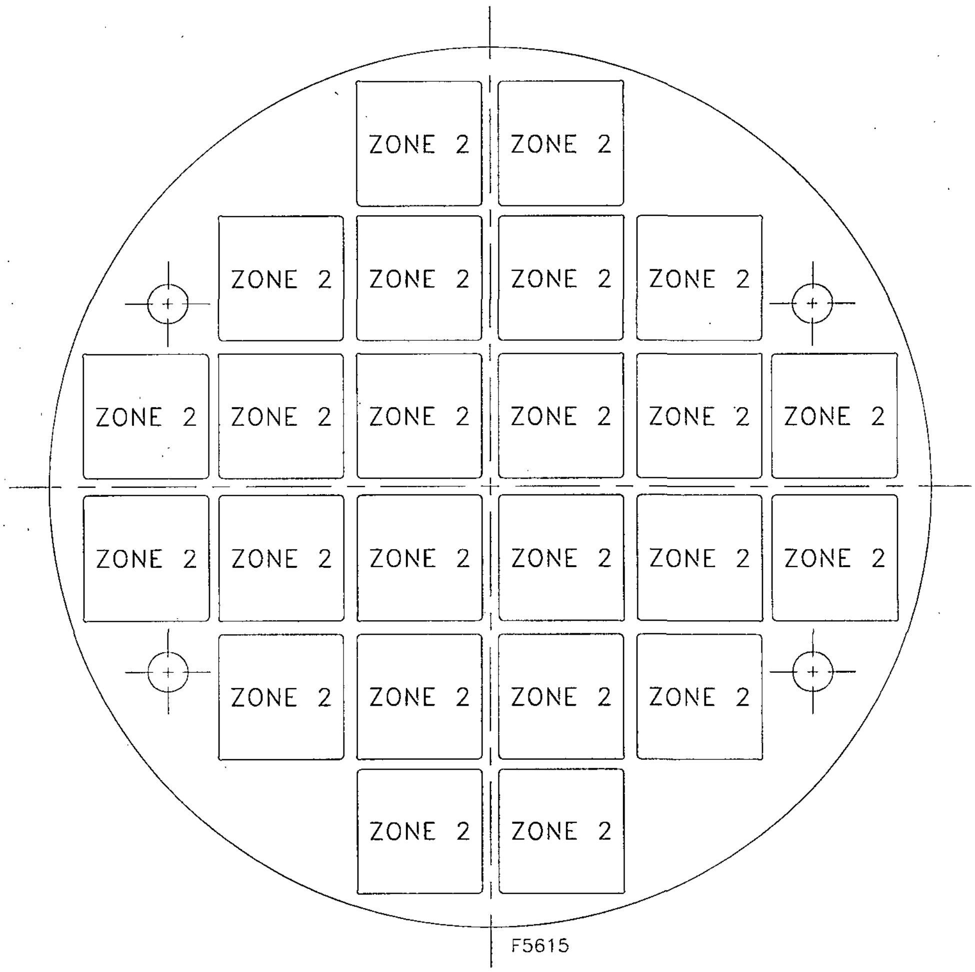
Note: Even though a minimum cooling time of 7 years is used, the minimum cooling time requirement with five or more damaged fuel assemblies from shielding requirements is per Table A.1.4.1-5.



Notes:

1. Locations identified as Zone A are for placement of up to 4 damaged fuel assemblies.
2. Locations identified as Zone B are for placement of up to 8 additional damaged fuel assemblies (Maximum of 12 damaged fuel assemblies allowed, Zones A and B combined).
3. Locations identified as Zone C are for placement of up to 12 intact fuel assemblies, including 4 empty slots in the center as shown in Figure A.1.4.1-4.
4. Poison Rodlets are to be located in the guide tubes of intact fuel assemblies placed in Zone C only per Table A.1.4.1-4.

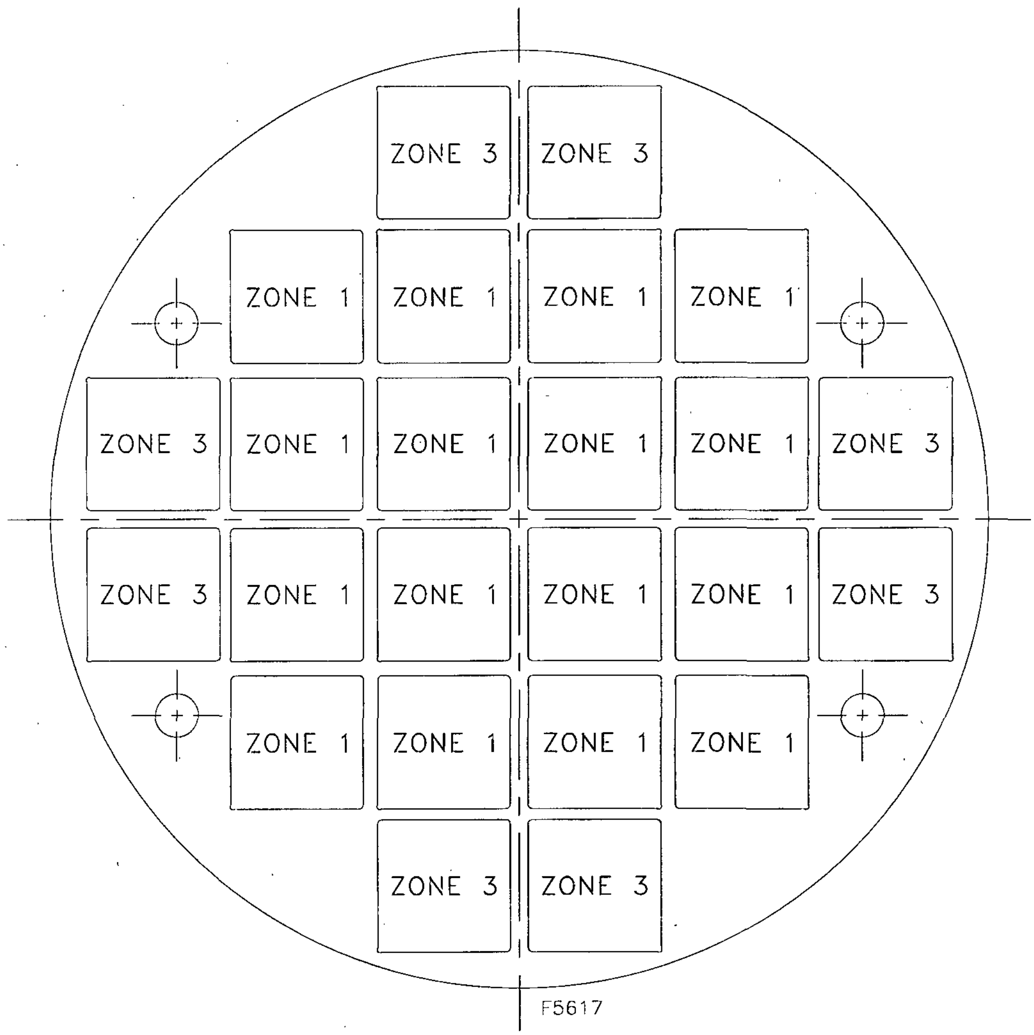
Figure A.1.4.1-1
Location of Failed Fuel Cans Inside the 24PT4 DSC



	Zone 1	Zone 2	Zone 3	Zone 4
Maximum Decay Heat (kWatts / FA)(1)	NA	1.0	NA	NA
Maximum Decay Heat per Zone (kW)	NA	24.0	NA	NA
Maximum Decay Heat per DSC (kW)	24.0			

(1) Decay heat per fuel assembly shall be determined using Table A.1.4.1-6.

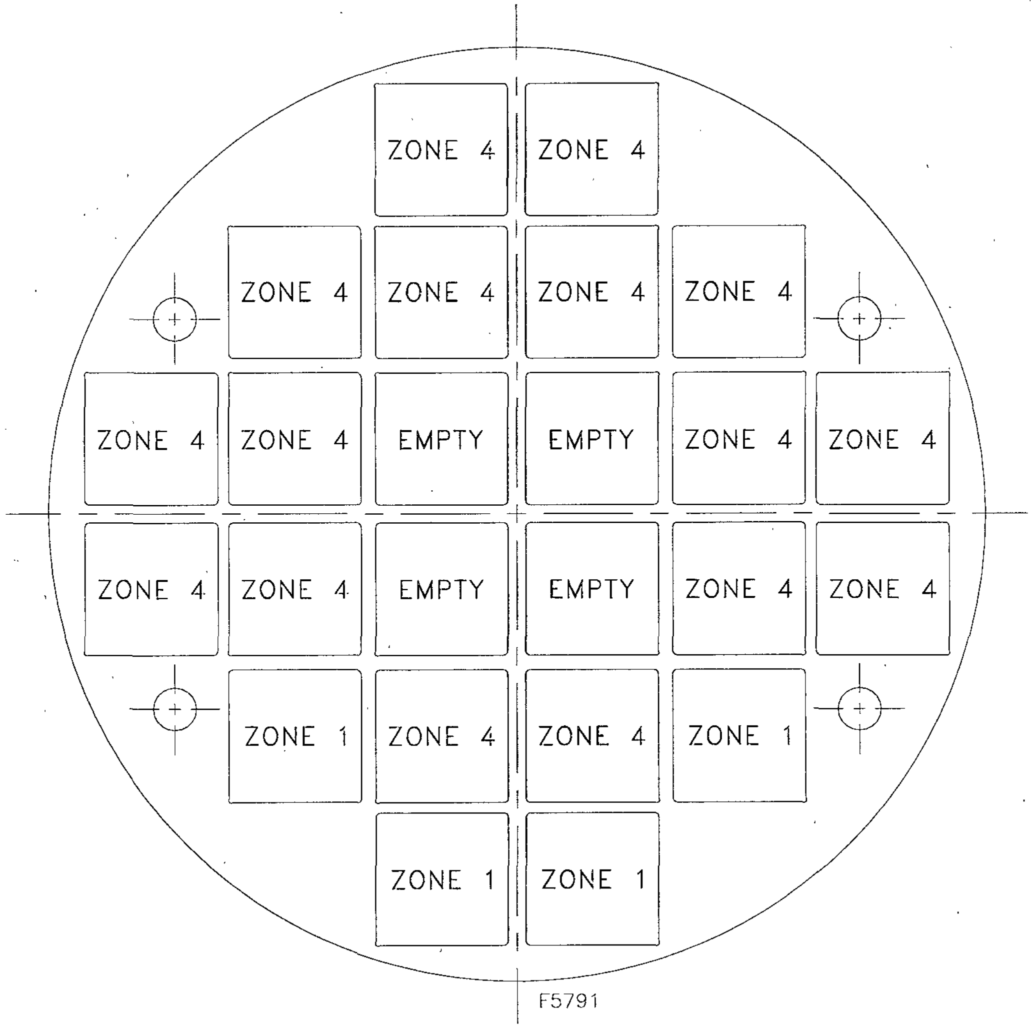
Figure A.1.4.1-2
Heat Load Configuration No. 1 for the 24PT4 DSC



	Zone 1	Zone 2	Zone 3	Zone 4
Maximum Decay Heat (kWatts / FA)(1)	0.9	NA	1.2	NA
Maximum Decay Heat per Zone (kW)	14.4	NA	9.6	NA
Maximum Decay Heat per DSC (kW)	24.0			

(1) Decay heat per fuel assembly shall be determined using Table A.1.4.1-6.

Figure A.1.4.1-3
Heat Load Configuration No. 2 for the 24PT4 DSC



	Zone 1	Zone 2	Zone 3	Zone 4
Maximum Decay Heat (kWatts / FA)(1)	0.9	NA	NA	1.26
Maximum Decay Heat per Zone (kW)	3.6	NA	NA	20.16
Maximum Decay Heat per DSC (kW)	24.0			

(1) Decay Heat per fuel assembly shall be determined using Table A.1.4.1-6.

Figure A.1.4.1-4
Heat Load Configuration No. 3 for the 24PT4 DSC

Appendix A.1.4.2
NUHOMS®-32PT DSC

TABLE OF CONTENTS

A.1.4.2.1 NUHOMS®-32PT DSC Description A.1.4.2-1
A.1.4.2.2 NUHOMS®-32PT Fuel Basket A.1.4.2-1
A.1.4.2.3 NUHOMS®-32PT DSC Contents A.1.4.2-2
A.1.4.2.4 References A.1.4.2-2

LIST OF TABLES

Table A.1.4.2-1 Nominal Dimensions and Weight of the NUHOMS®-32PT DSC A.1.4.2-3
Table A.1.4.2-2 Intact PWR Fuel Assembly Characteristics A.1.4.2-4
Table A.1.4.2-3 PWR Fuel Assembly Design Characteristics A.1.4.2-5
Table A.1.4.2-4 Thermal and Radiological Characteristics for Control Components Transported in the NUHOMS®-32PT DSCs A.1.4.2-6
Table A.1.4.2-5 Poison Rod Assembly (PRA) Description A.1.4.2-7
Table A.1.4.2-6 PWR Fuel Qualification Table for NUHOMS®-32PT DSC A.1.4.2-8
Table A.1.4.2-7 Acceptable Average Initial Enrichment / Minimum Burnup Combinations – NUHOMS®-32PT A.1.4.2-9
Table A.1.4.2-8 PWR Assembly Decay Heat for Heat Load Configurations A.1.4.2-12

LIST OF FIGURES

Figure A.1.4.2-1 Poison Rod Assemblies (PRAs) A.1.4.2-13
Figure A.1.4.2-2 Heat Load Configuration No. 1 for 32PT DSC A.1.4.2-14
Figure A.1.4.2-3 Heat Load Configuration No. 2 for 32PT DSC A.1.4.2-15
Figure A.1.4.2-4 Heat Load Configuration No. 3 for 32PT DSC A.1.4.2-16

Appendix A.1.4.2
NUHOMS®-32PT DSC

NOTE: References in this Appendix are shown as [1], [2], etc. and refer to the reference list in Section A.1.4.2.4.

A.1.4.2.1 NUHOMS®-32PT DSC Description

Each NUHOMS®-32PT DSC consists of a DSC shell assembly and a basket assembly. The shell assembly consists of a cylindrical shell, the inner cover plates of the top and bottom shield plug assemblies and outer top cover plate. *The DSC shell assembly is designed, fabricated and inspected in accordance with ASME B&PV Code Subsection NB [1]. Alternatives to the code are provided in Chapter A.2, Appendix A.2.13.13.* As shown in Table A.1.4.2-1, the 32PT DSC system consists of four design configurations or Types as follows:

- 32PT-S100, Short Canister
- 32PT-L100, Long Canister
- 32PT-S125, Short Canister
- 32PT-L125, Long Canister

Table A.1.4.2-1 provides the overall lengths and outer diameters for each 32PT DSC configuration. The shell assemblies are high integrity stainless steel welded pressure vessels that provide confinement of radioactive materials, encapsulate the fuel in an inert atmosphere (the canister is back-filled with helium before being seal welded closed), and provide biological shielding (in axial direction). The 32PT DSCs have double redundant seal welds that join the shell and the top and bottom cover plate assemblies to seal the canister. The bottom end assembly welds are made during fabrication of the 32PT DSCs. The top end closure welds are made after fuel loading. Both top plug penetrations (siphon and vent ports) are redundantly sealed after the 32PT DSC drying operations are complete.

The canister is designed to contain its fuel basket and fuel assemblies, and is completely supported by the transport cask. Under normal transport conditions, the canister rests on four canister rails, attached to the inside surface of the aluminum inner sleeve of the transport cask.

A.1.4.2.2 NUHOMS®-32PT Fuel Basket

The basket structures are designed, fabricated and inspected in accordance with ASME B&PV Code Subsection NG[1]. Alternatives to the code are provided in Chapter A.2, Appendix A.2.13.13. The overall lengths and diameters of the baskets for each canister configuration are provided in Table A.1.4.2-1. The details of the 32PT fuel baskets are shown in the drawings in Section A.1.4.10.3 of Appendix A.1.4.10. The 32PT baskets are designed to accommodate 32 intact PWR fuel assemblies with or without Control Components (CCs). The basket structure consists of a grid assembly of welded stainless steel plates or tubes that accommodate aluminum and/or poison plates and *surrounded by* support rails.

The basket structure is open at each end. Therefore, longitudinal fuel assembly loads are applied directly to the canister/cask body and not the fuel basket structure. The fuel assemblies are laterally supported by the stainless steel grid/tube assembly. The basket is laterally supported by the basket rails and the canister shell. The aluminum basket rails are oriented parallel to the axis of the canister, and are attached to the periphery of the basket to provide support, and to establish and maintain basket orientation.

A shear key, welded to the inner wall of the DSC, mates with a notch in one of the basket support rails to prevent the basket from rotating during normal operations.

Each fuel compartment accommodates aluminum and/or neutron absorbing poison plates. Three different arrangements are possible, based on the number and orientation of the poison plates within the DSC. These are described as the 16, 20, or 24 poison plate (PP) configurations. The poison plates are constructed from borated aluminum, or an aluminum/B4C metal matrix composite, and provide a heat conduction path from the fuel assemblies to the canister wall, as well as criticality control.

A.1.4.2.3 NUHOMS®-32PT DSC Contents

Each of the NUHOMS®-32PT DSC configurations is designed to transport 32 intact standard PWR fuel assemblies with or without CCs with the characteristics described in Table A.1.4.2-2. The CCs include Burnable Poison Rod Assemblies (BPRAs), Thimble Plug Assemblies (TPAs), Control Rod Assemblies (CRAs), Rod Cluster Control Assemblies (RCCAs), Axial Power Shaping Rod Assemblies (APSRAs), Orifice Rod Assemblies (ORAs), Vibration Suppression Inserts (VSIs), Neutron Source Assemblies (NSAs), and Neutron Sources.

The NUHOMS®-32PT DSC may transport PWR fuel assemblies arranged in any of three alternate heat zoning configurations with a maximum decay heat of 1.2 kW per assembly and a maximum heat load of 24 kW per canister. The heat load zoning configurations are shown in Figures A.1.4.2-2 through A.1.4.2-4. The NUHOMS®-32PT DSC is inerted and backfilled with helium at the time of loading.

The maximum fuel assembly weight with a CC is 1682 lbs.

All four NUHOMS®-32PT DSC design configurations have the same minimum boron content for the poison neutron plates. The minimum boron-10 content for the poison plates is 0.0070 g/cm^2. A basket may contain 0, 4, 8, or 16 Poison Rod Assemblies (PRAs) and is designated a Type A, Type B, Type C or Type D basket, respectively. The required Boron 10 content per rod of PRA and minimum number of PRAs for a given fuel assembly type are described in Table A.1.4.2-5. Figure A.1.4.2-1 shows typical dimensions of a PRA.

Reconstituted fuel assemblies with up to 56 solid stainless steel rods or an unlimited number of lower enrichment UO_2 rods that replace fuel rods are acceptable for the 32PT DSC payload. CE 15x15 fuel assemblies with plugging clusters are also acceptable.

A.1.4.2.4 References

1. American Society of Mechanical Engineers, ASME Boiler And Pressure Vessel Code, Section III, Division 1 - Subsections NB, NG and NF, 1998 edition including 2000 Addenda.

Table A.1.4.2-1
Nominal Dimensions and Weight of the NUHOMS®-32PT DSC

	32PT DSC Design Configuration			
	32PT-S100	**32PT-S125**	**32PT-L100**	**32PT-L125**
Canister Length (in.)	186.*55* *maximum*	186.*55* *maximum*	192.*55* *maximum*	192.*55* *maximum*
Outside Diameter (in.)	67.25	67.25	67.25	67.25
Cavity Length (in.)	169.6	167.1	175.6	173.1
Cavity Diameter (in.)	*66.19*	*66.19*	*66.19*	*66.19*
Basket Length (in.)	168.*6*	166.*1*	174.*6*	172.*1*
Basket Diameter (in.)	65.94	65.94	65.94	65.94

Table A.1.4.2-2
Intact PWR Fuel Assembly Characteristics

PHYSICAL PARAMETERS:	
Fuel Class	Only intact (including reconstituted) B&W 15x15, WE 17x17, CE 15x15, WE 15x15, CE 14x14 and WE 14x14 class PWR assemblies or equivalent reload fuel manufactured by same or other vendors that are enveloped by the fuel assembly design characteristics listed in Table A.1.4.2-3
Reconstituted Fuel Assemblies	≤ 32 assemblies per DSC with up to 56 stainless steel rods per assembly or unlimited number of lower enrichment UO_2 rods per assembly.
Fuel Cladding Material	Zircaloy
Fuel Damage	Cladding damage in excess of pinhole leaks or hairline cracks is not authorized to be transported as "Intact PWR Fuel."
Control Components (CCs)	• Up to 32 CCs are authorized for storage in 32PT DSC. • Authorized CCs include Burnable Poison Rod Assemblies (BPRAs), Thimble Plug Assemblies, (TPAs), Control Rod Assemblies (CRAs), Rod Cluster Control Assemblies (RCCAs), Axial Power Shaping Rod Assemblies (APSRAs), Orifice Rod Assemblies (ORAs), Vibration Suppression Inserts (VSIs), Neutron Source Assemblies (NSAs), and Neutron Sources. • Design basis thermal and radiological characteristics for the CCs are listed in Table A.1.4.2-4.
Maximum Assembly plus CC Weight	-1365 lbs for 32PT-S100 & 32PT-L100 DSC System -1682 lbs for 32PT-S125 & 32PT-L125 DSC System
CC Damage	CCs with cladding failures are acceptable for loading.
THERMAL/RADIOLOGICAL PARAMETERS:	
Fuel Assembly Average Burnup and Minimum Cooling Time, with or without CCs[(1)]	Per Table A.1.4.2-6; Table A.1.4.2-7 and decay heat and burnup credit restrictions below.
Decay Heat[(1)]	Per Figures A.1.4.2-2, A.1.4.2-3, or A.1.4.2-4
Burnup Credit and Criticality Restrictions	Table A.1.4.2-7 *The maximum cooling time shall not exceed 160 years.*

Notes:
[(1)] Minimum cooling time is the longer of that given in Table A.1.4.2-6, that calculated via the decay heat equation given in Table A.1.4.2-8 based on the restrictions provided in Figures A.1.4.2-2, A.1.4.2-3, or A.1.4.2-4, and Table A.1.4.2-7.

Table A.1.4.2-3
PWR Fuel Assembly Design Characteristics

Assembly Class	B&W 15x15	WE 17x17	CE 15x15(3), (4)	WE 15x15	CE 14x14	WE 14x14
DSC Configuration	**Max Unirradiated Length (in)**					
32PT-S100/32PT-S125	165.75(1)	165.75(1)	165.75	165.75(1)	165.75(1)	165.75(1)
32PT-L100/32PT-L125	171.71(1)	171.71(1)	171.71	171.71(1)	171.71(1)	171.71(1)
Fissile Material	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2
Maximum MTU/assembly(2)	0.475	0.475	0.475	0.475	0.475	0.475
Maximum Number of Fuel Rods	208	264	216	204	176	179
Maximum Number of Guide/ Instrument Tubes	17	25	9	21	5	17

(1) Maximum Assembly + CC Length (unirradiated)
(2) The maximum MTU/assembly is based on the shielding analysis. The listed value is higher than the actual.
(3) CE 15x15 assemblies with stainless steel plugging clusters installed are acceptable.
(4) Control Components are not authorized for transport with CE 15x15 class assemblies.

Table A.1.4.2-4
Thermal and Radiological Characteristics for Control Components Transported in the NUHOMS®-32PT DSCs

Parameter	BPRAs, NSAs, CRAs, RCCAs, VSIs, Neutron Sources, and APSRAs	TPAs and ORAs
Maximum Gamma Source (γ/sec/assembly)	3.89E+13	4.19E+12
Decay Heat (Watts/assembly)	8.0	8.0

Table A.1.4.2-5
Poison Rod Assembly (PRA) Description

Assembly Class	Minimum Number of Rods/PRA	Modeled B_4C Content per Rod (g/cm) (75% Credit)	Minimum B_4C Content per Rod (g/cm)
WE 17x17	24	0.59	0.79
B&W 15x15	16	0.72	0.96
WE 15x15	20	0.72	0.96
CE 14x14	5	3.14	4.19
WE 14x14	16	0.72	0.96

Table A.1.4.2-6
PWR Fuel Qualification Table for NUHOMS®-32PT DSC
(Minimum required years of cooling time after reactor core discharge)

BU GWD/ MTU	Assembly Average Initial U-235 Enrichment, wt %																																			
	1.1	1.2	1.4	1.6	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0
10	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
15	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
20	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
25	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
28	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
30	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
32	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
34	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
36	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
38	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
39	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
40	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
41	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
42	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
43	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
44	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
45	11.5	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0

Notes:

- BU = Assembly average burnup.
- Use burnup and enrichment to lookup minimum cooling time in years. Licensee is responsible for ensuring that uncertainties in fuel enrichment and burnup conservatively applied in determination of actual values for these two parameters.
- For reconstituted fuel assemblies with irradiated stainless steel rods, increase the cooling time by 1 year for fuel assemblies in the 16 peripheral locations of the canister with cooling times less than 10 years. No adjustment of cooling time is required for fuel assemblies in other locations or for those that have cooled for more than 10 years.
- Round burnup UP to next higher entry, round enrichments DOWN to next lower entry.
- Fuel with an initial enrichment either less than *1.1* or greater *than* 5.0 wt.% U-235 is unacceptable for Transport.
- Fuel with a burnup greater than 45 GWd/MTU is unacceptable for transport.
- Fuel with a burnup less than 10 GWd/MTU is acceptable for transport after 10-years cooling.
- Example: An assembly with an initial enrichment of 4.85 wt. % U-235 and a burnup of 41.5 GWd/MTU is acceptable for transport after a 10-year year cooling time as defined by 4.8 wt. % U-235 (rounding down) and 42 GWd/MTU (rounding up) on the qualification table (other considerations not withstanding).
- Even though cooling times less than 15 years are shown in this table, the minimum cooling time requirement for criticality from Table A.1.4.2.7 for transportation is 15 years.

Table A.1.4.2-7
Acceptable Average Initial Enrichment / Minimum Burnup Combinations - NUHOMS®-32PT
Part 1 of 2

	WE 17x17, WE 15x15, B&W 15x15, CE 14x14 and CE 15x15 Assembly Classes					
Enrichment (wt. % U-235)	*16 PP NO PRA 20PP NO PRA*	*24 PP NO PRA*	*20 PP 04 PRA*	*24 PP 04 PRA*	*24 PP 08 PRA 20 PP 08 PRA*	*24 PP 16 PRA 20 PP 16 PRA*
1.30	*fresh*	-	-	-	-	-
1.40	-	*fresh*	*fresh*	-	-	-
1.55	-	-	-	*fresh*	-	-
1.65	-	-	-	-	*fresh*	-
	Burnup (GWD/MTU) 40 Years Decay		*Burnup (GWD/MTU) 30 Years Decay*			*Burnup (GWD/MTU) 15 Years Decay*
2.00	*20*	*19*	*18*	*18*	*11*	*fresh*
2.25	*25*	*23*	*19*	*19*	*17*	*8*
2.50	*30*	*27*	*23*	*22*	*19*	*12*
2.75	*32*	*31*	*27*	*26*	*21*	*16*
3.00	*36*	*34*	*31*	*30*	*24*	*19*
3.25	*39*	*38*	*33*	*33*	*29*	*20*
3.50	*41*	*39*	*37*	*36*	*31*	*22*
3.75	*44*	*42*	*39*	*39*	*33*	*26*
4.00	-	*45*	*42*	*41*	*37*	*29*
4.20	-	-	*44*	*43*	*39*	*31*
4.40	-	-	-	-	*40*	*32*
4.60	-	-	-	-	*42*	*34*
4.80	-	-	-	-	*44*	*37*
5.00	-	-	-	-	*45*	*39*

Table A.1.4.2-7
Acceptable Average Initial Enrichment / Minimum Burnup Combinations - NUHOMS®-32PT

Part 2 of 2

	WE 14x14 Assembly Class				
Enrichment (wt. % U-235)	*16 PP NO PRA*	*24 PP NO PRA*	*20 PP NO PRA*	*20 PP 04 PRA 20 PP 08 PRA 24 PP 04 PRA 24 PP 08 PRA*	*20 PP 16 PRA 24 PP 16 PRA (see note)*
1.50	*fresh*	-	*fresh*	-	-
1.60	-	*fresh*	-	-	-
1.75	-	-	-	*fresh*	-
	Burnup GWD/MTU), 40 Years Decay			*Burnup (GWD/MTU), 15 Years Decay*	
2.00	*18*	*14*	*19*	*9*	*fresh*
2.25	*19*	*19*	*20*	*16*	*8*
2.50	*21*	*20*	*24*	*19*	*12*
2.75	*26*	*23*	*29*	*20*	*16*
3.00	*30*	*28*	*31*	*25*	*19*
3.25	*32*	*31*	*34*	*29*	*20*
3.50	*35*	*32*	*38*	*31*	*22*
3.75	*38*	*36*	*39*	*34*	*26*
4.00	*40*	*39*	*42*	*38*	*29*
4.20	*42*	*40*	*45*	*39*	*31*
4.40	*45*	*42*	-	*41*	*32*
4.60	-	*45*	-	*43*	*34*
4.80	-	-	-	*45*	*37*
5.00	-	-	-	-	*39*

Notes:

- *Use burnup and enrichment to lookup minimum cooling time in years. Licensee is responsible for ensuring that uncertainties in fuel enrichment and burnup are conservatively applied in determination of actual values for these parameters (uncertainty in enrichment to be added and uncertainty in burnup to be subtracted)*
- *Interpolation can be performed to determine the burnup for enrichment values (between 2.00 wt. % U-235 and 5.00 wt. % U-235) that are not explicitly shown herein. Alternatively, the burnup value corresponding to the next higher enrichment may be utilized.*
- *Extrapolation shall not be performed to determine burnup requirements.*
- *The burnup of the "fresh" assemblies is 0. For a given configuration, the enrichment corresponding to "fresh" in this Table is the maximum enrichment above which a burnup value is needed for fuel assemblies to qualify for transportation.*
- *An additional burnup of 3 GWD/MTU is required for loading fuel assemblies with control rod insertion deeper than 20 cm inside the active fuel during depletion.*

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Table A.1.4.2-8
PWR Assembly Decay Heat for Heat Load Configurations[1]

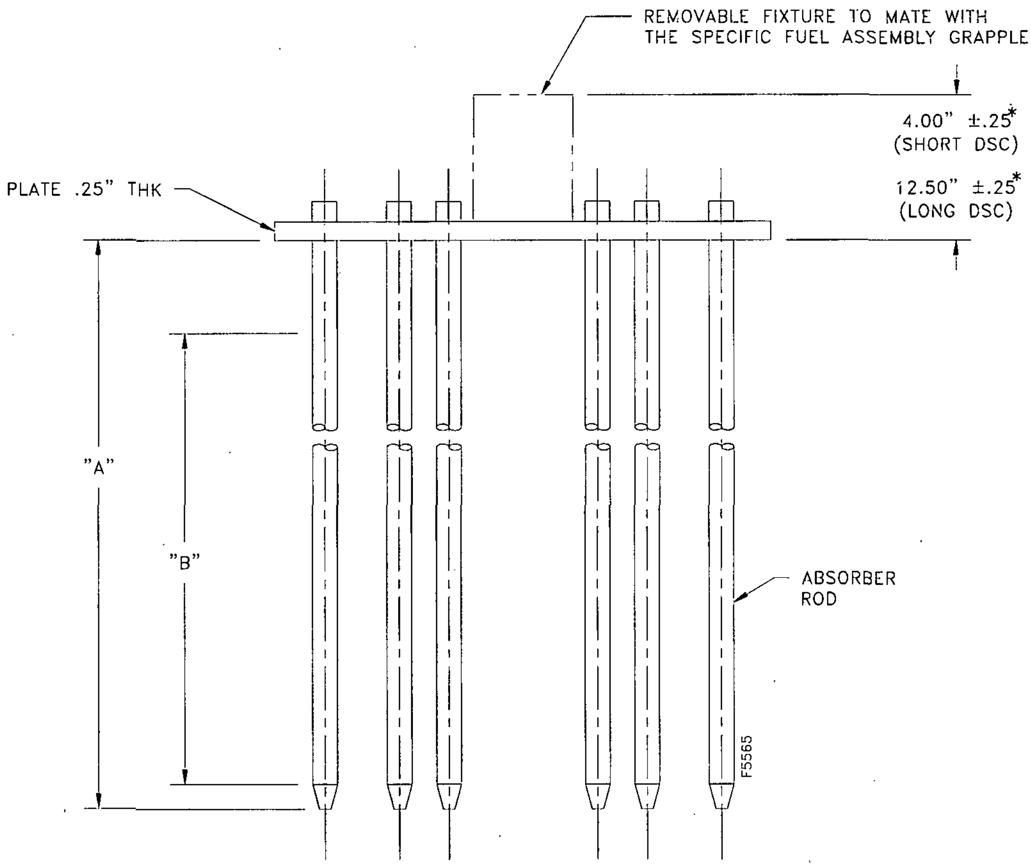
The Decay Heat (DH) in watts is expressed as:

$$F1 = -44.8 + 41.6*X1 - 37.1*X2 + 0.611*X1^2 - 6.80*X1*X2 + 24.0*X2^2$$
$$DH = F1*Exp(\{[1-(1.8/X3)]* -0.575\}*[(X3-4.5)^{0.169}]*[(X2/X1)^{-0.147}]) + 20$$

where,

- F1 Intermediate Function
- X1 Assembly Burnup in GWD/MTU
- X2 Initial Enrichment in wt. % U-235
- X3 Cooling Time in Years (minimum 10 years)

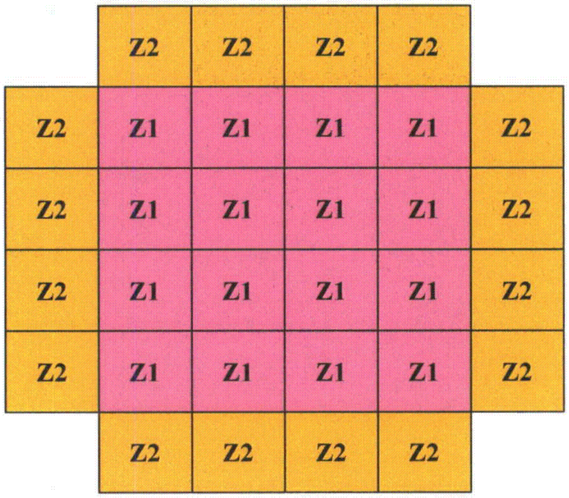
Note 1: Even though a minimum cooling time of 10 years is used, the minimum cooling time requirement for criticality from Table A.1.4.2-7 is 15 years.



*THESE DIMENSIONS ARE FOR USE WITH WESTINGHOUSE 17x17 FUEL ASSEMBLIES. DIMENSIONS WILL VARY AS REQUIRED BY FUEL ASSEMBLY TYPE.

DIMENSION	FUEL ASSEMBLY TYPE				
	WE 17x17	B&W 15x15	WE 15x15	CE 14x14	WE 14x14
ABSORBER ROD OD NOMINAL (IN)	.362	.438	.450	.975	.432
MINIMUM ABSORBER ROD DIMENSION "A"(IN)	156	160	156	143	156
MINIMUM B_4C PELLETS STACK HEIGHT, "B" (IN)	151	151	150	129	150
CLAD THICKNESS NOMINAL (IN)	.018	.022	.023	.049	.022
No. OF RODS	24	16	20	5	16
MATERIAL	304 SST	304 SST	304 SST	304 SST	304 SST

Figure A.1.4.2-1
Poison Rod Assemblies (PRAs)

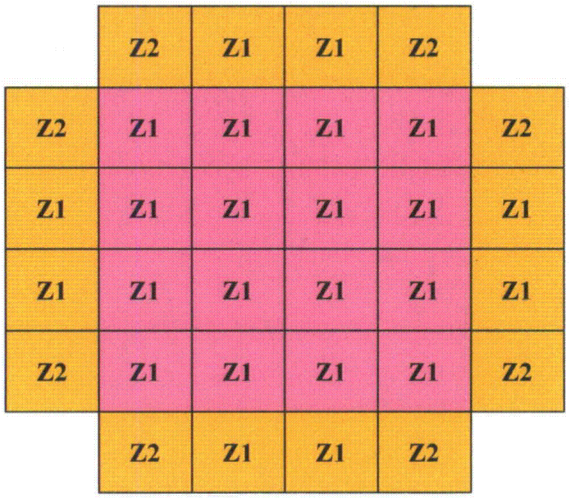


	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Max. Decay Heat / FA (kW)[(1)(2)]	0.63	0.87	N/A	N/A	N/A	N/A
Max. Decay Heat / Zone (kW)	10.08	13.92	N/A	N/A	N/A	N/A
Max. Decay Heat / DSC (kW)	24.0					

(1) Decay heat per fuel assembly shall be determined by Table A.1.4.2-8.

(2) If storing a CC with the fuel assembly, reduce allowable decay heat (DH) by 8 watts to account for the CC.

Figure A.1.4.2-2
Heat Load Configuration No. 1 for 32PT DSC

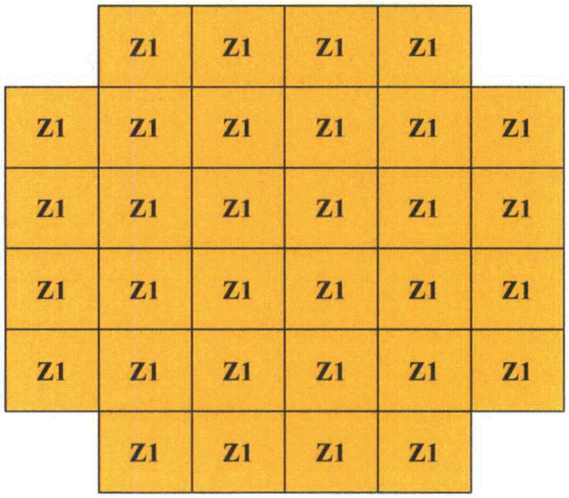


	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Max. Decay Heat / FA (kW)(1)(2)	0.6	1.2	N/A	N/A	N/A	N/A
Max. Decay Heat / Zone (kW)	14.4	9.6	N/A	N/A	N/A	N/A
Max. Decay Heat / DSC (kW)	24.0					

(1) Decay Heat per fuel assembly shall be determined by Table A.1.4.2-8.

(2) If storing a CC with the fuel assembly, reduce allowable decay heat (DH) by 8 watts to account for the CC.

Figure A.1.4.2-3
Heat Load Configuration No. 2 for 32PT DSC



	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Max. Decay Heat / FA (kW)	0.7	N/A	N/A	N/A	N/A	N/A
Max. Decay Heat / Zone (kW)	22.4	N/A	N/A	N/A	N/A	N/A
Max. Decay Heat / DSC (kW)	22.4					

(3) Decay Heat per fuel assembly shall be determined by Table A.1.4.2-8.

(4) If storing a CC with the fuel assembly, reduce allowable decay heat (DH) by 8 watts to account for the CC.

Figure A.1.4.2-4
Heat Load Configuration No. 3 for 32PT DSC