5.3.18 Mixed ANSTO-DIDO Payload Configuration

Previous sections have demonstrated the acceptability of transporting DIDO (annular ring), MOATA (MTR plate) and spiral assemblies. MOATA plate element and spiral assemblies have been defined to be ANSTO basket module payloads.

This section evaluates the placement of an ANSTO basket top module onto a DIDO basket stack. The DIDO baskets are loaded with DIDO fuel elements, while the ANSTO basket module may contain DIDO, MOATA or spiral fuel elements. The mixed payload ANSTO top module may also be located in the ANSTO basket assembly. Fuel elements may be disassembled and/or segmented and placed into an aluminum damaged fuel can (DFC) prior to placement within the ANSTO top basket module.

All three payloads are limited to their respective source (i.e., burnup and cool time limits) defined in their analysis sections. The DIDO elements placed within the ANSTO basket top module are limited to the 10 W payload limit, which is lower than the 18 W heat load defined in Section 5.3.9, to not require a top spacer.

Shielding discussions are divided into a basket comparison documenting acceptability of loading DIDO fuel into an ANSTO basket, a mixed payload discussion, and a canistered fuel discussion.

5.3.18.1 Basket Comparison

Based on the tube dimensions listed in the following table, the modeled basket for the DIDO payload evaluation bounds the ANSTO tube configuration. The ANSTO basket contains slightly larger and thicker tubes than the DIDO basket, providing a small increase in shield material. The aluminum components of the DIDO basket were not included in the DIDO shielding evaluations.

Parameter	DIDO Basket	ANSTO Basket
Fuel Assembly Openings	7	7
Fuel Tube OD (inch)	4.25	4.375
Fuel Tube Wall Thickness (inch)	0.120	0.125

5.3.18.2 Mixed Payload Discussion

All fuel types are comprised of uranium metal within an aluminum matrix, with ^{235}U being the fissile isotope. The neutron source as the result of (alpha, n) production is accounted for in each fuel type source definition. The cask is transported in a dry configuration, with a corresponding high neutron energy spectrum in the cavity, minimizing the effect of secondary particle production. Loading mixed payloads, therefore, does not result in adverse effects on system dose rates.

5.3.18.3 Canistered Fuel Element Discussion

Shielding evaluations of the bounding MEU DIDO payload, specified as bounding for the ANSTO spiral and plate fuels, applied the homogenized source region within an inch of the cask cavity lid (for a heat load of 18 W per basket module opening) and placed the source into a cylindrical shell near the tube surface. In addition, the homogenized density applied for self-shielding was significantly reduced in the DIDO models (volume fractions were calculated for a solid cylinder, while the material smear was then applied to a cylindrical shell extending from the inner to outer plate). As the aluminum DFC restrains fuel within a 9.84 cm envelope (5 mm larger than the modeled fuel region) and provides an offset from the lid of 3.8 cm, no adverse effects on dose rates occur due to loading of the material within the aluminum DFC.

Canned DIDO and ANSTO spiral fuel elements are further limited to a maximum heat load of 10 W per canister (MOATA elements are limited to less than 1 W per Section 5.3.16). This heat load reduction from the uncanistered configuration provides significant additional margin to the shielding evaluations.

5.3.18.4 Conclusions

Neither stacking ANSTO and DIDO baskets within the same basket assembly, nor including a mixed payload, nor the use of DFCs for compromised clad fuel results in increased dose rates. Conservatively, the DIDO MEU Transport Index (TI) may be assigned to the mixed and/or canned payloads.

5.3.19 Irradiated Hardware Shielding Evaluation

Irradiated hardware is evaluated for transport in the LWT cask. The irradiated hardware represents a potentially significant gamma source when compared to fuel material payloads due to the high energy spectrum feasible from activated materials. Typical irradiated hardware is irradiated steel where cobalt activation, and subsequent ^{60}Co decay, produces two gamma rays, each over 1 MeV in energy.

A source term for typical irradiated hardware is established by activating one kilogram of stainless steel with a 1.2 g/kg cobalt impurity in a PWR in-core neutron spectrum (PWR fuel assembly burnup to 45, 000 MWd/MTU at a 3.5 wt % ^{235}U initial enrichment, followed by a 90-day cool time). This material will represent a baseline to establish source limits in terms of gammas per second and energy per second (γ/s and MeV/s). The gamma source activity is determined in the SCALE 27-group neutron and 18-group gamma structures using the SAS2H sequence of SCALE 4.3. The activated hardware may contain surface contamination (including actinides), but this component has no significant effect on cask surface dose rates compared to the activated material itself and is, therefore, neglected from the analysis. The SAS2H input for the gamma source generation is listed in Figure. The resulting gamma spectrum is summarized in Figure 5.3.19-1.

A radial one-dimensional shielding analysis is performed using SAS1 with a void source region. A void source region is by default conservative since it neglects the substantial self-shielding of the activated hardware. A sample radial SAS1 input for irradiated hardware evaluations is shown in Figure 5.3.19-2 with material compositions for the cask given in Table 5.3.19-2. Note that various irradiated hardware heights (and two radial configurations) are evaluated using SAS1. The buckling height in each case is set to the source region height of the particular analysis. The same conservative assumptions used in previous radial shielding analysis were applied, i.e., minimum shield dimensions, lead gap, a 0.94 g/cm^3 neutron shield solution density, and no boron in the neutron shield solution. In the accident analysis, the neutron shield is modeled as void. A one-dimensional sketch of the modeled cask geometry is shown in Figure 5.3.19-3. As demonstrated in the shielding evaluations for various other payloads (e.g.., fuel skeleton with activated hardware), the axial dose of the NAC-LWT cask is not limiting. Therefore, only radial dose rates are evaluated in this section.

SAS1 dose rates are calculated using the SAS2H-generated gamma source (1 kg activated hardware). Dose rates are then scaled up to represent an increased source with a magnitude of 2×10^{14} γ/sec or 2.2×10^{14} MeV/sec (equivalent of 10 kg of the SAS2H activated stainless).

This source represents a radionuclide content of approximately 8.9×10^3 Ci, with a ^{60}Co portion of 2×10^3 Ci. Normal condition transport cask surface and 2 meter dose rates, as well as accident condition 1 meter dose rates, are plotted in Figure 5.3.19-4 through Figure 5.3.19-6 for the increased source. Dose rates are well below regulatory limits at the surface (300 mrem/hr) and 2 meters from the truck bed (7.6 mrem/hr). The transport index, based on the normal condition of transport dose rate at 1 meter from the package, is less than 35.

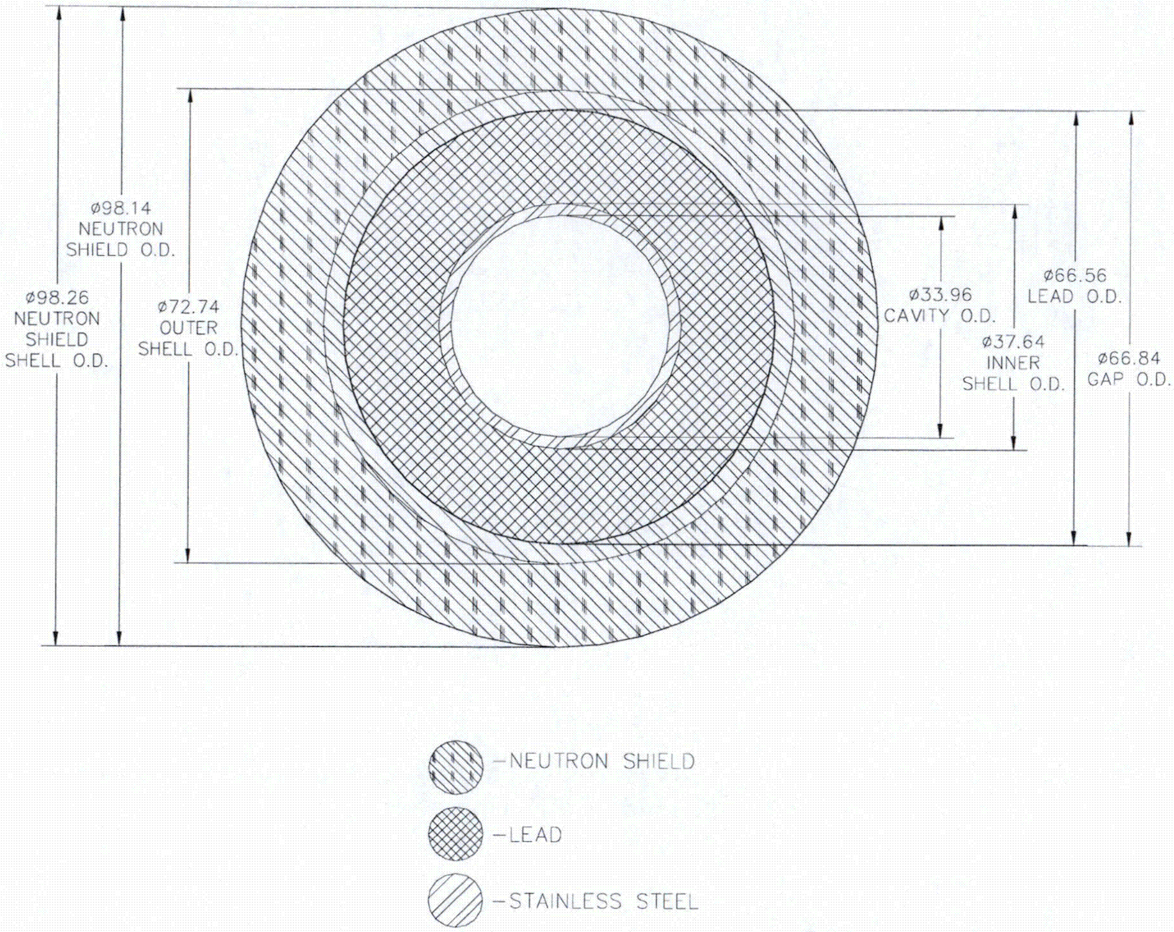
Figure 5.3.19-1 SAS2H Input for Irradiated Hardware (on a per kg basis)

```
=SAS2H      PARM=(HALT03,SKIPSHIPDATA)
WEST 15X15 3.5 WT % U235, 45000 MWd/MTU 5.0-10.0 YEAR COOLING
27GROUPNDF4 LATTICECELL
UO2         1 0.95 900 92235 3.5 92238 96.5 END
ZIRCALLOY  2 1.0 620 END
H2O         3 DEN=0.725 1.0 580 END
ARBM-BORMOD 0.725 1 1 0 0 5000 100 3 550.0E-6 580 END
END COMP
SQUAREPITCH 1.43 0.9294 1 3 1.0719 2 0.9489 0 END
NPIN=204 FUEL=365.76 NCYC=3 NLIB=1 PRIN=6 LIGH=5
INPL=1 NUMH=20 NUMI=1 ORTU=0.6922 SRTU=0.6541 END
POWER=16.28 BURN=428.0692 DOWN=60.0 END
POWER=16.28 BURN=428.0692 DOWN=60.0 END
POWER=16.28 BURN=428.0692 DOWN=0.0 END
FE 0.672 CR 0.190 NI 0.115 MN 0.020 CO 0.0012
END
=ORIGENS
0$$  A4 21 A8 26 A10 51 71  E
1$$  1 1T
COOLING 0.25-4 YEARS AND LIGHT ELEMENT GAMMA REBIN
3$$  21 0 1 A33 -86  E
54$$  A8 1 E T
35$$  0 T
56$$  0 6 A13 -2 5 3 E
57**  0.0 E T
COOLING 0.25-4 YEARS AND LIGHT ELEMENT GAMMA REBIN
SINGLE REACTOR ASSEMBLY
60**  0.25 0.5 0.75 1.0 1.5 2.0
65$$  A4 1 A7 1 A10 1 A25 1 A28 1 A31 1 A46 1 A49 1 A52 1 E
61**  F.01
81$$  2 51 26 1 E
82$$  F4 T
LIGHT ELEMENT SCALE GROUP STRUCTURE
LIGHT ELEMENT SCALE GROUP STRUCTURE
LIGHT ELEMENT SCALE GROUP STRUCTURE
LIGHT ELEMENT SCALE GROUP STRUCTURE
LIGHT ELEMENT SCALE GROUP STRUCTURE
LIGHT ELEMENT SCALE GROUP STRUCTURE
56$$ F0  T
END
```

Figure 5.3.19-2 Sample SAS1 Input for Irradiated Hardware (Source 1 kg Material)

```
SAS1
Irradiated Hardware - Nrm Model - 16 cm Radius Source - 150cm Height Source
27N-18COUPLE    INFHOMMEDIUM
AL       2  1.0 END
SS304    3  1.0 END
PB       4  1.0 END
ARBMGLYC  0.9437 3 0 1 0 6012 2 1001 6 8016 2 5 .585 END
H2O      5 0.4160 END
END COMP
END
LAST
Irradiated Hardware in the NAC-LWT - GAMMA SOURCE
CYLINDRICAL
0  8  30  -1  0  0.0  0.0  6.678E+08
0 16.9863  1 0
3 18.8214  4 0
4 33.2890 60 0
0 33.4264  1 0
3 36.3728 12 0
5 49.0728 30 0
3 49.1338  4 0
END ZONE
27Z
0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.631E-15 1.195E+05
7.709E+07 9.199E+09 3.249E+12 1.150E+13 3.950E+12 6.266E+08
5.980E+11 4.581E+11 5.615E+09 2.643E+10 6.543E+10 2.763E+11
DY=150 NDETEC=5
READ XSDOSE
150 49.1338 75 149.1338 75 249.1338 75
321.92 75 349.1338 75
END
```

Figure 5.3.19-3 Irradiated Hardware One-Dimensional Radial Model of NAC-LWT



Dimensions in cm.

Figure 5.3.19-4 Irradiated Hardware Normal Condition Surface Dose Rate as a Function of Irradiated Hardware Height

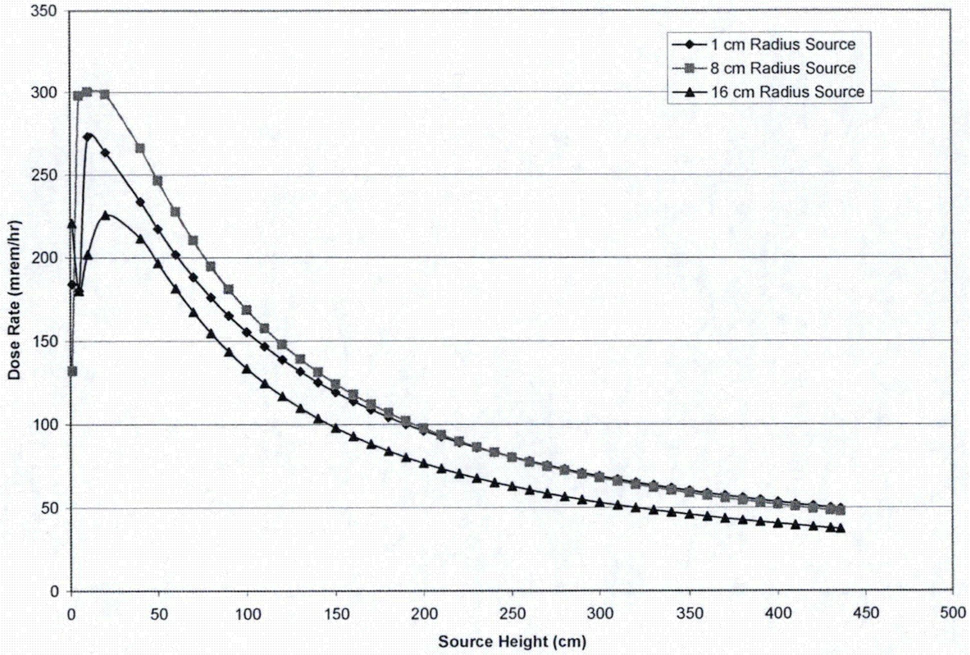


Figure 5.3.19-5 Irradiated Hardware Normal Condition 2 Meter Dose Rate as a Function of Irradiated Hardware Height

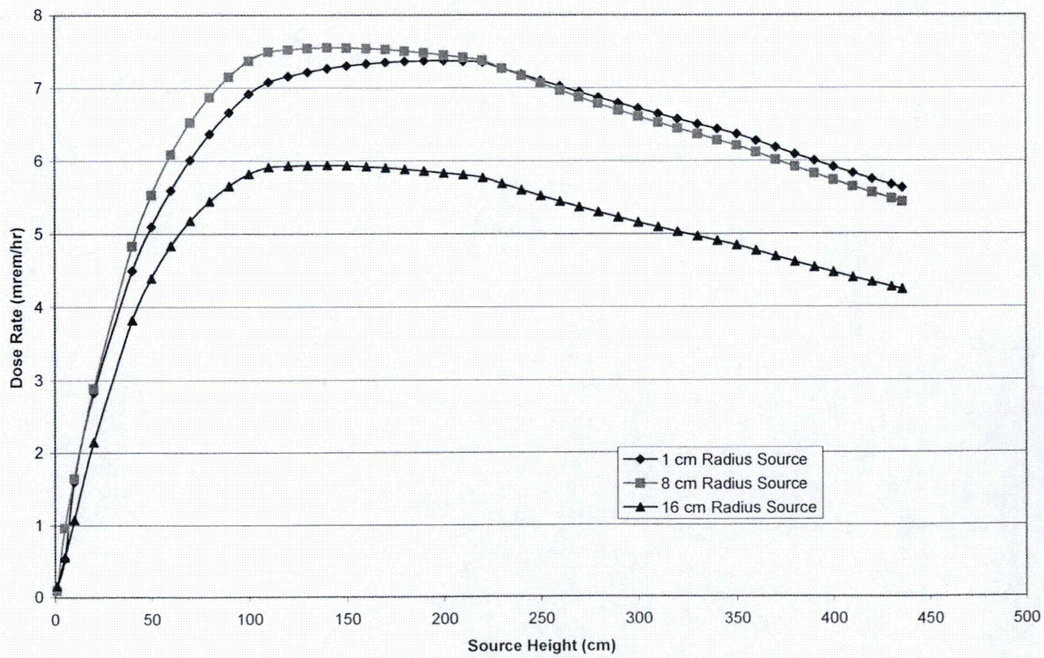


Figure 5.3.19-6 Irradiated Hardware Accident Condition 1 Meter Dose Rate as a Function of Irradiated Hardare Height

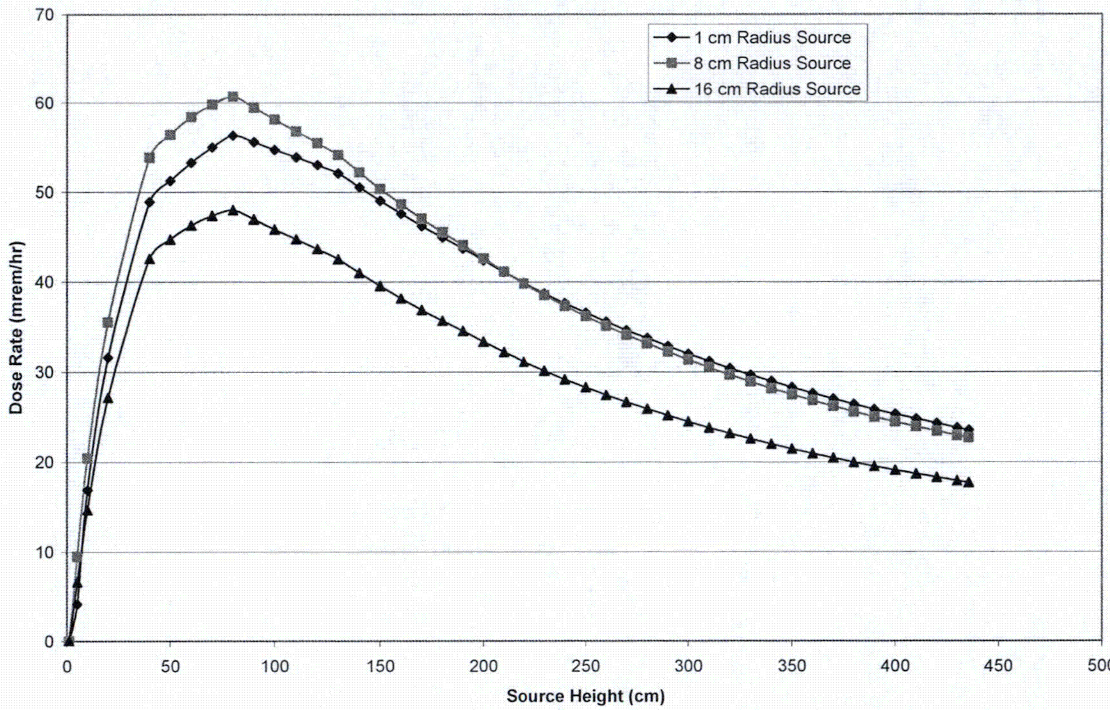


Table 5.3.19-1 Irradiated Hardware Gamma Spectra in SCALE Format (1 kg Activated Stainless Steel)

Energy Group	Source [gamma/sec]	Source [MeV/sec]
1	0.000E+00	0.000E+00
2	0.000E+00	0.000E+00
3	0.000E+00	0.000E+00
4	0.000E+00	0.000E+00
5	2.631E-15	9.209E-15
6	1.195E+05	3.287E+05
7	7.709E+07	1.735E+08
8	9.199E+09	1.683E+10
9	3.249E+12	4.857E+12
10	1.150E+13	1.340E+13
11	3.950E+12	3.555E+12
12	6.266E+08	4.386E+08
13	5.980E+11	2.990E+11
14	4.581E+11	1.603E+11
15	5.615E+09	1.404E+09
16	2.643E+10	3.964E+09
17	6.543E+10	4.907E+09
18	2.763E+11	8.290E+09
Total	2.014E+13	2.231E+13

Table 5.3.19-2 Material Compositions of the NAC-LWT

Material	SCALE Isotope/Element	Number Density [atom/b-cm]
Stainless Steel	CHROMIUM (SS304)	1.74286E-02
	MANGANESE	1.73633E-03
	IRON (SS304)	5.93579E-02
	NICKEL (SS304)	7.72070E-03
Lead	LEAD	3.29690E-02
Neutron Shield	HYDROGEN	5.99351E-02
	CARBON-12	1.07197E-02
	OXYGEN-16	2.46077E-02

5.3.20 SLOWPOKE Fuel Configuration

Results of a shielding analysis for up to 800 fuel rods in the LWT cask are presented in this section. Maximum dose rates are calculated to demonstrate that dose rate limits of 10 CFR 71.47 are not exceeded.

Dose rates are calculated using the MCNP (MCNP5, Version 1.30) three-dimensional transport code. Source terms are calculated using the TRITON/NEWT module of the SCALE package (SCALE 6.1). Cross section tables used in the MCNP analysis are the default provided in the MCNP5 1.30 distribution and draw on mcplib04 for gamma analysis and isotope dependent data from actia, rmccs, or t16_2003 data for neutron evaluations.

5.3.20.1 SLOWPOKE Fuel Source Term

Source terms are calculated to bound the irradiation history of the SLOWPOKE fuel rods. Fuel rod characteristics are summarized in Table 5.3.20-1. Inputs for irradiation and material parameters required by TRITON are given in Table 5.3.20-2. Key parameters differing between the input and analysis are reduced enrichment, increased fuel mass, and increased irradiation time. All parameters revised to produce bounding source terms. Each of the modified parameters is described below as to its effect on source:

- Increased fuel mass at a fixed depletion value (% ^{235}U depletion) increases source as the total amount of ^{235}U depleted increases, thereby increasing fission product sources.
- Reduced enrichment has opposing effects on source due to its relative effects on fission product versus higher actinide sources. For a fixed depletion percentage, a reduction in ^{235}U percentage will reduce the amount of material depleted, thereby reducing fission product sources, but increasing source as higher actinides are formed by parasitic absorption at a higher rate increasing both neutron and gamma sources. Overall, the source effect from enrichment variations is minor as the enrichment is decreased by only 3% for a high >90% enriched fuel source. This effect is significantly more pronounced for low enrichment fuels.
- Increased irradiation time, in conjunction with a continuous burn at full core power, increases source as it raises the depletion percentage with corresponding increases in both fission products and higher actinides generated. Overall, the conservative irradiation time and fuel core power depletion resulted in a core average ^{235}U depletion of 4.5% versus ~2% average reported for the cores to be transported.

TRITON input is shown in Figure 5.3.20-3, with the resulting TRITON material model shown in Figure 5.3.20-2. Neutron and gamma source terms for a cool time of 14 years from discharge are presented in Table 5.3.20-3 and Table 5.3.20-4, respectively. The calculated heat load at this cool time is 0.0027 W/rod or 2.17 W/cask (800 rods).

The SLOWPOKE core is designed to be critical using fixed beryllium reflectors surrounding the radial extent of the core and the core bottom. The beryllium reflector top, also referred to as beryllium shim, is adjusted to maintain a critical configuration. Top and bottom reflectors are not included within the scope of the 2-D Triton evaluation. A critical core was modeled by adjusting fuel rod pitch (actual pitch not available; core average source changes by less than 1% over evaluated range of pitch). By setting the system to critical (k_{eff} =1) at beginning of life assures that the neutron spectrum is representative of that in the actual core. k_{eff} decreased during the modeled burnup from 1.0 to 0.99. This minor decrease is not expected to significantly effect neutron spectrum or source produced by the calculation. As a full core was modeled, fuel source was extracted at three radial locations (inner, middle, outer ring) to determine which location produces maximum source. The maximum gamma source (controlling for shielding) was obtained from the middle ring location. The middle ring source was then applied to all fuel rods. While the 2-D analysis cannot capture axial distribution of source in a rod, loading of rods in 5x5 arrays four high will assure that the source is relatively uniformly spread through the axial extent of the cask. Any postulated localized peaking in source will be further reduced after penetrating through the radial shield of the NAC-LWT cask. No dose peaking is expected on the cask surface as a result of axial burnup profile of the individual SLOWPOKE rods.

The effect of subcritical neutron multiplication is directly computed in the MCNP analysis.

5.3.20.2 SLOWPOKE Fuel Shielding Model

MCNP three-dimensional shielding analysis allows detailed modeling of the fuel, basket, and cask shield configurations. Some fuel rod detail is homogenized in the model to simplify model input and improve computational efficiency. The basket and cask body details are explicitly modeled, including the axial extents described by the License Drawings.

The geometric description of a MCNP model is based on the combinatorial geometry system embedded in the code. In this system, bodies such as cylinders and rectangular parallelepipeds, and their logical intersections and unions, are used to describe the extent of material zones.

Source and Canister Models

Options for loading include fuel rod arrays of 4x4 and 5x5 rods. Only the 5x5 array is modeled as it contains maximum fuel/source inventory. These arrays are stacked four high within a canister that also contains a handle. The canister is made of aluminum. Dimensions for the tube array and canister are shown in Table 5.3.20-7. The source region is modeled as a smear within the canister tubes. The fuel homogenization, shown in Table 5.3.20-5, is based on an area bounded by the aluminum tube. The source height is the active fuel height, 22 cm.

While the fuel rods may be damaged, the results of this model will bound both normal and accident conditions. Aluminum metallic fuel, even when damaged, will not disperse through the canister. The material is also placed into individual tubes which will retain larger fuel sections. Shifts in the material within the canister will also be well bounded by having shifted the canister and payload.

Cross section of the VISED model of the source region are shown in Figure 5.3.20-4 and Figure 5.3.20-5. As shown, the model is moved to its maximum axial elevation which brings it closest to the reduced shielding area of the NAC-LWT. The lowest shielding region is the tapered area of the lead gamma neutron shield, the area below the cask cavity top with no lead shielding.

Basket Model

For a given fuel type, the MCNP description of the basket stack forms a common sub-model employed in the analysis. The key features of the model are the detailed representation of the basket structural members, base plates, and support plates. Basket models are identical to those described in Section 5.3.14. Only four of the basket openings are loaded with SLOWPOKE fuel and only the top two baskets are loaded. The lower two baskets are modeled as void, conservatively removing shielding material and increasing dose rates. Maximum of eight canisters per cask.

MCNP NAC-LWT Model

The three-dimensional model of the NAC-LWT cask is based on the following features.

Normal conditions:

- Radial neutron shield and shield shell
- Aluminum impact limiters with 0.5 g/cm^3 density (calculated based on the impact limiter weight and dimensions) and a diameter equal to the neutron shield shell diameter

Accident conditions:

- Removal of radial neutron shield and shield shell
- Loss of upper and lower impact limiters

Common to both the normal and accident conditions models is a 0.1374 cm gap between the lead outer diameter and the cask outer shell. As stated previously, the elevation of the source regions is set at its maximum axial extent. Detailed model parameters used in creating the three-dimensional model are taken directly from the License Drawings. Elevations associated with the three-dimensional features are established with respect to the center bottom of the NAC-LWT cask cavity for the MCNP combinatorial model. The cask model is identical to that described in Section 5.3.14. A sample input file is provided in Figure 5.3.14-5.

Shield Regional Densities

Based on the homogenization described for the source, the resulting fuel regional densities are shown in Table 5.3.20-5. Material compositions for structural and shield materials are shown in Table 5.3.20-6.

5.3.20.3 SLOWPOKE Fuel Shielding Evaluation

Calculational Methods

The shielding evaluation is performed using MCNP.

The MCNP shielding model described in Section 5.3.20.2 is utilized with the source terms described in Section 5.3.20.1 to estimate the dose rate profiles at various distances from the side, top and bottom of the cask for both normal and accident conditions. The method of solution is continuous energy Monte Carlo with a Monte Carlo based weight window generator to accelerate code convergence. Weight window and problem convergence is verified by the 10 statistical checks performed by MCNP. Radial or axial biasing is performed depending on the desired dose location.

Significant validation literature is available for MCNP as it is an industry standard tool for spent fuel cask evaluations. Available literature covers a range of shielding penetration problems ranging from slab geometry to spent fuel cask geometries. Confirmatory calculations against other validated shielding codes (SCALE and MCBEND) on NAC casks have further validated the use of MCNP for shielding evaluations.

MCNP Flux-to-Dose Conversion Factors

The ANSI/ANS 6.1.1-1977 flux-to-dose rate conversion factors are employed in the MCNP analysis.

Three-Dimensional Dose Rates for SLOWPOKE Fuel

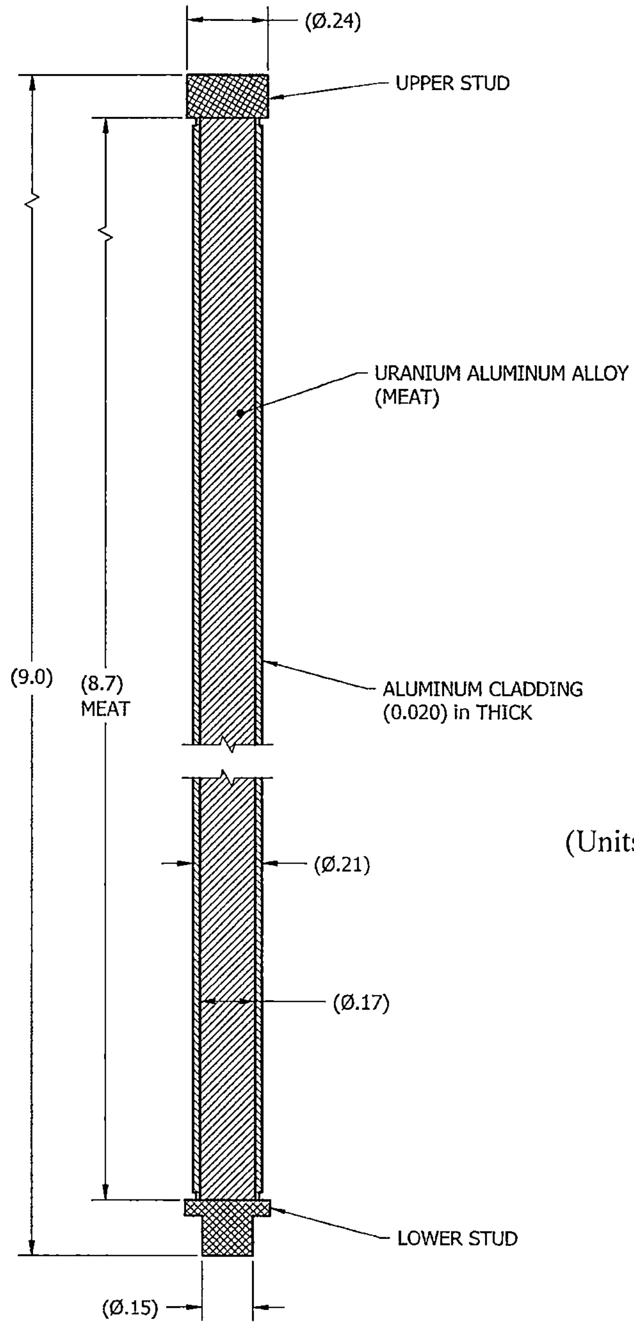
Table 5.3.20-8 provides maximum and average dose rates for the tabulated distances and transport conditions (normal and accident). Table 5.3.20-9 contains key results.

Calculated normal condition radial surface dose rates are below 200 mrem/hr, therefore do not require an exclusive use designation for the NAC-LWT. The maximum dose rate is dominated by the gamma component. The radial surface dose rate profile is shown in Figure 5.3.20-7. The normal condition maximum radial 2-meter dose rate is 0.002 mrem/hr. The dose rate profile is skewed towards the top of the cask, as shown Figure 5.3.20-8.

Accident condition radial 1-meter dose rates are well below the 1,000 mrem/hr limit. The dose rate profile is shown in Figure 5.3.20-9.

As shown in the dose summary table (Table 5.3.20-9), axial surface dose rates are well below limits for all three source models. Significant margin is present for the normal condition 2-meter and accident condition 1-meter dose rate limits.

Figure 5.3.20-1 SLOWPOKE Fuel Element



(Units in inches)

Figure 5.3.20-2 SLOWPOKE Core Model

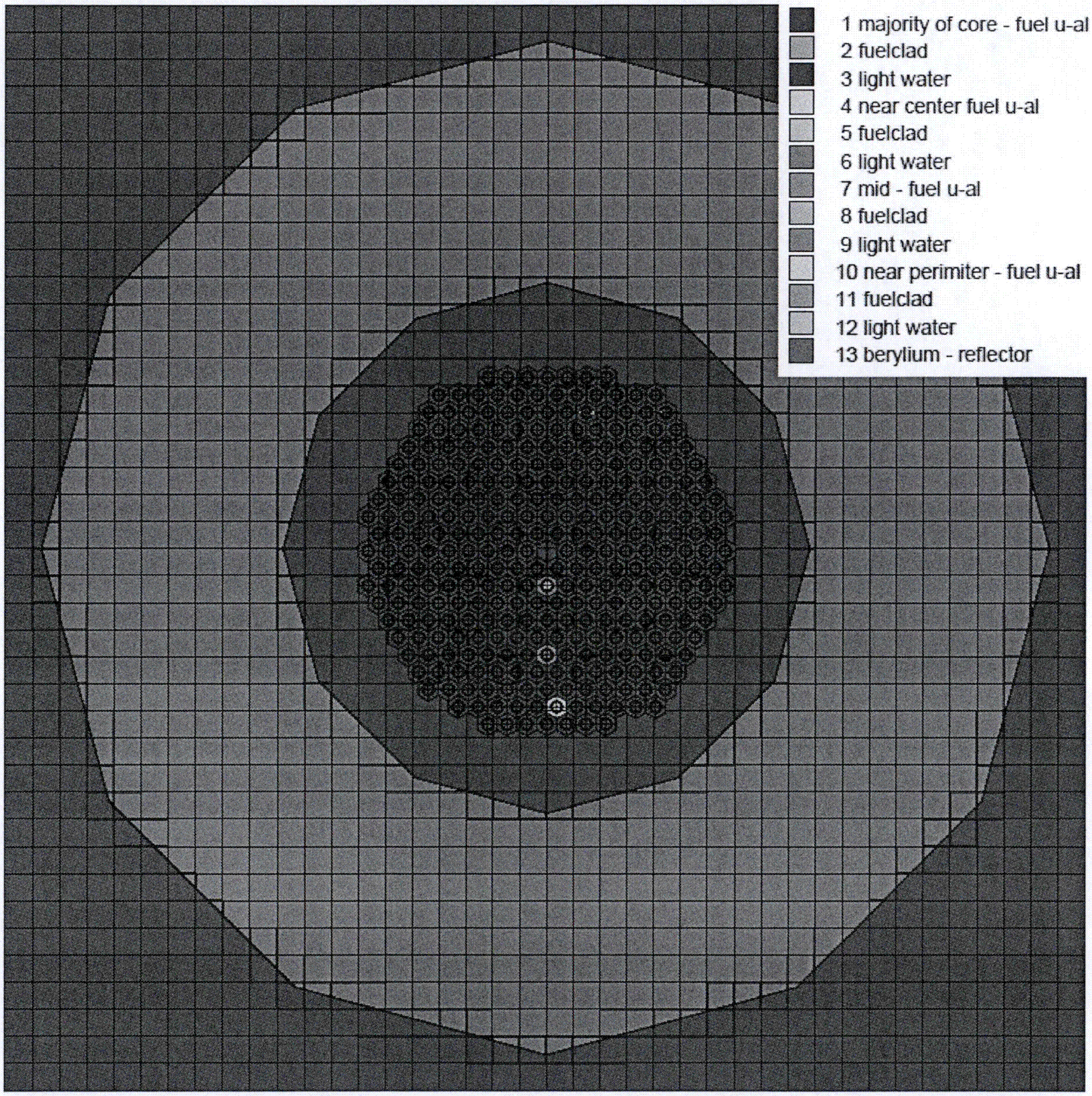


Figure 5.3.20-3 TRITON Input for SLOWPOKE Fuel

```
=t-depl
SLOWPOKE CORE NEWT / CENTRM Depletion - 0.85 cm Rod Pitch - 30 GWD/MTU
V7-238
read comp
U    1 DEN=3.51 0.288 373.0  92235 90.0  92238  10.0  END
AL   1 DEN=3.51 0.712 373.0  END
AL   2  1.0  363.0  END
H2O  3  1.0  313.0  END
U    4 DEN=3.51 0.288 373.0  92235 90.0  92238  10.0  END
AL   4 DEN=3.51 0.712 373.0  END
AL   5  1.0  363.0  END
H2O  6  1.0  313.0  END
U    7 DEN=3.51 0.288 373.0  92235 90.0  92238  10.0  END
AL   7 DEN=3.51 0.712 373.0  END
AL   8  1.0  363.0  END
H2O  9  1.0  313.0  END
U   10 DEN=3.51 0.288 373.0  92235 90.0  92238  10.0  END
AL  10 DEN=3.51 0.712 373.0  END
AL  11  1.0  363.0  END
H2O 12  1.0  313.0  END
BE   13  1.0  313.0  END
end comp
read celldata
latticecell triangpitch pitch=0.85 3 fueld=0.422 1 cladd=0.524 2 end
latticecell triangpitch pitch=0.85 6 fueld=0.422 4 cladd=0.524 5 end
latticecell triangpitch pitch=0.85 9 fueld=0.422 7 cladd=0.524 8 end
latticecell triangpitch pitch=0.85 12 fueld=0.422 10 cladd=0.524 11 end
end celldata
read depletion 1 4 7 10 end depletion
read opus
matl= 1 4 7 10 0 end units=grams
new case
units=watts
new case
typarams=gspectrum
units=part
new case
typarams=nspectrum
units=parts
end opus
read burndata
' 980 gram fuel - 20kW/Core  - Core Diameter 22 cm  - 7.8 l Water in Core
power=20 burn=1470 down=5100 end
end burndata
read model
SLOWPOKE 315 Rod Assembly - Berylium Reflector - Collapse 44-group
read parm
  prtflux=no  drawit=yes   collapse=yes
  xnlib=4 run=yes prtmxsec=no prtbroad=no
  prtmxtab=yes cmfd=no echo=yes
end parm
read materials
  1 1 !majority of core - fuel u-al! end
  2 1 !fuelclad! end
```

Figure 5.3.20-3 TRITON Input for SLOWPOKE Fuel (continued)

```
  3 2 !light water! end
  4 1 !near center fuel u-al! end
  5 1 !fuelclad! end
  6 2 !light water! end
  7 1 !mid - fuel u-al! end
  8 1 !fuelclad! end
  9 2 !light water! end
  10 1 !near perimiter - fuel u-al! end
  11 1 !fuelclad! end
  12 2 !light water! end
  13 2 !berylium - reflector! end
end materials
read collapse
7r1 2 3 2r4 5 6 7 8 8 8r9 14r10 6r11 10r12 13 7r14 11r15 12r16 30r17 16r18 2r19
6r20 3r21 6r22 14r23 3r24 5r25 4r26 5r27 5r28 5r29 10r30 5r31 32 33 34 2r35
36 37 38 2r39 2r40 3r41 2r42 43 44 45 46 47 3r48 9r49 end collapse
read geom
' Balance Core
unit 1
cylinder 10 0.2011
cylinder 20 0.262
hexprism 30 0.425
media 1 1 10
media 2 1 20 -10
media 3 1 30 -20
boundary 30 2 2
' Near Center
unit 2
cylinder 10 0.2011
cylinder 20 0.262
hexprism 30 0.425
media 4 1 10
media 5 1 20 -10
media 6 1 30 -20
boundary 30 2 2
' Mid Range
unit 3
cylinder 10 0.2011
cylinder 20 0.262
hexprism 30 0.425
media 7 1 10
media 8 1 20 -10
media 9 1 30 -20
boundary 30 2 2
' Near Perimeter
unit 4
cylinder 10 0.2011
cylinder 20 0.262
hexprism 30 0.425
media 10 1 10
media 11 1 20 -10
media 12 1 30 -20
boundary 30 2 2
global unit 10
cylinder 110 11.0
```

Figure 5.3.20-3 TRITON Input for SLOWPOKE Fuel (continued)

```
cylinder 120 21.0
cuboid 130 23.0 -23.0 23.0 -23.0
array 1 110 place 10 10 -0.425 -0.850
media 3 1 110
media 13 1 120 -110
media 3 1 130 -120
boundary 130 40 40
'
end geom
read array
ara=1 typ=shexagonal nux=21 nuy=21
fill
0 0 0 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0
0 0 0 0 0 1 1 1 1 1 4 1 1 1 1 1 0 0 0 0 0
0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0
0 0 0 1 1 1 1 1 1 1 3 1 1 1 1 1 1 1 0 0 0
0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0
0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 1 1 1 1 1 1 1 1 1 2 1 1 1 1 1 1 1 1 1 0
0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 0
0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0
0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0
0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0
0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0
0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0
0 0 0 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0
end fill
end array
read bounds all=vacuum end bounds
end model
end
```

Figure 5.3.20-4 VISED X-Y Slice – SLOWPOKE – Normal Conditions

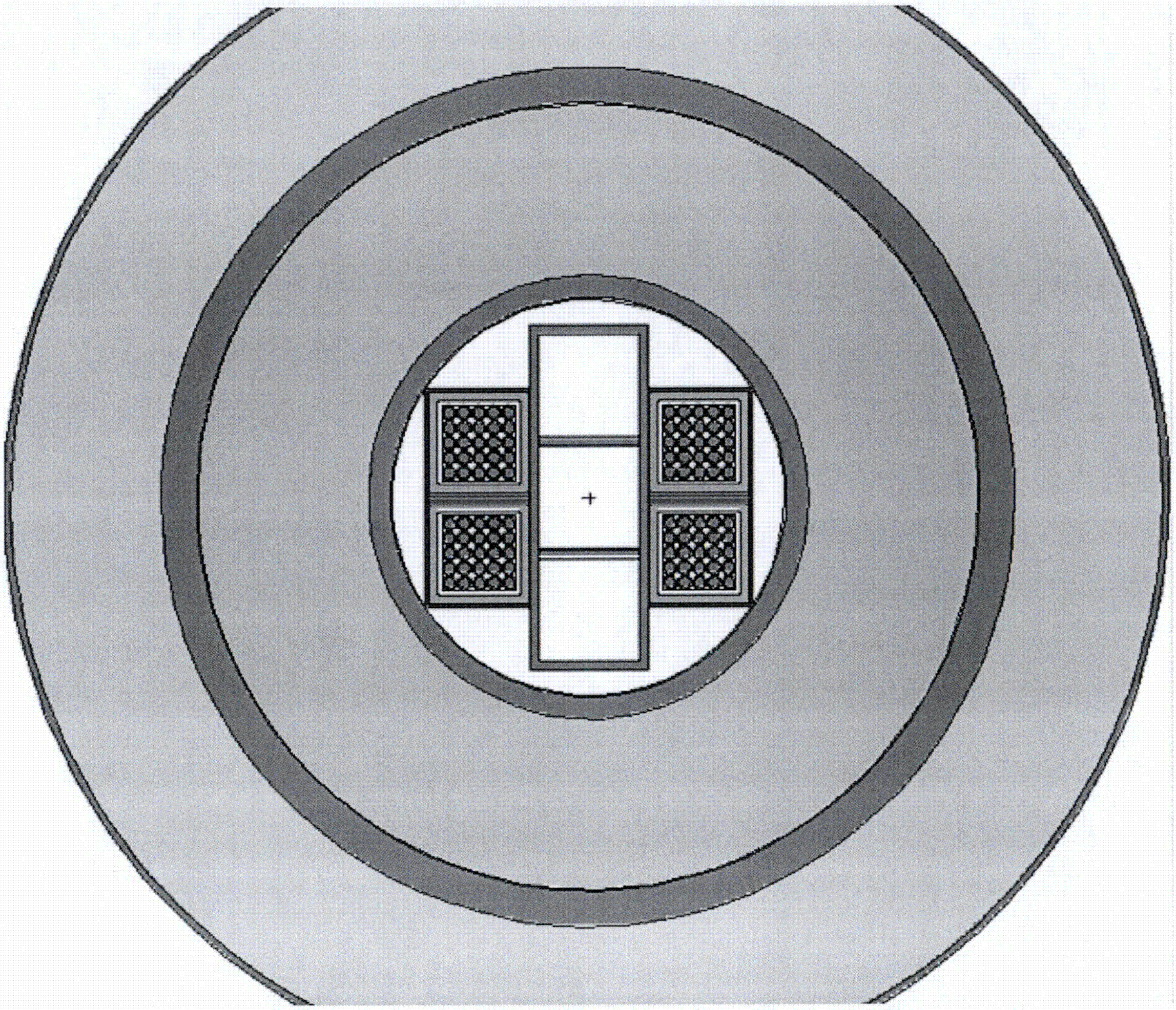
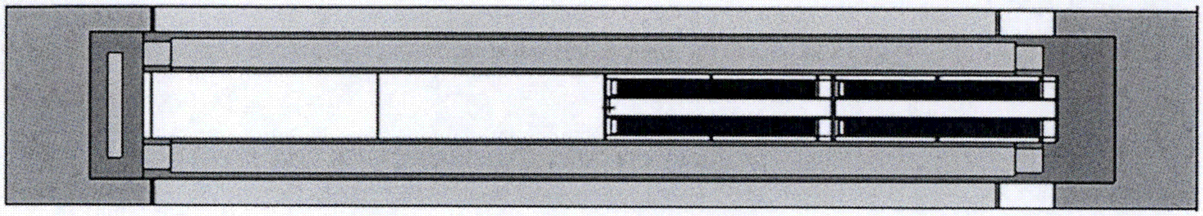


Figure 5.3.20-5 VISED Y-Z Slice – SLOWPOKE – Normal Conditions



Note: Conservatively moved material to cask cavity top.

Figure 5.3.20-6 Sample MCNP Input File – Normal Conditions

```
NAC-LWT Cask - Assy_30b90e14y - Normal Transport Conditions
C Radial Biasing - Fuel Gamma Source
C Fuel Assembly Cells
1 1 -0.8543 -1 +3    u=7 $ Homogenized Fuel Meat + Clad
2 0      -1 -3    u=7 $ Void
3 4 -2.7000 -2 +1    u=7 $ Tube OD
4 0      +2    u=7 $ Outside Tube
5 4 -2.7000 -5    u=6 $ Tube Base Plate
6 0      -4 fill=7 trcl = ( -2.5400 2.5400 0.6351 )    u=6 $ Tube 1
7 like 6 but fill=7 trcl = ( -1.2700 2.5400 0.6351 )    u=6 $ Tube 2
8 like 6 but fill=7 trcl = ( 0.0000 2.5400 0.6351 )    u=6 $ Tube 3
9 like 6 but fill=7 trcl = ( 1.2700 2.5400 0.6351 )    u=6 $ Tube 4
10 like 6 but fill=7 trcl = ( 2.5400 2.5400 0.6351 )    u=6 $ Tube 5
11 like 6 but fill=7 trcl = ( -2.5400 1.2700 0.6351 )    u=6 $ Tube 6
12 like 6 but fill=7 trcl = ( -1.2700 1.2700 0.6351 )    u=6 $ Tube 7
13 like 6 but fill=7 trcl = ( 0.0000 1.2700 0.6351 )    u=6 $ Tube 8
14 like 6 but fill=7 trcl = ( 1.2700 1.2700 0.6351 )    u=6 $ Tube 9
15 like 6 but fill=7 trcl = ( 2.5400 1.2700 0.6351 )    u=6 $ Tube 10
16 like 6 but fill=7 trcl = ( -2.5400 0.0000 0.6351 )    u=6 $ Tube 11
17 like 6 but fill=7 trcl = ( -1.2700 0.0000 0.6351 )    u=6 $ Tube 12
18 like 6 but fill=7 trcl = ( 0.0000 0.0000 0.6351 )    u=6 $ Tube 13
19 like 6 but fill=7 trcl = ( 1.2700 0.0000 0.6351 )    u=6 $ Tube 14
20 like 6 but fill=7 trcl = ( 2.5400 0.0000 0.6351 )    u=6 $ Tube 15
21 like 6 but fill=7 trcl = ( -2.5400 -1.2700 0.6351 )    u=6 $ Tube 16
22 like 6 but fill=7 trcl = ( -1.2700 -1.2700 0.6351 )    u=6 $ Tube 17
23 like 6 but fill=7 trcl = ( 0.0000 -1.2700 0.6351 )    u=6 $ Tube 18
24 like 6 but fill=7 trcl = ( 1.2700 -1.2700 0.6351 )    u=6 $ Tube 19
25 like 6 but fill=7 trcl = ( 2.5400 -1.2700 0.6351 )    u=6 $ Tube 20
26 like 6 but fill=7 trcl = ( -2.5400 -2.5400 0.6351 )    u=6 $ Tube 21
27 like 6 but fill=7 trcl = ( -1.2700 -2.5400 0.6351 )    u=6 $ Tube 22
28 like 6 but fill=7 trcl = ( 0.0000 -2.5400 0.6351 )    u=6 $ Tube 23
29 like 6 but fill=7 trcl = ( 1.2700 -2.5400 0.6351 )    u=6 $ Tube 24
30 like 6 but fill=7 trcl = ( 2.5400 -2.5400 0.6351 )    u=6 $ Tube 25
31 0      #5 #6 #7 #8 #9 #10 #11 #12 #13 #14 #15 #16 #17 #18
        #19 #20 #21 #22 #23 #24 #25 #26 #27 #28 #29 #30
             u=6 $ Void
32 4 -2.7000 -7    u=5 $ Can Base Plate
33 4 -2.7000 -9 +8 +7    u=5 $ Can
34 0      -6 fill=6 trcl = ( 0.0000 0.0000 3.0924 )    u=5 $ Tube Assy 1
35 like 34 but fill=6 trcl = ( 0.0000 0.0000 27.2225 )    u=5 $ Tube Assy 2
36 like 34 but fill=6 trcl = ( 0.0000 0.0000 51.3526 )    u=5 $ Tube Assy 3
37 like 34 but fill=6 trcl = ( 0.0000 0.0000 75.4827 )    u=5 $ Tube Assy 4
38 4 -2.7000 -10    u=5 $ Can Lid Bottom Plate
39 4 -2.7000 -11    u=5 $ Can Lid Top Plate
40 0      #32 #33 #34 #35 #36 #37 #38 #39    u=5 $ Void
C Cells - MTR 7 Element Basket
41 6 -7.9400 -13 +16 +17 +18 +19 +20 +21 +22    u=4 $ Base plate
42 6 -7.9400 -14 +23 +27    u=4 $ Support plate
43 6 -7.9400 -15 +23 +27    u=4 $ Support plate
44 6 -7.9400 -23 +24 #41 #42 #43    u=4 $ Center column
```

Figure 5.3.20-6 Sample MCNP Input File – Normal Conditions (continued)

```
45 6 -7.9400 -25 #41 #42 #43      u=4 $ Center divider upper
46 6 -7.9400 -26 #41 #42 #43      u=4 $ Center divider lower
47 6 -7.9400 -27 +28 +23 #41 #42 #43    u=4 $ Small side
48 6 -7.9400 -29 #41 #42 #43      u=4 $ Left divider
49 6 -7.9400 -30 #41 #42 #43      u=4 $ Right divider
50 0      #41 #42 #43 #44 #45 #46 #47 #48 #49      u=4 $ Void
C Cells - Basket Cavity
51 0      -12 fill=5 trcl = ( -9.5250 4.6990 3.1877 )    u=3 $ UL
52 like 51 but fill=5 trcl = ( -9.5250 -4.6990 3.1877 )    u=3 $ LL
53 like 51 but fill=5 trcl = ( 9.5250 4.6990 3.1877 )    u=3 $ UR
54 like 51 but fill=5 trcl = ( 9.5250 -4.6990 3.1877 )    u=3 $ LR
55 0      #51 #52 #53 #54      fill=4 u=3 $ Void
C Cells - LWT Cavity
56 0      -38      u=2
57 0      -39      u=2
58 0      -40 fill=3 ( 0.0000 0.0000 227.3300 )    u=2
59 0      -41 fill=3 ( 0.0000 0.0000 339.0900 )    u=2
60 0      #56 #57 #58 #59      u=2
C Cells - LWT Cask Normal Conditions
61 5 -11.344 -45      u=1 $ BotPb
62 0      -44 fill=2      u=1 $ Cavity
63 6 -7.9400 -42 -43 +45     u=1 $ Bottom
64 6 -7.9400 -42 +43 +47 +50 +44 u=1 $ OuterShell
65 6 -7.9400 -46 +49 +44     u=1 $ InnerShellTaper
66 6 -7.9400 -48 +44      u=1 $ InnerShell
67 5 -11.344 -49 +48      u=1 $ Lead
68 5 -11.344 -47 +46 +49     u=1 $ LeadTaper
69 0      -50 +49      u=1 $ LeadGap
70 3 -0.9669 -52 +42      u=1 $ NeutronShield
71 6 -7.9400 -51 +42 +52     u=1 $ NSShell
72 7 -0.4997 -53 +42      u=1 $ UpperLimiter
73 7 -0.4997 -54 +42      u=1 $ LowerLimiter
74 0      -55 +42 +51 +53 +54 u=1 $ Container
75 0      +55      u=1 $ Outside
C Detector Cells - Radial Biasing
100 0 -100 fill=1 $ Surface
200 0 -200 +100 $ 1ft
300 0 -300 +100 +200 $ 1m
400 0 -400 +100 +200 +300 $ 2m
500 0 -500 +100 +200 +300 +400 $ 2m+Convey
600 0 +100 +200 +300 +400 +500 $ Exterior

C Fuel Assembly Surfaces
1 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 23.4950 0.5080 $ Tube ID
2 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 23.4950 0.6349 $ Tube OD
3 PZ 1.4950         $ Fuel Cut Plain
4 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 23.4951 0.6350 $ Tube
5 RPP -3.1750 3.1750 -3.1750 3.1750 0.0000 0.6350   $ Tube Base Plate
6 RPP -3.1751 3.1751 -3.1751 3.1751 0.0000 24.1301   $ Tube Container
7 RPP -4.1910 4.1910 -4.1910 4.1910 0.0000 0.4699   $ Can Base Plate
8 RPP -3.5560 3.5560 -3.5560 3.5560 0.0000 100.6475    $ Can ID
```

Figure 5.3.20-6 Sample MCNP Input File – Normal Conditions (continued)

```
9 RPP -4.1910 4.1910 -4.1910 4.1910 0.0000 100.6475  $ Can OD
10 RPP -3.4925 3.4925 -3.4925 3.4925 99.6823 100.6475  $ Can Lid Lower Plate
11 RPP -4.1910 4.1910 -4.1910 4.1910 100.6475 102.2223  $ Can Lid Upper Plate
12 RPP -4.1911 4.1911 -4.1911 4.1911 0.0000 102.2223  $ Container
C Surfaces - MTR 7 Element Basket
13 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 1.2700 16.8466 $ Base plate
14 RCC 0.0000 0.0000 52.0700 0.0000 0.0000 1.2700 16.8466 $ Support plate
15 RCC 0.0000 0.0000 104.1400 0.0000 0.0000 1.2700 16.8466 $ Support plate
16 CZ 1.2700          $ Hole CC
17 C/Z 0.0000 9.5250 1.2700       $ Hole UC
18 C/Z 0.0000 -9.5250 1.2700       $ Hole LC
19 C/Z -9.5250 4.6990 1.2700       $ Hole UL
20 C/Z -9.5250 -4.6990 1.2700       $ Hole LL
21 C/Z 9.5250 4.6990 1.2700       $ Hole UR
22 C/Z 9.5250 -4.6990 1.2700       $ Hole LR
23 RPP -5.1604 5.1604 -14.6939 14.6939 1.2700 111.7600  $ Center column outer
24 RPP -4.3667 4.3667 -13.9002 13.9002 1.2700 111.7600  $ Center column inner
25 RPP -4.3667 4.3667 4.3688 5.1626 1.2700 111.7600  $ Center divider upper
26 RPP -4.3667 4.3667 -5.1626 -4.3688 1.2700 111.7600  $ Center divider lower
27 RPP -14.1986 14.1986 -9.3599 9.3599 1.2700 111.7600  $ Small side outer
28 RPP -13.8938 13.8938 -9.0551 9.0551 1.2700 111.7600  $ Small side inner
29 RPP -13.8938 -5.1604 -0.3175 0.3175 1.2700 111.7600  $ Left divider
30 RPP 5.1604 13.8938 -0.3175 0.3175 1.2700 111.7600  $ Right divider
C Surfaces - Basket Cavity
31 RPP -4.3667 4.3667 -4.3688 4.3688 1.2700 111.7600  $ CC
32 RPP -4.3667 4.3667 5.1626 13.9002 1.2700 111.7600  $ UC
33 RPP -4.3667 4.3667 -13.9002 -5.1626 1.2700 111.7600  $ LC
34 RPP -13.8938 -5.1604 0.6350 9.3726 1.2700 111.7600  $ UL
35 RPP -13.8938 -5.1604 -9.3726 -0.6350 1.2700 111.7600  $ LL
36 RPP 5.1604 13.8938 0.6350 9.3726 1.2700 111.7600  $ UR
37 RPP 5.1604 13.8938 -9.3726 -0.6350 1.2700 111.7600  $ LR
C Surfaces - LWT Cavity
38 RCC 0.0000 0.0000 3.8100 0.0000 0.0000 111.7600 16.8467 $ Basket
39 RCC 0.0000 0.0000 115.5700 0.0000 0.0000 111.7600 16.8467 $ Basket
40 RCC 0.0000 0.0000 227.3300 0.0000 0.0000 111.7600 16.8467 $ Basket
41 RCC 0.0000 0.0000 339.0900 0.0000 0.0000 111.7600 16.8467 $ Basket
C Surfaces - LWT Cask Normal Conditions
42 RCC 0.0000 0.0000 -26.6700 0.0000 0.0000 507.3650 36.5189 $ Lwt
43 RCC 0.0000 0.0000 -26.6700 0.0000 0.0000 26.6700 36.5189 $ Bottom
44 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 452.1200 16.9863 $ Cavity
45 RCC 0.0000 0.0000 -17.7800 0.0000 0.0000 7.6200 26.3525 $ Bottom gamma shield
46 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 444.5000 20.1740 $ Lead id - taper
47 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 444.5000 31.5976 $ Lead od - taper
48 RCC 0.0000 0.0000 13.8176 0.0000 0.0000 416.8648 18.9103 $ Lead id
49 RCC 0.0000 0.0000 13.8176 0.0000 0.0000 416.8648 33.3271 $ Lead od
50 RCC 0.0000 0.0000 13.8176 0.0000 0.0000 416.8648 33.4645 $ Lead gap
51 RCC 0.0000 0.0000 3.8100 0.0000 0.0000 419.1000 49.8183 $ Neutron shield shell
52 RCC 0.0000 0.0000 5.0800 0.0000 0.0000 416.5600 49.2189 $ Neutron shield
53 RCC 0.0000 0.0000 450.2150 0.0000 0.0000 70.5612 49.8183 $ Upper limiter
54 RCC 0.0000 0.0000 -68.0212 0.0000 0.0000 71.8312 49.8183 $ Lower limiter
55 RCC 0.0000 0.0000 -68.0212 0.0000 0.0000 588.7974 49.8183 $ Container
```

Figure 5.3.20-6 Sample MCNP Input File – Normal Conditions (continued)

```
C Radial Detector DRA (Surface)
100 RCC 0.0000 0.0000 -68.1212 0.0000 0.0000 588.9974 49.9184
101 PZ -38.6713
102 PZ -9.2215
103 PZ 20.2284
104 PZ 49.6783
105 PZ 79.1282
106 PZ 108.5780
107 PZ 138.0279
108 PZ 167.4778
109 PZ 196.9276
110 PZ 226.3775
111 PZ 255.8274
112 PZ 285.2772
113 PZ 314.7271
114 PZ 344.1770
115 PZ 373.6269
116 PZ 403.0767
117 PZ 432.5266
118 PZ 461.9765
119 PZ 491.4263
C Radial Detector DRB (1ft)
200 RCC 0.0000 0.0000 -98.6012 0.0000 0.0000 649.9574 80.2984
201 PZ -66.1033
202 PZ -33.6055
203 PZ -1.1076
204 PZ 31.3903
205 PZ 63.8882
206 PZ 96.3860
207 PZ 128.8839
208 PZ 161.3818
209 PZ 193.8796
210 PZ 226.3775
211 PZ 258.8754
212 PZ 291.3732
213 PZ 323.8711
214 PZ 356.3690
215 PZ 388.8669
216 PZ 421.3647
217 PZ 453.8626
218 PZ 486.3605
219 PZ 518.8583
C Radial Detector DRC (1m)
300 RCC 0.0000 0.0000 -168.1212 0.0000 0.0000 788.9974 149.8184
301 PZ -135.2463
302 PZ -102.3714
303 PZ -69.4965
304 PZ -36.6216
305 PZ -3.7467
306 PZ 29.1282
307 PZ 62.0030
```

Figure 5.3.20-6 Sample MCNP Input File – Normal Conditions (continued)

```
308 PZ 94.8779
309 PZ 127.7528
310 PZ 160.6277
311 PZ 193.5026
312 PZ 226.3775
313 PZ 259.2524
314 PZ 292.1273
315 PZ 325.0022
316 PZ 357.8771
317 PZ 390.7520
318 PZ 423.6269
319 PZ 456.5017
320 PZ 489.3766
321 PZ 522.2515
322 PZ 555.1264
323 PZ 588.0013
C Radial Detector DRD (2m)
400 RCC 0.0000 0.0000 -268.1212 0.0000 0.0000 988.9974 249.8184
401 PZ -226.9130
402 PZ -185.7048
403 PZ -144.4965
404 PZ -103.2883
405 PZ -62.0801
406 PZ -20.8719
407 PZ 20.3364
408 PZ 61.5446
409 PZ 102.7528
410 PZ 143.9611
411 PZ 185.1693
412 PZ 226.3775
413 PZ 267.5857
414 PZ 308.7940
415 PZ 350.0022
416 PZ 391.2104
417 PZ 432.4186
418 PZ 473.6269
419 PZ 514.8351
420 PZ 556.0433
421 PZ 597.2515
422 PZ 638.4598
423 PZ 679.6680
C Radial Detector DRE (2m+Convey)
500 RCC 0.0000 0.0000 -269.1212 0.0000 0.0000 990.9974 321.9200
501 PZ -227.8296
502 PZ -186.5381
503 PZ -145.2465
504 PZ -103.9550
505 PZ -62.6634
506 PZ -21.3719
507 PZ 19.9197
508 PZ 61.2113
```

Figure 5.3.20-6 Sample MCNP Input File – Normal Conditions (continued)

```
509 PZ 102.5028
510 PZ 143.7944
511 PZ 185.0859
512 PZ 226.3775
513 PZ 267.6691
514 PZ 308.9606
515 PZ 350.2522
516 PZ 391.5437
517 PZ 432.8353
518 PZ 474.1269
519 PZ 515.4184
520 PZ 556.7100
521 PZ 598.0015
522 PZ 639.2931
523 PZ 680.5846

C
C Materials List
C
C Homogenized U-Al Fuel
m1   92235 -1.7661E-01 92238 -1.9624E-02 13027 -8.0376E-01
C Water
m2   1001 6.6667E-01 8016 3.3333E-01
mt2  lwtr.01
C Water/Glycol
m3   1001 -1.03651E-01 8016 -6.75619E-01 6000 -2.20730E-01
C Aluminum
m4   13027 -1.0
C Lead
m5   82000 -1.0
C Stainless Steel 304
m6   26000 -0.695 24000 -0.190 28000 -0.095
     25055 -0.020
C Aluminum Honeycomb Impact Limiter
m7   13027 -1.0
C
C Cell Importances
imp:p 1 79r 0
C
C Source Definition - Fuel Gamma
C 30% burnup, wt % U-235, 14-year cool time, 2.786 g U-235 per rod, 0.003 W/rod
sdef RAD=d1 EXT=d2 ERG=d3 cell=100:62:d4:d5:d6:d7:1
    POS= 0.0000 0.0000 1.4950
    AXS= 0.0000 0.0000 1.0000
si1 0 0.5080
sp1 -21 1
si2 0 22.0000
sp2 -21 1
si3 1.000E-02 4.500E-02 1.000E-01 2.000E-01 3.000E-01 4.000E-01
    6.000E-01 8.000E-01 1.000E+00 1.330E+00 1.660E+00 2.000E+00
    2.500E+00 3.000E+00 4.000E+00 5.000E+00 6.500E+00 8.000E+00
```

Figure 5.3.20-6 Sample MCNP Input File – Normal Conditions (continued)

```
  1.000E+01
sp3 0.0000E+00 4.6619E+09 1.6170E+09 9.2992E+08 2.9371E+08 2.1001E+08
  1.5357E+08 6.8443E+09 3.0713E+07 1.9365E+07 3.4947E+06 5.3655E+05
  3.1683E+04 1.8502E+02 1.2818E+01 1.1290E-03 4.3894E-04 8.3643E-05
  1.7944E-05
si4 l 58 59
sp4 1.0 1.0
si5 l 51 52 53 54
sp5 1.0 1.0 1.0 1.0
si6 l 34 35 36 37
sp6 1.0 1.0 1.0 1.0
si7 l 6 7 8 9 10 11
   12 13 14 15 16 17
   18 19 20 21 22 23
   24 25 26 27 28 29
   30
sp7 1.0 1.0 1.0 1.0 1.0 1.0
  1.0 1.0 1.0 1.0 1.0 1.0
  1.0 1.0 1.0 1.0 1.0 1.0
  1.0 1.0 1.0 1.0 1.0 1.0
  1.0
mode p
nps 160000000
C
C ANSI/ANS-6.1.1-1977 - Gamma Flux-to-Dose Conversion Factors
C (mrem/hr)/(photons/cm2-sec)
de0 0.01 0.03 0.05 0.07 0.1 0.15 0.2
  0.25 0.3 0.35 0.4 0.45 0.5 0.55
  0.6 0.65 0.7 0.8 1 1.4 1.8
  2.2 2.6 2.8 3.25 3.75 4.25 4.75
  5 5.25 5.75 6.25 6.75 7.5 9
  11 13 15
df0 3.96E-03 5.82E-04 2.90E-04 2.58E-04 2.83E-04 3.79E-04 5.01E-04
  6.31E-04 7.59E-04 8.78E-04 9.85E-04 1.08E-03 1.17E-03 1.27E-03
  1.36E-03 1.44E-03 1.52E-03 1.68E-03 1.98E-03 2.51E-03 2.99E-03
  3.42E-03 3.82E-03 4.01E-03 4.41E-03 4.83E-03 5.23E-03 5.60E-03
  5.80E-03 6.01E-03 6.37E-03 6.74E-03 7.11E-03 7.66E-03 8.77E-03
  1.03E-02 1.18E-02 1.33E-02
C
C Weight Window Generation - Radial
wwg 2 0 0 0 0
wwp:p 5 3 5 0 -1 0
mesh geom=cyl ref=0 13 243 origin=0.1 0.1 -568
   imesh 16.8 17.0 18.9 33.3 36.5 49.2 49.8 549.8
   iints 1 1 1 5 1 1 1 1
   jmesh 500 541 550 558 568 577 1019 1020 1049 1089 1589
   jints 1 1 1 1 1 1 1 1 1 1 1
   kmesh 1
   kints 1
wwge:p 1e-3 1 20
fc2 Radial Surface Tally
```

Figure 5.3.20-6 Sample MCNP Input File – Normal Conditions (continued)

```
f2:p +100.1
fm2 1.18116E+13
fs2 -101 -102 -103 -104 -105 -106
   -107 -108 -109 -110 -111 -112
   -113 -114 -115 -116 -117 -118
   -119 T
tf2
fc12 Radial 1ft Tally
f12:p +200.1
fm12 1.18116E+13
fs12 -201 -202 -203 -204 -205 -206
   -207 -208 -209 -210 -211 -212
   -213 -214 -215 -216 -217 -218
   -219 T
tf12
fc22 Radial 1m Tally
f22:p +300.1
fm22 1.18116E+13
fs22 -301 -302 -303 -304 -305 -306
   -307 -308 -309 -310 -311 -312
   -313 -314 -315 -316 -317 -318
   -319 -320 -321 -322 -323 T
tf22
fc32 Radial 2m Tally
f32:p +400.1
fm32 1.18116E+13
fs32 -401 -402 -403 -404 -405 -406
   -407 -408 -409 -410 -411 -412
   -413 -414 -415 -416 -417 -418
   -419 -420 -421 -422 -423 T
tf32
fc42 Radial 2m+Convey Tally
f42:p +500.1
fm42 1.18116E+13
fs42 -501 -502 -503 -504 -505 -506
   -507 -508 -509 -510 -511 -512
   -513 -514 -515 -516 -517 -518
   -519 -520 -521 -522 -523 T
tf42
C
C Print Control
prdmp -30 -60 1 2
print
C Random Number Generator
rand gen=2 seed=15617098509349 stride=152917 hist=1
```

Figure 5.3.20-7 Normal Condition Radial Surface Dose Rate Profile by Source Type – SLOWPOKE Fuel

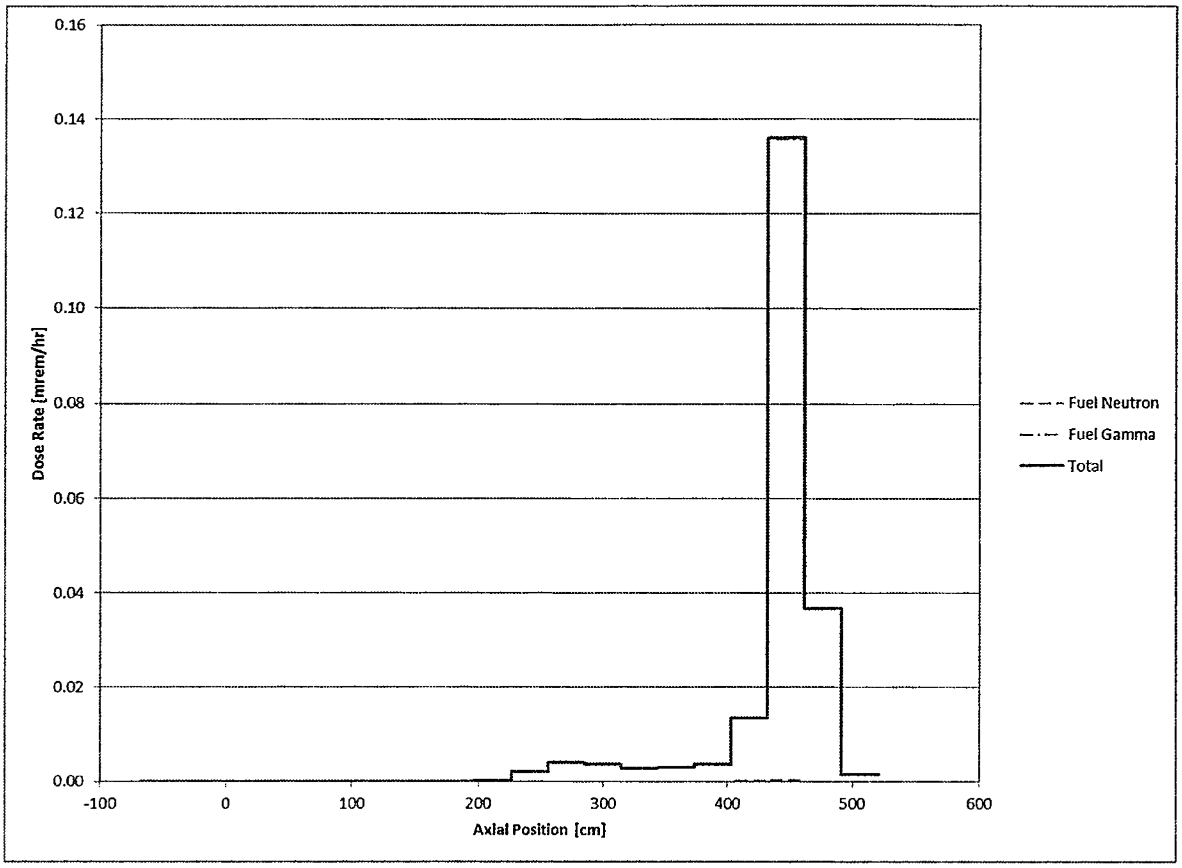


Figure 5.3.20-8 Normal Condition 2-m Radial Surface Dose Rate Profile by Source Type – SLOWPOKE Fuel

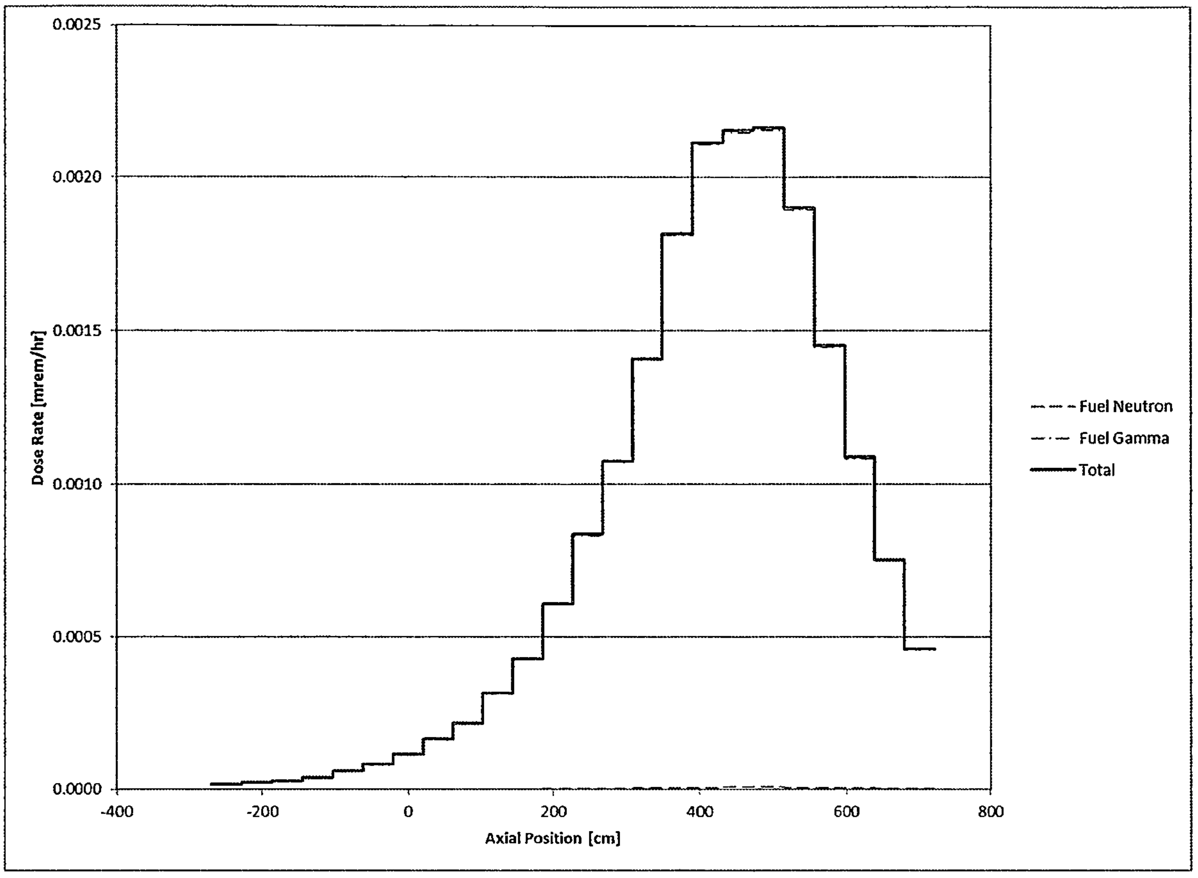


Figure 5.3.20-9 Accident Condition Radial 1m Dose Rate Profile by Source Type – SLOWPOKE

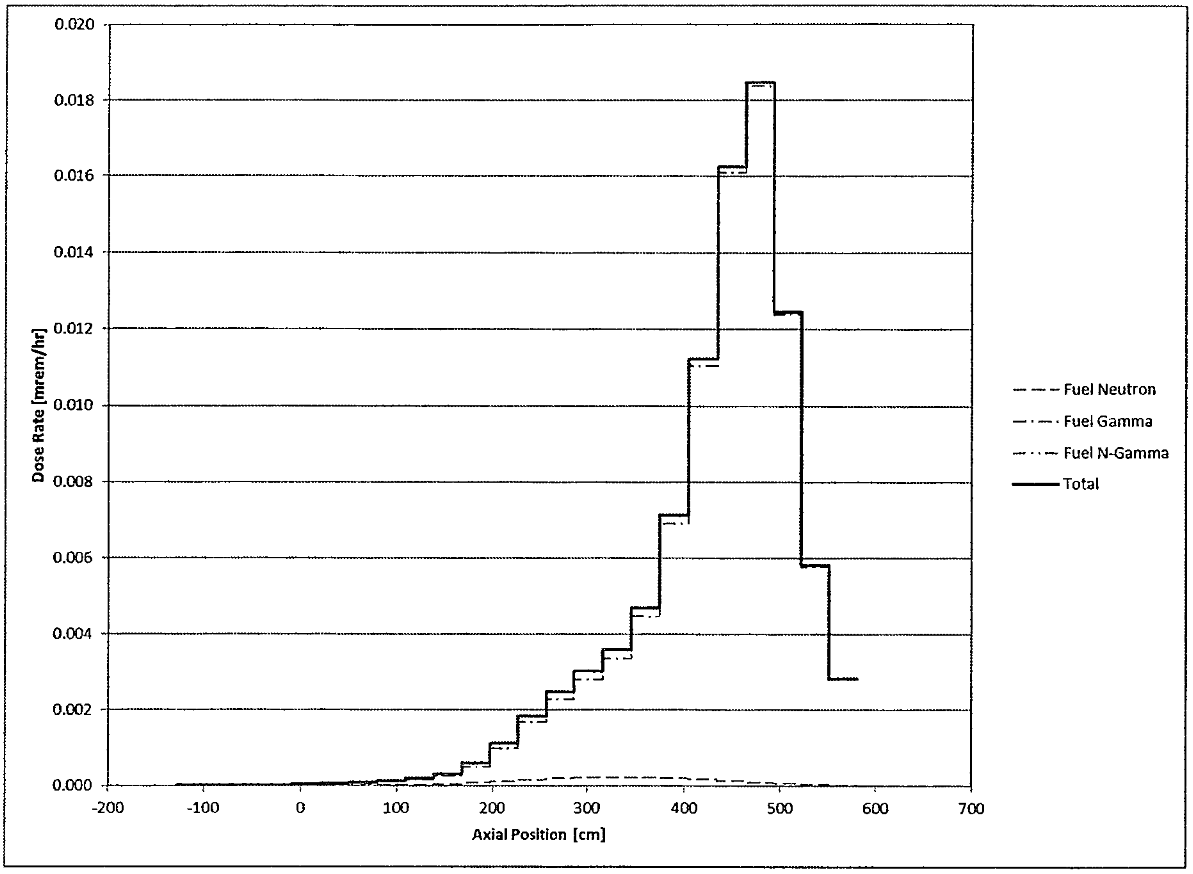


Table 5.3.20-1 SLOWPOKE Fuel Geometry and Materials

Fuel Element Type		Rod
Chemical Form		U-Al Alloy
Active Fuel Length	cm	22
Active Fuel Diameter	cm	0.422
Weight of U-235	g	2.786
Weight of total U	g	2.990
Alloy or compound material weight	g	7.688
Total weight of fuel meat	g	10.678
Clad Thickness	cm	0.051
Clad Weight (including caps)	g	4.981
Clad Material		Aluminum
Element Length	cm	22.83
Diameter (endcaps)	cm	0.61
Diameter (clad)	cm	0.53
Total weight of fuel element	g	15.659
Enrichment %	%	93
Burn Time	hrs	32000
Core Maximum Power	kW	20
Maximum Burnup (^{235}U depletion)	%	2

Table 5.3.20-2 Source Term Generation Parameters for SLOWPOKE Fuel

Parameter	Value
U Mass Per Rod (grams)	3.1
Core Power (kW)	20
Number of Hours Burned	35280
Number of Years Cooled	14
Number of Rods / Core	315
Initial Enrichment (wt % ^{235}U)	90
Burnup (% ^{235}U)	4.5
Burnup (GWd/MTU)	30
Moderator/Box Temperature (C)	40
Clad Temperature (C)	90
Fuel Temperature (C)	100

Table 5.3.20-3 SLOWPOKE Neutron Source Term (per MTU)

Group	E Lower [MeV]	E Upper [MeV]	Source [neutrons/sec]
1	6.380E+00	2.000E+01	8.392E+01
2	3.010E+00	6.380E+00	1.239E+03
3	1.830E+00	3.010E+00	2.221E+04
4	1.420E+00	1.830E+00	5.368E+04
5	9.070E-01	1.420E+00	9.340E+04
6	4.080E-01	9.070E-01	8.055E+04
7	1.110E-01	4.080E-01	3.950E+04
8	1.500E-02	1.110E-01	4.675E+03
9	3.040E-03	1.500E-02	1.404E+02
10	5.830E-04	3.040E-03	1.121E+01
11	1.010E-04	5.830E-04	1.063E+00
12	2.900E-05	1.010E-04	2.284E-02
13	1.070E-05	2.900E-05	3.852E-03
14	3.060E-06	1.070E-05	1.625E-04
15	1.860E-06	3.060E-06	1.011E-05
16	1.300E-06	1.860E-06	3.875E-06
17	1.130E-06	1.300E-06	1.030E-06
18	1.000E-06	1.130E-06	6.480E-07
19	8.000E-07	1.000E-06	1.132E-06
20	4.140E-07	8.000E-07	1.586E-06
21	3.250E-07	4.140E-07	2.069E-07
22	2.250E-07	3.250E-07	3.119E-07
23	1.000E-07	2.250E-07	2.064E-07
24	5.000E-08	1.000E-07	6.687E-08
25	3.000E-08	5.000E-08	3.531E-08
26	1.000E-08	3.000E-08	9.255E-11
27	1.000E-11	1.000E-08	5.251E-11
Total			2.955E+05

Table 5.3.20-4 SLOWPOKE Fuel Gamma Source Term (per MTU)

Group	E Lower [MeV]	E Upper [MeV]	Source [photons/sec]
1	8.00E+00	1.00E+01	5.7677E+00
2	6.50E+00	8.00E+00	2.6885E+01
3	5.00E+00	6.50E+00	1.4109E+02
4	4.00E+00	5.00E+00	3.6288E+02
5	3.00E+00	4.00E+00	4.1202E+06
6	2.50E+00	3.00E+00	5.9472E+07
7	2.00E+00	2.50E+00	1.0184E+10
8	1.66E+00	2.00E+00	1.7246E+11
9	1.33E+00	1.66E+00	1.1233E+12
10	1.00E+00	1.33E+00	6.2244E+12
11	8.00E-01	1.00E+00	9.8721E+12
12	6.00E-01	8.00E-01	2.2000E+15
13	4.00E-01	6.00E-01	4.9361E+13
14	3.00E-01	4.00E-01	6.7505E+13
15	2.00E-01	3.00E-01	9.4406E+13
16	1.00E-01	2.00E-01	2.9890E+14
17	4.50E-02	1.00E-01	5.1975E+14
18	1.00E-02	4.50E-02	1.4985E+15
Total			4.7457E+15

Table 5.3.20-5 Fuel Homogenization for SLOWPOKE Fuel

Component	Area [cm^2]	Area Fraction
Fuel	1.3987E-01	1.7252E-01
Gap	4.0055E-03	4.9406E-03
Clad	7.6746E-02	9.4663E-02
Void	5.9011E-01	7.2788E-01
Total	8.1073E-01	1.0000E+00

Note: Homogenization limited to smear of fuel rod within aluminum canister tube.

Table 5.3.20-6 Canister/Basket/Cask Material Descriptions for SLOWPOKE Fuel

Material	Element	Density [g/cm^3]	Number Density [atom/b-cm]
Aluminum	Al	2.67	7.278E-02
Stainless Steel 304	Fe	7.94	5.9505E-02
	Cr		1.7472E-02
	Ni		7.7392E-03
	Mn		1.7407E-03
Lead	Pb	11.34	3.2967E-02
Neutron Shield	H	0.97	5.9884E-02
	O		2.4595E-02
	C		1.0701E-02
Impact Limiter	Al	0.50	1.1153E-02

Table 5.3.20-7 Canister Dimensions SLOWPOKE Fuel

Description	Dimension [in]
CANISTER:	
Bottom Plate Thickness	0.375
Lid Thickness	1.00
OD	3.30
ID	2.80
Side Wall Height	39.44
Bottom Plate Inset 1	0.130
Bottom Plate Inset 2	0.060
Lid Lower Bottom Thickness	0.38
Lid Top Width	3.30
Lid Bottom Width	2.75
Lid Handle Height	2.500
CANISTER INSERT:	
Tube Length	9.25
Tube OD	0.50
Tube ID	0.40
Base Plate Thickness	0.25
Base Plate Width	2.50

Table 5.3.20-8 Maximum and Average Dose Rates for SLOWPOKE Fuel

Transport Condition	Dose Rate Location	Maximum		Average	
		[mrem/hr]	FSD	[mrem/hr]	FSD
Normal	Side Surface of Cask	0.14	7.6%	0.01	23.0%
	Top Surface of Cask	0.004	8.4%	0.002	14.9%
	Bottom Surface of Cask	< 0.00001	--	< 0.00001	--
	Side 1m (Transport Index)	0.01	7.1%	0.002	12.6%
	2m from Truck - Radial	0.002	7.6%	0.001	9.8%
	2m from Top	0.0004	58.3%	0.0004	47.7%
	2m from Bottom	< 0.00001	--	< 0.00001	--
	Edge of Truck - Top	0.0001	30.1%	0.00004	36.2%
	Edge of Truck - Bottom	< 0.00001	--	< 0.00001	--
	Dose at Cab of Truck	0.00005	37.2%	0.00003	46.0%
Accident	Side Surface of Cask	0.29	8.8%	0.02	24.5%
	Top Surface of Cask	0.03	8.6%	0.01	12.6%
	Bottom Surface of Cask	< 0.00001	--	< 0.00001	--
	Side 1m	0.02	7.9%	0.004	12.5%
	Top 1m	0.002	7.4%	0.001	9.7%
	Bottom 1m	< 0.00001	--	< 0.00001	--

Table 5.3.20-9 Summarized Maximum Dose Rates for SLOWPOKE Fuel

Transport Condition	Dose Rate Location	Maximum [mrem/hr]	Limit [mrem/hr]
Normal	Side Surface of Cask	0.14	200
	Side 1m (Transport Index)	0.01	10
	2m from Truck - Radial	0.002	N/A
Accident	Side 1m	0.02	1000

5.3.21 NRU and NRX Fuel Assemblies

Results of the shielding evaluation for up to 18 NRU (HEU or LEU) or up to 18 NRX fuel assemblies in the LWT cask are presented in this section. Fuel in undamaged and damaged configuration was considered for the shielding evaluation. The undamaged fuel configuration considers structurally sound rod or assemblies (i.e., any fuel not composed of rod section / broken rods). The NRU/NRX fuel is composed of a metal alloy and is not expected to fail during transport and will not produce rubble. Also included is a conservative damaged fuel configuration that analyzes the fuel collapsed at the top of the basket tubes to bound any hypothetical fuel reconfiguration. Both undamaged and damaged configuration are analyzed under normal and accident operating conditions to demonstrate compliance with 10 CFR 71.47 and 10 CFR 71.51.

NRU HEU, NRU LEU, and NRX HEU Source Terms

Source terms are calculated to bound the NRU and NRX assemblies using TRITON in SCALE 6.1. The TRITON models use the 238 group ENDF/B-VII library. Single unit cells were used for the TRITON source term calculation. The single unit cell (assembly reflected) was compared against a model using supercells (assembly plus surrounding incore material) to define surrounding fuel assemblies. The single unit cell was determined to be more conservative for neutron source terms and is not significantly different for gamma source terms which dominate dose rate contributions for the material. Unit cells were modeled using dimensions specified in AECL provided drawings. The assemblies are shown in Figure 5.3.21-1 and Figure 5.3.21-2 for the NRU and NRX assemblies, respectively. Key assembly dimensions are provided in Table 5.3.21-1 and Table 5.3.21-2 for the NRU and NRX assembly respectively.

NRU source terms are calculated using detailed operating histories for HEU and LEU fuel provided by AECL. NRX source terms are calculated using the maximum reactor power and ^{235}U Core Loading. The evaluated fuel material properties are provided in Table 5.3.21-3. The fuel material composition for the bounding properties is shown in Table 5.3.21-4. All sources are calculated for a ^{235}U depletion of greater than 80%. NRU LEU is composed of U_3-Si-Al. All Si is modeled as Al as aluminum will produce bounding neutron source terms due to (alpha,n) neutron production.

The TRITON inputs for all source term calculations are provided in Figure 5.3.21-3 through Figure 5.3.21-6. The comparison of neutron and gamma source terms for the single cell and supercell TRITON models are provided in Table 5.3.21-5 and Table 5.3.21-6, respectively. All source spectra are provided for each fuel type in Table 5.3.21-7 through Table 5.3.21-12.

For NAC thermal evaluations an alternative heat load for NRU LEU fuel is calculated that models a burnup of 347 MWd as oppose to the 363 MWd burnup for shielding evaluations. The burnup of 347 MWd still bounds the actual NRU LEU burnup of 327 MWd. The final burnup calculated in TRITON for the thermal evaluation heat load is 80.4%. The calculated heat load for thermal evaluations is 34 W/assembly (612 W for the loaded LWT). All shielding evaluations use the more conservative higher burnup source terms.

NRU and NRX Shielding Models

MCNP three dimensional shielding analysis allows detailed modeling of the source material, basket assembly, and cask shield configurations. The basket and cask are modeled as described in the license drawings. The basket spacer and lid collar have been conservatively omitted, but all axial extents are included to retain source position.

The geometric description of a MCNP model is based on the combinatorial geometry system embedded in the code. In this system, bodies such as cylinders and rectangular parallelepipes and their logical intersections and unions are used to describe the extent of material zones.

Both undamaged and damaged fuel configurations are analyzed under normal and accident operating conditions. The undamaged fuel configuration includes NRU and NRX pins modeled as cropped for loading in the LWT. The damaged fuel configuration collapses the fuel in the basket tubes fully. Collapsed fuel is modeled at the nominal fuel density. The fuel meat alloy will not compact as a result of any transport condition. Collapsed models do not include clad or end plug material. The fuel and basket have been shifted towards the top of the LWT cavity. The radial lead gamma shield extends from the bottom of the NAC-LWT cavity to approximately 3 inches (7.62 cm) below the top of the cavity. Positioning the fissile material closest to the point of minimum gamma shielding is conservative.

The accident conditions of transport include the loss of neutron shielding material. The neutron shielding shell and the impact limiters are also removed while modeling accident conditions.

While normal conditions include a gap between the lead and outer shell, lead slump is not evaluated for accident conditions as NAC procedures dictate that the lead is allowed to cool from the lowest point with molten lead from the top filling gaps formed during solidification. Therefore no gap is expected to occur and further accident analyses detailing potential shifting of the lead gap are not necessary.

Detailed model parameters used in creating the three-dimensional model are taken directly from the License Drawings. Elevations associated with the three-dimensional features are established with respect to the center bottom of the NAC-LWT cask cavity for the MCNP combinatorial model. Material compositions for structural and shield materials are shown in Table 5.3.21-13. The three-dimensional NAC-LWT MCNP models are shown in Figure 5.3.21-7 through Figure

5.3.21-9 while sketches are shown in Figure 5.3.21-11 and Figure 5.3.21-12. Figure 5.3.21-10 shows a VISED comparison of the fuel detail for the undamaged and collapsed fuel models. Selected basket dimensions critical to model and dose results are listed in Table 5.3.21-14. A sample MCNP input file is provided in Figure 5.3.21-13.

NRU and NRX Fuel Shielding Evaluation

The shielding evaluation is performed using MCNP5 v1.60. The MCNP shielding model is utilized with the source terms to estimate the dose rate profiles at various distances from the side, top and bottom of the cask for both normal and accident conditions. The method of solution is continuous energy Monte Carlo with a Monte Carlo based weight window generator to accelerate code convergence. Weight window and problem convergence is verified by the 10 statistical checks performed by MCNP. Radial or axial biasing is performed depending on the desired dose location.

The ANSI/ANS 6.1.1-1977 flux-to-dose rate conversion factors are employed in the MCNP analysis. The ANSI/ANS neutron and gamma dose conversion factors are shown in Table 5.3.21-15 and Table 5.3.21-16, respectively.

NRU and NRX Dose Rates

Dose rates were computed for the three fuel sources (NRU HEU, NRU LEU, and NRX HEU) for both undamaged and collapsed configurations. NRU HEU dose rates (normal and accident) for both the undamaged and collapsed fuel configurations are summarized in Table 5.3.21-17 and Table 5.3.21-18, respectively. NRU LEU dose rates (normal and accident) for both the undamaged and collapsed fuel configurations are summarized in Table 5.3.21-19 and Table 5.3.21-20, respectively. NRX dose rates (normal and accident) for both the undamaged and collapsed fuel configurations are summarized in Table 5.3.21-21 and Table 5.3.21-22, respectively.

Results are summarized and compared to dose rate limits in Table 5.3.21-23 and Table 5.3.21-24 for undamaged and collapsed fuel, respectively. NRU LEU fuel provides the maximum dose rates for all dose rate limits. A payload of 18 assemblies for NRU or NRX fuel is found to be in compliance of 10 CFR 71.47 and 10 CFR 71.51 for an exclusive use shipment. Dose rate profiles for the maximum dose rate cases are provided Figure 5.3.21-14 through Figure 5.3.21-16.

Figure 5.3.21-1 Sketch of NRU Assembly

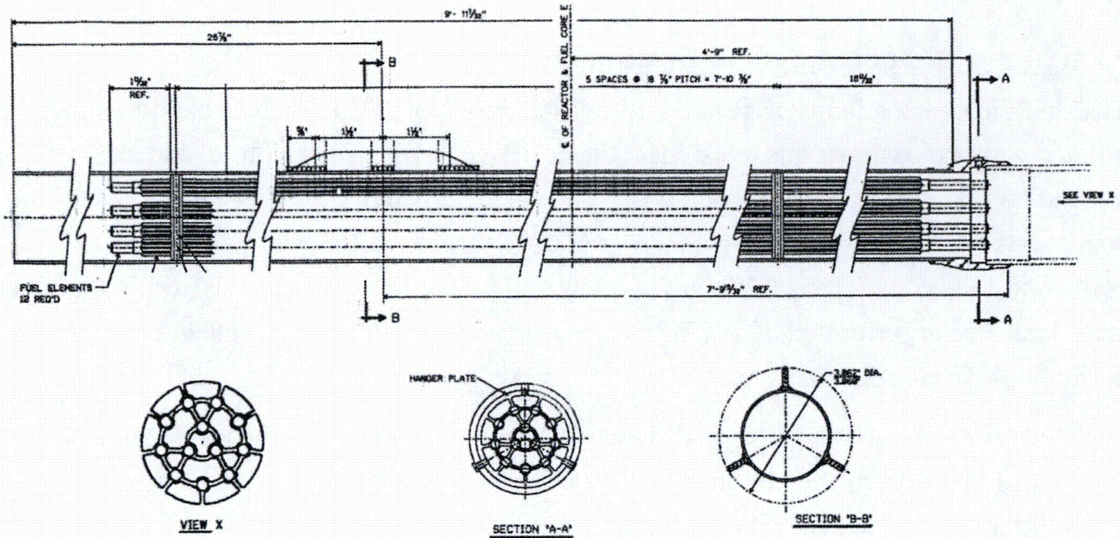


Figure 5.3.21-2 Sketch of NRX Assembly

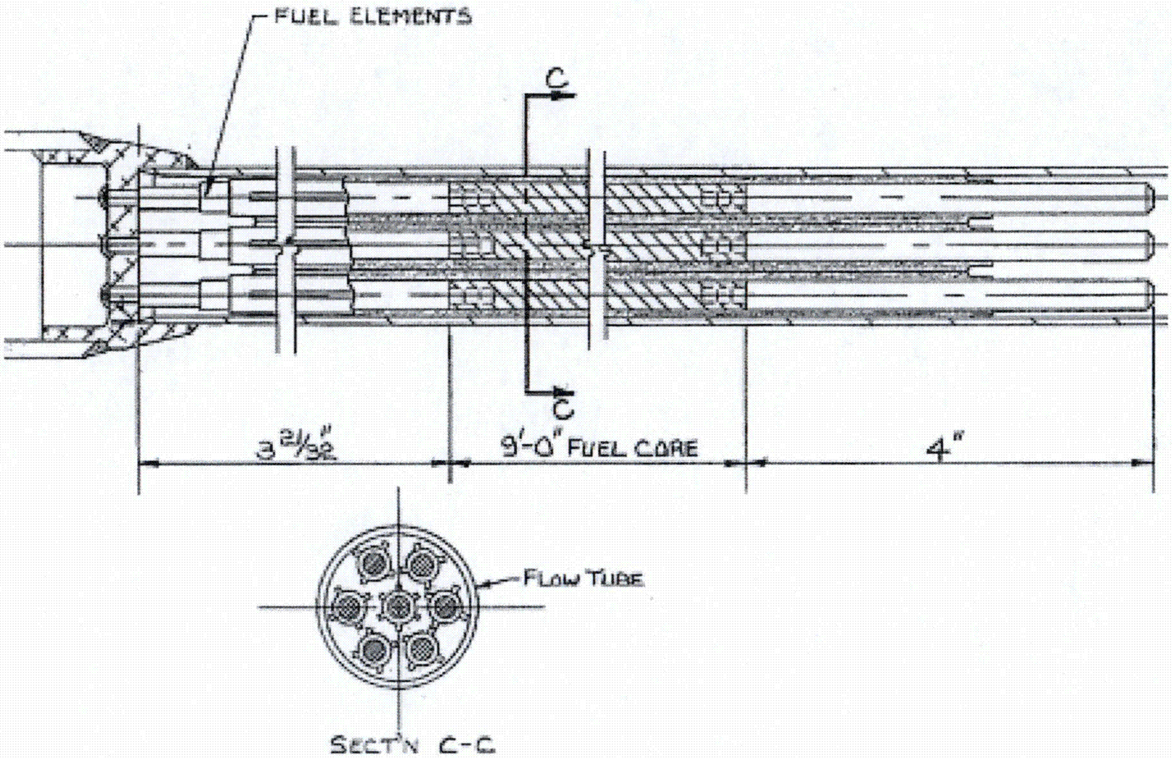


Figure 5.3.21-3 TRITON Input for NRU HEU Single Unit Cell

```
=t-depl
NRU CORE NEWT / CENTRM Depletion
V7-238
read comp
WTPTUAl  1  3.288  3  13000 77.570 92235 20.411  92238  2.019  1.0  373.0 END
AL   2  1.0  363.0  END
H2O  3  DEN=1.1  0.0015  311  END
D2O  3  DEN=1.1  0.9985  311  END
AL   4  1.0  309  END
H2O  5  DEN=1.1  0.00150  307  END
D2O  5  DEN=1.1  0.9984  307  END
b    5  DEN=1.1  0.0001 307  END
end comp
read celldata
latticecell triangpitch pitch=1.133 3 fueld=0.5486 1 cladd=0.7101 2 end
end celldata
read depletion -1 end depletion
read opus
matl= 1 end units=grams
new case
units=watts
new case
typarams=gspectrum
units=part
new case
typarams=nspectrum
units=part
end opus
read burndata
' power history
Power=2.321E+03  Burn=45  Down=0  nlib=5 end
Power=2.708E+03  Burn=135  Down=0  nlib=5 end
Power=1.355E+03  Burn=120  Down=6935  nlib=5 end
end burndata
read timetable
density 5 1 5010
0.0  1.08
22.50 0.96
92.50 0.75
150.50  0.50
250.5  0.25
280.0  0.13
320.0  0.05 end
end timetable
read model
NRU Core
read parm
  prtflux=no  drawit=yes   collapse=yes
  xnlib=4 run=yes prtmxsec=no prtbroad=no
  prtmxtab=yes cmfd=no echo=yes
end parm
read materials
  1 1 !fuel u-al! end
  2 1 !fuel clad! end
  3 2 !heavy water! end
  4 1 !flow tube! end
  5 2 !heavy water! end
end materials
read geom
' Fuel Pin
unit 1
cylinder 1 0.2745
cylinder 2 0.3761
media 1 1 1
media 2 1 2 -1
boundary 2 4 4
' Global unit
```

Figure 5.3.21-3 TRITON Input for NRU HEU Single Unit Cell (continued)

```
global unit 10
cylinder 10 2.4994
cylinder 20 2.6327
hexprism 50 9.85
hole 1 origin x=0.6502
hole 1 origin x=-0.3251 y=0.5631
hole 1 origin x=-0.3251 y=-0.5631
hole 1 origin x=1.6183 y=0.5890
hole 1 origin x=0.8611 y=1.4914
hole 1 origin x=-0.2990 y=1.6960
hole 1 origin x=-1.3192 y=1.1070
hole 1 origin x=-1.7221
hole 1 origin x=-1.3192 y=-1.1070
hole 1 origin x=-0.2990 y=-1.6960
hole 1 origin x=0.8611 y=-1.4914
hole 1 origin x=1.6183 y=-0.5890
media 3 1 10
media 4 1 20 -10
media 5 1 50 -20
boundary 50 50 50
end geom
read bounds all=white end bounds
end model
end
```

Figure 5.3.21-4 TRITON Input for NRU HEU Supercell Model

```
=t-depl
NRU CORE NEWT / CENTRM Depletion
V7-238
read composition
WTPTUAl  1  3.288  3  13000 77.570 92235 20.411  92238  2.019  1.0  373.0 END
AL   4  1.0  363.0  END
H2O  7  DEN=1.1  0.0015  311  END
D2O  7  DEN=1.1  0.9985  311  END
AL   10  1.0  309  END
H2O  11  DEN=1.1  0.0015  307  END
D2O  11 DEN=1.1  0.9985  307  END
WTPTsc1  2  1.1  4  1002 19.62  1001 0.01  8016 78.61  92235 1.76 1.0 307 END
AL   5  1.0  363.0  END
H2O  8  DEN=1.1  0.0015  311  END
D2O  8  DEN=1.1  0.9985  311  END
WTPTsc2  3  1.1  4  1002 19.65  1001 0.02  8016 78.74  92235 1.59 1.0 307 END
AL   6  1.0  363.0  END
H2O  9  DEN=1.1  0.0015  311  END
D2O  9  DEN=1.1  0.9985  311  END
WTPTb1  13  1.1  4  1002 19.97  1001 0.02  8016 80.00  5010 0.01 1.0 307 END
end composition
read celldata
latticecell triangpitch pitch=1.133 7 fueld=0.5486 1 cladd=0.7101 4 end
latticecell triangpitch pitch=1.133 8 fueld=0.5486 2 cladd=0.7101 5 end
latticecell triangpitch pitch=1.133 9 fueld=0.5486 3 cladd=0.7101 6 end
end celldata
read depletion -1 2 3 end depletion
read opus
matl= 1 end units=grams
new case
units=watts
new case
typarams=gspectrum
units=part
new case
typarams=nspectrum
units=part
end opus
read burndata
' power history
Power=2.321E+03  Burn=45  Down=0  nlib=10 end
Power=2.708E+03  Burn=135  Down=0  nlib=10 end
Power=1.355E+03  Burn=120  Down=6935  nlib=10 end
end burndata
read timetable
density 13 1 5010
0.0 1.26
22.50 0.94
92.50 0.67
150.50  0.25
200.0  0.15
250.5  0.10
290.0  0.00 end
end timetable
read model
NRU Core
read parm
```

Figure 5.3.21-4 TRITON Input for NRU HEU Supercell Model (continued)

```
  prtflux=no  drawit=yes   collapse=yes
  xnlib=4 run=yes prtmxsec=no prtbroad=no
  prtmxtab=yes cmfd=no echo=yes   outers=500
end parm
read materials
  1 1 !fuel u-al! end
  4 1 !fuel clad! end
  7 2 !heavy water! end
  10 1 !flow tube! end
  11 2 !heavy water! end
  2 1 !supercell 1! end
  3 1 !supercell 2! end
  13 2 !boron ring! end
end materials
read geom
' Fuel Pin
unit 1
cylinder 1 0.2745
cylinder 2 0.3761
media 1 1 1
media 4 1 2 -1
boundary 2 4 4
' Fuel Assembly
unit 2
' Flow Tube
cylinder 10 2.4994
cylinder 20 2.6327
hole 1 origin x=0.6502
hole 1 origin x=-0.3251 y=0.5631
hole 1 origin x=-0.3251 y=-0.5631
hole 1 origin x=1.6183 y=0.5890
hole 1 origin x=0.8611 y=1.4914
hole 1 origin x=-0.2990 y=1.6960
hole 1 origin x=-1.3192 y=1.1070
hole 1 origin x=-1.7221
hole 1 origin x=-1.3192 y=-1.1070
hole 1 origin x=-0.2990 y=-1.6960
hole 1 origin x=0.8611 y=-1.4914
hole 1 origin x=1.6183 y=-0.5890
media 7 1 10
media 10 1 20 -10
boundary 20 50 50
' Global unit
global unit 10
' Unit Cell
hexprism 50 9.85
' Supercell 1 - 2.394g U235/cm
cylinder 60 19.2
cylinder 70 20.2
' Supercell 2 - 4.341g U235/cm
cylinder 80 38.9
cylinder 90 39.9
' Boron ring to adjust k-eff
cylinder 100 60.0
cylinder 110 61.0
hexprism 120 70.0
hole 2
```

Figure 5.3.21-4 TRITON Input for NRU HEU Supercell Model (continued)

```
media 11 1 50
media 11 1 60 -50
media 2 1 70 -60
media 11 1 80 -70
media 3 1 90 -80
media 11 1 100 -90
media 13 1 110 -100
media 11 120 -110
boundary 120 10 10
end geom
read bounds all=white end bounds
end model
end
```

Figure 5.3.21-5 TRITON Input for NRU LEU Single Unit Cell

```
=t-depl
NRU CORE NEWT / CENTRM Depletion
v7-238
read comp
WTPTUA1  1  3.288  3  13000 37.838 92235 11.811  92238  50.351  1.0  373.0 END
AL   2  1.0  363.0  END
H2O  3  DEN=1.1  0.0015  311  END
D2O  3  DEN=1.1  0.9985  311  END
AL   4  1.0  309  END
H2O  5  DEN=1.1  0.00150  307  END
D2O  5  DEN=1.1  0.9984  307  END
b    5  DEN=1.1  0.0001 307  END
end comp
read celldata
latticecell triangpitch pitch=1.133 3 fueld=0.5486 1 cladd=0.7101 2 end
end celldata
read depletion -1 end depletion
read opus
matl= 1 end units=grams
new case
units=watts
new case
typarams=gspectrum
units=part
new case
typarams=nspectrum
units=part
end opus
read burndata
' power history
Power=4.844E+02  Burn=45  Down=0  nlib=2  end
Power=5.667E+02  Burn=135  Down=0  nlib=2  end
Power=2.783E+02  Burn=120  Down=1095  nlib=2  end
end burndata
read timetable
density 5 1 5010
0.0  0.75
22.50 0.65
92.50 0.52
150.50  0.30
250.5  0.18
280.0  0.09 end
end timetable
read model
NRU Core
read parm
  prtflux=no  drawit=yes   collapse=yes
  xnlib=4 run=yes prtmxsec=no prtbroad=no
  prtmxtab=yes cmfd=no echo=yes
end parm
read materials
  1 1 !fuel u-al! end
  2 1 !fuel clad! end
  3 2 !heavy water! end
  4 1 !flow tube! end
  5 2 !heavy water! end
end materials
```

Figure 5.3.21-5 TRITON Input for NRU LEU Single Unit Cell (continued)

```
read geom
' Fuel Pin
unit 1
cylinder 1 0.2745
cylinder 2 0.3761
media 1 1 1
media 2 1 2 -1
boundary 2 4 4
' Global unit
global unit 10
cylinder 10 2.4994
cylinder 20 2.6327
hexprism 50 9.85
hole 1 origin x=0.6502
hole 1 origin x=-0.3251 y=0.5631
hole 1 origin x=-0.3251 y=-0.5631
hole 1 origin x=1.6183 y=0.5890
hole 1 origin x=0.8611 y=1.4914
hole 1 origin x=-0.2990 y=1.6960
hole 1 origin x=-1.3192 y=1.1070
hole 1 origin x=-1.7221
hole 1 origin x=-1.3192 y=-1.1070
hole 1 origin x=-0.2990 y=-1.6960
hole 1 origin x=0.8611 y=-1.4914
hole 1 origin x=1.6183 y=-0.5890
media 3 1 10
media 4 1 20 -10
media 5 1 50 -20
boundary 50 50 50
end geom
read bounds all=white end bounds
end model
end
```

Figure 5.3.21-6 TRITON Input for NRX Single Unit Cell

```
=t-depl
NRX CORE NEWT / CENTRM Depletion
V7-238
read comp
WTPTUA1  1   3.2088   3   13000 68.929 92235 28.275   92238   2.796   1.0   373.0 END
AL    2   1.0   363.0   END
H2O   3   DEN=1.1   0.0015   311   END
D2O   3   DEN=1.1   0.9985   311   END
AL    4   1.0   309   END
H2O   5   DEN=1.1   0.00150   307   END
D2O   5   DEN=1.1   0.9984   307   END
b     5   DEN=1.1   0.0001 307   END
AL   6 1.0 307 END
end comp
read celldata
latticecell triangpitch pitch=1.054 3 fueld=0.635 1 cladd=0.8181 2 end
end celldata
read depletion -1 end depletion
read opus
matl= 1 end units=grams
new case
units=watts
new case
typarams=gspectrum
units=part
new case
typarams=nspectrum
units=part
end opus
read burndata
' power history
 Power= 1.685E+03  Burn=365  Down=6570  nlib=10 end
end burndata
read timetable
density 5 1 5010
0.0  1.22
22.50 1.06
92.50 0.93
150.50  0.82
250.5  0.55
280.0  0.42
320.0  0.32
365.0  0.15 end
end timetable
read model
NRX Core
read parm
  prtflux=no  drawit=yes   collapse=yes
  xnlib=4 run=yes prtmxsec=no prtbroad=no
  prtmxtab=yes cmfd=no echo=yes outers=500
end parm
read materials
  1 1 !fuel u-al! end
  2 1 !fuel clad! end
  3 2 !heavy water! end
  4 1 !flow tube! end
  5 2 !heavy water! end
```

Figure 5.3.21-6 TRITON Input for NRX Single Unit Cell (continued)

```
  6 1 !guide tube! end
end materials
read geom
' Fuel Pin
unit 1
cylinder 1 0.3175
cylinder 2 0.4090
media 1 1 1
media 2 1 2 -1
boundary 2 4 4
' Global unit
global unit 10
cylinder 10 1.5761
cylinder 20 1.7539
cylinder 30 2.8573
cylinder 40 3.0163
hexprism 50 8.6519
hole 1
hole 1 origin x=1.0541
hole 1 origin x=0.5271 y=0.913
hole 1 origin x=-0.5271 y=0.913
hole 1 origin x=-1.0541 y=0.000
hole 1 origin x=-0.5271 y=-0.913
hole 1 origin x=0.5271 y=-0.913
media 3 1 10
media 4 1 20 -10
media 5 1 30 -20
media 6 1 40 -30
media 5 1 50 -40
boundary 50 50 50
end geom
read bounds all=white end bounds
end model
end
```

Figure 5.3.21-7 VISED Sketch of LWT with NRU Fuel Radial Detail

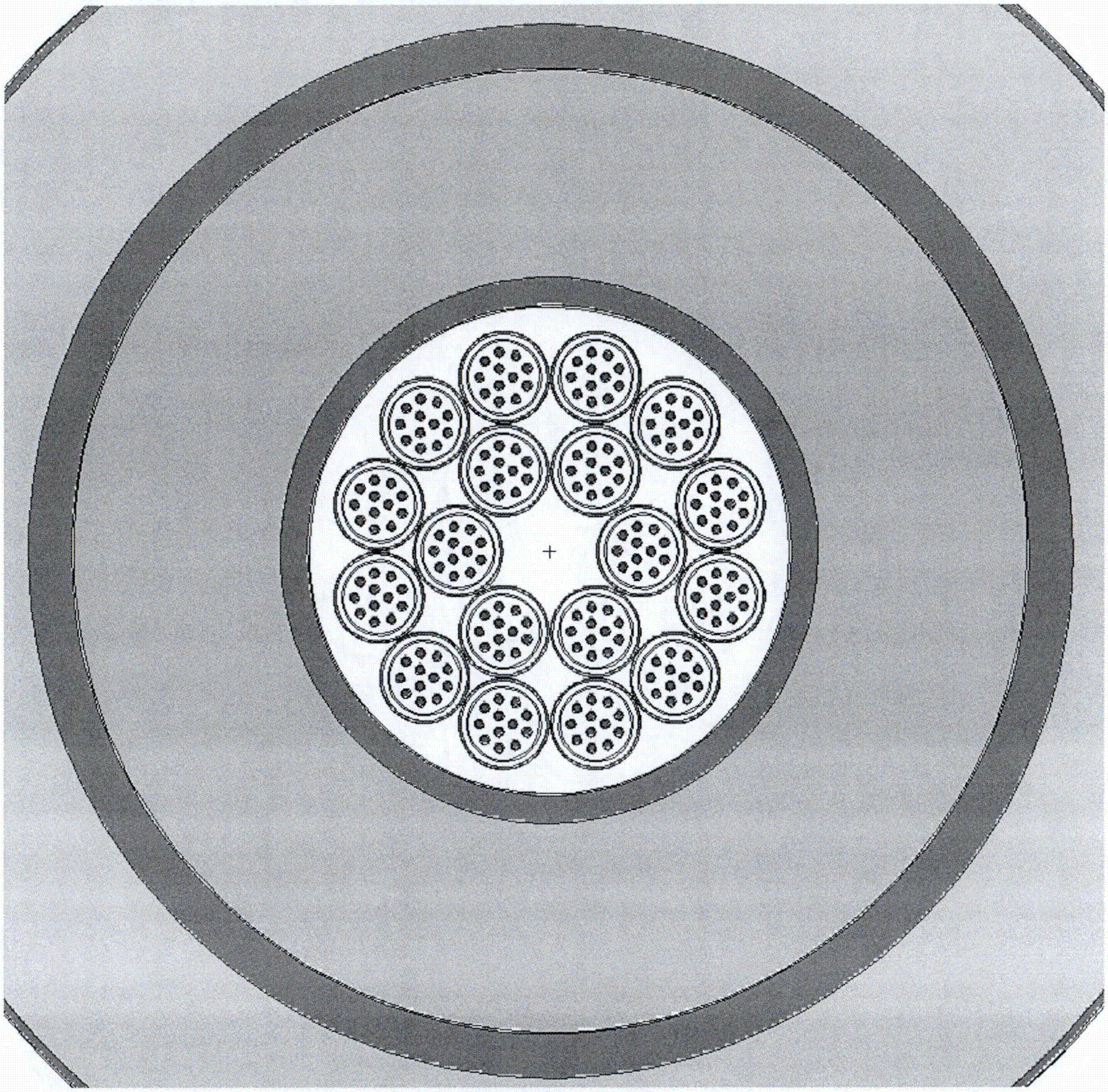


Figure 5.3.21-8 VISED Sketch of LWT with NRX Fuel Radial Detail

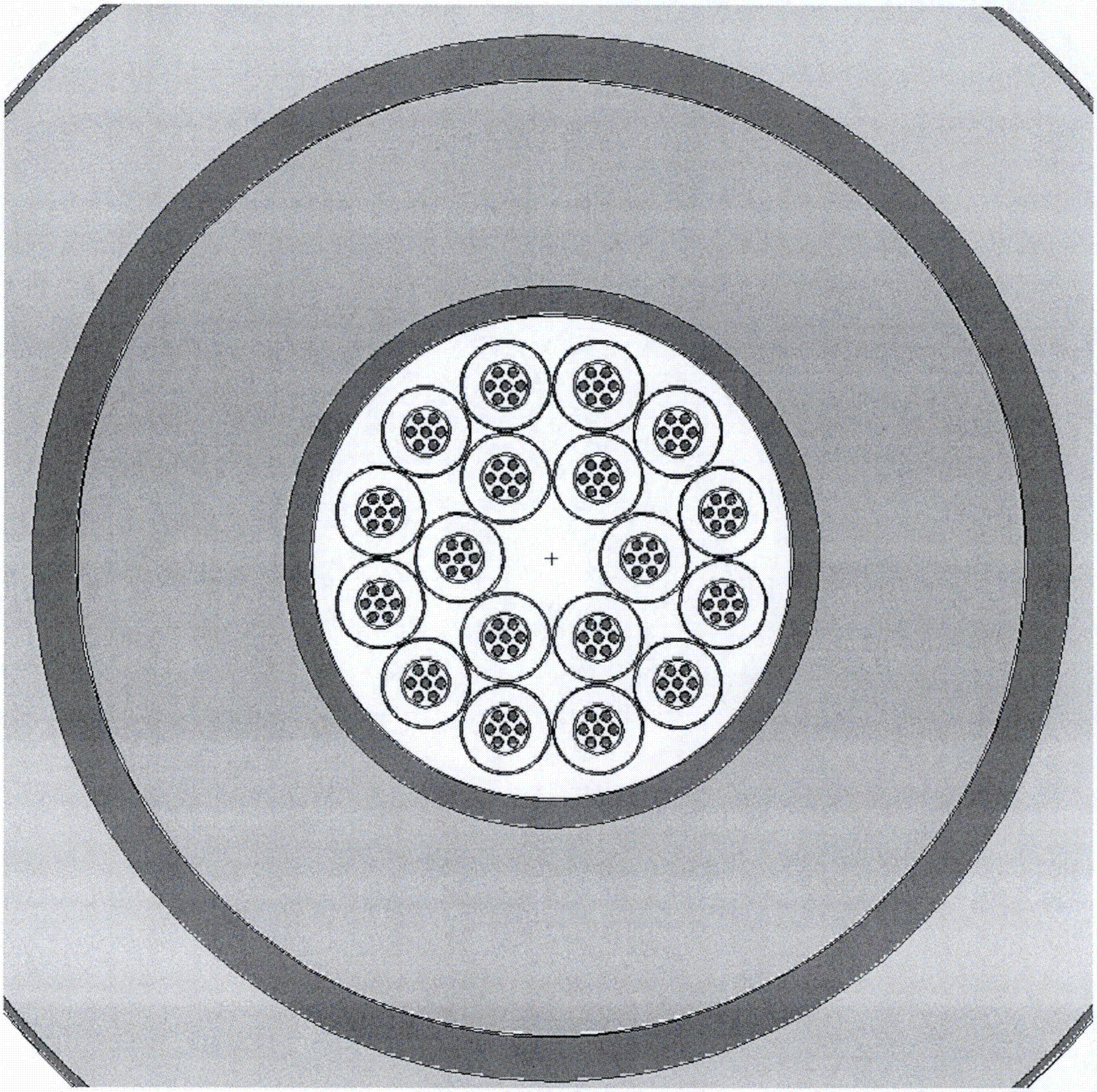


Figure 5.3.21-9 VISED Sketch of LWT Axial Detail

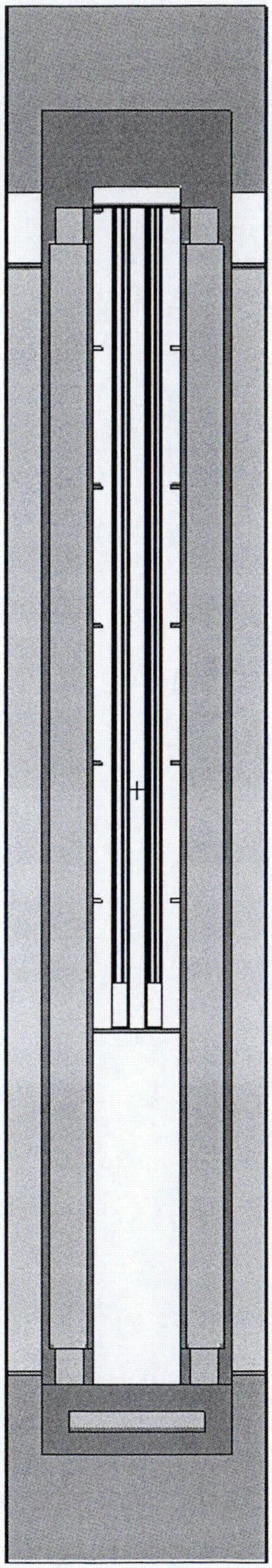


Figure 5.3.21-10 VISED Comparison of Collapsed Fuel (Left) and Undamaged Fuel (Right)

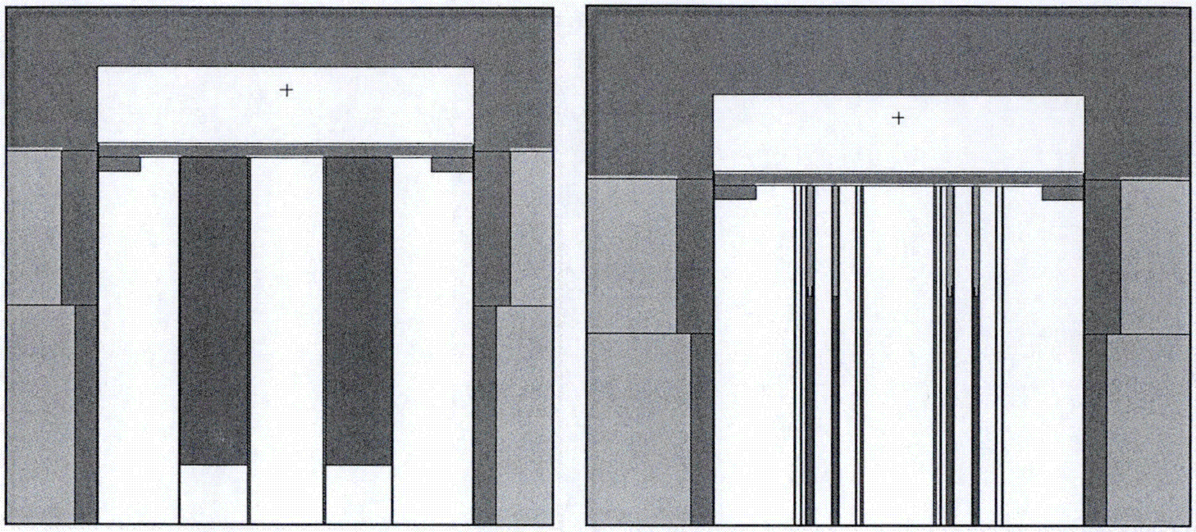


Figure 5.3.21-11 VISED Sketch of LWT Radial Detail

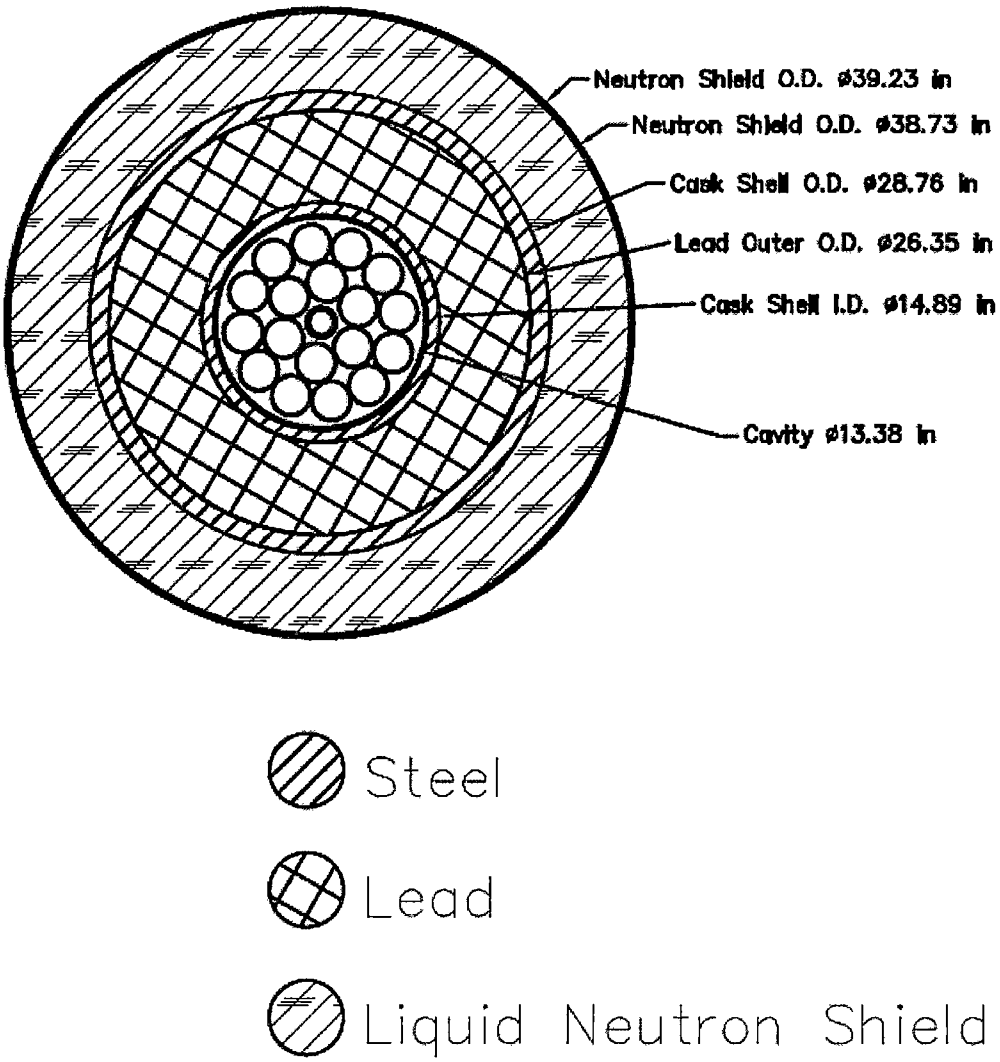


Figure 5.3.21-12 VISED Sketch of LWT Axial Detail

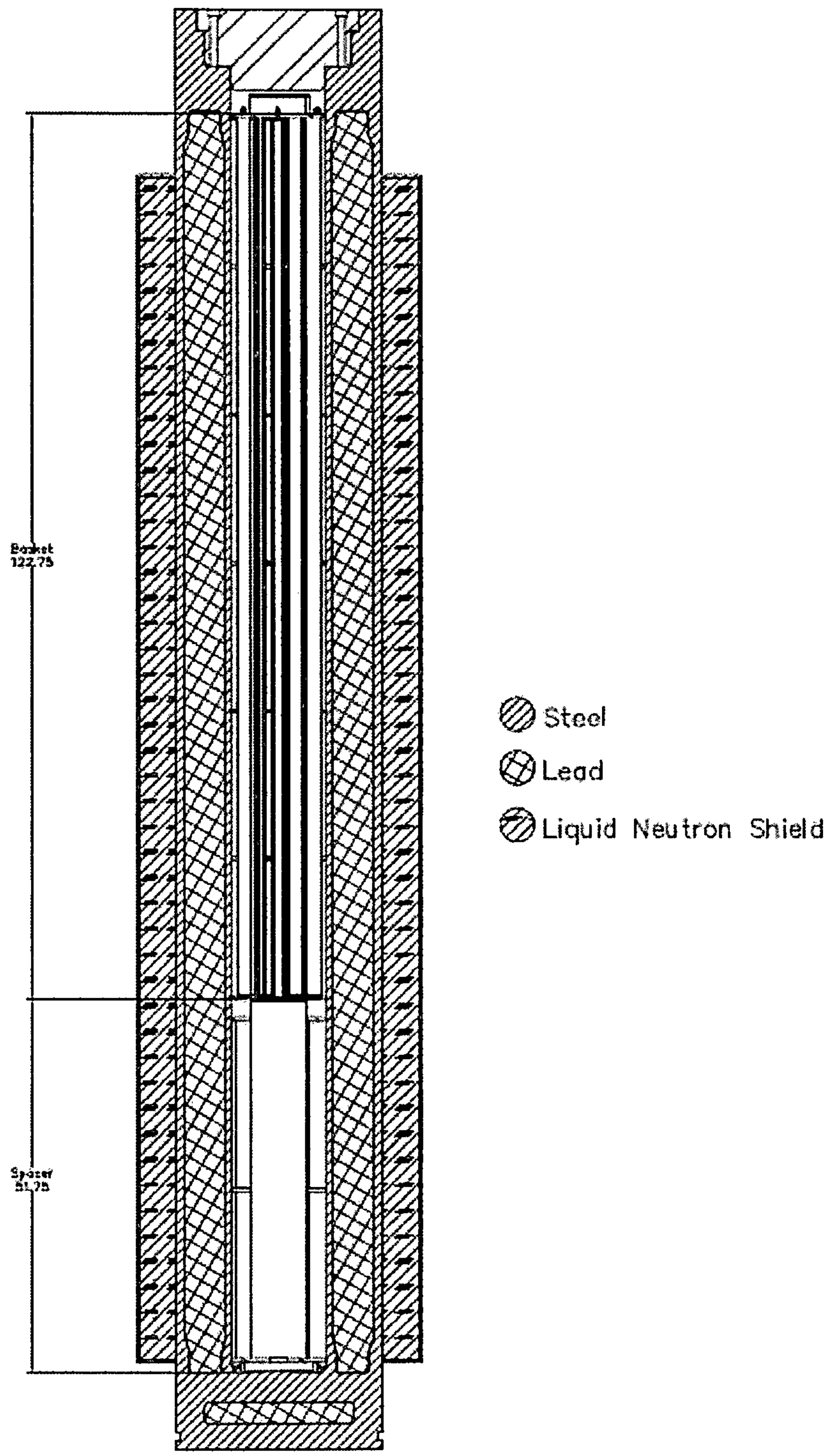


Figure 5.3.21-13 Sample MCNP Input for NRU or NRX Fuel

```
NAC-LWT Cask - NRU  - Normal Transport Conditions
C Radial Biasing - Gamma Source
C Fuel Rod Cells
1  4  -2.7000  -1  :  -2  :  -3  u=5    $ Bottom Plug
2  1  -3.2880  -4  +3  +5      u=5    $ Fuel Meat
3  4  -2.7000  -5  :  -6      u=5    $ Top Plug
4  4  -2.7000  -11  +4  +2  +6  +9  -10  u=5  $ Clad
5  0           +7  -9  #1   -11     u=5     $ Outside Lower Plug
6  0           +10  -8  +6  -11     u=5     $ Outside Top Plug
7  0           +11  :  -7  :  +8  u=5    $ Outside Fuel Rod
C Fuel Assembly Cells
14  0          -14  +15        u=4    $ Assembly Tube
15  0          -16  fill=5  trcl = ( 0.6502 0.0000 0.0000 )      u=4    $ Fuel Rod - Inner
16  like  15  but    trcl = ( -0.3251 0.5631 0.0000 )      u=4    $ Fuel Rod - Inner
17  like  15  but    trcl = ( -0.3251 -0.5631 0.0000 )      u=4    $ Fuel Rod - Inner
18  like  15  but    trcl = ( 1.6183 0.5890 0.0000 )      u=4    $ Fuel Rod - Outer
19  like  15  but    trcl = ( 0.8611 1.4914 0.0000 )      u=4    $ Fuel Rod - Outer
20  like  15  but    trcl = ( -0.2990 1.6960 0.0000 )      u=4    $ Fuel Rod - Outer
21  like  15  but    trcl = ( -1.3192 1.1070 0.0000 )      u=4    $ Fuel Rod - Outer
22  like  15  but    trcl = ( -1.7221 0.0000 0.0000 )      u=4    $ Fuel Rod - Outer
23  like  15  but    trcl = ( -1.3192 -1.1070 0.0000 )      u=4    $ Fuel Rod - Outer
24  like  15  but    trcl = ( -0.2990 -1.6960 0.0000 )      u=4    $ Fuel Rod - Outer
25  like  15  but    trcl = ( 0.8611 -1.4914 0.0000 )      u=4    $ Fuel Rod - Outer
26  like  15  but    trcl = ( 1.6183 -0.5890 0.0000 )      u=4    $ Fuel Rod - Outer
27  0  -15   #15 #16 #17 #18 #19 #20 #21 #22 #23 #24 #25 #26        u=4      $ Inside Tube
Assembly
28  0          +14          u=4    $ Outside Tube Assembly
C Basket Tube Cells
31  6  -7.9400  -33  +32        u=3    $ Basket Tube
32  0          -31  fill=4  trcl = ( 0.0000 0.0000 16.5100 )      u=3    $ Basket Tube Cavity
33  0          -32  #32        u=3    $ Inside Tube Cavity
34  0          +33          u=3    $ Outside Basket Tube
C Basket Assembly Cells
41  0          -69  fill=3  trcl = ( 6.4262 0.0000 1.9050 )      u=2    $ Assembly Inner Tube
42  like  41  but    trcl = ( 3.2131 5.5653 1.9050 )      u=2    $ Assembly Inner Tube
43  like  41  but    trcl = ( -3.2131 5.5653 1.9050 )      u=2    $ Assembly Inner Tube
44  like  41  but    trcl = ( -6.4262 0.0000 1.9050 )      u=2    $ Assembly Inner Tube
45  like  41  but    trcl = ( -3.2131 -5.5653 1.9050 )      u=2    $ Assembly Inner Tube
46  like  41  but    trcl = ( 3.2131 -5.5653 1.9050 )      u=2    $ Assembly Inner Tube
47  like  41  but    trcl = ( 11.9974 3.2147 1.9050 )      u=2    $ Assembly Outer Tube
48  like  41  but    trcl = ( 8.7827 8.7827 1.9050 )      u=2    $ Assembly Outer Tube
49  like  41  but    trcl = ( 3.2147 11.9974 1.9050 )      u=2    $ Assembly Outer Tube
50  like  41  but    trcl = ( -3.2147 11.9974 1.9050 )      u=2    $ Assembly Outer Tube
51  like  41  but    trcl = ( -8.7827 8.7827 1.9050 )      u=2    $ Assembly Outer Tube
52  like  41  but    trcl = ( -11.9974 3.2147 1.9050 )      u=2    $ Assembly Outer Tube
53  like  41  but    trcl = ( -11.9974 -3.2147 1.9050 )      u=2    $ Assembly Outer Tube
54  like  41  but    trcl = ( -8.7827 -8.7827 1.9050 )      u=2    $ Assembly Outer Tube
55  like  41  but    trcl = ( -3.2147 -11.9974 1.9050 )      u=2    $ Assembly Outer Tube
56  like  41  but    trcl = ( 3.2147 -11.9974 1.9050 )      u=2    $ Assembly Outer Tube
57  like  41  but    trcl = ( 8.7827 -8.7827 1.9050 )      u=2    $ Assembly Outer Tube
58  like  41  but    trcl = ( 11.9974 -3.2147 1.9050 )      u=2    $ Assembly Outer Tube
59  0          -50  #41        u=2    $ Assembly Inner Tube
60  0          -51  #42        u=2    $ Assembly Inner Tube
61  0          -52  #43        u=2    $ Assembly Inner Tube
62  0          -53  #44        u=2    $ Assembly Inner Tube
63  0          -54  #45        u=2    $ Assembly Inner Tube
64  0          -55  #46        u=2    $ Assembly Inner Tube
65  0          -56  #47        u=2    $ Assembly Outer Tube
66  0          -57  #48        u=2    $ Assembly Outer Tube
67  0          -58  #49        u=2    $ Assembly Outer Tube
68  0          -59  #50        u=2    $ Assembly Outer Tube
69  0          -60  #51        u=2    $ Assembly Outer Tube
70  0          -61  #52        u=2    $ Assembly Outer Tube
71  0          -62  #53        u=2    $ Assembly Outer Tube
72  0          -63  #54        u=2    $ Assembly Outer Tube
73  0          -64  #55        u=2    $ Assembly Outer Tube
74  0          -65  #56        u=2    $ Assembly Outer Tube
75  0          -66  #57        u=2    $ Assembly Outer Tube
76  0          -67  #58        u=2    $ Assembly Outer Tube
```

Figure 5.3.21-13 Sample MCNP Input for NRU or NRX Fuel (continued)

```
77  6  -7.9400  -41          u=2    $ Bottom Disk
78  6  -7.9400  -43  +50  +51  +52  +53  +54  +55
               +56  +57  +58  +59  +60  +61  +62  +63
               +64  +65  +66  +67  +42    u=2    $ Intermediate Disk 1
79  6  -7.9400  -44  +50  +51  +52  +53  +54  +55
               +56  +57  +58  +59  +60  +61  +62  +63
               +64  +65  +66  +67  +42    u=2    $ Intermediate Disk 2
80  6  -7.9400  -45  +50  +51  +52  +53  +54  +55
               +56  +57  +58  +59  +60  +61  +62  +63
               +64  +65  +66  +67  +42    u=2    $ Intermediate Disk 3
81  6  -7.9400  -46  +50  +51  +52  +53  +54  +55
               +56  +57  +58  +59  +60  +61  +62  +63
               +64  +65  +66  +67  +42    u=2    $ Intermediate Disk 4
82  6  -7.9400  -47  +50  +51  +52  +53  +54  +55
               +56  +57  +58  +59  +60  +61  +62  +63
               +64  +65  +66  +67  +42    u=2    $ Intermediate Disk 5
83  6  -7.9400  -49  +50  +51  +52  +53  +54  +55
               +56  +57  +58  +59  +60  +61  +62  +63
               +64  +65  +66  +67  +48    u=2    $ Top Disk
84  0            -68  +50  +51  +52  +53  +54  +55
               +56  +57  +58  +59  +60  +61  +62  +63
               +64  +65  +66  +67  #77    #78
               #79   #80   #81   #82   #83   #86   u=2    $ Inside Basket
85  0            +68          u=2    $ Outside Basket
86  6  -7.9400  -70          u=2    $ Basket Lid
C Cells - LWT Cask Normal Conditions
91  5  -11.344  -94              u=1  $ BotPb
92  0           -93  fill=2  ( 0 0 133.35 )       u=1  $ Cavity
93  6  -7.9400  -91  -92  +94         u=1  $ Bottom
94  6  -7.9400  -91  +92  +96  +99  +93     u=1  $ OuterShell
95  6  -7.9400  -95  +98  +93         u=1  $ InnerShellTaper
96  6  -7.9400  -97  +93            u=1  $ InnerShell
97  5  -11.344  -98  +97            u=1  $ Lead
98  5  -11.344  -96  +95  +98         u=1  $ LeadTaper
99  0           -99  +98            u=1  $ LeadGap
100  3  -0.9669  -101  +91           u=1  $ NeutronShield
101  6  -7.9400  -100  +91  +101         u=1  $ NSShell
102  7  -0.4997  -102  +91           u=1  $ UpperLimiter
103  7  -0.4997  -103  +91           u=1  $ LowerLimiter
104  0            -104  +91  +100  +102  +103    u=1  $ Container
105  0            +104          u=1  $ Outside
C Detector Cells - Radial Biasing
250  0  -250  fill=1  $ Surface
275  0  -275  +250  $ PbSlumpAzi
350  0  -350  +250  +275  $ 1ft
450  0  -450  +250  +275  +350  $ 1m
550  0  -550  +250  +275  +350  +450  $ 2m
650  0  -650  +250  +275  +350  +450  +550  $ 2m+Convey
750  0  +250  +275  +350  +450  +550  +650  $ Exterior

C Fuel Rod Surfaces
1  RCC  0.0  0.0  0.0000  0.0  0.0  1.1100  0.2350    $ Bottom Plug - Lower Section
2  RCC  0.0  0.0  1.1100  0.0  0.0  7.7800  0.2743    $ Bottom Plug - Mid Section
3  RCC  0.0  0.0  8.8900  0.0  0.0  0.9525  0.1905    $ Bottom Plug - Tip
4  RCC  0.0  0.0  8.8900  0.0  0.0  274.3200  0.2743    $ Fuel Meat
5  RCC  0.0  0.0  283.2100  0.0  0.0  -0.9525  0.1905    $ Top Plug - Tip
6  RCC  0.0  0.0  283.2100  0.0  0.0  8.8900  0.2743    $ Top Plug - Mid Section
7  PZ  0.0000                $ Bottom of Pin
8  PZ  292.1000               $ Top of Pin
9  PZ  2.3019                $ Bottom of Clad
10  PZ  290.8300              $ Top of Clad
11  CZ  0.3505               $ Clad
C Fuel Assembly Surfaces
14  RCC  0.0  0.0  0.0  0.0  0.0  292.1000  2.6264    $ Assembly Tube OD
15  RCC  0.0  0.0  0.0  0.0  0.0  292.1000  2.4994    $ Assembly ID
16  RCC  0.0  0.0  0.0000  0.0  0.0  292.1000  0.3510    $ Rod Outline
C Basket Tube Surfaces
31  RCC  0.0  0.0  0.0000  0.0  0.0  308.6100  3.0094    $ Assembly Outline
```

Figure 5.3.21-13 Sample MCNP Input for NRU or NRX Fuel (continued)

```
32  RCC  0.0  0.0  0.0000  0.0  0.0  308.6100  3.0099    $ Tube Inner Diameter
33  RCC  0.0  0.0  -0.6350  0.0  0.0  309.2450  3.1750    $ Tube Outer Diameter
C Basket Assembly Surfaces
41  RCC  0.0  0.0  0.0000  0.0  0.0  1.2700  16.8529    $ Bottom Disk
42  RCC  0.0  0.0  48.8950  0.0  0.0  209.5500  13.3350    $ Intermediate Disks ID
43  RCC  0.0  0.0  50.1650  0.0  0.0  -1.2700  16.8529    $ Intermediate Disk 1
44  RCC  0.0  0.0  102.2350  0.0  0.0  -1.2700  16.8529    $ Intermediate Disk 2
45  RCC  0.0  0.0  154.3050  0.0  0.0  -1.2700  16.8529    $ Intermediate Disk 3
46  RCC  0.0  0.0  206.3750  0.0  0.0  -1.2700  16.8529    $ Intermediate Disk 4
47  RCC  0.0  0.0  258.4450  0.0  0.0  -1.2700  16.8529    $ Intermediate Disk 5
48  RCC  0.0  0.0  310.5150  0.0  0.0  -1.2700  13.0810    $ Top Disk ID
49  RCC  0.0  0.0  310.5150  0.0  0.0  -1.2700  16.8529    $ Top Disk OD
50  RCC  6.4262  0.0000  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Inner Tube
51  RCC  3.2131  5.5653  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Inner Tube
52  RCC  -3.2131  5.5653  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Inner Tube
53  RCC  -6.4262  0.0000  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Inner Tube
54  RCC  -3.2131  -5.5653  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Inner Tube
55  RCC  3.2131  -5.5653  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Inner Tube
56  RCC  11.9974  3.2147  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Outer Tube
57  RCC  8.7827  8.7827  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Outer Tube
58  RCC  3.2147  11.9974  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Outer Tube
59  RCC  -3.2147  11.9974  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Outer Tube
60  RCC  -8.7827  8.7827  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Outer Tube
61  RCC  -11.9974  3.2147  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Outer Tube
62  RCC  -11.9974  -3.2147  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Outer Tube
63  RCC  -8.7827  -8.7827  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Outer Tube
64  RCC  -3.2147  -11.9974  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Outer Tube
65  RCC  3.2147  -11.9974  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Outer Tube
66  RCC  8.7827  -8.7827  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Outer Tube
67  RCC  11.9974  -3.2147  1.2700  0.0  0.0  309.2450  3.1760    $ Assembly Outer Tube
68  RCC  0.0  0.0  0.0000  0.0  0.0  311.7850  16.8534    $ Basket Outline
69  RCC  0.0  0.0  -0.6350  0.0  0.0  309.2450  3.1755    $ Tube Outline
70  RCC  0.0  0.0  310.5150  0.0  0.0  1.2700  16.8529    $ Basket Lid
C Surfaces - LWT Cask Normal Conditions
91  RCC  0.0000  0.0000  -26.6700  0.0000  0.0000  507.3650   36.5189  $ Lwt
92  RCC  0.0000  0.0000  -26.6700  0.0000  0.0000  26.6700   36.5189  $ Bottom
93  RCC  0.0000  0.0000  0.0000  0.0000  0.0000  452.1200   16.9863  $ Cavity
94  RCC  0.0000  0.0000  -17.7800  0.0000  0.0000  7.6200   26.3525  $ Bottom gamma shield
95  RCC  0.0000  0.0000  0.0000  0.0000  0.0000  444.5000   20.1740  $ Lead id - taper
96  RCC  0.0000  0.0000  0.0000  0.0000  0.0000  444.5000   31.5976  $ Lead od - taper
97  RCC  0.0000  0.0000  13.8176  0.0000  0.0000  416.8648   18.9103  $ Lead id
98  RCC  0.0000  0.0000  13.8176  0.0000  0.0000  416.8648   33.3271  $ Lead od
99  RCC  0.0000  0.0000  13.8176  0.0000  0.0000  416.8648   33.4645  $ Lead gap
100  RCC  0.0000  0.0000  3.8100  0.0000  0.0000  419.1000   49.8183  $ Neutron shield shell
101  RCC  0.0000  0.0000  5.0800  0.0000  0.0000  416.5600   49.2189  $ Neutron shield
102  RCC  0.0000  0.0000  450.2150  0.0000  0.0000  70.5612   49.8183  $ Upper limiter
103  RCC  0.0000  0.0000  -68.0212  0.0000  0.0000  71.8312   49.8183  $ Lower limiter
104  RCC  0.0000  0.0000  -68.0212  0.0000  0.0000  588.7974   49.8183  $ Container
C Radial Detector DRA (Surface)
250  RCC  0.0000  0.0000  -68.1212  0.0000  0.0000  588.9974  49.9184
251  PZ  -38.6713
252  PZ  -9.2215
253  PZ  20.2284
254  PZ  49.6783
255  PZ  79.1282
256  PZ  108.5780
257  PZ  138.0279
258  PZ  167.4778
259  PZ  196.9276
260  PZ  226.3775
261  PZ  255.8274
262  PZ  285.2772
263  PZ  314.7271
264  PZ  344.1770
265  PZ  373.6269
266  PZ  403.0767
267  PZ  432.5266
268  PZ  461.9765
```

Figure 5.3.21-13 Sample MCNP Input for NRU or NRX Fuel (continued)

```
269  PZ  491.4263
C Radial Detector DRAA (PbSlumpAzi)
275  RCC  0.0000  0.0000  275.4825  0.0000  0.0000  30.4800  49.9284
276     PX  0.0000
277  1  PX  0.0000
278  3  PX  0.0000
279  5  PX  0.0000
280  6  PX  0.0000
281  9  PX  0.0000
282  10  PX  0.0000
283  11  PX  0.0000
284  14  PX  0.0000
285     PY  0.0000
286  16  PX  0.0000
287  18  PX  0.0000
288  19  PX  0.0000
289  20  PX  0.0000
290  21  PX  0.0000
291  23  PX  0.0000
292  25  PX  0.0000
293  27  PX  0.0000
C Radial Detector DRB (1ft)
350  RCC  0.0000  0.0000  -98.6012  0.0000  0.0000  649.9574  80.2984
351  PZ  -66.1033
352  PZ  -33.6055
353  PZ  -1.1076
354  PZ  31.3903
355  PZ  63.8882
356  PZ  96.3860
357  PZ  128.8839
358  PZ  161.3818
359  PZ  193.8796
360  PZ  226.3775
361  PZ  258.8754
362  PZ  291.3732
363  PZ  323.8711
364  PZ  356.3690
365  PZ  388.8669
366  PZ  421.3647
367  PZ  453.8626
368  PZ  486.3605
369  PZ  518.8583
C Radial Detector DRC (1m)
450  RCC  0.0000  0.0000  -168.1212  0.0000  0.0000  788.9974  149.8184
451  PZ  -135.2463
452  PZ  -102.3714
453  PZ  -69.4965
454  PZ  -36.6216
455  PZ  -3.7467
456  PZ  29.1282
457  PZ  62.0030
458  PZ  94.8779
459  PZ  127.7528
460  PZ  160.6277
461  PZ  193.5026
462  PZ  226.3775
463  PZ  259.2524
464  PZ  292.1273
465  PZ  325.0022
466  PZ  357.8771
467  PZ  390.7520
468  PZ  423.6269
469  PZ  456.5017
470  PZ  489.3766
471  PZ  522.2515
472  PZ  555.1264
473  PZ  588.0013
C Radial Detector DRD (2m)
```

Figure 5.3.21-13 Sample MCNP Input for NRU or NRX Fuel (continued)

```
550  RCC  0.0000  0.0000  -268.1212  0.0000  0.0000  988.9974  249.8184
551  PZ  -226.9130
552  PZ  -185.7048
553  PZ  -144.4965
554  PZ  -103.2883
555  PZ  -62.0801
556  PZ  -20.8719
557  PZ  20.3364
558  PZ  61.5446
559  PZ  102.7528
560  PZ  143.9611
561  PZ  185.1693
562  PZ  226.3775
563  PZ  267.5857
564  PZ  308.7940
565  PZ  350.0022
566  PZ  391.2104
567  PZ  432.4186
568  PZ  473.6269
569  PZ  514.8351
570  PZ  556.0433
571  PZ  597.2515
572  PZ  638.4598
573  PZ  679.6680
C Radial Detector DRE (2m+Convey)
650  RCC  0.0000  0.0000  -269.1212  0.0000  0.0000  990.9974  321.9200
651  PZ  -227.8296
652  PZ  -186.5381
653  PZ  -145.2465
654  PZ  -103.9550
655  PZ  -62.6634
656  PZ  -21.3719
657  PZ  19.9197
658  PZ  61.2113
659  PZ  102.5028
660  PZ  143.7944
661  PZ  185.0859
662  PZ  226.3775
663  PZ  267.6691
664  PZ  308.9606
665  PZ  350.2522
666  PZ  391.5437
667  PZ  432.8353
668  PZ  474.1269
669  PZ  515.4184
670  PZ  556.7100
671  PZ  598.0015
672  PZ  639.2931
673  PZ  680.5846

C
C Materials List
C
C U-Al
m1     92235  -2.0411E-01
       92238  -2.0187E-02
       13027  -7.7570E-01
C Water
m2     1001  6.6667E-01  8016  3.3333E-01
mt2    lwtr.01
C Water/Glycol
m3     1001  -1.03651E-01  8016  -6.75619E-01  6000  -2.20730E-01
C Aluminum
m4     13027  -1.0
C Lead
m5     82000  -1.0
C Stainless Steel 304
m6     26000  -0.695  24000  -0.190  28000  -0.095
```

Figure 5.3.21-13 Sample MCNP Input for NRU or NRX Fuel (continued)

```
       25055  -0.020
C Aluminum Honeycomb Impact Limiter
m7     13027  -1.0
C
C Cell Importances
imp:p 1 92r 0
C
C Source Definition - Gamma
C
sdef  RAD=d1  EXT=d2  ERG=d3  cell=250:92:d4:32:d5:2
      POS=  0.0000  0.0000  0.0000
      AXS=  0.0000  0.0000  1.0000
si1  0  0.5486
sp1  0  1
si2  8.89  283.2100
sp2  0  1
si3  1.000E-02  4.500E-02  1.000E-01  2.000E-01  3.000E-01  4.000E-01
     6.000E-01  8.000E-01  1.000E+00  1.330E+00  1.660E+00  2.000E+00
     2.500E+00  3.000E+00  4.000E+00  5.000E+00  6.500E+00  8.000E+00
     1.000E+01
sp3  0.0000E+00  2.7550E+16  9.5130E+15  5.6100E+15  1.7620E+15  1.2380E+15
     1.0040E+15  4.0800E+16  3.5190E+14  3.3890E+14  3.3730E+13  3.1660E+12
     1.6300E+11  4.1940E+08  6.5250E+06  1.4530E+05  5.7290E+04  1.1060E+04
     2.3940E+03
si4 1  41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58
sp4  1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
si5 1  15 16 17 18 19 20 21 22 23 24 25 26
sp5  1 1 1 1 1 1 1 1 1 1 1 1
mode p
nps  1000000000
C
C ANSI/ANS-6.1.1-1977 - Gamma Flux-to-Dose Conversion Factors
C (mrem/hr)/(photons/cm2-sec)
de0  0.01  0.03  0.05  0.07  0.1  0.15  0.2
     0.25  0.3  0.35  0.4  0.45  0.5  0.55
     0.6  0.65  0.7  0.8  1  1.4  1.8
     2.2  2.6  2.8  3.25  3.75  4.25  4.75
     5  5.25  5.75  6.25  6.75  7.5  9
     11  13  15
df0  3.96E-03  5.82E-04  2.90E-04  2.58E-04  2.83E-04  3.79E-04  5.01E-04
     6.31E-04  7.59E-04  8.78E-04  9.85E-04  1.08E-03  1.17E-03  1.27E-03
     1.36E-03  1.44E-03  1.52E-03  1.68E-03  1.98E-03  2.51E-03  2.99E-03
     3.42E-03  3.82E-03  4.01E-03  4.41E-03  4.83E-03  5.23E-03  5.60E-03
     5.80E-03  6.01E-03  6.37E-03  6.74E-03  7.11E-03  7.66E-03  8.77E-03
     1.03E-02  1.18E-02  1.33E-02
C
C Weight Window Generation - Radial
wwg  2 0 0 0 0
wwp:p  5 3 5 0 -1 0
mesh  geom=cyl ref=0 14 292 origin=0.1 0.1 -668
      imesh  16.9 17.0 18.9 33.3 36.5 49.2 49.8 549.8
      iints  6 1 1 5 1 1 1 1
      jmesh  600 641 650 658 668 799 1110 1120 1149 1189 1989
      jints  1 1 1 1 1 1 1 1 1 1 1
      kmesh  1
      kints  1
wwge:p  1e-3 1 20
fc2 Radial Surface Tally
f2:p +250.1
fm2 9.14508E+14
fs2  -251  -252  -253  -254  -255  -256
     -257  -258  -259  -260  -261  -262
     -263  -264  -265  -266  -267  -268
     -269  T
tf2
fc12 Radial PbSlumpAzi Tally Q1 (+x+y)
f12:p +275.1
fm12 9.14508E+14
```

Figure 5.3.21-13 Sample MCNP Input for NRU or NRX Fuel (continued)

```
fs12 -276  -285
     -277  -278  -279  -280  -281  -282
     -283  -284  T
sd12 4.7809E+03  2.3905E+03  2.6561E+02  8r  9.5619E+03
tf12
fc22 Radial PbSlumpAzi Tally Q2 (-x+y)
f22:p +275.1
fm22 9.14508E+14
fs22 +276  -285
     +286  +287  +288  +289  +290  +291
     +292  +293  T
sd22 4.7809E+03  2.3905E+03  2.6561E+02  8r  9.5619E+03
tf22
fc32 Radial PbSlumpAzi Tally Q3 (-x-y)
f32:p +275.1
fm32 9.14508E+14
fs32 +276  +285
     +277  +278  +279  +280  +281  +282
     +283  +284  T
sd32 4.7809E+03  2.3905E+03  2.6561E+02  8r  9.5619E+03
tf32
fc42 Radial PbSlumpAzi Tally Q4 (+x-y)
f42:p +275.1
fm42 9.14508E+14
fs42 -276  +285
     -286  -287  -288  -289  -290  -291
     -292  -293  T
sd42 4.7809E+03  2.3905E+03  2.6561E+02  8r  9.5619E+03
tf42
fc52 Radial 1ft Tally
f52:p +350.1
fm52 9.14508E+14
fs52  -351  -352  -353  -354  -355  -356
     -357  -358  -359  -360  -361  -362
     -363  -364  -365  -366  -367  -368
     -369  T
tf52
fc62 Radial 1m Tally
f62:p +450.1
fm62 9.14508E+14
fs62  -451  -452  -453  -454  -455  -456
     -457  -458  -459  -460  -461  -462
     -463  -464  -465  -466  -467  -468
     -469  -470  -471  -472  -473  T
tf62
fc72 Radial 2m Tally
f72:p +550.1
fm72 9.14508E+14
fs72  -551  -552  -553  -554  -555  -556
     -557  -558  -559  -560  -561  -562
     -563  -564  -565  -566  -567  -568
     -569  -570  -571  -572  -573  T
tf72
fc82 Radial 2m+Convey Tally
f82:p +650.1
fm82 9.14508E+14
fs82  -651  -652  -653  -654  -655  -656
     -657  -658  -659  -660  -661  -662
     -663  -664  -665  -666  -667  -668
     -669  -670  -671  -672  -673  T
tf82
C
C Print Control
prdmp  -30 -60 1 2
print
C Random Number Generator
rand  gen=2  seed=33613157428409  stride=152917  hist=1
C
```

Figure 5.3.21-13 Sample MCNP Input for NRU or NRX Fuel (continued)

```
C Rotation Matrix
C
*TR1  0.0  0.0  0.0  10 100 90 -80 10 90 90 90 0
*TR2  0.0  0.0  0.0  12 102 90 -78 12 90 90 90 0
*TR3  0.0  0.0  0.0  20 110 90 -70 20 90 90 90 0
*TR4  0.0  0.0  0.0  24 114 90 -66 24 90 90 90 0
*TR5  0.0  0.0  0.0  30 120 90 -60 30 90 90 90 0
*TR6  0.0  0.0  0.0  40 130 90 -50 40 90 90 90 0
*TR7  0.0  0.0  0.0  45 135 90 -45 45 90 90 90 0
*TR8  0.0  0.0  0.0  48 138 90 -42 48 90 90 90 0
*TR9  0.0  0.0  0.0  50 140 90 -40 50 90 90 90 0
*TR10  0.0  0.0  0.0  60 150 90 -30 60 90 90 90 0
*TR11  0.0  0.0  0.0  70 160 90 -20 70 90 90 90 0
*TR12  0.0  0.0  0.0  72 162 90 -18 72 90 90 90 0
*TR13  0.0  0.0  0.0  78 168 90 -12 78 90 90 90 0
*TR14  0.0  0.0  0.0  80 170 90 -10 80 90 90 90 0
*TR15  0.0  0.0  0.0  96 186 90 6 96 90 90 90 0
*TR16  0.0  0.0  0.0  100 190 90 10 100 90 90 90 0
*TR17  0.0  0.0  0.0  102 192 90 12 102 90 90 90 0
*TR18  0.0  0.0  0.0  110 200 90 20 110 90 90 90 0
*TR19  0.0  0.0  0.0  120 210 90 30 120 90 90 90 0
*TR20  0.0  0.0  0.0  130 220 90 40 130 90 90 90 0
*TR21  0.0  0.0  0.0  140 230 90 50 140 90 90 90 0
*TR22  0.0  0.0  0.0  144 234 90 54 144 90 90 90 0
*TR23  0.0  0.0  0.0  150 240 90 60 150 90 90 90 0
*TR24  0.0  0.0  0.0  156 246 90 66 156 90 90 90 0
*TR25  0.0  0.0  0.0  160 250 90 70 160 90 90 90 0
*TR26  0.0  0.0  0.0  168 258 90 78 168 90 90 90 0
*TR27  0.0  0.0  0.0  170 260 90 80 170 90 90 90 0
*TR28  0.0  0.0  0.0  192 282 90 102 192 90 90 90 0
*TR29  0.0  0.0  0.0  216 306 90 126 216 90 90 90 0
*TR30  0.0  0.0  0.0  240 330 90 150 240 90 90 90 0
*TR31  0.0  0.0  0.0  264 354 90 174 264 90 90 90 0
*TR32  0.0  0.0  0.0  288 378 90 198 288 90 90 90 0
*TR33  0.0  0.0  0.0  312 402 90 222 312 90 90 90 0
*TR34  0.0  0.0  0.0  330 420 90 240 330 90 90 90 0
*TR35  0.0  0.0  0.0  336 426 90 246 336 90 90 90 0
*TR36  0.0  0.0  0.0  348 438 90 258 348 90 90 90 0
*TR37  0.0  0.0  0.0  350 440 90 260 350 90 90 90 0
```

Figure 5.3.21-14 Maximum Radial Surface Dose Rate Profile for Normal Conditions – NRU LEU Fuel – Collapsed

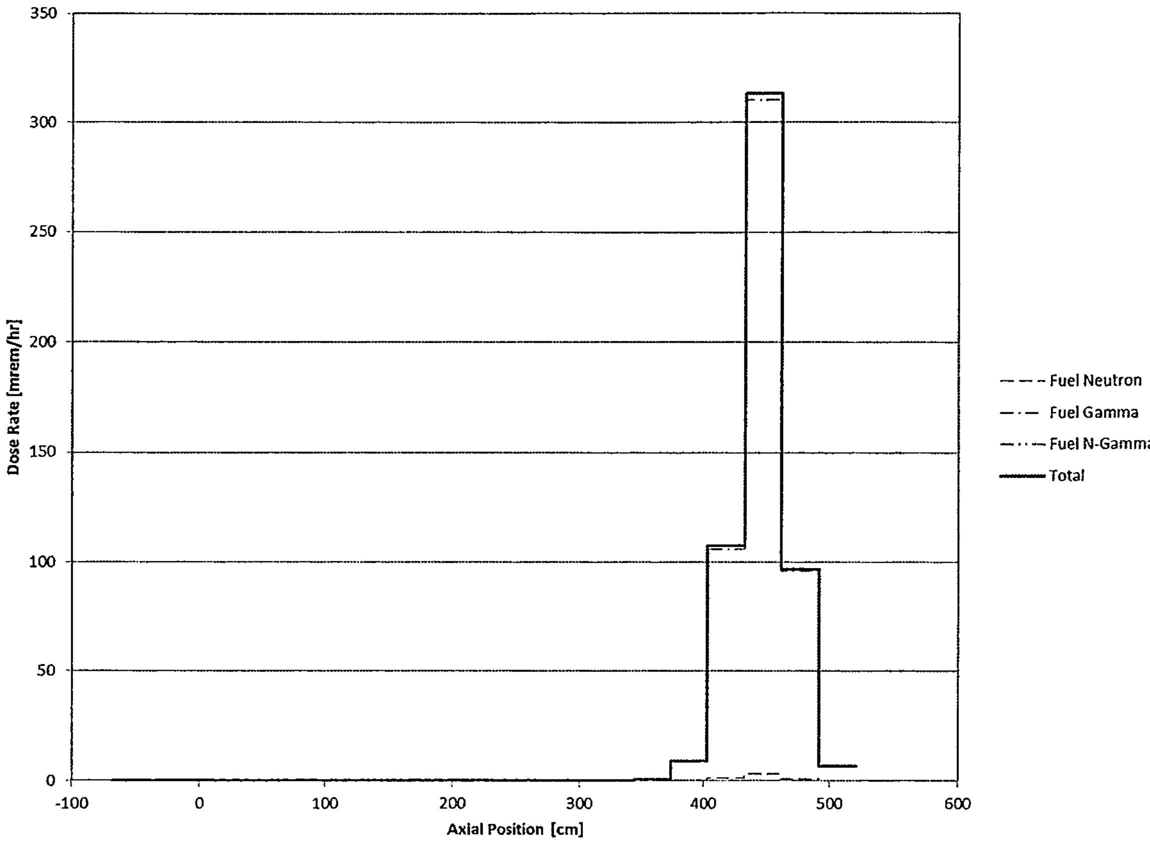


Figure 5.3.21-15 Maximum Radial 2m Dose Rate Profile for Normal Conditions – NRU LEU Fuel – Collapsed

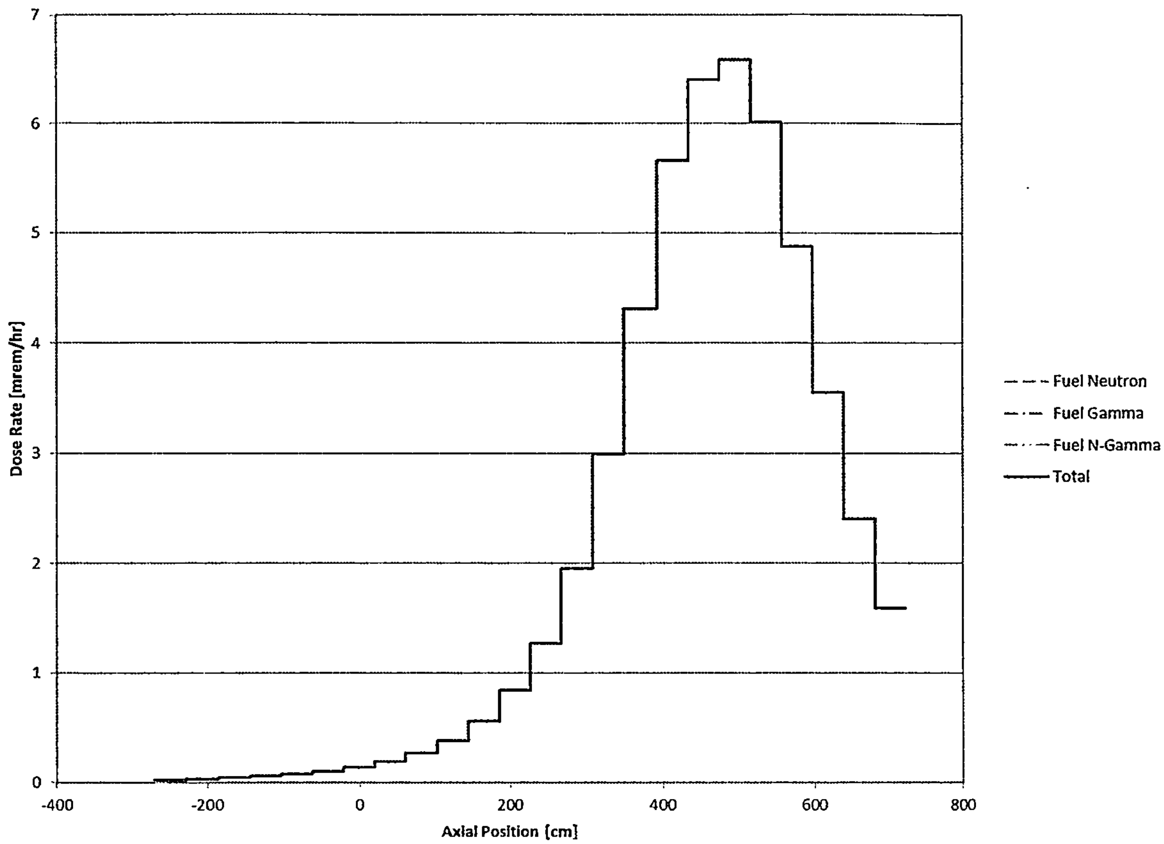


Figure 5.3.21-16 Maximum Radial 1m Dose Rate Profile for Accident Conditions – NRU LEU Fuel – Collapsed

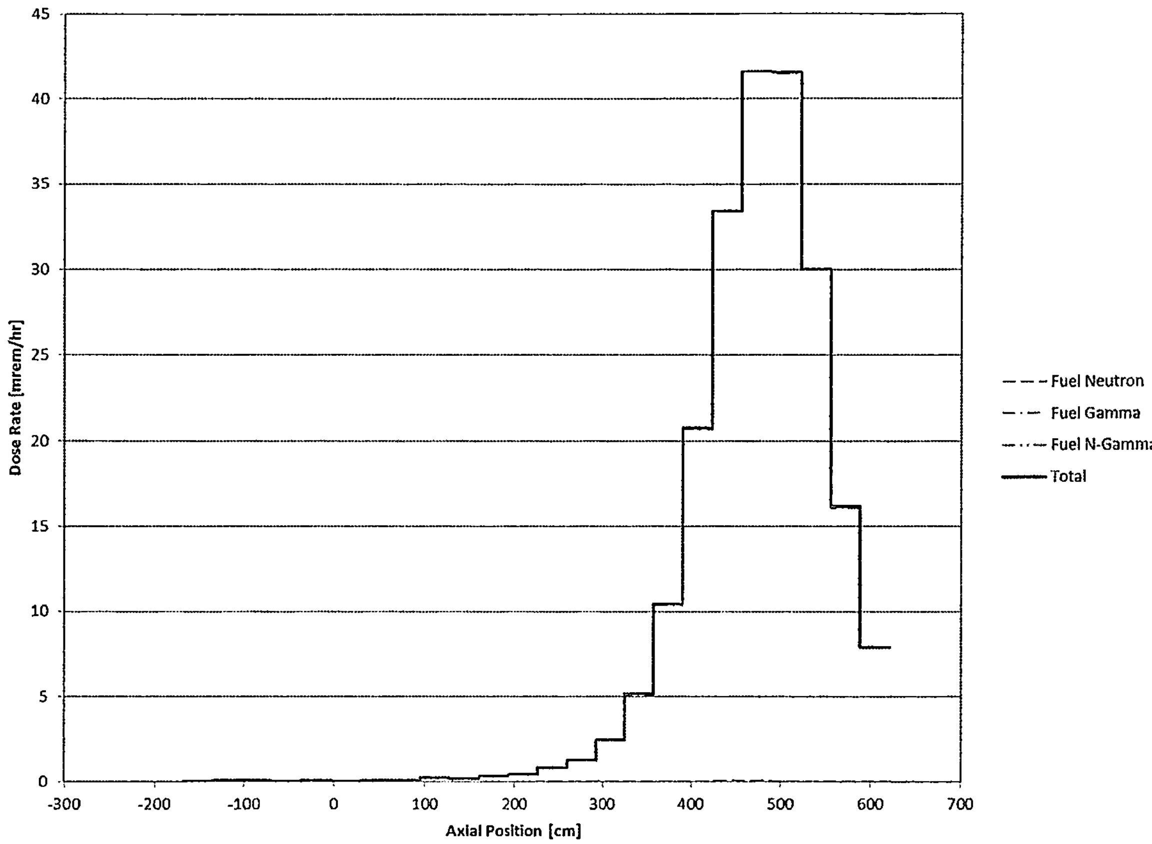


Table 5.3.21-1 NRU Fuel Assembly Dimensions

Description	Value [in]	Value [cm]
Fuel Meat Length	108	274.32
Fuel Rod Diameter	0.216	0.5486
Clad Thickness	0.03	0.0762
Top End Plug Length	3.5	8.89
Bottom End Plug Length	3.5	8.89
Assembly Tube Wall Thickness	0.050	0.127
Assembly Tube ID	1.9680	4.9987

Table 5.3.21-2 NRX Fuel Assembly Dimensions

Description	Value [in]	Value [cm]
Fuel Meat Length	108	274.32
Fuel Rod Diameter	0.25	0.6350
Clad Thickness	0.03	0.0762
Top End Plug Length	4.00	10.16
Bottom End Plug Length	4.00	10.16
Assembly Tube OD	1.3810	3.5077
Assembly Tube ID	1.2410	3.1521

Table 5.3.21-3 NRU and NRX Evaluated Fuel Material Properties

PARAMETER	NRU HEU	NRU LEU	NRX
Weight of ^{235}U (g per pin)	43.7	43.7	79.2
Weight of Total U (g per pin)	48.0	230	87.0
Enrichment (%)	91.0	19.0	91.0
Burnup (MWd)	364	363	375
^{235}U Depletion (%)	87.4	83.6	85.1
Minimum Cool Time (years)	19	3	18
Max Decay Heat (W/cask)	162	641	171

Table 5.3.21-4 Fuel Material Compositions

Element	NRU HEU Wt %	NRU LEU Wt %	NRX Wt %
^{235}U	20.411	11.811	28.275
^{238}U	2.019	50.351	2.796
Al	77.570	37.838	68.929

Table 5.3.21-5 Neutron Source Term Comparison for NRU HEU Fuel Assembly

Group	E Lower [MeV]	E Upper [MeV]	Single Cell Source [n/sec-MTU]	Supercell Source [n/sec-MTU]	Percent Difference
1	6.38E+00	2.00E+01	3.9105E+01	9.1798E+00	-76.5%
2	3.01E+00	6.38E+00	4.1109E+02	1.0543E+02	-74.4%
3	1.83E+00	3.01E+00	9.1987E+03	4.6275E+03	-49.7%
4	1.42E+00	1.83E+00	1.3219E+04	6.7836E+03	-48.7%
5	9.07E-01	1.42E+00	1.9198E+04	9.8613E+03	-48.6%
6	4.08E-01	9.07E-01	1.9509E+04	1.0014E+04	-48.7%
7	1.11E-01	4.08E-01	8.5190E+03	4.3704E+03	-48.7%
8	1.50E-02	1.11E-01	1.3876E+03	7.1183E+02	-48.7%
9	3.04E-03	1.50E-02	4.3073E+01	2.1978E+01	-49.0%
10	5.83E-04	3.04E-03	3.5136E+00	1.7896E+00	-49.1%
11	1.01E-04	5.83E-04	2.8702E-01	1.4610E-01	-49.1%
12	2.90E-05	1.01E-04	2.4486E-02	1.2558E-02	-48.7%
13	1.07E-05	2.90E-05	3.8771E-03	1.9841E-03	-48.8%
14	3.06E-06	1.07E-05	3.7135E-05	1.2127E-05	-67.3%
15	1.86E-06	3.06E-06	2.1928E-06	6.0681E-07	-72.3%
16	1.30E-06	1.86E-06	8.2886E-07	2.2720E-07	-72.6%
17	1.13E-06	1.30E-06	2.2810E-07	6.2452E-08	-72.6%
18	1.00E-06	1.13E-06	1.7407E-07	4.4165E-08	-74.6%
19	8.00E-07	1.00E-06	2.1421E-07	6.4780E-08	-69.8%
20	4.14E-07	8.00E-07	3.6300E-07	9.5193E-08	-73.8%
21	3.25E-07	4.14E-07	5.3205E-08	1.7026E-08	-68.0%
22	2.25E-07	3.25E-07	6.0826E-08	1.6177E-08	-73.4%
23	1.00E-07	2.25E-07	6.6240E-08	1.6427E-08	-75.2%
24	5.00E-08	1.00E-07	1.0858E-08	4.0357E-09	-62.8%
25	3.00E-08	5.00E-08	1.0944E-08	2.8958E-09	-73.5%
26	1.00E-08	3.00E-08	9.1411E-11	2.5999E-11	-71.6%
27	1.00E-11	1.00E-08	2.5569E-10	8.0739E-11	-68.4%
Total			7.1529E+04	3.6507E+04	-49.0%

Table 5.3.21-6 Gamma Source Term Comparison for NRU HEU Fuel Assembly

Group	E Lower [MeV]	E Upper [MeV]	Single Cell Source [g/sec-MTU]	Supercell Source [g/sec-MTU]	Percent Difference
1	8.00E+00	1.00E+01	2.3940E+03	7.0612E+02	-70.5%
2	6.50E+00	8.00E+00	1.1060E+04	3.2906E+03	-70.2%
3	5.00E+00	6.50E+00	5.7290E+04	1.7259E+04	-69.9%
4	4.00E+00	5.00E+00	1.4530E+05	4.4338E+04	-69.5%
5	3.00E+00	4.00E+00	6.5250E+06	6.1054E+06	-6.4%
6	2.50E+00	3.00E+00	4.1940E+08	2.9798E+08	-28.9%
7	2.00E+00	2.50E+00	1.6300E+11	1.6329E+11	0.2%
8	1.66E+00	2.00E+00	3.1660E+12	3.1706E+12	0.1%
9	1.33E+00	1.66E+00	3.3730E+13	3.1693E+13	-6.0%
10	1.00E+00	1.33E+00	3.3890E+14	3.1146E+14	-8.1%
11	8.00E-01	1.00E+00	3.5190E+14	3.2636E+14	-7.3%
12	6.00E-01	8.00E-01	4.0800E+16	4.0797E+16	0.0%
13	4.00E-01	6.00E-01	1.0040E+15	9.7981E+14	-2.4%
14	3.00E-01	4.00E-01	1.2380E+15	1.2400E+15	0.2%
15	2.00E-01	3.00E-01	1.7620E+15	1.7613E+15	0.0%
16	1.00E-01	2.00E-01	5.6100E+15	5.6001E+15	-0.2%
17	4.50E-02	1.00E-01	9.5130E+15	9.5202E+15	0.1%
18	1.00E-02	4.50E-02	2.7550E+16	2.7567E+16	0.1%
Total			8.8205E+16	8.8138E+16	-0.1%

Table 5.3.21-7 Neutron Source Terms for NRU HEU Fuel Assembly

Group	E Lower [MeV]	E Upper [MeV]	Source [neutrons/sec-MTU]
1	6.38E+00	2.00E+01	6.7890E+04
2	3.01E+00	6.38E+00	7.1370E+05
3	1.83E+00	3.01E+00	1.5970E+07
4	1.42E+00	1.83E+00	2.2950E+07
5	9.07E-01	1.42E+00	3.3330E+07
6	4.08E-01	9.07E-01	3.3870E+07
7	1.11E-01	4.08E-01	1.4790E+07
8	1.50E-02	1.11E-01	2.4090E+06
9	3.04E-03	1.50E-02	7.4780E+04
10	5.83E-04	3.04E-03	6.1000E+03
11	1.01E-04	5.83E-04	4.9830E+02
12	2.90E-05	1.01E-04	4.2510E+01
13	1.07E-05	2.90E-05	6.7310E+00
14	3.06E-06	1.07E-05	6.4470E-02
15	1.86E-06	3.06E-06	3.8070E-03
16	1.30E-06	1.86E-06	1.4390E-03
17	1.13E-06	1.30E-06	3.9600E-04
18	1.00E-06	1.13E-06	3.0220E-04
19	8.00E-07	1.00E-06	3.7190E-04
20	4.14E-07	8.00E-07	6.3020E-04
21	3.25E-07	4.14E-07	9.2370E-05
22	2.25E-07	3.25E-07	1.0560E-04
23	1.00E-07	2.25E-07	1.1500E-04
24	5.00E-08	1.00E-07	1.8850E-05
25	3.00E-08	5.00E-08	1.9000E-05
26	1.00E-08	3.00E-08	1.5870E-07
27	1.00E-11	1.00E-08	4.4390E-07
Total			1.2418E+08

Table 5.3.21-8 Gamma Source Terms for NRU HEU Fuel Assembly

Group	E Lower [MeV]	E Upper [MeV]	Source [photons/sec-MTU]
1	8.00E+00	1.00E+01	2.3940E+03
2	6.50E+00	8.00E+00	1.1060E+04
3	5.00E+00	6.50E+00	5.7290E+04
4	4.00E+00	5.00E+00	1.4530E+05
5	3.00E+00	4.00E+00	6.5250E+06
6	2.50E+00	3.00E+00	4.1940E+08
7	2.00E+00	2.50E+00	1.6300E+11
8	1.66E+00	2.00E+00	3.1660E+12
9	1.33E+00	1.66E+00	3.3730E+13
10	1.00E+00	1.33E+00	3.3890E+14
11	8.00E-01	1.00E+00	3.5190E+14
12	6.00E-01	8.00E-01	4.0800E+16
13	4.00E-01	6.00E-01	1.0040E+15
14	3.00E-01	4.00E-01	1.2380E+15
15	2.00E-01	3.00E-01	1.7620E+15
16	1.00E-01	2.00E-01	5.6100E+15
17	4.50E-02	1.00E-01	9.5130E+15
18	1.00E-02	4.50E-02	2.7550E+16
Total			8.8205E+16

Table 5.3.21-9 Neutron Source Terms for NRU LEU Fuel Assembly

Group	E Lower [MeV]	E Upper [MeV]	Source [neutrons/sec-MTU]
1	6.38E+00	2.00E+01	9.4220E+04
2	3.01E+00	6.38E+00	1.0060E+06
3	1.83E+00	3.01E+00	3.6630E+06
4	1.42E+00	1.83E+00	4.3320E+06
5	9.07E-01	1.42E+00	6.5140E+06
6	4.08E-01	9.07E-01	6.4600E+06
7	1.11E-01	4.08E-01	2.9010E+06
8	1.50E-02	1.11E-01	4.3960E+05
9	3.04E-03	1.50E-02	1.4680E+04
10	5.83E-04	3.04E-03	1.2240E+03
11	1.01E-04	5.83E-04	1.0320E+02
12	2.90E-05	1.01E-04	7.1260E+00
13	1.07E-05	2.90E-05	1.1320E+00
14	3.06E-06	1.07E-05	8.9590E-02
15	1.86E-06	3.06E-06	8.8510E-03
16	1.30E-06	1.86E-06	3.3040E-03
17	1.13E-06	1.30E-06	5.6500E-04
18	1.00E-06	1.13E-06	4.3130E-04
19	8.00E-07	1.00E-06	5.2580E-04
20	4.14E-07	8.00E-07	9.0870E-04
21	3.25E-07	4.14E-07	1.1730E-04
22	2.25E-07	3.25E-07	1.6490E-04
23	1.00E-07	2.25E-07	1.5810E-04
24	5.00E-08	1.00E-07	2.7700E-05
25	3.00E-08	5.00E-08	2.6320E-05
26	1.00E-08	3.00E-08	2.3080E-07
27	1.00E-11	1.00E-08	7.2050E-07
Total			2.5426E+07

Table 5.3.21-10 Gamma Source Terms for NRU LEU Fuel Assembly

Group	E Lower [MeV]	E Upper [MeV]	Source [photons/sec-MTU]
1	8.00E+00	1.00E+01	3.3110E+03
2	6.50E+00	8.00E+00	1.5150E+04
3	5.00E+00	6.50E+00	7.7470E+04
4	4.00E+00	5.00E+00	1.9370E+05
5	3.00E+00	4.00E+00	8.7460E+10
6	2.50E+00	3.00E+00	1.0900E+12
7	2.00E+00	2.50E+00	1.8520E+14
8	1.66E+00	2.00E+00	2.6290E+13
9	1.33E+00	1.66E+00	2.6780E+14
10	1.00E+00	1.33E+00	5.5510E+14
11	8.00E-01	1.00E+00	2.2570E+15
12	6.00E-01	8.00E-01	1.7910E+16
13	4.00E-01	6.00E-01	6.1870E+15
14	3.00E-01	4.00E-01	1.5540E+15
15	2.00E-01	3.00E-01	2.0350E+15
16	1.00E-01	2.00E-01	8.5930E+15
17	4.50E-02	1.00E-01	9.9880E+15
18	1.00E-02	4.50E-02	2.7200E+16
Total			7.6760E+16

Table 5.3.21-11 Neutron Source Terms for NRX Fuel Assembly

Group	E Lower [MeV]	E Upper [MeV]	Source [neutrons/sec-MTU]
1	6.380E+00	2.000E+01	8.7730E+04
2	3.010E+00	6.380E+00	9.0610E+05
3	1.830E+00	3.010E+00	1.5140E+07
4	1.420E+00	1.830E+00	2.1460E+07
5	9.070E-01	1.420E+00	3.1170E+07
6	4.080E-01	9.070E-01	3.1670E+07
7	1.110E-01	4.080E-01	1.3840E+07
8	1.500E-02	1.110E-01	2.2530E+06
9	3.040E-03	1.500E-02	7.0200E+04
10	5.830E-04	3.040E-03	5.7350E+03
11	1.010E-04	5.830E-04	4.6860E+02
12	2.900E-05	1.010E-04	3.9750E+01
13	1.070E-05	2.900E-05	6.2990E+00
14	3.060E-06	1.070E-05	7.5330E-02
15	1.860E-06	3.060E-06	4.7510E-03
16	1.300E-06	1.860E-06	1.7990E-03
17	1.130E-06	1.300E-06	4.9550E-04
18	1.000E-06	1.130E-06	3.8450E-04
19	8.000E-07	1.000E-06	4.5430E-04
20	4.140E-07	8.000E-07	7.9620E-04
21	3.250E-07	4.140E-07	1.1080E-04
22	2.250E-07	3.250E-07	1.3320E-04
23	1.000E-07	2.250E-07	1.4690E-04
24	5.000E-08	1.000E-07	2.1630E-05
25	3.000E-08	5.000E-08	2.4010E-05
26	1.000E-08	3.000E-08	1.7980E-07
27	1.000E-11	1.000E-08	4.7410E-07
Total			1.1660E+08

Table 5.3.21-12 Gamma Source Terms for NRX Fuel Assembly

Group	E Lower [MeV]	E Upper [MeV]	Source [photons/sec-MTU]
1	8.00E+00	1.00E+01	2.9410E+03
2	6.50E+00	8.00E+00	1.3550E+04
3	5.00E+00	6.50E+00	7.0020E+04
4	4.00E+00	5.00E+00	1.7700E+05
5	3.00E+00	4.00E+00	1.2010E+07
6	2.50E+00	3.00E+00	6.6300E+08
7	2.00E+00	2.50E+00	1.6340E+11
8	1.66E+00	2.00E+00	3.1520E+12
9	1.33E+00	1.66E+00	3.5670E+13
10	1.00E+00	1.33E+00	3.5100E+14
11	8.00E-01	1.00E+00	3.7940E+14
12	6.00E-01	8.00E-01	4.0630E+16
13	4.00E-01	6.00E-01	1.0520E+15
14	3.00E-01	4.00E-01	1.2330E+15
15	2.00E-01	3.00E-01	1.7560E+15
16	1.00E-01	2.00E-01	5.5950E+15
17	4.50E-02	1.00E-01	9.4790E+15
18	1.00E-02	4.50E-02	2.7460E+16
Total			8.7974E+16

Table 5.3.21-13 Cask/Basket Material Descriptions for NRU/NRX

Material	Element	Density [g/cm³]	Number Density [atom/b-cm]
Aluminum	Al	2.70	6.0265E-02
Stainless Steel 304	Fe	7.94	5.9505E-02
	Cr		1.7472E-02
	Ni		7.7392E-03
	Mn		1.7407E-03
Lead	Pb	11.34	3.2967E-02
Neutron Shield	H	0.97	5.9884E-02
	O		2.4595E-02
	C		1.0701E-02
Impact Limiter	Al	0.50	1.1153E-02

Table 5.3.21-14 NRU/NRX Basket Dimensions

Description	Value [in]	Value [cm]
Bottom Spacer Length	51.75	131.445
Basket Length	122.25	310.515
Tube Wall Thickness	0.065	0.1651
Tube OD	2.50	6.35
Tube Length	121.50	308.61
Tube Inner PCD	5.06	12.8524
Tube Outer PCD	9.78	24.8412
Lid Collar Height	2.50	6.985
Lid Plate Thickness	0.50	1.27

Table 5.3.21-15 ANSI/ANS 6.1.1-1977 Neutron Flux-to-Dose Conversion Factors

Energy [MeV]	Response [(rem/hr)/(n/cm^2/sec)]
20.0	2.27E-04
14.0	2.08E-04
10.0	1.47E-04
7.0	1.47E-04
5.0	1.56E-04
2.5	1.25E-04
1.0	1.32E-04
5.0E-01	9.26E-05
1.0E-01	2.17E-05
1.0E-02	3.56E-06
1.0E-03	3.76E-06
1.0E-04	4.18E-06
1.0E-05	4.54E-06
1.0E-06	4.46E-06
1.0E-07	3.67E-06
2.5E-08	3.67E-06

Table 5.3.21-16 ANSI/ANS 6.1.1-1977 Gamma Flux-to-Dose Conversion Factors

Energy, E [MeV]	Response [(rem/hr)/(γ/cm²/sec)]	Energy, E [MeV]	Response [(rem/hr)/(γ/cm²/sec)]
15.0	1.33E-05	1.0	1.98E-06
13.0	1.18E-05	0.8	1.68E-06
11.0	1.03E-05	0.7	1.52E-06
9.0	8.77E-06	0.65	1.44E-06
7.5	7.66E-06	0.6	1.36E-06
6.75	7.11E-06	0.55	1.27E-06
6.25	6.74E-06	0.5	1.17E-06
5.75	6.37E-06	0.45	1.08E-06
5.25	6.01E-06	0.4	9.85E-07
5.0	5.80E-06	0.35	8.78E-07
4.75	5.60E-06	0.3	7.59E-07
4.25	5.23E-06	0.25	6.31E-07
3.75	4.83E-06	0.2	5.01E-07
3.25	4.41E-06	0.15	3.79E-07
2.8	4.01E-06	0.1	2.83E-07
2.6	3.82E-06	0.07	2.58E-07
2.2	3.42E-06	0.05	2.90E-07
1.8	2.99E-06	0.03	5.82E-07
1.4	2.51E-06	0.01	3.96E-06

Table 5.3.21-17 Undamaged NRU HEU Fuel Dose Rate Summary

Transport Condition	Dose Rate Location	Maximum		Average	
		[mrem/hr]	FSD	[mrem/hr]	FSD
Normal	Side Surface of Cask	2.28	2.5%	0.444	3.9%
	Top Surface of Cask	0.191	17.0%	0.079	13.8%
	Bottom Surface of Cask	0.003	17.0%	0.001	15.7%
	Side 1m (Transport Index)	0.219	2.1%	0.089	2.5%
	2m from ISO - Radial	0.064	1.5%	0.030	2.1%
	Dose at Cab of Truck	0.001	26.4%	0.001	20.9%
Accident	Side Surface of Cask	4.52	3.0%	2.36	2.1%
	Top Surface of Cask	1.99	21.3%	0.530	22.0%
	Bottom Surface of Cask	0.036	25.2%	0.013	37.2%
	Side 1m	0.463	1.2%	0.236	1.9%
	Top 1m	0.095	11.1%	0.045	10.5%
	Bottom 1m	0.020	73.0%	0.006	103.5%

Table 5.3.21-18 Collapsed NRU HEU Fuel Dose Rate Summary

Transport Condition	Dose Rate Location	Maximum		Average	
		[mrem/hr]	FSD	[mrem/hr]	FSD
Normal	Side Surface of Cask	30.3	0.4%	2.26	1.5%
	Top Surface of Cask	1.48	4.4%	0.710	4.0%
	Bottom Surface of Cask	< 0.001	27.7%	< 0.001	28.1%
	Side 1m (Transport Index)	2.23	0.5%	0.453	1.0%
	2m from ISO - Radial	0.450	0.6%	0.152	0.9%
	Dose at Cab of Truck	0.010	26.1%	0.007	11.3%
Accident	Side Surface of Cask	61.3	1.2%	5.25	5.8%
	Top Surface of Cask	13.7	5.5%	4.02	5.7%
	Bottom Surface of Cask	0.001	19.4%	0.001	23.9%
	Side 1m	3.75	2.4%	0.700	4.7%
	Top 1m	0.903	39.1%	0.478	22.2%
	Bottom 1m	0.002	2.8%	0.001	4.0%

Table 5.3.21-19 Undamaged NRU LEU Fuel Dose Rate Summary

Transport Condition	Dose Rate Location	Maximum		Average	
		[mrem/hr]	FSD	[mrem/hr]	FSD
Normal	Side Surface of Cask	41.5	0.8%	21.5	1.3%
	Top Surface of Cask	4.65	8.4%	2.00	7.9%
	Bottom Surface of Cask	0.088	24.7%	0.036	30.6%
	Side 1m (Transport Index)	11.69	0.5%	4.81	0.8%
	2m from ISO - Radial	4.02	0.4%	1.72	0.7%
	Dose at Cab of Truck	0.057	64.4%	0.025	33.9%
Accident	Side Surface of Cask	113.4	1.2%	64.0	1.6%
	Top Surface of Cask	34.7	11.6%	10.6	13.3%
	Bottom Surface of Cask	0.594	28.7%	0.175	46.5%
	Side 1m	25.1	0.7%	10.7	1.1%
	Top 1m	2.48	7.4%	0.898	32.7%
	Bottom 1m	0.035	27.1%	0.013	33.3%

Table 5.3.21-20 Collapsed NRU LEU Fuel Dose Rate Summary

Transport Condition	Dose Rate Location	Maximum		Average	
		[mrem/hr]	FSD	[mrem/hr]	FSD
Normal	Side Surface of Cask	313.3	0.4%	26.7	1.1%
	Top Surface of Cask	24.2	2.8%	11.6	2.8%
	Bottom Surface of Cask	0.002	52.3%	0.001	66.7%
	Side 1m (Transport Index)	30.74	0.4%	5.99	0.8%
	2m from ISO - Radial	6.59	0.4%	2.10	0.7%
	Dose at Cab of Truck	0.153	3.9%	0.132	4.0%
Accident	Side Surface of Cask	626.5	0.7%	54.9	3.3%
	Top Surface of Cask	164.1	3.4%	56.4	4.8%
	Bottom Surface of Cask	0.027	74.2%	0.006	148.2%
	Side 1m	41.6	1.0%	8.90	2.7%
	Top 1m	11.8	2.4%	5.47	8.2%
	Bottom 1m	0.108	98.2%	0.023	210.2%

Table 5.3.21-21 Undamaged NRX Fuel Dose Rate Summary

Transport Condition	Dose Rate Location	Maximum		Average	
		[mrem/hr]	FSD	[mrem/hr]	FSD
Normal	Side Surface of Cask	1.98	2.5%	0.437	3.6%
	Top Surface of Cask	0.148	11.1%	0.075	13.0%
	Bottom Surface of Cask	0.002	3.5%	0.001	3.7%
	Side 1m (Transport Index)	0.206	2.1%	0.087	2.3%
	2m from ISO - Radial	0.065	1.3%	0.030	1.9%
	Dose at Cab of Truck	0.001	37.7%	0.001	22.2%
Accident	Side Surface of Cask	4.15	1.5%	2.38	2.1%
	Top Surface of Cask	1.55	15.9%	0.439	21.1%
	Bottom Surface of Cask	0.020	23.5%	0.008	27.8%
	Side 1m	0.481	1.4%	0.240	1.9%
	Top 1m	0.152	79.6%	0.045	48.7%
	Bottom 1m	0.009	36.0%	0.004	35.8%

Table 5.3.21-22 Collapsed NRX Fuel Dose Rate Summary

Transport Condition	Dose Rate Location	Maximum		Average	
		[mrem/hr]	FSD	[mrem/hr]	FSD
Normal	Side Surface of Cask	39.9	0.4%	2.93	1.5%
	Top Surface of Cask	1.79	3.4%	0.901	3.6%
	Bottom Surface of Cask	< 0.001	7.4%	< 0.001	7.8%
	Side 1m (Transport Index)	2.98	0.5%	0.597	1.0%
	2m from ISO - Radial	0.595	0.6%	0.202	0.9%
	Dose at Cab of Truck	0.011	20.6%	0.009	11.5%
Accident	Side Surface of Cask	78.3	1.3%	6.43	6.1%
	Top Surface of Cask	17.2	5.1%	5.21	5.4%
	Bottom Surface of Cask	0.006	72.9%	0.002	117.0%
	Side 1m	4.68	2.4%	0.885	4.9%
	Top 1m	1.25	51.1%	0.608	25.4%
	Bottom 1m	0.077	97.3%	0.016	206.8%

Table 5.3.21-23 Summarized Maximum Dose Rates for Undamaged Fuel

Transport Condition	Dose Rate Location	NRU HEU	NRU LEU	NRX HEU	Limit [mrem/hr]
Normal	Side Surface of Cask	2.28	41.5	1.98	1000
	2m from Truck - Radial	0.064	4.02	0.065	10
	Dose at Cab of Truck	0.001	0.057	0.001	2
Accident	Side 1m	0.463	25.1	0.481	1000

Table 5.3.21-24 Summarized Maximum Dose Rates for Collapsed Fuel

Transport Condition	Dose Rate Location	NRU HEU	NRU LEU	NRX HEU	Limit [mrem/hr]
Normal	Side Surface of Cask	30.3	313.3	39.9	1000
	2m from Truck - Radial	0.450	6.59	0.595	10
	Dose at Cab of Truck	0.010	0.153	0.011	2
Accident	Side 1m	3.75	41.6	4.68	1000

5.3.22 HEUNL

Results of the shielding evaluation for four HEUNL containers in the LWT cask are presented in this section. An inventory of gamma-emitting radionuclides is used with the actinide and nitrate contents to calculate gamma and neutron source terms. HEUNL containers are analyzed under normal and accident operating conditions to demonstrate compliance with 10 CFR 71.47 and 10 CFR 71.51.

HEUNL Source Terms

HEUNL source terms are calculated using an inventory of gamma-emitting radionuclides, actinide contents, and nitrate contents. The ORIGEN-S control module in SCALE 6.1 is used to calculate neutron and gamma source spectra.

Analysis reference composition of the HEUNL material is provided in Table 5.3.22-1. Analysis reference actinide concentrations (2003) are provided in Table 5.3.22-2. The reference inventory of gamma-emitting radionuclides (2012) is provided in Table 5.3.22-3 and consists of all fission products. There have been no additions of radioactive liquid containing fission products or fissile material since 2003.

Data provided in Tables 5.3.22-1, Table 5.3.22-2, and Table 5.3.22-3 are representative values applied as a starting point for the analysis presented in this chapter. Variations in the listed values do not impact the conclusion drawn from this evaluation to any significant extent provided the maximum curie per liter gamma emitter content specified later in this section is maintained. Material composition not producing gamma sources (e.g., inorganic content breakdown specified in Table 4.3.22-1) has no impact on the analysis. As this type of solution has no significant neutron emitter content, the actinide content used as reference data has a negligible effect on the conclusions of the chapter.

Actinides listed in Table 5.3.22-2 are the only neutron source producers of the HEUNL material and minor gamma source contributors. The primary gamma source contributors are fission products listed in the gamma-emitting radionuclide inventory in Table 5.3.22-3. There is no significant light element gamma source in the material. Actinide source calculations require the inclusion of the light element materials to accurately calculate the (alpha, n) component of the neutron source. Therefore, two ORIGEN-S calculations are used for the source term calculation, one for fission products and another for actinides and light elements. All results are provided on a "per liter" basis.

The fission product inventory credits some short-lived or metastable radionuclides to their parent radionuclide. In order to calculate source spectra, all gamma-emitting radionuclides must be accounted for in ORIGEN-S. Using a decay period in ORIGEN-S to achieve equilibrium between parent and daughter radionuclide is not desirable as some short-lived gamma producers (e.g. ^{140}La) who lack their long-lived parent radionuclides will be non-conservatively removed. Therefore, all undefined radionuclides are identified using an ORIGEN-S test case and are evaluated at 100% of the parent radionuclide activity. Undefined radionuclides are identified using the nuclide gamma power in the output.

Defined and undefined fission product Curie contents are provided in Table 5.3.22-4 and Table 5.3.22-5, respectively. Conversion from Bq/g to Ci/L is performed using the HEUNL density of 1.30 g/cc. A 50% increase in Curie content is applied to the uncertainty adjusted reference values as additional conservatism for the source term calculation. The reference concentration and uncertainty input values listed in Table 5.3.22-4 and Table 5.3.22-5 have no significant safety importance provided the Ci/liter limit, based on the evaluated column in Table 5.3.22-4, is met. The Curie limit for the source term evaluation is 9.0 Ci/L and determined using the defined fission product evaluated activity. The ORIGEN-S input used for determining undefined gamma emitters is shown in Figure 5.3.22-1. The ORIGEN-S output gamma power by radionuclide used for determining undefined gamma emitters is shown in Figure 5.3.22-2. The ORIGEN-S input for fission products is shown in Figure 5.3.22-3.

Calculation of the (alpha, n) neutron source in ORIGEN-S requires the light element nuclide concentrations of the nitrate solutions and actinide concentrations. The shielding model HEUNL material content evaluated is shown in Table 5.3.22-6. The isotopic content of actinides and light elements for insertion into ORIGEN-S is provided in Table 5.3.22-7. Decay time has negligible effects for the actinide contributions. A decay time of one year is applied to the calculation to allow for minor actinides not defined to be accounted for in the ORIGEN-S gamma spectra. Actinide gamma source is negligible in the results. The ORIGEN-S input for actinides and light elements is shown in Figure 5.3.22-4.

The neutron and gamma source terms per liter of HEUNL material are provided in Table 5.3.22-8 and Table 5.3.22-9, respectively. Neutron source terms are minor and primarily from (alpha, n) contributions from the actinide alpha interaction with light elements in the material. Gamma source terms are primarily from fission products. The source is applied in the shielding model for a container volume of 64.3 L.

HEUNL Shielding Models

MCNP three dimensional shielding analysis allows detailed modeling of the HEUNL containers and cask. The containers and cask are modeled as described in the license drawings. Tube quick disconnect fittings, the bottom portion of the container outer shell that rests on the shoulder and axially overlaps the container and neck, and base plate are conservatively omitted from the shielding model. Containers are shifted towards the top of the cask cavity. The radial lead gamma shield extends from the bottom of the NAC-LWT cavity to approximately 3 inches (7.62 cm) below the top of the cavity. Positioning the HEUNL material closest to the point of minimum gamma shielding is conservative.

[redacted]

The geometric description of an MCNP model is based on the combinatorial geometry system embedded in the code. In this system, bodies such as cylinders and rectangular parallelepipeds and their logical intersections and unions are used to describe the extent of material zones. The shielding evaluation considers both normal and accident conditions. The accident conditions of transport include the loss of neutron shielding material and lead slump. The neutron shielding shell and the impact limiters are also removed while modeling accident conditions.

While normal conditions include a gap between the lead and outer shell, lead slump is not evaluated for accident conditions as NAC procedures dictate that the lead is allowed to cool from the lowest point with molten lead from the top filling gaps formed during solidification. Therefore, no gap is expected to occur and further accident analyses detailing potential shifting of the lead gap are not necessary.

Detailed model parameters used in creating the three-dimensional model are derived from the license drawings. Elevations associated with the three-dimensional features are established with respect to the center bottom of the NAC-LWT cask cavity for the MCNP combinatorial model.

Material representation of the HEUNL material is modeled using the material content listed in Table 5.3.22-6. The isotopic content of the HEUNL material used as input into MCNP is provided in Table 5.3.22-10. ^{237}Np, ^{239}Pu, and ^{240}Pu are not included in the shielding model as they are minor constituents. Water content of the solution is calculated using the difference of the solution density and mass concentrations of all nitrates.

Material compositions for structural and shield materials are shown in Table 5.3.22-11. The three-dimensional NAC-LWT MCNP models are shown in Figure 5.3.22-5 through Figure 5.3.22-7, while sketches are shown in Figure 5.3.22-8 and Figure 5.3.22-9. Selected basket dimensions critical to model and dose results are listed in Table 5.3.22-12. A sample MCNP input file is provided in Figure 5.3.22-10.

HEUNL Shielding Evaluation

The shielding evaluation is performed using MCNP5 v1.60. The MCNP shielding model is utilized with the source terms to estimate the dose rate profiles at various distances from the side, top and bottom of the cask for both normal and accident conditions. The method of solution is continuous energy Monte Carlo with a Monte Carlo based weight window generator to accelerate code convergence. Weight window and problem convergence is verified by the 10 statistical checks performed by MCNP. Radial or axial biasing is performed depending on the desired dose location.

The ANSI/ANS 6.1.1-1977 flux-to-dose rate conversion factors are employed in the MCNP analysis. The ANSI/ANS neutron and gamma dose conversion factors are shown in Table 5.3.22-13 and Table 5.3.22-14, respectively.

HEUNL Dose Rates

Dose rates were computed for the HEUNL containers for both normal and accident conditions. HEUNL dose rates (normal and accident) are summarized in Table 5.3.22-15. The Transportation Index (TI) for the package is 1.5.

Results are summarized and compared to dose rate limits in Table 5.3.22-16. Gamma dose primarily from fission product sources is the dominant contributor to dose rates. A payload of 4 HEUNL containers is found to be in compliance of 10 CFR 71.47 and 10 CFR 71.51. Dose rate profiles for the maximum dose rate cases are provided in Figure 5.3.22-11 through Figure 5.3.22-13.

Figure 5.3.22-1 ORIGEN-S Input for Determining Undefined Fission Products

```
=ORIGENS
' 71 is FT71 temporary files for storing concentration
0$$  A11 71  E T
DECAY CASE
' Item 1: 21  - Library Unit number
' Item 2: 1 - Not used
' Item 3: 1 - Binary library position - no multiple libraries
' Item 4: -82 - xn27g19v7 energy group structure
' Item 11: 0  - print suppressed for for nuclear data library calculation
' Item 16: 4 - material input in Curies
' Item 33: -82 - xn27g19v7 energy group structure
3$$ 21 1 1 -82 A11 0 A16 4  A33 -82  E T
' Block not used - left for backward compatibility
35$$ 0 T
' Item 8: 1  - specify cut as percent of total
' Item 11: 0 - problem dependent material for alpha,n (0 would be UO2, 2 for problem dependent)
54$$ A8 1 A11 2  E
' Item 2: 6 - number of time intervals
' Item 6: 1 - continuation problem control (block 5 used)- not applicable here
' Item 10: 0 - new concentration input
' Item 13: 14 - number of nuclides input into 73,74,75 arrays
' Item 14: 2 - decay time unit control (Min)
' Item 15: 3 - input cards both title and basis entered
56$$ A2 6  A6 1  A10  0  A13 14  A14 2  A15 3 E
' Item 1: 0 - Time subtracted from 60* Array values
' Item 2: 1.30 - Density of material - Should not be needed in this case
' Item 3: 1e-05  alpha-n control for cut-off for determining important nuclides
57** 0 1.3 1E-05 E T
HEUNL MATERIAL
Curies PER Liter
' Decay time
60** 0.5 15 60 1440 43200 525600
' Cut-off for output table significance (fill array)
61** F1E-08
' Print all available data gram-atoms, grams, curies, watts but no m3
' GRAM-ATOMS   GRAMS    CURIES     WATTS-ALL  WATTS-GAMMA
65$$
 15R1 6R0
 15R1 6R0
 15R1 6R0
' Item 1: 2 - Apply line energy yield from master photon library
' Item 2: 0 - No longer used
' Item 3: 26 - Master photon library (default value is 26)
' Item 4: 1 - library is in binary format (2 for ascii)
81$$ 2 0 26 1  E
' Gamma source print-out trigger - 2 for total source per second (4/LE, 5/ACT, 6/FP)
82$$ 2 2 2 2 2 2
' Nuclide ids for input concentration - FP
73$$ 410950 400950 441030 441060 531310 521320 551370 561400
 571400 581410 581440 601470 631540 631550
' Material quantities of each nuclide - FP
74** 1.792E-01 6.851E-01 4.901E-01 1.476E-02 5.270E-01 2.793E-01
 1.897E+00 1.581E+00 1.528E+00 1.159E+00 2.214E-01 4.269E-01
 2.266E-03 5.270E-03' Determines library of each nuclide (1 for LE, 2 for Act, 3 for FP)
75$$ 3 3 3 3 3 3 3 3 3 3 3 3 3 3 T
56$$ F0 T
END
```

Figure 5.3.22-2 ORIGEN-S Output Gamma Power for Determining Undefined Fission Products

```
    HEUNL MATERIAL
fission products         page   57
0                                              nuclide gamma power, watts
                                               basis =Curies PER Liter
              initial       0 m       15 m       60 m     1440 m    43200 m   525600 m
     zr 95    2.973E-03 2.973E-03 2.973E-03 2.972E-03 2.941E-03 2.149E-03 5.719E-05
     nb 95    8.121E-04 8.121E-04 8.125E-04 8.139E-04 8.561E-04 1.615E-03 1.272E-04
     nb 95m   0.000E+00 7.140E-10 2.140E-08 8.532E-08 1.861E-06 8.167E-06 2.183E-07
     ru103    1.441E-03 1.441E-03 1.441E-03 1.440E-03 1.416E-03 8.487E-04 2.291E-06
     rh103m   0.000E+00 7.028E-07 1.930E-05 5.973E-05 1.123E-04 6.728E-05 1.816E-07
     rh106    0.000E+00 9.057E-06 1.803E-05 1.803E-05 1.800E-05 1.705E-05 9.159E-06
      i131    1.195E-03 1.195E-03 1.194E-03 1.190E-03 1.096E-03 8.940E-05 2.388E-17
     xe131m   0.000E+00 1.484E-11 4.450E-10 1.776E-09 3.976E-08 1.501E-07 8.046E-16
     te132    3.863E-04 3.863E-04 3.854E-04 3.828E-04 3.111E-04 5.865E-07 0.000E+00
      i132    0.000E+00 9.415E-06 2.721E-04 9.718E-04 3.107E-03 5.862E-06 0.000E+00
     cs137    1.849E-08 1.849E-08 1.849E-08 1.849E-08 1.849E-08 1.845E-08 1.807E-08
     ba137m   0.000E+00 8.069E-04 6.247E-03 6.355E-03 6.354E-03 6.343E-03 6.210E-03
     ba140    1.706E-03 1.706E-03 1.705E-03 1.703E-03 1.616E-03 3.341E-04 4.127E-12
     la140    2.091E-02 2.091E-02 2.091E-02 2.092E-02 2.094E-02 4.878E-03 6.025E-11
     ce141    5.252E-04 5.252E-04 5.251E-04 5.247E-04 5.141E-04 2.770E-04 2.189E-07
     ce144    2.521E-05 2.521E-05 2.521E-05 2.521E-05 2.515E-05 2.344E-05 1.038E-05
     pr144    0.000E+00 7.451E-07 1.704E-05 3.444E-05 3.778E-05 3.521E-05 1.559E-05
     pr144m   0.000E+00 3.504E-08 5.697E-07 7.433E-07 7.439E-07 6.932E-07 3.068E-07
     nd147    3.532E-04 3.531E-04 3.529E-04 3.522E-04 3.315E-04 5.315E-05 3.475E-14
     eu154    1.675E-05 1.675E-05 1.675E-05 1.675E-05 1.675E-05 1.664E-05 1.545E-05
     eu155    1.902E-06 1.902E-06 1.902E-06 1.902E-06 1.901E-06 1.879E-06 1.644E-06
   total      3.034E-02 3.117E-02 3.692E-02 3.778E-02 3.970E-02 1.676E-02 6.450E-03

1
```

Figure 5.3.22-3 ORIGEN-S Input for Fission Products

```
=ORIGENS
' 71 is FT71 temporary files for storing concentration
0$$  A11 71  E T
DECAY CASE
' Item 1: 21  - Library Unit number
' Item 2: 1 - Not used
' Item 3: 1 - Binary library postiion - no multiple libraries
' Item 4: -82 - xn27g19v7 energy group structure
' Item 11: 0  - print suppressed for for nuclear data library calcualtion
' Item 16: 4 - material input in Curies
' Item 33: -82 - xn27g19v7 energy group structure
3$$ 21 1 1 -82 A11 0 A16 4  A33 -82  E T
' Block not used - left for backward compatibility
35$$ 0 T
' Item 8: 1  - specify cut as percent of total
' Item 11: 0 - problem dependent material for alpha,n (0 would be UO2, 2 for problem dependent)
54$$ A8 1 A11 2  E
' Item 2: 6 - number of time intervals
' Item 6: 1 - continuation problem control (block 5 used)- not applicable here
' Item 10: 0 - new concentration input
' Item 13: 21 - number of nuclides input into 73,74,75 arrasy
' Item 14: 1 - decay time unit control (sec)
' Item 15: 3 - input cardsboth title and basis entered
56$$ A2 6  A6 1  A10  0  A13 21  A14 1  A15 3 E
' Item 1: 0 - Time subtracted from 60* Array values
' Item 2: 1.30 - Density of material - Should not be needed in this case
' Item 3: 1e-05  alpha-n control for cut-off for determining important nuclides
57** 0 1.3 1E-05 E T
HEUNL MATERIAL
Curies PER Liter
' Decay time
60** 0 1 60 1E3 1E4 1E5
' Cut-off for output table significance (fill array)
61** F1E-08
' Print all available data gram-atoms, grams, curies, watts but no m3
' GRAM-ATOMS   GRAMS    CURIES     WATTS-ALL  WATTS-GAMMA
65$$
 15R1 6R0
 15R1 6R0
 15R1 6R0
' Item 1: 2 - Apply line energy yield from master photon library
' Item 2: 0 - No longer used
' Item 3: 26 - Master photon library (default value is 26)
' Item 4: 1 - library is in binary format (2 for ascii)
81$$ 2 0 26 1  E
' Gamma source print-out trigger - 2 for total source per second (4/LE, 5/ACT, 6/FP)
82$$ 2 2 2 2 2 2
' Nuclide ids for input concentration - FP
73$$ 410950 410951 400950 441030 441060 451060 451031
531310 541311 521320 551370 561371 561400 571400 581410
581440 591440 591441 601470 631540 631550
' Material quanties of each nuclide - FP
74** 1.792E-01 6.851E-01 6.851E-01 4.901E-01 1.476E-02 1.476E-02 4.901E-01
5.270E-01 5.270E-01 2.793E-01 1.897E+00 1.897E+00 1.581E+00 1.528E+00
 1.159E+00 2.214E-01 2.214E-01 2.214E-01 4.269E-01 2.266E-03 5.270E-03
' Determines library of each nuclide (1 for LE, 2 for Act, 3 for FP)
75$$ 3 3 3 3 3 3 3 3 3 3 3 3 3 3
 3 3 3 3 3 3 3 T
56$$ F0 T
END
```

Figure 5.3.22-4 ORIGEN-S Model for Actinides and Light Elements

```
=ORIGENS
' 71 is FT71 temporary files for storing concentration
0$$  A11 71  E T
DECAY CASE
' Item 1: 21  - Library Unit number
' Item 2: 1 - Not used
' Item 3: 1 - Binary library postiion - no multiple libraries
' Item 4: -82 - xn27g19v7 energy group structure
' Item 11: 0  - print suppressed for for nuclear data library calcualtion
' Item 16: 2 - material input in Grams
' Item 33: -82 - xn27g19v7 energy group structure
3$$ 21 1 1 -82 A11 0 A16 2  A33 -82  E T
' Block not used - left for backward compatibility
35$$ 0 T
' Item 8: 1  - specify cut as percent of total
' Item 11: 0 - problem dependent material for alpha,n (0 would be UO2, 2 for problem dependent)
54$$ A8 1 A11 2  E
' Item 2: 4 - number of time intervals
' Item 6: 1 - continuation problem control (block 5 used)- not applicable here
' Item 10: 0 - new concentration input
' Item 13: 35 - number of nuclides input into 73,74,75 arrasy
' Item 14: 4 - decay time unit control (Days)
' Item 15: 3 - input cardsboth title and basis entered
56$$ A2 4  A6 1  A10  0  A13 35  A14 4  A15 3 E
' Item 1: 0 - Time subtracted from 60* Array values
' Item 2: 1.30 - Density of material - Should not be needed in this case
' Item 3: 1e-05  alpha-n control for cut-off for determining important nuclides
57** 0 1.3 1E-05 E T
HEUNL MATERIAL
MASS PER LR
' Decay time
60** 1 365 3288 3653
' Cut-off for output table significance (fill array)
61** F1E-08
' Print all available data gram-atoms, grams, curies, watts but no m3
' GRAM-ATOMS GRAMS  CURIES WATTS-ALL  WATTS-GAMMA
65$$
 15R1 6R0
 15R1 6R0
 15R1 6R0
' Item 1: 2 - Apply line energy yield from master photon library
' Item 2: 0 - No longer used
' Item 3: 26 - Master photon library (default value is 26)
' Item 4: 1 - library is in binary format (2 for ascii)
81$$ 2 0 26 1  E
' Gamma source print-out trigger - 2 for total source per second (4/LE, 5/ACT, 6/FP)
82$$ 2 2 2 2
' Nuclide ids for input concentration
73$$ 10010 10020 130270 801960 801980 801990 802000 802010
802020 802040 260540 260560 260570 260580 240500 240520
240530 240540 280580 280600 280610 280620 280640 70140
70150 80160 80170 80180 922340 922350 922360 922380
932370 942390 942400
' Material quanties of each nuclide - LE and Actinides
74** 9.675E-01 1.451E-04 4.047E+01 1.595E-02 1.060E+00
 1.793E+00 2.456E+00 1.401E+00 3.174E+00 7.304E-01
 6.154E-02 9.732E-01 2.334E-02 2.971E-03 1.130E-02
 2.178E-01 2.470E-02 6.149E-03 1.199E-01 4.617E-02
 2.007E-03 6.399E-03 1.631E-03 7.968E+01 2.927E-01
 2.744E+02 1.073E-01 5.530E-01 1.230E-01 7.000E+00
 1.530E-01 4.490E-01 1.720E-04 5.630E-04 1.070E-05
' Determines library of each nuclide (1 for LE, 2 for Act, 3 for FP)
75$$  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
 2 2 2 2 2 2 2 T
56$$ F0 T
END
```

Figure 5.3.22-5 Axial VISED Slice of LWT with HEUNL Container Detail

[redacted]

Figure 5.3.22-6 Axial VISED Slice of LWT with HEUNL Containers

[redacted]

Figure 5.3.22-7 Radial VISED Slice of LWT with HEUNL Containers

[redacted]

Figure 5.3.22-8 Axial Sketch of LWT with HEUNL Containers

[redacted]

Figure 5.3.22-9 Radial Sketch of LWT with HEUNL Containers

[redacted]

Figure 5.3.22-10 Sample MCNP Input for HEUNL

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Figure 5.3.22-11 Radial Surface Dose Rate Profile for Normal Conditions – HEUNL

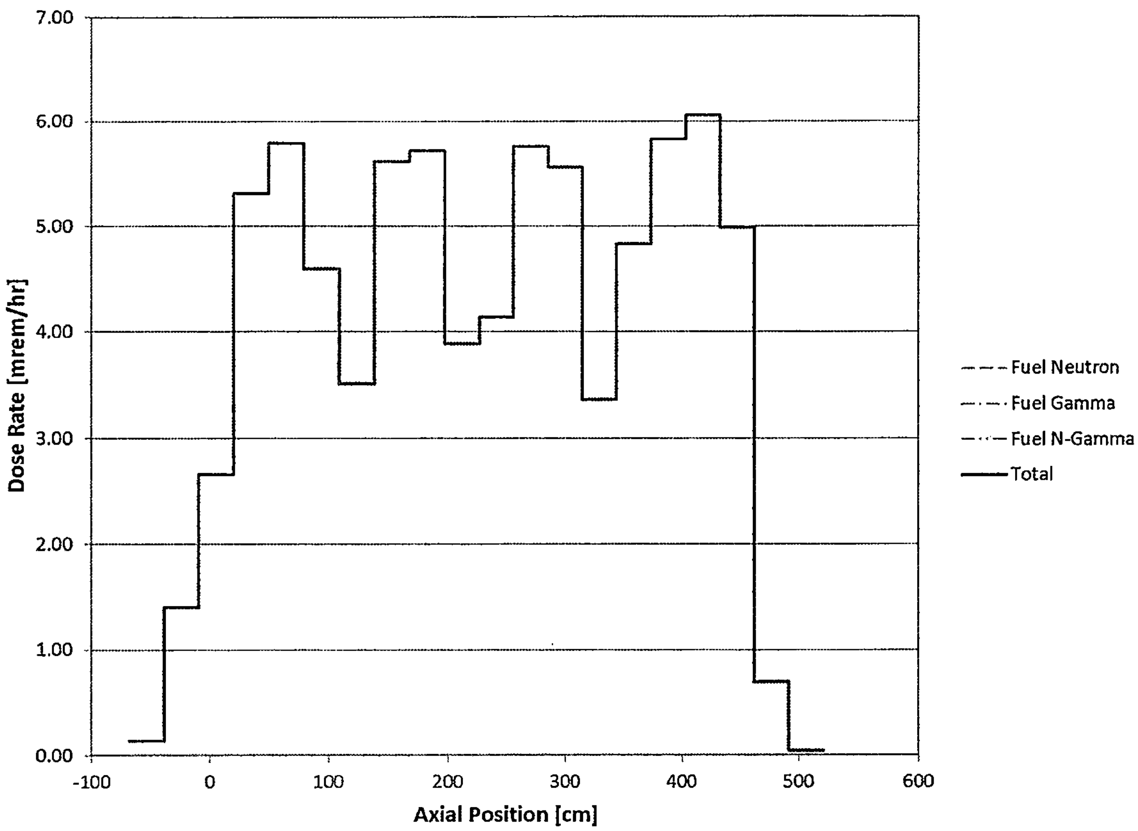


Figure 5.3.22-12 Radial 1 m Dose Rate Profile for Normal Conditions – HEUNL

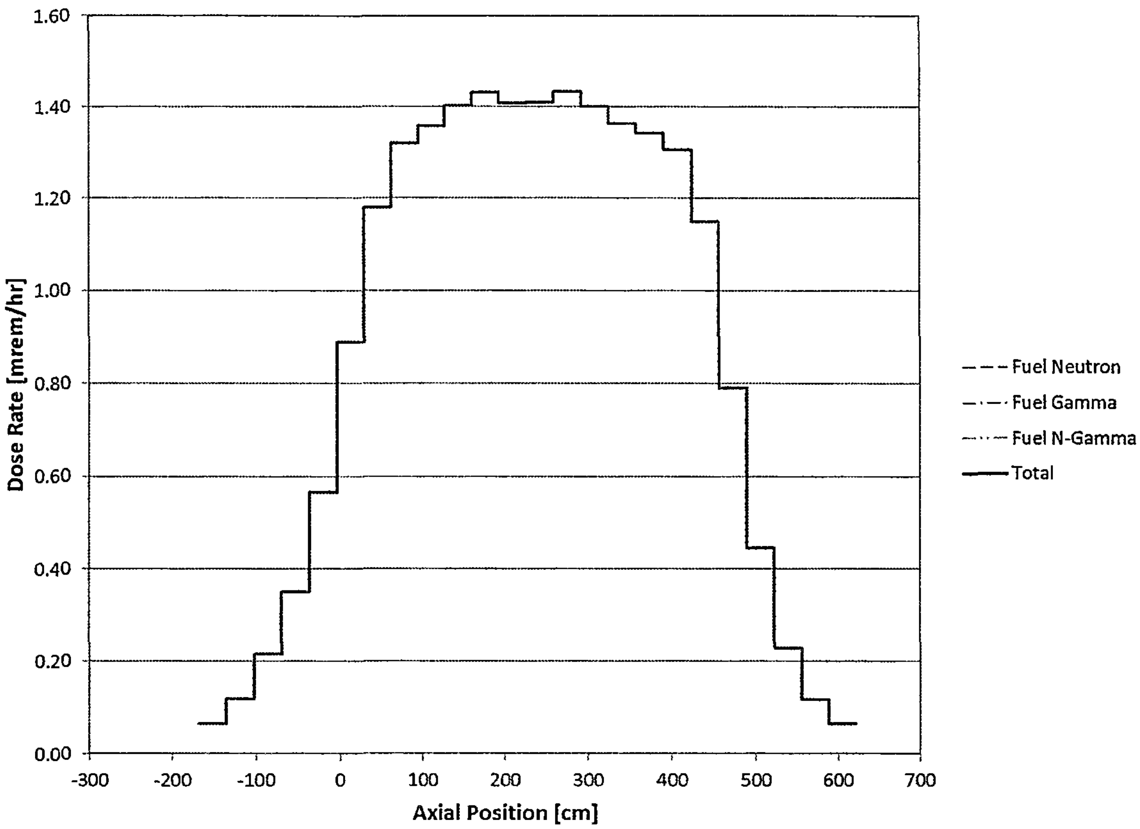


Figure 5.3.22-13 Radial 1m Dose Rate Profile for Accident Conditions – HEUNL

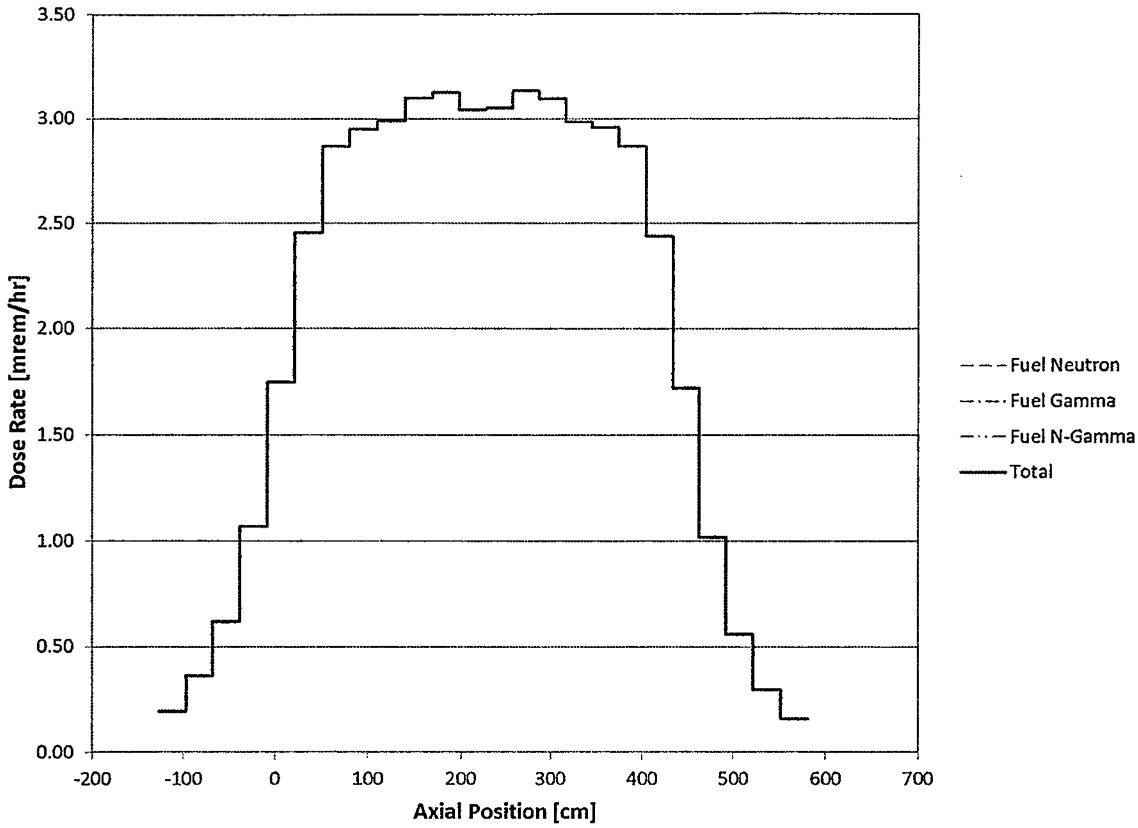


Table 5.3.22-1 Composition of Solution Inorganic Chemicals

Chemical Compound	Concentration (mol/L)	Concentration of Metal Ion (g/L)
HNO_3	0.96	N/A
$Al(NO_3)_3$	1.5	40.5
$Hg(NO_3)_2$	0.053	10.6
$Fe(NO_3)_3$	0.019	1.06
$Cr(NO_3)_3$	0.005	0.26
$Ni(NO_3)_2$	0.003	0.18

Table 5.3.22-2 Actinide Concentrations in the Solution

	Initial Concentration	
Nuclide	Bq/mL	g/L
^{234}U	2.84E+04	1.23E-01
^{235}U	5.59E+02	7.00E+00
^{236}U	3.66E+02	1.53E-01
^{238}U	5.59E+00	4.49E-01
^{237}Np	4.51E+00	1.72E-04
^{239}Pu	1.30E+03	5.63E-04
^{240}Pu	8.99E+01	1.07E-05

Table 5.3.22-3 Inventory of Gamma-Emitting Radionuclides

Radionuclide	Conc. (Bq/g)	σ[1] (Bq/g)
^{95}Nb	3.2E+06	1.0E+05
^{95}Zr	1.1E+07	1.0E+06
^{103}Ru	8.7E+06	3.0E+05
^{106}Ru	1.8E+05	5.0E+04
^{131}I	9.2E+06	4.0E+05
^{132}Te	4.3E+06	5.0E+05
^{137}Cs	3.4E+07	1.0E+06
^{140}Ba	2.8E+07	1.0E+06
^{140}La	2.7E+07	1.0E+06
^{141}Ce	2.0E+07	1.0E+06
^{144}Ce	3.8E+06	2.0E+05
^{147}Nd	7.3E+06	4.0E+05
^{154}Eu	2.7E+04	8.0E+03
^{155}Eu	8.0E+04	1.0E+04

[1] Uncertainty of measured content

Table 5.3.22-4 Fission Product Content for Defined Radionuclides

Isotope	Total (Bq/g)	σ (Bq/g)	Conc. + 2σ (Bq/g)	Eval. Conc. (Bq/g)	Eval. Conc. (Ci/L)
^{95}Nb	3.2E+06	1.0E+05	3.4E+06	5.1E+06	1.792E-01
^{95}Zr	1.1E+07	1.0E+06	1.3E+07	2.0E+07	6.851E-01
^{103}Ru	8.7E+06	3.0E+05	9.3E+06	1.4E+07	4.901E-01
^{106}Ru	1.8E+05	5.0E+04	2.8E+05	4.2E+05	1.476E-02
^{131}I	9.2E+06	4.0E+05	1.0E+07	1.5E+07	5.270E-01
^{132}Te	4.3E+06	5.0E+05	5.3E+06	8.0E+06	2.793E-01
^{137}Cs	3.4E+07	1.0E+06	3.6E+07	5.4E+07	1.897E+00
^{140}Ba	2.8E+07	1.0E+06	3.0E+07	4.5E+07	1.581E+00
^{140}La	2.7E+07	1.0E+06	2.9E+07	4.4E+07	1.528E+00
^{141}Ce	2.0E+07	1.0E+06	2.2E+07	3.3E+07	1.159E+00
^{144}Ce	3.8E+06	2.0E+05	4.2E+06	6.3E+06	2.214E-01
^{147}Nd	7.3E+06	4.0E+05	8.1E+06	1.2E+07	4.269E-01
^{154}Eu	2.7E+04	8.0E+03	4.3E+04	6.5E+04	2.266E-03
^{155}Eu	8.0E+04	1.0E+04	1.0E+05	1.5E+05	5.270E-03
Total	1.6E+08		1.7E+08	2.6E+08	8.998E+00

Table 5.3.22-5 Fission Product Content for Undefined Radionuclides

Isotope	Parent Isotope	Total (Bq/g)	σ (Bq/g)	Conc. + 2σ (Bq/g)	Eval. Conc. (Bq/g)	Eval. Conc. (Ci/L)
^{95m}Nb	^{95}Zr	1.1E+07	1.0E+06	1.3E+07	2.0E+07	6.851E-01
^{106}Rh	^{106}Ru	1.8E+05	5.0E+04	2.8E+05	4.2E+05	1.476E-02
^{103m}Rh	^{103}Ru	8.7E+06	3.0E+05	9.3E+06	1.4E+07	4.901E-01
^{131m}Xe	^{131}I	9.2E+06	4.0E+05	1.0E+07	1.5E+07	5.270E-01
^{137m}Ba	^{137}Cs	3.4E+07	1.0E+06	3.6E+07	5.4E+07	1.897E+00
^{144}Pr	^{144}Ce	3.8E+06	2.0E+05	4.2E+06	6.3E+06	2.214E-01
^{144m}Pr	^{144}Ce	3.8E+06	2.0E+05	4.2E+06	6.3E+06	2.214E-01
Total		7.1E+07		7.7E+07	1.2E+08	4.057E+00

Table 5.3.22-6 Modeled HEUNL Nitrate Contents

				Concentration (g/L)			
Solution	Metal Ion	mol/L	A_r (metal)	Ion	N	O	Total
HNO_3	H	0.96	1.00794	0.97	13.45	46.08	60.49
$Al(NO_3)_3$	Al	1.5	26.982	40.5	63.03	215.99	319.50
$Hg(NO_3)_2$	Hg	0.053	200.59	10.6	1.48	5.09	17.20
$Fe(NO_3)_3$	Fe	0.019	55.845	1.06	0.80	2.74	4.60
$Cr(NO_3)_3$	Cr	0.005	51.9961	0.26	0.21	0.72	1.19
$Ni(NO_3)_2$	Ni	0.003	58.6934	0.18	0.08	0.29	0.55
$UO_2(NO_3)_2$	U	0.0328	235.1783	7.73	0.92	4.20	12.85
				Total:	79.97	275.11	416.37

Table 5.3.22-7 **Isotopic Contents of Actinides and Light Elements for ORIGEN-S Source Term Calculation**

Element	Isotope	NA (%)	Conc. (g/L)
H	1	99.985	9.675E-01
	2	0.015	1.451E-04
Al	27	100	4.047E+01
Hg	196	0.15	1.595E-02
	198	9.97	1.060E+00
	199	16.87	1.793E+00
	200	23.1	2.456E+00
	201	13.18	1.401E+00
	202	29.86	3.174E+00
	204	6.87	7.304E-01
Fe	54	5.8	6.154E-02
	56	91.72	9.732E-01
	57	2.2	2.334E-02
	58	0.28	2.971E-03
Cr	50	4.345	1.130E-02
	52	83.789	2.178E-01
	53	9.501	2.470E-02
	54	2.365	6.149E-03
Ni	58	68.077	1.199E-01
	60	26.223	4.617E-02
	61	1.14	2.007E-03
	62	3.634	6.399E-03
	64	0.926	1.631E-03
N	14	99.634	7.968E+01
	15	0.366	2.927E-01
O	16	99.76	2.744E+02
	17	0.039	1.073E-01
	18	0.201	5.530E-01
U	234		1.230E-01
	235		7.000E+00
	236		1.530E-01
	238		4.490E-01
Np	237		1.720E-04
Pu	239		5.630E-04
	240		1.070E-05

Table 5.3.22-8 Neutron Source Terms per Liter

Group	E Lower [MeV]	E Upper [MeV]	Source [neutrons/sec/L]
1	6.380E+00	2.000E+01	1.9390E-04
2	3.010E+00	6.380E+00	1.0150E-01
3	1.830E+00	3.010E+00	5.0590E-01
4	1.420E+00	1.830E+00	1.6400E-01
5	9.070E-01	1.420E+00	2.3570E-01
6	4.080E-01	9.070E-01	1.9990E-01
7	1.110E-01	4.080E-01	6.2580E-02
8	1.500E-02	1.110E-01	1.0690E-02
9	3.040E-03	1.500E-02	6.0760E-04
10	5.830E-04	3.040E-03	5.1430E-05
11	1.010E-04	5.830E-04	4.2930E-06
12	2.900E-05	1.010E-04	3.2370E-07
13	1.070E-05	2.900E-05	1.0470E-08
14	3.060E-06	1.070E-05	2.5070E-09
15	1.860E-06	3.060E-06	3.7860E-10
16	1.300E-06	1.860E-06	1.7290E-10
17	1.130E-06	1.300E-06	5.4000E-11
18	1.000E-06	1.130E-06	3.8430E-11
19	8.000E-07	1.000E-06	6.1730E-11
20	4.140E-07	8.000E-07	1.1760E-10
21	3.250E-07	4.140E-07	2.6730E-11
22	2.250E-07	3.250E-07	3.0320E-11
23	1.000E-07	2.250E-07	3.1420E-11
24	5.000E-08	1.000E-07	9.3470E-12
25	3.000E-08	5.000E-08	3.7480E-12
26	1.000E-08	3.000E-08	2.8070E-12
27	1.000E-11	1.000E-08	6.3210E-16
Total			1.2811E+00

Table 5.3.22-9 Gamma Source Terms per Liter

Group	E Lower [MeV]	E Upper [MeV]	Source [photons/sec/L]
1	1.00E+01	2.00E+01	3.5920E-07
2	8.00E+00	1.00E+01	2.2040E-05
3	6.50E+00	8.00E+00	1.1990E-04
4	5.00E+00	6.50E+00	7.5230E-04
5	4.00E+00	5.00E+00	2.2670E-03
6	3.00E+00	4.00E+00	1.4540E+07
7	2.50E+00	3.00E+00	1.8860E+09
8	2.00E+00	2.50E+00	5.7190E+08
9	1.66E+00	2.00E+00	3.8810E+07
10	1.33E+00	1.66E+00	5.7640E+10
11	1.00E+00	1.33E+00	1.5950E+08
12	8.00E-01	1.00E+00	2.0900E+10
13	6.00E-01	8.00E-01	9.9190E+10
14	4.00E-01	6.00E-01	6.4380E+10
15	3.00E-01	4.00E-01	3.1060E+10
16	2.00E-01	3.00E-01	1.8480E+10
17	1.00E-01	2.00E-01	3.2181E+10
18	4.50E-02	1.00E-01	1.9170E+10
19	1.00E-02	4.50E-02	1.1040E+11
Total			4.5607E+11

Table 5.3.22-10 Isotopic Contents of HEUNL Materials for MCNP Shielding Evaluation

Element	Z	A	Conc. (g/L)	wt.%
H	1	1	9.676E-01	0.074%
Al	13	27	4.047E+01	3.113%
Hg	80	NA[1]	1.063E+01	0.818%
Fe	26	NA	1.061E+00	0.082%
Cr	24	NA	2.600E-01	0.020%
Ni	28	NA	1.761E-01	0.014%
N	7	14	7.997E+01	6.152%
O	8	16	2.751E+02	21.162%
U	92	234	1.230E-01	0.009%
	92	235	7.000E+00	0.538%
	92	236	1.530E-01	0.012%
	92	238	4.490E-01	0.035%
Np	93	237	1.720E-04	0.000%
Pu	94	239	5.630E-04	0.000%
	94	240	1.070E-05	0.000%
Total - Nitrates			4.164E+02	32.029%
Water Content				
H	1	1	9.818E+01	7.552%
O	8	16	7.854E+02	60.419%
Total - Water			8.836E+02	67.971%
Total - HEUNL			1.300E+03	

[1] Natural abundance

Table 5.3.22-11 Cask/Container Material Descriptions for HEUNL

Material	Element	Density [g/cm³]	Number Density [atom/b-cm]
Aluminum	Al	2.70	6.0265E-02
Stainless Steel 304	Fe	7.94	5.9505E-02
	Cr		1.7472E-02
	Ni		7.7392E-03
	Mn		1.7407E-03
Lead	Pb	11.34	3.2967E-02
Neutron Shield	H	0.97	5.9884E-02
	O		2.4595E-02
	C		1.0701E-02
Impact Limiter	Al	0.50	1.1153E-02

Table 5.3.22-12 HEUNL Container Dimensions

[redacted]

Table 5.3.22-13 ANSI/ANS 6.1.1-1977 Neutron Flux-to-Dose Conversion Factors

Energy [MeV]	Response [(rem/hr)/(n/cm²/sec)]
20.0	2.27E-04
14.0	2.08E-04
10.0	1.47E-04
7.0	1.47E-04
5.0	1.56E-04
2.5	1.25E-04
1.0	1.32E-04
5.0E-01	9.26E-05
1.0E-01	2.17E-05
1.0E-02	3.56E-06
1.0E-03	3.76E-06
1.0E-04	4.18E-06
1.0E-05	4.54E-06
1.0E-06	4.46E-06
1.0E-07	3.67E-06
2.5E-08	3.67E-06

Table 5.3.22-14 ANSI/ANS 6.1.1-1977 Gamma Flux-to-Dose Conversion Factors

Energy, E [MeV]	Response [(rem/hr)/(γ/cm²/sec)]	Energy, E [MeV]	Response [(rem/hr)/(γ/cm²/sec)]
15.0	1.33E-05	1.0	1.98E-06
13.0	1.18E-05	0.8	1.68E-06
11.0	1.03E-05	0.7	1.52E-06
9.0	8.77E-06	0.65	1.44E-06
7.5	7.66E-06	0.6	1.36E-06
6.75	7.11E-06	0.55	1.27E-06
6.25	6.74E-06	0.5	1.17E-06
5.75	6.37E-06	0.45	1.08E-06
5.25	6.01E-06	0.4	9.85E-07
5.0	5.80E-06	0.35	8.78E-07
4.75	5.60E-06	0.3	7.59E-07
4.25	5.23E-06	0.25	6.31E-07
3.75	4.83E-06	0.2	5.01E-07
3.25	4.41E-06	0.15	3.79E-07
2.8	4.01E-06	0.1	2.83E-07
2.6	3.82E-06	0.07	2.58E-07
2.2	3.42E-06	0.05	2.90E-07
1.8	2.99E-06	0.03	5.82E-07
1.4	2.51E-06	0.01	3.96E-06

Table 5.3.22-15 HEUNL Dose Rate Summary

Transport Condition	Dose Rate Location	Maximum		Average	
		[mrem/hr]	FSD	[mrem/hr]	FSD
Normal	Side Surface of Cask	6.05E+00	0.2%	3.99E+00	0.2%
	Top Surface of Cask	5.37E-02	2.8%	3.25E-02	3.3%
	Bottom Surface of Cask	3.66E-01	1.9%	2.05E-01	2.1%
	Side 1m (Transport Index)	1.43E+00	0.1%	8.90E-01	0.2%
Accident	Side Surface of Cask	1.59E+01	0.2%	1.20E+01	0.2%
	Top Surface of Cask	4.08E-01	5.2%	1.30E-01	5.2%
	Bottom Surface of Cask	2.54E+00	2.2%	1.01E+00	3.0%
	Side 1m	3.13E+00	0.1%	2.03E+00	0.2%

Table 5.3.22-16 Summarized Maximum Dose Rates for HEUNL Transport

Transport Condition	Dose Rate Location	Maximum [mrem/hr]	Limit [mrem/hr]
Normal	Surface of Cask	6.05	200
	1m (Transport Index)	1.5	10
Accident	1m	3.13	1000

5.3.23 SLOWPOKE Core Configuration

Results of a shielding analysis for one SLOWPOKE core (up to 298 fuel rods and 930 g U) in the LWT cask are presented in this section. Maximum dose rates are calculated to demonstrate that dose rate limits of 10 CFR 71.47 and 10 CFR 71.51 are not exceeded.

Dose rates are calculated using the MCNP (MCNP5, Version 1.60) three-dimensional transport code. Source terms are calculated using the TRITON module of the SCALE package (SCALE 6.1).

5.3.23.1 SLOWPOKE Core Source Term

Source terms are calculated to bound the irradiation history of the SLOWPOKE core. A sketch of the fuel rod is shown in Figure 5.3.23-1. Reference fuel design characteristics, i.e., those documented in available references, are summarized in Table 5.3.23-1. Depletion and shielding evaluation code input characteristics, i.e., input data applied in TRITON depletion/irradiation and MCNP shielding model parameters, are given in Table 5.3.23-2. Key parameters differing between the reference information code and input are reduced enrichment, increased fuel mass, and increased irradiation time. All parameters are revised to produce bounding source terms. Each of the modified parameters is described below as to its effect on source:

- Increased fuel mass at a fixed depletion value (% ^{235}U depletion) increases source as the total amount of ^{235}U depleted increases, thereby increasing fission product sources.
- Reduced enrichment has opposing effects on source due to its relative effects on fission product versus higher actinide sources. For a fixed depletion percentage, a reduction in ^{235}U percentage will reduce the amount of material depleted, thereby reducing fission product sources, but increasing source as higher actinides are formed by parasitic absorption at a higher rate, increasing both neutron and gamma sources. Overall, the source effect from enrichment variations is minor, as the enrichment is decreased by only 3% for a high >90% enriched fuel source. This effect is significantly more pronounced for low enrichment fuels.
- Increased irradiation time, in conjunction with a continuous burn at full core power, increases source as it raises the depletion percentage with corresponding increases in both fission products and higher actinides generated.

As the exact configuration of the rods in the core is unknown, two configurations were evaluated; a reference core and a compact core. The configuration shown in Figure 5.3.23-2 is referred to as the reference configuration in which the rods are symmetrically distributed through the core. Figure 5.3.23-3 displays the compact core in which the rods are all shifted towards the center of the core. As the reference core configuration produces maximum gamma source spectra, it is used for the dose rate evaluation.

The SLOWPOKE core is designed to be critical, using fixed beryllium reflectors surrounding the radial extent of the core and the core bottom. The beryllium reflector top, also referred to as beryllium shim, is adjusted to maintain a critical configuration. Top and bottom reflectors are not included within the scope of the 2-D TRITON evaluation.

As a full core was modeled, fuel source was extracted at each ring of the core to determine which location produces maximum source spectra. The maximum gamma source (controlling for shielding) was obtained from the inner ring location (ring 1). This source was then applied to all fuel rods for the dose rate analysis. Gamma source from ring 1 (adjust on a per rod basis) is 24 percent higher for the reference core than the compact core model. The ring 1 per rod source of the reference model is 44 percent higher than the core average per rod source of the reference model.

No axial burnup profile for the SLOWPOKE core is available in open literature. Burnup profile impacts gamma and neutron source shape. The primary impact of a burnup profile is neutron source shape because burnup impacts fuel neutron source significantly faster than gamma source. SLOWPOKE HEU cores do not produce a significant neutron source. SLOWPOKE cores apply beryllium reflectors which will reduce axial shape effects. Radial core burnup studies demonstrate a slightly higher power in the periphery rather than a typical drop off. This type of effect from the axial reflectors would produce a slight flattening of the axial dose profile. Furthermore, as the core is ~22 cm in diameter versus a ~100 cm diameter, cask surface geometry effects/dispersion will assure that any minor axial profile on the core will not result in any significant cask surface dose changes.

TRITON input is shown in Figure 5.3.23-4, with the resulting TRITON material model shown in Figure 5.3.23-2. Neutron and gamma source terms for a cool time of 14 days from discharge are presented in Table 5.3.23-3 and Table 5.3.23-4, respectively. The modeled heat load in the dose rate analysis is 56.6 W. The calculated core average heat load at this cool time is 39.3 W or 42.2 kW/MTU.

The effect of subcritical neutron multiplication is directly computed in the MCNP analysis.

5.3.23.2 SLOWPOKE Core Shielding Model

MCNP three-dimensional shielding analysis allows detailed modeling of the fuel, basket, and cask shield configurations. The geometric description of a MCNP model is based on the combinatorial geometry system embedded in the code. In this system, bodies such as cylinders and rectangular parallelepipeds, and their logical intersections and unions, are used to describe the extent of material zones.

Fuel Models

The SLOWPOKE core is modeled in MCNP in the same configuration which produced the bounding source spectra. The fuel rods are explicitly modeled.

Cross-section of the VISED model of the source region are shown in Figure 5.3.23-5 and Figure 5.3.23-6 under normal conditions and Figure 5.3.23-8 and Figure 5.3.23-9 under accident conditions. As shown, the model is moved to its maximum axial elevation which brings it closest to the reduced shielding area of the NAC-LWT. The lowest shielding region is the tapered area of the lead gamma neutron shield, the area below the cask cavity top with no lead shielding.

Basket Model

For a given fuel type, the MCNP description of the basket stack forms a common sub-model employed in the analysis. For the SLOWPOKE core analysis, only the top basket containing the SLOWPOKE fuel is modeled. The remaining baskets are modeled as void, conservatively removing material from the shielding model. Similarly, the basket handle structure is modeled as void.

The characteristics of the analyzed SLOWPOKE core basket are summarized in Table 5.3.23-6. The analyzed design for the basket contains a 3-inch steel shield plug attached to the bottom (inside) of the basket lid and a separate spacer to push the fuel down in the basket. The design was updated to incorporate the shield plug and spacer into a single piece. The resulting spacer has a 2.5-inch top plate and a 1.5-inch bottom plate and maintains the 15.75-inch total spacing from the bottom of the lid to the top of the SLOWPOKE core. The modeled basket is conservative as the updated spacer contains an additional inch of shielding material as well as placing shielding directly above the core.

The as modeled basket can be seen in Figure 5.3.23-9, while a sketch of the updated lid design is shown in Figure 5.3.23-10.

MCNP NAC-LWT Model

The three-dimensional model of the NAC-LWT cask is based on the following features:

Normal conditions:

- Radial neutron shield and shield shell
- Aluminum impact limiters with 0.5 g/cm^3 density (calculated based on the impact limiter weight and dimensions) and a diameter equal to the neutron shield shell diameter

Accident conditions:

- Removal of radial neutron shield and shield shell

- Loss of upper and lower impact limiters
- Lead slump – Radial and Axial modeled simultaneously

A 0.1374 cm gap between the lead outer diameter and the cask outer shell is applied under normal conditions of operations. A lead gap slump, based on the normal condition gap, is evaluated under hypothetical accident conditions. The lead gap volume is applied to both the axial slump and radial slump simultaneously. No lead slump is expected as the cask lead shield is poured in stages, with heaters controlling lead conditions, assuring minimal contraction gaps. The modeled top end drop gap is 2.71 inches which is conservative versus the gap calculated in Chapter 2. The radial gap modeled is 0.788 inch. The modeled radial and axial lead slump can be seen in Figure 5.3.23-8 and Figure 5.3.23-9, respectively. As stated previously, the elevation of the source regions is set at its maximum axial extent. Elevations associated with the three-dimensional features are established with respect to the center bottom of the NAC-LWT cask cavity for the MCNP combinatorial model. Sample input files are provided in Figure 5.3.23-7 and Figure 5.3.23-11 for normal and accident conditions, respectively.

Tally/Detector Description

MCNP surface (F2) tallies are applied in the calculation of system dose rates. As the normal condition cask model is symmetric around the z-axis, dose rates are calculated as averages around the circumference of the cask. The dose rate profile as a function of z-elevation is generated at the radius of the neutron shield shell for normal conditions. An additional tally is placed in the gap between impact limiter and neutron shield shell on the cask outer shell. Hypothetical accident condition dose rates remove both impact limiter and neutron shield and shield shell. Axial and radial lead slumps are included. As a radial lead slump is evaluated, the tally results are not symmetric around the cask periphery (peaking at the radial slump location). Azimuthal tally divisions are applied to capture peaks around the circumference of the cask. While the plot of dose versus z-elevation for the accident condition displays circumferential average dose rates, the maximum accident condition dose rates reported in the summary table are based on the azimuthal tally results.

Shield Regional Densities

Material compositions for structural and shield materials are shown in Table 5.3.23-5.

5.3.23.3 SLOWPOKE Core Shielding Evaluation

Calculational Methods

The shielding evaluation is performed using MCNP5 v1.6.

The MCNP shielding model described in Section 5.3.23.2 is utilized with the source terms described in Section 5.3.23.1 to estimate the dose rate profiles at various distances from the side, top and bottom of the cask for both normal and accident conditions. The method of solution is continuous energy Monte Carlo with a Monte Carlo based weight window generator to accelerate code convergence. Weight window and problem convergence is verified by the 10 statistical checks performed by MCNP. Radial or axial biasing is performed depending on the desired dose location.

Significant validation literature is available for MCNP as it is an industry standard tool for spent fuel cask evaluations. Available literature covers a range of shielding penetration problems ranging from slab geometry to spent fuel cask geometries. Confirmatory calculations against other validated shielding codes (SCALE and MCBEND) on NAC casks have further validated the use of MCNP for shielding evaluations.

MCNP Flux-to-Dose Conversion Factors

The ANSI/ANS 6.1.1-1977 flux-to-dose rate conversion factors are employed in the MCNP analysis.

Three-Dimensional Dose Rates for SLOWPOKE Fuel

Table 5.3.23-7 provides maximum dose rates for the tabulated distances and transport conditions (normal and accident). Table 5.3.23-8 contains key results. Significant margin is present for all dose rate limits.

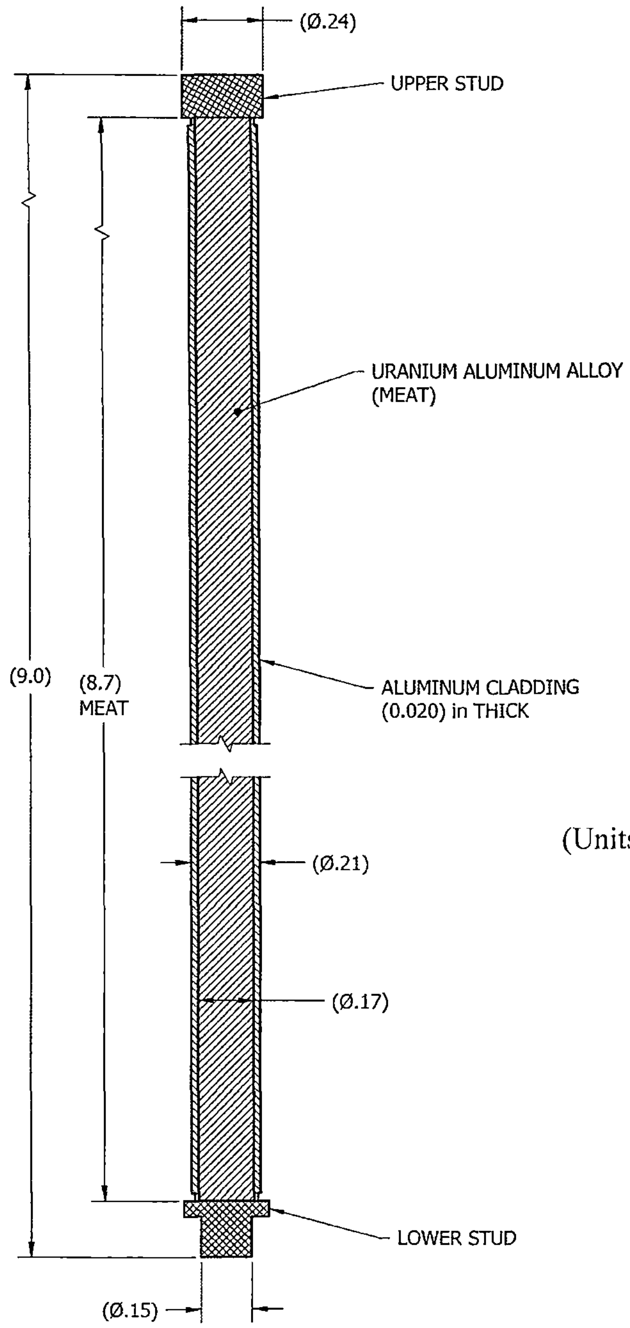
Calculated normal condition radial surface dose rates are below 200 mrem/hr. The Transportation Index (TI) is 15.2 (dose at 1 meter). As the transport index is over 10, an exclusive use designation for the NAC-LWT is used.

The maximum dose rate is dominated by the gamma component. The radial surface dose rate profile is shown in Figure 5.3.23-12. The normal condition maximum radial 2-meter dose rate is 3.1 mrem/hr. As expected, the dose rate profile is skewed towards the top of the cask, as shown Figure 5.3.23-13.

The maximum dose rate at the exposed cask surface above the neutron shield is 42.3 mrem/hr, significantly below the maximum radial dose rate taken from the surface of the neutron shield shell.

Accident condition radial 1-meter dose rates are well below the 1,000 mrem/hr limit. The radial dose rate profile is shown in Figure 5.3.23-14, with the bounding dose rate taken from the azimuthal profile shown in Figure 5.3.23-15.

Figure 5.3.23-1 SLOWPOKE Fuel Element



(Units in inches)

Figure 5.3.23-2 SLOWPOKE Core TRITON Model - Reference

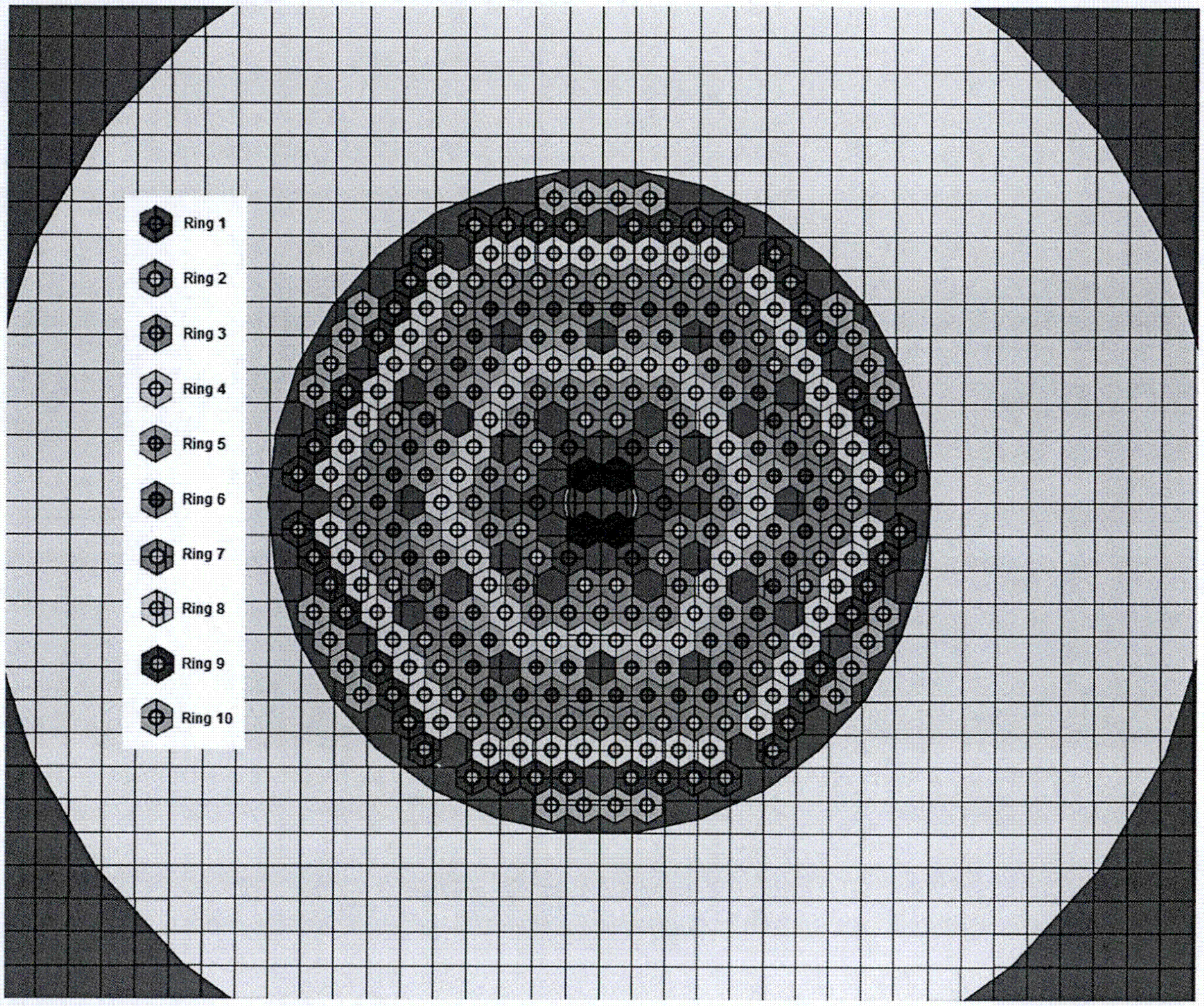


Figure 5.3.23-3 SLOWPOKE Core TRITON Model - Compact

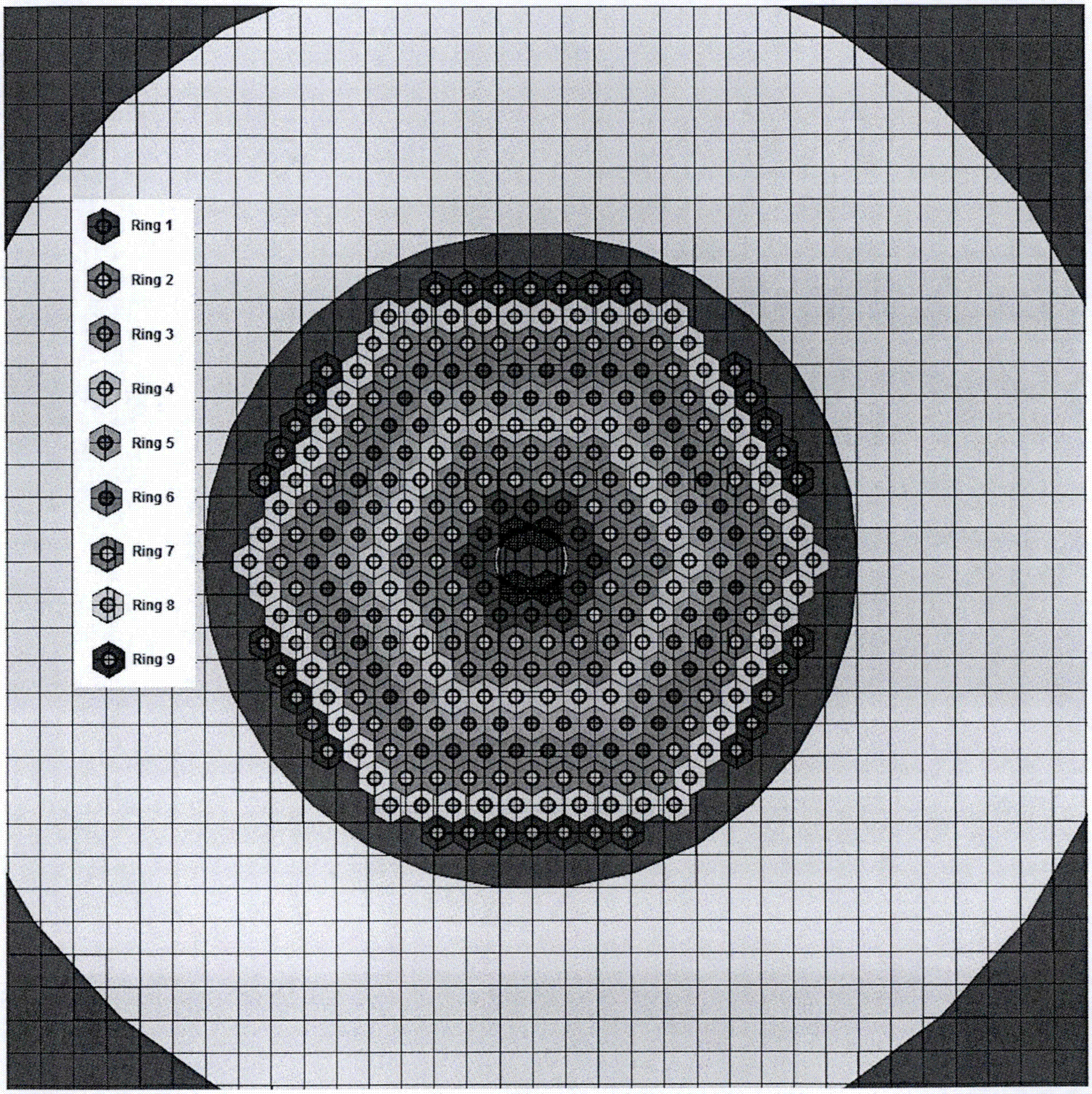


Figure 5.3.23-4 TRITON Input for SLOWPOKE Fuel - Reference

```
=t-depl        (parm=centrm)
SLOWPOKE CORE NEWT / CENTRM Depletion - 1.104 cm Rod Pitch - 15 GWD/MTU
V7-238
read comp
U     1 DEN=3.51 0.288 373.0  92235 90.0  92238  10.0  END
AL    1 DEN=3.51 0.712 373.0  END
AL   11  1.0  363.0  END
H2O  21  1.0  313.0  END
U     2 DEN=3.51 0.288 373.0  92235 90.0  92238  10.0  END
AL    2 DEN=3.51 0.712 373.0  END
AL   12  1.0  363.0  END
H2O  22  1.0  313.0  END
U     3 DEN=3.51 0.288 373.0  92235 90.0  92238  10.0  END
AL    3 DEN=3.51 0.712 373.0  END
AL   13  1.0  363.0  END
H2O  23  1.0  313.0  END
U     4 DEN=3.51 0.288 373.0  92235 90.0  92238  10.0  END
AL    4 DEN=3.51 0.712 373.0  END
AL   14  1.0  363.0  END
H2O  24  1.0  313.0  END
U     5 DEN=3.51 0.288 373.0  92235 90.0  92238  10.0  END
AL    5 DEN=3.51 0.712 373.0  END
AL   15  1.0  363.0  END
H2O  25  1.0  313.0  END
U     6 DEN=3.51 0.288 373.0  92235 90.0  92238  10.0  END
AL    6 DEN=3.51 0.712 373.0  END
AL   16  1.0  363.0  END
H2O  26  1.0  313.0  END
U     7 DEN=3.51 0.288 373.0  92235 90.0  92238  10.0  END
AL    7 DEN=3.51 0.712 373.0  END
AL   17  1.0  363.0  END
H2O  27  1.0  313.0  END
U     8 DEN=3.51 0.288 373.0  92235 90.0  92238  10.0  END
AL    8 DEN=3.51 0.712 373.0  END
AL   18  1.0  363.0  END
H2O  28  1.0  313.0  END
U     9 DEN=3.51 0.288 373.0  92235 90.0  92238  10.0  END
AL    9 DEN=3.51 0.712 373.0  END
AL   19  1.0  363.0  END
H2O  29  1.0  313.0  END
U    10 DEN=3.51 0.288 373.0  92235 90.0  92238  10.0  END
AL   10 DEN=3.51 0.712 373.0  END
AL   20  1.0  363.0  END
H2O  30  1.0  313.0  END
BE   33  1.0  313.0  END
end comp
read celldata
latticecell triangpitch pitch=1.104  21 fueld=0.422 1 cladd=0.524 11 end
latticecell triangpitch pitch=1.104  22 fueld=0.422 2 cladd=0.524 12 end
latticecell triangpitch pitch=1.104  23 fueld=0.422 3 cladd=0.524 13 end
latticecell triangpitch pitch=1.104  24 fueld=0.422 4 cladd=0.524 14 end
latticecell triangpitch pitch=1.104  25 fueld=0.422 5 cladd=0.524 15 end
latticecell triangpitch pitch=1.104  26 fueld=0.422 6 cladd=0.524 16 end
latticecell triangpitch pitch=1.104  27 fueld=0.422 7 cladd=0.524 17 end
latticecell triangpitch pitch=1.104  28 fueld=0.422 8 cladd=0.524 18 end
latticecell triangpitch pitch=1.104  29 fueld=0.422 9 cladd=0.524 19 end
latticecell triangpitch pitch=1.104  30 fueld=0.422 10 cladd=0.524 20 end
end celldata
read depletion 1 2 3 4 5 6 7 8 9 10 end depletion
read opus
matl= 1 2 3 4 5 6 7 8 9 10 0 end units=grams
new case
units=watts
new case
typarams=gspectrum
units=part
new case
```

```
typarams=nspectrum
units=parts
end opus
read burndata
' 298rods-927 gram fuel - 20kW/Core  (21.50MW/MTU)
power=21.50 burn=100 down=0 end
power=21.50 burn=200 down=0 end
power=21.50 burn=200 down=0 end
power=21.50 burn=198 down=14 end
end burndata
read model
SLOWPOKE 298 Rod Assembly - Berylium Reflector - Collapse 44-group
read parm
  prtflux=no  drawit=yes
  xnlib=4 run=yes prtmxsec=no prtbroad=no
  prtmxtab=yes cmfd=no echo=yes
end parm
read materials
  mix=1  pn=1 end
  mix=11 pn=1  end
  mix=21  pn=2  end
  mix=2  pn=1 end
  mix=12 pn=1  end
  mix=22  pn=2  end
  mix=3  pn=1  end
  mix=13 pn=1  end
  mix=23  pn=2  end
  mix=4  pn=1  end
  mix=14 pn=1  end
  mix=24  pn=2  end
  mix=5  pn=1  end
  mix=15 pn=1  end
  mix=25  pn=2  end
  mix=6  pn=1  end
  mix=16 pn=1  end
  mix=26  pn=2  end
  mix=7  pn=1  end
  mix=17 pn=1  end
  mix=27  pn=2  end
  mix=8  pn=1  end
  mix=18 pn=1  end
  mix=28  pn=2  end
  mix=9  pn=1  end
  mix=19 pn=1  end
  mix=29  pn=2  end
  mix=10 pn=1  end
  mix=20 pn=1  end
  mix=30  pn=2  end
  mix=33 pn=2 end
end materials
read geom
' Ring 1
unit 1
cylinder 10 0.211
cylinder 20 0.262
hexprism 30 0.552
media  1 1 10
media 11 1 20 -10
media 21 1 30 -20
boundary 30 2 2
' Ring 2
unit 2
cylinder 10 0.211
cylinder 20 0.262
hexprism 30 0.552
media  2 1 10
media 12 1 20 -10
media 22 1 30 -20
boundary 30 2 2
' Ring 3
unit 3
```

```
cylinder 10 0.211
cylinder 20 0.262
hexprism 30 0.552
media  3 1 10
media 13 1 20 -10
media 23 1 30 -20
boundary 30 2 2
' Ring 4
unit 4
cylinder 10 0.211
cylinder 20 0.262
hexprism 30 0.552
media  4 1 10
media 14 1 20 -10
media 24 1 30 -20
boundary 30 2 2
' Ring 5
unit 5
cylinder 10 0.211
cylinder 20 0.262
hexprism 30 0.552
media  5 1 10
media 15 1 20 -10
media 25 1 30 -20
boundary 30 2 2
' Ring 6
unit 6
cylinder 10 0.211
cylinder 20 0.262
hexprism 30 0.552
media  6 1 10
media 16 1 20 -10
media 26 1 30 -20
boundary 30 2 2
' Ring 7
unit 7
cylinder 10 0.211
cylinder 20 0.262
hexprism 30 0.552
media  7 1 10
media 17 1 20 -10
media 27 1 30 -20
boundary 30 2 2
' Ring 8
unit 8
cylinder 10 0.211
cylinder 20 0.262
hexprism 30 0.552
media  8 1 10
media 18 1 20 -10
media 28 1 30 -20
boundary 30 2 2
' Ring 9
unit 9
cylinder 10 0.211
cylinder 20 0.262
hexprism 30 0.552
media  9 1 10
media 19 1 20 -10
media 29 1 30 -20
boundary 30 2 2
' Ring 10
unit 10
cylinder 10 0.211
cylinder 20 0.262
hexprism 30 0.552
media 10 1 10
media 20 1 20 -10
media 30 1 30 -20
boundary 30 2 2
' Center Empty
```

```
unit 11
hexprism 30 0.552
media 21 1 30
boundary 30 2 2
' Around Center Empty
unit 12
hexprism 30 0.552
media 21 1 30
boundary 30 2 2
' Right Side Test Unit
unit 14
cylinder 20 1.1684 sides=36 origin x=-1.102
                   chord +x=-0.20 chord +y=-0.55
                   chord -y=+0.55
cylinder 25 1.27   sides=36 origin x=-1.102
                   chord +x=-0.20 chord +y=-0.55
                   chord -y=+0.55
hexprism 30 0.552
media 21 1 20 30
media 11 1 25 30 -20
media 21 1 30 -25 -20
boundary 30 2 2
' Bottom Right Side Test Unit
unit 15
cuboid 20  0.5  0.0  0.2  0.1   rotate a1=35
cuboid 25  -0.0  -0.5  -0.00  -0.10   rotate a1=12
hexprism 30 0.552
media 11 1 20
media 11 1 25
media 21 1 30 -20 -25
boundary 30 15 15
' Bottom Left Side Test Unit
unit 16
cuboid 20   0.5   0.0  -0.0  -0.10   rotate a1=-12
cuboid 25  -0.0  -0.5   0.2   0.1   rotate a1=-35
hexprism 30 0.552
media 11 1 20
media 11 1 25
media 21 1 30 -20 -25
boundary 30 15 15
' Left Side Test Unit
unit 17
cylinder 20 1.1684 sides=36 origin x=1.102
                   chord -x=0.20 chord +y=-0.55
                   chord -y=+0.55
cylinder 25 1.27   sides=36 origin x=1.102
                   chord -x=0.20 chord +y=-0.55
                   chord -y=+0.55
hexprism 30 0.552
media 21 1 20 30
media 11 1 25 30 -20
media 21 1 30 -25 -20
boundary 30 2 2
' Top Right Side Test Unit
unit 18
cuboid 20   0.5   0.0  -0.00  -0.10  rotate a1=-35
cuboid 25  -0.0  -0.5   0.2    0.1   rotate a1=-12
hexprism 30 0.552
media 11 1 20
media 11 1 25
media 21 1 30 -20 -25
boundary 30 15 15
' Top Left Side Test Unit
unit 19
cuboid 20   0.5   0.0   0.2   0.1   rotate a1=12
cuboid 25  -0.0  -0.5  -0.0  -0.10   rotate a1=35
hexprism 30 0.552
media 11 1 20
media 11 1 25
media 21 1 30 -20 -25
boundary 30 15 15
```

```
'
global unit 40
' Disk 8.66 inch - 11 cm radius - use 11.5 cm for clearance
cylinder 110 11.5 sides=30
' 10 cm Be reflector
cylinder 120 21.5 sides=30
cuboid 130 23.0 -23.0 23.0 -23.0
array 1 110 place 12 11 -0.552 -0.9558
media 21 1 110
media 33 1 120 -110
media 21 1 130 -120
boundary 130 40 40
'
end geom
read array
ara=1 typ=shexagonal nux=23 nuy=23
fill
0 0 0 0 0 0 0  0 0 0 10 10 10 10 0 0 0  0 0 0 0 0 0
 0 0 0 0 0 0  0 9 9 9  9  0  9  9 9 9 0  0 0 0 0 0 0
0 0 0 0 0 0  9 0 8 8 8  8  8  8  8 8 0 9  0 0 0 0 0
 0 0 0 0 0  9 8 7 7 7  7  7  7 7  7 7 8 9  0 0 0 0 0
0 0 0 0 10 9 8 7 6 6 6  6  6  6 6  6 7 8 9 10 0 0 0
 0 0 0 10 9 8 7 6 0 5  5  0  5 5 0  6 7 8 9 10 0 0 0
0 0 0 10 0 8 7 6 5 4 4  4  4  4 4 5  6 7 8 0 10 0 0
 0 0 10 9 8 0 6 5 4 3  3  3  3 3 4 5  6 0 8 9 10 0 0
0 0 0  9 8 7 6 0 4 3 0  2  2  0 3 4 0  6 7 8 9  0 0
 0 0  9 8 7 6 5 4 0 2 1  0  1  2 0 4 5  6 7 8 9  0 0
0 0  9 8 7 6 5 4 3 2 0 16 15  0 2 3 4 5  6 7 8 9  0
 0  0 0 7 6 0 4 3 0 1 17 11 14 1 0 3 4 0  6 7 0 0  0
0 0  9 8 7 6 5 4 3 2 0 19 18  0 2 3 4 5  6 7 8 9  0
 0 0  9 8 7 6 5 4 0 2 1  0  1  2 0 4 5  6 7 8 9  0 0
0 0 0  9 8 7 6 0 4 3 0  2  2  0 3 4 0  6 7 8 9  0 0
 0 0 10 9 8 0 6 5 4 3  3  3  3 3 4 5  6 0 8 9 10 0 0
0 0 0 10 0 8 7 6 5 4 4  4  4  4 4 5  6 7 8 0 10 0 0
 0 0 0 10 9 8 7 6 0 5  5  0  5 5 0  6 7 8 9 10 0 0 0
0 0 0 0 10 9 8 7 6 6 6  6  6  6 6  6 7 8 9 10 0 0 0
 0 0 0 0 0  9 8 7 7 7  7  7  7 7  7 7 8 9  0 0 0 0 0
0 0 0 0 0 0  9 0 8 8 8  8  8  8  8 8 0 9  0 0 0 0 0
 0 0 0 0 0 0  0 9 9 9  9  0  9  9 9 9 0  0 0 0 0 0 0
0 0 0 0 0 0 0  0 0 0 10 10 10 10 0 0 0  0 0 0 0 0 0
end fill
end array
read bounds all=vacuum end bounds
end model
end
```

Figure 5.3.23-5 VISED X-Y Slice – SLOWPOKE Core – Normal Conditions

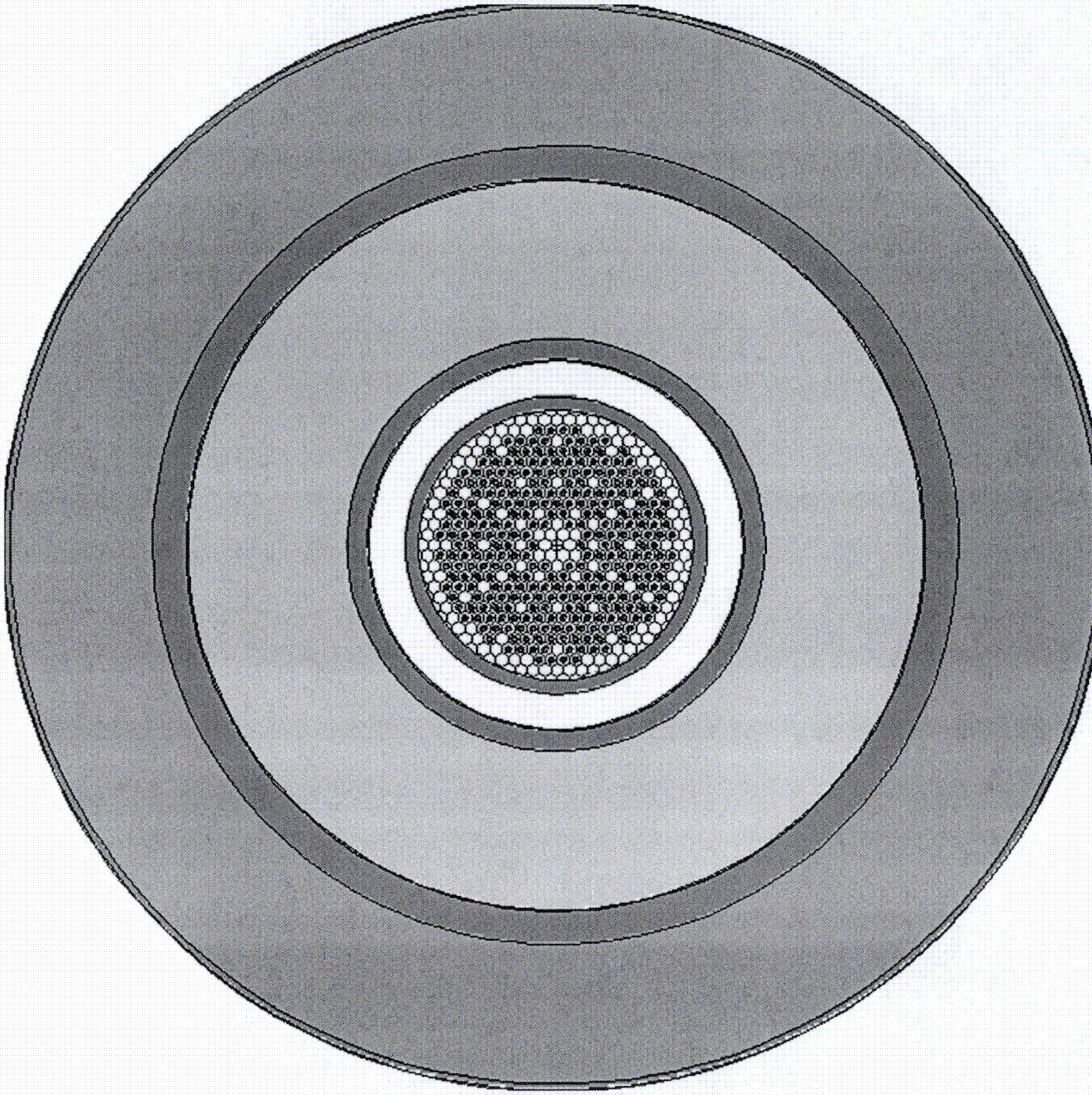
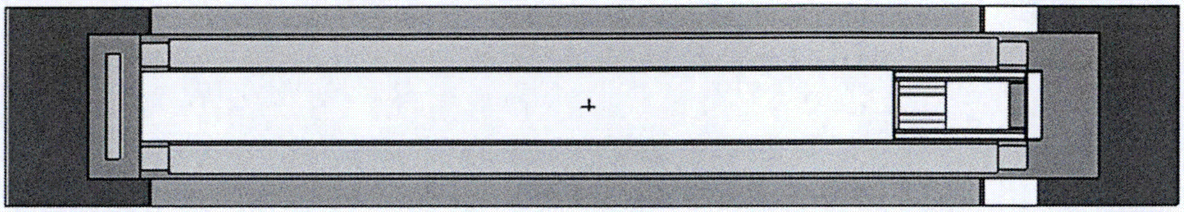


Figure 5.3.23-6 VISED Y-Z Slice – SLOWPOKE Core – Normal Conditions



Note: SLOWPOKE fuel core basket is shifted to the NAC-LWT lid. Void space indicated by model is the space occupied by the basket lid collar whose material, but not spacing, is conservatively removed from the model. Location of the fuel core near the bottom of the basket cavity is maintained by a spacer structurally evaluated to survive both normal and accident conditions of transport.

Figure 5.3.23-7 Sample MCNP Input File – Normal Conditions

```
NAC-LWT Cask - 15b90e14d - Normal Transport Conditions
C Radial Biasing - Fuel Gamma Source
C Fuel Rod Cells
1 1 -3.4819 -1 +3 -4   u=5 $ Fuel Meat
2 4 -2.7000 -2 +1 3 -4  u=5 $ Clad
3 4 -2.7000 -5 : -6     u=5 $ Top Cap
4 4 -2.7000 -7     u=5 $ Bottom Cap
5 0         #1 #2 #3 #4      u=5 $ Outside Rod
C Fuel Core Array Cell
6 0         -8 u=4 lat=2 fill=-15:15 -15:15 0:0  $ Core Array
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 5 5 5 5 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 5 5 5 5 4 5 5 5 5 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 5 4 5 5 5 5 5 5 5 5 4 5 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 5 5 5 5 5 4 5 5 4 5 5 4 5 5 5 5 5 4 4 4 4
     4 4 4 4 4 4 4 4 4 5 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 4 5 4 4 4 4
     4 4 4 4 4 4 4 4 5 5 5 4 5 5 5 5 5 5 5 5 5 5 5 4 5 5 5 4 4 4 4
     4 4 4 4 4 4 4 4 5 5 5 5 4 5 5 4 5 5 4 5 5 4 5 5 5 5 4 4 4 4 4
     4 4 4 4 4 4 4 5 5 5 5 5 5 4 5 5 4 5 5 4 5 5 5 5 5 5 4 4 4 4 4
     4 4 4 4 4 4 5 5 5 5 5 5 5 5 4 4 4 4 5 5 5 5 5 5 5 5 4 4 4 4 4
     4 4 4 4 4 4 4 5 5 4 5 5 4 5 4 4 4 5 4 5 5 4 5 5 4 4 4 4 4 4 4
     4 4 4 4 4 5 5 5 5 5 5 5 5 4 4 4 4 5 5 5 5 5 5 5 5 4 4 4 4 4 4
     4 4 4 4 4 5 5 5 5 5 5 4 5 5 4 5 5 4 5 5 5 5 5 5 4 4 4 4 4 4 4
     4 4 4 4 4 5 5 5 5 4 5 5 4 5 5 4 5 5 4 5 5 5 5 4 4 4 4 4 4 4 4
     4 4 4 4 5 5 5 4 5 5 5 5 5 5 5 5 5 5 5 4 5 5 5 4 4 4 4 4 4 4 4
     4 4 4 4 5 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 4 5 4 4 4 4 4 4 4 4 4
     4 4 4 4 5 5 5 5 5 4 5 5 4 5 5 4 5 5 5 5 5 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 5 4 5 5 5 5 5 5 5 5 4 5 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 5 5 5 5 4 5 5 5 5 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 5 5 5 5 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
C Cells - SLOWPOKE Core Basket
7 0         -9 fill=4 ( 0.0000 0.0000 3.3274 )   u=3 $ SLOWPOKE Core
8 6 -7.9400 -10      u=3 $ Base Plate
9 6 -7.9400 -11 +12     u=3 $ Basket Tube
10 6 -7.9400 -13     u=3 $ Shield Plug
11 6 -7.9400 -14     u=3 $ Lid Plate
12 0         -15     u=3 $ Lid Spacer
13 0         #7 #8 #9 #10 #11 #12      u=3 $ Void
C Cells - LWT Cavity
14 0         -16 fill=3 ( 0.0000 0.0000 377.6980 )   u=2
15 0         #14      u=2
C Cells - LWT Cask Normal Conditions
16 5 -11.344 -20     u=1 $ BotPb
17 0         -19 fill=2    u=1 $ Cavity
18 6 -7.9400 -17 -18 +20   u=1 $ Bottom
19 6 -7.9400 -17 +18 +22 +25 +19 u=1 $ OuterShell
20 6 -7.9400 -21 +24 +19   u=1 $ InnerShellTaper
21 6 -7.9400 -23 +19    u=1 $ InnerShell
22 5 -11.344 -24 +23    u=1 $ Lead
23 5 -11.344 -22 +21 +24   u=1 $ LeadTaper
24 0         -25 +24    u=1 $ LeadGap
25 3 -0.9400 -27 +17    u=1 $ NeutronShield
26 6 -7.9400 -26 +17 +27   u=1 $ NSShell
27 7 -0.4997 -28 +17    u=1 $ UpperLimiter
28 7 -0.4997 -29 +17    u=1 $ LowerLimiter
29 0         -30 +17 +26 +28 +29 u=1 $ Container
30 0         +30     u=1 $ Outside
C Detector Cells - Radial Biasing
```

```
100 0 -100 fill=1 $ AziTrun
110 0 -110 +100 fill=1 $ Surface
310 0 -310 +110 $ AziSurFuel
329 0 -329 +110 +310 $ 1ft
429 0 -429 +110 +310 +329 $ 1m
529 0 -529 +110 +310 +329 +429 $ Azi1m
548 0 -548 +110 +310 +329 +429 +529 $ 2m
648 0 -648 +110 +310 +329 +429 +529 +548 $ 2m+Convey
748 0 -748 +110 +310 +329 +429 +529 +548 +648 $ Azi2m+Con
848 0 +110 +310 +329 +429 +529 +548 +648 +748 $ Exterior

C Fuel Rod Surfaces
1 CZ 0.2108       $ Fuel Meat OD
2 CZ 0.2616       $ Clad OD
3 PZ 0.4572       $ Lower Fuel Cut Plain
4 PZ 22.4536       $ Upper Fuel Cut Plain
5 RCC 0.0000 0.0000 0.3302 0.0000 0.0000 0.1270 0.3048 $ Lower Stud Rim
6 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 0.3302 0.1930 $ Lower Stud Cap
7 RCC 0.0000 0.0000 22.4536 0.0000 0.0000 0.3810 0.3048 $ Upper Stud
C Fuel Core Lattice Surface
8 RHP 0.0 0.0 0.0 0.0 0.0 22.8346
       0.5518 0.0 0.0    $ Lattice Cell
C Surfaces - SLOWPOKE Core Basket
9 RCC 0.0000 0.0000 3.3274 0.0000 0.0000 22.8346 12.3824 $ Core
10 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 1.2700 16.8466 $ Base Plate
11 RCC 0.0000 0.0000 1.2700 0.0000 0.0000 64.8970 13.6525 $ Tube OD
12 RCC 0.0000 0.0000 1.2700 0.0000 0.0000 64.8970 12.3825 $ Tube ID
13 RCC 0.0000 0.0000 58.5470 0.0000 0.0000 7.6200 10.9982 $ Shield Plug
14 RCC 0.0000 0.0000 66.1670 0.0000 0.0000 1.2700 16.8466 $ Lid Plate
15 RCC 0.0000 0.0000 67.4370 0.0000 0.0000 6.9850 16.84655 $ Lid Spacer
C Surfaces - LWT Cavity
16 RCC 0.0000 0.0000 377.6980 0.0000 0.0000 74.4220 16.8467 $ Basket
C Surfaces - LWT Cask Normal Conditions
17 RCC 0.0000 0.0000 -26.6700 0.0000 0.0000 507.3650 36.5189 $ Lwt
18 RCC 0.0000 0.0000 -26.6700 0.0000 0.0000 26.6700 36.5189 $ Bottom
19 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 452.1200 16.9863 $ Cavity
20 RCC 0.0000 0.0000 -17.7800 0.0000 0.0000 7.6200 26.3525 $ Bottom gamma shield
21 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 444.5000 20.1740 $ Lead id - taper
22 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 444.5000 31.5976 $ Lead od - taper
23 RCC 0.0000 0.0000 13.8176 0.0000 0.0000 416.8648 18.9103 $ Lead id
24 RCC 0.0000 0.0000 13.8176 0.0000 0.0000 416.8648 33.3271 $ Lead od
25 RCC 0.0000 0.0000 13.8176 0.0000 0.0000 416.8648 33.4645 $ Lead gap
26 RCC 0.0000 0.0000 3.8100 0.0000 0.0000 419.1000 49.8183 $ Neutron shield shell
27 RCC 0.0000 0.0000 5.0800 0.0000 0.0000 416.5600 49.2189 $ Neutron shield
28 RCC 0.0000 0.0000 450.2150 0.0000 0.0000 70.5612 49.8183 $ Upper limiter
29 RCC 0.0000 0.0000 -68.0212 0.0000 0.0000 71.8312 49.8183 $ Lower limiter
30 RCC 0.0000 0.0000 -68.0212 0.0000 0.0000 588.7974 49.8183 $ Container
C Radial Detector DRA (AziTrun)
100  RCC  0.0000  0.0000  422.9200  0.0000  0.0000  27.2850  36.6189
101  PZ  425.6485
102  PZ  428.3770
103  PZ  431.1055
104  PZ  433.8340
105  PZ  436.5625
106  PZ  439.2910
107  PZ  442.0195
108  PZ  444.7480
109  PZ  447.4765
C Radial Detector DRB (Surface)
110  RCC  0.0000  0.0000  -68.1212  0.0000  0.0000  588.9974  49.9184
111  PZ  -65.1762
112  PZ  -62.2312
113  PZ  -59.2862
114  PZ  -56.3413
115  PZ  -53.3963
116  PZ  -50.4513
117  PZ  -47.5063
118  PZ  -44.5613
119  PZ  -41.6163
120  PZ  -38.6713
121  PZ  -35.7263
```

```
122  PZ  -32.7814
123  PZ  -29.8364
124  PZ  -26.8914
125  PZ  -23.9464
126  PZ  -21.0014
127  PZ  -18.0564
128  PZ  -15.1114
129  PZ  -12.1664
130  PZ  -9.2215
131  PZ  -6.2765
132  PZ  -3.3315
133  PZ  -0.3865
134  PZ  2.5585
135  PZ  5.5035
136  PZ  8.4485
137  PZ  11.3934
138  PZ  14.3384
139  PZ  17.2834
140  PZ  20.2284
141  PZ  23.1734
142  PZ  26.1184
143  PZ  29.0634
144  PZ  32.0084
145  PZ  34.9533
146  PZ  37.8983
147  PZ  40.8433
148  PZ  43.7883
149  PZ  46.7333
150  PZ  49.6783
151  PZ  52.6233
152  PZ  55.5683
153  PZ  58.5132
154  PZ  61.4582
155  PZ  64.4032
156  PZ  67.3482
157  PZ  70.2932
158  PZ  73.2382
159  PZ  76.1832
160  PZ  79.1282
161  PZ  82.0731
162  PZ  85.0181
163  PZ  87.9631
164  PZ  90.9081
165  PZ  93.8531
166  PZ  96.7981
167  PZ  99.7431
168  PZ  102.6880
169  PZ  105.6330
170  PZ  108.5780
171  PZ  111.5230
172  PZ  114.4680
173  PZ  117.4130
174  PZ  120.3580
175  PZ  123.3030
176  PZ  126.2479
177  PZ  129.1929
178  PZ  132.1379
179  PZ  135.0829
180  PZ  138.0279
181  PZ  140.9729
182  PZ  143.9179
183  PZ  146.8629
184  PZ  149.8078
185  PZ  152.7528
186  PZ  155.6978
187  PZ  158.6428
188  PZ  161.5878
189  PZ  164.5328
190  PZ  167.4778
191  PZ  170.4227
192  PZ  173.3677
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193  PZ  176.3127
194  PZ  179.2577
195  PZ  182.2027
196  PZ  185.1477
197  PZ  188.0927
198  PZ  191.0377
199  PZ  193.9826
200  PZ  196.9276
201  PZ  199.8726
202  PZ  202.8176
203  PZ  205.7626
204  PZ  208.7076
205  PZ  211.6526
206  PZ  214.5976
207  PZ  217.5425
208  PZ  220.4875
209  PZ  223.4325
210  PZ  226.3775
211  PZ  229.3225
212  PZ  232.2675
213  PZ  235.2125
214  PZ  238.1574
215  PZ  241.1024
216  PZ  244.0474
217  PZ  246.9924
218  PZ  249.9374
219  PZ  252.8824
220  PZ  255.8274
221  PZ  258.7724
222  PZ  261.7173
223  PZ  264.6623
224  PZ  267.6073
225  PZ  270.5523
226  PZ  273.4973
227  PZ  276.4423
228  PZ  279.3873
229  PZ  282.3323
230  PZ  285.2772
231  PZ  288.2222
232  PZ  291.1672
233  PZ  294.1122
234  PZ  297.0572
235  PZ  300.0022
236  PZ  302.9472
237  PZ  305.8921
238  PZ  308.8371
239  PZ  311.7821
240  PZ  314.7271
241  PZ  317.6721
242  PZ  320.6171
243  PZ  323.5621
244  PZ  326.5071
245  PZ  329.4520
246  PZ  332.3970
247  PZ  335.3420
248  PZ  338.2870
249  PZ  341.2320
250  PZ  344.1770
251  PZ  347.1220
252  PZ  350.0670
253  PZ  353.0119
254  PZ  355.9569
255  PZ  358.9019
256  PZ  361.8469
257  PZ  364.7919
258  PZ  367.7369
259  PZ  370.6819
260  PZ  373.6269
261  PZ  376.5718
262  PZ  379.5168
263  PZ  382.4618
```

```
264  PZ  385.4068
265  PZ  388.3518
266  PZ  391.2968
267  PZ  394.2418
268  PZ  397.1867
269  PZ  400.1317
270  PZ  403.0767
271  PZ  406.0217
272  PZ  408.9667
273  PZ  411.9117
274  PZ  414.8567
275  PZ  417.8017
276  PZ  420.7466
277  PZ  423.6916
278  PZ  426.6366
279  PZ  429.5816
280  PZ  432.5266
281  PZ  435.4716
282  PZ  438.4166
283  PZ  441.3616
284  PZ  444.3065
285  PZ  447.2515
286  PZ  450.1965
287  PZ  453.1415
288  PZ  456.0865
289  PZ  459.0315
290  PZ  461.9765
291  PZ  464.9214
292  PZ  467.8664
293  PZ  470.8114
294  PZ  473.7564
295  PZ  476.7014
296  PZ  479.6464
297  PZ  482.5914
298  PZ  485.5364
299  PZ  488.4813
300  PZ  491.4263
301  PZ  494.3713
302  PZ  497.3163
303  PZ  500.2613
304  PZ  503.2063
305  PZ  506.1513
306  PZ  509.0963
307  PZ  512.0412
308  PZ  514.9862
309  PZ  517.9312
C Radial Detector DRBA (AziSurFuel)
310  RCC  0.0000  0.0000  385.0000  0.0000  0.0000  10.0000  49.9185
311     PX  0.0000
312  1  PX  0.0000
313  2  PX  0.0000
314  3  PX  0.0000
315  4  PX  0.0000
316  5  PX  0.0000
317  6  PX  0.0000
318  7  PX  0.0000
319  8  PX  0.0000
320     PY  0.0000
321  10  PX  0.0000
322  11  PX  0.0000
323  12  PX  0.0000
324  13  PX  0.0000
325  14  PX  0.0000
326  15  PX  0.0000
327  16  PX  0.0000
328  17  PX  0.0000
C Radial Detector DRC (1ft)
329  RCC  0.0000  0.0000  -98.6012  0.0000  0.0000  649.9574  80.2984
330  PZ  -92.1016
331  PZ  -85.6021
332  PZ  -79.1025
```

```
333  PZ  -72.6029
334  PZ  -66.1033
335  PZ  -59.6038
336  PZ  -53.1042
337  PZ  -46.6046
338  PZ  -40.1050
339  PZ  -33.6055
340  PZ  -27.1059
341  PZ  -20.6063
342  PZ  -14.1067
343  PZ  -7.6072
344  PZ  -1.1076
345  PZ  5.3920
346  PZ  11.8916
347  PZ  18.3911
348  PZ  24.8907
349  PZ  31.3903
350  PZ  37.8899
351  PZ  44.3894
352  PZ  50.8890
353  PZ  57.3886
354  PZ  63.8882
355  PZ  70.3877
356  PZ  76.8873
357  PZ  83.3869
358  PZ  89.8864
359  PZ  96.3860
360  PZ  102.8856
361  PZ  109.3852
362  PZ  115.8847
363  PZ  122.3843
364  PZ  128.8839
365  PZ  135.3835
366  PZ  141.8830
367  PZ  148.3826
368  PZ  154.8822
369  PZ  161.3818
370  PZ  167.8813
371  PZ  174.3809
372  PZ  180.8805
373  PZ  187.3801
374  PZ  193.8796
375  PZ  200.3792
376  PZ  206.8788
377  PZ  213.3784
378  PZ  219.8779
379  PZ  226.3775
380  PZ  232.8771
381  PZ  239.3766
382  PZ  245.8762
383  PZ  252.3758
384  PZ  258.8754
385  PZ  265.3749
386  PZ  271.8745
387  PZ  278.3741
388  PZ  284.8737
389  PZ  291.3732
390  PZ  297.8728
391  PZ  304.3724
392  PZ  310.8720
393  PZ  317.3715
394  PZ  323.8711
395  PZ  330.3707
396  PZ  336.8703
397  PZ  343.3698
398  PZ  349.8694
399  PZ  356.3690
400  PZ  362.8686
401  PZ  369.3681
402  PZ  375.8677
403  PZ  382.3673
```

```
404   PZ   388.8669
405   PZ   395.3664
406   PZ   401.8660
407   PZ   408.3656
408   PZ   414.8651
409   PZ   421.3647
410   PZ   427.8643
411   PZ   434.3639
412   PZ   440.8634
413   PZ   447.3630
414   PZ   453.8626
415   PZ   460.3622
416   PZ   466.8617
417   PZ   473.3613
418   PZ   479.8609
419   PZ   486.3605
420   PZ   492.8600
421   PZ   499.3596
422   PZ   505.8592
423   PZ   512.3588
424   PZ   518.8583
425   PZ   525.3579
426   PZ   531.8575
427   PZ   538.3571
428   PZ   544.8566
C Radial Detector DRD (1m)
429   RCC  0.0000  0.0000  -168.1212  0.0000  0.0000  788.9974  149.8184
430   PZ   -160.2312
431   PZ   -152.3413
432   PZ   -144.4513
433   PZ   -136.5613
434   PZ   -128.6713
435   PZ   -120.7814
436   PZ   -112.8914
437   PZ   -105.0014
438   PZ   -97.1114
439   PZ   -89.2215
440   PZ   -81.3315
441   PZ   -73.4415
442   PZ   -65.5515
443   PZ   -57.6616
444   PZ   -49.7716
445   PZ   -41.8816
446   PZ   -33.9916
447   PZ   -26.1017
448   PZ   -18.2117
449   PZ   -10.3217
450   PZ   -2.4317
451   PZ   5.4582
452   PZ   13.3482
453   PZ   21.2382
454   PZ   29.1282
455   PZ   37.0181
456   PZ   44.9081
457   PZ   52.7981
458   PZ   60.6880
459   PZ   68.5780
460   PZ   76.4680
461   PZ   84.3580
462   PZ   92.2479
463   PZ   100.1379
464   PZ   108.0279
465   PZ   115.9179
466   PZ   123.8078
467   PZ   131.6978
468   PZ   139.5878
469   PZ   147.4778
470   PZ   155.3677
471   PZ   163.2577
472   PZ   171.1477
473   PZ   179.0377
```

```
474  PZ  186.9276
475  PZ  194.8176
476  PZ  202.7076
477  PZ  210.5976
478  PZ  218.4875
479  PZ  226.3775
480  PZ  234.2675
481  PZ  242.1574
482  PZ  250.0474
483  PZ  257.9374
484  PZ  265.8274
485  PZ  273.7173
486  PZ  281.6073
487  PZ  289.4973
488  PZ  297.3873
489  PZ  305.2772
490  PZ  313.1672
491  PZ  321.0572
492  PZ  328.9472
493  PZ  336.8371
494  PZ  344.7271
495  PZ  352.6171
496  PZ  360.5071
497  PZ  368.3970
498  PZ  376.2870
499  PZ  384.1770
500  PZ  392.0670
501  PZ  399.9569
502  PZ  407.8469
503  PZ  415.7369
504  PZ  423.6269
505  PZ  431.5168
506  PZ  439.4068
507  PZ  447.2968
508  PZ  455.1867
509  PZ  463.0767
510  PZ  470.9667
511  PZ  478.8567
512  PZ  486.7466
513  PZ  494.6366
514  PZ  502.5266
515  PZ  510.4166
516  PZ  518.3065
517  PZ  526.1965
518  PZ  534.0865
519  PZ  541.9765
520  PZ  549.8664
521  PZ  557.7564
522  PZ  565.6464
523  PZ  573.5364
524  PZ  581.4263
525  PZ  589.3163
526  PZ  597.2063
527  PZ  605.0963
528  PZ  612.9862
C Radial Detector DRDA (Azilm)
529  RCC  0.0000  0.0000  385.0000  0.0000  0.0000  15.0000  149.8185
530      PX  0.0000
531  1   PX  0.0000
532  2   PX  0.0000
533  3   PX  0.0000
534  4   PX  0.0000
535  5   PX  0.0000
536  6   PX  0.0000
537  7   PX  0.0000
538  8   PX  0.0000
539      PY  0.0000
540  10   PX  0.0000
541  11   PX  0.0000
542  12   PX  0.0000
543  13   PX  0.0000
```

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544   14   PX   0.0000
545   15   PX   0.0000
546   16   PX   0.0000
547   17   PX   0.0000
C Radial Detector DRE (2m)
548   RCC   0.0000   0.0000   -268.1212   0.0000   0.0000   988.9974   249.8184
549   PZ   -258.2312
550   PZ   -248.3413
551   PZ   -238.4513
552   PZ   -228.5613
553   PZ   -218.6713
554   PZ   -208.7814
555   PZ   -198.8914
556   PZ   -189.0014
557   PZ   -179.1114
558   PZ   -169.2215
559   PZ   -159.3315
560   PZ   -149.4415
561   PZ   -139.5515
562   PZ   -129.6616
563   PZ   -119.7716
564   PZ   -109.8816
565   PZ   -99.9916
566   PZ   -90.1017
567   PZ   -80.2117
568   PZ   -70.3217
569   PZ   -60.4317
570   PZ   -50.5418
571   PZ   -40.6518
572   PZ   -30.7618
573   PZ   -20.8719
574   PZ   -10.9819
575   PZ   -1.0919
576   PZ   8.7981
577   PZ   18.6880
578   PZ   28.5780
579   PZ   38.4680
580   PZ   48.3580
581   PZ   58.2479
582   PZ   68.1379
583   PZ   78.0279
584   PZ   87.9179
585   PZ   97.8078
586   PZ   107.6978
587   PZ   117.5878
588   PZ   127.4778
589   PZ   137.3677
590   PZ   147.2577
591   PZ   157.1477
592   PZ   167.0377
593   PZ   176.9276
594   PZ   186.8176
595   PZ   196.7076
596   PZ   206.5976
597   PZ   216.4875
598   PZ   226.3775
599   PZ   236.2675
600   PZ   246.1574
601   PZ   256.0474
602   PZ   265.9374
603   PZ   275.8274
604   PZ   285.7173
605   PZ   295.6073
606   PZ   305.4973
607   PZ   315.3873
608   PZ   325.2772
609   PZ   335.1672
610   PZ   345.0572
611   PZ   354.9472
612   PZ   364.8371
613   PZ   374.7271
```

```
614   PZ   384.6171
615   PZ   394.5071
616   PZ   404.3970
617   PZ   414.2870
618   PZ   424.1770
619   PZ   434.0670
620   PZ   443.9569
621   PZ   453.8469
622   PZ   463.7369
623   PZ   473.6269
624   PZ   483.5168
625   PZ   493.4068
626   PZ   503.2968
627   PZ   513.1867
628   PZ   523.0767
629   PZ   532.9667
630   PZ   542.8567
631   PZ   552.7466
632   PZ   562.6366
633   PZ   572.5266
634   PZ   582.4166
635   PZ   592.3065
636   PZ   602.1965
637   PZ   612.0865
638   PZ   621.9765
639   PZ   631.8664
640   PZ   641.7564
641   PZ   651.6464
642   PZ   661.5364
643   PZ   671.4263
644   PZ   681.3163
645   PZ   691.2063
646   PZ   701.0963
647   PZ   710.9862
C Radial Detector DRF (2m+Convey)
648   RCC   0.0000   0.0000   -269.1212   0.0000   0.0000   990.9974   321.9200
649   PZ   -259.2112
650   PZ   -249.3013
651   PZ   -239.3913
652   PZ   -229.4813
653   PZ   -219.5713
654   PZ   -209.6614
655   PZ   -199.7514
656   PZ   -189.8414
657   PZ   -179.9314
658   PZ   -170.0215
659   PZ   -160.1115
660   PZ   -150.2015
661   PZ   -140.2915
662   PZ   -130.3816
663   PZ   -120.4716
664   PZ   -110.5616
665   PZ   -100.6516
666   PZ   -90.7417
667   PZ   -80.8317
668   PZ   -70.9217
669   PZ   -61.0117
670   PZ   -51.1018
671   PZ   -41.1918
672   PZ   -31.2818
673   PZ   -21.3719
674   PZ   -11.4619
675   PZ   -1.5519
676   PZ   8.3581
677   PZ   18.2680
678   PZ   28.1780
679   PZ   38.0880
680   PZ   47.9980
681   PZ   57.9079
682   PZ   67.8179
683   PZ   77.7279
```

```
684  PZ  87.6379
685  PZ  97.5478
686  PZ  107.4578
687  PZ  117.3678
688  PZ  127.2778
689  PZ  137.1877
690  PZ  147.0977
691  PZ  157.0077
692  PZ  166.9177
693  PZ  176.8276
694  PZ  186.7376
695  PZ  196.6476
696  PZ  206.5576
697  PZ  216.4675
698  PZ  226.3775
699  PZ  236.2875
700  PZ  246.1974
701  PZ  256.1074
702  PZ  266.0174
703  PZ  275.9274
704  PZ  285.8373
705  PZ  295.7473
706  PZ  305.6573
707  PZ  315.5673
708  PZ  325.4772
709  PZ  335.3872
710  PZ  345.2972
711  PZ  355.2072
712  PZ  365.1171
713  PZ  375.0271
714  PZ  384.9371
715  PZ  394.8471
716  PZ  404.7570
717  PZ  414.6670
718  PZ  424.5770
719  PZ  434.4870
720  PZ  444.3969
721  PZ  454.3069
722  PZ  464.2169
723  PZ  474.1269
724  PZ  484.0368
725  PZ  493.9468
726  PZ  503.8568
727  PZ  513.7667
728  PZ  523.6767
729  PZ  533.5867
730  PZ  543.4967
731  PZ  553.4066
732  PZ  563.3166
733  PZ  573.2266
734  PZ  583.1366
735  PZ  593.0465
736  PZ  602.9565
737  PZ  612.8665
738  PZ  622.7765
739  PZ  632.6864
740  PZ  642.5964
741  PZ  652.5064
742  PZ  662.4164
743  PZ  672.3263
744  PZ  682.2363
745  PZ  692.1463
746  PZ  702.0563
747  PZ  711.9662
C Radial Detector DRFA (Azi2m+Con)
748  RCC  0.0000  0.0000  390.0000  0.0000  0.0000  20.0000  321.9201
749     PX  0.0000
750  1  PX  0.0000
751  2  PX  0.0000
752  3  PX  0.0000
753  4  PX  0.0000
```

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754  5  PX  0.0000
755  6  PX  0.0000
756  7  PX  0.0000
757  8  PX  0.0000
758     PY  0.0000
759  10  PX  0.0000
760  11  PX  0.0000
761  12  PX  0.0000
762  13  PX  0.0000
763  14  PX  0.0000
764  15  PX  0.0000
765  16  PX  0.0000
766  17  PX  0.0000

C
C Materials List
C
C U-Al Fuel
m1    92235 -2.5201E-01 92238 -2.8001E-02 13027 -7.1999E-01
C Water
m2    1001 6.6667E-01 8016 3.3333E-01
mt2   lwtr.01
C Water/Glycol
m3    1001 -1.03200E-01 8016 -6.82400E-01 6000 -2.14400E-01
C Aluminum
m4    13027 -1.0
C Lead
m5    82000 -1.0
C Stainless Steel 304
m6    26000 -0.695 24000 -0.190 28000 -0.095
      25055 -0.020
C Aluminum Honeycomb Impact Limiter
m7    13027 -1.0
C
C Cell Importances
imp:p 1 38r 0
C
C Source Definition - Fuel Gamma
C 15 GWd/MTU burnup, 90 wt% U-235, 14-day cool time, 2.786 g U-235 per rod, 39 W/core
sdef RAD=d1 EXT=d2 ERG=d3 cell=d4
     POS= 0.0000 0.0000 0.4572
     AXS= 0.0000 0.0000 1.0000
si1 0 0.2108
sp1 -21 1
si2 0 21.9964
sp2 0 1
si3 1.000E-02 4.500E-02 1.000E-01 2.000E-01 3.000E-01 4.000E-01
     6.000E-01 8.000E-01 1.000E+00 1.330E+00 1.660E+00 2.000E+00
     2.500E+00 3.000E+00 4.000E+00 5.000E+00 6.500E+00 8.000E+00
     1.000E+01
sp3 0.0000E+00 3.1684E+11 1.0982E+11 1.3380E+11 2.3964E+10 5.7276E+10
     1.5811E+11 4.3248E+11 4.1310E+10 2.5592E+09 1.0587E+11 3.5978E+08
     2.0105E+09 3.4304E+09 2.6553E+07 7.9396E-04 1.8338E-04 3.4862E-05
     7.4653E-06
# SI4  SP4
     L  D
     110:17:14:7:6:-1  1.0000
mode p
nps 6.40E+07
C
C ANSI/ANS-6.1.1-1977 - Gamma Flux-to-Dose Conversion Factors
C (mrem/hr)/(photons/cm2-sec)
de0 0.01 0.03 0.05 0.07 0.1 0.15 0.2
     0.25 0.3 0.35 0.4 0.45 0.5 0.55
     0.6 0.65 0.7 0.8 1 1.4 1.8
     2.2 2.6 2.8 3.25 3.75 4.25 4.75
     5 5.25 5.75 6.25 6.75 7.5 9
     11 13 15
df0 3.96E-03 5.82E-04 2.90E-04 2.58E-04 2.83E-04 3.79E-04 5.01E-04
     6.31E-04 7.59E-04 8.78E-04 9.85E-04 1.08E-03 1.17E-03 1.27E-03
     1.36E-03 1.44E-03 1.52E-03 1.68E-03 1.98E-03 2.51E-03 2.99E-03
```

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     3.42E-03 3.82E-03 4.01E-03 4.41E-03 4.83E-03 5.23E-03 5.60E-03
     5.80E-03 6.01E-03 6.37E-03 6.74E-03 7.11E-03 7.66E-03 8.77E-03
     1.03E-02 1.18E-02 1.33E-02
c
C Weight Window Generation - Radial
wwg 2 0 0 0 0
wwp:p 5 3 5 0 -1 0
mesh geom=cyl ref=0 13 402 origin=0.1 0.1 -568
     imesh 16.8 17.0 18.9 33.3 36.5 49.2 49.8 549.8
     iints 1 1 1 5 1 1 1 1
     jmesh 500 541 550 558 568 947 969 1020 1049 1089 1589
     jints 1 1 1 1 1 1 1 1 1 1 1
     kmesh 1
     kints 1
wwge:p  1e-3 1 20
fc2 Radial AziTrun Tally
f2:p +100.1
fm2 4.13583E+14
fs2  -101  -102  -103  -104  -105  -106
     -107  -108  -109  T
tf2
fc12 Radial Surface Tally
f12:p +110.1
fm12 4.13583E+14
fs12  -111  -112  -113  -114  -115  -116
     -117  -118  -119  -120  -121  -122
     -123  -124  -125  -126  -127  -128
     -129  -130  -131  -132  -133  -134
     -135  -136  -137  -138  -139  -140
     -141  -142  -143  -144  -145  -146
     -147  -148  -149  -150  -151  -152
     -153  -154  -155  -156  -157  -158
     -159  -160  -161  -162  -163  -164
     -165  -166  -167  -168  -169  -170
     -171  -172  -173  -174  -175  -176
     -177  -178  -179  -180  -181  -182
     -183  -184  -185  -186  -187  -188
     -189  -190  -191  -192  -193  -194
     -195  -196  -197  -198  -199  -200
     -201  -202  -203  -204  -205  -206
     -207  -208  -209  -210  -211  -212
     -213  -214  -215  -216  -217  -218
     -219  -220  -221  -222  -223  -224
     -225  -226  -227  -228  -229  -230
     -231  -232  -233  -234  -235  -236
     -237  -238  -239  -240  -241  -242
     -243  -244  -245  -246  -247  -248
     -249  -250  -251  -252  -253  -254
     -255  -256  -257  -258  -259  -260
     -261  -262  -263  -264  -265  -266
     -267  -268  -269  -270  -271  -272
     -273  -274  -275  -276  -277  -278
     -279  -280  -281  -282  -283  -284
     -285  -286  -287  -288  -289  -290
     -291  -292  -293  -294  -295  -296
     -297  -298  -299  -300  -301  -302
     -303  -304  -305  -306  -307  -308
     -309  T
tf12
fc22 Radial AziSurFuel Tally Q1 (+x+y)
f22:p +310.1
fm22 4.13583E+14
fs22 -311  -320
     -312  -313  -314  -315  -316  -317
     -318  -319  T
sd22 1.5682E+03  7.8412E+02  8.7124E+01  8r  3.1365E+03
tf22
fc32 Radial AziSurFuel Tally Q2 (-x+y)
f32:p +310.1
fm32 4.13583E+14
fs32 +311  -320
```

```
     +321  +322  +323  +324  +325  +326
     +327  +328  T
sd32 1.5682E+03  7.8412E+02  8.7124E+01  8r  3.1365E+03
tf32
fc42 Radial AziSurFuel Tally Q3 (-x-y)
f42:p +310.1
fm42 4.13583E+14
fs42 +311  +320
     +312  +313  +314  +315  +316  +317
     +318  +319  T
sd42 1.5682E+03  7.8412E+02  8.7124E+01  8r  3.1365E+03
tf42
fc52 Radial AziSurFuel Tally Q4 (+x-y)
f52:p +310.1
fm52 4.13583E+14
fs52 -311  +320
     -321  -322  -323  -324  -325  -326
     -327  -328  T
sd52 1.5682E+03  7.8412E+02  8.7124E+01  8r  3.1365E+03
tf52
fc62 Radial 1ft Tally
f62:p +329.1
fm62 4.13583E+14
fs62  -330  -331  -332  -333  -334  -335
     -336  -337  -338  -339  -340  -341
     -342  -343  -344  -345  -346  -347
     -348  -349  -350  -351  -352  -353
     -354  -355  -356  -357  -358  -359
     -360  -361  -362  -363  -364  -365
     -366  -367  -368  -369  -370  -371
     -372  -373  -374  -375  -376  -377
     -378  -379  -380  -381  -382  -383
     -384  -385  -386  -387  -388  -389
     -390  -391  -392  -393  -394  -395
     -396  -397  -398  -399  -400  -401
     -402  -403  -404  -405  -406  -407
     -408  -409  -410  -411  -412  -413
     -414  -415  -416  -417  -418  -419
     -420  -421  -422  -423  -424  -425
     -426  -427  -428  T
tf62
fc72 Radial 1m Tally
f72:p +429.1
fm72 4.13583E+14
fs72  -430  -431  -432  -433  -434  -435
     -436  -437  -438  -439  -440  -441
     -442  -443  -444  -445  -446  -447
     -448  -449  -450  -451  -452  -453
     -454  -455  -456  -457  -458  -459
     -460  -461  -462  -463  -464  -465
     -466  -467  -468  -469  -470  -471
     -472  -473  -474  -475  -476  -477
     -478  -479  -480  -481  -482  -483
     -484  -485  -486  -487  -488  -489
     -490  -491  -492  -493  -494  -495
     -496  -497  -498  -499  -500  -501
     -502  -503  -504  -505  -506  -507
     -508  -509  -510  -511  -512  -513
     -514  -515  -516  -517  -518  -519
     -520  -521  -522  -523  -524  -525
     -526  -527  -528  T
tf72
fc82 Radial Azi1m Tally Q1 (+x+y)
f82:p +529.1
fm82 4.13583E+14
fs82 -530  -539
     -531  -532  -533  -534  -535  -536
     -537  -538  T
sd82 7.0600E+03  3.5300E+03  3.9222E+02  8r  1.4120E+04
tf82
fc92 Radial Azi1m Tally Q2 (-x+y)
```

```
f92:p +529.1
fm92 4.13583E+14
fs92 +530  -539
     +540  +541  +542  +543  +544  +545
     +546  +547  T
sd92 7.0600E+03  3.5300E+03  3.9222E+02  8r  1.4120E+04
tf92
fc102 Radial Azi1m Tally Q3 (-x-y)
f102:p +529.1
fm102 4.13583E+14
fs102 +530  +539
     +531  +532  +533  +534  +535  +536
     +537  +538  T
sd102 7.0600E+03  3.5300E+03  3.9222E+02  8r  1.4120E+04
tf102
fc112 Radial Azi1m Tally Q4 (+x-y)
f112:p +529.1
fm112 4.13583E+14
fs112 -530  +539
     -540  -541  -542  -543  -544  -545
     -546  -547  T
sd112 7.0600E+03  3.5300E+03  3.9222E+02  8r  1.4120E+04
tf112
fc122 Radial 2m Tally
f122:p +548.1
fm122 4.13583E+14
fs122  -549  -550  -551  -552  -553  -554
     -555  -556  -557  -558  -559  -560
     -561  -562  -563  -564  -565  -566
     -567  -568  -569  -570  -571  -572
     -573  -574  -575  -576  -577  -578
     -579  -580  -581  -582  -583  -584
     -585  -586  -587  -588  -589  -590
     -591  -592  -593  -594  -595  -596
     -597  -598  -599  -600  -601  -602
     -603  -604  -605  -606  -607  -608
     -609  -610  -611  -612  -613  -614
     -615  -616  -617  -618  -619  -620
     -621  -622  -623  -624  -625  -626
     -627  -628  -629  -630  -631  -632
     -633  -634  -635  -636  -637  -638
     -639  -640  -641  -642  -643  -644
     -645  -646  -647  T
tf122
fc132 Radial 2m+Convey Tally
f132:p +648.1
fm132 4.13583E+14
fs132  -649  -650  -651  -652  -653  -654
     -655  -656  -657  -658  -659  -660
     -661  -662  -663  -664  -665  -666
     -667  -668  -669  -670  -671  -672
     -673  -674  -675  -676  -677  -678
     -679  -680  -681  -682  -683  -684
     -685  -686  -687  -688  -689  -690
     -691  -692  -693  -694  -695  -696
     -697  -698  -699  -700  -701  -702
     -703  -704  -705  -706  -707  -708
     -709  -710  -711  -712  -713  -714
     -715  -716  -717  -718  -719  -720
     -721  -722  -723  -724  -725  -726
     -727  -728  -729  -730  -731  -732
     -733  -734  -735  -736  -737  -738
     -739  -740  -741  -742  -743  -744
     -745  -746  -747  T
tf132
fc142 Radial Azi2m+Con Tally Q1 (+x+y)
f142:p +748.1
fm142 4.13583E+14
fs142 -749  -758
     -750  -751  -752  -753  -754  -755
     -756  -757  T
```

```
sd142 2.0227E+04  1.0113E+04  1.1237E+03  8r  4.0454E+04
tf142
fc152 Radial Azi2m+Con Tally Q2 (-x+y)
f152:p +748.1
fm152 4.13583E+14
fs152 +749  -758
     +759  +760  +761  +762  +763  +764
     +765  +766  T
sd152 2.0227E+04  1.0113E+04  1.1237E+03  8r  4.0454E+04
tf152
fc162 Radial Azi2m+Con Tally Q3 (-x-y)
f162:p +748.1
fm162 4.13583E+14
fs162 +749  +758
     +750  +751  +752  +753  +754  +755
     +756  +757  T
sd162 2.0227E+04  1.0113E+04  1.1237E+03  8r  4.0454E+04
tf162
fc172 Radial Azi2m+Con Tally Q4 (+x-y)
f172:p +748.1
fm172 4.13583E+14
fs172 -749  +758
     -759  -760  -761  -762  -763  -764
     -765  -766  T
sd172 2.0227E+04  1.0113E+04  1.1237E+03  8r  4.0454E+04
tf172
C
C Print Control
prdmp -30 -60 1 2
print
C Random Number Generator
rand gen=2 seed=33982735979567 stride=152917 hist=1
C
C Rotation Matrix
C
*TR1 0.0 0.0 0.0 10 100 90 -80 10 90 90 90 0
*TR2 0.0 0.0 0.0 20 110 90 -70 20 90 90 90 0
*TR3 0.0 0.0 0.0 30 120 90 -60 30 90 90 90 0
*TR4 0.0 0.0 0.0 40 130 90 -50 40 90 90 90 0
*TR5 0.0 0.0 0.0 50 140 90 -40 50 90 90 90 0
*TR6 0.0 0.0 0.0 60 150 90 -30 60 90 90 90 0
*TR7 0.0 0.0 0.0 70 160 90 -20 70 90 90 90 0
*TR8 0.0 0.0 0.0 80 170 90 -10 80 90 90 90 0
*TR9 0.0 0.0 0.0 90 180 90 0 90 90 90 90 0
*TR10 0.0 0.0 0.0 100 190 90 10 100 90 90 90 0
*TR11 0.0 0.0 0.0 110 200 90 20 110 90 90 90 0
*TR12 0.0 0.0 0.0 120 210 90 30 120 90 90 90 0
*TR13 0.0 0.0 0.0 130 220 90 40 130 90 90 90 0
*TR14 0.0 0.0 0.0 140 230 90 50 140 90 90 90 0
*TR15 0.0 0.0 0.0 150 240 90 60 150 90 90 90 0
*TR16 0.0 0.0 0.0 160 250 90 70 160 90 90 90 0
*TR17 0.0 0.0 0.0 170 260 90 80 170 90 90 90 0
*TR18 0.0 0.0 0.0 180 270 90 90 180 90 90 90 0
*TR19 0.0 0.0 0.0 190 280 90 100 190 90 90 90 0
*TR20 0.0 0.0 0.0 200 290 90 110 200 90 90 90 0
*TR21 0.0 0.0 0.0 210 300 90 120 210 90 90 90 0
*TR22 0.0 0.0 0.0 220 310 90 130 220 90 90 90 0
*TR23 0.0 0.0 0.0 230 320 90 140 230 90 90 90 0
*TR24 0.0 0.0 0.0 240 330 90 150 240 90 90 90 0
*TR25 0.0 0.0 0.0 250 340 90 160 250 90 90 90 0
*TR26 0.0 0.0 0.0 260 350 90 170 260 90 90 90 0
*TR27 0.0 0.0 0.0 270 360 90 180 270 90 90 90 0
*TR28 0.0 0.0 0.0 280 370 90 190 280 90 90 90 0
*TR29 0.0 0.0 0.0 290 380 90 200 290 90 90 90 0
*TR30 0.0 0.0 0.0 300 390 90 210 300 90 90 90 0
*TR31 0.0 0.0 0.0 310 400 90 220 310 90 90 90 0
*TR32 0.0 0.0 0.0 320 410 90 230 320 90 90 90 0
*TR33 0.0 0.0 0.0 330 420 90 240 330 90 90 90 0
*TR34 0.0 0.0 0.0 340 430 90 250 340 90 90 90 0
*TR35 0.0 0.0 0.0 350 440 90 260 350 90 90 90 0
*TR36 0.0 0.0 0.0 360 450 90 270 360 90 90 90 0
```

Figure 5.3.23-8 VISED X-Y Slice – SLOWPOKE Core – Accident Conditions

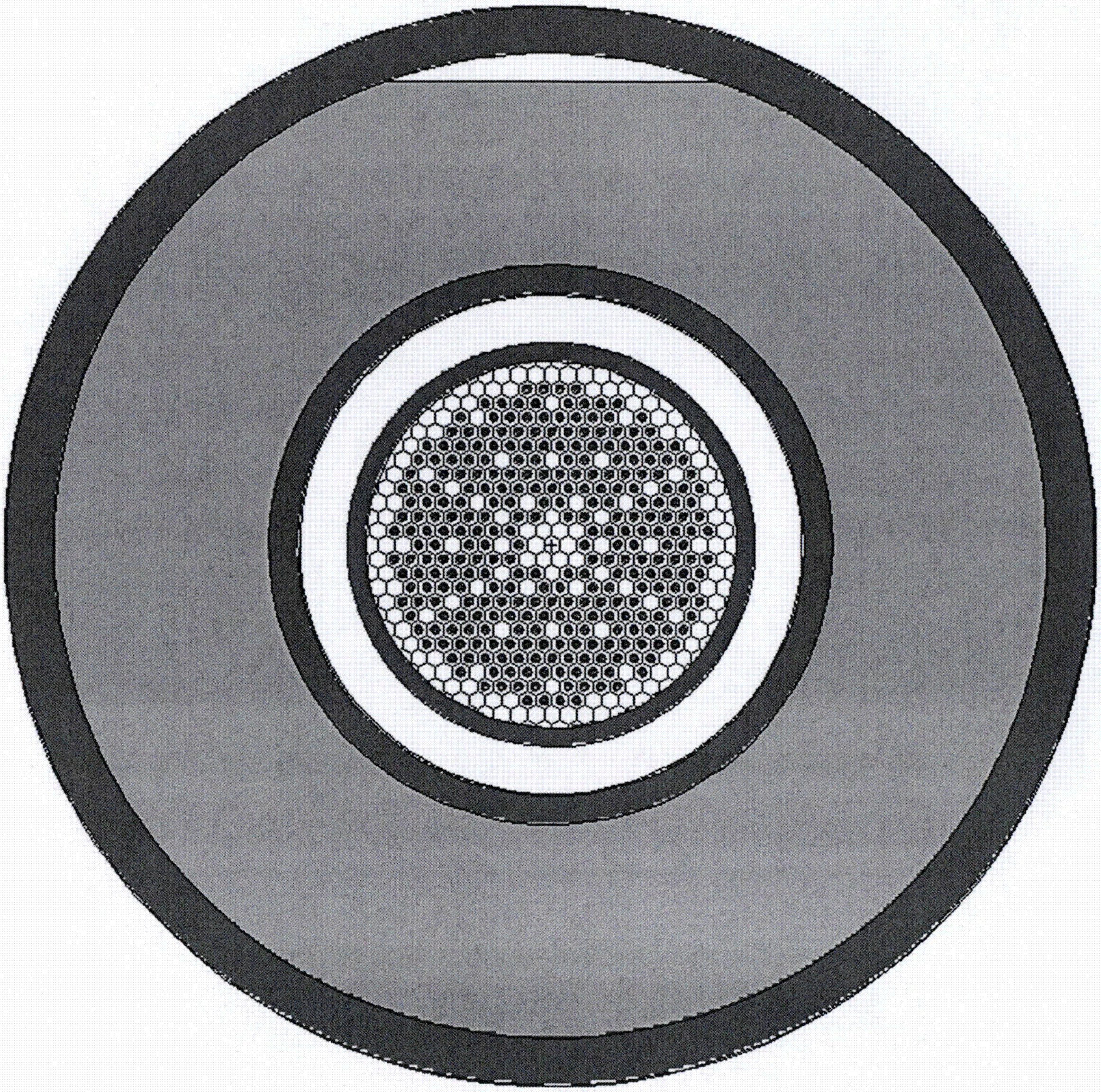
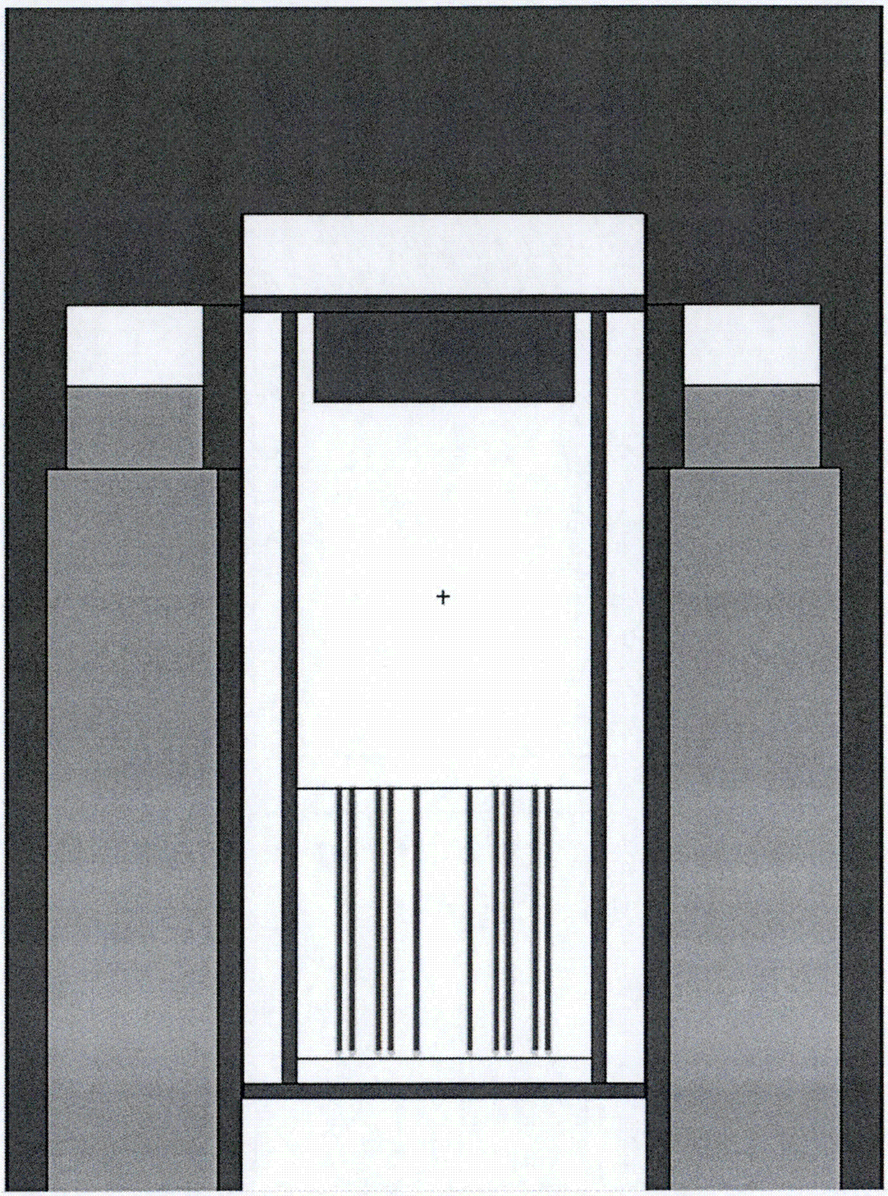


Figure 5.3.23-9 VISED Y-Z Slice – SLOWPOKE – Accident Conditions



Note: SLOWPOKE fuel core basket is shifted to the NAC-LWT lid. Void space indicated by the model is the space occupied by the basket lid collar whose material, but not spacing, is conservatively removed from the model. Location of the fuel core near the bottom of the basket cavity is maintained by a spacer structurally evaluated to survive both normal and accident conditions of transport.

Figure 5.3.23-10 SLOWPOKE Core Basket Sketch

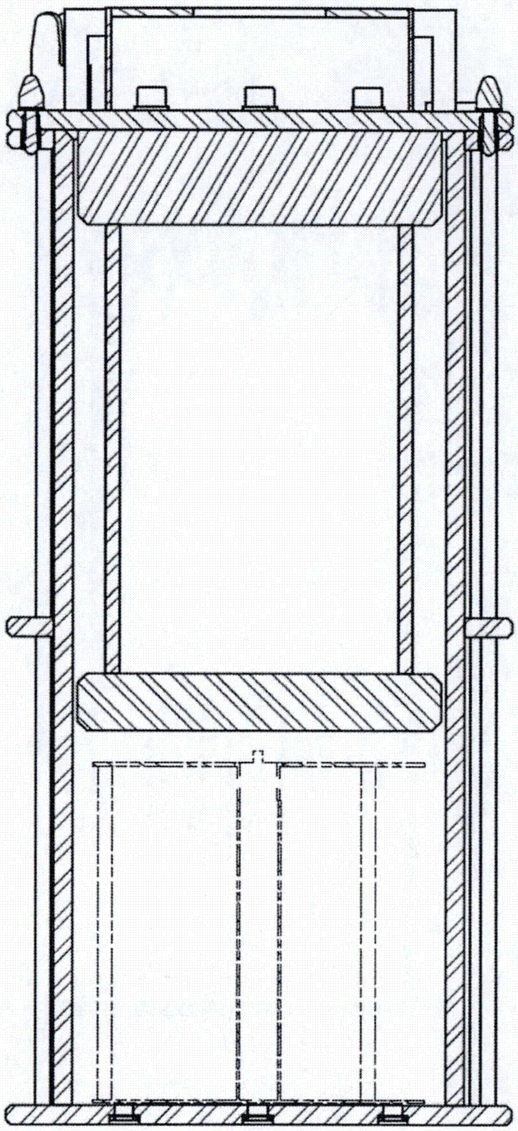


Figure 5.3.23-11 Sample MCNP Input File – Accident Conditions

```
NAC-LWT Cask - 15b90e14d - Accident Transport Conditions
C Top Axial Biasing - Fuel Neutron Source
C Fuel Rod Cells
1 1 -3.4819 -1 +3 -4   u=5 $ Fuel Meat
2 4 -2.7000 -2 +1 3 -4  u=5 $ Clad
3 4 -2.7000 -5 : -6     u=5 $ Top Cap
4 4 -2.7000 -7     u=5 $ Bottom Cap
5 0         #1 #2 #3 #4      u=5 $ Outside Rod
C Fuel Core Array Cell
6 0         -8 u=4 lat=2 fill=-15:15 -15:15 0:0  $ Core Array
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 5 5 5 5 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 5 5 5 5 4 5 5 5 5 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 5 4 5 5 5 5 5 5 5 5 4 5 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 5 5 5 5 5 4 5 5 4 5 5 4 5 5 5 5 5 4 4 4 4
     4 4 4 4 4 4 4 4 4 5 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 4 5 4 4 4 4
     4 4 4 4 4 4 4 4 5 5 5 4 5 5 5 5 5 5 5 5 5 5 5 4 5 5 5 4 4 4 4
     4 4 4 4 4 4 4 4 5 5 5 5 4 5 5 4 5 5 4 5 5 4 5 5 5 5 4 4 4 4 4
     4 4 4 4 4 4 4 5 5 5 5 5 5 4 5 5 4 5 5 4 5 5 5 5 5 5 4 4 4 4 4
     4 4 4 4 4 4 5 5 5 5 5 5 5 5 4 4 4 4 5 5 5 5 5 5 5 5 4 4 4 4 4
     4 4 4 4 4 4 4 5 5 4 5 5 4 5 4 4 4 5 4 5 5 4 5 5 4 4 4 4 4 4 4
     4 4 4 4 4 5 5 5 5 5 5 5 5 4 4 4 4 5 5 5 5 5 5 5 5 4 4 4 4 4 4
     4 4 4 4 4 5 5 5 5 5 5 4 5 5 4 5 5 4 5 5 5 5 5 5 4 4 4 4 4 4 4
     4 4 4 4 4 5 5 5 5 4 5 5 4 5 5 4 5 5 4 5 5 5 5 4 4 4 4 4 4 4 4
     4 4 4 4 5 5 5 4 5 5 5 5 5 5 5 5 5 5 5 4 5 5 5 4 4 4 4 4 4 4 4
     4 4 4 4 5 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 4 5 4 4 4 4 4 4 4 4 4
     4 4 4 4 5 5 5 5 5 4 5 5 4 5 5 4 5 5 5 5 5 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 5 4 5 5 5 5 5 5 5 5 4 5 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 5 5 5 5 4 5 5 5 5 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 5 5 5 5 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
     4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
C Cells - SLOWPOKE Core Basket
7 0         -9 fill=4 ( 0.0000 0.0000 3.3274 )   u=3 $ SLOWPOKE Core
8 6 -7.9400 -10     u=3 $ Base Plate
9 6 -7.9400 -11 +12    u=3 $ Basket Tube
10 6 -7.9400 -13     u=3 $ Shield Plug
11 6 -7.9400 -14     u=3 $ Lid Plate
12 0         -15     u=3 $ Lid Spacer
13 0         #7 #8 #9 #10 #11 #12      u=3 $ Void
C Cells - LWT Cavity
14 0         -16 fill=3 ( 0.0000 0.0000 377.6980 )   u=2
15 0         #14     u=2
C Cells - LWT Cask Accident Conditions
16 5 -11.344 -20     u=1 $ BotPb
17 0         -19 fill=2    u=1 $ Cavity
18 6 -7.9400 -18 +20    u=1 $ Bottom
19 6 -7.9400 -17 +18 +22 +24 +19 u=1 $ Outer Shell
20 6 -7.9400 -21 +24 +19    u=1 $ Inner Shell Taper
21 6 -7.9400 -23 +19    u=1 $ Inner Shell
22 5 -11.344 -24 +23 -25    u=1 $ Lead
23 5 -11.344 -22 +21 +24 -27 -26 u=1 $ Lead Taper
24 0         -22 +21 +24 +27  u=1 $ Axial Lead Slump
25 0         -24 +25    u=1 $ Radial Lead Slump - Main
26 0         -22 +24 -27 +26  u=1 $ Radial Lead Slump - Taper
27 0         +17     u=1 $ Outside
C Detector Cells - Axial Biasing
100  0  -100  fill=1  $ Surface
200  0  -200  +100  $ 1m
```

```
300  0  -300  +100  +200  $ 2m
400  0  -400  +100  +200  +300  $ 5m
500  0  -500  +100  +200  +300  +400  $ Edge
600  0  -600  +100  +200  +300  +400  +500  $ Driver
700  0  +100  +200  +300  +400  +500  +600  $ Exterior

C Fuel Rod Surfaces
1 CZ 0.2108        $ Fuel Meat OD
2 CZ 0.2616        $ Clad OD
3 PZ 0.4572        $ Lower Fuel Cut Plain
4 PZ 22.4536        $ Upper Fuel Cut Plain
5 RCC 0.0000 0.0000 0.3302 0.0000 0.0000 0.1270 0.3048 $ Lower Stud Rim
6 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 0.3302 0.1930 $ Lower Stud Cap
7 RCC 0.0000 0.0000 22.4536 0.0000 0.0000 0.3810 0.3048 $ Upper Stud
C Fuel Core Lattice Surface
8 RHP 0.0 0.0 0.0 0.0 0.0 22.8346
         0.5518 0.0 0.0    $ Lattice Cell
C Surfaces - SLOWPOKE Core Basket
9 RCC 0.0000 0.0000 3.3274 0.0000 0.0000 22.8346 12.3824 $ Core
10 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 1.2700 16.8466 $ Base Plate
11 RCC 0.0000 0.0000 1.2700 0.0000 0.0000 64.8970 13.6525 $ Tube OD
12 RCC 0.0000 0.0000 1.2700 0.0000 0.0000 64.8970 12.3825 $ Tube ID
13 RCC 0.0000 0.0000 58.5470 0.0000 0.0000 7.6200 10.9982 $ Shield Plug
14 RCC 0.0000 0.0000 66.1670 0.0000 0.0000 1.2700 16.8466 $ Lid Plate
15 RCC 0.0000 0.0000 67.4370 0.0000 0.0000 6.9850 16.84655 $ Lid Spacer
C Surfaces - LWT Cavity
16 RCC 0.0000 0.0000 377.6980 0.0000 0.0000 74.4220 16.8467 $ Basket
C Surfaces - LWT Cask Accident Conditions
17 RCC 0.0000 0.0000 -26.6700 0.0000 0.0000 507.3650 36.5189 $ Lwt
18 RCC 0.0000 0.0000 -26.6700 0.0000 0.0000 26.6700 36.5189 $ Bottom
19 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 452.1200 16.9863 $ Cavity
20 RCC 0.0000 0.0000 -17.7800 0.0000 0.0000 7.6200 26.3525 $ Bottom Gamma Shield
21 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 444.5000 20.1740 $ Lead ID - Taper
22 RCC 0.0000 0.0000 0.0000 0.0000 0.0000 444.5000 31.5976 $ Lead OD - Taper
23 RCC 0.0000 0.0000 13.8176 0.0000 0.0000 416.8648 18.9103 $ Lead ID
24 RCC 0.0000 0.0000 13.8176 0.0000 0.0000 416.8648 33.3271 $ Lead OD
25 PY 31.4618        $ Radial Slump - Main
26 PY 31.4618        $ Radial Slump - Taper
27 PZ 437.6266        $ Top Lead Slump
C Axial Detector DTA (Surface)
100  RCC  0.0000  0.0000  -26.7700  0.0000  0.0000  507.5650  36.5190
101  CZ  7.3038
102  CZ  14.6076
103  CZ  21.9114
104  CZ  29.2152
C Axial Detector DTB (1m)
200  RCC  0.0000  0.0000  -26.7700  0.0000  0.0000  607.5650  136.5190
201  CZ  27.3038
202  CZ  54.6076
203  CZ  81.9114
204  CZ  109.2152
C Axial Detector DTC (2m)
300  RCC  0.0000  0.0000  -26.7700  0.0000  0.0000  707.5650  236.5190
301  CZ  47.3038
302  CZ  94.6076
303  CZ  141.9114
304  CZ  189.2152
C Axial Detector DTD (5m)
400  RCC  0.0000  0.0000  -26.7700  0.0000  0.0000  1007.5650  236.6190
401  CZ  47.3238
402  CZ  94.6476
403  CZ  141.9714
404  CZ  189.2952
C Axial Detector DTE (Edge)
500  RCC  0.0000  0.0000  -26.7700  0.0000  0.0000  1091.6650  236.7190
501  CZ  47.3438
502  CZ  94.6876
503  CZ  142.0314
504  CZ  189.3752
C Axial Detector DTF (Driver)
600  RCC  0.0000  0.0000  -26.7700  0.0000  0.0000  1244.0650  236.8190
```

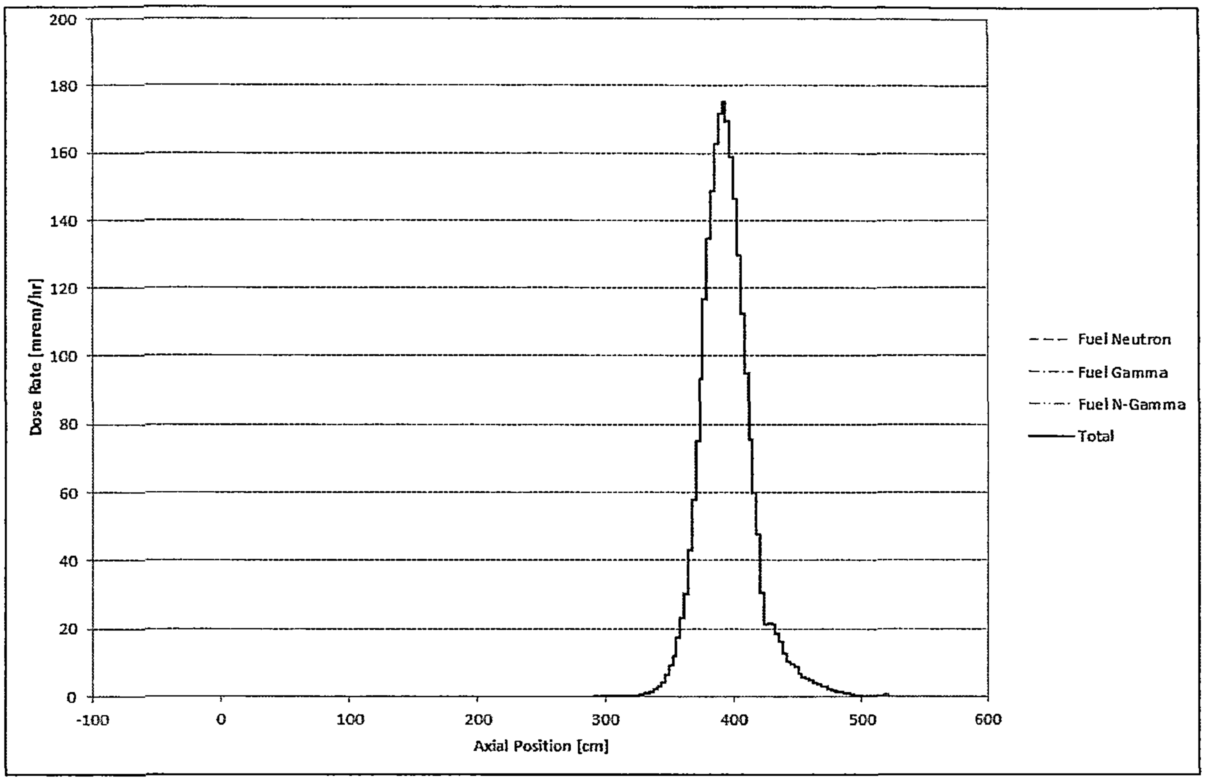
```
601  CZ  47.3638
602  CZ  94.7276
603  CZ  142.0914
604  CZ  189.4552

C
C Materials List
C
C U-Al Fuel
m1    92235 -2.5201E-01 92238 -2.8001E-02 13027 -7.1999E-01
C Water
m2    1001 6.6667E-01 8016 3.3333E-01
mt2   lwtr.01
C Water/Glycol
m3    1001 -1.03200E-01 8016 -6.82400E-01 6000 -2.14400E-01
C Aluminum
m4    13027 -1.0
C Lead
m5    82000 -1.0
C Stainless Steel 304
m6    26000 -0.695 24000 -0.190 28000 -0.095
      25055 -0.020
C Aluminum Honeycomb Impact Limiter
m7    13027 -1.0
C
C Cell Importances
imp:n 1 32r 0
C
C Source Definition - Fuel Neutron
C 15 GWd/MTU burnup, 90 wt% U-235, 14-day cool time, 2.786 g U-235 per rod, 39 W/core
sdef RAD=d1 EXT=d2 ERG=d3 cell=d4
     POS= 0.0000 0.0000 0.4572
     AXS= 0.0000 0.0000 1.0000
si1 0 0.2108
sp1 -21 1
si2 0 21.9964
sp2 0 1
si3   1.000E-11 1.000E-08 3.000E-08 5.000E-08 1.000E-07 2.250E-07
     3.250E-07 4.140E-07 8.000E-07 1.000E-06 1.130E-06 1.300E-06
     1.860E-06 3.060E-06 1.070E-05 2.900E-05 1.010E-04 5.830E-04
     3.040E-03 1.500E-02 1.110E-01 4.080E-01 9.070E-01 1.420E+00
     1.830E+00 3.010E+00 6.380E+00 2.000E+01
sp3 0.0000E+00 7.7644E-17 1.7532E-16 3.4335E-14 7.9442E-14 2.6321E-13
     4.0690E-13 2.2042E-13 2.1252E-12 1.5718E-12 8.2450E-13 1.3824E-12
     6.4949E-12 1.6664E-11 1.8663E-10 2.4523E-09 1.5003E-08 1.2291E-06
     1.2619E-05 1.5888E-04 5.3354E-03 4.7898E-02 9.6974E-02 1.1373E-01
     6.2345E-02 2.3453E-02 1.4419E-03 8.5813E-05
# SI4  SP4
     L  D
     100:17:14:7:6:-1  1.0000
mode n
nps 6.40E+06
C
C ANSI/ANS-6.1.1-1977 - Neutron Flux-to-Dose Conversion Factors
C (mrem/hr)/(neutrons/cm2-sec)
de0 2.5E-08 1E-07 1E-06 0.00001 0.0001 0.001 0.01
     0.1 0.5 1 2.5 5 7 10
     14 20
df0 3.67E-03 3.67E-03 4.46E-03 4.54E-03 4.18E-03 3.76E-03 3.56E-03
     2.17E-02 9.26E-02 1.32E-01 1.25E-01 1.56E-01 1.47E-01 1.47E-01
     2.08E-01 2.27E-01
C
C Weight Window Generation - Top Axial
wwg 2 0 0 0 0
wwp:n 5 3 5 0 -1 0
mesh geom=cyl ref=0 0 400 origin=0.1 0.1 -527
     imesh 16.8 17.0 18.9 33.3 36.5 536.5
     iints 1 1 1 1 1 1
     jmesh 500 509 517 527 906 928 979 1007 1507
     jints 1 1 1 1 1 12 1 1 1
     kmesh 1
```

```
     kints 1
wwge:n  1e-5 1e-3 1 20
fc2 Axial Surface Tally
f2:n +100.2
fm2 1.04728E+02
fs2  -101  -102  -103  -104  T
tf2
fc12 Axial 1m Tally
f12:n +200.2
fm12 1.04728E+02
fs12  -201  -202  -203  -204  T
tf12
fc22 Axial 2m Tally
f22:n +300.2
fm22 1.04728E+02
fs22  -301  -302  -303  -304  T
tf22
fc32 Axial 5m Tally
f32:n +400.2
fm32 1.04728E+02
fs32  -401  -402  -403  -404  T
tf32
fc42 Axial Edge Tally
f42:n +500.2
fm42 1.04728E+02
fs42  -501  -502  -503  -504  T
tf42
fc52 Axial Driver Tally
f52:n +600.2
fm52 1.04728E+02
fs52  -601  -602  -603  -604  T
tf52
C
C Print Control
prdmp -30 -60 1 2
print
C Random Number Generator
rand gen=2 seed=46929924663793 stride=152917 hist=1
C
C Rotation Matrix
C
*TR1 0.0 0.0 0.0 10 100 90 -80 10 90 90 90 0
*TR2 0.0 0.0 0.0 20 110 90 -70 20 90 90 90 0
*TR3 0.0 0.0 0.0 30 120 90 -60 30 90 90 90 0
*TR4 0.0 0.0 0.0 40 130 90 -50 40 90 90 90 0
*TR5 0.0 0.0 0.0 50 140 90 -40 50 90 90 90 0
*TR6 0.0 0.0 0.0 60 150 90 -30 60 90 90 90 0
*TR7 0.0 0.0 0.0 70 160 90 -20 70 90 90 90 0
*TR8 0.0 0.0 0.0 80 170 90 -10 80 90 90 90 0
*TR9 0.0 0.0 0.0 90 180 90 0 90 90 90 90 0
*TR10 0.0 0.0 0.0 100 190 90 10 100 90 90 90 0
*TR11 0.0 0.0 0.0 110 200 90 20 110 90 90 90 0
*TR12 0.0 0.0 0.0 120 210 90 30 120 90 90 90 0
*TR13 0.0 0.0 0.0 130 220 90 40 130 90 90 90 0
*TR14 0.0 0.0 0.0 140 230 90 50 140 90 90 90 0
*TR15 0.0 0.0 0.0 150 240 90 60 150 90 90 90 0
*TR16 0.0 0.0 0.0 160 250 90 70 160 90 90 90 0
*TR17 0.0 0.0 0.0 170 260 90 80 170 90 90 90 0
*TR18 0.0 0.0 0.0 180 270 90 90 180 90 90 90 0
*TR19 0.0 0.0 0.0 190 280 90 100 190 90 90 90 0
*TR20 0.0 0.0 0.0 200 290 90 110 200 90 90 90 0
*TR21 0.0 0.0 0.0 210 300 90 120 210 90 90 90 0
*TR22 0.0 0.0 0.0 220 310 90 130 220 90 90 90 0
*TR23 0.0 0.0 0.0 230 320 90 140 230 90 90 90 0
*TR24 0.0 0.0 0.0 240 330 90 150 240 90 90 90 0
*TR25 0.0 0.0 0.0 250 340 90 160 250 90 90 90 0
*TR26 0.0 0.0 0.0 260 350 90 170 260 90 90 90 0
*TR27 0.0 0.0 0.0 270 360 90 180 270 90 90 90 0
*TR28 0.0 0.0 0.0 280 370 90 190 280 90 90 90 0
*TR29 0.0 0.0 0.0 290 380 90 200 290 90 90 90 0
*TR30 0.0 0.0 0.0 300 390 90 210 300 90 90 90 0
```

```
*TR31 0.0 0.0 0.0 310 400 90 220 310 90 90 90 0
*TR32 0.0 0.0 0.0 320 410 90 230 320 90 90 90 0
*TR33 0.0 0.0 0.0 330 420 90 240 330 90 90 90 0
*TR34 0.0 0.0 0.0 340 430 90 250 340 90 90 90 0
*TR35 0.0 0.0 0.0 350 440 90 260 350 90 90 90 0
*TR36 0.0 0.0 0.0 360 450 90 270 360 90 90 90 0
```

Figure 5.3.23-12 Normal Condition Radial Surface Dose Rate Profile by Source Type – SLOWPOKE Core



Note: Results based on tally located at the radius of the cask neutron shield shell. Peak dose rates occur at the SLOWPOKE core centerline elevation. Dose rates at the cask surface between impact limiter and neutron shield shell are lower than at the fuel core midplane.

Figure 5.3.23-13 Normal Condition 2-m + Conveyance Radial Surface Dose Rate Profile by Source Type – SLOWPOKE Core

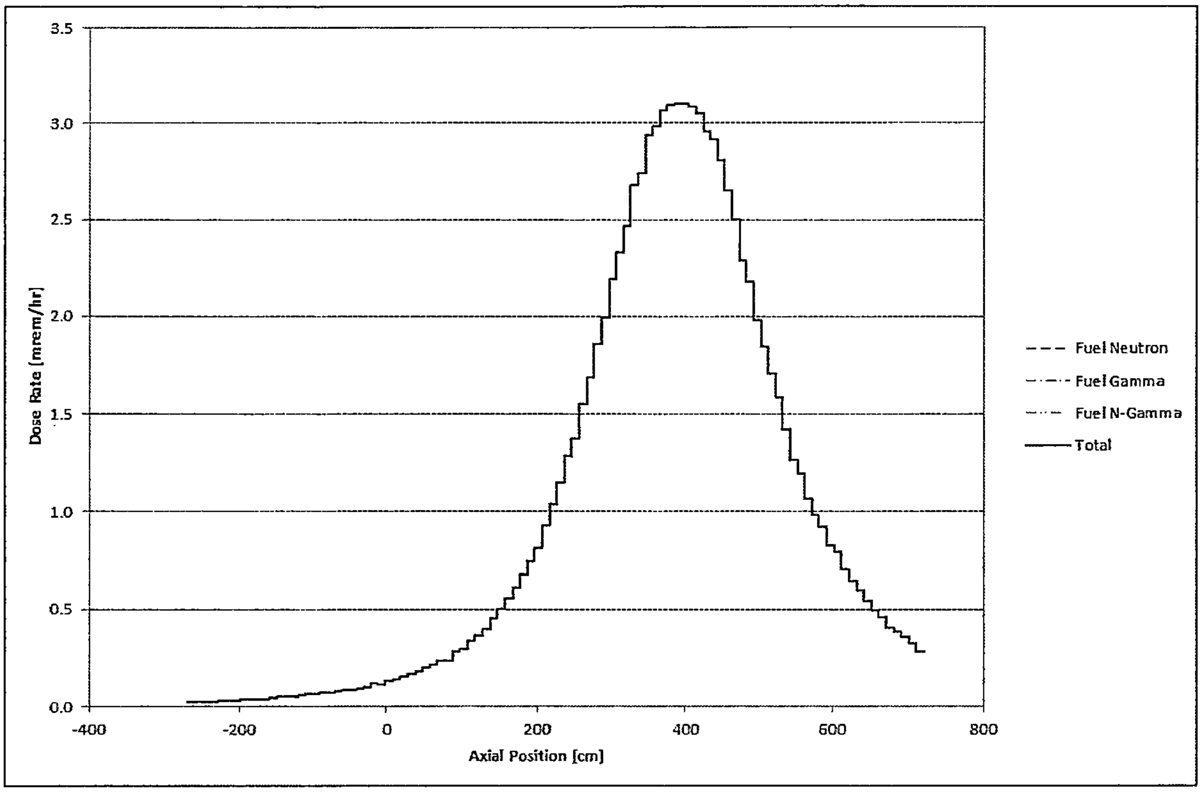
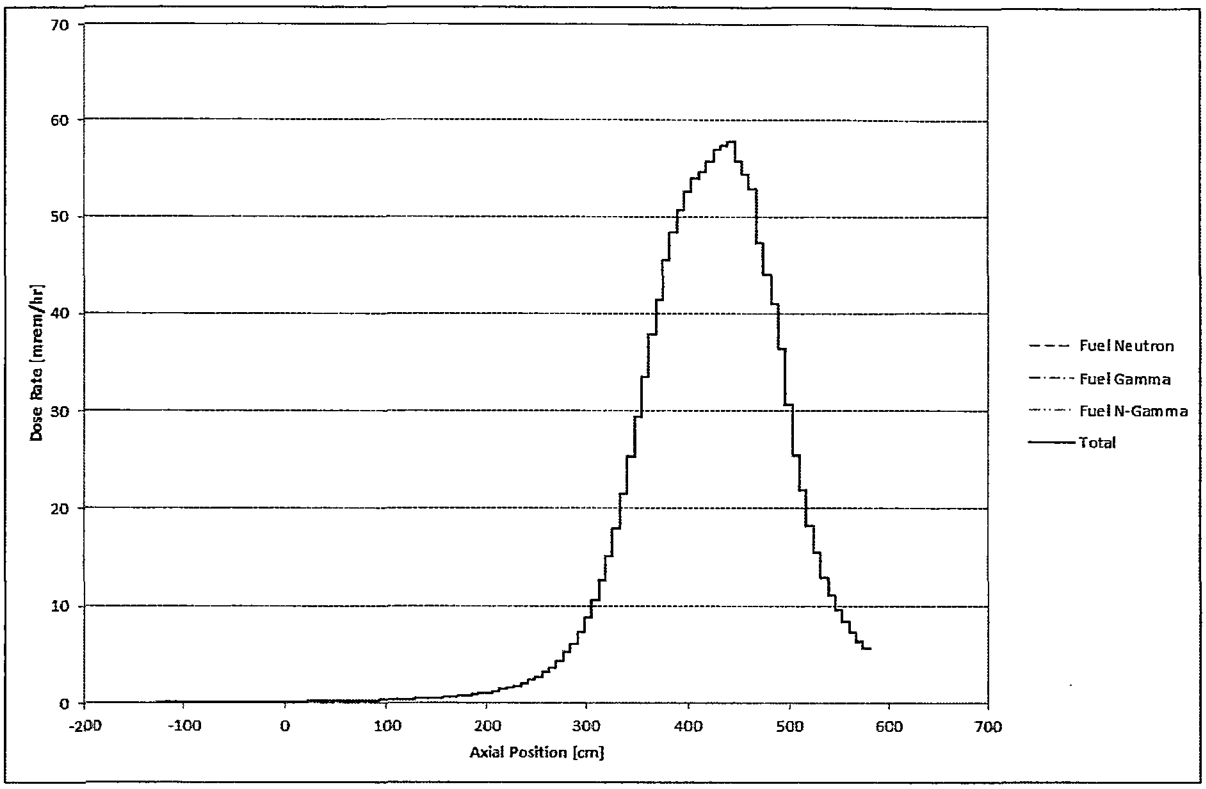


Figure 5.3.23-14 Accident Condition Radial 1m Dose Rate Profile by Source Type – SLOWPOKE Core



Note: Dose rates are circumferential average. Maximum dose rate of 80.7 mrem/hr was calculated using an azimuthal tally at the location of the lead slump.

Figure 5.3.23-15 Accident Condition Radial 1m Dose Rate Azimuthal Profile at Fuel Height – SLOWPOKE Core

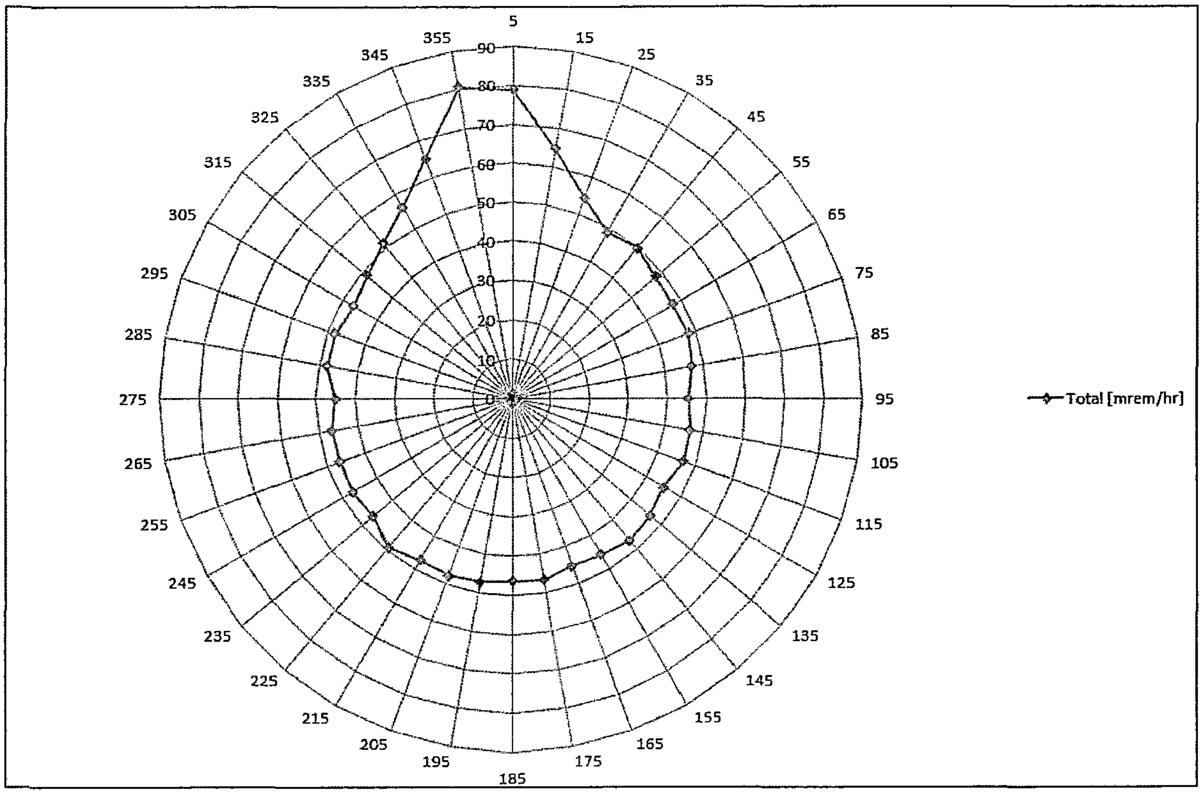


Table 5.3.23-1 SLOWPOKE Fuel Geometry and Materials

Fuel Element Type		Rod
Chemical Form		U-Al Alloy
Active Fuel Length	cm	22
Active Fuel Diameter	cm	0.422
Weight of U-235	g	2.795
Weight of total U	g	3.0
Alloy or compound material weight	g	7.714
Total weight of fuel meat	g	10.714
Clad Thickness	cm	0.051
Clad Weight (including caps)	g	4.981
Clad Material		Aluminum
Element Length	cm	22.83
Diameter (endcaps)	cm	0.61
Diameter (clad)	cm	0.52
Total weight of fuel element	g	15.695
Enrichment %	%	93
Core Maximum Power	kW	20
Maximum Burnup (^{235}U depletion)	%	0.65

Table 5.3.23-2 Source Term Generation Parameters for SLOWPOKE Fuel

Parameter	Value
U Mass Per Rod (grams)	3.121
^{235}U per Core (grams)	837.1
Core Power (kW)	20
Number of Hours Burned	16752
Number of Days Cooled	14
Number of Rods / Core	298
Initial Enrichment (wt % ^{235}U)	90
Burnup (% ^{235}U)	2.12
Burnup (GWd/MTU)	15
Moderator/Box Temperature (C)	40
Clad Temperature (C)	90
Fuel Temperature (C)	100

Table 5.3.23-3 SLOWPOKE Neutron Source Term (per rod)

Group	E Lower [MeV]	E Upper [MeV]	Source [neutrons/sec]
1	6.380E+00	2.000E+01	8.581E-05
2	3.010E+00	6.380E+00	1.442E-03
3	1.830E+00	3.010E+00	2.345E-02
4	1.420E+00	1.830E+00	6.234E-02
5	9.070E-01	1.420E+00	1.137E-01
6	4.080E-01	9.070E-01	9.697E-02
7	1.110E-01	4.080E-01	4.790E-02
8	1.500E-02	1.110E-01	5.335E-03
9	3.040E-03	1.500E-02	1.589E-04
10	5.830E-04	3.040E-03	1.262E-05
11	1.010E-04	5.830E-04	1.229E-06
12	2.900E-05	1.010E-04	1.500E-08
13	1.070E-05	2.900E-05	2.452E-09
14	3.060E-06	1.070E-05	1.866E-10
15	1.860E-06	3.060E-06	1.666E-11
16	1.300E-06	1.860E-06	6.495E-12
17	1.130E-06	1.300E-06	1.382E-12
18	1.000E-06	1.130E-06	8.245E-13
19	8.000E-07	1.000E-06	1.572E-12
20	4.140E-07	8.000E-07	2.125E-12
21	3.250E-07	4.140E-07	2.204E-13
22	2.250E-07	3.250E-07	4.069E-13
23	1.000E-07	2.250E-07	2.632E-13
24	5.000E-08	1.000E-07	7.944E-14
25	3.000E-08	5.000E-08	3.433E-14
26	1.000E-08	3.000E-08	1.753E-16
27	1.000E-11	1.000E-08	7.764E-17
Total			3.514E-01

Table 5.3.23-4 SLOWPOKE Fuel Gamma Source Term (per rod)

Group	E Lower [MeV]	E Upper [MeV]	Source [photons/sec]
1	8.00E+00	1.00E+01	7.4653E-06
2	6.50E+00	8.00E+00	3.4862E-05
3	5.00E+00	6.50E+00	1.8338E-04
4	4.00E+00	5.00E+00	7.9396E-04
5	3.00E+00	4.00E+00	2.6553E+07
6	2.50E+00	3.00E+00	3.4304E+09
7	2.00E+00	2.50E+00	2.0105E+09
8	1.66E+00	2.00E+00	3.5978E+08
9	1.33E+00	1.66E+00	1.0587E+11
10	1.00E+00	1.33E+00	2.5592E+09
11	8.00E-01	1.00E+00	4.1310E+10
12	6.00E-01	8.00E-01	4.3248E+11
13	4.00E-01	6.00E-01	1.5811E+11
14	3.00E-01	4.00E-01	5.7276E+10
15	2.00E-01	3.00E-01	2.3964E+10
16	1.00E-01	2.00E-01	1.3380E+11
17	4.50E-02	1.00E-01	1.0982E+11
18	1.00E-02	4.50E-02	3.1684E+11
Total			1.3879E+12

Table 5.3.23-5 Canister/Basket/Cask Material Descriptions for SLOWPOKE Fuel

Material	Element	Density [g/cm³]	Number Density [atom/b-cm]
Aluminum	Al	2.67	7.278E-02
Stainless Steel 304	Fe	7.94	5.9505E-02
	Cr		1.7472E-02
	Ni		7.7392E-03
	Mn		1.7407E-03
Lead	Pb	11.34	3.2967E-02
Neutron Shield	H	0.94	5.7965E-02
	O		2.4151E-02
	C		1.0105E-02
Impact Limiter	Al	0.50	1.1153E-02

Table 5.3.23-6 Modeled SLOWPOKE Core Basket Dimensions

Description	Dimension [in]
Core Basket Base Plate Thickness	0.500
Core Basket Base Plate OD	13.265
Core Basket Spacer Height	12.750
Core Basket Lid Height	3.250
Core Basket Lid Plate Thickness	0.500
Core Basket Lid OD	13.265
Core Basket Shield Thickness	3.000
Core Basket Shield OD	8.660
Core Basket Tube Height	25.550
Core Basket Tube OD	10.750
Core Basket Tube Thickness	0.500

Table 5.3.23-7 Maximum Dose Rates for SLOWPOKE Fuel

Transport Condition	Dose Rate Location	Maximum	
		[mrem/hr]	FSD
Normal	Side Surface of Cask	175.1	0.9%
	Top Surface of Cask	3.1	1.2%
	Bottom Surface of Cask	0.29	8.2%
	Side 1ft	57.2	0.8%
	Side 1m (Transport Index)	15.2	1.0%
	2m from Truck - Radial	3.1	1.1%
	2m from Top	0.24	1.2%
	Edge of Truck - Top	0.045	2.5%
	Edge of Truck - Bottom	0.018	8.4%
	Dose at Cab of Truck	0.031	3.3%
Accident	Side Surface of Cask	2127	1.7%
	Top Surface of Cask	16.3	0.8%
	Bottom Surface of Cask	1.2	9.8%
	Side 1m	80.7	2.1%
	Top 1m	2.0	26.6%
	Bottom 1m	0.15	9.9%

Note: The bounding accident side 1 meter dose rate is taken from the azimuthal tally at the fuel height.

Table 5.3.23-8 Summarized Maximum Dose Rates for SLOWPOKE Fuel

Transport Condition	Dose Rate Location	Maximum [mrem/hr]	Limit [mrem/hr]
Normal	Side Surface of Cask	175.1	1000
	Side 1ft	57.2	200
	Side 1m (Transport Index)	15.2	N/A
	2m from Truck - Radial	3.1	10
Accident	Side 1m	80.7	1000

Note: The side 1 ft detector is closer to the cask than the edge of the conveyance where the 200 mrem/hr limit occurs.

5.4 Shielding Evaluation

5.4.1 Shielding Evaluation Codes

The two codes used in the shielding evaluation of the NAC-LWT cask are XSDRNPM (NUREG/CR-0200, Vol. 2, F3) and QAD-CG (Cain). XSDRNPM is a 1-dimensional multigroup code developed by Oak Ridge National Laboratories (ORNL) for reactivity calculations. In this case, it is used to perform shielding analysis by solving the Boltzmann transport equation including anisotropic scattering by the discrete ordinates method. In this analysis, the P_3S_8 approximation is used for a more accurate dose rate calculation. The SCALE (NUREG/CR-0200) 27N/18G group coupled neutron-gamma cross section master library is processed through NITAWL (NUREG/CR-0200, Vol. 2, F2) and XSDRNPM for self-shielding resonance treatment and cell weighting. This step is necessary to generate the working data library required as input for XSDRNPM to perform dose rate calculations. The QAD-CG combinatorial geometry version of QAD was also developed at ORNL. It is a 3-dimensional computer code that is used extensively in industry and yields good results for gamma-ray calculations and usually satisfactory results for neutron calculations. The code uses buildup factors based on the Goldstein and Wilkins moments method calculations for gamma-ray transport in an infinite homogeneous medium. The code uses Capo's fit to the Goldstein-Wilkins data with bivariant polynomial expressions to calculate the approximate buildup factors as a function of the gamma-ray energy and the number of mean free paths from the source to the detector. The buildup factor selected for all of the shielding calculations in this case is for iron, which yields conservative results. For neutron dose calculations, the code uses either a modified Albert-Welton kernel or kernels obtained from the moments method solution of the Boltzmann transport equation. With the moments method kernels, the neutron spectrum penetrating a shield is determined on the basis of the equivalent length of a reference material between the source point and the receiver point.

XSDRNPM has been shown to be an accurate shielding code, but it has geometrical limitations. To perform calculations with XSDRNPM, a flat source distribution along the fuel axial direction and an equivalent circularized cylindrical source core are used. For the design basis Westinghouse 15 × 15 PWR assembly, the fuel area is 458.05 square centimeters, which yields an effective radius of 12.07 centimeters, as shown in Figure 5.3.3-6. In actuality, an axial source distribution (Figure 3.4-2) exists, which introduces higher dose rates at the peak axial source location. Also, the circularized core underestimates the dose at points where the real source region is nearer the cask surface.

QAD-CG is used to correct for the axial source distribution and the three-dimensional effects of geometry. Calculations are done with QAD for a three-dimensional model with an axial source distribution (Table 5.4.1-1) and for a 1-dimensional model with a flat source distribution. The flux to dose conversion factors for these models are found in the Radiological Health Handbook and are listed in Table 5.4.1-2. The buildup factor used for both of these models is for iron, since it has the largest number of mean free paths. The detector points are placed on the surface for the flat source distribution and at 2 meters from the personnel barrier for the axial source distribution. This gives a 3-dimensional to 1-dimensional correction factor, which is applied to the XSDRNPM results to calculate the actual dose. This method is used to calculate the dose rates from the side of the cask, at the surface, and at 2 meters from the personnel barrier (Table 5.1.1-4).

For the radial dose rates, an additional correction factor is applied to account for scattering. Schaeffer's Reactor Engineering for Nuclear Engineers is used to determine the scattering factors of 5 percent for primary and secondary gammas and 45 percent for neutrons. These values are found in tables 7.10 and 7.18 (Schaeffer) generated using total albedos. The use of total albedos rather than differential albedos is conservative, since total albedos take into account scattering angles that do not allow radiation to reach the detector point. It is also important to note that since this is high energy radiation, the probability of it scattering through large angles is very low.

The end-fitting calculations are straight forward. To calculate the end-fitting gamma as well as the fuel contribution to the dose rates at the ends of the cask, a simple QAD-CG model is used. The model is an arrangement of stacked disks and uses a flat source distribution so that a correction factor is not necessary. The various contributions are added together to obtain the total dose rate. The dose rates are included in Table 5.1.1-4.

The dose rates for a loss of the neutron shield are calculated using both XSDRNPM and QAD-CG. XSDRNPM is used to calculate a ratio of the dose rate on the surface with the neutron shield to the dose rate without the neutron shield. QAD-CG is used to calculate a 3-dimensional to 1-dimensional geometrical correction factor. The QAD-CG dose points are located on the surface, with a flat source distribution, and at 1 meter using an axial source distribution (Figure 3.4-2). The dose rates at 1 meter without the neutron shield are obtained by multiplying the normal operations dose rate at the surface by the 3-dimensional to 1-dimensional geometric correction factor. This product is then multiplied by the ratio of dose rates without water to with water, to obtain the hypothetical accident dose rate at 1 meter. The dose rate at 1 meter from the surface of the cask for this accident is 77.5 mrem/hour (Table 5.1.1-5), which is well below the limits of 49 CFR 173.

The lead slump accident is analyzed using QAD-CG. Models are created for the top and bottom end-fittings of a PWR and the bottom end-fitting of a BWR. The BWR bottom end-fitting is analyzed since it is bigger and has a larger ^{60}Co source than the PWR bottom end-fitting. It also sits closer to the bottom of the cask and, therefore, closer to the lead slump than the PWR bottom end-fitting. The analysis is not performed for the BWR top end-fitting because it is smaller and, therefore, has a lower source strength than the BWR bottom end-fitting. Detector points are placed at various positions along the outside of the cask in order to determine if the lead "window" that could be created during the cask drop would have adverse shielding consequences. The resulting dose rates are presented in Table 5.1.1-6.

For completeness, a normal transport conditions shielding analysis is performed for the NAC-LWT cask, which takes into account the shell tolerances found in the license drawings (Section 1.4). The method used is identical to the one used for the fuel radial calculations; however, neutrons and secondary gammas are not recalculated because a small reduction in the lead thickness would not significantly affect either the neutrons or the secondary gammas. The lead density in this analysis was determined by multiplying the maximum density at room temperature (11.35 g/cc) by a ratio of the volume of lead at 620°F to the volume of lead at room temperature (335,779.9/339,930.5). A thermal insulator is used to preclude lead melt during the 10 CFR 71 hypothetical fire accident. The displacement of the lead by the thermal insulator is also taken into account. The dose rate, accounting for tolerances and thermal insulator, is 8.93 mrem/hour at the fuel midplane, 2 meters from the personnel barrier, an increase of only 0.79 mrem/hour. Therefore, under normal transport conditions, with the tolerances and the thermal insulator taken into account, the cask is within the limits of 10 CFR 71.

Table 5.4.1-1 Discrete Axial Source Distribution

Axial Location Above Bottom of Active Fuel Length (cm)	Relative Axial Source Strength	Axial Location Above Bottom of Active Fuel Length (cm)	Relative Axial Source Strength
0.0	0.35	99.72	1.20
5.54	0.45	105.26	1.20
11.08	0.563	110.80	1.20
16.62	0.685	116.34	1.20
22.16	0.768	121.88	1.20
27.70	0.843	127.42	1.20
33.24	0.909	132.96	1.20
38.78	0.965	138.50	1.20
44.32	1.015	144.04	1.20
49.86	1.039	149.58	1.20
55.40	1.074	155.12	1.20
60.94	1.103	160.66	1.20
66.48	1.128	166.20	1.20
72.02	1.148	171.74	1.20
77.56	1.166	177.28	1.20
83.10	1.175	182.82	1.20
88.64	1.20	188.36	1.20
94.18	1.20	193.90	1.187

Table 5.4.1-1 Discrete Axial Source Distribution (Continued)

Axial Location Above Bottom of Active Fuel Length (cm)	Relative Axial Source Strength	Axial Location Above Bottom of Active Fuel Length (cm)	Relative Axial Source Strength
199.44	1.175	288.08	1.04
204.98	1.175	293.62	0.934
210.52	1.175	299.16	0.88
216.06	1.175	304.70	0.88
221.60	1.152	310.24	0.88
227.14	1.14	315.78	0.88
232.68	1.14	321.32	0.88
238.22	1.14	326.86	0.88
243.76	1.14	332.40	0.839
249.30	1.14	337.94	0.769
254.84	1.14	343.48	0.665
260.38	1.089	349.02	0.591
265.92	1.04	354.56	0.513
271.46	1.04	360.10	0.523
277.00	1.04	365.75	0.301
282.54	1.04		

Table 5.4.1-2 Flux to Dose Conversion Factors

Energy (MeV)	Flux-to-Dose
0.35	5.13E-4
0.452	8.00E-4
0.79	1.52E-3
0.90	1.67E-3
1.25	2.17E-3
1.29	2.38E-3
1.58	2.63E-3
1.74	2.86E-3
2.35	3.45E-3