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CALCULATION

Document No.:	CALC-3020462	**Rev. No.**	000	**Page 1 of 45**
Project No.:	01910.00.B001.28	**Project Name:**	BRRC Letter Amendment	
Title:	BRR Fuel Rod Segment Shielding Analysis			

Summary:

The Battelle Energy Alliance (BEA) Research Reactor (BRR) package is currently used to transport spent fuel from a variety of research reactors. A one-time NRC letter amendment has been requested to allow for the shipment of a spent fuel payload from Oak Ridge National Laboratory (ORNL) to Idaho National Laboratory (INL). The following analysis demonstrates that the BRR package complies with the external radiation requirements of 10 CFR 71 for exclusive use transport of the spent fuel payload. In addition to the shielding analysis, a fissile mass assessment is performed to show that the spent fuel payload is exempt from criticality analysis per 10 CFR 71.

Safety ☒ **Non-Safety** ☐

Contains Unverified Input / Assumptions: **Yes:** ☐ **No:** ☒

Software Utilized: Yes **Software Active in FS EASI: Yes:** ☒ **NA*:** ☐ *Not Applicable per Section 5.7 of FS-EN-PRC-002 **Error Notices & Associated Corrective Actions Reviewed: Yes:** ☒ **No:** ☐	**Version:** SCALE 6.2.1 MCNP6.1 Excel 2010*	**Storage Media: Yes:** ☒ **No:** ☐ **Location:** COLDStor

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RELEASED by RM
APR 19 2018
UNCONTROLLED DUPLICATE

Revision History

Rev.	Changes
000	Initial Release

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1.0 PURPOSE

The Battelle Energy Alliance (BEA) Research Reactor (BRR) package is currently used to transport spent fuel from a variety of research reactors. A one-time NRC letter amendment is requested to allow for the shipment of a spent fuel payload from Oak Ridge National Laboratory (ORNL) to Idaho National Laboratory (INL). The composition of the spent fuel payload is detailed in a spreadsheet attachment included with [1].

The following analysis demonstrates that the BRR package complies with the external radiation requirements of 10 CFR 71 for exclusive use transport of the spent fuel payload. A fissile mass assessment is also performed to show that the spent fuel payload is exempt from criticality analysis per 10 CFR 71.

2.0 METHODOLOGY

The shielding performance of the BRR package during transport of the spent fuel payload is evaluated using SCALE and MCNP. SCALE is used to decay the payload contents and generate gamma and neutron source terms. SCALE is also used to determine the fissile mass content of the payload. The MCNP model is based on the current SAR shielding model (taken from Section 5, *Shielding Evaluation*, of [2]). The SAR model cask dimensions are maintained, while new source terms and tallies are developed to accurately model and evaluate the new payload. The spent fuel and fuel basket geometry are conservatively ignored, bounding real-world shielding performance.

The BRR package shielding performance is evaluated in accordance with 10 CFR 71 [3] and documented per the requirements in NUREG-1609 [4] and Regulatory Guide 7.9 [5]. The package is shipped vertically-oriented under exclusive use requirements using an open (flat-bed) transport vehicle. The requirements for exclusive use under normal conditions for transport (NCT) and hypothetical accident conditions (HAC), per 10 CFR 71.47(b) and 10 CFR 71.51(a)(2), are summarized and applied as follows:

Limits for Normal Conditions for Transport

- 200 mrem/hr on the external surface of the package
- 200 mrem/hr for the projected outer surfaces of the transport vehicle (trailer side edges and the top and bottom surfaces of the impact limiters)
- 10 mrem/hr at any point 2 meters from the projected side surfaces of the transport vehicle
- 2 mrem/hr in any normally occupied space (assumed 25 feet from the package centerline consistent with previous analysis in Section 5 of [2])

Limits for Hypothetical Accident Conditions

- 1000 mrem/hr at any point 1 meter from the outer surfaces of the package (i.e. the cask only as no credit for the impact limiters is taken during HAC)

The BRR package is shown to be exempt from criticality analysis per 10 CFR 71.15(b).

3.0 ASSUMPTIONS

3.1 Unverified Assumptions

There are no unverified assumptions.

3.2 Justified Assumptions

1. The vehicle width is assumed 8 feet, consistent with Section 5 of [2]. This is the standard width of a trailer.
2. The cask lead radial shrinkage gap is 0.0625 inches and the cask lead axial gap is 1.18 inches, consistent with Section 5 of [2].
3. The occupied location (i.e. vehicle driver) is assumed to be 25 feet from the centerline of the cask, consistent with Section 5 of [2]. This is a reasonable assumption based on the transportation configuration.
4. All spent fuel and fuel basket geometry is conservatively ignored. The spent fuel source is modeled as a point source within a 1 cm diameter sphere. The source is able to move to any location within the cask inner cavity, bounding any possible reconfiguration of the spent fuel during NCT or HAC. The real-world spent fuel will be contained within a robust, sealed container. The container will be constrained within one of the openings of the square fuel basket.
5. Subcritical multiplication is not accounted for. The package payload is exempt from criticality analysis, and thus it is reasonable to assume that the effective multiplication factor is low enough that subcritical multiplication does not have a significant effect on dose rates. The steady-state neutron level, *N*, is equal to the product of the neutron source strength, *S*, and the subcritical multiplication factor, *M* (see module 4 of [14]).

$$N = S * M = S * \left(\frac{1}{1 - k_{eff}}\right)$$

Neutron and secondary gamma dose rates, $\dot{D}$, vary proportionally with the neutron level. Based on the limiting results in Section 6.2 (NCT side surface dose rate), an effective multiplication factor greater than 0.85 would be necessary to exceed regulatory limits (in the limiting case, $\dot{D}_{primary\,\gamma}$ is 0.01 mrem/hr).

$$\frac{\dot{D}_M}{\dot{D}_{calculated}} = \frac{S * M}{S}$$

$$to\ solve\ for\ k_{eff,max} : \left[\frac{\dot{D}_{limit} - \dot{D}_{primary\,\gamma}}{\dot{D}_{neutron} + \dot{D}_{secondary\,\gamma}}\right]_{NCT,Side\ Surface} \approx \frac{\dot{D}_{limit}}{\dot{D}_{total}} = \left(\frac{1}{1 - k_{eff,max}}\right)$$

$$\rightarrow k_{eff,max} = 1 - \frac{\dot{D}_{total}}{\dot{D}_{limit}} = 1 - \frac{29.7\,\frac{mrem}{hr}}{200\,\frac{mrem}{hr}} = 0.8515$$

4.0 DESIGN INPUTS

4.1 Design Features

4.1.1 BRR Packaging

The principal design features of the BRR package are a thick lead-filled shield plug, lead-filled cask, and lead-filled bottom. The lead in the side wall of the cask is 8-in thick. Also in the side wall, the inner steel shell is 1-in thick and the outer stainless steel shell is 2-in thick.

The top plug consists of approximately 9.5-in lead with a 1-in stainless steel bottom cover plate and 0.5-in stainless steel top plate. The lid is constructed of stainless steel 2-in thick. The cask bottom consists of 7.7-in of lead through the centerline, with a 1-in stainless steel bottom cover plate, and approximately 1.2-in stainless steel inner forging.

An external view of the BRR package is shown in Figure 4-1, while a cross-section of the package is shown in Figure 4-2.

4.1.2 Spent Fuel Payload

Per Section 4 of [1] and [15], the spent fuel payload consists of fuel segments between 1.0 and 13 inches in length. The fuel segments have a ~0.4-in outer diameter and may be open ended. The spent fuel payload will be transported using the Square Fuel Basket shown in Figure 4-3. The spent fuel payload and Square Fuel Basket are not geometrically modeled.

The spent fuel payload is composed of three radioactive isotope sets corresponding to payload fuel segments, labeled "605", "616", and "649/650". The radioactive isotope composition of the payload is per a spreadsheet attachment, *Proposed ORNL Shipment to HFEF.xlsx*, included with [1]. Radioactive isotope sets "605", "616", and "649/650" are shown in Table 4-1, Table 4-2, and Table 4-3, respectively. Per discussion with the customer [13], an additional 20 inches of set "616" and 9 inches of set "649/650" may be included in the payload (Table 4-1 and Table 4-3 show the customer-provided radioisotope sets corresponding to total aggregate fuel lengths of 12 inches for "616" and 27 inches for "649/650").

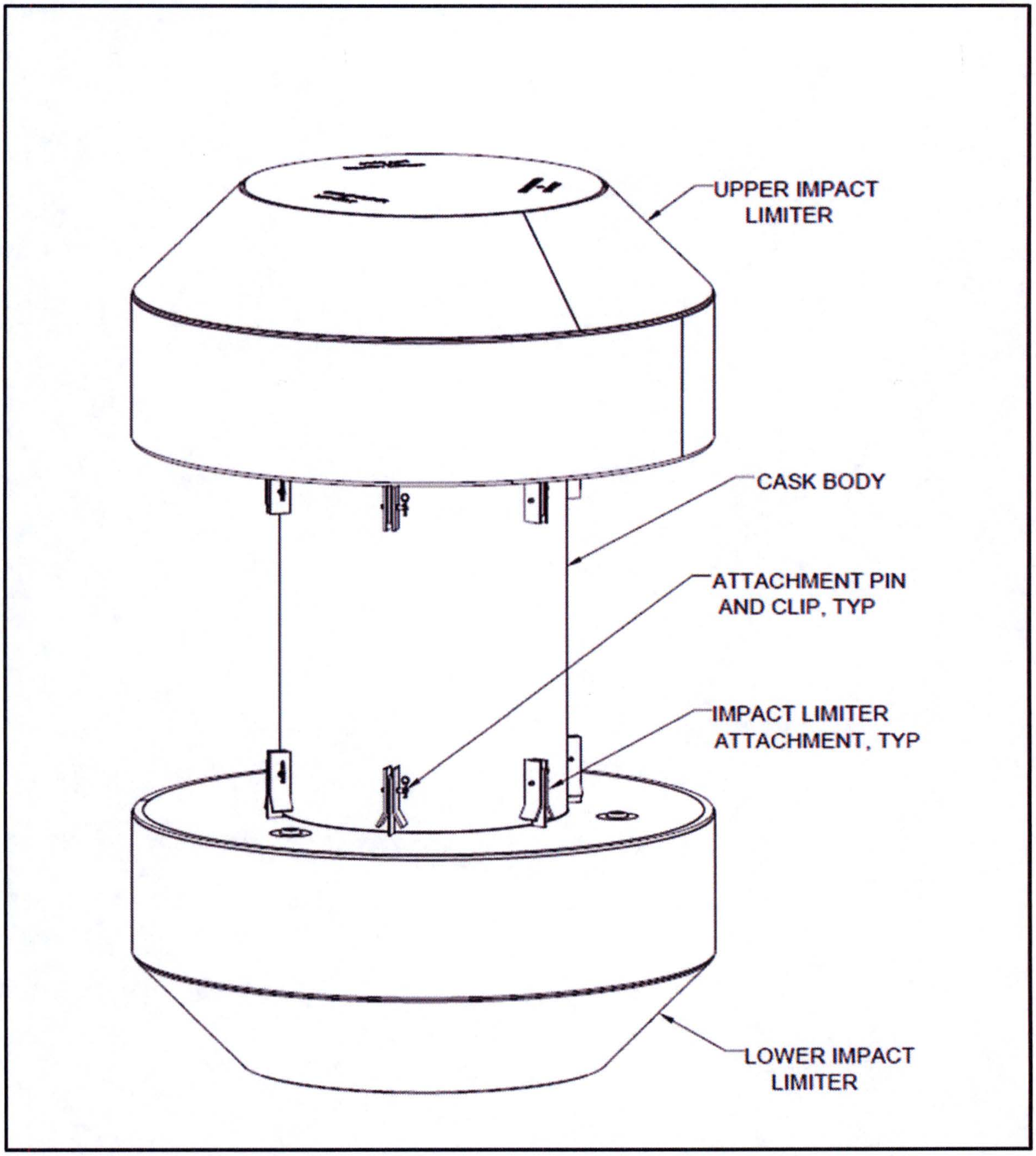


Figure 4-1: BRR Packaging Components

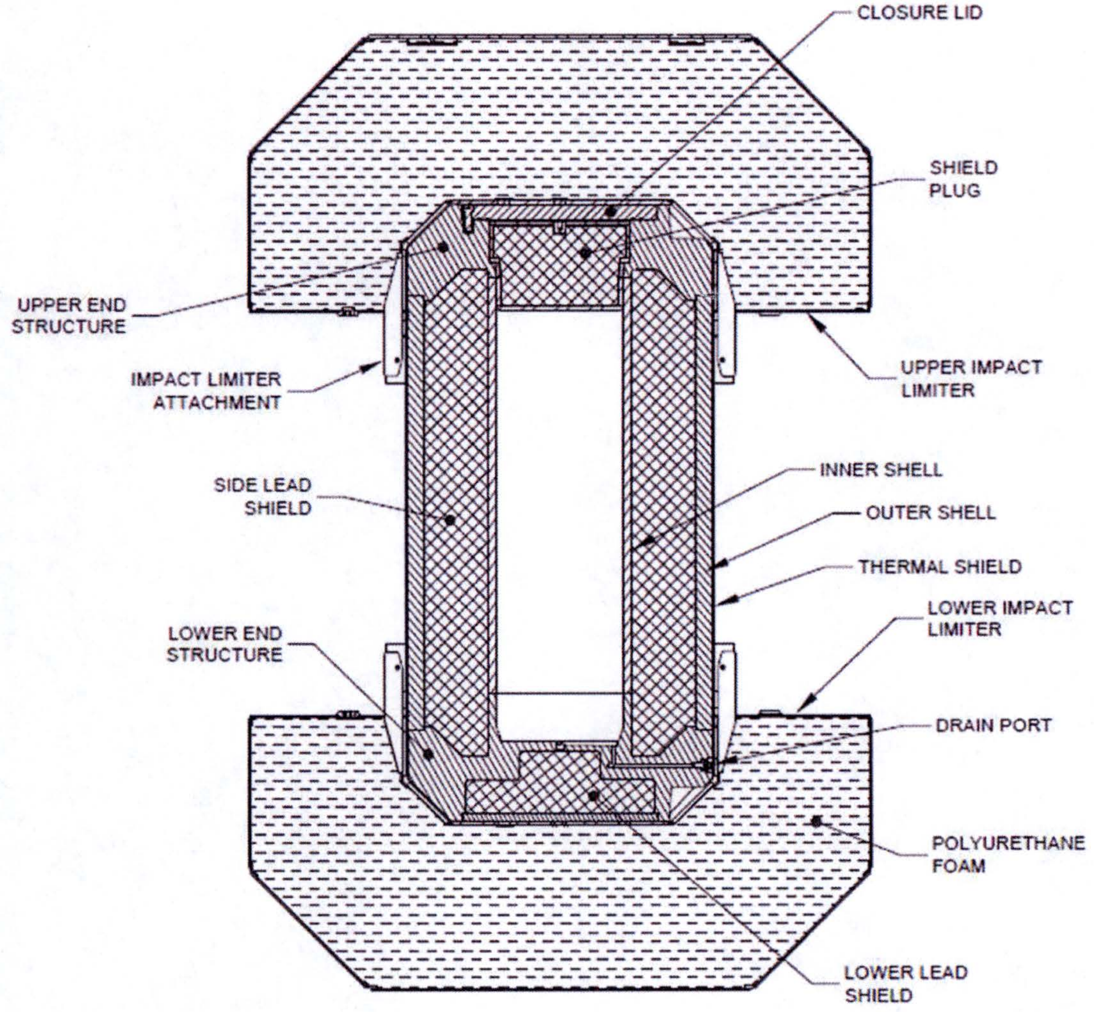


Figure 4-2: BRR Package Cross-Section

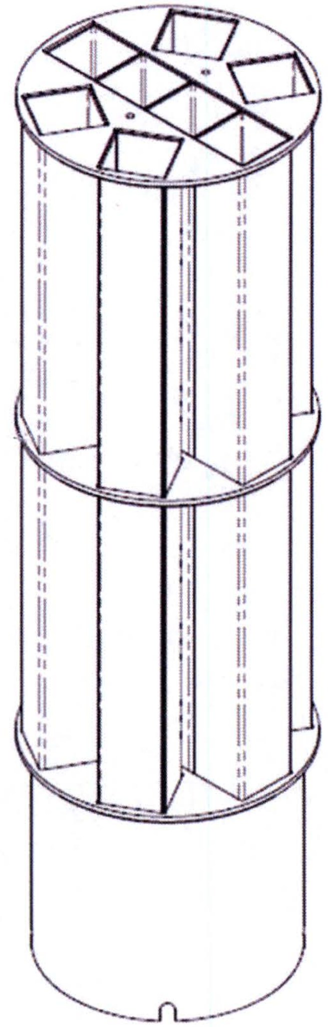


Figure 4-3: Square Fuel Basket

Table 4-1: Radioactive Isotope Set "605" (Evaluated 5/1/2000, fuel length of 12.5 inches)

Isotope	Activity (Ci)	Isotope	Activity (Ci)	Isotope	Activity (Ci)	Isotope	Activity (Ci)	Isotope	Activity (Ci)
Ac-225	3.27E-10	Cf-251	1.83E-07	Nb-94	7.13E-12	Pu-240	1.05E-01	Tc-99	4.66E-03
Ac-227	5.72E-10	Cf-252	2.54E-05	Nb-95	1.14E-06	Pu-241	2.18E+01	Te-123m	1.51E-08
Ac-228	2.60E-14	Cf-254	2.34E-18	Nb-95m	1.09E-08	Pu-242	7.82E-04	Te-125m	2.00E-01
Ag-109m	4.30E-09	Cm-242	2.23E-02	Ni-63	5.82E-12	Pu-243	1.42E-08	Te-127	2.14E-05
Ag-110	1.44E-03	Cm-243	1.00E-02	Np-237	1.04E-04	Pu-244	7.93E-15	Te-127m	2.17E-05
Ag-110m	1.10E-02	Cm-244	7.77E+00	Np-239	2.38E-02	Ra-223	5.72E-10	Te-129	3.17E-16
Am-241	2.46E-01	Cm-245	2.23E-03	Np-240m	7.93E-15	Ra-224	1.04E-05	Te-129m	4.93E-16
Am-242	6.51E-03	Cm-246	1.55E-03	Pa-231	2.66E-09	Ra-225	3.27E-10	Th-227	5.67E-10
Am-242m	6.51E-03	Cm-247	1.42E-08	Pa-233	1.04E-04	Ra-226	1.01E-11	Th-228	1.04E-05
Am-243	2.38E-02	Cm-248	1.52E-07	Pa-234	5.22E-08	Ra-228	2.60E-14	Th-229	3.27E-10
Am-244	1.03E-17	Cm-250	5.56E-14	Pa-234m	5.22E-05	Rb-87	5.52E-09	Th-230	3.50E-09
Am-245	3.26E-10	Co-60	1.45E-04	Pb-209	3.27E-10	Rh-103m	2.14E-12	Th-231	2.93E-07
Ar-39	3.17E-25	Cr-51	3.03E-21	Pb-210	1.63E-12	Rh-106	3.29E+00	Th-232	4.32E-14
At-217	3.27E-10	Cs-134	1.46E+01	Pb-211	5.72E-10	Rn-219	5.72E-10	Th-234	5.22E-05
Ba-137m	2.64E+01	Cs-135	9.68E-05	Pb-212	1.04E-05	Rn-220	1.04E-05	Tl-207	5.72E-10
Be-10	1.27E-12	Cs-137	2.83E+01	Pb-214	1.01E-11	Rn-222	1.01E-11	Tl-208	3.76E-06
Bi-210	1.63E-12	Eu-152	3.18E-03	Pd-107	5.92E-05	Ru-103	2.14E-12	Tl-209	7.18E-12
Bi-211	5.72E-10	Eu-154	2.92E+00	Pm-147	3.89E+00	Ru-106	3.29E+00	U-232	1.27E-05
Bi-212	1.04E-05	Eu-155	5.22E-01	Pm-148	3.29E-14	Sb-124	1.25E-10	U-233	6.02E-09
Bi-213	3.27E-10	Fe-55	1.31E-02	Pm-148m	4.07E-13	Sb-125	4.82E-01	U-234	6.82E-05
Bi-214	1.01E-11	Fe-59	2.21E-15	Po-210	1.63E-12	Sb-126	2.63E-04	U-235	2.93E-07
Bk-249	2.18E-05	Fr-221	3.27E-10	Po-211	1.72E-12	Sb-126m	2.66E-04	U-236	4.24E-05
Bk-250	5.56E-14	Fr-223	8.02E-12	Po-212	6.73E-06	Sc-46	1.91E-22	U-237	5.22E-04
C-14	1.07E-07	Gd-153	4.81E-04	Po-213	3.20E-10	Se-79	1.29E-04	U-238	5.22E-05
Ca-45	9.08E-18	H-3	1.42E-01	Po-214	1.01E-11	Sm-151	3.21E-01	U-240	7.93E-15
Cd-109	4.30E-09	Ho-166M	3.27E-06	Po-215	5.72E-10	Sn-119m	4.47E-05	Y-90	1.50E+01
Cd-113m	1.04E-02	I-129	1.41E-05	Po-216	1.04E-05	Sn-121m	1.60E-04	Y-91	3.58E-08
Cd-115m	1.52E-14	In-114	9.59E-14	Po-218	1.01E-11	Sn-123	5.42E-05	Zn-65	9.08E-20
Ce-141	1.57E-15	In-114m	9.93E-14	Pr-144	1.27E+00	Sn-126	2.66E-04	Zr-93	6.32E-04
Ce-144	1.27E+00	Kr-85	1.28E+00	Pu-236	6.73E-05	Sr-89	1.51E-09	Zr-95	5.27E-07
Cf-249	3.70E-06	Mn-54	1.21E-04	Pu-238	2.64E+00	Sr-90	1.50E+01		
Cf-250	1.40E-05	Nb-93m	3.46E-04	Pu-239	5.87E-02	Tb-160	1.35E-08		

Table 4-2: Radioactive Isotope Set "616" (Evaluated 8/1/2008, fuel length of 12 inches)

Isotope	Activity (Ci)	Isotope	Activity (Ci)	Isotope	Activity (Ci)	Isotope	Activity (Ci)	Isotope	Activity (Ci)
Ag-110	1.03E-03	Cm-244	6.64E+00	Np-237	8.33E-05	Rb-87	4.17E-09	Te-127	1.59E-05
Ag-110m	8.01E-03	Cm-245	2.13E-03	Np-239	2.18E-02	Rh-103m	1.58E-12	Te-127m	1.60E-05
Am-241	2.00E-01	Cm-246	1.17E-03	Pa-233	8.15E-05	Ru-106	2.49E+00	Te-129	2.32E-16
Am-242	6.62E-03	Cs-134	1.09E+01	Pb-212	7.54E-06	Sb-124	8.94E-11	Te-129m	3.63E-16
Am-243	8.15E-03	Cs-135	7.41E-05	Pd-107	4.33E-05	Sb-125	3.63E-08	Th-228	7.54E-06
Bi-212	7.54E-06	Cs-137	2.58E+01	Pm-147	3.01E+00	Sb-126m	1.96E-04	Th-234	4.13E-05
Bk-249	1.36E-05	Eu-152	2.51E-03	Pm-148	2.44E-14	Se-79	9.71E-05	U-232	1.16E-05
Cd-109	2.87E-09	Eu-154	2.16E+00	Pm-148m	3.04E-13	Sm-151	5.74E-02	U-234	2.04E-04
Cd-113m	7.13E-03	Eu-155	3.87E-01	Po-210	1.16E-12	Sn-119m	1.28E-05	U-235	2.43E-06
Cd-115m	1.10E-14	Gd-153	3.42E-04	Pu-236	6.27E-05	Sn-121m	4.31E-07	U-236	6.00E-05
Ce-141	1.17E-15	H-3	1.06E-01	Pu-238	9.19E-01	Sn-126	1.93E-04	U-237	5.09E-04
Ce-144	9.71E-01	In-113m	5.75E-14	Pu-239	5.76E-02	Sr-89	1.12E-09	U-238	5.33E-05
Cf-251	1.12E-07	In-114m	6.25E-14	Pu-240	2.69E-01	Sr-90	1.13E+01	Y-90	1.13E+01
Cf-252	6.13E-05	Nb-93m	2.40E-04	Pu-241	2.45E+01	Tb-160	9.28E-03	Y-91	2.67E-08
Cm-242	2.15E-02	Nb-95	8.22E-07	Pu-242	6.01E-04	Tc-99	3.06E-03	Zr-93	4.36E-04
Cm-243	9.71E-03	Nb-95m	6.61E-09	Ra-224	7.54E-06	Te-125m	1.51E-01	Zr-95	3.81E-07

Table 4-3: Radioactive Isotope Set "649/650" (Evaluated 5/1/2007, fuel length of 27 inches)

Isotope	Activity (Ci)	Isotope	Activity (Ci)	Isotope	Activity (Ci)	Isotope	Activity (Ci)	Isotope	Activity (Ci)
Ag-110	2.17E-03	Co-60	2.87E-01	Mo-93	1.84E-05	Pu-240	2.70E-01	Ta-182	7.25E-04
Ag-110m	1.60E-01	Cr-51	1.85E-12	Nb-93m	1.30E-01	Pu-241	6.30E+01	Tb-160	3.25E-05
Am-241	4.65E-01	Cs-134	4.46E+01	Nb-94	3.98E-03	Pu-242	2.20E-03	Tc-99	8.44E-03
Am-242	9.79E-03	Cs-135	3.20E-04	Nb-95	7.18E-03	Rb-86	2.54E-18	Te-123m	2.72E-05
Am-242m	9.79E-03	Cs-136	3.15E-24	Nb-95m	3.84E-05	Re-188	5.99E-08	Te-125m	4.35E-01
Am-243	4.01E-02	Cs-137	6.83E+01	Nd-147	1.89E-28	Rh-102	7.39E-04	Te-127	4.91E-03
Ar-37	3.96E-13	Eu-152	4.28E-03	Ni-59	1.41E-04	Rh-103m	2.26E-06	Te-127m	5.03E-03
Ba-136m	3.52E-25	Eu-154	4.80E+00	Ni-63	2.16E-02	Rh-106	3.02E+01	Te-129	2.04E-09
Ba-137m	6.45E+01	Eu-155	1.56E+00	Np-235	3.25E-06	Ru-103	2.26E-06	Te-129m	3.18E-09
Ba-140	7.46E-24	Eu-156	3.86E-20	Np-237	2.42E-04	Ru-106	3.02E+01	Th-234	1.01E-04
Bk-249	7.61E-05	Fe-55	2.30E-01	Np-238	4.43E-05	S-35	1.52E-06	U-232	2.80E-05
C-14	2.20E-04	Fe-59	1.43E-09	Np-239	4.01E-02	Sb-124	2.19E-06	U-234	2.76E-04
Ca-45	5.25E-06	Gd-153	1.16E-03	Pa-233	2.42E-04	Sb-125	1.79E+00	U-236	1.26E-04
Cd-113m	2.61E-02	H-3	2.61E-01	Pa-234m	1.01E-04	Sb-126m	4.46E-04	U-237	1.51E-03
Cd-115m	7.09E-09	Hf-175	3.67E-08	Pm-146	1.87E-03	Sc-46	3.11E-08	U-238	1.01E-04
Ce-141	3.42E-08	Hf-181	9.36E-09	Pm-147	2.35E+01	Sm-151	2.17E-01	W-181	3.79E-06
Ce-144	1.95E+01	In-113m	2.84E-06	Pm-148	4.54E-09	Sn-113	2.84E-06	W-185	4.32E-06
Cf-252	2.19E-05	In-114	1.20E-09	Pm-148m	8.59E-08	Sn-117m	9.44E-27	W-188	5.94E-08
Cl-36	6.35E-06	In-114m	1.26E-09	Pr-143	2.28E-22	Sn-119m	5.70E-03	Xe-131m	2.40E-27
Cm-242	6.64E-01	Ir-192	3.34E-08	Pr-144	1.95E+01	Sn-121	1.39E-03	Y-89m	5.36E-09
Cm-243	4.16E-02	Ir-194m	2.76E-08	Pr-144m	2.73E-01	Sn-121m	1.79E-03	Y-90	4.13E+01
Cm-244	9.79E+00	Kr-85	3.90E+00	Pu-236	2.95E-04	Sn-123	5.26E-04	Y-91	6.26E-04
Cm-245	1.22E-03	La-140	8.59E-24	Pu-237	5.36E-10	Sn-126	4.46E-04	Zn-65	8.67E-06
Cm-246	7.31E-04	Lu-177m	3.23E-08	Pu-238	4.39E+00	Sr-89	5.78E-05	Zr-93	8.53E-04
Co-58	5.17E-06	Mn-54	8.54E-03	Pu-239	1.34E-01	Sr-90	4.13E+01	Zr-95	3.27E-03

4.2 Source Specification

The spent fuel payload source term is generated in two steps. First, decay modeling is performed to determine the current radioactive isotope inventory of the spent fuel payload (as of January 1st, 2018). Set "605" is decayed 17.67 years, set "616" is decayed 9.42 years, and set "649/650" is decayed 10.67 years. Second, all isotope sets are combined to generate gamma and neutron source spectrums. Sets "616" and "649/650" are multiplied by factors of 2.67 and 1.33, respectively, to account for possible additional lengths of fuel beyond that described in [1]. All source term data is calculated using the ORIGEN module of SCALE 6.2.1 code package [6].

Decay of the "605", "616", and "649/650" isotope sets are performed using input files *605_Decay.inp*, *616_Decay.inp,* and *649_650_Decay.inp*. Generation of the payload source term is calculated using the input file *Combined_Shipment.inp*. All source term data processing is contained in the spreadsheet *Source Term.xlsx*.

4.2.1 Gamma Source

The gamma source spectrum is shown in Table 4-4. An ENDF/B-VII.1 19-group energy distribution is used, closely resembling the energy grouping used in Section 5 of [2]. The source term includes modeling of Bremsstrahlung but does not include secondary gamma radiation, which is instead modeled within MCNP.

Table 4-4: Spent Fuel Payload Gamma Source

Gamma Energy (MeV)	Gamma Source (γ/s)
2.00E+01 - 1.00E+01	2.2075E+02
1.00E+01 - 8.00E+00	3.0158E+03
8.00E+00 - 6.50E+00	1.4042E+04
6.50E+00 - 5.00E+00	7.2039E+04
5.00E+00 - 4.00E+00	1.7670E+05
4.00E+00 - 3.00E+00	6.1175E+05
3.00E+00 - 2.50E+00	2.4912E+06
2.50E+00 - 2.00E+00	2.5469E+07
2.00E+00 - 1.66E+00	2.7277E+08
1.66E+00 - 1.33E+00	1.4272E+10
1.33E+00 - 1.00E+00	1.3684E+11
1.00E+00 - 8.00E-01	7.8785E+10
8.00E-01 - 6.00E-01	4.8675E+12
6.00E-01 - 4.00E-01	1.0866E+11
4.00E-01 - 3.00E-01	8.1119E+10
3.00E-01 - 2.00E-01	1.3905E+11
2.00E-01 - 1.00E-01	4.6700E+11
1.00E-01 - 4.50E-02	7.3578E+11
4.50E-02 - 1.00E-02	2.5455E+12
Total	9.1748E+12

4.2.2 Neutron Source

The neutron source spectrum is shown in Table 4-5. An ENDF/B-VII.1 28-group energy distribution is used, closely resembling the energy grouping used in Section 5 of [2]. Neutrons from subcritical multiplication are not accounted for due to the low mass of fissile material (see Section 4.2.3).

Table 4-5: Spent Fuel Payload Neutron Source

Neutron Energy (MeV)	Neutron Source (n/s)
2.000E+01 - 6.376E+00	7.9778E+04
6.376E+00 - 3.012E+00	7.8487E+05
3.012E+00 - 1.827E+00	8.9950E+05
1.827E+00 - 1.423E+00	4.2093E+05
1.423E+00 - 9.072E-01	6.0368E+05
9.072E-01 - 4.076E-01	5.8829E+05
4.076E-01 - 1.111E-01	2.7052E+05
1.111E-01 - 1.503E-02	4.7356E+04
1.503E-02 - 3.035E-03	2.3234E+03
3.035E-03 - 5.830E-04	2.1302E+02
5.830E-04 - 1.013E-04	1.8174E+01
1.013E-04 - 2.902E-05	1.2029E+00
2.902E-05 - 1.068E-05	1.6888E-01
1.068E-05 - 5.000E-06	3.2900E-02
5.000E-06 - 3.059E-06	8.0911E-03
3.059E-06 - 1.855E-06	3.9178E-03
1.855E-06 - 1.300E-06	1.4505E-03
1.300E-06 - 1.125E-06	4.0044E-04
1.125E-06 - 1.000E-06	2.6888E-04
1.000E-06 - 8.000E-07	3.9483E-04
8.000E-07 - 4.140E-07	6.2350E-04
4.140E-07 - 3.250E-07	1.1258E-04
3.250E-07 - 2.250E-07	1.0906E-04
2.250E-07 - 1.000E-07	1.0426E-04
1.000E-07 - 5.000E-08	2.8366E-05
5.000E-08 - 3.000E-08	8.3033E-06
3.000E-08 - 1.000E-08	5.8228E-06
1.000E-08 - 1.000E-11	1.3876E-06
Total	3.6975E+06

4.2.3 Additional Source Characteristics

Per 10 CFR 71.4, fissile material is defined as "the radionuclides uranium-233, uranium-235, plutonium-239, and plutonium-241, or any combination of these radionuclides". The spent fuel payload contains 3.14 grams U-235, 6.30 grams Pu-239, and 0.97 grams Pu-241. The spent fuel payload does not contain a significant amount of U-233. The package is exempt from the criticality analysis requirements of 10 CFR 71 due to meeting the following exemption requirements per 10 CFR 71.15(b):

- The total fissile material mass is 10.41 grams, which is less than the maximum allowable of 15 grams
- The total nonfissile material mass (which includes cask body steel but not lead) is greater than 200 grams per gram of fissile material (total empty cask weight is greater than 26,000 lbs per Table 2.1-2, *BRR Package Component Weights*, of [2])

The spent fuel payload decay heat is 2.68 watts. The heat load of the Square Fuel Basket is limited to 30 watts per compartment per Section 1.2.2.5, *Square Fuel and Loose Plates*, of [2].

4.3 Material Properties

The cask is constructed of stainless steel and lead. The stainless steel composition and density utilized in the MCNP models is obtained from [7] and provided in Table 4-6. The lead is modeled as pure with a density of 11.35 g/cm^3 [8]. All empty space within the cask is modeled as dry air. Empty space outside the cask is modeled as void. The impact limiters are also modeled as void. The air composition and density utilized is obtained from [7] and provided in Table 4-7.

Table 4-6: Stainless Steel 304 Composition (Density = 7.94 g/cm^3)

Element	Wt. %
C	0.08
Si	1.0
P	0.045
Cr	19.0
Mn	2.0
Fe	68.375
Ni	9.5

Table 4-7: Dry Air Composition (Density = 0.0012 g/cm^3)

Element	Wt. %
N	76.508
O	23.4793
C	0.0126

5.0 CALCULATIONS

5.1 Methods

The dose rates for the spent fuel payload are computed using MCNP6.1 [9]. The spent fuel point source is evaluated in five worst-case locations with three runs per location (primary gamma dose rates, neutron dose rates, and secondary gamma dose rates), resulting in 15 total unique runs. All relevant package features are modeled in three-dimensions except for the spent fuel and fuel basket. The impact limiters are modeled as void. All space outside of the package is modeled as void.

For NCT dose rates, credit is taken for the geometry of the impact limiters (i.e. applicable surface dose rates are measured at the location of the impact limiter surface). For HAC dose rates, no credit for the geometry of the impact limiters is taken, bounding the crush of the impact limiters during an accident. As a result, the same MCNP model is used to calculate both NCT and HAC dose rates. All reconfiguration of the cask internal cavity during an accident condition is bounded by the evaluated worst-case locations (due to the non-physical concentration of the spent fuel source term).

Dose rates are computed using segmented mesh tallies (except for conical surfaces, which use segmented surface tallies) to ensure that the maximum dose rates are properly captured. Mesh tallies compute fluxes in thin, non-physical volumes (using track-length estimates) before converting to dose rates using the flux-to-dose rate conversion factors found in Section 5.3. Cylindrical tallies are split into six circumferential segments to properly capture circumferential variations in dose rates.

5.2 Configuration of Source and Shielding

All relevant design features of the BRR cask are modeled in MCNP while the spent fuel and fuel basket geometries are conservatively ignored. The key dimensions relevant to the modeled cask are summarized in Table 5-1, which is identical to Table 5.3-1, *Key Cask Model Dimensions*, from [2] (except for impact limiter diameter). The modeled package is shown in Figure 5-1. Some details are not included in the dimension table but may be inferred from the figure. The yellow dots superimposed on Figure 5-1 roughly correspond to the five evaluated source locations. The five source locations within the cask cavity are:

1. Source shifted to the lower wall and radial wall ("Bottom" case)
2. Source shifted to the lower wall and aligned with the drain port ("Drain" case)
3. Source shifted to the radial wall in the axial center of the cavity ("Middle" case)
4. Source shifted to the upper wall and radial wall ("Top" case)
5. Source shifted to the upper wall and aligned with the vent port ("Vent" case)

The approved SAR model is taken from Section 5 of [2] and modified as necessary. The only geometry change made to the existing SAR model is the correction of the impact limiters. The impact limiter diameter is changed to 78 inches and chamfered corners are added. Chamfered corners are added to ensure dose rates are measured as close as possible to the source. The dimensions for the impact limiters are taken from the impact limiter drawings in Section 1.3.3, *Packaging General Arrangement Drawings*, of [2]. All air outside of the package in the original SAR model has been converted to void to simplify variance reduction.

Table 5-1: Key Cask Model Dimensions

Item	***Dimension (in)***
Cask Radial	
Cask inner diameter	16.0
Cask inner steel thickness	1.0
Cask lead thickness	8.0, modeled as 7.9375
Cask lead radial shrinkage gap (assumed)	0.0625
Cask outer steel thickness	2.0
Cask outer diameter (w/o heat shield)	38.0
Cask to heat shield gap	0.105
Heat shield thickness	0.105
Upper and lower impact limiter diameter	78.0
Cask Axial Top	
Shield plug bottom plate thickness	1.0
Shield plug lead thickness	9.7, modeled as 9.58
Shield plug top plate thickness	0.5
Shield plug overall height	11.2, modeled as 11.08
Shield plug vent pipe inner diameter (schedule 40S)	0.824
Lid thickness	2.0
Upper impact limiter thickness at centerline	21.2
Overall height (including impact limiters)	119.5
Cask Axial Bottom	
Bottom outer plate thickness	1.0
Bottom lead thickness at centerline	7.7, modeled as 7.72
Bottom casting inner thickness (after machining)	1.1, modeled as 1.22
Bottom lead major diameter	23.7
Bottom lead minor diameter	10.3, modeled as 9.75
Drain hole diameter	0.5
Lower impact limiter thickness at centerline	21.2

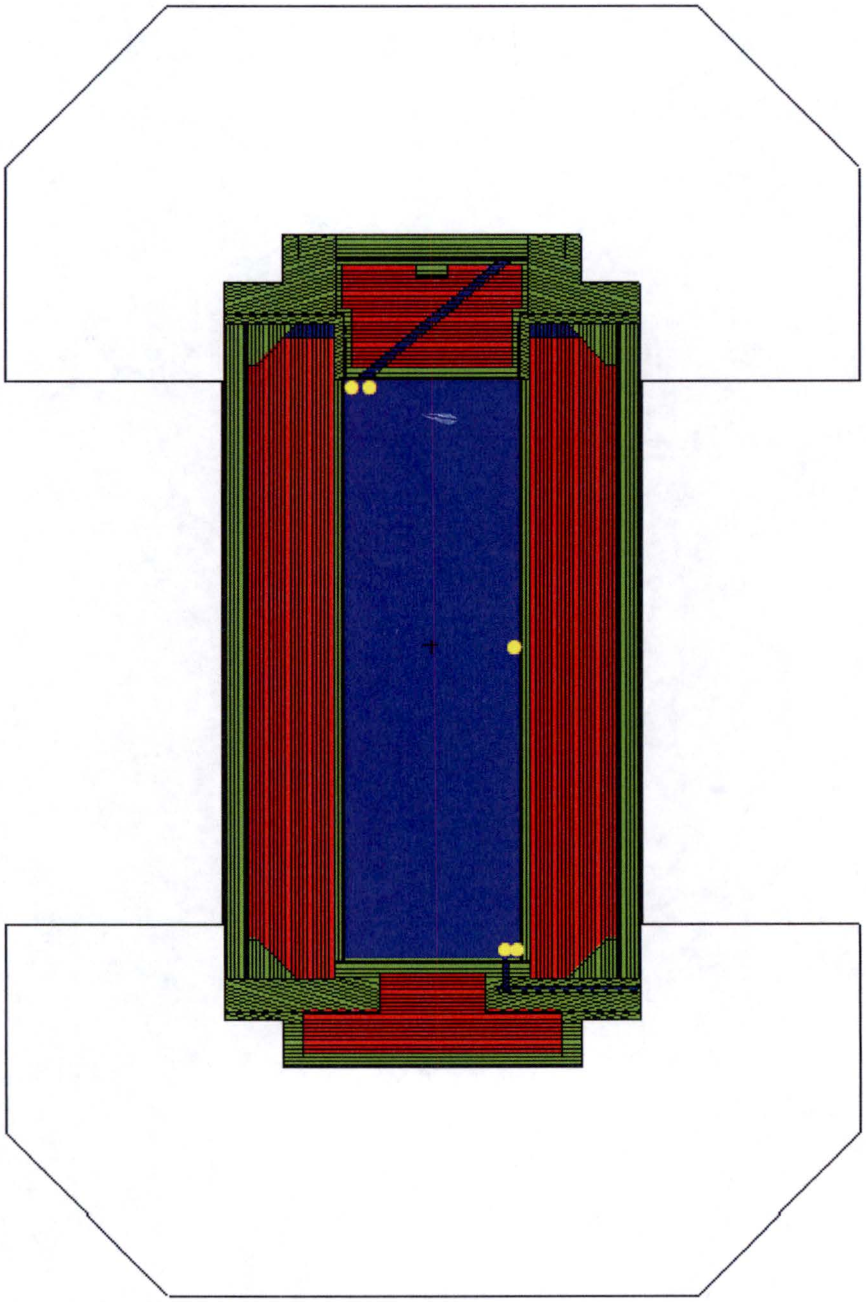


Figure 5-1: BRR Package Model with Superimposed Source Locations

5.3 Flux-to-Dose Rate Conversion

ANSI/ANS-6.1.1-1977 photon and neutron flux-to-dose rate conversion factors are used in this analysis. These factors are obtained from the MCNP6 User's Manual, Appendix D, Tables 11-1 and 11-2 [9]. The conversion factors in [9] have been multiplied by a factor of 1000 to generate dose rates in units of mrem/hr rather than rem/hr. The conversion factors are provided in Table 5-2 and Table 5-3.

Table 5-2: ANSI/ANS-6.1.1-1977 Photon Flux-to-Dose Rate Conversion Factors

Energy (MeV)	Gamma Factors (mrem/hr)/(γ/cm^2-s)	Energy (MeV)	Gamma Factors (mrem/hr)/(γ/cm^2-s)
0.01	3.96E-03	1.40	2.51E-03
0.03	5.82E-04	1.80	2.99E-03
0.05	2.90E-04	2.20	3.42E-03
0.07	2.58E-04	2.60	3.82E-03
0.10	2.83E-04	2.80	4.01E-03
0.15	3.79E-04	3.25	4.41E-03
0.20	5.01E-04	3.75	4.83E-03
0.25	6.31E-04	4.25	5.23E-03
0.30	7.59E-04	4.75	5.60E-03
0.35	8.78E-04	5.00	5.80E-03
0.40	9.85E-04	5.25	6.01E-03
0.45	1.08E-03	5.75	6.37E-03
0.50	1.17E-03	6.25	6.74E-03
0.55	1.27E-03	6.75	7.11E-03
0.60	1.36E-03	7.50	7.66E-03
0.65	1.44E-03	9.00	8.77E-03
0.70	1.52E-03	11.00	1.03E-02
0.80	1.68E-03	13.00	1.18E-02
1.00	1.98E-03	15.00	1.33E-02

Table 5-3: ANSI/ANS-6.1.1-1977 Neutron Flux-to-Dose Rate Conversion Factors

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

6.0 RESULTS AND CONCLUSIONS

6.1 External Radiation Levels

The objective is to determine bounding maximum dose rates resulting from transport of the spent fuel payload. The evaluated worst-case source locations are described in Section 5.2. The applicable dose rate limits are discussed in Section 2.

Tallies are divided into sub-tallies to ensure all local maximum dose rates are properly captured. All side tallies are vertically segmented into ~4-in (~10 cm) subdivisions. Similarly, top and bottom tallies are radially segmented into ~4-in (~10 cm) subdivisions. All mesh tallies are rotationally segmented into six 60° subdivisions. The only exceptions to these rules are the impact limiter conical surface tally (which is not rotationally segmented) and the occupied space tally (no rotational subdivisions and a ~6-foot height).

For NCT, package surface dose rates are measured using five mesh tallies at the following locations: the cask side surface, the top surface of the top impact limiter, the bottom surface of the bottom impact limiter, the impact limiter side surfaces, and the impact limiter 'underside' surfaces. The impact limiter 'underside' surfaces are considered to be part of the package side surface. Additionally, two segmented surface tallies are used on the conical surfaces of the top and bottom impact limiters. These conical surfaces are considered to be parts of the top and bottom surfaces of the package (rather than the side). Vehicle surface dose rates are measured using one mesh tally at the projected transport vehicle side surface (4 feet from cask centerline). The vehicle top surface is the same as the package top surface, while the vehicle bottom surface is conservatively measured at the package bottom surface. 2 meter dose rates are measured using one mesh tally 2 meters from the transport vehicle projected side surface. For HAC, 1 meter dose rates are measured using three mesh tallies at the following locations: 1 meter from the cask side, 1 meter from the cask top surface, and 1 meter from the cask bottom surface.

All tallies are processed in individual spreadsheets before being compiled in the spreadsheet *Compiled Shielding Results.xlsx*. The maximum total dose rates for each location (naming per Section 5.2) are shown in Table 6-1, Table 6-2, Table 6-3, Table 6-4, and Table 6-5. Tally total dose rates are calculated by summing the maximum primary gamma, neutron, and secondary gamma dose rates within each tally. Total dose rate relative errors are a function of the component dose rates, $\dot{D}$, and their associated relative errors, R. The associated relative errors output by MCNP are equal to the standard deviation as a fraction of the output dose ($R = \sigma/\dot{D}$). The total dose rate relative errors are calculated using the following equation (derived from the fundamental error propagation formula in [12] and converted to MCNP output terms):

$$R_{total} = \frac{\sqrt{\left(\dot{D}_{1\gamma} * R_{1\gamma}\right)^2 + \left(\dot{D}_n * R_n\right)^2 + \left(\dot{D}_{2\gamma} * R_{2\gamma}\right)^2}}{\dot{D}_{total}}$$

Relative errors for maximum total dose rates are all less than 5%, with typical relative errors less than 1%.

The dose rate at the normally occupied space (25 feet from the cask centerline) is 0.04 to 0.05 mrem/hr (0.3% max relative error) for all configurations.

Table 6-1: Tally Maximum Dose Rates (mrem/hr), Bottom Case

	NCT						**HAC**	
	Package Surface		**Vehicle Surface**		**2 meter**		**1 meter**	
Reference Location	*Result*	*Error*	*Result*	*Error*	*Result*	*Error*	*Result*	*Error*
Side	22.6	0.1%	2.7	0.1%	0.3	0.8%	1.5	0.4%
Top	0.1	0.2%	0.1	0.2%	-	-	0.1	3.1%
Bottom	4.3	0.2%	4.3	0.2%	-	-	1.8	0.3%

Table 6-2: Tally Maximum Dose Rates (mrem/hr), Drain Case

	NCT						**HAC**	
	Package Surface		**Vehicle Surface**		**2 meter**		**1 meter**	
Reference Location	*Result*	*Error*	*Result*	*Error*	*Result*	*Error*	*Result*	*Error*
Side	20.6	0.1%	2.6	0.2%	0.3	1.3%	1.5	0.8%
Top	0.2	0.3%	0.2	0.3%	-	-	0.1	3.1%
Bottom	4.4	0.2%	4.4	0.2%	-	-	1.8	0.3%

Table 6-3: Tally Maximum Dose Rates (mrem/hr), Middle Case

	NCT						**HAC**	
	Package Surface		**Vehicle Surface**		**2 meter**		**1 meter**	
Reference Location	*Result*	*Error*	*Result*	*Error*	*Result*	*Error*	*Result*	*Error*
Side	25.7	0.1%	2.5	0.1%	0.3	0.2%	1.6	0.1%
Top	0.5	0.1%	0.5	0.1%	-	-	0.2	1.9%
Bottom	0.7	1.0%	0.7	1.0%	-	-	0.3	1.5%

Table 6-4: Tally Maximum Dose Rates (mrem/hr), Top Case

	NCT						**HAC**	
	Package Surface		**Vehicle Surface**		**2 meter**		**1 meter**	
Reference Location	*Result*	*Error*	*Result*	*Error*	*Result*	*Error*	*Result*	*Error*
Side	29.7	0.1%	2.5	0.1%	0.3	0.2%	1.6	0.1%
Top	2.5	0.3%	2.5	0.3%	-	-	1.1	0.4%
Bottom	0.2	1.6%	0.2	1.6%	-	-	0.1	1.5%

Table 6-5: Tally Maximum Dose Rates (mrem/hr), Vent Case

	NCT						**HAC**	
	Package Surface		**Vehicle Surface**		**2 meter**		**1 meter**	
Reference Location	*Result*	*Error*	*Result*	*Error*	*Result*	*Error*	*Result*	*Error*
Side	23.9	0.1%	3.5	1.4%	0.3	0.4%	1.4	0.1%
Top	15.3	2.9%	15.3	2.9%	-	-	5.2	2.8%
Bottom	0.2	1.7%	0.2	1.7%	-	-	0.1	2.6%

6.2 Summary Table of Maximum Radiation Levels

The summary of the maximum dose rates are shown in Table 6-6 and Table 6-7 for NCT and HAC, respectively.

Table 6-6: Summary of Maximum NCT Total Dose Rates (Exclusive Use)

Normal Conditions of Transport	**Package Surface (mrem/hr)**			**Vehicle Surface (mrem/hr)**		
Radiation	*Top*	*Side*	*Bottom*	*Top*	*Side*	*Bottom*
Gamma	12.9	0.1	0.3	12.9	1.3	0.3
Neutron	2.5	29.6	4.0	2.5	2.2	4.0
Total	15.3	29.7	4.4	15.3	3.5	4.4
10 CFR 71.47 (b) Limit	200	200	200	200	200	200

Normal Conditions of Transport	**2 Meters from Vehicle Surface (mrem/hr)**			**Occupied Location (mrem/hr)**
Radiation	*Top*	*Side*	*Bottom*	*25 ft from cask center*
Gamma	-	2.85E-02	-	8.69E-05
Neutron	-	0.3	-	4.94E-02
Total	-	0.3	-	4.95E-02
10 CFR 71.47 (b) Limit	10	10	10	2

Table 6-7: Summary of Maximum HAC Total Dose Rates (Exclusive Use)

Hypothetical Accident Conditions	**1 Meter from Package Surface (mrem/hr)**		
Radiation	*Top*	*Side*	*Bottom*
Gamma	4.2	2.80E-03	0.2
Neutron	1.0	1.6	1.6
Total	5.2	1.6	1.8
10 CFR 71.51 (a)(2) Limit	1000	1000	1000

Note: The total dose rates listed in Table 6-6 and Table 6-7 are the sum of the unrounded gamma and neutron dose rates.

6.3 Fissile Mass Assessment

The fissile mass assessment performed in Section 4.2.3 demonstrates that the spent fuel payload is exempt from criticality analysis per 10 CFR 71.

7.0 COMPUTER SOFTWARE USAGE

Computer Name:	EGONSIOROWSKI1
Hardware Profile of Computer:	Intel® Xeon® CPU E5-1650 @ 3.50 GHz, 16.0 GB RAM
Operating System:	64-bit Windows 7 Enterprise, Service Pack 1

7.1 In-Use Testing

7.1.1 SCALE 6.2.1

Input files *1cc_PuBe.inp* and *1Ci_Cs137.inp* are taken from the SCALE 6.2.1 software dedication report [10] for in-use testing. Both files are run on 2/27/2018. The resulting output files are identical to those in [10] except for run-unique parameters (such as date and time of run), indicating that SCALE 6.2.1 performs as expected and is acceptable for use.

7.1.2 MCNP6.1

Input files *buildup_fe_5_mfp.i* and *buildup_pb_1_mfp.i* are taken from the MCNP6.1 software dedication report [11] for in-use testing. Both files are run on 2/27/2018. The resulting output files are identical to those in [11] except for run-unique parameters (such as date and time of run), indicating that MCNP6.1 performs as expected and is acceptable for use.

7.2 File Listing

```
    Directory: Runs\MCNP\In-Use Testing

Mode                LastWriteTime     Length Name
-a---         9/21/2017   2:20 PM       2974 buildup_fe_5_mfp.i
-a---         2/27/2018   2:07 PM      26440 buildup_fe_5_mfp.o
-a---         9/21/2017   2:20 PM       2706 buildup_pb_1_mfp.i
-a---         2/27/2018   2:08 PM      23829 buildup_pb_1_mfp.o

    Directory: Runs\MCNP\Shielding\Bottom

Mode                LastWriteTime     Length Name
-a---         2/27/2018   4:01 PM      32531 BRR_rodlet_n_bot.i
-a---         2/27/2018   8:04 PM       2574 BRR_rodlet_n_bot.m
-a---         2/27/2018   8:04 PM      97797 BRR_rodlet_n_bot.mt
-a---         2/27/2018   8:04 PM     209083 BRR_rodlet_n_bot.o
-a---         2/27/2018   4:01 PM      34282 BRR_rodlet_pg_bot.i
-a---          3/1/2018   1:31 PM       2366 BRR_rodlet_pg_bot.m
-a---          3/1/2018   1:31 PM     113507 BRR_rodlet_pg_bot.mt
-a---          3/1/2018   1:31 PM     200727 BRR_rodlet_pg_bot.o
-a---         2/27/2018   4:01 PM      33453 BRR_rodlet_sg_bot.i
-a---         2/28/2018   5:09 PM       2366 BRR_rodlet_sg_bot.m
-a---         2/28/2018   5:09 PM     113507 BRR_rodlet_sg_bot.mt
-a---         2/28/2018   5:09 PM     292167 BRR_rodlet_sg_bot.o

    Directory: Runs\MCNP\Shielding\Drain

Mode                LastWriteTime     Length Name
-a---         2/27/2018   4:01 PM      32530 BRR_rodlet_n_drain.i
-a---         2/28/2018  12:04 AM       2574 BRR_rodlet_n_drain.m
-a---         2/28/2018  12:04 AM      97797 BRR_rodlet_n_drain.mt
-a---         2/28/2018  12:04 AM     205701 BRR_rodlet_n_drain.o
-a---         2/27/2018   4:01 PM      34281 BRR_rodlet_pg_drain.i
-a---          3/1/2018   5:32 PM       3094 BRR_rodlet_pg_drain.m
-a---          3/1/2018   5:32 PM     113507 BRR_rodlet_pg_drain.mt
-a---          3/1/2018   5:32 PM     199847 BRR_rodlet_pg_drain.o
-a---         2/27/2018   4:01 PM      33452 BRR_rodlet_sg_drain.i
-a---         2/28/2018   9:10 PM       2366 BRR_rodlet_sg_drain.m
-a---         2/28/2018   9:10 PM     113507 BRR_rodlet_sg_drain.mt
-a---         2/28/2018   9:10 PM     292036 BRR_rodlet_sg_drain.o

    Directory: Runs\MCNP\Shielding\Middle

Mode                LastWriteTime     Length Name
-a---         2/27/2018   4:01 PM      32531 BRR_rodlet_n_mid.i
-a---         2/28/2018   4:05 AM       2574 BRR_rodlet_n_mid.m
-a---         2/28/2018   4:05 AM      97797 BRR_rodlet_n_mid.mt
-a---         2/28/2018   4:05 AM     201922 BRR_rodlet_n_mid.o
-a---         2/27/2018   4:01 PM      34282 BRR_rodlet_pg_mid.i
-a---          3/1/2018   9:35 PM       3302 BRR_rodlet_pg_mid.m
-a---          3/1/2018   9:35 PM     113507 BRR_rodlet_pg_mid.mt
-a---          3/1/2018   9:35 PM     200327 BRR_rodlet_pg_mid.o
-a---         2/27/2018   4:01 PM      33453 BRR_rodlet_sg_mid.i
-a---          3/1/2018   1:10 AM       3198 BRR_rodlet_sg_mid.m
```

```
-a---          3/1/2018   1:10 AM     113507 BRR_rodlet_sg_mid.mt
-a---          3/1/2018   1:10 AM     292857 BRR_rodlet_sg_mid.o

    Directory: Runs\MCNP\Shielding\Top

Mode                LastWriteTime     Length Name
-a---         2/27/2018   4:01 PM      32533 BRR_rodlet_n_top.i
-a---         2/28/2018   8:05 AM       2470 BRR_rodlet_n_top.m
-a---         2/28/2018   8:05 AM      97797 BRR_rodlet_n_top.mt
-a---         2/28/2018   8:05 AM     205512 BRR_rodlet_n_top.o
-a---         2/27/2018   4:01 PM      34284 BRR_rodlet_pg_top.i
-a---          3/2/2018   2:03 AM       2990 BRR_rodlet_pg_top.m
-a---          3/2/2018   2:03 AM     113507 BRR_rodlet_pg_top.mt
-a---          3/2/2018   2:03 AM     199705 BRR_rodlet_pg_top.o
-a---         2/27/2018   4:01 PM      33455 BRR_rodlet_sg_top.i
-a---          3/1/2018   5:11 AM       2366 BRR_rodlet_sg_top.m
-a---          3/1/2018   5:11 AM     113507 BRR_rodlet_sg_top.mt
-a---          3/1/2018   5:11 AM     296816 BRR_rodlet_sg_top.o

    Directory: Runs\MCNP\Shielding\Vent

Mode                LastWriteTime     Length Name
-a---         2/27/2018   4:01 PM      32530 BRR_rodlet_n_vent.i
-a---         2/28/2018  12:05 PM       2470 BRR_rodlet_n_vent.m
-a---         2/28/2018  12:05 PM      97797 BRR_rodlet_n_vent.mt
-a---         2/28/2018  12:05 PM     205559 BRR_rodlet_n_vent.o
-a---         2/27/2018   4:01 PM      34281 BRR_rodlet_pg_vent.i
-a---          3/2/2018   7:49 AM       2886 BRR_rodlet_pg_vent.m
-a---          3/2/2018   7:49 AM     113507 BRR_rodlet_pg_vent.mt
-a---          3/2/2018   7:49 AM     198860 BRR_rodlet_pg_vent.o
-a---         2/27/2018   4:01 PM      33452 BRR_rodlet_sg_vent.i
-a---          3/1/2018   9:11 AM       2366 BRR_rodlet_sg_vent.m
-a---          3/1/2018   9:11 AM     113507 BRR_rodlet_sg_vent.mt
-a---          3/1/2018   9:11 AM     292214 BRR_rodlet_sg_vent.o

    Directory: Runs\SCALE\In-Use Testing

Mode                LastWriteTime     Length Name
-a---        11/16/2016   3:30 PM        621 1cc_PuBe.inp
-a---         2/27/2018   2:11 PM      35481 1cc_PuBe.out
-a---        11/16/2016  11:43 AM        556 1Ci_Cs137.inp
-a---         2/27/2018   2:11 PM      22783 1Ci_Cs137.out

    Directory: Runs\SCALE\Source Term

Mode                LastWriteTime     Length Name
-a---          2/8/2018   2:04 PM     189448 605_Decay.f71
-a---          2/8/2018   1:10 PM       6341 605_Decay.inp
-a---          2/8/2018   2:04 PM      52068 605_Decay.out
-a---          2/8/2018   2:04 PM     189448 616_Decay.f71
-a---          2/8/2018   1:43 PM       3453 616_Decay.inp
-a---          2/8/2018   2:04 PM      44950 616_Decay.out
-a---          2/8/2018   2:04 PM     189448 649_650_Decay.f71
-a---          2/8/2018   1:22 PM       5124 649_650_Decay.inp
-a---          2/8/2018   2:04 PM      53142 649_650_Decay.out
```

```
-a---        2/27/2018  12:46 PM      1927 Combined_Shipment.inp
-a---        2/27/2018  12:46 PM    223216 Combined_Shipment.out

    Directory: Spreadsheets

Mode                LastWriteTime     Length Name
-a---         3/6/2018   4:16 PM     38844 Compiled Shielding Results.xlsx
-a---        2/12/2018  10:24 AM     33183 Formatted Isotopes Table.xlsx
-a---         2/6/2018  10:55 AM     14746 General Tables.xlsx
-a---       12/22/2017   9:11 AM     11507 Materials.xlsx
-a---        2/27/2018   1:17 PM     16475 Source Term.xlsx

    Directory: Spreadsheets\Shielding Results

Mode                LastWriteTime     Length Name
-a---         3/5/2018   8:04 AM    493520 Bottom Shielding Results.xlsx
-a---         3/5/2018   8:07 AM    493094 Drain Shielding Results.xlsx
-a---         3/5/2018   8:12 AM    490954 Middle Shielding Results.xlsx
-a---         3/5/2018   8:17 AM    493439 Top Shielding Results.xlsx
-a---         3/5/2018   8:30 AM    491218 Vent Shielding Results.xlsx
```

8.0 REFERENCES

1. INL/EXT-17-44054, *Sample Selection Report for the Irradiation and Post Irradiation Examination of Ultra High Burnup Fuel*, Project Number 32792, Revision 1, January 2018
2. AREVA Federal Services SAR, *BEA Research Reactor Package Safety Analysis Report*, Revision 10, May 2016
3. Title 10, "Energy", Code of Federal Regulations, Part 71, *Packaging and Transportation of Radioactive Material*
4. NUREG-1609, *Standard Review Plan for Transportation Packages for Radioactive Material,* March 1999
5. Regulatory Guide 7.9, *Standard Format and Content of Part 71 Applications for Approval of Packages for Radioactive Material,* Revision 2, March 2005
6. ORNL/TM-2005/39, *SCALE Code System*, Oak Ridge National Laboratory, Version 6.2.1, August 2016, RSICC Package ID C00834MNYCP02
7. ORNL/TM-2005/39, Version 6, Volume III, Section M8, *Standard Composition Library*, Oak Ridge National Laboratory, January 2009
8. PNNL-15870, *Compendium of Material Composition Data for Radiation Transport Modeling*, Pacific Northwest National Laboratory, Revision 1, March 2011
9. LA-CP-13-00634, *MCNP6^{TM} User's Manual,* Los Alamos National Laboratory, Version 1.0, May 2013, RSICC Package ID C810MNYCP00
10. AREVA Federal Services Calculation, CALC-3018409, *Software Dedication Report for SCALE 6.2.1,* Revision 0
11. AREVA Federal Services Calculation, CALC-3012588, *Software Dedication Report for MCNP v6.1.00*, Revision 0
12. *NIST/SEMATECH e-Handbook of Statistical Methods*, http://www.itl.nist.gov/div898/handbook/mpc/section5/mpc55.htm, January 17, 2018.
13. Knight, Collin J., "Re: Draft Rod Fragments Container", Message to Phil Noss, February 2018, E-mail (See Section 8.1 for email content)
14. DOE-HDBK-1019/2-93, *DOE Fundamentals Handbook: Nuclear Physics and Reactor Theory*, U.S. Department of Energy, Volume 2, January 1993
15. Knight, Collin J., "LWR Fuel Shipping Details", Message to Phil Noss, March 2018, E-mail (see Section 8.2 for email content)

8.1 E-mail Reference 1

From: Knight, Collin J
Sent: Monday, February 26, 2018 3:42 PM
To: NOSS Philip (ORN-RE)
Cc: SMITH Richard (ORN-RE); Case, Susan M; Daniel M Wachs; Nicholas Meacham
Subject: Re: Draft Rod Fragments Container

Phil,

Just wanted to touch base with you. I apologize for the slow response in getting you the information you have requested. I have had a difficult time in getting information from ORNL and INL has had some folks out as well. I haven't forgot that I owe you some information.

With regards to the small "buffer" or excess material, if we were to receive some additional fuel, it is expected that it would be in the form of 9 inches of fuel segment 650 and 20 inches of fuel segment 616. I hope this helps. If this gives us problems, please let me know.

I still hope to get back to you this week with feedback on the container. In general, I haven't heard anyone say anything significant about the container design. I think there was some concern that the bolt which will be used to hook and remove the spacer underneath the container might gouge the basket. That might be something worth a slight modification.

Please let me know if you have any concerns or issues.

Thank you.

Collin

8.2 E-mail Reference 2

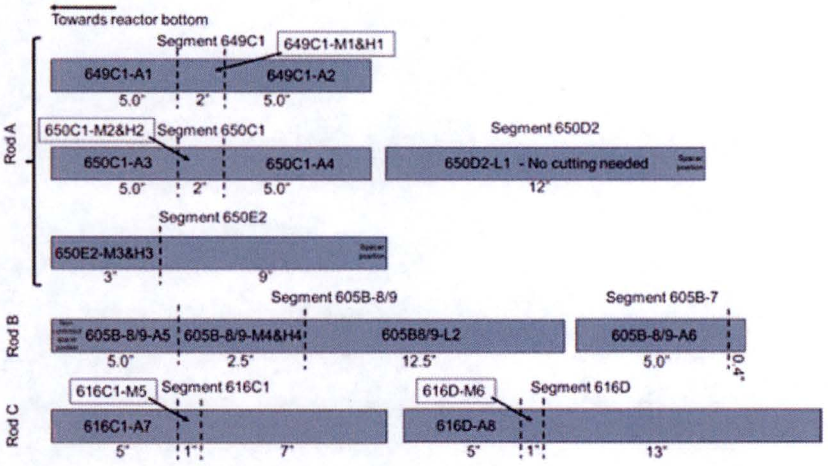
From: Knight, Collin J
Sent: Wednesday, March 07, 2018 10:27 AM
To: NOSS Philip (ORN-RE)
Cc: SMITH Richard (ORN-RE); Daniel M Wachs; David A Sell; Nicholas Meacham
Subject: LWR Fuel Shipping Details

Phil,

For clarification, shown in the table below are the 14 segments that are planned to be shipped from ORNL to HFEF. For the "buffer", we would like to add 3 segments. These segments are found in the cutting diagram below. They include the 9" cut shown for Rod A segment 650E2-M3&H3, the 7" cut shown for Rod C segment 616C1-A7, and the 13" cut shown for Rod C segment 616D-A8. These would be open ended like the smaller segments shown in the table. I included the total shipment isotopics, including the 3 additional segments, in the attached spreadsheet.

Table 8. Transportation plan with segment lengths to be shipped to INL from ORNL.

Segment Specimen ID	Containing Samples	Original Segment ID	Specimen Length (in.)	Fueled Length (in.)	Avg. Burnup MWd/kgU	Discharge Year	Comment
649C1-A1	ATR-1	649C1	6.8	5.0	82	2004	Endcapped
649C1-A2	ATR-2	649C1	6.8	5.0	82	2004	Endcapped
649C1-A3	ATR-3	649C1	6.8	5.0	73	2004	Endcapped
649C1-A4	ATR-4	649C1	6.8	5.0	73	2004	Endcapped
605B8/9-A5	ATR-5	605B-8/9	6.8	5.0	69-72	1995	Endcapped
605B8/9-A6	ATR-6	605B-8/9	6.8	5.0	69-72	1995	Endcapped
616C1-A7	ATR-7	616C1	6.8	5.0	51	1997	Endcapped
616D-A8	ATR-8	616D	6.8	5.0	51	1997	Endcapped
649C1-M1&H1	Met-1 & Heating-1	649C1	2.0	2.0	82	2004	Open-ended
650C1-M2&H2	Met-2 & Heating-2	650C1	2.0	2.0	73	2004	Open-ended
650E2-M3&H3	Met-3 & Heating-3	605E2	3.0	3.0	73	2004	Open-ended
6058/9-M4&H4	Met-4 & Heating-4	605B-8/9	2.5	2.5	69-72	1995	Open-ended
616C1-M5	Met-5	616C1	1.0	1.0	51	1997	Open-ended
616D-M6	Met-6	616D	1.0	1.0	51	1997	Open-ended



We met with the HFEF hot cell folks today and got feedback from them on the shipping container. When would you be available to discuss the results of our meeting?

Please advise.
Collin

APPENDIX A: INPUT DATA

A.1 Sample SCALE Input File (Combined_Shipment.inp)

```
=origen
bounds{
    gamma = 'v7.1-28n19g' % 19 Gamma Groups
    neutron = 'v7.1-28n19g' % 28 Neutron Groups
}

solver{
    type = cram
    opt{
        substeps = 4
    }
}

case(mat_605){
    lib{file="end7dec"}
    mat{
        load{file="C:\SCALE-6.2.1\SCALE_Run_Folder\BRR_Letter\605_Decay.f71" pos=7}
    }
    time{
        units = seconds
        t=0.1
    }
    print{
        rel_cutoff = no
        cutoffs[curies = 1e-15]
        nuc{
            units=[grams curies]
        }
    }
}

case(mat_616){
    lib{file="end7dec"}
    mat{
        load{file="C:\SCALE-6.2.1\SCALE_Run_Folder\BRR_Letter\616_Decay.f71" pos=7}
    }
    time{
        units = seconds
        t=0.1
    }
    print{
        rel_cutoff = no
        cutoffs[curies = 1e-15]
        nuc{
            units=[grams curies]
        }
    }
}

case(mat_649_650){
    lib{file="end7dec"}
    mat{
        load{file="C:\SCALE-6.2.1\SCALE_Run_Folder\BRR_Letter\649_650_Decay.f71" pos=7}
    }
    time{
        units = seconds
        t=0.1
    }
    print{
        rel_cutoff = no
        cutoffs[curies = 1e-15]
        nuc{
            units=[grams curies]
        }
    }
```

```
}

case{
    lib{file="end7dec"}
    time{
        units = seconds
        t=0.1
    }
    print{
        rel_cutoff = no
        gamma{
            spectra = yes
            summary = yes
        }
        nuc{
            units = [curies watts grams]
            total = yes
        }
        neutron{
            spectra = yes
            summary = yes
            detailed = yes
        }
    }
    gamma{
        conserve_line_energy = no
        brem_medium = uo2
    }
    neutron{
        alphan_medium = uo2
    }
    save{file="Combined_Shipment.f71"}
    mat{
        blend[mat_605 = 1
              mat_616 = 2.67
              mat_649_650 = 1.33]
    }
}
end
```

A.2 Sample MCNP Input File (BRR_rodlet_pg_bot.i)

```
BRR Rodlets Shielding
c *** Cell Cards ***
c
c ===== Air Gaps and Thermal Shield
1   1  -0.0012    101 -102   19 -20           imp:p=1 fill=22  $ radial gap (Pb shrinkage 1/16")
2   1  -0.0012    133 -132    3 -301          imp:p=1 fill=22  $ top axial gap (Pb shrinkage 1/4")
3   1  -0.0012    201 -200   24 -25           imp:p=1 fill=22  $ air gap thermal shield
4   4  -7.94      201 -200   25 -26           imp:p=1 fill=21  $ SS shell over thermal gap
5   1  -0.0012    309 -100 -306               imp:p=1 fill=32  $ vertical drain hole 95
6   1  -0.0012   -307 308 -24 (-309:306)      imp:p=1 fill=32  $ horizontal drain hole 96
7   1  -0.0012   -135 137   37  -36           imp:p=1 fill=14  $ radial gap at lid
8   1  -0.0012    157 -150 (44 303) (-1:-302) imp:p=1 fill=14  $ Air below shield plug
9   1  -0.0012   (150 -141 40 -41):
                 (141 -137 -41)               imp:p=1 fill=14  $ Air above shield plug
10  1  -0.0012    157 -141 -161               imp:p=1 fill=13  $ Shield plug drain
c
c ===== Rebuilt cells
11  8  -11.35    (1555 -1431 161 -45):
                 (160 -140 46 -43 161)        imp:p=1 fill=10  $ Shield plug lead
12  4  -7.94    ((157 -150 (-44:-303) 161) (-1555:45)):
                 (150 -160 45 -40):
                 (160 -141 43 -40):
                 (140 -141 -43 161)           imp:p=1 fill=11  $ Shield plug steel
13  4  -7.94      1431 -140 -46               imp:p=1 fill=11  $ Shield plug steel insert
14  4  -7.94     (157 -132 (1 302) -3):
                 (132 -150 302 -24)           imp:p=1 fill=12  $ Lower top steel
15  4  -7.94     (150 -135 41 -24)
                (-138:-35) (-37:36:-137)      imp:p=1 fill=12  $ Corner top steel
16  4  -7.94      137 -135 -41                imp:p=1 fill=11  $ Upper top steel
17  8  -11.35   ((103 -300) (-133 -301) 3 -19):
                 (101 -102 3 -19)             imp:p=1 fill=20  $ Side wall lead
18  4  -7.94      100 -157 1 -3               imp:p=1 fill=21  $ Inner side wall steel
19  4  -7.94      103 -132 3 -20
                ((300 -101):(301 102))        imp:p=1 fill=21  $ Side wall steel wedges
20  4  -7.94      103 -132 20 -24             imp:p=1 fill=21  $ Outer side wall steel
21  8  -11.35     125 -106 -33 (-27:-114)     imp:p=1 fill=30  $ Bottom lead
22  4  -7.94      114 -100 -24 (27:106) (-103:-3)
                (-309:100:306) (-308:24:307)  imp:p=1 fill=31  $ Upper bottom steel
23  4  -7.94      127 -114 -24
                 (126:-35) (-125:33)          imp:p=1 fill=31  $ Lower bottom steel
c
24  0            -1 100 -157
               fill=1 (19.82 0 -0.1426)           imp:p=1          $ insert basket
25  0          ((351.1:351.2:350.1:350.2:50) -999):
                 (201 -200 26 -50)            imp:p=1          $ Outer air
26  0             999                         imp:p=0
27  0            (24:135:(138 35))
                 (200 350.3 -50):-350          imp:p=1          $ Uppper impact limiter
28  0            (24:-127:(-126 35))
                 (351.3 -201 -50):-351         imp:p=1          $ Lower impact limiter
c
c ===== Universe 1: Source Sphere
100 0             -400                     imp:p=1 u=1
101 1 -0.0012      400                     imp:p=1 u=1
c ===== Universe 10: Top Lead Splitting Layers
1003 8 -11.35    -1003                     imp:p=2.42E+01 u=10
1004 8 -11.35    -1004 1003                imp:p=6.74E+01 u=10
1005 8 -11.35    -1005 1004                imp:p=1.34E+02 u=10
1006 8 -11.35    -1006 1005                imp:p=2.54E+02 u=10
1007 8 -11.35    -1007 1006                imp:p=4.74E+02 u=10
1008 8 -11.35    -1008 1007                imp:p=8.72E+02 u=10
1009 8 -11.35    -1009 1008                imp:p=1.58E+03 u=10
1010 8 -11.35    -1010 1009                imp:p=2.87E+03 u=10
1011 8 -11.35    -1011 1010                imp:p=5.10E+03 u=10
1012 8 -11.35    -1012 1011                imp:p=8.88E+03 u=10
1013 8 -11.35    -1013 1012                imp:p=1.54E+04 u=10
1014 8 -11.35    -1014 1013                imp:p=2.58E+04 u=10
```

```
1015 8 -11.35    -1015 1014                 imp:p=4.30E+04 u=10
1016 8 -11.35    -1016 1015                 imp:p=7.32E+04 u=10
1017 8 -11.35    -1017 1016                 imp:p=1.72E+04 u=10
1018 8 -11.35    -1018 1017                 imp:p=4.98E+04 u=10
1019 8 -11.35    -1019 1018                 imp:p=1.02E+05 u=10
1020 8 -11.35    -1020 1019                 imp:p=1.95E+05 u=10
1021 8 -11.35    -1021 1020                 imp:p=3.57E+05 u=10
1022 8 -11.35    -1022 1021                 imp:p=6.04E+05 u=10
1023 8 -11.35    -1023 1022                 imp:p=9.84E+05 u=10
1024 8 -11.35    -1024 1023                 imp:p=1.59E+06 u=10
1025 8 -11.35    -1025 1024                 imp:p=2.43E+06 u=10
1026 8 -11.35          1025                 imp:p=2.99E+06 u=10
c
c ===== Universe 11: Top Steel Splitting Layers
1100 4 -7.94     -1000                      imp:p=8.00E+00 u=11
1101 4 -7.94     -1001 1000                 imp:p=1.04E+01 u=11
1102 4 -7.94     -1002 1001                 imp:p=1.65E+01 u=11
1103 4 -7.94     -1003 1002                 imp:p=2.42E+01 u=11
1104 4 -7.94     -1004 1003                 imp:p=3.24E+01 u=11
1105 4 -7.94     -1005 1004                 imp:p=4.51E+01 u=11
1106 4 -7.94     -1006 1005                 imp:p=6.44E+01 u=11
1107 4 -7.94     -1007 1006                 imp:p=9.44E+01 u=11
1108 4 -7.94     -1008 1007                 imp:p=1.42E+02 u=11
1109 4 -7.94     -1009 1008                 imp:p=2.14E+02 u=11
1110 4 -7.94     -1010 1009                 imp:p=3.27E+02 u=11
1111 4 -7.94     -1011 1010                 imp:p=5.10E+02 u=11
1112 4 -7.94     -1012 1011                 imp:p=8.08E+02 u=11
1113 4 -7.94     -1013 1012                 imp:p=1.18E+03 u=11
1114 4 -7.94     -1014 1013                 imp:p=7.09E+02 u=11
1115 4 -7.94     -1015 1014                 imp:p=7.11E+02 u=11
1116 4 -7.94     -1016 1015                 imp:p=7.56E+02 u=11
1117 4 -7.94     -1017 1016                 imp:p=8.96E+02 u=11
1118 4 -7.94     -1018 1017                 imp:p=1.44E+03 u=11
1119 4 -7.94     -1019 1018                 imp:p=2.18E+03 u=11
1120 4 -7.94     -1020 1019                 imp:p=3.09E+03 u=11
1121 4 -7.94     -1021 1020                 imp:p=4.39E+03 u=11
1122 4 -7.94     -1022 1021                 imp:p=6.21E+03 u=11
1123 4 -7.94     -1023 1022                 imp:p=8.72E+03 u=11
1124 4 -7.94     -1024 1023                 imp:p=1.21E+04 u=11
1125 4 -7.94     -1025 1024                 imp:p=1.70E+04 u=11
1126 4 -7.94     -1026 1025                 imp:p=2.38E+04 u=11
1127 4 -7.94     -1027 1026                 imp:p=3.39E+04 u=11
1128 4 -7.94     -1028 1027                 imp:p=5.14E+04 u=11
1129 4 -7.94     -1029 1028                 imp:p=9.12E+04 u=11
1130 4 -7.94     -1030 1029                 imp:p=1.34E+05 u=11
1131 4 -7.94     -1031 1030                 imp:p=2.04E+05 u=11
1132 4 -7.94     -1032 1031                 imp:p=3.11E+05 u=11
1133 4 -7.94           1032                 imp:p=4.98E+05 u=11
c
c ===== Universe 12: Top Steel Corner Splitting Layers
1200 4 -7.94     -1050                      imp:p=8.00E+00 u=12
1201 4 -7.94     -1051 1050                 imp:p=1.04E+01 u=12
1202 4 -7.94     -1052 1051                 imp:p=1.65E+01 u=12
1203 4 -7.94     -1053 1052                 imp:p=2.42E+01 u=12
1204 4 -7.94     -1054 1053                 imp:p=3.24E+01 u=12
1205 4 -7.94     -1055 1054                 imp:p=4.51E+01 u=12
1206 4 -7.94     -1056 1055                 imp:p=6.44E+01 u=12
1207 4 -7.94     -1057 1056                 imp:p=9.44E+01 u=12
1208 4 -7.94     -1058 1057                 imp:p=1.42E+02 u=12
1209 4 -7.94     -1059 1058                 imp:p=2.14E+02 u=12
1210 4 -7.94     -1060 1059                 imp:p=3.27E+02 u=12
1211 4 -7.94     -1061 1060                 imp:p=5.10E+02 u=12
1212 4 -7.94     -1062 1061                 imp:p=8.08E+02 u=12
1213 4 -7.94     -1063 1062                 imp:p=1.18E+03 u=12
1214 4 -7.94     -1064 1063                 imp:p=7.09E+02 u=12
1215 4 -7.94     -1065 1064                 imp:p=7.11E+02 u=12
1216 4 -7.94     -1066 1065                 imp:p=7.56E+02 u=12
1217 4 -7.94     -1067 1066                 imp:p=8.96E+02 u=12
1218 4 -7.94     -1068 1067                 imp:p=1.44E+03 u=12
```

```
1219 4 -7.94    -1069 1068                imp:p=2.18E+03 u=12
1220 4 -7.94    -1070 1069                imp:p=3.09E+03 u=12
1221 4 -7.94    -1071 1070                imp:p=4.39E+03 u=12
1222 4 -7.94    -1072 1071                imp:p=6.21E+03 u=12
1223 4 -7.94    -1073 1072                imp:p=8.72E+03 u=12
1224 4 -7.94    -1074 1073                imp:p=1.21E+04 u=12
1225 4 -7.94    -1075 1074                imp:p=1.70E+04 u=12
1226 4 -7.94    -1076 1075                imp:p=2.38E+04 u=12
1227 4 -7.94    -1077 1076                imp:p=3.39E+04 u=12
1228 4 -7.94    -1078 1077                imp:p=5.14E+04 u=12
1229 4 -7.94    -1079 1078                imp:p=7.79E+04 u=12
1230 4 -7.94    -1080 1079                imp:p=1.15E+05 u=12
1231 4 -7.94    -1081 1080                imp:p=1.70E+05 u=12
1232 4 -7.94    -1082 1081                imp:p=2.41E+05 u=12
1233 4 -7.94    -1083 1082                imp:p=3.57E+05 u=12
1234 4 -7.94    -1084 1083                imp:p=5.26E+05 u=12
1235 4 -7.94    -1085 1084                imp:p=8.40E+05 u=12
1236 4 -7.94    -1086 1085                imp:p=1.50E+06 u=12
1237 4 -7.94    -1087 1086                imp:p=1.50E+06 u=12
1238 4 -7.94          1087                imp:p=1.50E+06 u=12
c
c ===== Universe 13: Central Drain Air Splitting Layers
1300 1 -0.0012  -1000                     imp:p=8.00E+00 u=13
1301 1 -0.0012  -1001 1000                imp:p=1.04E+01 u=13
1302 1 -0.0012  -1002 1001                imp:p=1.65E+01 u=13
1303 1 -0.0012  -1003 1002                imp:p=2.42E+01 u=13
1304 1 -0.0012  -1004 1003                imp:p=6.74E+01 u=13
1305 1 -0.0012  -1005 1004                imp:p=1.34E+02 u=13
1306 1 -0.0012  -1006 1005                imp:p=2.54E+02 u=13
1307 1 -0.0012  -1007 1006                imp:p=4.74E+02 u=13
1308 1 -0.0012  -1008 1007                imp:p=8.72E+02 u=13
1309 1 -0.0012  -1009 1008                imp:p=1.58E+03 u=13
1310 1 -0.0012  -1010 1009                imp:p=2.87E+03 u=13
1311 1 -0.0012  -1011 1010                imp:p=5.10E+03 u=13
1312 1 -0.0012  -1012 1011                imp:p=8.88E+03 u=13
1313 1 -0.0012  -1013 1012                imp:p=1.54E+04 u=13
1314 1 -0.0012  -1014 1013                imp:p=2.58E+04 u=13
1315 1 -0.0012  -1015 1014                imp:p=4.30E+04 u=13
1316 1 -0.0012  -1016 1015                imp:p=7.32E+04 u=13
1317 1 -0.0012  -1017 1016                imp:p=1.72E+04 u=13
1318 1 -0.0012  -1018 1017                imp:p=4.98E+04 u=13
1319 1 -0.0012  -1019 1018                imp:p=1.02E+05 u=13
1320 1 -0.0012  -1020 1019                imp:p=1.95E+05 u=13
1321 1 -0.0012  -1021 1020                imp:p=3.57E+05 u=13
1322 1 -0.0012  -1022 1021                imp:p=6.04E+05 u=13
1323 1 -0.0012  -1023 1022                imp:p=9.84E+05 u=13
1324 1 -0.0012  -1024 1023                imp:p=1.59E+06 u=13
1325 1 -0.0012  -1025 1024                imp:p=2.43E+06 u=13
1326 1 -0.0012  -1026 1025                imp:p=2.99E+06 u=13
1327 1 -0.0012  -1027 1026                imp:p=3.39E+04 u=13
1328 1 -0.0012        1027                imp:p=5.14E+04 u=13
c
c ===== Universe 14: Shield Plug Side Air Splitting Layers
1400 1 -0.0012  -1000                     imp:p=8.00E+00 u=14
1401 1 -0.0012  -1001 1000                imp:p=1.04E+01 u=14
1402 1 -0.0012  -1002 1001                imp:p=1.65E+01 u=14
1403 1 -0.0012  -1003 1002                imp:p=2.42E+01 u=14
1404 1 -0.0012  -1004 1003                imp:p=3.24E+01 u=14
1405 1 -0.0012  -1005 1004                imp:p=4.51E+01 u=14
1406 1 -0.0012  -1006 1005                imp:p=6.44E+01 u=14
1407 1 -0.0012  -1007 1006                imp:p=9.44E+01 u=14
1408 1 -0.0012  -1008 1007                imp:p=1.42E+02 u=14
1409 1 -0.0012  -1009 1008                imp:p=2.14E+02 u=14
1410 1 -0.0012  -1010 1009                imp:p=3.27E+02 u=14
1411 1 -0.0012  -1011 1010                imp:p=5.10E+02 u=14
1412 1 -0.0012  -1012 1011                imp:p=8.08E+02 u=14
1413 1 -0.0012  -1013 1012                imp:p=1.18E+03 u=14
1414 1 -0.0012  -1014 1013                imp:p=7.09E+02 u=14
1415 1 -0.0012  -1015 1014                imp:p=7.11E+02 u=14
```

```
1416 1 -0.0012    -1016 1015                 imp:p=7.56E+02 u=14
1417 1 -0.0012    -1017 1016                 imp:p=8.96E+02 u=14
1418 1 -0.0012    -1018 1017                 imp:p=1.44E+03 u=14
1419 1 -0.0012    -1019 1018                 imp:p=2.18E+03 u=14
1420 1 -0.0012    -1020 1019                 imp:p=3.09E+03 u=14
1421 1 -0.0012    -1021 1020                 imp:p=4.39E+03 u=14
1422 1 -0.0012    -1022 1021                 imp:p=6.21E+03 u=14
1423 1 -0.0012    -1023 1022                 imp:p=8.72E+03 u=14
1424 1 -0.0012    -1024 1023                 imp:p=1.21E+04 u=14
1425 1 -0.0012    -1025 1024                 imp:p=1.70E+04 u=14
1426 1 -0.0012    -1026 1025                 imp:p=2.38E+04 u=14
1427 1 -0.0012    -1027 1026                 imp:p=3.39E+04 u=14
1428 1 -0.0012    -1028 1027                 imp:p=5.14E+04 u=14
1429 1 -0.0012    -1029 1028                 imp:p=2.41E+05 u=14
1430 1 -0.0012    -1030 1029                 imp:p=3.57E+05 u=14
1431 1 -0.0012    -1031 1030                 imp:p=5.26E+05 u=14
1432 1 -0.0012    -1032 1031                 imp:p=8.40E+05 u=14
1433 1 -0.0012          1032                 imp:p=1.50E+06 u=14
c
c ===== Universe 20: Side Lead Splitting Layers
2002 8 -11.35     -2002 2001                 imp:p=2.75E+00 u=20
2003 8 -11.35     -2003 2002                 imp:p=3.70E+00 u=20
2004 8 -11.35     -2004 2003                 imp:p=8.60E+00 u=20
2005 8 -11.35     -2005 2004                 imp:p=1.73E+01 u=20
2006 8 -11.35     -2006 2005                 imp:p=3.38E+01 u=20
2007 8 -11.35     -2007 2006                 imp:p=6.55E+01 u=20
2008 8 -11.35     -2008 2007                 imp:p=1.27E+02 u=20
2009 8 -11.35     -2009 2008                 imp:p=2.42E+02 u=20
2010 8 -11.35     -2010 2009                 imp:p=4.65E+02 u=20
2011 8 -11.35     -2011 2010                 imp:p=8.83E+02 u=20
2012 8 -11.35     -2012 2011                 imp:p=1.68E+03 u=20
2013 8 -11.35     -2013 2012                 imp:p=3.20E+03 u=20
2014 8 -11.35     -2014 2013                 imp:p=6.05E+03 u=20
2015 8 -11.35     -2015 2014                 imp:p=1.15E+04 u=20
2016 8 -11.35     -2016 2015                 imp:p=2.15E+04 u=20
2017 8 -11.35     -2017 2016                 imp:p=4.03E+04 u=20
2018 8 -11.35     -2018 2017                 imp:p=7.78E+04 u=20
2019 8 -11.35     -2019 2018                 imp:p=1.47E+05 u=20
2020 8 -11.35     -2020 2019                 imp:p=2.75E+05 u=20
2021 8 -11.35     -2021 2020                 imp:p=5.15E+05 u=20
2022 8 -11.35     -2022 2021                 imp:p=9.78E+05 u=20
2023 8 -11.35     -2023 2022                 imp:p=1.84E+06 u=20
c
c ===== Universe 21: Side Steel Splitting Layers
2100 4 -7.94      -2000                      imp:p=1.00E+00 u=21
2101 4 -7.94      -2001 2000                 imp:p=1.34E+00 u=21
2102 4 -7.94      -2002 2001                 imp:p=2.01E+00 u=21
2111 4 -7.94      -2011 2010                 imp:p=8.83E+02 u=21
2112 4 -7.94      -2012 2011                 imp:p=1.36E+03 u=21
2113 4 -7.94      -2013 2012                 imp:p=2.14E+03 u=21
2114 4 -7.94      -2014 2013                 imp:p=1.70E+03 u=21
2115 4 -7.94      -2015 2014                 imp:p=3.20E+03 u=21
2116 4 -7.94      -2016 2015                 imp:p=5.80E+03 u=21
2117 4 -7.94      -2017 2016                 imp:p=1.10E+04 u=21
2118 4 -7.94      -2018 2017                 imp:p=2.01E+04 u=21
2119 4 -7.94      -2019 2018                 imp:p=3.65E+04 u=21
2120 4 -7.94      -2020 2019                 imp:p=6.50E+04 u=21
2121 4 -7.94      -2021 2020                 imp:p=1.18E+05 u=21
2122 4 -7.94      -2022 2021                 imp:p=2.14E+05 u=21
2123 4 -7.94      -2023 2022                 imp:p=1.84E+06 u=21
2124 4 -7.94      -2024 2023                 imp:p=2.18E+06 u=21
2125 4 -7.94      -2025 2024                 imp:p=2.80E+06 u=21
2126 4 -7.94      -2026 2025                 imp:p=3.78E+06 u=21
2127 4 -7.94      -2027 2026                 imp:p=5.45E+06 u=21
2128 4 -7.94            2027                 imp:p=7.93E+06 u=21
c
c ===== Universe 22: Side Air Splitting Layers
2202 1 -0.0012    -2002 2001                 imp:p=2.75E+00 u=22
2203 1 -0.0012    -2003 2002                 imp:p=1.89E+00 u=22
```

```
2204 1 -0.0012   -2004 2003                imp:p=2.28E+00 u=22
2205 1 -0.0012   -2005 2004                imp:p=3.50E+00 u=22
2206 1 -0.0012   -2006 2005                imp:p=4.88E+00 u=22
2207 1 -0.0012   -2007 2006                imp:p=6.40E+00 u=22
2208 1 -0.0012   -2008 2007                imp:p=8.33E+00 u=22
2209 1 -0.0012   -2009 2008                imp:p=1.08E+01 u=22
2210 1 -0.0012   -2010 2009                imp:p=1.23E+01 u=22
2211 1 -0.0012   -2011 2010                imp:p=1.44E+01 u=22
2212 1 -0.0012   -2012 2011                imp:p=2.49E+01 u=22
2213 1 -0.0012   -2013 2012                imp:p=4.13E+01 u=22
2214 1 -0.0012   -2014 2013                imp:p=2.78E+02 u=22
2223 1 -0.0012   -2023 2022                imp:p=1.84E+06 u=22
2228 1 -0.0012         2027                imp:p=7.93E+06 u=22
c
c ===== Universe 30: Bottom Lead Splitting Layers
3003  8 -11.35         3003                imp:p=2.19E+01 u=30
3004  8 -11.35   -3003 3004                imp:p=5.27E+01 u=30
3005  8 -11.35   -3004 3005                imp:p=1.01E+02 u=30
3006  8 -11.35   -3005 3006                imp:p=1.86E+02 u=30
3007  8 -11.35   -3006 3007                imp:p=3.24E+02 u=30
3008  8 -11.35   -3007 3008                imp:p=5.35E+02 u=30
3009  8 -11.35   -3008 3009                imp:p=9.01E+02 u=30
3010  8 -11.35   -3009 3010                imp:p=1.44E+03 u=30
3011  8 -11.35   -3010 3011                imp:p=2.26E+03 u=30
3012  8 -11.35   -3011 3012                imp:p=2.26E+03 u=30
3013  8 -11.35   -3012 3013                imp:p=5.71E+03 u=30
3014  8 -11.35   -3013 3014                imp:p=1.19E+04 u=30
3015  8 -11.35   -3014 3015                imp:p=2.34E+04 u=30
3016  8 -11.35   -3015 3016                imp:p=4.50E+04 u=30
3017  8 -11.35   -3016 3017                imp:p=8.51E+04 u=30
3018  8 -11.35   -3017 3018                imp:p=1.60E+05 u=30
3019  8 -11.35   -3018 3019                imp:p=2.99E+05 u=30
3020  8 -11.35   -3019 3020                imp:p=5.57E+05 u=30
3021  8 -11.35   -3020 3021                imp:p=1.03E+06 u=30
3022  8 -11.35   -3021                     imp:p=1.80E+06 u=30
c
c ===== Universe 31: Bottom Steel Splitting Layers
3100 4 -7.94           3000                imp:p=8        u=31
3101 4 -7.94     -3000 3001                imp:p=1.10E+01 u=31
3102 4 -7.94     -3001 3002                imp:p=1.55E+01 u=31
3103 4 -7.94     -3002 3003                imp:p=2.19E+01 u=31
3104 4 -7.94     -3003 3014      -3050     imp:p=2.19E+01 u=31
3105 4 -7.94     -3003 3014 3050 -3051     imp:p=2.19E+01 u=31
3106 4 -7.94     -3003 3014 3051 -3052     imp:p=2.76E+01 u=31
3107 4 -7.94     -3003 3014 3052 -3053     imp:p=3.80E+01 u=31
3108 4 -7.94     -3003 3014 3053 -3054     imp:p=5.19E+01 u=31
3109 4 -7.94     -3003 3014 3054 -3055     imp:p=7.24E+01 u=31
3110 4 -7.94     -3003 3014 3055 -3056     imp:p=1.02E+02 u=31
3111 4 -7.94     -3003 3014 3056 -3057     imp:p=1.44E+02 u=31
3112 4 -7.94     -3003 3014 3057 -3058     imp:p=2.23E+02 u=31
3113 4 -7.94     -3003 3014 3058 -3059     imp:p=4.18E+02 u=31
3114 4 -7.94     -3003 3014 3059 -3060     imp:p=1.15E+03 u=31
3115 4 -7.94     -3003 3014 3060 -3061     imp:p=5.31E+03 u=31
3116 4 -7.94     -3003 3014 3061 -3062     imp:p=2.48E+04 u=31
3117 4 -7.94     -3003 3014 3062 -3063     imp:p=6.93E+04 u=31
3118 4 -7.94     -3003 3014 3063 -3064     imp:p=1.35E+05 u=31
3119 4 -7.94     -3003 3014 3064 -3065     imp:p=2.18E+05 u=31
3120 4 -7.94     -3003 3014 3065 -3066     imp:p=4.18E+05 u=31
3121 4 -7.94     -3003 3014 3066 -3067     imp:p=4.76E+06 u=31
3122 4 -7.94     -3003 3014 3067 -3068     imp:p=2.38E+07 u=31
3123 4 -7.94     -3003 3014 3068           imp:p=2.86E+07 u=31
3124 4 -7.94     -3014 3015                imp:p=4.18E+05 u=31
3125 4 -7.94     -3015 3016                imp:p=5.39E+05 u=31
3126 4 -7.94     -3016 3017                imp:p=8.37E+05 u=31
3127 4 -7.94     -3017 3018                imp:p=1.48E+06 u=31
3128 4 -7.94     -3018 3019                imp:p=2.88E+06 u=31
3129 4 -7.94     -3019 3020                imp:p=5.35E+06 u=31
3130 4 -7.94     -3020 3021                imp:p=1.19E+07 u=31
3131 4 -7.94     -3021 3022                imp:p=1.19E+07 u=31
```

```
3132 4 -7.94      -3022 3023                imp:p=1.19E+07 u=31
3133 4 -7.94      -3023 3024                imp:p=1.54E+07 u=31
3134 4 -7.94      -3024                     imp:p=2.15E+07 u=31
c
c ===== Universe 32: Bottom Air Splitting Layers
3200 1 -0.0012          3000                imp:p=8        u=32
3201 1 -0.0012    -3000 3001                imp:p=1.10E+01 u=32
3202 1 -0.0012    -3001 3002                imp:p=1.55E+01 u=32
3203 1 -0.0012    -3002 3003                imp:p=2.19E+01 u=32
3204 1 -0.0012    -3003 3014      -3050     imp:p=2.19E+01 u=32
3205 1 -0.0012    -3003 3014 3050 -3051     imp:p=2.19E+01 u=32
3206 1 -0.0012    -3003 3014 3051 -3052     imp:p=2.76E+01 u=32
3207 1 -0.0012    -3003 3014 3052 -3053     imp:p=3.80E+01 u=32
3208 1 -0.0012    -3003 3014 3053 -3054     imp:p=5.19E+01 u=32
3209 1 -0.0012    -3003 3014 3054 -3055     imp:p=7.24E+01 u=32
3210 1 -0.0012    -3003 3014 3055 -3056     imp:p=1.02E+02 u=32
3211 1 -0.0012    -3003 3014 3056 -3057     imp:p=1.44E+02 u=32
3212 1 -0.0012    -3003 3014 3057 -3058     imp:p=2.23E+02 u=32
3213 1 -0.0012    -3003 3014 3058 -3059     imp:p=4.18E+02 u=32
3214 1 -0.0012    -3003 3014 3059 -3060     imp:p=1.15E+03 u=32
3215 1 -0.0012    -3003 3014 3060 -3061     imp:p=5.31E+03 u=32
3216 1 -0.0012    -3003 3014 3061 -3062     imp:p=2.48E+04 u=32
3217 1 -0.0012    -3003 3014 3062 -3063     imp:p=6.93E+04 u=32

c *** Surface Cards ***
c ***** cylindrical cask surfaces
c
1     cz   20.32         $ cask inner surface cavity wall radius
3     cz   22.86         $ outside inner shell radius
19     cz   43.02125     $ outer gamma shield (Pb shrinkage surface - 1/16")
20     cz   43.18        $ cask inner surface outer wall
24     cz   48.26        $ cask outer surface outer wall
25     cz   48.5267      $ air gap ( 0.105 ")
26     cz   48.7934      $ thermal shield outer surface
27     cz   12.3825      $ bottom lead sheet cavity (small)
c
33     cz   30.099       $ bottom lead sheet cavity (large)
35     cz   34.6837      $ bottom and top cask SS outer surface
36     cz   31.115       $ top cask inner cavity for closure lid
37     cz   30.7975      $ closure lid radius
c
40     cz   22.1361      $ shield plug - SS outer radius(upper cylindrical region)
41     cz   22.3901      $ shield plug cavity
43     cz   21.1836      $ shield plug- SS inner radius (upper cylindrical region)
44     cz   20.066       $ shield plug - SS outer radius (lower cylindrical region)
45     cz   18.796       $ shield plug - SS inner radius (lower cylindrical region)
46     cz    3.81        $  SS bar at center of shield plug
c
50     cz   99.06        $ outer radius of impact limiter, 78" OD per 3000219-002
c
c  tally surfaces
c
c 51     cz   800          $ problem  radial delimiter
c
c **** Horizontal  planes
c
100    pz  -0.6426     $  bottom of cask inner cavity
101    pz  4.445       $  horizontal surface for lateral gamma shield
102    pz  139.7       $  horizontal surface at top of  lateral gamma shield +3"
103    pz  -5.08       $  horizontal surface at bottom of lateral gamma shield
c
106    pz  -3.7338     $  bottom cask interface of SS - shrinkage gap
114    pz  -12.7       $  bottom cask - Pb split
125    pz  -23.3426    $  bottom cask - lower Pb surface
126    pz  -14.9352    $  bottom cask - SS outer surface (shoulder)
127    pz  -25.8826    $  bottom cask - SS outer surface
c
132    pz 149.225       $  horizontal surface at top of  lateral Pb shield cavity
133    pz  146.2278     $  top surface of lateral Pb shield after drop (1.12")
```

```
135     pz  170.0276   $  top surface of closure lid
137     pz  164.9476   $  seating surface for top lid
138     pz  159.0802
c
140     pz  163.3728   $  shield plug Pb top surface
141     pz  164.6428   $  shield plug top surface
1431    pz  160.6296   $  surface for SS rod (surface 141- 1.5")
150     pz  151.7396   $  shield plug Pb split surface - modified
1555     pz  139.0396  $  bottom plug steel
157     pz  136.4996   $  bottom surface of shield plug -modified
160     pz  153.0096   $  upper SS surface at seating ring -new
161  10  cz  1.04648     $  pipe in shield plug
c
c  surfaces for IL
c
200     pz  135.9916   $  upper interface IL with thermal shield
201     pz    8.1534   $  lower interface IL with thermal shield
c 202     pz  223.8756   $  upper surface of top impact limiter
c 203     pz  -79.7306   $  bottom surface of bottom impact limiter
c
c
c various conical surfaces
c
300     kz -36.3601 1 1          $ tapered surface at bottom of lateral gamma shield
301     kz  180.5051 1 -1        $  tapered surface at top of lateral gamma shield
302     kz -143.9353 0.00489 1    $ tapered surface at cask top tapered cavity
303     kz -140.2468 0.00489 1    $ tapered surface at shield plug (SS)
c 304     kz -220.38 0.00275 1   $ tapered surface at shield plug (gap)
c 305     kz -122.0849 0.00489 1    $ tapered surface at shield plug (lead surface)
c
c bottom drain
c
306     c/z  17.145 0 0.635      $ vertical cylinder for bottom drain
307     c/x  0  -7.5184 0.635    $ horizontal cylinder for bottom drain
308     px  15.24                $ start of horizontal bottom drain
309     pz  -7.94                $ depth of vertical drain
c
999    sz 100 1000
c
c ===== New Impact Limiter Surfaces
350 trc 0 0 185.7756 0 0 38.1 99.06 61.595     $ Upper impact limiter cone
351 trc 0 0 -41.6306 0 0 -38.1 99.06 61.595    $ Lower impact limiter cone
c
352 pz 198.4756 $ Upper impact limiter cone tally segmenting surfaces
353 pz 211.1756
c
354 pz -54.3306 $ Lower impact limiter cone tally segmenting surfaces
355 pz -67.0306
c
c ===== Source Sphere
400 so 0.5 $ 1 cm diameter source sphere
c ===== Top Splitting Layers
c Vertical Layers
1000 pz 137
1001 pz 138
1002 pz 139
1003 pz 140
1004 pz 141
1005 pz 142
1006 pz 143
1007 pz 144
1008 pz 145
1009 pz 146
1010 pz 147
1011 pz 148
1012 pz 149
1013 pz 150
1014 pz 151
1015 pz 152
```

```
1016 pz 153
1017 pz 154
1018 pz 155
1019 pz 156
1020 pz 157
1021 pz 158
1022 pz 159
1023 pz 160
1024 pz 161
1025 pz 162
1026 pz 163
1027 pz 164
1028 pz 165
1029 pz 166
1030 pz 167
1031 pz 168
1032 pz 169
c
c Cone Layers
1050 kz 143.5 10 -1
1051 kz 144.5 10 -1
1052 kz 145.5 10 -1
1053 kz 146.5 10 -1
1054 kz 147.5 10 -1
1055 kz 148.5 10 -1
1056 kz 149.5 10 -1
1057 kz 150.5 10 -1
1058 kz 151.5 10 -1
1059 kz 152.5 10 -1
1060 kz 153.5 10 -1
1061 kz 154.5 10 -1
1062 kz 155.5 10 -1
1063 kz 156.5 10 -1
1064 kz 157.5 10 -1
1065 kz 158.5 10 -1
1066 kz 159.5 10 -1
1067 kz 160.5 10 -1
1068 kz 161.5 10 -1
1069 kz 162.5 10 -1
1070 kz 163.5 10 -1
1071 kz 164.5 10 -1
1072 kz 165.5 10 -1
1073 kz 166.5 10 -1
1074 kz 167.5 10 -1
1075 kz 168.5 10 -1
1076 kz 169.5 10 -1
1077 kz 170.5 10 -1
1078 kz 171.5 10 -1
1079 kz 172.5 10 -1
1080 kz 173.5 10 -1
1081 kz 174.5 10 -1
1082 kz 175.5 10 -1
1083 kz 176.5 10 -1
1084 kz 177.5 10 -1
1085 kz 178.5 10 -1
1086 kz 179.5 10 -1
1087 kz 180.5 10 -1
c
c ===== Side Splitting Layers
2000 cz 21
2001 cz 22
2002 cz 23
2003 cz 24
2004 cz 25
2005 cz 26
2006 cz 27
2007 cz 28
2008 cz 29
2009 cz 30
```

```
2010 cz 31
2011 cz 32
2012 cz 33
2013 cz 34
2014 cz 35
2015 cz 36
2016 cz 37
2017 cz 38
2018 cz 39
2019 cz 40
2020 cz 41
2021 cz 42
2022 cz 43
2023 cz 44
2024 cz 45
2025 cz 46
2026 cz 47
2027 cz 48
c
c ===== Bottom Splitting Layers
c Vertical Layers
3000 pz -1.5
3001 pz -2.5
3002 pz -3.5
3003 pz -4.5
3004 pz -5.5
3005 pz -6.5
3006 pz -7.5
3007 pz -8.5
3008 pz -9.5
3009 pz -10.5
3010 pz -11.5
3011 pz -12.5
3012 pz -13.5
3013 pz -14.5
3014 pz -15.5
3015 pz -16.5
3016 pz -17.5
3017 pz -18.5
3018 pz -19.5
3019 pz -20.5
3020 pz -21.5
3021 pz -22.5
3022 pz -23.5
3023 pz -24.5
3024 pz -25.5
c
c Cone Layers
3050 kz -10.5 10 1
3051 kz -11.5 10 1
3052 kz -12.5 10 1
3053 kz -13.5 10 1
3054 kz -14.5 10 1
3055 kz -15.5 10 1
3056 kz -16.5 10 1
3057 kz -17.5 10 1
3058 kz -18.5 10 1
3059 kz -19.5 10 1
3060 kz -20.5 10 1
3061 kz -21.5 10 1
3062 kz -22.5 10 1
3063 kz -23.5 10 1
3064 kz -24.5 10 1
3065 kz -25.5 10 1
3066 kz -26.5 10 1
3067 kz -27.5 10 1
3068 kz -28.5 10 1

c *** Data Cards ***
```

```
c ===== TRCL definitions
*tr1     0 0 0         45 135 90 45 45 90 $ 45 CW
*tr2     0 0 -0.6426 22.5 112.5 90 67.5 22.5 90
*tr10    0 0 150.022 50 90 140 90 0 90 40 90 50
c
c ===== Materials
c ==============================================
c Dry Air
c Density = 0.0012 g/cm^3
c Reference: SCALE 6.0 Standard Comp. Library
c ==============================================
m1       7014   -76.508
         8016   -23.4793
         6000   -0.0126
c ==============================================
c Stainless Steel 304
c Density = 7.94 g/cm^3
c Reference: SCALE 6.0 Standard Comp. Library
c ==============================================
m4       6012   -0.08
        14000   -1.0
        15000   -0.045
        24000   -19
        25000   -2
        26000   -68.375
        28000   -9.5
c ==============================================
c Lead
c Density = 11.35 g/cm^3
c Reference: PNNL-15870 Rev. 1
c ==============================================
m8      82000   1.0  $ lead
c
c ===== Source Definition
sdef  cel=d1 pos=0 0 0 rad=d2
      par=p erg=d3 wgt=9.1748E+12
c
si1 L (100<24)
sp1 D 1
c
si2 H 0 0.5
sp2 D -21 1
c
c Energy distribution taken from SCALE 6.2.1. model
#        si3            sp3
          H              D
      1.00E-02           0
      4.50E-02       2.5455E+12
      1.00E-01       7.3578E+11
      2.00E-01       4.6700E+11
      3.00E-01       1.3905E+11
      4.00E-01       8.1119E+10
      6.00E-01       1.0866E+11
      8.00E-01       4.8675E+12
      1.00E+00       7.8785E+10
      1.33E+00       1.3684E+11
      1.66E+00       1.4272E+10
      2.00E+00       2.7277E+08
      2.50E+00       2.5469E+07
      3.00E+00       2.4912E+06
      4.00E+00       6.1175E+05
      5.00E+00       1.7670E+05
      6.50E+00       7.2039E+04
      8.00E+00       1.4042E+04
      1.00E+01       3.0158E+03
      2.00E+01       2.2075E+02
c
c ===== Dose Tallies
c ansi/ans-6.1.1-1977 flux-to-dose, photons (mrem/hr)/(p/cm**2/s)
```

```
de0        0.01   0.03   0.05   0.07   0.10   0.15   0.20   0.25   0.30
           0.35   0.40   0.45   0.50   0.55   0.60   0.65   0.70   0.80
           1.00   1.40   1.80   2.20   2.60   2.80   3.25   3.75   4.25
           4.75   5.00   5.25   5.75   6.25   6.75   7.50   9.00   11.0
           13.0   15.0
df0        3.96-3 5.82-4 2.90-4 2.58-4 2.83-4 3.79-4 5.01-4 6.31-4 7.59-4
           8.78-4 9.85-4 1.08-3 1.17-3 1.27-3 1.36-3 1.44-3 1.52-3 1.68-3
           1.98-3 2.51-3 2.99-3 3.42-3 3.82-3 4.01-3 4.41-3 4.83-3 5.23-3
           5.60-3 5.80-3 6.01-3 6.37-3 6.74-3 7.11-3 7.66-3 8.77-3 1.03-2
           1.18-2 1.33-2
fc4 NCT Trailer Side Surface Mesh (4 ft from cask centerline)
fmesh4:p geom=cyl origin=0 0 -79.7306 axs=0 0 1 vec=0.866 -0.5 0
      imesh=121.92 122.92      iints=1 1
      jmesh=303.6062           jints=30
      kmesh=1                  kints=6
c
fc14 NCT Top Surface Mesh (measured from IL top)
fmesh14:p geom=cyl origin=0 0 223.8756 axs=0 0 1 vec=0.866 -0.5 0
      imesh=61.595 iints=6
      jmesh=1      jints=1
      kmesh=1      kints=6
c
fc24 NCT Bottom Surface Mesh (measured from IL bottom)
fmesh24:p geom=cyl origin=0 0 -80.7306 axs=0 0 1 vec=0.866 -0.5 0
      imesh=61.595 iints=6
      jmesh=1      jints=1
      kmesh=1      kints=6
c
fc104 NCT Trailer Side 2m Mesh
fmesh104:p geom=cyl origin=0 0 -79.7306 axs=0 0 1 vec=0.866 -0.5 0
      imesh=321.92 322.92      iints=1 1
      jmesh=303.6062           jints=30
      kmesh=1                  kints=6
c
fc204 HAC Side 1m Mesh (Measured from cask side)
fmesh204:p geom=cyl origin=0 0 -25.8826 axs=0 0 1 vec=0.866 -0.5 0
      imesh=148.7934 149.7934  iints=1 1
      jmesh=195.9102           jints=20
      kmesh=1                  kints=6
c
fc214 HAC Top 1m Mesh (Measured from cask top)
fmesh214:p geom=cyl origin=0 0 270.0276 axs=0 0 1 vec=0.866 -0.5 0
      imesh=99.06  iints=10
      jmesh=1      jints=1
      kmesh=1      kints=6
c
fc224 HAC Bottom 1m Mesh (Measured from cask bottom)
fmesh224:p geom=cyl origin=0 0 -125.8826 axs=0 0 1 vec=0.866 -0.5 0
      imesh=99.06  iints=10
      jmesh=1      jints=1
      kmesh=1      kints=6
c
fc394 Occupied Location Dose (25 ft from cask centerline)
fmesh394:p geom=cyl origin=0 0 -25.8826 axs=0 0 1 vec=0.866 -0.5 0
      imesh=762 772  iints=1 1
      jmesh=195.9102 jints=1
      kmesh=1        kints=6
c
fc504 NCT Cask Side Surface Mesh (between impact limiters)
fmesh504:p geom=cyl origin=0 0 8.1534 axs=0 0 1 vec=0.866 -0.5 0
      imesh=48.7934 49.7934  iints=1 1
      jmesh=127.8382         jints=13
      kmesh=1                kints=6
c
fc514 NCT Impact Limiter Side Surface Mesh
fmesh514:p geom=cyl origin=0 0 -41.6306 axs=0 0 1 vec=0.866 -0.5 0
      imesh=99.06 100.06             iints=1 1
      jmesh=49.784 177.6222 227.4062 jints=5 1 5
      kmesh=1                        kints=6
```

```
c
fc524 NCT Impact Limiter 'Underside' Surface Mesh
fmesh524:p geom=cyl origin=0 0 8.1534 axs=0 0 1 vec=0.866 -0.5 0
      imesh=48.7934 99.06          iints=1 5
      jmesh=1 126.8382 127.8382    jints=1 1 1
      kmesh=1                      kints=6
c
c Surface area of a conical frustum (TRC macrobody, r1 > r2) excluding top and bottom is:
c A = pi*(r1+r2) * sqrt[(r1-r2)^2+h^2] = 26969 cm^2
fc32 Upper Surface (Cone)
f32:p 350.1
fs32 -352 -353
sd32 8990 8990 8990
fc42 Lower Surface (Cone)
f42:p 351.1
fs42 354 355
sd42 8990 8990 8990
c
c fc444 DEBUG TALLY
c fmesh444:p geom=xyz origin=-100 -100 -85
c       imesh=100   iints=75
c       jmesh=100   jints=75
c       kmesh=310   kints=155
c
c ===== Run Options
mode p
prdmp   j j 1 2
ctme 29040
rand gen=2 stride=152917123  $ Use larger period and stride
print 120
```