- **Calculation Package, 72B-CAL-0003, Revision 0, *Self-shielding Surrogate Material Evaluation for RH-TRU 72-B***

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2. Document Number: 72B-CAL-0003	3. Document Revision: 0	4. Page: 1 of 31

5. Summary Description

This calculation evaluates the comparable efficacy of common waste payload materials in providing self-shielding of distributed ^{137}Cs and ^{60}Co gamma sources. The study is applied to the general payload case of the RH-TRU Waste Canister in an RH-TRU 72-B, but the comparison is also applicable to other authorized payload canisters in the RH-TRU 72-B packaging. The evaluations consider only normal conditions of transport (NCT) geometries as NCT is the only configuration where self-shielding in distributed waste forms is credited in meeting the regulatory dose rate limits under exclusive use requirements. Particularly, the study evaluates the relative efficacy of zirconium as the waste material surrogate for other common waste material constituents (i.e., aluminum, brick, concrete, leaded glass, lead, nylon, polyethylene, carbon steel, and wood) and demonstrates that zirconium is a reasonable surrogate material to represent the dose rate attenuation due to self-shielding in remote-handled transuranic waste.

6. Software Usage

Software Name	Version
1. MCNP5	1.60
2.	
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0	All	New Issue

1.0 INTRODUCTION

The RH-TRU 72-B package is used to transport remote-handled (RH) transuranic (TRU) waste. By definition, RH-TRU waste is restricted to require the dose rate at the surface of the payload canister to be greater than 200 mrem/hr. Two sets of activity limits for the packagings are established for each of the authorized payload canister configurations; one set for concentrated sources and one set for distributed sources. For distributed sources, the limits are provided as a function of the limiting bulk density of the payload materials from 0.1 to 8 g/cc. Zirconium is utilized as the surrogate waste material to conservatively represent the myriad of materials that are transported in TRU waste. This calculation compares the self-shielding efficacy of the zirconium surrogate with common materials present in TRU waste for two common gamma radionuclides; namely, ^{137}Cs and ^{60}Co.

This calculation demonstrates that zirconium is a reasonable and appropriate surrogate to represent the self-shielding property of common TRU waste materials, as a function of the waste bulk density, when used in shielding models to predict the dose rate attenuation of gamma energies in distributed source configurations.

2.0 ANALYSIS MODEL

All model parameters used to compare the efficacy of zirconium to common waste materials (i.e., aluminum, brick, concrete, leaded glass, lead, nylon, polyethylene, carbon steel, and wood) were taken directly from 72B-CAL-0001[1] for the RH-TRU waste canister case with a distributed waste assumption. All calculational methodologies, with the exception of the source material specification, are identical to the shielding model that is also documented in the RH-TRU 72-B Safety Analysis Report[2] (SAR). MCNP5 v1.60 is used for the shielding analysis.[3] MCNP5 is a standard, well-accepted shielding program utilized to compute dose rates for shielding licenses.

2.1 Self-Shielding Materials and Source Specification

The elemental composition of each of the evaluated self-shielding materials listed in Table 2-1 was obtained from PNNL-15870[4]. The evaluated materials were each analyzed at multiple fractional densities up to the theoretical density, with zirconium being evaluated from 0.1 to 8 g/cc as in the RH-TRU 72-B SAR shielding analysis.

Based on the assumed bulk density of the waste contents, the height of the source in the RH-TRU 72-B was modestly adjusted to retain the inside diameter of the payload cavity (i.e., the payload drums) and satisfy the authorized maximum gross weight of the payload contents. This approach ensures that the primary factor influencing the dose rate is material attenuation for a source that is axially shrinking as density is increased rather than distance attenuation for a source that is radially shrinking as density is increased. Figure 2-1 shows the shielding model with a 0.1 g/cc source and Figure 2-2 shows the shielding model with an 8 g/cc source. Two radionuclides, ^{137}Cs and ^{60}Co, were chosen for evaluation with unit source strength of 1 gamma/second (γ/s). The source energies and intensities are provided in Table 2-2.[5]

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[1] B. A. Day, *RH-TRU 72-B Shielding Analysis*, 72B-CAL-0001, Rev. 0, Nuclear Waste Partership LLC, Carlsbad, NM, September 2014.

[2] U.S. Department of Energy (DOE), *RH-TRU 72-B Safety Analysis Report*, USNRC Certificate of Compliance 71-9212, U.S. Department of Energy, Carlsbad Area Office, Carlsbad, New Mexico.

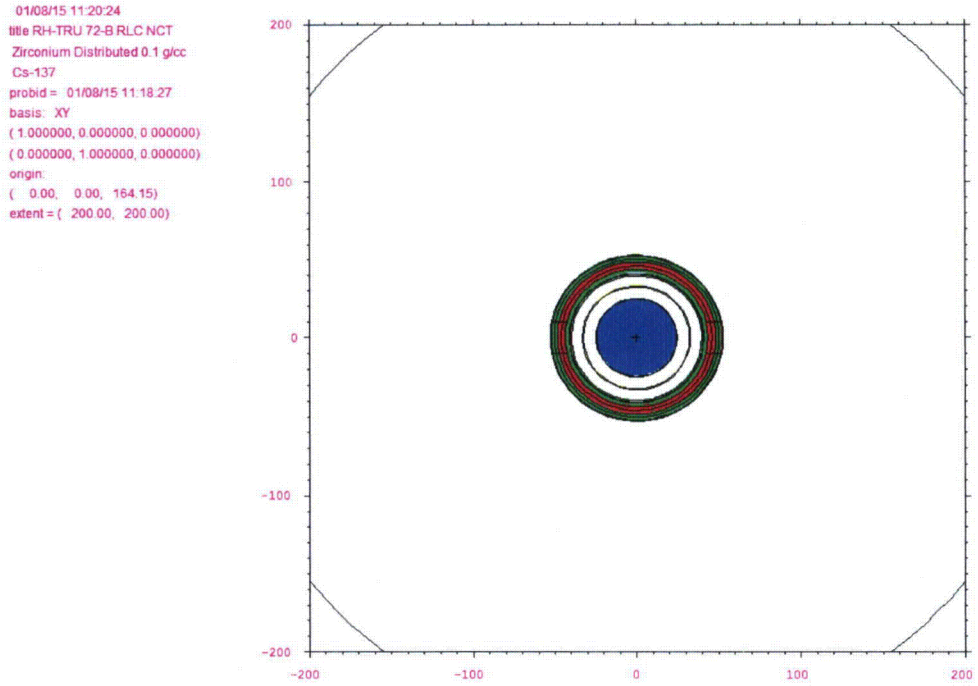
[3] LA-CP-03-0245, *MCNP – A General Monte Carlo N-Particle Transport Code, Version 5, Vol. 2: User's Guide*, Los Alamos National Laboratory, February 2008.

[4] R.G. Williams III, et. al., *Compendium of Material Composition Data for Radiation Transport Modeling*, PNNL-15870, Pacific Northwest National Laboratory, April 2006.

[5] R.R. Kinsey, et al., *The NUDAT/PCNUDAT Program for Nuclear Data*, paper submitted to the 9th International Symposium of Capture Gamma-Ray Spectroscopy and Related Topics, Budapest, Hungary, October 1996; data extracted from the NUDAT database, version September 7, 2000, CD-ROM.

Table 2-1 – Evaluated Self-Shielding Materials

Material	Theoretical Density (g/cc)	MCNP Material Card
Aluminum	2.6989	13000 -1.000000
Brick (Silica)	1.80	8000 -0.524858 13000 -0.005227 14000 -0.449011 20000 -0.014419 26000 -0.007213
Concrete (Ordinary)	2.30	1000 -0.022100 6000 -0.002484 8000 -0.574930 11000 -0.015208 12000 -0.001266 13000 -0.019953 14000 -0.304627 19000 -0.010045 20000 -0.042951 26000 -0.006435
Glass (Lead)	6.22	8000 -0.156453 14000 -0.080866 22000 -0.008092 33000 -0.002651 82000 -0.751938
Lead	11.35	82000 -1.000000
Nylon (Type 6)	1.14	1000 -0.097976 6000 -0.636856 7000 -0.123779 8000 -0.141389
Polyethylene (Normal)	0.93	1000 -0.143716 6000 -0.856284
Steel (Carbon)	7.82	6000 -0.005 26000 -0.995
Wood (Southern Pine)	0.650	1000 -0.057889 6000 -0.482667 8000 -0.459444
Zirconium	6.506	40000 -1.000000



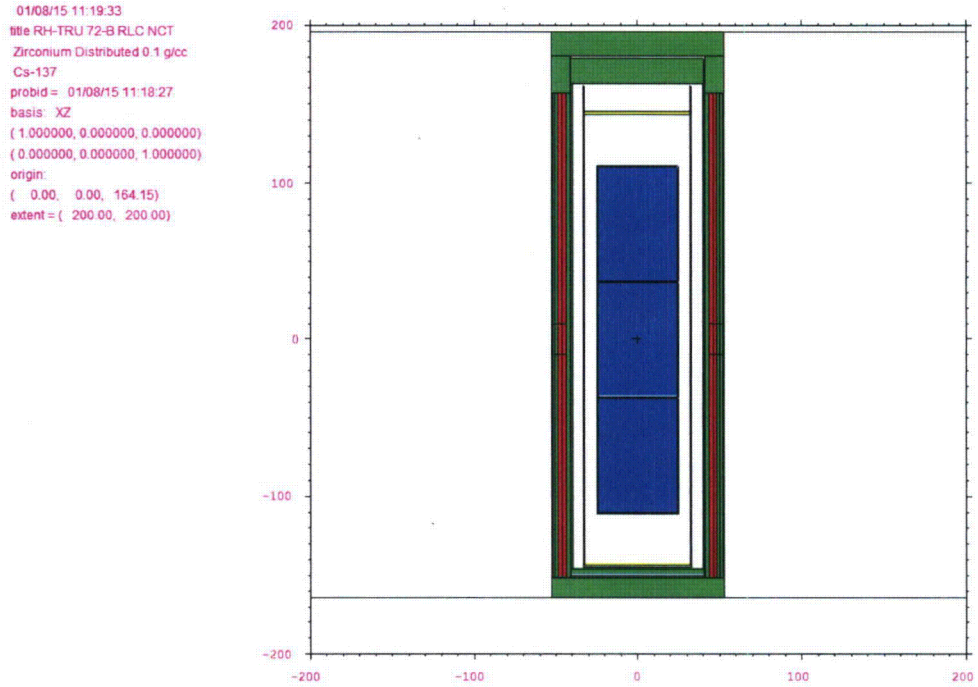
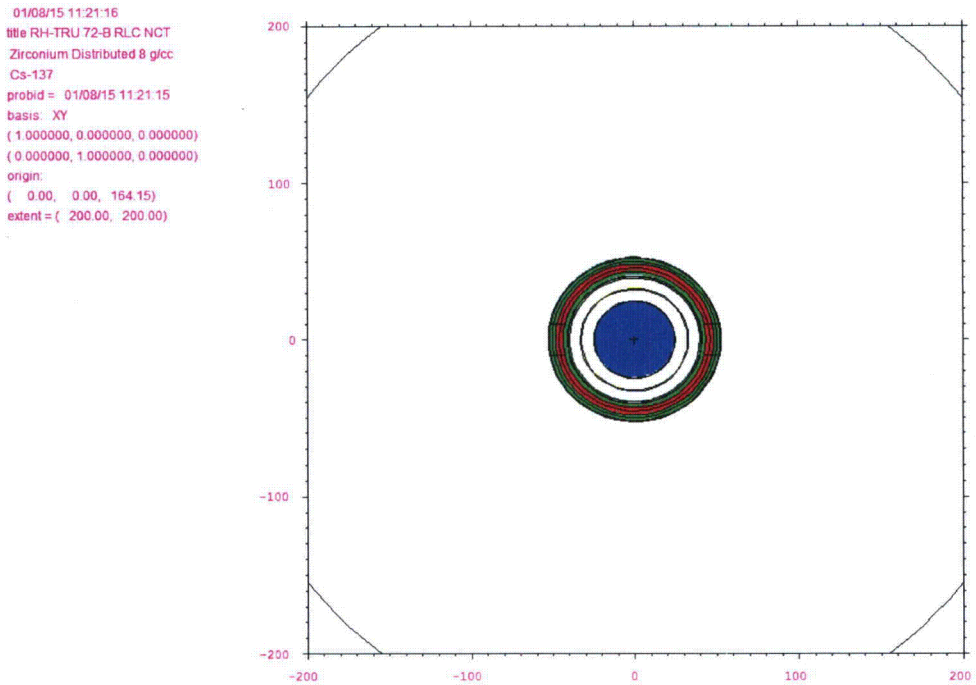


Figure 2-1 – RH-TRU 72-B with 0.1 g/cc Distributed Source



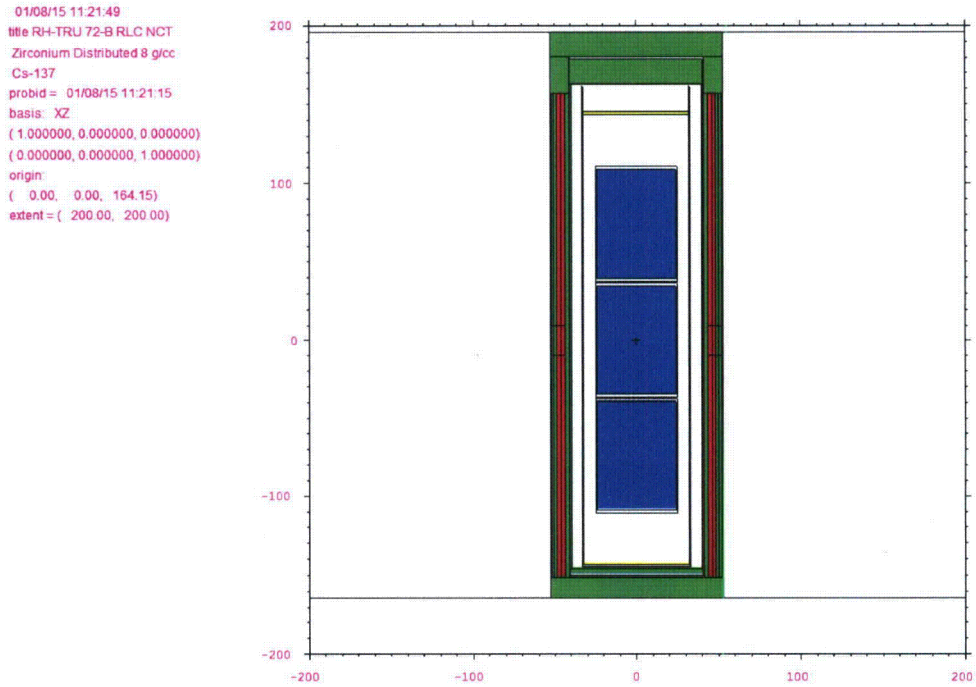


Figure 2-2 – RH-TRU 72-B with 8 g/cc Distributed Source

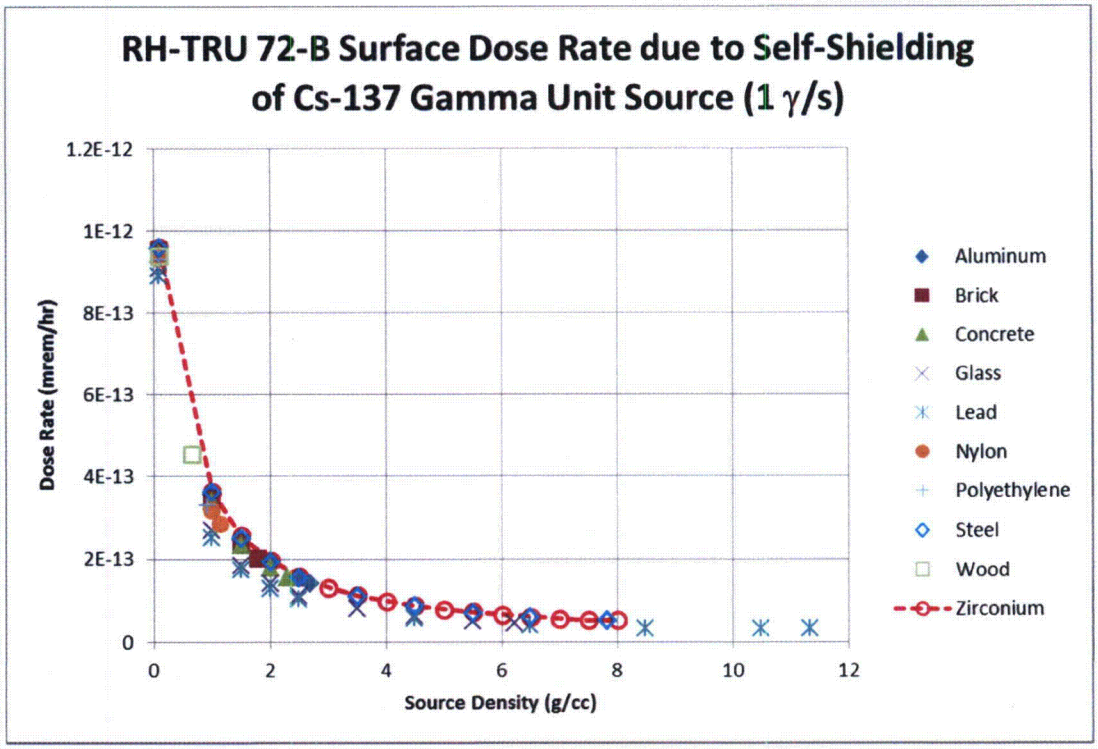
Table 2-2 – Gamma Source Data

Radionuclide	Photon Energy (MeV)	Intensity (%)
^{137}Cs	2.835000E-01	5.800000E-04
	6.616570E-01	8.510000E+01
^{60}Co	3.469300E-01	7.600000E-03
	8.262800E-01	7.600000E-03
	1.173237E+00	9.997360E+01
	1.332501E+00	9.998560E+01
	2.158770E+00	1.110000E-03
	2.505000E+00	2.000000E-06

3.0 RESULTS

The dose rates due to ^{60}Co and ^{137}Cs distributed sources at the surface and at 2-meters from the surface of the RH-TRU 72-B were determined for all of the self-shielding materials at a range of fractional densities up to the theoretical density for each material. All results passed the MCNP statistical checks with a tally error less than 2%. As the 2-meter dose rate is limiting by a large margin for both NCT and Hypothetical Accident Condition (HAC) dose rate compliance, the 2-meter results are of primary importance in comparing the relative efficacy of the waste materials analyzed to the zirconium surrogate.

As shown in Figure 3-1 and Figure 3-2, the highest dose rates are associated with the self-shielding materials with the least efficacy. Zirconium is seen to be a conservative surrogate to represent the self-shielding properties of TRU waste with a high-energy, ^{60}Co, gamma source term as it results in the highest dose rates and provides the least amount of gamma dose rate attenuation at the surface of the package and at 2-meters in comparison to the other common TRU waste materials. For the moderate-energy, ^{137}Cs, gamma source term, the results are similarly conservative for Zr in comparison to the other common TRU waste materials. The numerical results for all evaluations are summarized in Table 3-1 and Table 3-2.



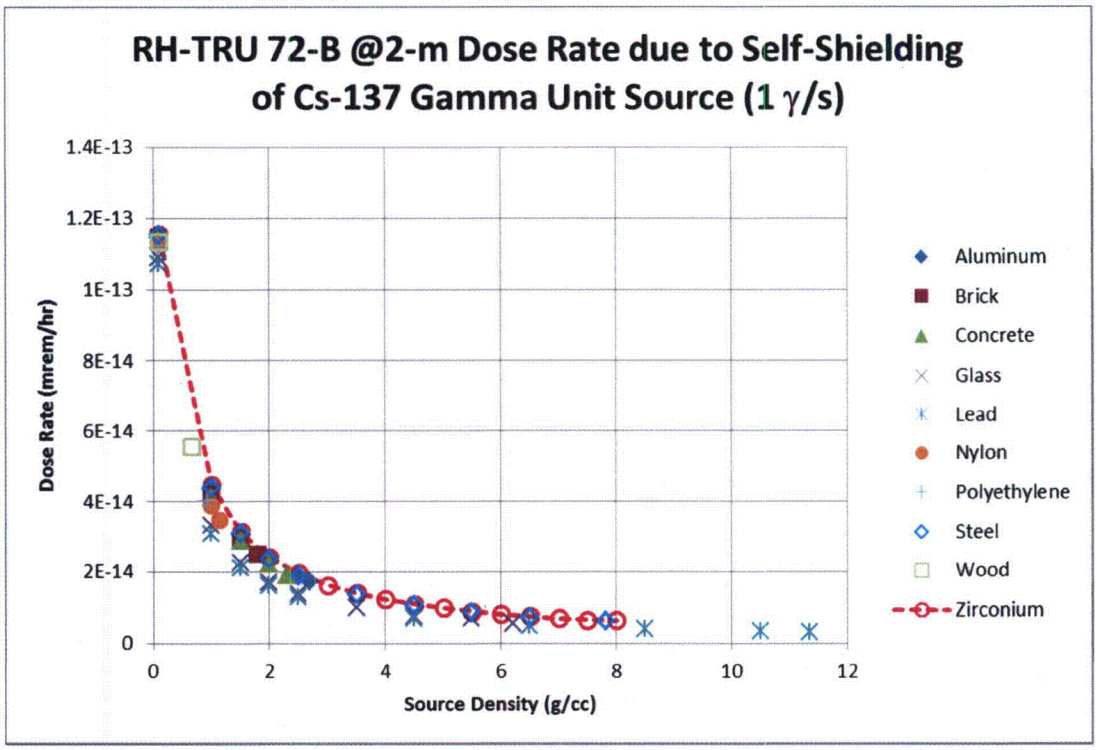
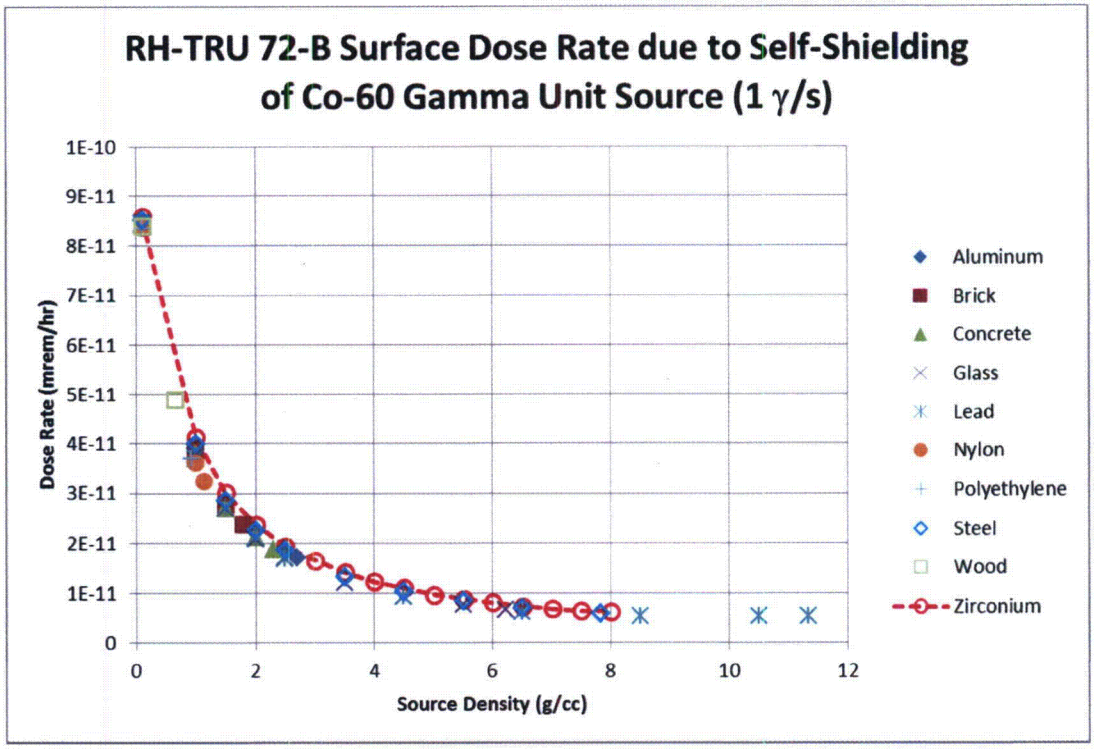


Figure 3-1 – ^{137}Cs Dose Rate Comparison



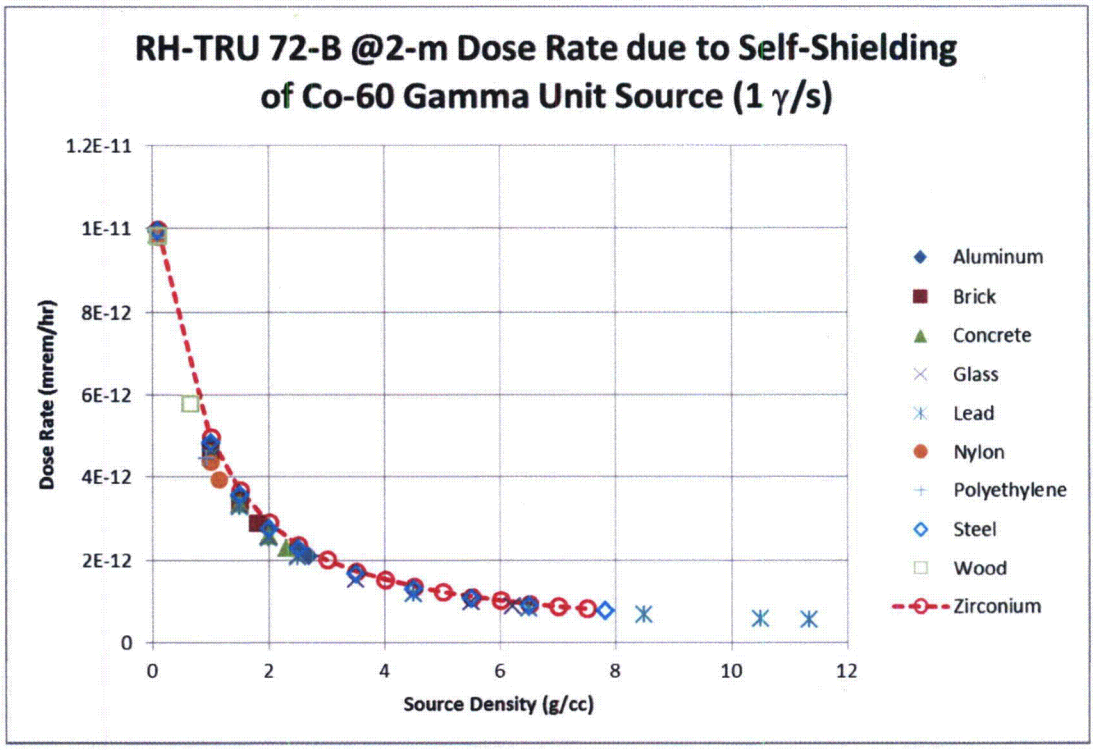


Figure 3-2 – ^{60}Co Dose Rate Comparison

Table 3-1 – RH-TRU 72-B – Distributed ^{137}Cs Source Dose Rates

Case	Material	Source Density (g/cc)	Dose Rate at Surface (mrem/hr)	Dose Rate at 2-meters (mrem/hr)
7sa100.i	Aluminum	0.1	9.55E-13	1.14E-13
7sa101.i	Aluminum	1	3.56E-13	4.35E-14
7sa102.i	Aluminum	1.5	2.48E-13	3.05E-14
7sa103.i	Aluminum	2	1.89E-13	2.34E-14
7sa104.i	Aluminum	2.5	1.53E-13	1.88E-14
7sa105.i	Aluminum	2.6989	1.41E-13	1.74E-14
7sb100.i	Brick	0.1	9.54E-13	1.15E-13
7sb101.i	Brick	1	3.46E-13	4.16E-14
7sb102.i	Brick	1.5	2.39E-13	2.94E-14
7sb103.i	Brick	1.8	2.03E-13	2.50E-14
7sc100.i	Concrete	0.1	9.45E-13	1.14E-13
7sc101.i	Concrete	1	3.40E-13	4.11E-14
7sc102.i	Concrete	1.5	2.36E-13	2.89E-14
7sc103.i	Concrete	2	1.79E-13	2.22E-14
7sc104.i	Concrete	2.3	1.55E-13	1.92E-14
7sg100.i	Glass	0.1	9.09E-13	1.09E-13
7sg101.i	Glass	1	2.71E-13	3.31E-14
7sg102.i	Glass	1.5	1.84E-13	2.27E-14
7sg103.i	Glass	2	1.40E-13	1.72E-14
7sg104.i	Glass	2.5	1.11E-13	1.38E-14
7sg105.i	Glass	3.5	7.97E-14	9.89E-15
7sg106.i	Glass	4.5	6.18E-14	7.62E-15
7sg107.i	Glass	5.5	5.08E-14	6.96E-15
7sg108.i	Glass	6.22	4.47E-14	5.54E-15
7sl100.i	Lead	0.1	8.93E-13	1.07E-13
7sl101.i	Lead	1	2.53E-13	3.08E-14
7sl102.i	Lead	1.5	1.73E-13	2.11E-14
7sl103.i	Lead	2	1.28E-13	1.60E-14
7sl104.i	Lead	2.5	1.04E-13	1.28E-14

Case	Material	Source Density (g/cc)	Dose Rate at Surface (mrem/hr)	Dose Rate at 2-meters (mrem/hr)
7sl105.i	Lead	4.5	5.72E-14	7.10E-15
7sl106.i	Lead	6.5	3.98E-14	4.96E-15
7sl107.i	Lead	8.5	3.31E-14	4.04E-15
7sl108.i	Lead	10.5	3.30E-14	3.46E-15
7sl109.i	Lead	11.35	3.28E-14	3.25E-15
7sn100.i	Nylon	0.1	9.35E-13	1.13E-13
7sn101.i	Nylon	1	3.19E-13	3.88E-14
7sn102.i	Nylon	1.14	2.85E-13	3.47E-14
7sp100.i	Polyethylene	0.1	9.30E-13	1.12E-13
7sp101.i	Polyethylene	0.93	3.30E-13	4.00E-14
7ss100.i	Steel	0.1	9.59E-13	1.15E-13
7ss101.i	Steel	1	3.64E-13	4.40E-14
7ss102.i	Steel	1.5	2.53E-13	3.12E-14
7ss103.i	Steel	2	1.95E-13	2.38E-14
7ss104.i	Steel	2.5	1.56E-13	1.91E-14
7ss105.i	Steel	3.5	1.11E-13	1.38E-14
7ss106.i	Steel	4.5	8.69E-14	1.08E-14
7ss107.i	Steel	5.5	7.10E-14	8.76E-15
7ss108.i	Steel	6.5	6.00E-14	7.37E-15
7ss109.i	Steel	7.82	5.13E-14	6.33E-15
7sw100.i	Wood	0.1	9.41E-13	1.13E-13
7sw101.i	Wood	0.65	4.55E-13	5.55E-14
7sz100.i	Zirconium	0.1	9.60E-13	1.16E-13
7sz101.i	Zirconium	1	3.64E-13	4.46E-14
7sz102.i	Zirconium	1.5	2.56E-13	3.14E-14
7sz103.i	Zirconium	2	1.97E-13	2.40E-14
7sz104.i	Zirconium	2.5	1.59E-13	1.95E-14
7sz105.i	Zirconium	3	1.31E-13	1.62E-14
7sz106.i	Zirconium	3.5	1.12E-13	1.40E-14
7sz107.i	Zirconium	4	9.89E-14	1.22E-14

Case	Material	Source Density (g/cc)	Dose Rate at Surface (mrem/hr)	Dose Rate at 2-meters (mrem/hr)
7sz108.i	Zirconium	4.5	8.77E-14	1.09E-14
7sz109.i	Zirconium	5	7.86E-14	9.81E-15
7sz110.i	Zirconium	5.5	7.14E-14	8.86E-15
7sz111.i	Zirconium	6	6.59E-14	8.10E-15
7sz112.i	Zirconium	6.5	6.04E-14	7.47E-15
7sz113.i	Zirconium	7	5.60E-14	6.95E-15
7sz114.i	Zirconium	7.5	5.22E-14	6.50E-15
7sz115.i	Zirconium	8	5.15E-14	6.34E-15

Table 3-2 – RH-TRU 72-B – Distributed ^{60}Co Source Dose Rates

Case	Material	Source Density (g/cc)	Dose Rate at Surface (mrem/hr)	Dose Rate at 2-meters (mrem/hr)
7oa100.i	Aluminum	0.1	8.50E-11	9.92E-12
7oa101.i	Aluminum	1	3.90E-11	4.77E-12
7oa102.i	Aluminum	1.5	2.84E-11	3.53E-12
7oa103.i	Aluminum	2	2.22E-11	2.74E-12
7oa104.i	Aluminum	2.5	1.80E-11	2.25E-12
7oa105.i	Aluminum	2.6989	1.70E-11	2.09E-12
7ob100.i	Brick	0.1	8.46E-11	9.86E-12
7ob101.i	Brick	1	3.86E-11	4.64E-12
7ob102.i	Brick	1.5	2.75E-11	3.41E-12
7ob103.i	Brick	1.8	2.37E-11	2.89E-12
7oc100.i	Concrete	0.1	8.45E-11	9.88E-12
7oc101.i	Concrete	1	3.80E-11	4.58E-12
7oc102.i	Concrete	1.5	2.70E-11	3.35E-12
7oc103.i	Concrete	2	2.11E-11	2.60E-12
7oc104.i	Concrete	2.3	1.87E-11	2.29E-12
7og100.i	Glass	0.1	8.47E-11	9.84E-12
7og101.i	Glass	1	3.76E-11	4.52E-12
7og102.i	Glass	1.5	2.69E-11	3.31E-12
7og103.i	Glass	2	2.09E-11	2.58E-12
7og104.i	Glass	2.5	1.71E-11	2.10E-12
7og105.i	Glass	3.5	1.21E-11	1.52E-12
7og106.i	Glass	4.5	9.32E-12	1.18E-12
7og107.i	Glass	5.5	7.64E-12	9.66E-13
7og108.i	Glass	6.22	6.70E-12	8.65E-13
7ol100.i	Lead	0.1	8.45E-11	9.84E-12
7ol101.i	Lead	1	3.70E-11	4.48E-12
7ol102.i	Lead	1.5	2.71E-11	3.29E-12
7ol103.i	Lead	2	2.11E-11	2.55E-12

Case	Material	Source Density (g/cc)	Dose Rate at Surface (mrem/hr)	Dose Rate at 2-meters (mrem/hr)
7ol104.i	Lead	2.5	1.69E-11	2.08E-12
7ol105.i	Lead	4.5	9.32E-12	1.17E-12
7ol106.i	Lead	6.5	6.36E-12	8.24E-13
7ol107.i	Lead	8.5	5.44E-12	6.80E-13
7ol108.i	Lead	10.5	5.36E-12	5.74E-13
7ol109.i	Lead	11.35	5.36E-12	5.47E-13
7on100.i	Nylon	0.1	8.37E-11	9.79E-12
7on101.i	Nylon	1	3.61E-11	4.36E-12
7on102.i	Nylon	1.14	3.23E-11	3.94E-12
7op100.i	Polyethylene	0.1	8.35E-11	9.76E-12
7op101.i	Polyethylene	0.93	3.69E-11	4.46E-12
7os100.i	Steel	0.1	8.52E-11	9.96E-12
7os101.i	Steel	1	4.01E-11	4.85E-12
7os102.i	Steel	1.5	2.86E-11	3.59E-12
7os103.i	Steel	2	2.26E-11	2.77E-12
7os104.i	Steel	2.5	1.86E-11	2.29E-12
7os105.i	Steel	3.5	1.33E-11	1.67E-12
7os106.i	Steel	4.5	1.05E-11	1.30E-12
7os107.i	Steel	5.5	8.50E-12	1.06E-12
7os108.i	Steel	6.5	7.09E-12	9.00E-13
7os109.i	Steel	7.82	6.14E-12	7.77E-13
7ow100.i	Wood	0.1	8.40E-11	9.83E-12
7ow101.i	Wood	0.65	4.90E-11	5.81E-12
7oz100.i	Zirconium	0.1	8.58E-11	9.98E-12
7oz101.i	Zirconium	1	4.12E-11	4.98E-12
7oz102.i	Zirconium	1.5	3.00E-11	3.70E-12
7oz103.i	Zirconium	2	2.38E-11	2.91E-12
7oz104.i	Zirconium	2.5	1.93E-11	2.38E-12
7oz105.i	Zirconium	3	1.64E-11	2.01E-12
7oz106.i	Zirconium	3.5	1.41E-11	1.73E-12

Case	Material	Source Density (g/cc)	Dose Rate at Surface (mrem/hr)	Dose Rate at 2-meters (mrem/hr)
7oz107.i	Zirconium	4	1.22E-11	1.52E-12
7oz108.i	Zirconium	4.5	1.10E-11	1.36E-12
7oz109.i	Zirconium	5	9.68E-12	1.22E-12
7oz110.i	Zirconium	5.5	8.81E-12	1.11E-12
7oz111.i	Zirconium	6	8.10E-12	1.02E-12
7oz112.i	Zirconium	6.5	7.37E-12	9.34E-13
7oz113.i	Zirconium	7	6.83E-12	8.75E-13
7oz114.i	Zirconium	7.5	6.37E-12	8.25E-13
7oz115.i	Zirconium	8	6.30E-12	7.96E-13

4.0 CONCLUSIONS

Although it is generally understood from an evaluation of mass attenuation coefficients that the amount of material attenuation typically (note: hydrogen is a notable exception) increases with increasing atomic (Z) number, the calculational results presented herein demonstrate that zirconium (Z=40) reasonably represents the common materials present in TRU waste by producing a relatively low amount of material self-attenuation for moderate to high energy gamma source terms. Other potential elemental surrogates such as lithium (Z=3) and argon (Z=18) have relatively low mass attenuation coefficients in comparison to zirconium, but are not present in dominant quantities (by mass) in TRU waste.

In comparison with the common TRU waste materials, zirconium produces the least amount of material attenuation for both the ^{60}Co and ^{137}Cs source term. Lower energy gamma source terms are not of primary importance due to the fact that the approximately 1/4-inch thickness of stainless or carbon steel in the canister shell, along with the exceedingly large thicknesses of stainless steel and lead in the packaging, limit the ability of lower energy gammas to escape the package and significantly affect the package dose rate at 2-meters. Additionally, lower-energy gammas are not of concern because the dose rate emanating from TRU waste is dominated by the two gamma radionuclides (or others with similar energy ranges) analyzed herein. Also, it is seen that the conservative self-shielding surrogate characteristics of Zr are enhanced at higher gamma energies.

Due to the increasing penetration of gammas with increasing energy, it is preferential to have the surrogate material represent a conservative bound for material attenuation subject to higher gamma energies while still reasonably representing the self-shielding effects of common TRU waste materials subject to moderate gamma energies. As such, zirconium is an appropriate and reasonable surrogate to represent the self-shielding properties of the common and predominant (by mass) materials present in TRU waste as it is the most conservative choice for gamma energies in excess of 1.0 MeV and it is insignificantly different from other common TRU waste materials for moderate gamma energies.

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5.1 Sample MCNP Input Files

5.1.1 RH-TRU 72-B – RH-TRU Waste Canister

5.1.1.1 Distributed 137Cs Gamma Source with 0.1 g/cc Aluminum – 7sa100.i

```
title RH-TRU 72-B RLC NCT Aluminum Distributed 0.1 g/cc Cs-137
C
C Cell Cards
C
10  1 -0.1        10  -11  -16                imp:p=1    $ Source #1
11  1 -0.1        12  -13  -17                imp:p=1    $ Source #2
12  1 -0.1        14  -15  -18                imp:p=1    $ Source #3
20  0           20  -21  -26
              (-10:  11:  16)               imp:p=1    $ Drum #1 cavity
21  0           22  -23  -27
              (-12:  13:  17)               imp:p=1    $ Drum #2 cavity
22  0           24  -25  -28
              (-14:  15:  18)               imp:p=1    $ Drum #3 cavity
40  0           41  -45  -43
               #10  #11  #12
               #20  #21  #22                imp:p=1    $ RLC cavity
41  3 -7.85260  40  -41  -42                imp:p=1    $ RLC base
42  3 -7.85260  41  -46   43  -42           imp:p=1    $ RLC shell
43  3 -7.85260  45  -44  -43                imp:p=1    $ RLC lid
50  0           51  -53  -55
              (-40:  42:  46)
             :( 44  -46  -43)               imp:p=1    $ IV cavity
51  2 -8.01280  50  -51  -52                imp:p=1    $ IV base
52  2 -8.01280  51  -55   53  -52           imp:p=2    $ IV shell
53  2 -8.01280  55  -54  -52                imp:p=1    $ IV lid
60  0           61  -63  -65
              (-50:  52:  54)               imp:p=2    $ OC cavity
61  2 -8.01280  60  -61  -69                imp:p=1    $ OC base
62  2 -8.01280  61  -66   65  -64           imp:p=5    $ OC ishell
63  4 -11.3500  61  -66   64  -76  71       imp:p=3E1  $ OC lead in
64  4 -11.3500  61  -66   76  -68  71       imp:p=3E2  $ OC lead out
65  2 -8.01280  61  -66   68  -77  71       imp:p=3E3  $ OC oshell in
66  2 -8.01280  61  -66   77  -67  71       imp:p=6E3  $ OC oshell out
67  0           61  -66   67  -70  71       imp:p=1E5  $ OC airgap
68  2 -8.01280  61  -66   70  -69  71       imp:p=2E5  $ OC tshell
69  2 -8.01280  66  -63   65  -69           imp:p=1    $ OC flange
70  2 -8.01280  63  -62  -69                imp:p=1    $ OC lid
71  4 -11.3500  64  -78  -71                imp:p=3E1  $ OC lead punct in
72  4 -11.3500  78  -73  -71                imp:p=3E2  $ OC lead punct out
73  2 -8.01280  73  -79  -71                imp:p=3E3  $ OC oshell punct in
74  2 -8.01280  79  -72  -71                imp:p=6E3  $ OC oshell punct out
75  0           72  -75  -71                imp:p=1E5  $ OC airgap punct
76  2 -8.01280  75  -74  -71                imp:p=2E5  $ OC tshell punct
777 0           69  -80   60  -62           imp:p=2E5  $ Outside to tally
888 0          -999
              (-60:  80:  62)               imp:p=1E1  $ Outside pkg
999 0           999                         imp:p=0    $ Outside world

C
C Geometry Cards
C
10  pz 53.658                                          $ Source #1 bottom
11  pz 126.683                                           $ Source #1 top
12  pz 127.635                                        $ Source #2 bottom
13  pz 200.66                                        $ Source #2 top
```

```
14  pz 201.613                                  $ Source #3 bottom
15  pz 274.638                                  $ Source #3 top
16  c/z 0 0 24.448                                $ Source #1 radius
17  c/z 0 0 24.448                                $ Source #2 radius
18  c/z 0 0 24.448                                $ Source #3 radius
C
20  pz 53.34                                    $ Drum #1 bottom
21  pz 127                                    $ Drum #1 top
22  pz 127.318                                  $ Drum #2 bottom
23  pz 200.978                                  $ Drum #2 top
24  pz 201.295                                  $ Drum #3 bottom
25  pz 274.955                                  $ Drum #3 top
26  c/z 0 0 24.765                               $ Drum #1 radius
27  c/z 0 0 24.765                               $ Drum #2 radius
28  c/z 0 0 24.765                               $ Drum #3 radius
C
40  pz 19.368                                   $ RLC base (outside)
41  pz 20.638                                   $ RLC base (inside)
42  c/z 0 0 33.02                               $ RLC shell (outside)
43  c/z 0 0 32.385                              $ RLC shell (inside)
44  pz 309.563                                  $ RLC lid (outside)
45  pz 307.658                                  $ RLC lid (inside)
46  pz 325.438                                  $ RLC top (outside)
C
50  pz 14.288                                   $ IV base (outside)
51  pz 18.098                                   $ IV base (inside)
52  c/z 0 0 40.64                               $ IV shell (outside)
53  c/z 0 0 39.688                              $ IV shell (inside)
54  pz 343.218                                  $ IV top (outside)
55  pz 326.708                                  $ IV top (inside)
C
60  pz 0                                        $ OC bottom (outside)
61  pz 12.7                                     $ OC bottom (inside)
62  pz 360.045                                  $ OC top (outside)
63  pz 344.805                                  $ OC top (inside)
64  cz 43.656                                   $ OC ishell (outside)
65  cz 41.116                                   $ OC ishell (inside)
66  pz 320.675                                  $ OC lead (upper)
67  cz 52.229                                   $ OC oshell (outside)
68  cz 48.419                                   $ OC oshell (inside)
69  cz 52.838                                   $ OC therm (outside)
70  cz 52.495                                   $ OC therm (inside)
71  c/x 0 164.148 10.033                        $ OC puncture radius
72  cz 52.229                                   $ OC oshell punct (out)
73  cz 48.419                                   $ OC oshell punct (in)
74  cz 52.838                                   $ OC therm punct (out)
75  cz 52.495                                   $ OC therm punct (in)
76  cz 46.038                                   $ OC lead (mid)
77  cz 50.324                                   $ OC oshell (mid)
78  cz 46.038                                   $ OC lead punct (mid)
79  cz 50.324                                   $ OC oshell punct (mid)
C
80  cz 252.838                                  $ 2-meter from OC therm
C
777 pz 161.608                                  $ Ring tally (lower)
888 pz 166.688                                  $ Ring tally (upper)
999 sz 164.148 379.838                          $ Outside world

C
C Physics Cards
C
mode p
C
C Source Cards
C
C Cylindrical Sources
sdef pos=d1 erg=d2 par=2 axs=0 0 1 rad=d3 ext=d4
```

```
sc1 Cs-137 MeV
C Source Position and Fraction
si1 L 0 0 90.17
      0 0 164.148
      0 0 238.125
sp1   1 1 1
C Source Energy (MeV) and Intensity (%)
si2 L 0.2835 0.661657
sp2 5.8000E-04 8.5100E+01
C Source Radius
si3 0 24.448
sp3 -21 1
C Source Extent
si4 -36.513 36.513
sp4 -21 0
C
C Tally Cards
C
f2:p 69
fc2 Surface Dose (mrem/hr)                                  $ Surface detector
fs2 888 777 t
sd2 1.0 1686.525 1.0 1.0                                    $ Surface tally area
f22:p 80
fc22 2-meter Dose (mrem/hr)                                 $ 2-m detector
fs22 888 777 t
sd22 1.0 8070.229 1.0 1.0                                   $ Surface tally area
C
C ANSI/ANS-6.1.1-1977 Gamma Flux to Dose Factors (mrem/hr)
de0 1.0e-02 3.0e-02 5.0e-02 7.0e-02 1.0e-01                 $ Energy (Mev)
     1.5e-01 2.0e-01 2.5e-01 3.0e-01 3.5e-01
     4.0e-01 4.5e-01 5.0e-01 5.5e-01 6.0e-01
     6.5e-01 7.0e-01 8.0e-01 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
     11.00 13.00 15.0000
df0 3.96e-03 5.82e-04 2.90e-04 2.58e-04 2.83e-04            $ Conversion (mrem/hr)
     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 Material Cards
C
m1   13000 -1.00                                            $ Aluminum
m2   14000 -0.01                                            $ Stainless Steel
     24000 -0.19
     25000 -0.02
     26000 -0.68
     28000 -0.10
m3   26000 -1.00                                            $ Carbon Steel (iron)
m4   82000 -1.00                                            $ Lead
C
C Runtime and Print Cards
C
prdmp j j 1 2
ctme 20
```

5.1.1.2 Distributed 137Cs Gamma Source with 8.0 g/cc Zirconium – 7sz115.i

```
title RH-TRU 72-B RLC NCT Zirconium Distributed 8 g/cc Cs-137
C
```

```
C Cell Cards
C
10  1 -8          10  -11  -16                  imp:p=1    $ Source #1
11  1 -8          12  -13  -17                  imp:p=1    $ Source #2
12  1 -8          14  -15  -18                  imp:p=1    $ Source #3
20  0             20  -21  -26
                (-10:  11:  16)                 imp:p=1    $ Drum #1 cavity
21  0             22  -23  -27
                (-12:  13:  17)                 imp:p=1    $ Drum #2 cavity
22  0             24  -25  -28
                (-14:  15:  18)                 imp:p=1    $ Drum #3 cavity
40  0             41  -45  -43
                 #10  #11  #12
                 #20  #21  #22                  imp:p=1    $ RLC cavity
41  3 -7.85260   40  -41  -42                   imp:p=1    $ RLC base
42  3 -7.85260   41  -46   43  -42               imp:p=1    $ RLC shell
43  3 -7.85260   45  -44  -43                   imp:p=1    $ RLC lid
50  0            51  -53  -55
                (-40:  42:  46)
               :( 44  -46  -43)                 imp:p=1    $ IV cavity
51  2 -8.01280   50  -51  -52                   imp:p=1    $ IV base
52  2 -8.01280   51  -55   53  -52               imp:p=2    $ IV shell
53  2 -8.01280   55  -54  -52                   imp:p=1    $ IV lid
60  0            61  -63  -65
                (-50:  52:  54)                 imp:p=2    $ OC cavity
61  2 -8.01280   60  -61  -69                   imp:p=1    $ OC base
62  2 -8.01280   61  -66   65  -64               imp:p=5    $ OC ishell
63  4 -11.3500   61  -66   64  -76  71          imp:p=3E1  $ OC lead in
64  4 -11.3500   61  -66   76  -68  71          imp:p=3E2  $ OC lead out
65  2 -8.01280   61  -66   68  -77  71          imp:p=3E3  $ OC oshell in
66  2 -8.01280   61  -66   77  -67  71          imp:p=6E3  $ OC oshell out
67  0            61  -66   67  -70  71          imp:p=1E5  $ OC airgap
68  2 -8.01280   61  -66   70  -69  71          imp:p=2E5  $ OC tshell
69  2 -8.01280   66  -63   65  -69               imp:p=1    $ OC flange
70  2 -8.01280   63  -62  -69                   imp:p=1    $ OC lid
71  4 -11.3500   64  -78  -71                   imp:p=3E1  $ OC lead punct in
72  4 -11.3500   78  -73  -71                   imp:p=3E2  $ OC lead punct out
73  2 -8.01280   73  -79  -71                   imp:p=3E3  $ OC oshell punct in
74  2 -8.01280   79  -72  -71                   imp:p=6E3  $ OC oshell punct out
75  0            72  -75  -71                   imp:p=1E5  $ OC airgap punct
76  2 -8.01280   75  -74  -71                   imp:p=2E5  $ OC tshell punct
777 0            69  -80   60  -62               imp:p=2E5  $ Outside to tally
888 0           -999
                (-60:  80:  62)                 imp:p=1E1  $ Outside pkg
999 0            999                            imp:p=0    $ Outside world

C
C Geometry Cards
C
10  pz 55.444                                    $ Source #1 bottom
11  pz 124.896                                     $ Source #1 top
12  pz 129.421                                   $ Source #2 bottom
13  pz 198.874                                   $ Source #2 top
14  pz 203.399                                   $ Source #3 bottom
15  pz 272.851                                   $ Source #3 top
16  c/z 0 0 24.448                                 $ Source #1 radius
17  c/z 0 0 24.448                                 $ Source #2 radius
18  c/z 0 0 24.448                                 $ Source #3 radius
C
20  pz 53.34                                     $ Drum #1 bottom
21  pz 127                                     $ Drum #1 top
22  pz 127.318                                   $ Drum #2 bottom
23  pz 200.978                                   $ Drum #2 top
24  pz 201.295                                   $ Drum #3 bottom
25  pz 274.955                                   $ Drum #3 top
26  c/z 0 0 24.765                                 $ Drum #1 radius
27  c/z 0 0 24.765                                 $ Drum #2 radius
```

```
28  c/z 0 0 24.765                                  $ Drum #3 radius
C
40  pz 19.368                                       $ RLC base (outside)
41  pz 20.638                                       $ RLC base (inside)
42  c/z 0 0 33.02                                   $ RLC shell (outside)
43  c/z 0 0 32.385                                  $ RLC shell (inside)
44  pz 309.563                                      $ RLC lid (outside)
45  pz 307.658                                      $ RLC lid (inside)
46  pz 325.438                                      $ RLC top (outside)
C
50  pz 14.288                                       $ IV base (outside)
51  pz 18.098                                       $ IV base (inside)
52  c/z 0 0 40.64                                   $ IV shell (outside)
53  c/z 0 0 39.688                                  $ IV shell (inside)
54  pz 343.218                                      $ IV top (outside)
55  pz 326.708                                      $ IV top (inside)
C
60  pz 0                                            $ OC bottom (outside)
61  pz 12.7                                         $ OC bottom (inside)
62  pz 360.045                                      $ OC top (outside)
63  pz 344.805                                      $ OC top (inside)
64  cz 43.656                                       $ OC ishell (outside)
65  cz 41.116                                       $ OC ishell (inside)
66  pz 320.675                                      $ OC lead (upper)
67  cz 52.229                                       $ OC oshell (outside)
68  cz 48.419                                       $ OC oshell (inside)
69  cz 52.838                                       $ OC therm (outside)
70  cz 52.495                                       $ OC therm (inside)
71  c/x 0 164.148 10.033                            $ OC puncture radius
72  cz 52.229                                       $ OC oshell punct (out)
73  cz 48.419                                       $ OC oshell punct (in)
74  cz 52.838                                       $ OC therm punct (out)
75  cz 52.495                                       $ OC therm punct (in)
76  cz 46.038                                       $ OC lead (mid)
77  cz 50.324                                       $ OC oshell (mid)
78  cz 46.038                                       $ OC lead punct (mid)
79  cz 50.324                                       $ OC oshell punct (mid)
C
80  cz 252.838                                      $ 2-meter from OC therm
C
777 pz 161.608                                      $ Ring tally (lower)
888 pz 166.688                                      $ Ring tally (upper)
999 sz 164.148 379.838                              $ Outside world

C
C Physics Cards
C
mode p
C
C Source Cards
C
C Cylindrical Sources
sdef pos=d1 erg=d2 par=2 axs=0 0 1 rad=d3 ext=d4
sc1 Cs-137 MeV
C Source Position and Fraction
si1 L 0 0 90.17
      0 0 164.148
      0 0 238.125
sp1   1 1 1
C Source Energy (MeV) and Intensity (%)
si2 L 0.2835 0.661657
sp2 5.8000E-04 8.5100E+01
C Source Radius
si3 0 24.448
sp3 -21 1
C Source Extent
si4 -34.726 34.726
```

```
sp4 -21 0
C
C Tally Cards
C
f2:p 69
fc2 Surface Dose (mrem/hr)                                  $ Surface detector
fs2 888 777 t
sd2 1.0 1686.525 1.0 1.0                                    $ Surface tally area
f22:p 80
fc22 2-meter Dose (mrem/hr)                                 $ 2-m detector
fs22 888 777 t
sd22 1.0 8070.229 1.0 1.0                                   $ Surface tally area
C
C ANSI/ANS-6.1.1-1977 Gamma Flux to Dose Factors (mrem/hr)
de0 1.0e-02 3.0e-02 5.0e-02 7.0e-02 1.0e-01                 $ Energy (Mev)
     1.5e-01 2.0e-01 2.5e-01 3.0e-01 3.5e-01
     4.0e-01 4.5e-01 5.0e-01 5.5e-01 6.0e-01
     6.5e-01 7.0e-01 8.0e-01 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
     11.00 13.00 15.0000
df0 3.96e-03 5.82e-04 2.90e-04 2.58e-04 2.83e-04            $ Conversion (mrem/hr)
     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 Material Cards
C
m1   40000 -1.00                                            $ Zirconium
m2   14000 -0.01                                            $ Stainless Steel
     24000 -0.19
     25000 -0.02
     26000 -0.68
     28000 -0.10
m3   26000 -1.00                                            $ Carbon Steel (iron)
m4   82000 -1.00                                            $ Lead
C
C Runtime and Print Cards
C
prdmp j j 1 2
ctme 20
```

5.1.1.3 Distributed 60C0 Gamma Source with 0.1 g/cc Steel – 7os100.i

```
title RH-TRU 72-B RLC NCT Steel Distributed 0.1 g/cc Co-60
C
C Cell Cards
C
10  1 -0.1        10  -11  -16                imp:p=1    $ Source #1
11  1 -0.1        12  -13  -17                imp:p=1    $ Source #2
12  1 -0.1        14  -15  -18                imp:p=1    $ Source #3
20  0           20  -21  -26
               (-10:  11:  16)              imp:p=1    $ Drum #1 cavity
21  0           22  -23  -27
               (-12:  13:  17)              imp:p=1    $ Drum #2 cavity
22  0           24  -25  -28
               (-14:  15:  18)              imp:p=1    $ Drum #3 cavity
40  0           41  -45  -43
               #10  #11  #12
               #20  #21  #22                imp:p=1    $ RLC cavity
```

```
41  3 -7.85260  40  -41  -42                    imp:p=1    $ RLC base
42  3 -7.85260  41  -46   43  -42               imp:p=1    $ RLC shell
43  3 -7.85260  45  -44  -43                    imp:p=1    $ RLC lid
50  0           51  -53  -55
              (-40:  42:  46)
             :( 44  -46  -43)                   imp:p=1    $ IV cavity
51  2 -8.01280  50  -51  -52                    imp:p=1    $ IV base
52  2 -8.01280  51  -55   53  -52               imp:p=2    $ IV shell
53  2 -8.01280  55  -54  -52                    imp:p=1    $ IV lid
60  0           61  -63  -65
              (-50:  52:  54)                   imp:p=2    $ OC cavity
61  2 -8.01280  60  -61  -69                    imp:p=1    $ OC base
62  2 -8.01280  61  -66   65  -64               imp:p=5    $ OC ishell
63  4 -11.3500  61  -66   64  -76  71           imp:p=3E1  $ OC lead in
64  4 -11.3500  61  -66   76  -68  71           imp:p=3E2  $ OC lead out
65  2 -8.01280  61  -66   68  -77  71           imp:p=3E3  $ OC oshell in
66  2 -8.01280  61  -66   77  -67  71           imp:p=6E3  $ OC oshell out
67  0           61  -66   67  -70  71           imp:p=1E5  $ OC airgap
68  2 -8.01280  61  -66   70  -69  71           imp:p=2E5  $ OC tshell
69  2 -8.01280  66  -63   65  -69               imp:p=1    $ OC flange
70  2 -8.01280  63  -62  -69                    imp:p=1    $ OC lid
71  4 -11.3500  64  -78  -71                    imp:p=3E1  $ OC lead punct in
72  4 -11.3500  78  -73  -71                    imp:p=3E2  $ OC lead punct out
73  2 -8.01280  73  -79  -71                    imp:p=3E3  $ OC oshell punct in
74  2 -8.01280  79  -72  -71                    imp:p=6E3  $ OC oshell punct out
75  0           72  -75  -71                    imp:p=1E5  $ OC airgap punct
76  2 -8.01280  75  -74  -71                    imp:p=2E5  $ OC tshell punct
777 0           69  -80   60  -62               imp:p=2E5  $ Outside to tally
888 0         -999
              (-60:  80:  62)                   imp:p=1E1  $ Outside pkg
999 0           999                             imp:p=0    $ Outside world

C
C Geometry Cards
C
10  pz 53.658                                   $ Source #1 bottom
11  pz 126.683                                  $ Source #1 top
12  pz 127.635                                  $ Source #2 bottom
13  pz 200.66                                   $ Source #2 top
14  pz 201.613                                  $ Source #3 bottom
15  pz 274.638                                  $ Source #3 top
16  c/z 0 0 24.448                              $ Source #1 radius
17  c/z 0 0 24.448                              $ Source #2 radius
18  c/z 0 0 24.448                              $ Source #3 radius
C
20  pz 53.34                                    $ Drum #1 bottom
21  pz 127                                      $ Drum #1 top
22  pz 127.318                                  $ Drum #2 bottom
23  pz 200.978                                  $ Drum #2 top
24  pz 201.295                                  $ Drum #3 bottom
25  pz 274.955                                  $ Drum #3 top
26  c/z 0 0 24.765                              $ Drum #1 radius
27  c/z 0 0 24.765                              $ Drum #2 radius
28  c/z 0 0 24.765                              $ Drum #3 radius
C
40  pz 19.368                                   $ RLC base (outside)
41  pz 20.638                                   $ RLC base (inside)
42  c/z 0 0 33.02                               $ RLC shell (outside)
43  c/z 0 0 32.385                              $ RLC shell (inside)
44  pz 309.563                                  $ RLC lid (outside)
45  pz 307.658                                  $ RLC lid (inside)
46  pz 325.438                                  $ RLC top (outside)
C
50  pz 14.288                                   $ IV base (outside)
51  pz 18.098                                   $ IV base (inside)
52  c/z 0 0 40.64                               $ IV shell (outside)
53  c/z 0 0 39.688                              $ IV shell (inside)
```

```
54  pz 343.218                                  $ IV top (outside)
55  pz 326.708                                  $ IV top (inside)
C
60  pz 0                                        $ OC bottom (outside)
61  pz 12.7                                     $ OC bottom (inside)
62  pz 360.045                                  $ OC top (outside)
63  pz 344.805                                  $ OC top (inside)
64  cz 43.656                                   $ OC ishell (outside)
65  cz 41.116                                   $ OC ishell (inside)
66  pz 320.675                                  $ OC lead (upper)
67  cz 52.229                                   $ OC oshell (outside)
68  cz 48.419                                   $ OC oshell (inside)
69  cz 52.838                                   $ OC therm (outside)
70  cz 52.495                                   $ OC therm (inside)
71  c/x 0 164.148 10.033                        $ OC puncture radius
72  cz 52.229                                   $ OC oshell punct (out)
73  cz 48.419                                   $ OC oshell punct (in)
74  cz 52.838                                   $ OC therm punct (out)
75  cz 52.495                                   $ OC therm punct (in)
76  cz 46.038                                   $ OC lead (mid)
77  cz 50.324                                   $ OC oshell (mid)
78  cz 46.038                                   $ OC lead punct (mid)
79  cz 50.324                                   $ OC oshell punct (mid)
C
80  cz 252.838                                  $ 2-meter from OC therm
C
777 pz 161.608                                  $ Ring tally (lower)
888 pz 166.688                                  $ Ring tally (upper)
999 sz 164.148 379.838                          $ Outside world

C
C Physics Cards
C
mode p
C
C Source Cards
C
C Cylindrical Sources
sdef pos=d1 erg=d2 par=2 axs=0 0 1 rad=d3 ext=d4
sc1 Co-60 MeV
C Source Position and Fraction
si1 L 0 0 90.17
      0 0 164.148
      0 0 238.125
sp1   1 1 1
C Source Energy (MeV) and Intensity (%)
si2 L 3.469300E-01 8.262800E-01 1.173237E+00 1.332501E+00
     2.158770E+00 2.505000E+00
sp2 7.600000E-03 7.600000E-03 9.997360E+01 9.998560E+01
     1.110000E-03 2.000000E-06
C Source Radius
si3 0 24.448
sp3 -21 1
C Source Extent
si4 -36.513 36.513
sp4 -21 0
C
C Tally Cards
C
f2:p 69
fc2 Surface Dose (mrem/hr)                      $ Surface detector
fs2 888 777 t
sd2 1.0 1686.525 1.0 1.0                        $ Surface tally area
f22:p 80
fc22 2-meter Dose (mrem/hr)                     $ 2-m detector
fs22 888 777 t
sd22 1.0 8070.229 1.0 1.0                       $ Surface tally area
```

```
C
C ANSI/ANS-6.1.1-1977 Gamma Flux to Dose Factors (mrem/hr)
de0 1.0e-02 3.0e-02 5.0e-02 7.0e-02 1.0e-01              $ Energy (Mev)
     1.5e-01 2.0e-01 2.5e-01 3.0e-01 3.5e-01
     4.0e-01 4.5e-01 5.0e-01 5.5e-01 6.0e-01
     6.5e-01 7.0e-01 8.0e-01 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
     11.00 13.00 15.0000
df0 3.96e-03 5.82e-04 2.90e-04 2.58e-04 2.83e-04         $ Conversion (mrem/hr)
     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 Material Cards
C
m1   6000  -0.005                                         $ Steel (Carbon)
     26000 -0.995
m2   14000 -0.01                                          $ Stainless Steel
     24000 -0.19
     25000 -0.02
     26000 -0.68
     28000 -0.10
m3   26000 -1.00                                          $ Carbon Steel (iron)
m4   82000 -1.00                                          $ Lead
C
C Runtime and Print Cards
C
prdmp j j 1 2
ctme 20
```

5.1.1.4 Distributed 60C0 Gamma Source with 8.0 g/cc Zirconium – 7oz115.i

```
title RH-TRU 72-B RLC NCT Zirconium Distributed 8 g/cc Co-60
C
C Cell Cards
C
10  1 -8        10  -11  -16                imp:p=1    $ Source #1
11  1 -8        12  -13  -17                imp:p=1    $ Source #2
12  1 -8        14  -15  -18                imp:p=1    $ Source #3
20  0           20  -21  -26
              (-10:  11:  16)               imp:p=1    $ Drum #1 cavity
21  0           22  -23  -27
              (-12:  13:  17)               imp:p=1    $ Drum #2 cavity
22  0           24  -25  -28
              (-14:  15:  18)               imp:p=1    $ Drum #3 cavity
40  0           41  -45  -43
               #10  #11  #12
               #20  #21  #22                imp:p=1    $ RLC cavity
41  3 -7.85260  40  -41  -42                imp:p=1    $ RLC base
42  3 -7.85260  41  -46   43  -42           imp:p=1    $ RLC shell
43  3 -7.85260  45  -44  -43                imp:p=1    $ RLC lid
50  0           51  -53  -55
              (-40:  42:  46)
             :( 44  -46  -43)               imp:p=1    $ IV cavity
51  2 -8.01280  50  -51  -52                imp:p=1    $ IV base
52  2 -8.01280  51  -55   53  -52           imp:p=2    $ IV shell
53  2 -8.01280  55  -54  -52                imp:p=1    $ IV lid
60  0           61  -63  -65
              (-50:  52:  54)               imp:p=2    $ OC cavity
```

```
61  2 -8.01280  60  -61  -69                imp:p=1    $ OC base
62  2 -8.01280  61  -66   65  -64           imp:p=5    $ OC ishell
63  4 -11.3500  61  -66   64  -76  71       imp:p=3E1  $ OC lead in
64  4 -11.3500  61  -66   76  -68  71       imp:p=3E2  $ OC lead out
65  2 -8.01280  61  -66   68  -77  71       imp:p=3E3  $ OC oshell in
66  2 -8.01280  61  -66   77  -67  71       imp:p=6E3  $ OC oshell out
67  0           61  -66   67  -70  71       imp:p=1E5  $ OC airgap
68  2 -8.01280  61  -66   70  -69  71       imp:p=2E5  $ OC tshell
69  2 -8.01280  66  -63   65  -69           imp:p=1    $ OC flange
70  2 -8.01280  63  -62  -69                imp:p=1    $ OC lid
71  4 -11.3500  64  -78  -71                imp:p=3E1  $ OC lead punct in
72  4 -11.3500  78  -73  -71                imp:p=3E2  $ OC lead punct out
73  2 -8.01280  73  -79  -71                imp:p=3E3  $ OC oshell punct in
74  2 -8.01280  79  -72  -71                imp:p=6E3  $ OC oshell punct out
75  0           72  -75  -71                imp:p=1E5  $ OC airgap punct
76  2 -8.01280  75  -74  -71                imp:p=2E5  $ OC tshell punct
777 0           69  -80   60  -62           imp:p=2E5  $ Outside to tally
888 0          -999
              (-60:  80:  62)               imp:p=1E1  $ Outside pkg
999 0           999                         imp:p=0    $ Outside world

C
C Geometry Cards
C
10  pz 55.444                                          $ Source #1 bottom
11  pz 124.896                                         $ Source #1 top
12  pz 129.421                                         $ Source #2 bottom
13  pz 198.874                                         $ Source #2 top
14  pz 203.399                                         $ Source #3 bottom
15  pz 272.851                                         $ Source #3 top
16  c/z 0 0 24.448                                     $ Source #1 radius
17  c/z 0 0 24.448                                     $ Source #2 radius
18  c/z 0 0 24.448                                     $ Source #3 radius
C
20  pz 53.34                                           $ Drum #1 bottom
21  pz 127                                             $ Drum #1 top
22  pz 127.318                                         $ Drum #2 bottom
23  pz 200.978                                         $ Drum #2 top
24  pz 201.295                                         $ Drum #3 bottom
25  pz 274.955                                         $ Drum #3 top
26  c/z 0 0 24.765                                     $ Drum #1 radius
27  c/z 0 0 24.765                                     $ Drum #2 radius
28  c/z 0 0 24.765                                     $ Drum #3 radius
C
40  pz 19.368                                          $ RLC base (outside)
41  pz 20.638                                          $ RLC base (inside)
42  c/z 0 0 33.02                                      $ RLC shell (outside)
43  c/z 0 0 32.385                                     $ RLC shell (inside)
44  pz 309.563                                         $ RLC lid (outside)
45  pz 307.658                                         $ RLC lid (inside)
46  pz 325.438                                         $ RLC top (outside)
C
50  pz 14.288                                          $ IV base (outside)
51  pz 18.098                                          $ IV base (inside)
52  c/z 0 0 40.64                                      $ IV shell (outside)
53  c/z 0 0 39.688                                     $ IV shell (inside)
54  pz 343.218                                         $ IV top (outside)
55  pz 326.708                                         $ IV top (inside)
C
60  pz 0                                               $ OC bottom (outside)
61  pz 12.7                                            $ OC bottom (inside)
62  pz 360.045                                         $ OC top (outside)
63  pz 344.805                                         $ OC top (inside)
64  cz 43.656                                          $ OC ishell (outside)
65  cz 41.116                                          $ OC ishell (inside)
66  pz 320.675                                         $ OC lead (upper)
67  cz 52.229                                          $ OC oshell (outside)
```

```
68  cz 48.419                                          $ OC oshell (inside)
69  cz 52.838                                          $ OC therm (outside)
70  cz 52.495                                          $ OC therm (inside)
71  c/x 0 164.148 10.033                               $ OC puncture radius
72  cz 52.229                                          $ OC oshell punct (out)
73  cz 48.419                                          $ OC oshell punct (in)
74  cz 52.838                                          $ OC therm punct (out)
75  cz 52.495                                          $ OC therm punct (in)
76  cz 46.038                                          $ OC lead (mid)
77  cz 50.324                                          $ OC oshell (mid)
78  cz 46.038                                          $ OC lead punct (mid)
79  cz 50.324                                          $ OC oshell punct (mid)
C
80  cz 252.838                                         $ 2-meter from OC therm
C
777 pz 161.608                                         $ Ring tally (lower)
888 pz 166.688                                         $ Ring tally (upper)
999 sz 164.148 379.838                                 $ Outside world

C
C Physics Cards
C
mode p
C
C Source Cards
C
C Cylindrical Sources
sdef pos=d1 erg=d2 par=2 axs=0 0 1 rad=d3 ext=d4
sc1 Co-60 MeV
C Source Position and Fraction
si1 L 0 0 90.17
      0 0 164.148
      0 0 238.125
sp1   1 1 1
C Source Energy (MeV) and Intensity (%)
si2 L 3.469300E-01 8.262800E-01 1.173237E+00 1.332501E+00
     2.158770E+00 2.505000E+00
sp2 7.600000E-03 7.600000E-03 9.997360E+01 9.998560E+01
     1.110000E-03 2.000000E-06
C Source Radius
si3 0 24.448
sp3 -21 1
C Source Extent
si4 -34.726 34.726
sp4 -21 0
C
C Tally Cards
C
f2:p 69
fc2 Surface Dose (mrem/hr)                             $ Surface detector
fs2 888 777 t
sd2 1.0 1686.525 1.0 1.0                               $ Surface tally area
f22:p 80
fc22 2-meter Dose (mrem/hr)                            $ 2-m detector
fs22 888 777 t
sd22 1.0 8070.229 1.0 1.0                              $ Surface tally area
C
C ANSI/ANS-6.1.1-1977 Gamma Flux to Dose Factors (mrem/hr)
de0 1.0e-02 3.0e-02 5.0e-02 7.0e-02 1.0e-01            $ Energy (Mev)
     1.5e-01 2.0e-01 2.5e-01 3.0e-01 3.5e-01
     4.0e-01 4.5e-01 5.0e-01 5.5e-01 6.0e-01
     6.5e-01 7.0e-01 8.0e-01 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
     11.00 13.00 15.0000
df0 3.96e-03 5.82e-04 2.90e-04 2.58e-04 2.83e-04       $ Conversion (mrem/hr)
```

```
     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 Material Cards
C
m1   40000 -1.00                                    $ Zirconium
m2   14000 -0.01                                    $ Stainless Steel
     24000 -0.19
     25000 -0.02
     26000 -0.68
     28000 -0.10
m3   26000 -1.00                                    $ Carbon Steel (iron)
m4   82000 -1.00                                    $ Lead
C
C Runtime and Print Cards
C
prdmp j j 1 2
ctme 20
```