ENGINEERING DESIGN FILE

ETR Beryllium Reflector and Vessel
Transuranic Inventories

EDF No.: 7222 EDF Rev. No.: 0 Project File No.: ____

1.	Title: ETR Beryllium Reflector and Vessel Transuranic Inventories
2.	Index Codes: Building/Type 642 SSC ID ____ Site Area ETR
3.	NPH Performance Category: ____ or ☒ N/A
4.	EDF Safety Category: ____ or ☒ N/A SCC Safety Category: ____ or ☒ N/A

5. Summary:

The transuranic inventory of the second beryllium reflector irradiated in the Engineering Test Reactor (ETR) has been estimated using a combination of computer modeling and physical sampling as requested by Task Baseline Agreement (TBA) C-276 [1]. This Engineering Design File (EDF) presents the methods, limitations, and results of the computer modeling used to estimate this inventory. The Monte Carlo N-Particle computer code, MCNP (version 5 release 1.30), and the radionuclide generation and depletion computer code, ORIGEN2 (version 2.1), were both used to model and analyze the ETR beryllium reflector. A single point on the top of the ETR reflector was sampled and the data were used to verify and adjust the model results of the entire ETR reflector. The determination of the ETR reflector transuranic activity is necessary to permit the determination of total ETR vessel transuranic activity for disposal purposes.

This analysis determined that the transuranic inventory of the ETR beryllium reflector was 177 nCi/gm. When averaged over the entire ETR vessel ungrouted mass, the transuranic inventory contribution from the beryllium reflector is 1.29 nCi/gm. The total transuranic inventory for the entire vessel including the beryllium is 1.99 nCi/gm.

EDFs are maintained by document control to provide a controlled summary of the analysis performed and results, as well as a retrievable record of the review and approval process of the analysis.

6. Review (R) and Approval (A) and Acceptance (Ac) Signatures:
(See instructions for definitions of terms and significance of signatures.)

	R/A	Typed Name/Organization	Signature	Date
Performer/ Author	N/A	J. R. Parry/C230	J R Parry	9-11-06
Technical Checker	R	M. A. Lillo/C230	M. A. Lillo	9-18-06
Independent Peer Reviewer (if applicable)	R			
Approver	A	F. M. Marshall/C230	Frances Marshall	9-18-06
Requestor (if applicable)	Ac	A. B. Culp	Bruce Culp	9-20-06

ENGINEERING DESIGN FILE
ETR Beryllium Reflector and Vessel
Transuranic Inventories

EDF No.: 7222 EDF Rev. No.: 0 Project File No.:

1. Title: ETR Beryllium Reflector and Vessel Transuranic Inventories

2. Index Codes:

Building/Type 642 SSC ID Site Area ETR

Doc. Control		Kathryn Jenson EROB	Kathryn Jenson	10-2-06

7. Distribution: (Name and Mail Stop) Document Control (MS 7116), A. B. Culp (MS 7141), M. A. Lillo (MS 3870), F. M. Marshall (MS 7101), J. R. Parry (MS 3870)

8. Does document contain sensitive unclassified information? ☐ Yes ☒ No
If Yes, what category:

9. Can document be externally distributed? ☒ Yes ☐ No

10. Uniform File Code: 8205 Disposition Authority: A-17-30-c-1
Record Retention Period: Until dismantlement or disposal of the facility

11. For QA Records Classification Only: ☐ Lifetime ☒ Nonpermanent ☐ Permanent
Item and activity to which the QA Record apply:

12. NRC related? ☐ Yes ☒ No

13. Registered Professional Engineer's Stamp (if required)

Introduction

The transuranic inventory of the second beryllium reflector irradiated in the Engineering Test Reactor (ETR) has been estimated using a combination of computer modeling and physical sampling. This Engineering Design File (EDF) presents the methods, limitations, and results of the computer modeling used to estimate this inventory. The Monte Carlo N-Particle computer code, MCNP, version 5 release 1.30 [2] and the radionuclide generation and depletion computer code, ORIGEN2 version 2.1 [3] were used to model and analyze the ETR beryllium reflector. A single point on the top of the ETR reflector was sampled and the data was used to verify and adjust the model results of the entire ETR reflector. The determination of the ETR reflector transuranic activity is necessary to permit the determination of total ETR vessel transuranic activity for disposal purposes.

Background

The ETR was constructed with a beryllium reflector surrounding the core. The ETR core first went critical in 1957 and was operated from 1958 until 1972, during which it supported water loop testing programs. Conversion of the ETR to support fast breeder reactor programs was started in May 1973. In support of this effort, a sodium loop safety facility (SLSF) was installed in the northeast (NE) quadrant of the ETR core. The first reflector was utilized until March 1970 when it was determined to be embrittled due to radiation damage or hydrogen generation within the beryllium. The first reflector was then replaced with a second new beryllium reflector which was 4.5 inches thick and 37.5 inches high. The second beryllium reflector was constructed with ten slabs stacked on top of each other to form each side. Four of the stacks surrounded the core, resulting in a total of 40 slabs. The first beryllium reflector experienced 380,002 MWd of irradiation while the second reflector experienced about 120,102 MWd of irradiation.

Since it is known that beryllium metal can contain small amounts of uranium as an impurity, it is the purpose of this study to determine the transuranic inventory residing in the second ETR reflector. This determination is based partly on measured data obtained from a beryllium sample taken from the top of the ETR reflector plug, and computer code calculations that extrapolate these measured results to the entire reflector. All measured data were decay corrected to June 2006. Radionuclide inventories were estimated by first creating a detailed computer model of the ETR reactor core and the structures near it. The MCNP code was then used to determine the neutron flux and various neutron reaction rates for each side of the reflector and the reflector plug. Using the calculated neutron flux data, the ORIGEN2 (Version 2.1) code was then used with the average reactor power history, component masses, cross-section data, and the estimated material composition of the beryllium reflector to determine the transuranic radioisotopes that exist in this reflector as of February 2006. The result of this analysis indicates that the average transuranic inventory of the whole reflector is 177 nCi/gm.

Assumptions

Various assumptions were made in order to complete the analysis. The assumptions are listed here along with the effects the assumptions have on the final results.

1. All Cs-137 is produced from the fission of U-235. This assumption provides a conservative estimate of the initial uranium concentration by neglecting contributions from other sources of production such as U-233, U238, Pu-239, etc.

2. All transuranics are produced from the activation of uranium. This assumption provides a conservative estimate of the initial uranium concentration by neglecting contributions from other sources of production such as Th-232.
3. The current beryllium was irradiated in two distinctly separate campaigns [4] with a decay period in between. The first was for 107,726 MWd during 1971 and 1972 before the SLSF was installed, and the second was for 12,376 MWd from 1975 through 1981 after the SLSF was installed. The decay time between campaigns is assumed to be 730 days (Jan.1, 1973 to Jan. 1, 1975).
4. The total MWd of irradiation are averaged over the operating campaign to determine the reactor power for the activation. This causes an error for short lived isotopes, which are of no consequence to this analysis, while the effect on the long-lived isotopes of concern is insignificant.
5. The ratio of the sampled results to the calculated results is applied to the entire ETR reflector.
6. TRU waste is defined [5] as waste containing more than 100 nCi of alpha emitting transuranic isotopes with half-lives greater than 20 years per gram of waste.

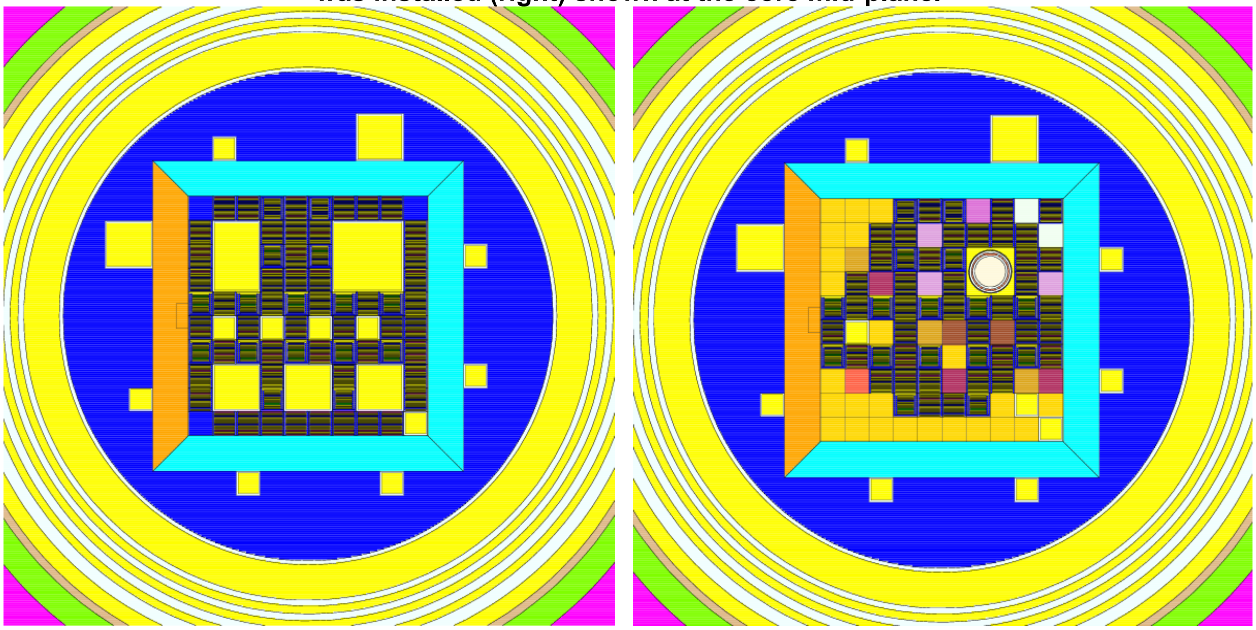
MCNP Model

The model of the ETR was developed using MCNP version 5, release 1.30 and consists of explicitly modeled components and homogenous mixtures in areas deemed appropriate. Dimensions within the model were based on text descriptions from Kaiser et. al. [6] and Phillips Petroleum Company [7], as well as various drawings [8]. The core configuration modeled contained 49 fuel elements (no longer present in the vessel core) and all the In-Pile tubes (IPTs) filled with water. The explicitly modeled components include:

- Fuel plates
- In-Pile tubes
- Control rods
- Control rod guide tubes
- Beryllium reflector (simplified geometry)
- Aluminum reflector (simplified geometry)

The rest of the reactor components were modeled as homogenous mixtures of the major materials in the volume occupied by the component. A cross section view of the ETR core near the mid-plane is shown in Figure 1.

Figure 1: MCNP model of the ETR reactor before the SLSF was installed (left) and after the SLSF was installed (right) shown at the core mid-plane.



Analysis and Calculations

The neutron flux was determined using the full core explicit 3-D MCNP model of the ETR. Neutron flux tallies were configured for each side (North, South, East, and West) of the beryllium reflector. The neutron flux is the average flux for the whole side of the reflector. The material composition for the beryllium reflector is shown in Table 1 [9]. The referenced material analysis did not list uranium as an element for analysis. However, uranium is typically an impurity in beryllium. Thus,10 ppm uranium was added to the beryllium used in the MCNP model as an estimate of the uranium impurity.

Table 1: Beryllium reflector composition.

Element	Impurity w/o
Beryllium	99.618400%
Boron	0.000100%
Carbon	0.060000%
Nitrogen	0.017000%
Magnesium	0.005000%
Aluminum	0.058000%
Silicon	0.032000%
Titanium	0.015000%
Chromium	0.004000%
Manganese	0.014000%
Iron	0.140000%
Cobalt	0.000500%
Nickel	0.027000%
Copper	0.008000%
Uranium	0.001000%

The MCNP model was also used to generate the collapsed 1-group cross section for the various reactions of interest. MCNP calculates a reaction rate of the form $\int \varphi(E)\sigma(E)dE$. Dividing by the integrated flux provides the microscopic cross section for the reaction of interest. The ETR model used standard cross section libraries distributed with the MCNP code.

MCNP reports tally results normalized per fission neutron. The flux tallies have units of neutrons / cm^2 per fission neutron. To scale the results to the reactor operating conditions, the results are multiplied by normalization factors. The normalization factors used for the flux tallies are listed below.

Neutron Flux Normalization Factor

$$\left(\frac{fission\ neutrons}{fission}\right)\left(\frac{fission}{MeV}\right)\left(\frac{MeV}{MW_{core\ power}-s}\right)=Flux\ Normalizaiton \quad (1)$$

$$\left(\frac{2.435\ fission\ neutrons}{fission}\right)\left(\frac{fission}{200\ MeV}\right)\left(\frac{6.2422\times10^{18}\ MeV}{MW_{core\ power}-s}\right)=7.5999\times10^{16}\frac{fission\ neutrons}{MW_{core\ power}-s}$$

The flux, reaction rates, power history, and material composition were input into ORIGEN2 to calculate the isotopic inventory at a specific time. The power history was estimated using ETR documentation [10], [11]. A sample from the second ETR reflector (top of the reflector plug) was taken and analyzed by Southwest Research Institute as detailed in Appendix B to determine the uranium concentration in the beryllium. This concentration was used to calculate the beryllium reflector transuranic inventory and ultimately the ETR vessel transuranic inventory. Since the uranium impurity in the ETR beryllium is unknown, analysis was performed on the sample taken from the top of the reflector plug of the second ETR reflector to determine the uranium concentration in the beryllium. Since this was an irradiated sample, the initial uranium concentration had to be back calculated from the sample results. Within the ORIGEN2 input file, the uranium concentration of the beryllium was adjusted to the calculated value based on the sampling results.

Software

The two computer codes (MCNP, ORIGEN2) used to perform the beryllium transuranic inventory estimate are listed as verified and validated (V&V'd) software in the Idaho National Laboratory (INL) Enterprise Architecture Repository and are accepted as qualified scientific and engineering analysis software. The software V&V tracking numbers are listed in Table 2. The computer configurations used to perform the analysis are listed in Tables 3 and 4.

Table 2: INL qualified analysis software version and tracking number.

Code Name	Version	V&V Tracking Number
MCNP	5 (Release 1.30)	171103
ORIGEN2	2.1	64556

Table 3: Computer configuration for INL qualified MCNP5 installations.

Computer System Name	Computer Model	Processor	Operating System	Property Number
parrjr	Dell Precision 670	Dual Intel Xeon	Windows XP	375414
OZONE	230 Sun Microsystems V20z nodes, two AMD Opteron Model 248 CPUs (2.2GHz) per node, 4GB RAM per node.	AMD Opteron	Mandrake Linux 10.0, gcc version 3.3.2-6.1 mdk, kernel version 2.6.3-11 mdksmp	N/A

Table 4: configuration for INL qualified ORIGEN2 installations.

Computer System Name	Computer Model	Processor	Operating System	Property Number
parrjr	Dell Precision 670	Dual Intel Xeon	Windows XP	375414

Data Retention

The input, output, and data files generated to support this analysis and EDF will be recorded to a CD or DVD and stored within the project file.

Results

Beryllium Reflector Transuranic Activity

The concentration of the uranium in the reflector beryllium was calculated to be 6933 µg/kg or 6.9 ppm. The calculation is shown in Appendix A. The MCNP calculated neutron flux and collapsed 1-group cross sections used for the sample location are shown in Tables 5 and 6. The differences between the sample results and the modeling data are shown in Table 7. The complete sampling results are provided in Appendix B. In 2003, modeling of the Advanced Test Reactor beryllium demonstrated that the methodology used predicts plutonium generation accurately, while the total transuranic inventory is not predicted as accurately. The total transuranic inventory in the report was under predicted by roughly 70%. Therefore, a conservative approach for the prediction of the transuranic inventory in the ETR beryllium incorporates the use of scaling factors calculated from the differences in the sampled data and the modeling data. These scaling factors are also shown in Table 7.

Table 5: Neutron flux at the sample location.

Model	1 MW Flux (n/cm^2-s)
Before SLSF	5.078E+11
After SLSF	2.635E+11

Table 6: Cross sections calculated with MCNP at the sample location.

Isotope	Cross Sections (barns)			
	N,G	N,2N	N,3N or N,A	N,F or N,P
Th-232	5.253E+00	2.051E-03	2.403E-05	8.823E-03
Th-233	7.134E+02	9.162E-03	6.369E-05	9.115E+00
Pa-231	3.609E+01	5.887E-04	1.051E-05	5.546E-02
U-233	2.644E+01	7.177E-04	2.542E-07	2.808E+02
U-234	6.329E+01	2.166E-04	3.962E-06	4.155E-01
U-235	5.173E+01	1.509E-03	1.736E-06	2.935E+02
U-236	8.713E+00	1.065E-03	1.775E-05	1.764E-01
U-237	2.425E+02	3.005E-03	3.540E-05	1.208E+00
U-238	6.420E+00	1.879E-03	1.457E-05	3.621E-02
U-239	1.402E+01	8.169E-03	9.193E-05	1.192E+01
U-240	4.429E+00	4.312E-03	9.724E-05	2.750E-02
Np-235	9.230E+02	5.665E-04	1.067E-05	2.123E-01
Np-236	5.239E+01	1.602E-03	5.523E-06	1.323E+03
Np-237	1.073E+02	4.288E-04	5.764E-07	1.951E-01
Np-238	5.239E+01	1.921E-03	1.115E-05	1.095E+03
Pu-237	2.772E+02	2.959E-04	4.536E-06	1.084E+03
Pu-238	2.706E+02	6.195E-04	1.473E-05	8.803E+00
Pu-239	1.822E+02	8.047E-04	9.615E-07	4.348E+02
Pu-240	3.124E+02	3.253E-04	1.053E-06	2.719E-01
Pu-241	1.958E+02	2.677E-03	4.745E-06	5.651E+02
Pu-242	3.290E+01	8.414E-04	8.460E-06	1.581E-01
Pu-243	4.916E+01	6.567E-03	5.505E-05	1.011E+02
Am-241	3.636E+02	9.602E-05	3.657E-08	2.104E+00
Am-242	7.703E+02	1.522E-03	1.002E-05	3.785E+03
Am-243	7.286E+01	1.062E-04	1.325E-06	2.238E-01
Cm-242	1.043E+01	2.379E-05	6.490E-08	1.646E+00
Cm-243	3.420E+01	1.452E-03	2.134E-06	3.895E+02
Cm-244	1.534E+01	5.032E-04	1.102E-05	7.096E-01
Cm-245	1.634E+02	2.615E-03	1.270E-05	1.071E+03
Cm-246	2.532E+00	6.905E-04	3.103E-05	2.898E-01
Cm-247	4.012E+01	3.976E-03	2.658E-05	5.873E+01
Cm-248	5.645E+00	8.499E-04	3.253E-05	3.830E-01
Bk-249	6.901E+02	1.971E-04	2.782E-06	3.895E+00
Cf-249	2.548E+02	6.634E-04	1.146E-06	8.564E+02
Cf-250	1.062E+03	1.408E-03	2.059E-05	3.484E-01
Cf-251	1.470E+03	4.676E-03	2.862E-05	2.788E+03
Cf-252	1.109E+01	1.104E-03	1.602E-05	1.832E+01

Table 7: Beryllium sample location modeling results.

Isotope	Units	Sampling Results	Uncertainty	% Uncertainty	Modleing Results	Scaling Factor
Cs-137	Ci/gm	5.000E-07	5.500E-08	11.0%	2.347E-07	2.130
Th-232	g/gm	1.623E-07	2.610E-08	16.1%	1.608E-07	1.010
U-233	g/gm	2.730E-09	3.917E-10	14.3%	2.277E-09	1.199
U-234	g/gm	7.860E-10	2.267E-10	28.8%	5.060E-10	1.553
U-235	g/gm	3.943E-09	8.873E-10	22.5%	8.475E-09	0.465
U-236	g/gm	8.200E-09	1.067E-09	13.0%	6.079E-09	1.349
U-238	g/gm	6.533E-06	6.703E-07	10.3%	6.661E-06	0.981
Pu-238	Ci/gm	1.440E-08	1.575E-09	10.9%	2.894E-09	4.976
Pu-239/240	Ci/gm	1.508E-08	1.625E-09	10.8%	1.016E-08	1.484
Pu-241	Ci/gm	3.275E-07	6.825E-08	20.8%	1.813E-07	1.806
Pu-242	g/gm	1.207E-08	1.307E-09	10.8%	2.819E-09	4.281
Am-241	Ci/gm	4.273E-08	3.300E-09	7.7%	2.125E-08	2.011
Am-243	g/gm	7.530E-10	1.250E-10	16.6%	1.099E-10	6.852
Cm-242	Ci/gm	3.025E-10	1.800E-10	59.5%	3.712E-11	8.149
Cm-243/244	Ci/gm	3.800E-09	7.575E-10	19.9%	3.535E-10	10.750
Cm-245	g/gm	1.547E-11	5.083E-11	328.7%	8.50E-14	182
Cm-246	g/gm	2.057E-11	5.143E-11	250.1%	1.16E-14	1781
Cm-247	g/gm	1.557E-11	5.083E-11	326.5%	1.82E-17	856742

Tables 8 through 11 show the modeling results from ORIGEN along with the scaled results using the scaling factors given in Table 7 for each of the four sides of the reflector. Note that even though there are large scaling factors in Table 7, they do not result in large changes in the total transuranic inventory of the beryllium. Also note that the isotopes for plutonium, americium, and curium account for approximately 99% of the TRU inventory. Tables 8 through 11 also include comments on the choice of scaling factors when sample data was not provided for the specific transuranic isotope and therefore a specific scaling factor could not be calculated. The transuranic inventory for the sampled location of the plug is shown in Table 12. The average for the total reflector is shown in Table 13.

Table 8: Transuranic inventory for the ETR reflector North side.

Element	Origen Result (Ci/gm)	Origen Result (nCi/gm)	Scaling Factor Used	Scaled Result (nCi/gm)	Comments
Np-237	6.20E-13	6.20E-04	4.976	3.08E-03	Used the largest scaling factor for the uraniums and plutoniums.
Pu-238	2.09E-08	2.09E+01	4.976	1.04E+02	Pu-238 scaling factor.
Pu-239	3.90E-09	3.90E+00	1.484	5.78E+00	Pu-239/240 scaling factor.
Pu-240	9.11E-09	9.11E+00	1.484	1.35E+01	Pu-239/240 scaling factor.
Pu-242	1.35E-10	1.35E-01	4.281	5.76E-01	Pu-242 scaling factor.
Pu-244	6.54E-17	6.54E-08	4.976	3.26E-07	Largest plutonium scaling factor.
Am-241	4.18E-08	4.18E+01	2.011	8.41E+01	Am-241 scaling factor.
Am-242M	2.51E-10	2.51E-01	6.852	1.72E+00	Largest americium scaling factor.
Am-243	1.09E-09	1.09E+00	6.852	7.45E+00	Am-243 scaling factor.
Cm-243	1.03E-10	1.03E-01	10.750	1.11E+00	Cm-243/244 scaling factor.
Cm-245	6.51E-12	6.51E-03	182	1.18E+00	Cm-245 scaling factor.
Cm-246	9.74E-12	9.74E-03	1781	1.73E+01	Cm-246 scaling factor.
Cm-247	2.05E-17	2.05E-08	856742	1.75E-02	Cm-247 scaling factor.
Cm-248	1.12E-16	1.12E-07	856742	9.61E-02	Largest curium scaling factor.
Cm-250	5.69E-24	5.69E-15	856742	4.87E-09	Largest curium scaling factor.
Cf-249	4.44E-16	4.44E-07	856742	3.81E-01	Largest curium scaling factor.
Cf-251	1.12E-17	1.12E-08	856742	9.60E-03	Largest curium scaling factor.
Total	7.73E-08	77		237	

Table 9: Transuranic inventory for the ETR reflector South side.

Element	Origen Result (Ci/gm)	Origen Result (nCi/gm)	Scaling Factor Used	Scaled Result (nCi/gm)	Comments
Np-237	3.34E-13	3.34E-04	4.976	1.66E-03	Used the largest scaling factor for the uraniums and plutoniums.
Pu-238	7.94E-09	7.94E+00	4.976	3.95E+01	Pu-238 scaling factor.
Pu-239	4.16E-09	4.16E+00	1.484	6.18E+00	Pu-239/240 scaling factor.
Pu-240	6.86E-09	6.86E+00	1.484	1.02E+01	Pu-239/240 scaling factor.
Pu-242	1.84E-11	1.84E-02	4.281	7.89E-02	Pu-242 scaling factor.
Pu-244	4.23E-19	4.23E-10	4.976	2.10E-09	Largest plutonium scaling factor.
Am-241	2.74E-08	2.74E+01	2.011	5.50E+01	Am-241 scaling factor.
Am-242M	1.23E-10	1.23E-01	6.852	8.43E-01	Largest americium scaling factor.
Am-243	4.93E-11	4.93E-02	6.852	3.38E-01	Am-243 scaling factor.
Cm-243	1.80E-11	1.80E-02	10.750	1.93E-01	Cm-243/244 scaling factor.
Cm-245	4.94E-14	4.94E-05	182	8.98E-03	Cm-245 scaling factor.
Cm-246	1.59E-14	1.59E-05	1781	2.83E-02	Cm-246 scaling factor.
Cm-247	1.00E-20	1.00E-11	856742	8.59E-06	Cm-247 scaling factor.
Cm-248	1.40E-20	1.40E-11	856742	1.20E-05	Largest curium scaling factor.
Cm-250	1.49E-29	1.49E-20	856742	1.27E-14	Largest curium scaling factor.
Cf-249	3.05E-20	3.05E-11	856742	2.61E-05	Largest curium scaling factor.
Cf-251	3.30E-22	3.30E-13	856742	2.83E-07	Largest curium scaling factor.
Total	4.65E-08	47		112	

Table 10: Transuranic inventory for the ETR reflector West side.

Element	Origen Result (Ci/gm)	Origen Result (nCi/gm)	Scaling Factor Used	Scaled Result (nCi/gm)	Comments
Np-237	4.89E-13	4.89E-04	4.976	2.43E-03	Used the largest scaling factor for the uraniums and plutoniums.
Pu-238	1.41E-08	1.41E+01	4.976	7.04E+01	Pu-238 scaling factor.
Pu-239	4.06E-09	4.06E+00	1.484	6.02E+00	Pu-239/240 scaling factor.
Pu-240	8.31E-09	8.31E+00	1.484	1.23E+01	Pu-239/240 scaling factor.
Pu-242	5.06E-11	5.06E-02	4.281	2.16E-01	Pu-242 scaling factor.
Pu-244	4.35E-18	4.35E-09	4.976	2.17E-08	Largest plutonium scaling factor.
Am-241	3.78E-08	3.78E+01	2.011	7.59E+01	Am-241 scaling factor.
Am-242M	1.97E-10	1.97E-01	6.852	1.35E+00	Largest americium scaling factor.
Am-243	2.22E-10	2.22E-01	6.852	1.52E+00	Am-243 scaling factor.
Cm-243	4.84E-11	4.84E-02	10.750	5.21E-01	Cm-243/244 scaling factor.
Cm-245	4.74E-13	4.74E-04	182	8.63E-02	Cm-245 scaling factor.
Cm-246	2.87E-13	2.87E-04	1781	5.11E-01	Cm-246 scaling factor.
Cm-247	3.00E-19	3.00E-10	856742	2.57E-04	Cm-247 scaling factor.
Cm-248	7.30E-19	7.30E-10	856742	6.26E-04	Largest curium scaling factor.
Cm-250	3.88E-27	3.88E-18	856742	3.32E-12	Largest curium scaling factor.
Cf-249	2.10E-18	2.10E-09	856742	1.80E-03	Largest curium scaling factor.
Cf-251	3.48E-20	3.48E-11	856742	2.98E-05	Largest curium scaling factor.
Total	6.48E-08	65		169	

Table 11: Transuranic inventory for the ETR reflector East side.

Element	Origen Result (Ci/gm)	Origen Result (nCi/gm)	Scaling Factor Used	Scaled Result (nCi/gm)	Comments
Np-237	5.05E-13	5.05E-04	4.976	2.51E-03	Used the largest scaling factor for the uraniums and plutoniums.
Pu-238	1.75E-08	1.75E+01	4.976	8.69E+01	Pu-238 scaling factor.
Pu-239	4.14E-09	4.14E+00	1.484	6.14E+00	Pu-239/240 scaling factor.
Pu-240	8.48E-09	8.48E+00	1.484	1.26E+01	Pu-239/240 scaling factor.
Pu-242	5.44E-11	5.44E-02	4.281	2.33E-01	Pu-242 scaling factor.
Pu-244	4.40E-18	4.40E-09	4.976	2.19E-08	Largest plutonium scaling factor.
Am-241	3.91E-08	3.91E+01	2.011	7.86E+01	Am-241 scaling factor.
Am-242M	2.33E-10	2.33E-01	6.852	1.60E+00	Largest americium scaling factor.
Am-243	2.50E-10	2.50E-01	6.852	1.72E+00	Am-243 scaling factor.
Cm-243	6.05E-11	6.05E-02	10.750	6.51E-01	Cm-243/244 scaling factor.
Cm-245	5.78E-13	5.78E-04	182	1.05E-01	Cm-245 scaling factor.
Cm-246	3.58E-13	3.58E-04	1781	6.37E-01	Cm-246 scaling factor.
Cm-247	3.96E-19	3.96E-10	856742	3.39E-04	Cm-247 scaling factor.
Cm-248	1.01E-18	1.01E-09	856742	8.64E-04	Largest curium scaling factor.
Cm-250	3.85E-27	3.85E-18	856742	3.30E-12	Largest curium scaling factor.
Cf-249	3.06E-18	3.06E-09	856742	2.62E-03	Largest curium scaling factor.
Cf-251	5.39E-20	5.39E-11	856742	4.62E-05	Largest curium scaling factor.
Total	6.98E-08	70		189	

Table 12: Transuranic inventory for the sample location of the beryllium plug.

Element	Origen Result (Ci/gm)	Origen Result (nCi/gm)	Scaling Factor Used	Scaled Result (nCi/gm)	Comments
Np-237	2.71E-13	2.71E-04	4.976	1.35E-03	Used the largest scaling factor for the uraniums and plutoniums.
Pu-238	2.82E-09	2.82E+00	4.976	1.40E+01	Pu-238 scaling factor.
Pu-239	4.19E-09	4.19E+00	1.484	6.22E+00	Pu-239/240 scaling factor.
Pu-240	5.88E-09	5.88E+00	1.484	8.72E+00	Pu-239/240 scaling factor.
Pu-242	1.04E-11	1.04E-02	4.281	4.45E-02	Pu-242 scaling factor.
Pu-244	2.03E-19	2.03E-10	4.976	1.01E-09	Largest plutonium scaling factor.
Am-241	2.12E-08	2.12E+01	2.011	4.25E+01	Am-241 scaling factor.
Am-242M	4.49E-11	4.49E-02	6.852	3.08E-01	Largest americium scaling factor.
Am-243	2.10E-11	2.10E-02	6.852	1.44E-01	Am-243 scaling factor.
Cm-243	7.29E-12	7.29E-03	10.750	7.84E-02	Cm-243/244 scaling factor.
Cm-245	1.42E-14	1.42E-05	182	2.58E-03	Cm-245 scaling factor.
Cm-246	3.35E-15	3.35E-06	1781	5.96E-03	Cm-246 scaling factor.
Cm-247	1.60E-21	1.60E-12	856742	1.37E-06	Cm-247 scaling factor.
Cm-248	1.67E-21	1.67E-12	856742	1.43E-06	Largest curium scaling factor.
Cm-250	3.30E-30	3.30E-21	856742	2.83E-15	Largest curium scaling factor.
Cf-249	3.07E-21	3.07E-12	856742	2.63E-06	Largest curium scaling factor.
Cf-251	2.68E-21	2.68E-12	856742	2.29E-06	Largest curium scaling factor.
Total	3.41E-08	34		72	

Table 13: Average transuranic inventory for the whole ETR reflector.

Element	Origen Result (Ci/gm)	Origen Result (nCi/gm)	Scaling Factor Used	Scaled Result (nCi/gm)	Comments
Np-237	4.87E-13	4.87E-04	4.98E+00	2.42E-03	Used the largest scaling factor for the uraniums and plutoniums.
Pu-238	1.51E-08	1.51E+01	4.98E+00	7.51E+01	Pu-238 scaling factor.
Pu-239	4.06E-09	4.06E+00	1.48E+00	6.03E+00	Pu-239/240 scaling factor.
Pu-240	8.19E-09	8.19E+00	1.48E+00	1.21E+01	Pu-239/240 scaling factor.
Pu-242	6.45E-11	6.45E-02	4.28E+00	2.76E-01	Pu-242 scaling factor.
Pu-244	1.87E-17	1.87E-08	4.98E+00	9.28E-08	Largest plutonium scaling factor.
Am-241	3.65E-08	3.65E+01	2.01E+00	7.34E+01	Am-241 scaling factor.
Am-242M	2.01E-10	2.01E-01	6.85E+00	1.38E+00	Largest americium scaling factor.
Am-243	4.02E-10	4.02E-01	6.85E+00	2.76E+00	Am-243 scaling factor.
Cm-243	5.75E-11	5.75E-02	1.08E+01	6.18E-01	Cm-243/244 scaling factor.
Cm-245	1.90E-12	1.90E-03	1.82E+02	3.46E-01	Cm-245 scaling factor.
Cm-246	2.60E-12	2.60E-03	1.78E+03	4.63E+00	Cm-246 scaling factor.
Cm-247	5.29E-18	5.29E-09	8.57E+05	4.54E-03	Cm-247 scaling factor.
Cm-248	2.85E-17	2.85E-08	8.57E+05	2.44E-02	Largest curium scaling factor.
Cm-250	1.42E-24	1.42E-15	8.57E+05	1.22E-09	Largest curium scaling factor.
Cf-249	1.12E-16	1.12E-07	8.57E+05	9.63E-02	Largest curium scaling factor.
Cf-251	2.82E-18	2.82E-09	1.82E-17	5.13E-26	Largest curium scaling factor.
Total	6.46E-08	65		177	

The results above contain some conservative assumptions made when quantities were not explicitly known. These conservative assumptions along with an explanation are listed below.

- The scaling factors were determined by calculating a ratio using the sampled data and the modeled results for the specified sampled region.
- The initial mass of the uranium included measured Cs-137 concentration, the uranium, and the actinide concentrations (all isotopes were decay corrected to 1981).
- All Cs-137 was assumed to originate from U-235, neglecting any fission contribution from U-233. The yield of Cs-137 from U-235 fission is 6.19%, which is lower than the yield from either Pu-239 fission at 6.61% or U-233 fission at 6.76%, thus increasing the initial uranium concentration.
- All isotopes above U-233 (decay corrected to 1981) were assumed to have originated from uranium atoms, neglecting the activation of Th-232 and other isotopes.
- All the sample data was assumed to be accurate and used as reported.
- Although the uncertainty in some of the curium data (Cm-245, Cm246, Cm247) is as much as ± 300%, the largest scaling factor was used for Cm-248, Cm-250, Cf-249, and Cf-251.
- If a scaling factor was not available for a specific isotope, the largest scaling factor for that element was used. If there was not a scaling factor for any isotopes of the same element (e.g. Np-237, all californium isotopes), the largest scaling factor from the element with the closest atomic number was used.
- With only one sampling position, it was assumed the scaling factors used to to match the ORIGEN2 results to the measured results were applicable for the whole reflector.
- Because of the heterogeneous nature of the flux, the measured sample data could not be propagated directly through the reflector. Not only does the magnitude of the flux change throughout the reflector, but the spectrum, and therefore the effective reaction cross sections, also change. The sampled data was taken in a lower flux region with a slightly softened flux due to the moderator above the reflector. It could not represent the highest flux, hardest spectrum region (roughly the inner side of the reflector in the middle of the north side) or the lowest flux softest spectrum region (roughly the outer side of the reflector in the southwest upper corner). Using the modeled results and adjusting the values by applying the scaling factors, the scaled results are more conservative and more accurate than applying the raw sampled data to the entire reflector.

Vessel Transuranic Activity

The transuranic activity of the ETR vessel includes the contribution of the transuranics from the beryllium reflector and the other activated components.

The transuranic activity in the reflector was determined to be 9.59 $x10^7$ nCi. It was obtained by multiplying the average transuranic specific activity for the reflector, 177 nCi/gm, by the total beryllium mass, 5.424 $x10^5$ gm [12].

The transuranic activity for the other activated components in the vessel was determined to be 5.25 $x10^7$ nCi. It was calculated using the total vessel source term of 59,273 Ci [13] and the scaling factors reported in EDF-6958 [14]. An explanation of the use of the scaling factors was provided by C. A. Nesshoefer [15]. The scaling factors extracted from EDF-6958 are provided in Appendix E.

The total transuranic activity for the ETR reactor is 1.484 $x10^8$ nCi, the sum of transuranic activities for both the reflector and other activated components in the vessel.

Using the total metal mass of the ungrouted ETR vessel, 7.4535 $x10^7$ gm [12], the total transuranic specific activity for the ETR vessel is determined to be 1.99 nCi/gm. The total transuranic inventory was calculated using data from EDF-6133 with the exception that the beryllium reflector transuranic data was replaced with transuranic concentrations based on beryllium sample data. The beryllium reflector TRU inventory contribution and the remainder of the reactor TRU inventory in the total vessel TRU inventory is listed by isotope in Table 14.

Table 14: Vessel TRU inventory contribution by isotope.

Element	Origen Result (nCi/gm)	Scaling Factor Used	Scaled Result (nCi/gm)	Total TRU in Reflector (nCi)	Total TRU in Remainder of Reactor (nCi)	Beryllium Contribution to Vessel TRU Inventory (nCi/gm)	Remainder of Reactor Contribution to Vessel TRU Inventory (nCi/gm)	Total (nCi/gm)
Np-237	4.87E-04	4.98E+00	2.42E-03	1.31E+03	2.61E+02	1.76E-05	3.50E-06	2.11E-05
Pu-238	1.51E+01	4.98E+00	7.51E+01	4.08E+07	5.69E+06	5.47E-01	7.63E-02	6.23E-01
Pu-239	4.06E+00	1.48E+00	6.03E+00	3.27E+06	5.53E+06	4.39E-02	7.42E-02	1.18E-01
Pu-240	8.19E+00	1.48E+00	1.21E+01	6.59E+06	4.14E+06	8.84E-02	5.55E-02	1.44E-01
Pu-242	6.45E-02	4.28E+00	2.76E-01	1.50E+05	8.73E+03	2.01E-03	1.17E-04	2.13E-03
Pu-244	1.87E-08	4.98E+00	9.28E-08	5.03E-02	1.30E-02	6.75E-10	1.74E-10	8.50E-10
Am-241	3.65E+01	2.01E+00	7.34E+01	3.98E+07	2.23E+07	5.34E-01	3.00E-01	8.34E-01
Am-242M	2.01E-01	6.85E+00	1.38E+00	7.47E+05		1.00E-02		1.00E-02
Am-243	4.02E-01	6.85E+00	2.76E+00	1.49E+06	5.71E+04	2.01E-02	7.67E-04	2.08E-02
Cm-243	5.75E-02	1.08E+01	6.18E-01	3.35E+05	2.21E+04	4.50E-03	2.96E-04	4.79E-03
Cm-244	--	--	--	--	1.47E+07	--	1.97E-01	1.97E-01
Cm-245	1.90E-03	1.82E+02	3.46E-01	1.88E+05	3.47E+03	2.52E-03	4.66E-05	2.57E-03
Cm-246	2.60E-03	1.78E+03	4.63E+00	2.51E+06	1.91E+04	3.37E-02	2.56E-04	3.39E-02
Cm-247	5.29E-09	8.57E+05	4.54E-03	2.46E+03	2.54E-01	3.30E-05	3.41E-09	3.30E-05
Cm-248	2.85E-08	8.57E+05	2.44E-02	1.32E+04	7.44E+00	1.78E-04	9.99E-08	1.78E-04
Cm-250	1.42E-15	8.57E+05	1.22E-09	6.62E-04	--	8.88E-12	--	8.88E-12
Cf-249	1.12E-07	8.57E+05	9.63E-02	5.22E+04	--	7.01E-04	--	7.01E-04
Cf-251	2.82E-09	1.82E-17	5.13E-26	2.78E-20	--	3.73E-28	--	3.73E-28
Total	6.46E+01		1.77E+02	9.59E+07	5.25E+07	1.29	0.70	1.99E+00

References

[1] Task Baseline Agreement C-276, "ETR Beryllium Reflector Computer Analysis," October 2005.

[2] Tim Goorley, Jeff Bull, Forrest Brown, et. al., "Release of MCNP5_RSICC_1.30," MCNP Monte Carlo Team X-5, LA-UR-04-4519, Los Alamos National Laboratory, November 2004.

[3] A. G. Croff, "ORIGEN2: A Versatile Computer Code for Calculating the Nuclide Compositions and Characteristics of Nuclear Materials," Nuclear Technology, Vol. 62, pp. 335-352, (1983).

[4] G. R. Longhurst, "Radiological Characterization of ETR for Disposal," EDF-4986, Rev. 1, Idaho National Engineering and Environmental Laboratory, May 2005.

[5] Memorandum Order, Case No. CV 91-054-s-EJL, United States District Court for the District of Idaho, May 2006.

[6] L. L. Kaiser, R. L. Rolfe, B. J. Sneed, E. L. Wills, "Characterization of the Engineering Test Reactor Facility," EG&G Idaho, Inc., September 1982.

[7] "Fundamentals in the Operation of Nuclear Test Reactors," Phillips Petroleum Company, Atomic energy Division.

[8] Engineering Test Reactor drawings,

- 400579, "Guide Tube Control Rod ETR"
- 126220, 55-4694-7, "Reactor Pressure Vessel Internal Thermal Shield"
- 126218, 55-4694-5, "Reactor Pressure Vessel Inner Reactor Tank"
- 126214, 55-4694-1, "Reactor Pressure Vessel Assembly"
- 101082, ETR-5528-MTR-642-M-771, "Beryllium Reflector Assembly"
- 101060, ETR-5528-MTR-642-M-726, "Regulating Rod Drive Assembly"
- 100963, ETR-5528-MTR-642-M-34, "Reactor Building External Thermal Shield Assembly + Sections"
- 021103, ETR-E-1724, "ETR Reac Cont SP Latch Cont Rod Gray Poison Sect Assy & Details"
- 020688, ETR-E-1390, "ETR Reac Cont SP Latch Cont Rod Cadmium Poison Sect Assy"
- 020624, ETR-E-1257, "ETR Reac Cont SP Latch Cont Rod Shock Sect Assy"
- 020126, ETR-D-1052, "ETR Reg Rod Cadmium Poison Sect Assy"

[9] Letter from The Brush Beryllium Company to Idaho Nuclear Corporation, February, 1970. (See Appendix C.)

[10] E. H. Smith, et al., 1970, *ETR Operations Branch Progress Report for Cycle No. 105 November 7, 1969—January 11, 1970*, IN-1373.

[11] L. L. Kaiser, R. L. Rolfe, B. J. Sneed, and E. L. Wills, 1982, *Characterization of the Engineering Test Reactor Facility—September 1982*, EGG-PR-5784, EG&G, Idaho National Engineering Laboratory.

[12] H. A. Heidkamp, "Engineering Test Reactor Vessel and Internal Components' Volumes and Weights," EDF-6060, Rev. 0, Idaho Cleanup Project, October 2005.

[13] C. A. Nesshoefer, "ETR Reactor Source Term and External Dose Rates," EDF-6133, Rev. 0, Idaho Cleanup Project, October 2005.

[14] C. A. Nesshoefer, “Release of D&D Building Structural Waste,” EDF-6958, Rev. 1, Idaho Cleanup Project, October 2005.

[15] C. A. Nesshoefer, email to J. R. Parry September 2006. (See Appendix D.)

Appendix A

Initial Uranium Mass Calculation for the Beryllium Reflector.

Uranium Mass Content Back Calculation

Constants

$N_A := 6.022142 \cdot 10^{23}$ $\mu g := 1 \cdot 10^{-6} \cdot gm$

$Ci := 3.7 \cdot 10^{10} \cdot Bq$

$pCi := 1 \cdot 10^{-12} \cdot Ci$ $nCi := 1 \cdot 10^{-9} \cdot Ci$ $\mu Ci := 1 \cdot 10^{-6} \cdot Ci$ $mCi := 1 \cdot 10^{-3} \cdot Ci$

Atomic Mass

$A_{Th232} := 232.038050 \cdot gm$

$A_{U233} := 233.039628 \cdot gm$ $A_{U234} := 234.040946 \cdot gm$ $A_{U235} := 235.043923 \cdot gm$

$A_{U236} := 236.045562 \cdot gm$ $A_{U238} := 238.050783 \cdot gm$

$A_{Pu242} := 242.058737 \cdot gm$

$A_{Am243} := 243.061373 \cdot gm$

$A_{Cm245} := 245.065486 \cdot gm$ $A_{Cm246} := 246.067218 \cdot gm$ $A_{Cm247} := 247.070347 \cdot gm$

Percent Abundance

$Abund_{U234} := 0.0055\%$ $Abund_{U235} := 0.7200\%$

$Abund_{U238} := 99.2745\%$

Time From June 2006 to November 1981

$Dec\_Time := (2005 - 1981) \cdot 365.25 \cdot day + 182 \cdot day$ $Dec\_Time = 7.731072 \times 10^{8}\ s$

Half Lifes

$Cs137_H := 30.07 \cdot yr$ $Th232_H := 1.4 \cdot 10^{10} \cdot yr$

$U233_H := 1.592 \cdot 10^5 \cdot yr$ $U234_H := 2.46 \cdot 10^5 \cdot yr$ $U235_H := 7.04 \cdot 10^8 \cdot yr$ $U236_H := 2.342 \cdot 10^7 \cdot yr$

$U238_H := 4.47 \cdot 10^9 \cdot yr$

$Pu238_H := 87.7 \cdot yr$ $Pu239_H := 2.410 \cdot 10^4 \cdot yr$ $Pu240_H := 6.56 \cdot 10^3 \cdot yr$ $Pu241_H := 14.4 \cdot yr$

$Pu242_H := 3.75 \cdot 10^5 \cdot yr$

$Am241_H := 432.7 \cdot yr$ $Am243_H := 737 \cdot 10^3 \cdot yr$ $Cm242_H := 162.8 \cdot day$ $Cm244_H := 18.1 \cdot yr$

$Cm245_H := 8.5 \cdot 10^3 \cdot yr$ $Cm246_H := 4.76 \cdot 10^3 \cdot yr$ $Cm247_H := 1.56 \cdot 10^7 \cdot yr$

$\lambda_{Cs137} := \frac{\ln(2)}{Cs137_H}$

$\lambda_{U233} := \frac{\ln(2)}{U233_H}$ $\lambda_{U234} := \frac{\ln(2)}{U234_H}$ $\lambda_{U235} := \frac{\ln(2)}{U235_H}$ $\lambda_{U236} := \frac{\ln(2)}{U236_H}$

$\lambda_{U238} := \frac{\ln(2)}{U238_H}$

$\lambda_{Pu238} := \frac{\ln(2)}{Pu238_H}$ $\lambda_{Pu239} := \frac{\ln(2)}{Pu239_H}$ $\lambda_{Pu240} := \frac{\ln(2)}{Pu240_H}$ $\lambda_{Pu241} := \frac{\ln(2)}{Pu241_H}$

$\lambda_{Pu242} := \frac{\ln(2)}{Pu242_H}$

$\lambda_{Am241} := \frac{\ln(2)}{Am241_H}$ $\lambda_{Am243} := \frac{\ln(2)}{Am243_H}$ $\lambda_{Cm242} := \frac{\ln(2)}{Cm242_H}$ $\lambda_{Cm244} := \frac{\ln(2)}{Cm244_H}$

$\lambda_{Cm245} := \frac{\ln(2)}{Cm242_H}$ $\lambda_{Cm246} := \frac{\ln(2)}{Cm244_H}$ $\lambda_{Cm247} := \frac{\ln(2)}{Cm242_H}$

Cs-137 Fission Yields

$Yield_{U233} := 6.76\%$ $Yield_{U235} := 6.19\%$ $Yield_{Pu239} := 6.61\%$

SWRI Measured Concentrations

Cs-137

$Cs137_1 := 427900 \cdot \frac{pCi}{gm}$ $\Delta Cs137_1 := 47000 \cdot \frac{pCi}{gm}$

$Cs137_2 := 508000 \cdot \frac{pCi}{gm}$ $\Delta Cs137_2 := 56000 \cdot \frac{pCi}{gm}$

$Cs137_3 := 522000 \cdot \frac{pCi}{gm}$ $\Delta Cs137_3 := 57000 \cdot \frac{pCi}{gm}$

$Cs137_4 := 542000 \cdot \frac{pCi}{gm}$ $\Delta Cs137_4 := 60000 \cdot \frac{pCi}{gm}$

$$Cs137 := \frac{Cs137_1 + Cs137_2 + Cs137_3 + Cs137_4}{4} \qquad \Delta Cs137 := \frac{\Delta Cs137_1 + \Delta Cs137_2 + \Delta Cs137_3 + \Delta Cs137_4}{4}$$

$$Cs137 = 499975 \frac{pCi}{gm} \qquad \Delta Cs137 = 55000 \frac{pCi}{gm} \qquad \frac{\Delta Cs137}{Cs137} = 11.00055\%$$

Th-232

$Th232_1 := 113 \cdot \frac{\mu g}{kg}$ $\Delta Th232_1 := 21.2 \cdot \frac{\mu g}{kg}$

$Th232_2 := 178 \cdot \frac{\mu g}{kg}$ $\Delta Th232_2 := 27.8 \cdot \frac{\mu g}{kg}$

$Th232_3 := 196 \cdot \frac{\mu g}{kg}$ $\Delta Th232_3 := 29.4 \cdot \frac{\mu g}{kg}$

$$Th232 := \frac{Th232_1 + Th232_2 + Th232_3}{3} \qquad \Delta Th232 := \frac{\Delta Th232_1 + \Delta Th232_2 + \Delta Th232_3}{3}$$

$$Th232 = 162.333333 \frac{\mu g}{kg} \qquad \Delta Th232 = 26.133333 \frac{\mu g}{kg} \qquad \frac{\Delta Th232}{Th232} = 16.098563\%$$

U-233

$U233_1 := 2.23 \cdot \frac{\mu g}{kg}$ $\Delta U233_1 := 0.341 \cdot \frac{\mu g}{kg}$

$U233_2 := 3.18 \cdot \frac{\mu g}{kg}$ $\Delta U233_2 := 0.438 \cdot \frac{\mu g}{kg}$

$U233_3 := 2.78 \cdot \frac{\mu g}{kg}$ $\Delta U233_3 := 0.396 \cdot \frac{\mu g}{kg}$

$U233 := \frac{U233_1 + U233_2 + U233_3}{3}$ $\Delta U233 := \frac{\Delta U233_1 + \Delta U233_2 + \Delta U233_3}{3}$

$U233 = 2.73 \times 10^{-9} \frac{gm}{gm}$ $\Delta U233 = 3.916667 \times 10^{-10} \frac{gm}{gm}$ $\frac{\Delta U233}{U233} = 14.346764\%$

U-234

$U234_1 := 0.830 \cdot \frac{\mu g}{kg}$ $\Delta U234_1 := 0.231 \cdot \frac{\mu g}{kg}$

$U234_2 := 0.724 \cdot \frac{\mu g}{kg}$ $\Delta U234_2 := 0.222 \cdot \frac{\mu g}{kg}$

$U234_3 := 0.803 \cdot \frac{\mu g}{kg}$ $\Delta U234_3 := 0.227 \cdot \frac{\mu g}{kg}$

$U234 := \frac{U234_1 + U234_2 + U234_3}{3}$ $\Delta U234 := \frac{\Delta U234_1 + \Delta U234_2 + \Delta U234_3}{3}$

$U234 = 0.785667 \frac{\mu g}{kg}$ $\Delta U234 = 0.226667 \frac{\mu g}{kg}$ $\frac{\Delta U234}{U234} = 28.850233\%$

U-235

$U235_1 := 3.96 \cdot \frac{\mu g}{kg}$ $\Delta U235_1 := 0.888 \cdot \frac{\mu g}{kg}$

$U235_2 := 3.73 \cdot \frac{\mu g}{kg}$ $\Delta U235_2 := 0.870 \cdot \frac{\mu g}{kg}$

$U235_3 := 4.14 \cdot \frac{\mu g}{kg}$ $\Delta U235_3 := 0.904 \cdot \frac{\mu g}{kg}$

$U235\_1 := \frac{U235_1 + U235_2 + U235_3}{3}$ $\Delta U235\_1 := \frac{\Delta U235_1 + \Delta U235_2 + \Delta U235_3}{3}$

$U235\_1 = 3.943333 \frac{\mu g}{kg}$ $\Delta U235\_1 = 0.887333 \frac{\mu g}{kg}$ $\frac{\Delta U235\_1}{U235\_1} = 22.502113\,\%$

$U235_4 := 690 \cdot \frac{pCi}{gm}$ $\Delta U235_4 := 960 \cdot \frac{pCi}{gm}$

$U235_5 := 660 \cdot \frac{pCi}{gm}$ $\Delta U235_5 := 850 \cdot \frac{pCi}{gm}$

$U235_6 := 50 \cdot \frac{pCi}{gm}$ $\Delta U235_6 := 890 \cdot \frac{pCi}{gm}$

$U235_7 := 20 \cdot \frac{pCi}{gm}$ $\Delta U235_7 := 860 \cdot \frac{pCi}{gm}$

$U235\_2 := \frac{U235_4 + U235_5 + U235_6 + U235_7}{4}$ $\Delta U235\_2 := \frac{\Delta U235_4 + \Delta U235_5 + \Delta U235_6 + \Delta U235_7}{4}$

$U235\_2 = 355 \frac{pCi}{gm}$ $\Delta U235\_2 = 890 \frac{pCi}{gm}$ $\frac{\Delta U235\_2}{U235\_2} = 250.704225\,\%$

U-236

$U236_1 := 9.35 \cdot \frac{\mu g}{kg}$ $\Delta U236_1 := 1.18 \cdot \frac{\mu g}{kg}$

$U236_2 := 7.90 \cdot \frac{\mu g}{kg}$ $\Delta U236_2 := 1.04 \cdot \frac{\mu g}{kg}$

$U236_3 := 7.35 \cdot \frac{\mu g}{kg}$ $\Delta U236_3 := 0.980 \cdot \frac{\mu g}{kg}$

$U236 := \frac{U236_1 + U236_2 + U236_3}{3}$ $\Delta U236 := \frac{\Delta U236_1 + \Delta U236_2 + \Delta U236_3}{3}$

$U236 = 8.2 \frac{\mu g}{kg}$ $\Delta U236 = 1.066667 \frac{\mu g}{kg}$ $\frac{\Delta U236}{U236} = 13.00813\,\%$

U-238

$U238_1 := 6460 \cdot \frac{\mu g}{kg}$ $\Delta U238_1 := 663 \cdot \frac{\mu g}{kg}$

$U238_2 := 6650 \cdot \frac{\mu g}{kg}$ $\Delta U238_2 := 682 \cdot \frac{\mu g}{kg}$

$U238_3 := 6489 \cdot \frac{\mu g}{kg}$ $\Delta U238_3 := 666 \cdot \frac{\mu g}{kg}$

$U238 := \frac{U238_1 + U238_2 + U238_3}{3}$ $\Delta U238 := \frac{\Delta U238_1 + \Delta U238_2 + \Delta U238_3}{3}$

$U238 = 6533 \frac{\mu g}{kg}$ $\Delta U238 = 670.333333 \frac{\mu g}{kg}$ $\frac{\Delta U238}{U238} = 10.260728\,\%$

Pu-238

$Pu238_1 := 11600 \cdot \frac{pCi}{gm}$ $\Delta Pu238_1 := 1300 \cdot \frac{pCi}{gm}$

$Pu238_2 := 14600 \cdot \frac{pCi}{gm}$ $\Delta Pu238_2 := 1700 \cdot \frac{pCi}{gm}$

$Pu238_3 := 15900 \cdot \frac{pCi}{gm}$ $\Delta Pu238_3 := 1600 \cdot \frac{pCi}{gm}$

$Pu238_4 := 15500 \cdot \frac{pCi}{gm}$ $\Delta Pu238_4 := 1700 \cdot \frac{pCi}{gm}$

$Pu238 := \frac{Pu238_1 + Pu238_2 + Pu238_3 + Pu238_4}{4}$ $\Delta Pu238 := \frac{\Delta Pu238_1 + \Delta Pu238_2 + \Delta Pu238_3 + \Delta Pu238_4}{4}$

$Pu238 = 14400 \frac{pCi}{gm}$ $\Delta Pu238 = 1575 \frac{pCi}{gm}$ $\frac{\Delta Pu238}{Pu238} = 10.9375\,\%$

Pu-239 & Pu-240

$Pu3940_1 := 14900 \cdot \frac{pCi}{gm}$ $\Delta Pu3940_1 := 1600 \cdot \frac{pCi}{gm}$

$Pu3940_2 := 15300 \cdot \frac{pCi}{gm}$ $\Delta Pu3940_2 := 1700 \cdot \frac{pCi}{gm}$

$Pu3940_3 := 14400 \cdot \frac{pCi}{gm}$ $\Delta Pu3940_3 := 1500 \cdot \frac{pCi}{gm}$

$Pu3940_4 := 15700 \cdot \frac{pCi}{gm}$ $\Delta Pu3940_4 := 1700 \cdot \frac{pCi}{gm}$

$Pu3940 := \frac{Pu3940_1 + Pu3940_2 + Pu3940_3 + Pu3940_4}{4}$ $\Delta Pu3940 := \frac{\Delta Pu3940_1 + \Delta Pu3940_2 + \Delta Pu3940_3 + \Delta Pu3940_4}{4}$

$Pu3940 = 15075 \frac{pCi}{gm}$ $\Delta Pu3940 = 1625 \frac{pCi}{gm}$ $\frac{\Delta Pu3940}{Pu3940} = 10.779436\,\%$

Pu-241

$Pu241_1 := 256000 \cdot \frac{pCi}{gm}$ $\Delta Pu241_1 := 63000 \cdot \frac{pCi}{gm}$

$Pu241_2 := 312000 \cdot \frac{pCi}{gm}$ $\Delta Pu241_2 := 71000 \cdot \frac{pCi}{gm}$

$Pu241_3 := 359000 \cdot \frac{pCi}{gm}$ $\Delta Pu241_3 := 68000 \cdot \frac{pCi}{gm}$

$Pu241_4 := 383000 \cdot \frac{pCi}{gm}$ $\Delta Pu241_4 := 71000 \cdot \frac{pCi}{gm}$

$Pu241 := \frac{Pu241_1 + Pu241_2 + Pu241_3 + Pu241_4}{4}$ $\Delta Pu241 := \frac{\Delta Pu241_1 + \Delta Pu241_2 + \Delta Pu241_3 + \Delta Pu241_4}{4}$

$Pu241 = 327500 \frac{pCi}{gm}$ $\Delta Pu241 = 68250 \frac{pCi}{gm}$ $\frac{\Delta Pu241}{Pu241} = 20.839695\,\%$

Pu-242

$Pu242_1 := 13.6 \cdot \frac{\mu g}{kg}$ $\Delta Pu242_1 := 1.46 \cdot \frac{\mu g}{kg}$

$Pu242_2 := 12.8 \cdot \frac{\mu g}{kg}$ $\Delta Pu242_2 := 1.38 \cdot \frac{\mu g}{kg}$

$Pu242_3 := 9.8 \cdot \frac{\mu g}{kg}$ $\Delta Pu242_3 := 1.08 \cdot \frac{\mu g}{kg}$

$Pu242 := \frac{Pu242_1 + Pu242_2 + Pu242_3}{3}$ $\Delta Pu242 := \frac{\Delta Pu242_1 + \Delta Pu242_2 + \Delta Pu242_3}{3}$

$Pu242 = 12.066667 \frac{\mu g}{kg}$ $\Delta Pu242 = 1.306667 \frac{\mu g}{kg}$ $\frac{\Delta Pu242}{Pu242} = 10.828729\,\%$

Am-241

$Am241_1 := 41600 \cdot \frac{pCi}{gm}$ $\Delta Am241_1 := 3200 \cdot \frac{pCi}{gm}$

$Am241_2 := 44500 \cdot \frac{pCi}{gm}$ $\Delta Am241_2 := 3400 \cdot \frac{pCi}{gm}$

$Am241_3 := 43900 \cdot \frac{pCi}{gm}$ $\Delta Am241_3 := 3300 \cdot \frac{pCi}{gm}$

$Am241_4 := 47100 \cdot \frac{pCi}{gm}$ $\Delta Am241_4 := 3500 \cdot \frac{pCi}{gm}$

$Am241_5 := 36700 \cdot \frac{pCi}{gm}$ $\Delta Am241_5 := 2900 \cdot \frac{pCi}{gm}$

$Am241_6 := 41500 \cdot \frac{pCi}{gm}$ $\Delta Am241_6 := 3300 \cdot \frac{pCi}{gm}$

$Am241_7 := 41100 \cdot \frac{pCi}{gm}$ $\Delta Am241_7 := 3300 \cdot \frac{pCi}{gm}$

$Am241_8 := 45400 \cdot \frac{pCi}{gm}$ $\Delta Am241_8 := 3500 \cdot \frac{pCi}{gm}$

$$Am241 := \frac{Am241_1 + Am241_2 + Am241_3 + Am241_4 + Am241_5 + Am241_6 + Am241_7 + Am241_8}{8}$$

$$Am241 = 42725 \frac{pCi}{gm}$$

$$\Delta Am241 := \frac{\Delta Am241_1 + \Delta Am241_2 + \Delta Am241_3 + \Delta Am241_4 + \Delta Am241_5 + \Delta Am241_6 + \Delta Am241_7 + \Delta Am241_8}{8}$$

$\Delta Am241 = 3300 \frac{pCi}{gm}$ $\frac{\Delta Am241}{Am241} = 7.723815\%$

Am-243

$Am243_1 := 0.903 \cdot \frac{\mu g}{kg}$ $\Delta Am243_1 := 0.140 \cdot \frac{\mu g}{kg}$

$Am243_2 := 0.789 \cdot \frac{\mu g}{kg}$ $\Delta Am243_2 := 0.129 \cdot \frac{\mu g}{kg}$

$Am243_3 := 0.567 \cdot \frac{\mu g}{kg}$ $\Delta Am243_3 := 0.106 \cdot \frac{\mu g}{kg}$

$Am243 := \frac{Am243_1 + Am243_2 + Am243_3}{3}$ $\Delta Am243 := \frac{\Delta Am243_1 + \Delta Am243_2 + \Delta Am243_3}{3}$

$Am243 = 0.753 \frac{\mu g}{kg}$ $\Delta Am243 = 0.125 \frac{\mu g}{kg}$ $\frac{\Delta Am243}{Am243} = 16.600266\,\%$

Cm-242

$Cm242_1 := 260 \cdot \frac{pCi}{gm}$ $\Delta Cm242_1 := 170 \cdot \frac{pCi}{gm}$

$Cm242_2 := 210 \cdot \frac{pCi}{gm}$ $\Delta Cm242_2 := 140 \cdot \frac{pCi}{gm}$

$Cm242_3 := 410 \cdot \frac{pCi}{gm}$ $\Delta Cm242_3 := 210 \cdot \frac{pCi}{gm}$

$Cm242_4 := 330 \cdot \frac{pCi}{gm}$ $\Delta Cm242_4 := 200 \cdot \frac{pCi}{gm}$

$Cm242 := \frac{Cm242_1 + Cm242_2 + Cm242_3 + Cm242_4}{4}$ $\Delta Cm242 := \frac{\Delta Cm242_1 + \Delta Cm242_2 + \Delta Cm242_3 + \Delta Cm242_4}{4}$

$Cm242 = 302.5 \frac{pCi}{gm}$ $\Delta Cm242 = 180 \frac{pCi}{gm}$ $\frac{\Delta Cm242}{Cm242} = 59.504132\,\%$

Cm-243 & Cm-244

$Cm2434_1 := 2190 \cdot \frac{pCi}{gm}$ $\Delta Cm2434_1 := 620 \cdot \frac{pCi}{gm}$

$Cm2434_2 := 4010 \cdot \frac{pCi}{gm}$ $\Delta Cm2434_2 := 800 \cdot \frac{pCi}{gm}$

$Cm2434_3 := 4480 \cdot \frac{pCi}{gm}$ $\Delta Cm2434_3 := 810 \cdot \frac{pCi}{gm}$

$Cm2434_4 := 4520 \cdot \frac{pCi}{gm}$ $\Delta Cm2434_4 := 800 \cdot \frac{pCi}{gm}$

$$Cm2434 := \frac{Cm2434_1 + Cm2434_2 + Cm2434_3 + Cm2434_4}{4}$$

$$\Delta Cm2434 := \frac{\Delta Cm2434_1 + \Delta Cm2434_2 + \Delta Cm2434_3 + \Delta Cm2434_4}{4}$$

$Cm2434 = 3800 \frac{pCi}{gm}$ $\Delta Cm2434 = 757.5 \frac{pCi}{gm}$ $\frac{\Delta Cm2434}{Cm2434} = 19.934211\,\%$

Cm-245

$Cm245_1 := 0.0162 \cdot \frac{\mu g}{kg}$ $\Delta Cm245_1 := 0.0508 \cdot \frac{\mu g}{kg}$

$Cm245_2 := 0.0150 \cdot \frac{\mu g}{kg}$ $\Delta Cm245_2 := 0.0512 \cdot \frac{\mu g}{kg}$

$Cm245_3 := 0.0152 \cdot \frac{\mu g}{kg}$ $\Delta Cm245_3 := 0.0505 \cdot \frac{\mu g}{kg}$

$$Cm245 := \frac{Cm245_1 + Cm245_2 + Cm245_3}{3}$$

$$\Delta Cm245 := \frac{\Delta Cm245_1 + \Delta Cm245_2 + \Delta Cm245_3}{3}$$

$Cm245 = 0.015467 \frac{\mu g}{kg}$ $\Delta Cm245 = 0.050833 \frac{\mu g}{kg}$ $\frac{\Delta Cm245}{Cm245} = 328.663793\,\%$

Cm-246

$Cm246_1 := 0.0163 \cdot \frac{\mu g}{kg}$ $\quad \Delta Cm246_1 := 0.0508 \cdot \frac{\mu g}{kg}$

$Cm246_2 := 0.0301 \cdot \frac{\mu g}{kg}$ $\quad \Delta Cm246_2 := 0.0527 \cdot \frac{\mu g}{kg}$

$Cm246_3 := 0.0153 \cdot \frac{\mu g}{kg}$ $\quad \Delta Cm246_3 := 0.0508 \cdot \frac{\mu g}{kg}$

$$Cm246 := \frac{Cm246_1 + Cm246_2 + Cm246_3}{3} \qquad \Delta Cm246 := \frac{\Delta Cm246_1 + \Delta Cm246_2 + \Delta Cm246_3}{3}$$

$$Cm246 = 0.020567 \frac{\mu g}{kg} \qquad \Delta Cm246 = 0.051433 \frac{\mu g}{kg} \qquad \frac{\Delta Cm246}{Cm246} = 250.081037\,\%$$

Cm-247

$Cm247_1 := 0.0163 \cdot \frac{\mu g}{kg}$ $\quad \Delta Cm247_1 := 0.0508 \cdot \frac{\mu g}{kg}$

$Cm247_2 := 0.0151 \cdot \frac{\mu g}{kg}$ $\quad \Delta Cm247_2 := 0.0512 \cdot \frac{\mu g}{kg}$

$Cm247_3 := 0.0153 \cdot \frac{\mu g}{kg}$ $\quad \Delta Cm247_3 := 0.0505 \cdot \frac{\mu g}{kg}$

$$Cm247 := \frac{Cm247_1 + Cm247_2 + Cm247_3}{3} \qquad \Delta Cm247 := \frac{\Delta Cm247_1 + \Delta Cm247_2 + \Delta Cm247_3}{3}$$

$$Cm247 = 0.015567 \frac{\mu g}{kg} \qquad \Delta Cm247 = 0.050833 \frac{\mu g}{kg} \qquad \frac{\Delta Cm247}{Cm247} = 326.552463\,\%$$

Atoms November 1981

$$Atom_{Cs137} := \frac{Cs137}{\exp(-\lambda_{Cs137} \cdot Dec\_Time)} \cdot \frac{1}{\lambda_{Cs137}} \qquad Atom_{Cs137} = 4.45461 \times 10^{13} \frac{1}{gm}$$

$$Fis\_U235_{Cs137} := \frac{Atom_{Cs137}}{Yield_{U235}} \qquad Fis\_U235_{Cs137} = 7.196461 \times 10^{14} \frac{1}{gm}$$

$$Atom_{Th232} := \frac{Th232}{A_{Th232}} \cdot N_A \qquad Atom_{Th232} = 4.213078 \times 10^{14} \frac{1}{gm}$$

$$Atom_{U233} := \frac{U233}{A_{U233}} \cdot N_A \qquad Atom_{U233} = 7.054786 \times 10^{12} \frac{1}{gm}$$

$$Atom_{U234} := \frac{U234}{A_{U234}} \cdot N_A \qquad Atom_{U234} = 2.02161 \times 10^{12} \frac{1}{gm}$$

$$Atom_{U235} := \frac{U235_1}{A_{U235}} \cdot N_A \qquad Atom_{U235} = 1.014605 \times 10^{13} \frac{1}{gm}$$

$$Atom_{U236} := \frac{U236}{A_{U236}} \cdot N_A \qquad Atom_{U236} = 2.092035 \times 10^{13} \frac{1}{gm}$$

$$Atom_{U238} := \frac{U238}{A_{U238}} \cdot N_A \qquad Atom_{U238} = 1.6527 \times 10^{16} \frac{1}{gm}$$

$$Atom_{Utotal} := Atom_{U234} + Atom_{U235} + Atom_{U236} + Atom_{U238}$$

$$Atom_{Utotal} = 1.656009 \times 10^{16} \frac{1}{gm}$$

$$Atom_{Pu238} := \frac{Pu238}{\exp(-\lambda_{Pu238} \cdot Dec\_Time)} \cdot \frac{1}{\lambda_{Pu238}} \qquad Atom_{Pu238} = 2.581815 \times 10^{12} \frac{1}{gm}$$

$$Atom_{Pu3940} := \frac{Pu3940}{\exp(-\lambda_{Pu240} \cdot Dec\_Time)} \cdot \frac{1}{\lambda_{Pu240}} \qquad Atom_{Pu3940} = 1.670153 \times 10^{14} \frac{1}{gm}$$

$$Atom_{Pu241} := \frac{Pu241}{\exp(-\lambda_{Pu241} \cdot Dec\_Time)} \cdot \frac{1}{\lambda_{Pu241}} \qquad Atom_{Pu241} = 2.583384 \times 10^{13} \frac{1}{gm}$$

$$Atom_{Pu242} := \frac{Pu242}{A_{Pu242}} \cdot N_A \qquad Atom_{Pu242} = 3.002047 \times 10^{13} \frac{1}{gm}$$

$$Atom_{Pu\_total} := Atom_{Pu238} + Atom_{Pu3940} + Atom_{Pu241} + Atom_{Pu242}$$

$$Atom_{Pu\_total} = 2.254515 \times 10^{14} \frac{1}{gm}$$

$$Atom_{Am241} := \frac{Am241}{\exp(-\lambda_{Am241} \cdot Dec\_Time)} \cdot \frac{1}{\lambda_{Am241}} \qquad Atom_{Am241} = 3.238797 \times 10^{13} \frac{1}{gm}$$

$$Atom_{Am243} := \frac{Am243}{A_{Am243}} \cdot N_A \qquad Atom_{Am243} = 1.865649 \times 10^{12} \frac{1}{gm}$$

$$Atom_{Amtotal} := Atom_{Am241} + Atom_{Am243} \qquad Atom_{Amtotal} = 3.425362 \times 10^{13} \frac{1}{gm}$$

$$Atom_{Cm242} := \frac{Cm242}{\exp(-\lambda_{Cm242} \cdot Dec\_Time)} \cdot \frac{1}{\lambda_{Cm242}} \qquad Atom_{Cm242} = 7.976733 \times 10^{24} \frac{1}{gm}$$

$$Atom_{Cm2434} := \frac{Cm2434}{\exp(-\lambda_{Cm244} \cdot Dec\_Time)} \cdot \frac{1}{\lambda_{Cm244}} \qquad Atom_{Cm2434} = 2.960635 \times 10^{11} \frac{1}{gm}$$

$$Atom_{Cm245} := \frac{Cm245}{A_{Cm245}} \cdot N_A \qquad Atom_{Cm245} = 3.800717 \times 10^{10} \frac{1}{gm}$$

$$Atom_{Cm246} := \frac{Cm246}{A_{Cm246}} \cdot N_A \qquad Atom_{Cm246} = 5.033396 \times 10^{10} \frac{1}{gm}$$

$$Atom_{Cm247} := \frac{Cm247}{A_{Cm247}} \cdot N_A \qquad Atom_{Cm247} = 3.79425 \times 10^{10} \frac{1}{gm}$$

$$Atom_{Cmtotal} := Atom_{Cm2434} + Atom_{Cm245} + Atom_{Cm246} + Atom_{Cm247}$$

$$Atom_{Cmtotal} = 4.223472 \times 10^{11} \frac{1}{gm}$$

Assume all Pu, Am, and Cm isotopes originate from uranium and all Cs-137 is from U235 fission.
Uranium in the beryllium must be natural abundance.
Assume all U233 came from Th-232

Thorium Atoms

$$Atom_{Thtotal} := Atom_{Th232} + Atom_{U233}$$

$$Atom_{Thtotal} = 4.283626 \times 10^{17} \frac{1}{kg}$$

$$Mass_{Th} := \frac{Atom_{Thtotal} \cdot A_{Th232}}{N_A}$$

$$Mass_{Th} = 165.0516 \frac{\mu g}{kg}$$

Uranium atoms

$$Atoms_{Unat} := Fis\_U235_{Cs137} + Atom_{Utotal} + Atom_{Pu\_total} + Atom_{Amtotal} + Atom_{Cmtotal}$$

$$Atoms_{Unat} = 1.753986 \times 10^{16} \frac{1}{gm}$$

$$Atoms_{U234} := Abund_{U234} \cdot Atoms_{Unat}$$

$$Atoms_{U234} = 9.646924 \times 10^{14} \frac{1}{kg}$$

$$Mass_{U234} := \frac{Atoms_{U234} \cdot A_{U234}}{N_A}$$

$$Mass_{U234} = 0.374912 \frac{\mu g}{kg}$$

$$Atoms_{U235} := Abund_{U235} \cdot Atoms_{Unat}$$

$$Atoms_{U235} = 1.26287 \times 10^{17} \frac{1}{kg}$$

$$Mass_{U235} := \frac{Atoms_{U235} \cdot A_{U235}}{N_A}$$

$$Mass_{U235} = 49.28976 \frac{\mu g}{kg}$$

$$Atoms_{U238} := Abund_{U238} \cdot Atoms_{Unat}$$

$$Atoms_{U238} = 1.741261 \times 10^{19} \frac{1}{kg}$$

$$Mass_{U238} := \frac{Atoms_{U238} \cdot A_{U238}}{N_A}$$

$$Mass_{U238} = 6883.074986 \frac{\mu g}{kg}$$

$$Mass_U := Mass_{U234} + Mass_{U235} + Mass_{U238}$$

$$Mass_U = 6932.739658 \frac{\mu g}{kg}$$

Appendix B

Table 15: SWRI beryllium sample analysis results.

LABORATORY ANALYSES OF ETR BERYLLIUM REFLECTOR SAMPLE				ANALYSES								
				#1		#2		#3		#4		
Radioisotopes	Laboratory Technique	EPA SW-846 Method	MDA or Reporting Limit	Sample TRA782019A	TPU	Laboratory Matrix QC Duplicate	TPU	Sample TRA782029A	TPU	Laboratory Matrix QC Duplicate	TPU	Sample Average
Am-241	Alpha Spec	NA	220/150 pCi/g	41,600 pCi/g	3200 pCi/g	44,500 pCi/g	3400 pCi/g	43,900 pCi/g	3300 pCi/g	47,100 pCi/g	3500 pCi/g	44,275 pCi/g
Am-241	Gamma Spec	NA	1700/ pCi/g	36,700 pCi/g	2900 pCi/g	41,500 pCi/g	3300 pCi/g	41,100 pCi/g	3300 pCi/g	45,400 pCi/g	3500 pCi/g	41,175 pCi/g
Am-243	ICP-MS	Method 6020 modified	0.1 ug/kg	0.903 ug/kg	0.14 ug/kg	0.789 ug/kg	0.129 ug/kg	0.567 ug/kg	0.106 ug/kg	—	—	0.753 ug/kg
Pu-238	Alpha Spec	NA	220/200 pCi/g	11,600 pCi/g	1300 pCi/g	14,600 pCi/g	1700 pCi/g	15,900 pCi/g	1600 pCi/g	15,500 pCi/g	1700 pCi/g	14,400 pCi/g
Pu-239/-240	Alpha Spec	NA	69/64 pCi/g	14,900 pCi/g	1600 pCi/g	15,300 pCi/g	1700 pCi/g	14,400 pCi/g	1500 pCi/g	15,700 pCi/g	1700 pCi/g	15,075 pCi/g
Pu-241	Beta LSC	NA	61,000/57,000 pCi/g	256,000 pCi/g	63,000 pCi/g	312,000 pCi/g	71,000 pCi/g	359,000 pCi/g	68,000 pCi/g	383,000 pCi/g	71,000 pCi/g	327,500 pCi/g
Pu-242	ICP-MS	Method 6020 modified	0.2 uCi/g	13.6 ug/kg	1.46 ug/kg	12.8 ug/kg	1.38 ug/kg	9.8 ug/kg	1.08 ug/kg	—	—	12.1 ug/kg
Cm-242	Alpha Spec	NA	0.05 pCi/g	260 pCi/g	170 pCi/g	210 pCi/g	140 pCi/g	410 pCi/g	210 pCi/g	330 pCi/g	200 pCi/g	302.5 pCi/g
Cm-243/-244	Alpha Spec	NA	150/210 pCi/g	2190 pCi/g	620 pCi/g	4010 pCi/g	800 pCi/g	4480 pCi/g	810 pCi/g	4520 pCi/g	800 pCi/g	3800 pCi/g
Cm-245	ICP-MS	Method 6020	0.10 ug/kg	0.0162 ug/kg (U)	0.0508 ug/kg	0.0150 ug/kg (U)	0.0512 ug/kg	0.0152 ug/kg (U)	0.0505 ug/kg	—	—	Below RL
Cm-246	ICP-MS	Method 6020	0.10 ug/kg	0.0163 ug/kg (U)	0.0508 ug/kg	0.0301 ug/kg (U)	0.0527 ug/kg	0.0153 ug/kg (U)	0.0508 ug/kg	—	—	Below RL
Cm-247	ICP-MS	Method 6020	0.10 ug/kg	0.0163 ug/kg (U)	0.0508 ug/kg	0.0151 ug/kg (U)	0.0512 ug/kg	0.0153 ug/kg (U)	0.0505 ug/kg	—	—	Below RL
U-233	ICP-MS	Method 6020 modified	0.24 ug/kg	2.23 ug/kg	0.341 ug/kg	3.18 ug/kg	0.438 ug/kg	2.78 ug/kg	0.396 ug/kg	—	—	2.73 ug/kg
U-234	ICP-MS	Method 6020 modified	0.30 ug/kg	0.83 ug/kg	0.231 ug/kg	0.724 ug/kg	0.222 ug/kg	0.803 ug/kg	0.227 ug/kg	—	—	0.786 ug/kg
U-235	ICP-MS	Method 6020 modified	1.0 ug/kg	3.96 ug/kg	0.888 ug/kg	3.73 ug/kg	0.870 ug/kg	4.14 ug/kg	0.904 ug/kg	—	—	3.94 ug/kg
U-235	Gamma Spec	NA	1600/1400 pCi/g	690 pCi/g (U)	960 pCi/g	660 pCi/g (U)	850 pCi/g	50 pCi/g (U)	890 pCi/g	20 pCi/g (U)	860 pCi/g	Below MDA
U-236	ICP-MS	Method 6020 modified	0.5 ug/kg	9.35 ug/kg	1.18 ug/kg	7.90 ug/kg	1.04 ug/kg	7.35 ug/kg	0.980 ug/kg	—	—	8.2 ug/kg
U-238	ICP-MS	Method 6020 modified	34.0 ug/kg	6460 ug/kg	663 ug/kg	6650 ug/kg	682 ug/kg	6489 ug/kg	666 ug/kg	—	—	6533 ug/kg
U (total)	ICP-MS	Method 6020 modified	34.0 ug/kg	6453 ug/kg	662 ug/kg	6641 ug/kg	681 ug/kg	6480 ug/kg	665 ug/kg	—	—	6525 ug/kg
Be-10	ICP-MS	Method 6020 modified	0.200 mg/kg	14.2 mg/kg	1.62 mg/kg	14.2 mg/kg	1.62 mg/kg	14.4 mg/kg	1.64 mg/kg	—	—	14.27 mg/kg
Be-7	Gamma Spec	NA	28,000 pCi/g	(-) 21000 (U)	17,000 pCi/g	(-) 3800 (U)	8600 pCi/g	2000 pCi/g	16,000 pCi/g	(-) 11000 (U)	16,000 pCi/g	Below MDA
H-3	Beta LSC	NA	6.2 E+04/6.1 E+04 pCi/g	2.15 E+08 pCi/g	1.0 E+07 pCi/g	2.11 E+08 pCi/g	1.0 E+07 pCi/g	1.97 E+08 pCi/g	9.5E+06 pCi/g	2.22 E+08 pCi/g	1.1E+07 pCi/g	2.11 E+08 pCi/g
Mn-54	Gamma Spec	NA	3400/3200 pCi/g	(-) 2000 pCi/g (U)	2100 pCi/g	900 pCi/g (U)	1700 pCi/g	1300 pCi/g (U)	1900 pCi/g	(-) 900 pCi/g (U)	1900 pCi/g	Below MDA
C-14	Beta LSC	NA	71/65 pCi/g	26,590 pCi/g	1762 pCi/g	—	—	22,170 pCi/g	1514 pCi/g	17,520 pCi/g	1346 pCi/g	22,093 pCi/g
Co-60	Gamma Spec	NA	1400/1200 pCi/g	6,930,000 pCi/g	360,000 pCI/g	5,220,000 pCi/g	270,000 pCI/g	5,470,000 pCi/g	290,000 pCI/g	5,280,000 pCi/g	280,000 pCI/g	5,725,000 pCi/g
Nb-93	ICP-MS	Method 6020 modified	0.020 mg/kg	1.28 mg/kg (J)	0.137 mg/kg	1.30 mg/kg	0.14 mg/kg	1.26 mg/kg (J)	0.136 mg/kg	—	—	1.28 mg/kg
Nb-94	ICP-MS	Method 6020 modified	0.020 mg/kg	(-) 0.0117 mg/kg R	0.011 mg/kg	0.0125 mg/kg (U)	0.0112 mg/kg	0.00643 mg/kg R	0.0104 mg/kg	—	—	Below RL
N-14	CHN An. as total N	ASTM D5291	0.05%	<0.05%	—	<0.05%	—	<0.05%	—	—	—	<0.05%
Cs-137	Gamma Spec	NA	2600/2400 pCi/g	427,900 pCi/g	47,000 pCi/g	508,000 pCi/g	56,000 pCi/g	522,000 pCi/g	57,000 pCi/g	542,000 pCi/g	60,000 pCi/g	499,975 pCi/g
Ni-59	ICP-MS	Method 6020 modified	0.08 mg/kg	2.33 mg/kg	0.272 mg/kg	2.15 mg/kg	0.255 mg/kg	1.93 mg/kg	0.233 mg/kg	—	—	2.91 mg/kg
Ni-63	ICP-MS	Method 6020 modified	0.02 mg/kg	0.427 mg/kg	0.0526 mg/kg	0.266mg/kg	0.0365 mg/kg	0.341 mg/kg	0.0439 mg/kg	—	—	0.345 mg/kg
Tc-99	ICP-MS	Method 6020 modified	10 pCi/g	169 pCi/g	41.5 pCi/g	167 pCi/g	41.6 pCi/g	140 pCi/g	38.5 pCi/g	—	—	158.7 pCi/g
Sr-90	Gas Flow Proport.	NA	337/382 pCi/g	163,000 pCi/g	11,000 pCi/g	173,000 pCi/g	11,000 pCi/g	197,000 pCi/g	13,000 pCi/g	202,000 pCi/g	13,000 pCi/g	183,750 pCi/g
I-129	ICP-MS	Method 6020 modified	2.00 mg/kg	0.186 mg/kg (UJ)	0.63 mg/kg	0.673 mg/kg (U)	0.631 mg/kg	0.615 mg/kg (UJ)	0.908 mg/kg	—	—	Below RL
K-40	Gamma Spec	NA	10,000 pCi/g	(-) 2700 pCi/g (U)	6200 pCi/g	(-) 4800 pCi/g (U)	5400 pCi/g	4500 pCi/g (U)	5600 pCi/g	(-) 1900 pCi/g (U)	5500 pCi/g	Below MDA
Th-232	ICP-MS	Method 6020 modified	20.0 ug/kg	113 ug/kg	21.2 ug/kg	178 ug/kg	27.8 ug/kg	196 ug/kg	29.4 ug/kg	—	—	162.3 ug/kg

Table Notations:

- **"U" qualifiers indicate than an analyte was not detected above the laboratory's reporting limit.**
- **"R" qualifiers mean the accuracy of the data is so questionable that it is recomended the data not be used.**

- **"UJ" qualifiers indicates that the material was analyzed for, but was not detected. The associated value is an estimate and may be inaccurate or imprecise.**
- **"J" qualifiers indicate the material was analyzed for and was detected at or above the applicable detection limit. The associated value is an estimate and may be inaccurate or imprecise.**
- **"RL" stands for reporting limit.**
- **"MDA" stands for minimum detectable activity.**
- **"TPU" stands for total propagated uncertainty. The TPU is expressed as ± value(s) reported at 1 sigma. For example, if the sample value is 5 and the TPU is 1.05, then the sample result should be regarded as 5 ±1.05, indicating that the value could be 6.05 or 3.95 at 1 sigma and 7.1 or 2.9 at 2 sigma.**

Appendix C

THE BRUSH BERYLLIUM COMPANY
17876 ST. CLAIR AVENUE
CLEVELAND, OHIO 44110
486-4200

CABLE ADDRESS
BRUSH CLEVELAND

TELETYPE (TWX)
810-421-8828

February 19, 1970

FEB 24 12 54 PM '70
RECEIVED
MATERIEL BRANCH

Idaho Nuclear Corporation
Post Office Box 1845
Idaho Falls, Idaho 83401

Atten: Mr. Harold Sudweeks

Subject: INC Purchase Order S-7086
Brush Sales Order D196

Reference: INC/BBC Telecon of 2/17/70

Gentlemen:

Your comments concerning the X-ray film for tensile bars, chemical analysis for titanium on sample #10, plus grain size and density for sample #34 were passed on to Mr. J. Jesberger in our Quality Control Department.

Enclosed you will find four copies of the corrected report, hand dated 2/19/70. The five X-ray films involved in the tensile bars are enclosed. The corrected reports show titanium content for sample #10 to be .014% as opposed to .14% which was shown in the first report. Grain size and density of sample #34 have been added to the respective page.

We hope this will complete your requirements, however, if the need for further information arises, please do not hesitate to contact the undersigned.

Very truly yours,

THE BRUSH BERYLLIUM COMPANY

James O. Root
James O. Root
Sales Coordinator

JOR/mms

Encls. - 4 copies of Report
X-Rays K-2446-7-8-9-50

copy of letter and 3 reports to Tolman 2-24-70

IDAHO NUCLEAR CORPORATION

INTEROFFICE CORRESPONDENCE

February 25, 1970

ETR Replacement Beryllium
Tob-4-70

R. S. McPherson
MTR-604

Reference: Serr-2-70, Be-6-70

The AEC owned beryllium to be used for replacement of the ETR reflector has been analyzed for chemical and physical properties by the Brush Beryllium Company. Copies of their analyses are attached to this correspondence for your reference.

Basically, the analyses have indicated that the beryllium presently under consideration for the ETR reflector is not N-50-B nuclear grade beryllium, but more closely resembles S200 structural grade beryllium in chemical and physical properties. However, 3 of the 17 test samples, numbers 2, 14 and 20 meet N-200-A (1961) nuclear grade beryllium criteria. Brush Beryllium was requested to locate a 1957 nuclear grade specification for comparison with the beryllium properties, but their records did not include a specification of that vintage. Brush indicated that the specification would probably not have varied much over that period of time.

All analyzed samples of the beryllium contain small amounts of titanium and zinc impurities. Brush indicated that the same approximate concentrations are in all grades of beryllium and therefore are not listed as constituents in the nuclear or structural grade specifications.

As stated in a previous correspondence, Tob-1-70, it was emphasized that if the replacement reflector units met nuclear grade beryllium specifications and the material strength characteristics were not greatly altered by the amount of inclusions in the material, the radiographic acceptance criteria would be waived. This criteria requires the combined volumes of voids and inclusions per cubic inch of material to be no greater than the volume of a 0.050 inch diameter sphere. Investigation into the actual requirements of this criteria determined it to be a plating specification and not a requirement pertaining to material strength. It is felt that waiving this criteria will not effect a compromise of material properties that have a direct bearing on material strength and ductility. The radiographs did determine the need for adequate chemical and physical analyses to ascertain the grade and characteristics of the beryllium. Although most of the slabs contain high density inclusions, relatively few voids are in the material.

R. S. McPherson
File: Tob-4-70
February 25, 1970
Page 2

Evaluation of the physical properties of the beryllium samples has indicated a variation exists in the strength and ductility of the various slabs. Of the 5 samples tested for tensile strength and elongation (10 tests), 3 tests had elongation values less than the 1% minimum specification. Of particular interest is sample #30, having an elongation of 0.6% in both tests, indicating a very brittle condition. If the samples tested are representative of the sample lot, one may expect approximately 30% of the finished beryllium slabs to be very brittle and therefore warrant expeditious care in handling and assembly.

Grain size is acceptable in each sample as all grains were under 25 microns in size. Sample #22 does not meet the minimum bulk density requirements of 1.84 grams per cubic centimeter. This is probably due to the amount of inclusions noted in the beryllium slab which might have caused inadequate compaction during the fabrication process. This sample also had the lowest ultimate strength in a tensile test, 39,400 lb/in^2. It is recommended that refelctor units fabricated from this slab be utilized as spares. Of the 5 samples tested for tensile strength data, the average σ_u is 46,400 lb/in^2 and average σ_y is 33,950 lb/in^2. Specified strength of N-50-B beryllium is σ_u = 35,000 lb/in^2 and σ_y = 25,000 lb/in^2.

The high amount of carbon or carbide impurities in the beryllium is expected to increase the pitting corrosion rate 1.5 to 2 times the present rate experienced in the reactor. The frequency and severity of localized pitting of beryllium in corrosive environments involving water appears to be associated with the carbon content, as Be_2C is readily hydrolized by water. However, at the present there is very little data to support this postulation.

From a nuclear physics standpoint, Fe, Al, B, Cd, Li, Cu, Mn, Ni and rare earth elements are critical in reactor operation. Inasmuch as many of the samples contained Fe, C, N, Mg, Mn, and Ni impurity levels higher than nuclear grade specifications allow, calculations to determine the Total Danger Summation (TDS) for the impurities were required. The TDS is the ratio, expressed as a percent, of the macroscopic thermal absorption cross section of the impurities in the beryllium sample to the macroscopic thermal absorption cross section of the beryllium. In the TDS calculations, conducted by Mr. W. Serrano, Reactor Physics Group, BeO and Be_2C were considered as impurities. The TDS values were calculated using the maximum concentration values of each isotope as given in the chemical analysis. As a base reference, N-50-B reactor grade beryllium with the maximum allowable impurity composition was utilized. Under these conditions, N-50-B grade beryllium would have a TDS value of 35.0. Test samples of the replacement beryllium have the following TDS values:

Sample	2	4	6	8	10*	12*
TDS	28.46	28.83	24.57	29.16	30.40	30.82

R. S. McPherson
File: Tob-4-70
February 25, 1970
Page 3

Sample	14	16	18*	20	22	24*
TDS	28.71	27.51	30.53	23.84	26.84	31.42

Sample	28*	30	32*	34	36*
TDS	33.06	29.55	36.14	29.43	32.69

Comparative evaluation of the replacement beryllium impurity composition with the maximum impurity composition of N-50-B nuclear grade beryllium indicates a level of acceptability for the replacement beryllium. However, N-50-B nuclear grade beryllium would probably have a nominal TDS value of 10-15, inasmuch as it is highly improbable that all impurities would be the maximum allowable amounts.

ETR beryllium specifications call for a maximum TDS value of 30 (Engineering Test Reactor, specification #5528 G.E. M512, 1956). Slabs from which samples 10, 12, 18, 24, 28, 32 and 36 were taken are not within this TDS value. However, in view of the more recent ATR beryllium criteria (specification M182, January 1964), wherein a TDS value of 75 is acceptable, the M512 specification appears outdated and possibly more stringent than is required. We must be cognizant that the experiments positioned within the reflector are poisons and the beryllium reflector permits considerable leakage of neutrons into the aluminum reflector region. In view of these factors, it is doubtful if the beryllium slabs that have TDS values slightly higher than 30 will have a significant effect on the overall reactor physics properties of the reflector.

Service life of the replacement beryllium is limited by the effects of cracking and spalling, which are proportional to the strength and ductility of the beryllium. The chemical analyses indicate that samples 8, 10, 12, 22, 24, 28 and 30 may have impurity levels that would reduce the ductility and service life of the beryllium slabs from which they were taken. Therefore, reflector units fabricated from these slabs should be preferentially placed in regions of lower fluence levels, i.e., the top and bottom sections of the reflector.

The Nuclear Engineering and Analysis Branch considers the proposed beryllium to be acceptable for use in the ETR reactor, but cautions that a reduction in lifetime from the original beryllium is to be expected.

DATobias:ks Dale A. Tobias

cc: M. J. Neder /r/ S. Cohen
C. R. Snyder
E. H. Smith
J. M. Beeston
W. Serrano
J. E. Pfunder
J. L. Liebenthal
C. A. Moore
G. E. Laurhammer
H. L. Magleby - ETR Reactor General
D. A. Tobias - Letter File

Idaho Nuclear Corp.
Fiscal Section
P.O. Box 1845
Idaho Falls, Idaho 83401

February 19, 1970

Purchase Order S 7086
Sales Order D 196

The following pages contain all the test data on seventeen (17) Beryllium samples supplied on the subject order. All testing has been conducted per the special instructions on the Purchase order.

This cover letter is to certify that the test results contained herein are correct. Substantiating reports are on file in our Quality Control office.

THE BRUSH BERYLLIUM COMPANY

J. J. Gesberger
Quality Control

JJJ:jb

2/19/70

age 1.

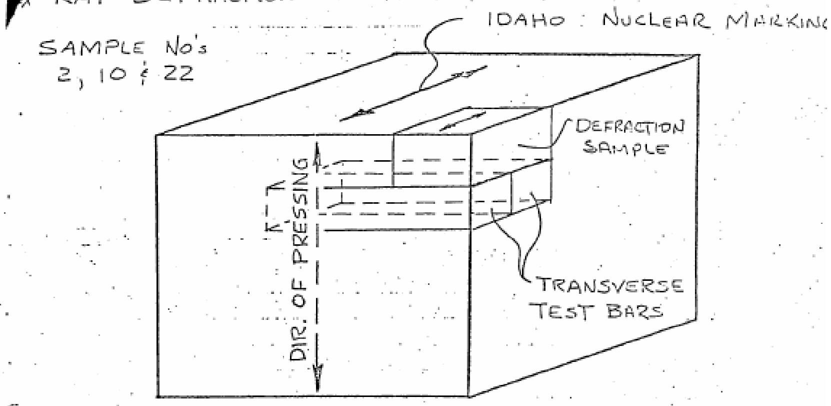
TENSILE PROPERTIES
(Sample Numbers 2,10,22,30,& 32)

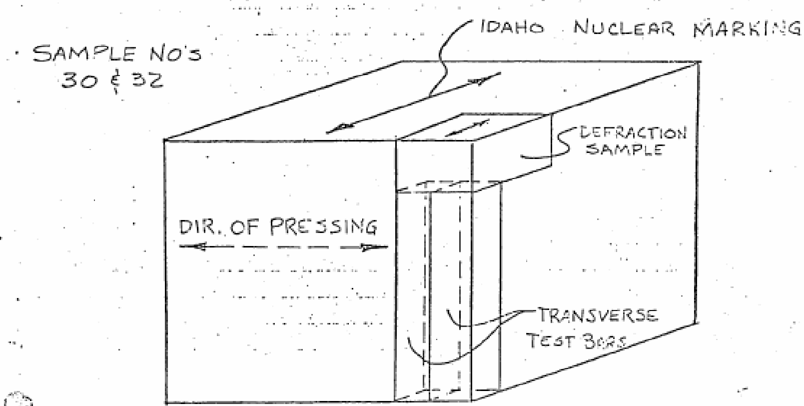
SAMPLE NO.	DIR. OF PRESS	ULT. TENS. STR. (psi)	YIELD STR.AT 0.2%OFFSET(psi)	% ELONG.	TEST BAR DENSITIES gm/cc
2	Trans	52,800	32,600	5.0	1.8544
2	Trans	52,400	33,500	4.2	1.8543
10	Trans	47,000	31,000	2.1	1.8567
10	Trans	46,100	28,700	2.9	1.8556
22	Trans	39,400	32,300	0.9	1.8319
22	Trans	47,600	34,900	1.8	1.8147
30	Trans	42,800	33,400	0.6	1.8557
30	Trans	43,200	38,800	0.6	1.7863
32	Trans	45,800	37,000	1.0	1.8500
32	Trans	47,000	37,300	1.2	1.8500

For determination of pressing direction by X-ray defraction,see the following page.

2/19/70

DETERMINATION OF PRESSING DIRECTION BY X-RAY DEFRACTION.





2/19/76

Page 2.

CHEMICAL ANALYSIS

ELEMENT	SAMPLE	#2	#4	#6	#8	#10	#12	#14
Be		98.85	98.86	98.99	98.07	98.03	98.08	98.72
BeO (HCL)		1.24	1.44	1.03	2.30	2.27	2.41	1.41
Fe		.140	.169	.146	.160	.180	.149	.146
C		.060	.077	.051	.119	.192	.195	.115
N		.017	.010	.009	.024	.021	.030	.017
Al		.058	.063	.072	.051	.060	.058	.045
Cd		≤.00007	≤.00007	≤.00007	≤.00007	≤.00007	≤.00007	≤.00007
Cr		.004	.005	.004	.006	.006	.006	.004
Li		≤.0003	≤.0003	≤.0003	≤.0003	≤.0003	≤.0003	≤.0003
Mg		.005	.002	.009	.002	.005	.004	.003
Mn		.014	.014	.014	.012	.012	.012	.014
Ni		.027	.028	.025	.025	.024	.026	.022
Ti		.015	.007	.006	.017	.014	.015	.018
B		.0001	.00011	.00007	.00008	.00009	.00010	.00010
Ag		≤.0003	≤.0003	≤.0003	≤.0003	≤.0003	≤.0003	≤.0003
Ca		≤.0085	≤.0085	≤.0085	≤.0085	.0260	≤.0085	≤.0085
Co		.0005	.0005	.0005	.0004	.0005	.0005	.0005
Cu		.008	.008	.006	.008	.009	.009	.009
Mo		≤.0008	≤.0008	≤.0008	≤.0008	≤.0008	≤.0008	≤.0008
Pb		≤.0006	≤.0006	≤.0006	≤.0006	≤.0008	≤.0006	≤.0006
Si		.032	.032	.030	.032	.053	.036	.033
Zn		≤.0055	≤.0055	≤.0055	≤.0055	≤.0055	≤.0055	≤.0055

ALL RESULTS ARE IN %

2/19/76

Page 3.

JE Fox - 2714
- 4389

CHEMICAL ANALYSIS

ELEMENT	SAMPLE	#16	#18	#20	#22	#24	#28	#30
Be		99.14	98.74	98.73	98.28	98.02	97.82	97.96
BeO (HCL)		1.02	1.40	1.49	2.02	2.42	2.46	2.44
Fe		.131	.164	.140	.140	.175	.157	.163
C		.091	.101	.081	.158	.157	.142	.151
N		.017	.039	.014	.026	.027	.026	.014
Al		.062	.075	.047	.040	.057	.070	.060
Cd		≤.00007	≤.00007	≤.00007	≤.00007	≤.00007	≤.00007	≤.00007
Cr		.003	.005	.005	.005	.008	.005	.007
Li		≤.0003	≤.0003	≤.0003	≤.0003	≤.0003	≤.0003	≤.0003
Mg		.003	.006	.002	.002	.003	.002	.002
Mn		.014	.014	.012	.012	.012	.014	.012
Ni		.024	.028	.023	.028	.026	.023	.026
Ti		.021	.012	.012	.013	.017	.016	.015
B		.00009	.00007	.00005	.00006	.00010	.00013	.0001
Ag		≤.0003	≤.0003	≤.0005	≤.0003	≤.0003	≤.0004	≤.0004
Ca		≤.0085	≤.0085	≤.0085	≤.0085	≤.0085	≤.0085	≤.0085
Co		.0004	.0005	.0005	.0005	.0004	.0005	.0005
Cu		.006	.012	.007	.007	.0009	.008	.009
Mo		≤.0008	≤.0008	≤.0008	≤.0008	≤.0008	≤.0008	≤.0008
Pb		≤.0006	≤.0006	≤.0006	≤.0006	≤.0006	≤.0006	≤.0008
Si		.028	.035	.026	.052	.040	.035	.026
Zn		≤.0055	≤.0055	≤.0055	≤.0055	≤.0055	≤.0055	≤.0055

ALL RESULTS ARE IN %

2/19/70

ge 4.

CHEMICAL ANALYSIS

ELEMENT	SAMPLE	#32	#34	#36
Be		98.55	99.10	98.73
BeO (HCL)		1.33	.99	1.21
Fe		.130	.130	.155
C		.144	.151	.094
N		.034	.033	.069
Al		.020	.043	.031
Cd		≤.00007	≤.00007	≤.00007
Cr		.010	.011	.011
Li		≤.0003	≤.0003	≤.0003
Mg		.002	.009	.012
Mn		.011	.012	.011
Ni		.019	.021	.020
Ti		.003	.003	.003
B		.00015	.00012	.00009
Ag		≤.0003	≤.0003	≤.0003
Ca		≤.0085	≤.0085	≤.0085
Co		.0010	.0010	.0010
Cu		.005	.005	.005
Mo		≤.0008	≤.0008	≤.0008
Pb		≤.0006	≤.0006	≤.0006
Si		.047	.050	.032
Zn		≤.0055	≤.0055	≤.0055

ALL RESULTS ARE IN %

2/15/70

Page 5.

GRAIN SIZE AND DENSITY RESULTS

SAMPLE NO.	GRAIN SIZE (microns)	DENSITY gm/cc
2	16	1.8520
4	13	1.8481
6	18	1.8501
8	13	1.8425
10	21	1.8555
12	11.4	1.8535
14	13	1.8490
16	14	1.8513
18	13	1.8504
20	12	1.8507
22	16	1.8327
24	11.1	1.8414
28	13	1.8459
30	14	1.8547
32	12	1.8474
36	13	1.8496
34	16	1.8479

Appendix D

1ew Memo | 2eply | 3eply To All | 4orward | 5elete | 6ollow Up | 7older | 8opy Into New | 9hat | Tools

"Nesshoefer, Craig A" <Craig.Nesshoefer@icp.doe.gov>
09/11/2006 09:49 AM

To "Parry, James R" <James.Parry@inl.gov>
cc "Culp, A Bruce" <A.Culp@icp.doe.gov>
bcc
Subject FW: 347 Spec

History: This message has been replied to.

Attached is the component activity values given in EDF-6133 Rev02 based on the ratios presented in EDF-6958 (neither of the current revisions to these EDFs are on EDMS, it is going on 2 weeks since I sent them to document control and I don't know what the hang up is). 6133 gives the methodology used to obtain this data and it was as follows:

Using the calculated vessel source term value and the percent activity values and component radionuclide scaling factors determined in EDF-6958, the activity of each component in the vessel was determined as presented in the example below.

This example calculates the tritium (H-3) in the Be reflector. This same methodology was used to calculate the activity values for each radionuclide in each component in the vessel.

The total activity of the reactor is 59,273 Ci. The percentage of activity that the Be reflector contributes to the total vessel source term, determined in EDF-6958, is 55.60%. The activity of the Be reflector is then determined as follows:

$$Be\_reflector\_activity = 59{,}273\,Ci * 55.60\% = 32{,}956\,Ci$$

The sum of all of the individual activity values for the radionuclides in the Be reflector equals the total Be reflector source term as shown in the equation below:

$$H\text{-}3_{activity} + Be\text{-}10_{activity} + \ldots + Cm\text{-}248_{activity} = 32{,}956\ Ci$$

The activity value of each radionuclide is determined from the Co-60 activity and the scaling factor (SF) of that radionuclide to Co-60 presented in EDF-6958 and Attachment 2. For example, the H-3 activity is determined as follows:

$$2.97E4 * Co\text{-}60_{activity} = H\text{-}3_{activity}$$

Thus, the equation for the Be reflector activity becomes:

$$(2.97E4 * Co\text{-}60_{activity}) + (3.36E\text{-}1 * Co\text{-}60_{activity}) + \ldots + (9.05E\text{-}10 * Co\text{-}60_{activity}) = 32{,}956\ Ci$$

The above equation can be simplified as shown below:

$$Co60_{activity} * \sum_{i=1}^{n} SF_i = 32{,}956\,Ci$$

Where:

n = The radionuclides in the Be reflector;
SF_i = The scaling factor of radionuclide i to Co-60;

For the Be reflector, $\sum_{i=1}^{n} SF_i = 2.97 * 10^4\ Ci/Ci$

The Co-60 activity can then be determined as shown below:

$$Co60_{activity} = \frac{32{,}956\,Ci}{2.97 * 10^4\,Ci/Ci} = 1.11\,Ci$$

Once the Co-60 activity is determined, the H-3 activity can be determined as follows:

$$H3_{activity} = 2.97 * 10^4 * 1.11\,Ci = 3.3 * 10^4\,Ci$$

Take a look at the attached data and let me know if this answers your question.

Craig A. Nesshoefer
D&D Rad Engineering
Phone: 533-0553
Cell: 360-0399

Isotope	Be Reflector (Ci)	Grid Plate (Ci)	I-Beams (Ci)	C-7 In-Pile Tube (Ci)	F-10 In-Pile Tube (Ci)	M-13 In-Pile Tube (Ci)	N-14 In-Pile Tube (Ci)	Upper Support Frame (Ci)	Inner Tank (Ci)	Internal Thermal Shields (Ci)	External Thermal Shield (Ci)	External Tank (Ci)	Black Rod Poison (Ci)	Gray Rod Poison (Ci)	Total **Not Including Reflector** (Ci)
H-3	3.29E+04	4.75E+00	1.57E-06	1.48E-01	1.12E-01	1.12E-01	9.03E-02	3.83E-07	3.20E+00	9.50E-02	8.24E-04	1.91E-03	1.19E-01	1.40E-04	8.63E+00
Be-10	3.73E-01	8.57E-07	2.73E-13	3.02E-08	8.40E-08	3.79E-08	1.94E-08	6.68E-14	5.84E-07	1.65E-08	1.82E-10	4.20E-10	1.95E-07	1.25E-06	3.08E-06
C-14	2.97E+00	4.71E+00	1.31E-06	1.77E-01	5.42E-01	2.40E-01	1.17E-01	3.20E-07	3.18E+00	7.94E-02	7.19E-05	2.09E-04	1.25E+00	3.99E-04	1.03E+01
Cl-36	3.63E-02	4.83E-02	1.04E-08	1.39E-03	3.91E-03	1.82E-03	9.12E-04	2.54E-09	2.51E-02	6.30E-04	1.62E-07	7.40E-07	7.94E-03	1.34E-05	9.00E-02
Mn-54	9.16E-09	1.63E-06	3.11E-13	4.83E-08	1.64E-07	1.45E-07	6.30E-08	7.61E-14	7.56E-07	1.88E-08	1.03E-10	2.43E-10	3.74E-07	6.05E-09	3.20E-06
Ni-59	2.69E-02	5.55E+00	7.31E-06	9.03E-01	1.74E+00	1.04E+00	5.76E-01	1.79E-06	1.70E+01	4.45E-01	1.14E-04	5.21E-04	2.17E+00	1.03E+02	1.32E+02
Co-60	1.11E+00	5.51E+02	2.07E-04	2.98E+01	8.11E+01	5.80E+01	2.82E+01	5.08E-05	4.96E+02	1.26E+01	5.72E-03	2.04E-02	1.39E+02	5.76E+02	1.97E+03
Ni-63	3.88E+00	6.35E+02	7.73E-04	1.03E+02	2.77E+02	1.37E+02	6.93E+01	1.90E-04	1.86E+03	4.71E+01	1.27E-02	5.55E-02	5.08E+02	2.06E+04	2.42E+04
Zn-65	4.29E-11	3.85E-11	7.69E-18	1.31E-12	6.68E-12	4.62E-12	1.77E-12	1.87E-18	1.95E-11	4.66E-13	2.77E-15	1.38E-15	2.36E-11	3.22E-11	1.29E-10
Sr-90	7.52E-01	4.87E-02	3.43E-09	1.36E-03	6.22E-03	2.72E-03	1.09E-03	8.40E-10	1.78E-02	2.11E-04	8.36E-07	2.01E-06	1.30E-02	3.27E-06	9.11E-02
Nb-94	8.19E-03	4.75E+00	1.78E-08	2.35E-03	6.35E-03	3.05E-03	1.54E-03	4.33E-09	4.29E-02	1.08E-03	1.58E-06	4.20E-06	1.21E-02	3.24E-06	4.82E+00
Tc-99	5.51E-04	3.22E-03	7.06E-10	9.03E-05	2.25E-04	1.13E-04	5.88E-05	1.72E-10	1.65E-03	4.24E-05	1.13E-08	5.08E-08	3.80E-04	1.07E-07	5.78E-03
Ru-106	3.07E-07	3.85E-09	1.74E-17	1.21E-10	4.62E-10	4.62E-10	1.80E-10	4.24E-18	1.28E-09	1.44E-12	4.14E-15	9.96E-15	7.44E-10	1.67E-13	7.10E-09
Ag-108m	3.50E-02	6.51E-02	1.42E-08	1.89E-03	5.17E-03	2.51E-03	1.27E-03	3.46E-09	3.41E-02	8.57E-04	4.20E-03	8.03E-06	9.25E-02	2.64E-06	2.08E-01
Ag-110m	2.61E-11	1.23E-11	3.51E-18	4.18E-13	3.26E-13	7.65E-13	4.87E-13	8.57E-19	7.52E-12	2.13E-13	1.05E-12	1.99E-15	2.47E-11	3.91E-17	4.77E-11
Sb-125	6.89E-04	2.85E-03	6.05E-10	9.33E-05	3.28E-04	2.48E-04	1.08E-04	1.48E-10	1.47E-03	3.67E-05	1.36E-07	4.33E-08	7.86E-04	1.51E-07	5.92E-03
I-129	4.09E-06	9.50E-08	2.17E-15	2.57E-09	1.19E-08	5.04E-09	1.99E-09	5.34E-16	3.03E-08	1.38E-10	5.17E-13	1.24E-12	2.21E-08	6.09E-12	1.69E-07
Cs-134	2.33E-03	3.27E-04	7.56E-11	1.08E-05	2.49E-05	2.55E-05	1.27E-05	1.85E-11	1.76E-04	4.58E-06	1.17E-09	5.38E-09	3.23E-05	8.32E-09	6.14E-04
Cs-137	2.52E+00	1.01E-01	3.73E-09	2.79E-03	1.36E-02	5.93E-03	2.30E-03	9.12E-10	3.35E-02	2.32E-04	9.03E-07	2.17E-06	2.79E-02	7.06E-06	1.87E-01
Ce-144	2.20E-09	3.71E-11	1.42E-18	1.18E-12	4.37E-12	4.33E-12	1.71E-12	3.47E-19	1.36E-11	8.91E-14	3.47E-16	8.32E-16	7.35E-12	1.63E-15	6.97E-11
Eu-152	1.53E-02	3.74E-02	2.75E-07	1.57E-03	6.77E-06	9.46E-05	5.63E-04	6.72E-08	1.08E-01	1.64E-02	6.14E-04	1.39E-03	5.30E-06	1.76E-09	1.66E-01
Eu-154	8.99E-01	9.03E-02	1.57E-08	2.75E-03	2.09E-03	3.18E-03	2.13E-03	3.85E-09	4.41E-02	9.54E-04	3.49E-05	7.94E-05	9.88E-04	3.69E-07	1.47E-01
Pb-210	1.61E-11	1.66E-11	4.37E-14	4.13E-13	4.54E-12	9.29E-13	2.62E-13	8.82E-14	5.84E-12	3.37E-12	1.11E-12	2.22E-12	1.74E-11	3.78E-15	5.29E-11
Ra-226	2.24E-11	4.08E-11	1.26E-13	1.04E-12	3.92E-12	1.41E-12	6.01E-13	2.56E-13	1.56E-11	9.71E-12	3.22E-12	6.43E-12	6.05E-12	2.01E-15	8.92E-11
Ac-227	1.27E-07	5.08E-07	7.90E-13	1.48E-08	1.59E-08	1.27E-08	8.53E-09	1.35E-12	3.04E-07	8.53E-09	1.43E-10	3.24E-10	1.24E-08	4.62E-12	8.86E-07
Th-228	6.30E-05	6.35E-05	4.96E-09	1.66E-06	1.15E-05	4.54E-06	1.47E-06	1.00E-08	1.60E-05	3.81E-07	4.79E-07	9.12E-07	1.61E-05	5.08E-09	1.17E-04
Th-229	1.06E-07	6.09E-07	2.29E-13	1.79E-08	1.27E-08	1.14E-08	9.12E-09	5.59E-14	4.12E-07	1.28E-08	2.06E-10	4.71E-10	1.07E-08	3.90E-12	1.10E-06
Th-230	3.27E-09	3.79E-09	1.27E-11	9.88E-11	3.83E-10	1.63E-10	6.56E-11	2.58E-11	1.40E-09	9.75E-10	3.25E-10	6.47E-10	5.51E-10	1.77E-13	8.43E-09
Th-232	1.30E-08	1.02E-07	5.00E-09	3.31E-09	1.33E-09	1.47E-09	1.53E-09	1.01E-08	1.26E-07	3.80E-07	4.83E-07	9.20E-07	1.00E-09	3.66E-13	2.04E-06
Pa-231	2.02E-07	7.35E-07	1.57E-12	2.17E-08	2.40E-08	1.98E-08	1.31E-08	2.82E-12	4.37E-07	1.23E-08	2.17E-10	4.87E-10	1.94E-08	7.02E-12	1.28E-06

Isotope	Be Reflector	Grid Plate	I-Beams	C-7 In-Pile Tube	F-10 In-Pile Tube	M-13 In-Pile Tube	N-14 In-Pile Tube	Upper Support Frame	Inner Tank	Internal Thermal Shields	External Thermal Shield	External Tank	Black Rod Poison	Gray Rod Poison	Total **Not Including Reflector**
	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)
U-232	6.14E-05	6.14E-05	2.50E-16	1.62E-06	1.12E-05	4.41E-06	1.42E-06	4.50E-17	1.54E-05	3.58E-09	6.60E-13	1.82E-12	1.57E-05	4.96E-09	1.11E-04
U-233	3.49E-05	1.69E-04	6.39E-11	5.13E-06	3.53E-06	3.63E-06	2.90E-06	1.56E-11	1.15E-04	3.58E-06	5.76E-08	1.32E-07	2.79E-06	9.96E-10	3.06E-04
U-234	1.37E-05	7.19E-06	3.08E-08	1.94E-07	7.77E-07	4.24E-07	1.59E-07	6.26E-08	2.48E-06	2.34E-06	7.86E-07	1.57E-06	9.50E-07	2.88E-10	1.70E-05
U-235	3.82E-09	1.01E-08	1.40E-09	3.67E-10	6.09E-11	5.04E-11	1.18E-10	2.84E-09	2.26E-08	1.06E-07	3.57E-08	7.10E-08	8.49E-11	2.48E-14	2.51E-07
U-236	5.51E-07	9.41E-08	3.32E-14	2.85E-09	2.25E-09	1.91E-09	1.58E-09	8.11E-15	6.47E-08	2.01E-09	7.86E-12	1.89E-11	3.78E-09	9.75E-13	1.73E-07
U-238	2.40E-06	6.01E-07	3.04E-08	1.95E-08	6.64E-09	8.19E-09	8.91E-09	6.18E-08	7.56E-07	2.32E-06	7.77E-07	1.55E-06	3.79E-09	1.56E-12	6.13E-06
Np-237	1.89E-06	1.79E-07	6.05E-15	4.75E-09	7.10E-09	5.76E-09	3.31E-09	1.48E-15	5.17E-08	3.62E-10	1.43E-12	3.43E-12	8.61E-09	2.49E-12	2.61E-07
Pu-238	7.77E-02	4.33E-03	1.20E-16	9.29E-05	3.49E-04	2.05E-04	6.64E-05	3.55E-18	4.14E-04	5.55E-09	2.62E-13	7.61E-13	2.31E-04	8.70E-08	5.69E-03
Pu-239	1.27E-02	2.79E-03	1.61E-09	8.78E-05	3.51E-05	4.29E-05	4.37E-05	3.95E-10	2.42E-03	9.54E-05	3.81E-07	9.16E-07	2.01E-05	8.28E-09	5.53E-03
Pu240	1.81E-02	2.61E-03	9.71E-15	7.61E-05	6.60E-05	5.67E-05	4.62E-05	2.86E-16	1.20E-03	4.58E-07	2.12E-11	6.14E-11	8.32E-05	2.64E-08	4.14E-03
Pu-241	1.64E+00	1.29E-01	2.79E-18	3.52E-03	4.45E-03	4.83E-03	2.91E-03	9.92E-21	2.95E-02	1.06E-07	5.63E-14	1.98E-13	3.58E-03	1.24E-06	1.77E-01
Pu-242	2.76E-04	4.96E-06	3.63E-28	1.16E-07	1.30E-06	5.93E-07	1.41E-07	1.55E-31	4.13E-07	1.09E-14	6.77E-23	2.86E-22	1.21E-06	4.50E-10	8.73E-06
Pu-244	2.54E-10	9.46E-14	0.00E+00	1.83E-15	1.63E-12	1.87E-13	7.61E-15	0.00E+00	1.25E-15	2.09E-27	1.77E-39	1.08E-38	1.11E-11	1.74E-15	1.30E-11
Am-241	1.59E-01	1.65E-02	3.58E-19	4.37E-04	4.71E-04	5.13E-04	3.24E-04	1.27E-21	3.80E-03	1.35E-08	7.23E-15	2.53E-14	3.27E-04	1.22E-07	2.23E-02
Am-243	2.71E-03	1.52E-05	4.79E-33	3.10E-07	1.70E-05	4.50E-06	5.38E-07	2.45E-37	5.25E-07	1.14E-16	8.24E-27	4.20E-26	1.91E-05	6.89E-09	5.71E-05
CM-243	4.83E-04	1.42E-05	6.01E-33	2.98E-07	3.45E-06	1.68E-06	3.44E-07	3.10E-37	5.88E-07	1.43E-16	1.04E-26	5.30E-26	1.56E-06	7.73E-10	2.21E-05
CM-244	3.06E-01	3.27E-04	3.91E-37	5.88E-06	3.43E-03	3.29E-04	1.62E-05	0.00E+00	4.41E-06	7.44E-18	6.26E-30	3.86E-29	1.06E-02	2.73E-06	1.47E-02
CM-245	5.72E-05	3.47E-08	0.00E+00	5.72E-10	8.03E-07	5.76E-08	1.93E-09	0.00E+00	2.32E-10	3.71E-24	3.64E-38	2.70E-37	2.58E-06	6.81E-10	3.47E-06
CM-246	4.79E-05	5.59E-09	0.00E+00	7.98E-11	1.36E-06	3.11E-08	4.16E-10	0.00E+00	1.44E-11	1.79E-27	4.50E-44	1.56E-42	1.77E-05	2.87E-09	1.91E-05
CM-247	2.15E-10	6.51E-15	0.00E+00	8.19E-17	9.92E-12	9.96E-14	6.18E-16	0.00E+00	6.85E-18	6.89E-36	0.00E+00	0.00E+00	2.44E-10	3.35E-14	2.54E-10
CM-248	1.00E-09	7.10E-15	0.00E+00	7.82E-17	8.99E-11	3.19E-13	8.66E-16	0.00E+00	2.98E-18	2.40E-38	0.00E+00	0.00E+00	7.35E-09	6.77E-13	7.44E-09
Total Activity	3.30E+04	1.21E+03	9.91E-04	1.34E+02	3.60E+02	1.96E+02	9.84E+01	2.43E-04	2.38E+03	6.03E+01	2.42E-02	8.00E-02	6.51E+02	2.12E+04	2.63E+04

The component activities in the table above are calculated using the formulas in the previous email using the scaling factors from EDF-6958 and the total source term from EDF-6133. The beryllium reflector transuranic activity reported in the results section of this EDF will replace the data in this table.

Appendix E

Isotope	Be Reflector (Be) (Ci/Ci)	Grid Plate (304-SS) (Ci/Ci)	I-Beams (all 6, 304-SS) (Ci/Ci)	C-7 In-Pile Tube (304-SS) (Ci/Ci)	F-10 In-Pile Tube (304-SS) (Ci/Ci)	M-13 In-Pile Tube (304-SS)	N-14 In-Pile Tube (304-SS) (Ci/Ci)	Upper Support Frame (304-SS) (Ci/Ci)	Inner Tank (304-SS, Steel) (Ci/Ci)	Internal Thermal Shields (304-SS) (Ci/Ci)	External Thermal Shield (304-SS. Pb) (Ci/Ci)	External Tank (304-SS, Steel) (Ci/Ci)	Black Rod Poison (Cd) (Ci/Ci)	Gray Rod Poison (Ni) (Ci/Ci)	Reactor Totals (Ci/Ci)
H-3	2.97E+04	8.63E-03	7.57E-03	4.94E-03	1.38E-03	1.93E-03	3.20E-03	7.54E-03	6.46E-03	7.56E-03	1.44E-01	9.36E-02	8.55E-04	2.42E-07	1.67E+01
Be-10	3.36E-01	1.56E-09	1.32E-09	1.01E-09	1.04E-09	6.54E-10	6.88E-10	1.31E-09	1.18E-09	1.31E-09	3.19E-08	2.06E-08	1.40E-09	2.18E-09	1.89E-04
C-14	2.67E+00	8.55E-03	6.31E-03	5.93E-03	6.68E-03	4.13E-03	4.15E-03	6.29E-03	6.42E-03	6.32E-03	1.26E-02	1.03E-02	9.00E-03	6.93E-07	6.74E-03
Cl-36	3.27E-02	8.78E-05	5.01E-05	4.65E-05	4.82E-05	3.14E-05	3.23E-05	5.00E-05	5.06E-05	5.02E-05	2.83E-05	3.63E-05	5.71E-05	2.33E-08	6.40E-05
Mn-54	8.26E-09	2.95E-09	1.50E-09	1.62E-09	2.02E-09	2.51E-09	2.23E-09	1.50E-09	1.53E-09	1.50E-09	1.80E-08	1.19E-08	2.69E-09	1.05E-11	1.63E-09
Ni-59	2.42E-02	1.01E-02	3.53E-02	3.03E-02	2.15E-02	1.79E-02	2.04E-02	3.52E-02	3.43E-02	3.55E-02	1.99E-02	2.56E-02	1.56E-02	1.79E-01	6.72E-02
Co-60	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Ni-63	3.50E+00	1.15E+00	3.73E+00	3.45E+00	3.41E+00	2.36E+00	2.46E+00	3.73E+00	3.75E+00	3.75E+00	2.21E+00	2.72E+00	3.66E+00	3.57E+01	1.23E+01
Zn-65	3.86E-11	6.98E-14	3.71E-14	4.39E-14	8.24E-14	7.97E-14	6.28E-14	3.69E-14	3.94E-14	3.71E-14	4.85E-13	6.78E-14	1.69E-13	5.59E-14	8.68E-14
Sr-90	6.78E-01	8.85E-05	1.66E-05	4.56E-05	7.67E-05	4.68E-05	3.87E-05	1.65E-05	3.59E-05	1.68E-05	1.46E-04	9.86E-05	9.34E-05	5.67E-09	4.29E-04
Nb-94	7.39E-03	8.63E-03	8.58E-05	7.89E-05	7.82E-05	5.25E-05	5.46E-05	8.51E-05	8.64E-05	8.56E-05	2.77E-04	2.06E-04	8.67E-05	5.64E-09	2.45E-03
Tc-99	4.96E-04	5.84E-06	3.41E-06	3.03E-06	2.78E-06	1.94E-06	2.08E-06	3.39E-06	3.33E-06	3.38E-06	1.97E-06	2.49E-06	2.73E-06	1.85E-10	3.22E-06
Ru-106	2.77E-07	7.00E-12	8.40E-14	4.06E-12	5.70E-12	7.97E-12	6.37E-12	8.35E-14	2.58E-12	1.15E-13	7.24E-13	4.89E-13	5.35E-12	2.91E-16	1.59E-10
Ag-108m	3.16E-02	1.18E-04	6.84E-05	6.32E-05	6.37E-05	4.33E-05	4.48E-05	6.81E-05	6.87E-05	6.82E-05	7.35E-01	3.94E-04	6.65E-04	4.59E-09	1.23E-04
Ag-110m	2.35E-11	2.23E-14	1.69E-14	1.40E-14	4.02E-15	1.32E-14	1.73E-14	1.69E-14	1.52E-14	1.69E-14	1.83E-10	9.77E-14	1.77E-13	6.79E-20	3.75E-14
Sb-125	6.21E-04	5.18E-06	2.92E-06	3.13E-06	4.04E-06	4.28E-06	3.84E-06	2.92E-06	2.96E-06	2.92E-06	2.38E-05	2.12E-06	5.65E-06	2.63E-10	3.35E-06
I-129	3.69E-06	1.73E-10	1.05E-11	8.61E-11	1.47E-10	8.70E-11	7.05E-11	1.05E-11	6.12E-11	1.10E-11	9.04E-11	6.10E-11	1.59E-10	1.06E-14	2.15E-09
Cs-134	2.10E-03	5.94E-07	3.65E-07	3.62E-07	3.07E-07	4.40E-07	4.51E-07	3.63E-07	3.55E-07	3.65E-07	2.05E-07	2.64E-07	2.32E-07	1.45E-11	1.49E-06
Cs-137	2.27E+00	1.83E-04	1.80E-05	9.35E-05	1.68E-04	1.02E-04	8.14E-05	1.79E-05	6.76E-05	1.85E-05	1.58E-04	1.06E-04	2.00E-04	1.23E-08	1.37E-03
Ce-144	1.98E-09	6.74E-14	6.86E-15	3.94E-14	5.39E-14	7.46E-14	6.06E-14	6.83E-15	2.74E-14	7.09E-15	6.07E-14	4.08E-14	5.29E-14	2.82E-18	1.15E-12
Eu-152	1.38E-02	6.80E-05	1.33E-03	5.25E-05	8.34E-08	1.63E-06	1.99E-05	1.32E-03	2.19E-04	1.30E-03	1.07E-01	6.80E-02	3.81E-08	3.05E-12	9.23E-05
Eu-154	8.11E-01	1.64E-04	7.59E-05	9.21E-05	2.58E-05	5.48E-05	7.54E-05	7.56E-05	8.90E-05	7.59E-05	6.11E-03	3.90E-03	7.10E-06	6.42E-10	5.31E-04
Pb-210	1.45E-11	3.02E-14	2.11E-10	1.38E-14	5.60E-14	1.60E-14	9.27E-15	1.74E-09	1.18E-14	2.68E-13	1.95E-10	1.09E-10	1.25E-13	6.57E-18	3.50E-14
Ra-226	2.02E-11	7.41E-14	6.09E-10	3.48E-14	4.83E-14	2.43E-14	2.13E-14	5.03E-09	3.14E-14	7.73E-13	5.63E-10	3.15E-10	4.35E-14	3.50E-18	5.65E-14
Ac-227	1.14E-07	9.24E-10	3.81E-09	4.97E-10	1.96E-10	2.20E-10	3.02E-10	2.66E-08	6.14E-10	6.79E-10	2.51E-08	1.59E-08	8.91E-11	8.03E-15	5.14E-10
Th-228	5.68E-05	1.15E-07	2.39E-05	5.58E-08	1.42E-07	7.83E-08	5.19E-08	1.98E-04	3.22E-08	3.03E-08	8.38E-05	4.47E-05	1.16E-07	8.83E-12	9.10E-08
Th-229	9.51E-08	1.11E-09	1.10E-09	6.00E-10	1.56E-10	1.96E-10	3.23E-10	1.10E-09	8.31E-10	1.02E-09	3.60E-08	2.31E-08	7.70E-11	6.77E-15	6.10E-10
Th-230	2.95E-09	6.88E-12	6.15E-08	3.31E-12	4.72E-12	2.80E-12	2.32E-12	5.08E-07	2.81E-12	7.76E-11	5.69E-08	3.18E-08	3.96E-12	3.07E-16	5.95E-12
Th-232	1.17E-08	1.85E-10	2.41E-05	1.11E-10	1.64E-11	2.53E-11	5.40E-11	1.99E-04	2.54E-10	3.03E-08	8.46E-05	4.52E-05	7.19E-12	6.35E-16	1.04E-09
Pa-231	1.82E-07	1.34E-09	7.57E-09	7.27E-10	2.95E-10	3.41E-10	4.64E-10	5.55E-08	8.81E-10	9.77E-10	3.79E-08	2.39E-08	1.39E-10	1.22E-14	7.53E-10
U-232	5.53E-05	1.11E-07	1.21E-12	5.42E-08	1.38E-07	7.61E-08	5.04E-08	8.84E-13	3.11E-08	2.85E-10	1.15E-10	8.91E-11	1.13E-07	8.61E-12	8.76E-08
U-233	3.15E-05	3.07E-07	3.08E-07	1.72E-07	4.36E-08	6.26E-08	1.03E-07	3.07E-07	2.32E-07	2.85E-07	1.01E-05	6.45E-06	2.00E-08	1.73E-12	1.73E-07
U-234	1.24E-05	1.31E-08	1.48E-04	6.49E-09	9.59E-09	7.32E-09	5.63E-09	1.23E-03	4.99E-09	1.86E-07	1.38E-04	7.69E-05	6.83E-09	5.01E-13	1.56E-08

Isotope	Be Reflector (Be) (Ci/Ci)	Grid Plate (304-SS) (Ci/Ci)	I-Beams (all 6, 304-SS) (Ci/Ci)	C-7 In-Pile Tube (304-SS) (Ci/Ci)	F-10 In-Pile Tube (304-SS) (Ci/Ci)	M-13 In-Pile Tube (304-SS)	N-14 In-Pile Tube (304-SS) (Ci/Ci)	Upper Support Frame (304-SS) (Ci/Ci)	Inner Tank (304-SS, Steel) (Ci/Ci)	Internal Thermal Shields (304-SS) (Ci/Ci)	External Thermal Shield (304-SS. Pb) (Ci/Ci)	External Tank (304-SS, Steel) (Ci/Ci)	Black Rod Poison (Cd) (Ci/Ci)	Gray Rod Poison (Ni) (Ci/Ci)	Reactor Totals (Ci/Ci)
U-235	3.44E-09	1.83E-11	6.75E-06	1.23E-11	7.51E-13	8.70E-13	4.17E-12	5.59E-05	4.55E-11	8.46E-09	6.25E-06	3.48E-06	6.10E-13	4.31E-17	1.29E-10
U-236	4.96E-07	1.71E-10	1.60E-10	9.55E-11	2.78E-11	3.30E-11	5.58E-11	1.60E-10	1.31E-10	1.60E-10	1.38E-09	9.26E-10	2.72E-11	1.69E-15	3.67E-10
U-238	2.17E-06	1.09E-09	1.47E-04	6.55E-10	8.19E-11	1.41E-10	3.15E-10	1.21E-03	1.53E-09	1.84E-07	1.36E-04	7.59E-05	2.72E-11	2.72E-15	4.33E-09
Np-237	1.70E-06	3.25E-10	2.92E-11	1.59E-10	8.76E-11	9.93E-11	1.17E-10	2.91E-11	1.04E-10	2.88E-11	2.50E-10	1.68E-10	6.19E-11	4.32E-15	1.09E-09
Pu-238	7.01E-02	7.86E-06	5.80E-13	3.11E-06	4.30E-06	3.54E-06	2.35E-06	6.98E-14	8.36E-07	4.41E-10	4.58E-11	3.73E-11	1.66E-06	1.51E-10	4.24E-05
Pu-239	1.14E-02	5.07E-06	7.79E-06	2.94E-06	4.33E-07	7.39E-07	1.55E-06	7.76E-06	4.87E-06	7.59E-06	6.66E-05	4.49E-05	1.44E-07	1.44E-11	9.21E-06
Pu240	1.63E-02	4.73E-06	4.69E-11	2.55E-06	8.13E-07	9.78E-07	1.64E-06	5.62E-12	2.42E-06	3.65E-08	3.71E-09	3.01E-09	5.98E-07	4.58E-11	1.13E-05
Pu-241	1.48E+00	2.34E-04	1.35E-14	1.18E-04	5.49E-05	8.33E-05	1.03E-04	1.95E-16	5.96E-05	8.39E-09	9.85E-12	9.69E-12	2.57E-05	2.15E-09	9.21E-04
Pu-242	2.49E-04	9.01E-09	1.75E-24	3.87E-09	1.61E-08	1.02E-08	5.00E-09	3.05E-27	8.33E-10	8.66E-16	1.18E-20	1.40E-20	8.70E-09	7.81E-13	1.44E-07
Pu-244	2.29E-10	1.72E-16	0.00E+00	6.13E-17	2.01E-14	3.22E-15	2.69E-16	0.00E+00	2.52E-18	1.66E-28	3.09E-37	5.32E-37	7.95E-14	3.03E-18	1.36E-13
Am-241	1.44E-01	2.99E-05	1.73E-15	1.46E-05	5.80E-06	8.84E-06	1.15E-05	2.50E-17	7.66E-06	1.07E-09	1.26E-12	1.24E-12	2.35E-06	2.12E-10	9.21E-05
Am-243	2.44E-03	2.76E-08	2.31E-29	1.04E-08	2.10E-07	7.75E-08	1.90E-08	4.83E-33	1.06E-09	9.06E-18	1.44E-24	2.06E-24	1.37E-07	1.20E-11	1.40E-06
Cm-243	4.36E-04	2.57E-08	2.90E-29	1.00E-08	4.26E-08	2.89E-08	1.22E-08	6.09E-33	1.19E-09	1.14E-17	1.82E-24	2.60E-24	1.12E-08	1.34E-12	2.56E-07
Cm-244	2.75E-01	5.93E-07	1.89E-33	1.97E-07	4.23E-05	5.67E-06	5.73E-07	0.00E+00	8.90E-09	5.92E-19	1.10E-27	1.89E-27	7.61E-05	4.74E-09	1.62E-04
Cm-245	5.15E-05	6.31E-11	0.00E+00	1.92E-11	9.90E-09	9.93E-10	6.82E-11	0.00E+00	4.68E-13	2.95E-25	6.37E-36	1.32E-35	1.85E-08	1.18E-12	3.07E-08
Cm-246	4.32E-05	1.02E-11	0.00E+00	2.68E-12	1.67E-08	5.36E-10	1.47E-11	0.00E+00	2.91E-14	1.43E-28	7.87E-42	7.65E-41	1.27E-07	4.98E-12	3.39E-08
Cm-247	1.94E-10	1.18E-17	0.00E+00	2.75E-18	1.22E-13	1.72E-15	2.19E-17	0.00E+00	1.38E-20	5.48E-37	0.00E+00	0.00E+00	1.76E-12	5.82E-17	2.39E-13
Cm-248	9.05E-10	1.29E-17	0.00E+00	2.62E-18	1.11E-12	5.50E-15	3.07E-17	0.00E+00	6.00E-21	1.91E-39	0.00E+00	0.00E+00	5.29E-11	1.18E-15	4.29E-12
% of Total Reactor Activity	55.60%	2.03%	1.70E-08	0.23%	0.61%	0.33%	0.17%	4.10E-09	4.02%	0.10%	4.10E-07	0.00%	1.10%	35.81%	100%
*ΣSF_i	2.97E+04	2.19E+00	4.78E+00	4.49E+00	4.44E+00	3.38E+00	3.49E+00	4.78E+00	4.80E+00	4.80E+00	4.24E+00	3.92E+00	4.69E+00	3.69E+01	3.01E+01

* Additional row added to the scaling factors table from EDF-6958 to show the sum of the scaling (ΣSF_i) factors for ease of calculating the Co-60 source term.