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Neutron Source Rates for TRU Waste

ED-042

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1.0 SCOPE

It is imperative to have an accurate knowledge of all significant sources of neutrons due to the decay of radionuclides. These sources can include neutrons resulting from the spontaneous fission of actinides and the interaction of actinide decay α-particles in (α,n) reactions with low- or medium-Z nuclides. There is a need for a definitive basis to be used for neutron source strengths since there is a significant variation in the waste forms and potential isotopic compositions in transuranic (TRU) waste streams. Therefore, this analysis establishes the neutron source strength and spectra resulting from spontaneous fission and (α,n) reactions assuming a UO_2 matrix of 38 isotopes that have the potential to be in TRU waste. The computer code SOURCES-4A is used to determine the neutron production rates and spectra.

2.0 REFERENCE DOCUMENTS

1. Los Alamos National Laboratory, "SOURCES 4A: A Code for Calculating (α,n), Spontaneous Fission, and Delayed Neutron Sources and Spectra," LA-13639-MS, September 1999.
2. R. Firestone, et al., Book of Isotopes, 8 edition, John Wiley & Sons, December 4, 1998.
3. Brookhaven National Laboratory, Table of Nuclides.
4. J. Shultis and R. Faw, Radiation Shielding, Prentice Hall PTR, 1996, pg. 82.

3.0 SOURCES-4A CODE DESCRIPTION

SOURCES-4A [1] is a computer code that determines neutron production rates and spectra from (α,n) reactions, spontaneous fission, and delayed neutron emission due to the decay of radionuclides. The code is capable of calculating (α,n) source rates and spectra in four types of problems: homogeneous media (i.e., a mixture of α-emitting source material and low-Z target material), two-region interface problems (i.e., a slab of α-emitting source material in contact with a slab of low-Z target material), three-region interface problems (i.e., a thin slab of low-Z target material sandwiched between α-emitting source material and low-Z target material), and (α,n) reactions induced by a monoenergetic beam of α-particles incident on a slab of target material. Spontaneous fission spectra are calculated with evaluated half-life, spontaneous fission branching, and Watt spectrum parameters for 43 actinides. The (α,n) spectra are calculated using an assumed isotropic angular distribution in the center-of-mass system with a library of 89 nuclide decay α-particle spectra, 24 sets of measured and/or evaluated (α,n) cross sections and product nuclide level branching fractions, and functional α-particle stopping cross sections for Z<106. The code outputs the magnitude and spectra of the resultant neutron source. It also provides an analysis of the contributions to that source by each nuclide in the problem.

4.0 SOURCES-4A INPUT

For the purposes of this calculation it was assumed that the TRU waste form could be modeled as a homogeneous mixture. A homogeneous mixture problem is one in which the α-emitting material and spontaneous fission sources are intimately mixed with the low-Z target material (i.e., atoms of α-emitting material are directly adjacent to the target atoms). Two sources of neutrons exist in these problems, namely spontaneous fission neutrons and neutrons emitted as a result of (α,n) reactions during the slowing down of the α-particles. It is assumed in all homogeneous mixture calculations that the target is thick (i.e., that the dimensions of the target are much larger than the range of the α-particles); and thus, all α-particles are stopped within the mixture.

Naturally enriched UO_2 was selected as the matrix material since it is most representative of the TRU waste form. Therefore, the problems were set up to determine the neutron source magnitudes from the homogeneous mixture of radioisotopes in a UO_2 matrix. The (α,n) targets are ^{17}O and ^{18}O in natural oxygen. Upper neutron energies of the energy bins of 15, 10, 8, 6, 4, 3, 2, 1, 0.5 MeV were selected to determine the total neutron spectrum. The source isotopes and the associated atom densities for a unit density of 1 gram/cm^3 are presented in Table 1.

Table 1: Source Isotopes

Radionuclides	$T_{1/2}$	Atomic Weight, g	Density, g/cm^3	Atom Density, atoms/cm^3
^{230}Th	75380 Y	230.0331266	1	2.61788E+21
^{232}Th	1.405e10 Y	232.0380504	1	2.59526E+21
^{231}Pa	32760 Y	231.0358789	1	2.60652E+21
^{232}U	68.9 Y	232.0371463	1	2.59527E+21
^{233}U	159200 Y	233.0396282	1	2.58411E+21
^{234}U	245500 Y	234.0409456	1	2.57305E+21
^{235}U	703800000 Y	235.0439231	1	2.56207E+21
^{236}U	23420000 Y	236.0455619	1	2.5512E+21
^{238}U	4.468E+9 Y	238.0507826	1	2.52971E+21
^{237}Np	2144000 Y	237.0481673	1	2.54041E+21
^{236}Pu	2.858 Y	236.0460481	1	2.5512E+21
^{238}Pu	87.7 Y	238.0495534	1	2.52973E+21
^{239}Pu	24110 Y	239.0521565	1	2.51912E+21
^{240}Pu	6564 Y	240.0538075	1	2.5086E+21
^{241}Pu	14.35 Y	241.0568453	1	2.49817E+21
^{242}Pu	373300 Y	242.0587368	1	2.48783E+21
^{244}Pu	80800000 Y	244.0641977	1	2.46738E+21
^{241}Am	432.2 Y	241.0568229	1	2.49817E+21
^{242m}Am (2.2 MeV)	14 mS	242.059543	1	2.48782E+21
^{242m}Am (.048 MeV)	141 Y	242.059543	1	2.48782E+21
^{243}Am	7370 Y	243.0613727	1	2.47756E+21
^{240}Cm	27 D	240.055519	1	2.50859E+21
^{242}Cm	162.8 D	242.0588293	1	2.48782E+21
^{243}Cm	29.1 Y	243.0613822	1	2.47756E+21
^{244}Cm	18.10 Y	244.0627463	1	2.4674E+21
^{245}Cm	8500Y	245.0654856	1	2.4573E+21
^{246}Cm	4730 Y	246.0672176	1	2.4473E+21
^{248}Cm	340000 Y	248.0723422	1	2.42752E+21
^{250}Cm	~9700 Y	250.0783507	1	2.40805E+21
^{249}Bk	330 D	249.0749799	1	2.41775E+21
^{249}Cf	351 Y	249.0748468	1	2.41775E+21
^{250}Cf	13.08 Y	250.0764	1	2.40806E+21
^{251}Cf	898 Y	251.0795801	1	2.39844E+21
^{252}Cf	2.645 Y	252.0816196	1	2.38891E+21
^{254}Cf	60.5 D	254.0873162	1	2.37005E+21
^{253}Es	20.47 D	253.084818	1	2.37944E+21
^{254}Es	275.7 D	254.088016	1	2.37004E+21
^{254m}Es	39.3 H	254.088016	1	2.37004E+21

5.0 SOURCES-4A OUTPUT

Depending upon the neutron source output requested, SOURCES-4A can create between two and five output files. In this case, the tape 7 file was used to generate the neutron source outputs. The tape7 file lists the absolute neutron spectra (i.e., neutrons per second per unit volume). This file first lists the multigroup neutron spectra (i.e., the energy bounds) used in the calculations in decreasing order. The absolute neutron spectra listed by neutron target combination are then displayed in order coinciding with the group structure specified at the beginning of the file. Totals per target nuclide for (α,n) reactions, totals for all (α,n) reactions, and totals for spontaneous fission neutrons are listed. For reporting purposes, the neutron source strengths in neutrons per second per unit volume were converted to neutrons per second per unit mass by dividing the SOURCES-4A output by the unit density. The total source strength was then converted from units of neutrons per second per unit mass to units of neutrons per second per unit activity by dividing this number by the isotope's specific activity.

There are no spontaneous fission data for some of the isotopes in the SOURCES-4A tape5 decay library. The decay library of SOURCES-4A is limited to significant SF source nuclides that might be produce in a thermal reactor. A number of higher-mass actinides are not included in the data library. Isotopes included in decay library are presented in Section 5.1. Those isotopes missing data are presented in Section 5.2.

5.1 Normal SOURCES-4A Decay Data Library

The absolute neutron spectra (i.e., neutrons per second per unit activity) for 25 of the source isotopes fully defined in the SOURCES-4A decay data library (tape 5) are presented in Tables 2 and 3. Total neutron source strengths for both (α,n) reactions and SF are presented in Table 2. The absolute neutron spectra listed per energy bin are presented in Table 3.

Table 2: Total Neutron Source Strength for Normal Cases

Radionuclides	Total (α,n), neutrons/sec-g	Total SF, neutrons/sec-g	Total Neutrons, neutrons/sec-g	Specific Activity, Ci/g	Total Neutrons, neutrons/sec-Ci	Average Neutron Energy, MeV
^{230}Th	9.13E+00	8.52E-04	9.13E+00	2.10E-02	4.35E+02	2.16
^{232}Th	2.26E-05	1.22E-07	2.28E-05	1.10E-07	2.07E+02	1.92
^{231}Pa	2.64E+01	1.01E-02	2.64E+01	4.70E-02	5.61E+02	2.22
^{232}U	1.50E+04	1.22E+00	1.50E+04	2.20E+01	6.82E+02	2.32
^{233}U	4.83E+00	8.16E-04	4.83E+00	9.70E-03	4.98E+02	2.18
^{234}U	3.03E+00	5.02E-03	3.03E+00	6.20E-03	4.89E+02	2.17
^{235}U	7.19E-04	2.99E-04	1.02E-03	2.20E-06	4.63E+02	2.03
^{236}U	2.39E-02	5.49E-03	2.94E-02	6.50E-05	4.52E+02	2.05
^{238}U	8.35E-05	1.36E-02	1.37E-02	3.40E-07	4.03E+04	1.69
^{237}Np	3.43E-01	1.14E-04	3.43E-01	7.10E-04	4.83E+02	2.18
^{236}Pu	4.99E+05	3.39E+04	5.33E+05	5.30E+02	1.01E+03	2.45
^{238}Pu	1.36E+04	2.59E+03	1.62E+04	1.70E+01	9.51E+02	2.32
^{239}Pu	3.86E+01	2.18E-02	3.86E+01	6.20E-02	6.23E+02	2.27
^{240}Pu	1.42E+02	1.03E+03	1.17E+03	2.30E-01	5.08E+03	1.97
^{241}Pu	1.31E+00	4.94E-02	1.35E+00	1.00E+02	1.35E-02	2.19
^{242}Pu	2.07E+00	1.72E+03	1.72E+03	3.90E-03	4.41E+05	1.96
^{244}Pu	7.24E-03	1.90E+03	1.90E+03	1.80E-05	1.06E+08	1.77
^{241}Am	2.71E+03	1.18E+00	2.71E+03	3.40E+00	7.97E+02	2.38
^{243}Am	1.36E+02	3.93E+00	1.40E+02	2.00E-01	7.00E+02	2.30
^{240}Cm	2.55E+07	6.93E+07	9.48E+07	2.00E+04	4.74E+03	2.45
^{242}Cm	3.80E+06	2.10E+07	2.48E+07	3.30E+03	7.51E+03	2.17
^{243}Cm	5.01E+04	3.59E+05	4.10E+05	5.20E+01	7.88E+03	2.26
^{244}Cm	7.80E+04	1.08E+07	1.09E+07	8.10E+01	1.35E+05	2.11
^{245}Cm	1.25E+02	3.69E+03	3.82E+03	1.72E-01	2.22E+04	2.13
^{246}Cm	2.32E+02	9.68E+06	9.68E+06	3.10E-01	3.12E+07	2.07
^{248}Cm	2.29E+00	4.03E+07	4.03E+07	4.20E-03	9.60E+09	1.95
^{251}Cf	1.52E+03	0.00E+00	1.52E+03	1.60E+00	9.51E+02	2.47

Table 3: Total Neutron Spectra

	Total Neutron Spectrum								
	Neutron Multigroup Structure (MeV)								
Radionuclide	15.0-10.0	10.0-8.0	8.0-6.0	6.0-4.0	4.0-3.0	3.0-2.0	2.0-1.0	1.0-0.5	0.5-0.0
^{230}Th	9.36E-08	7.58E-07	6.16E-06	3.63E-02	9.24E-01	4.84E+00	2.65E+00	3.27E-01	3.59E-01
^{232}Th	4.83E-12	5.19E-11	5.39E-10	4.34E-08	3.39E-07	9.82E-06	1.13E-05	9.83E-07	2.71E-07
^{231}Pa	4.98E-06	2.62E-05	1.49E-04	1.32E-01	3.96E+00	1.33E+01	6.74E+00	1.05E+00	1.19E+00
^{232}U	1.33E-03	5.56E-03	2.61E-02	1.95E+02	3.09E+03	6.95E+03	3.42E+03	7.40E+02	6.26E+02
^{233}U	6.64E-07	3.03E-06	1.52E-05	2.15E-02	5.90E-01	2.52E+00	1.31E+00	1.75E-01	2.12E-01
^{234}U	1.96E-06	1.11E-05	6.66E-05	1.33E-02	3.49E-01	1.59E+00	8.40E-01	1.09E-01	1.30E-01
^{235}U	1.19E-07	6.71E-07	4.00E-06	2.35E-05	6.89E-05	4.34E-04	3.52E-04	8.30E-05	5.21E-05
^{236}U	1.46E-06	9.20E-06	6.05E-05	4.32E-04	2.09E-03	1.38E-02	9.73E-03	1.96E-03	1.33E-03
^{238}U	1.25E-06	1.07E-05	9.05E-05	6.57E-04	1.15E-03	2.53E-03	4.52E-03	2.76E-03	1.99E-03
^{237}Np	7.85E-08	3.77E-07	1.97E-06	1.49E-03	3.98E-02	1.80E-01	9.48E-02	1.23E-02	1.47E-02
^{236}Pu	7.11E+01	2.44E+02	9.83E+02	2.60E+04	1.34E+05	2.05E+05	1.12E+05	3.17E+04	2.32E+04
^{238}Pu	2.06E+00	9.49E+00	4.81E+01	5.22E+02	3.46E+03	6.42E+03	3.71E+03	1.16E+03	8.47E+02
^{239}Pu	2.28E-05	9.66E-05	4.58E-04	2.85E-01	6.84E+00	1.88E+01	9.29E+00	1.71E+00	1.73E+00
^{240}Pu	5.13E-01	2.71E+00	1.53E+01	7.74E+01	1.32E+02	2.67E+02	3.49E+02	1.89E+02	1.37E+02
^{241}Pu	3.65E-05	1.71E-04	8.81E-04	1.01E-02	1.82E-01	6.81E-01	3.59E-01	5.73E-02	6.48E-02
^{242}Pu	1.03E+00	5.15E+00	2.78E+01	1.33E+02	1.81E+02	3.32E+02	5.23E+02	3.01E+02	2.16E+02
^{244}Pu	3.23E-01	2.32E+00	1.70E+01	1.08E+02	1.73E+02	3.55E+02	6.12E+02	3.68E+02	2.65E+02
^{241}Am	1.75E-03	6.68E-03	2.91E-02	5.98E+01	6.31E+02	1.18E+03	5.87E+02	1.43E+02	1.07E+02
^{243}Am	3.51E-03	1.56E-02	7.68E-02	1.92E+00	2.76E+01	6.44E+01	3.24E+01	7.23E+00	6.24E+00
^{240}Cm	2.35E+05	6.94E+05	2.49E+06	1.07E+07	1.58E+07	2.22E+07	2.36E+07	1.13E+07	7.82E+06
^{242}Cm	2.35E+04	9.81E+04	4.59E+05	2.22E+06	3.43E+06	5.47E+06	6.90E+06	3.64E+06	2.56E+06
^{243}Cm	7.14E+02	2.49E+03	1.01E+04	3.97E+04	5.60E+04	8.99E+04	1.12E+05	5.82E+04	4.10E+04
^{244}Cm	1.32E+04	5.36E+04	2.45E+05	1.01E+06	1.25E+06	2.15E+06	3.18E+06	1.77E+06	1.25E+06
^{245}Cm	4.75E+00	1.89E+01	8.55E+01	3.47E+02	4.49E+02	7.79E+02	1.10E+03	6.06E+02	4.29E+02
^{246}Cm	9.72E+03	4.17E+04	2.00E+05	8.52E+05	1.08E+06	1.89E+06	2.86E+06	1.61E+06	1.14E+06
^{248}Cm	2.27E+04	1.16E+05	6.36E+05	3.09E+06	4.22E+06	7.78E+06	1.23E+07	7.09E+06	5.06E+06
^{251}Cf	0.00E+00	0.00E+00	6.01E-02	7.58E+01	3.98E+02	5.98E+02	3.10E+02	8.07E+01	5.87E+01

5.2 Modified SOURCES-4A Decay Data Library

In order to determine the contribution of spontaneous fission neutrons to the source strength of several of the higher order actinides, it was necessary to modify the SOURCES-4A decay data library (tape 5) to include the data necessary to generate the required output. The changes necessary for each of the modified isotopes is discussed in the following sections. It should be noted that there is uncertainty in the data used to generate the modified Tape 5. Reference 2 and 3 were in agreement for the most part. Therefore, for consistency, Reference 2 was used exclusively for the SF Branching % when the data was available. Reference 3 was used to supplement the information available from Reference 2. The Nu-Bar data was obtained exclusively from Reference 4.

The absolute neutron source strength and spectra for the isotopes not fully defined in Tape 5 are presented in Tables 4 and 5. Total neutron source strengths for both (α,n) reactions and SF are presented in Table 4. The absolute neutron spectra listed per energy bin are presented in Table 5.

5.2.1 ^{242}Am

There are two metastable states of ^{242}Am that decay by spontaneous fission. SOURCES-4A models the metastable energy state at 0.048 MeV correctly. Tape 5 was modified to model the 2.2 MeV metastable energy state. The ^{242}Am data entry was modified by adjusting the branching fraction to 100% and by adding the alpha energy spectrum for 100% decay at 6.5 MeV. The actual α-decay energy is 7.788 MeV but SOURCES-4A is limited to α energies up to 6.5 MeV.

Isotope	SF Branching % (Reference 3)	Watts Fission Spectrum A	Watts Fission Spectrum B	Nu-Bar (Reference 4)	Alpha Energy, MeV (Reference 3)
^{242m}Am (2.2 MeV)	100	Code default	Code default	Code default	6.5

5.2.2 ^{250}Cm

SOURCES-4A does not include spontaneous fission data for this isotope. The isotopic data entry in Tape 5 was modified by editing the decay data library (tape 5) to include the Branching %, Watts Fission Spectrum constants, and Nu-Bar. The Watts Fission Spectrum constants were assumed to be similar to ^{248}Cm.

Isotope	SF Branching % (Reference 2)	Watts Fission Spectrum		Nu-Bar
		A	B	(Reference 4)
^{250}Cm	86	3.11	8.08387e-01	3.31

5.2.3 ^{249}Bk

SOURCES-4A does not include spontaneous fission data for this isotope. The isotopic data entry in Tape 5 was modified by editing the decay data library (tape 5) to include the Branching %, Watts Fission Spectrum constants, and Nu-Bar. The Watts Fission Spectrum constants were assumed to be similar to ^{248}Cm.

Isotope	SF Branching % (Reference 2)	Watts Fission Spectrum		Nu-Bar
		A	B	(Reference 4)
^{249}Bk	4.76000e-08	3.11	8.08387e-01	3.67

5.2.4 ^{249}Cf

SOURCES-4A does not include spontaneous fission data for this isotope. The isotopic data entry in Tape 5 was modified by editing the decay data library (tape 5) to include the Branching %, Watts Fission Spectrum constants, and Nu-Bar. The Watts Fission Spectrum constants were assumed to be similar to ^{248}Cf.

Isotope	SF Branching % (Reference 2)	Watts Fission Spectrum		Nu-Bar
		A	B	(Reference 4)
^{249}Cf	4.4e-07	3.34	1.02772	3.2

5.2.5 ^{250}Cf

SOURCES-4A does not include spontaneous fission data for this isotope. The isotopic data entry in Tape 5 was modified by editing the decay data library (tape 5) to include the Branching %, Watts Fission Spectrum constants, and Nu-Bar. The Watts Fission Spectrum constants were assumed to be similar to ^{248}Cf.

Isotope	SF Branching % (Reference 2)	Watts Fission Spectrum A	Watts Fission Spectrum B	Nu-Bar (Reference 4)
^{250}Cf	0.08	3.34	1.02772	3.49

5.2.6 ^{252}Cf

SOURCES-4A does not include spontaneous fission data for this isotope. The isotopic data entry in Tape 5 was modified by editing the decay data library (tape 5) to include the Branching %, Watts Fission Spectrum constants, and Nu-Bar. The Watts Fission Spectrum constants were assumed to be similar to ^{248}Cf.

Isotope	SF Branching % (Reference 2)	Watts Fission Spectrum A	Watts Fission Spectrum B	Nu-Bar (Reference 4)
^{252}Cf	3.092	3.34	1.02772	3.73

5.2.7 ^{254}Cf

SOURCES-4A does not include spontaneous fission data for this isotope. The isotopic data entry in Tape 5 was modified by editing the decay data library (tape 5) to include the Branching %, Watts Fission Spectrum constants, and Nu-Bar. The Watts Fission Spectrum constants were assumed to be similar to ^{248}Cf.

Isotope	SF Branching % (Reference 2)	Watts Fission Spectrum A	Watts Fission Spectrum B	Nu-Bar (Reference 4)
^{254}Cf	99.69	3.34	1.02772	3.89

5.2.8 ^{253}Es

SOURCES-4A does not include spontaneous fission data for this isotope. The isotopic data entry in Tape 5 was modified by editing the decay data library (tape 5) to include the Branching %, Watts Fission Spectrum constants, and Nu-Bar. The Watts Fission Spectrum constants were assumed to be similar to ^{249}Cf. SOURCES-4A will not run with α energies above 6.5 MeV. Therefore, the actual α-decay energy used in Tape 5 was limited to α energies up to 6.5 MeV.

Isotope	SF Branching % (Reference 3)	Watts Fission Spectrum A	B	Nu-Bar (Reference 4)
^{253}Es	8.9e-06	3.34	1.02772	3.7

5.2.9 ^{254}Es

SOURCES-4A does not include spontaneous fission data for this isotope. The isotopic data entry in Tape 5 was modified by editing the decay data library (tape 5) to include the Branching %, Watts Fission Spectrum constants, and Nu-Bar. The Watts Fission Spectrum constants were assumed to be similar to ^{249}Cf.

Isotope	SF Branching % (Reference 3)	Watts Fission Spectrum A	B	Nu-Bar (Reference 4)
^{254}Es	3.0-06	3.34	1.02772	3.7

5.2.10 ^{254m}Es

SOURCES-4A does not include spontaneous fission data for this isotope. The isotopic data entry in Tape 5 was modified by editing the decay data library (tape 5) to include the Branching %, Watts Fission Spectrum constants, and Nu-Bar. The Watts Fission Spectrum constants were assumed to be similar to ^{249}Cf. SOURCES-4A will not run with α energies above 6.5 MeV. Therefore, the actual α-decay energy used in Tape 5 was limited to α energies up to 6.5 MeV.

Isotope	SF Branching % (Reference 3)	Watts Fission Spectrum A	B	Nu-Bar (Reference 4)
^{254m}Es	3.0-06	3.34	1.02772	3.7

Table 4: Total Neutron Source Strength for Modified Cases

Radionuclides	Total (α,n), neutrons/sec-g	Total SF, neutrons/sec-g	Total Neutrons, neutrons/sec-g	Specific Activity, Ci/g	Total Neutrons, neutrons/sec-Ci	Average Neutron Energy, MeV
^{242m}Am (2.2 MeV)	1.14E+09	7.39E+16	7.39E+16	3.30E+12	2.24E+04	2.10E+00
^{242m}Am (.048 MeV)	3.01E+01	1.35E+02	1.65E+02	1.00E+01	1.65E+01	2.13E+00
^{250}Cm	8.00E+01	1.25E+10	1.25E+10	1.50E-01	8.33E+10	1.75E+00
^{249}Bk	1.78E+01	1.65E+05	1.65E+05	1.60E+03	1.03E+02	1.81E+00
^{249}Cf	4.03E+03	2.23E+03	6.26E+03	4.10E+00	1.53E+03	2.45E+00
^{250}Cf	1.20E+05	1.08E+10	1.08E+10	1.10E+02	9.82E+07	2.46E+00
^{252}Cf	9.01E+05	2.05E+12	2.05E+12	5.40E+02	3.80E+09	2.53E+00
^{254}Cf	2.59E+04	1.05E+15	1.05E+15	8.50E+03	1.23E+11	2.57E+00
^{253}Es	3.54E+07	2.77E+08	3.13E+08	2.50E+04	1.25E+04	2.54E+00
^{254}Es	2.52E+06	6.91E+06	9.43E+06	1.90E+03	4.96E+03	2.56E+00
^{254m}Es	1.33E+06	1.94E+13	1.94E+13	3.10E+05	6.25E+07	2.52E+00

Table 5: Total Neutron Spectra

	Total Neutron Spectrum								
	Neutron Multigroup Structure (MeV)								
Radionuclide	15.0-10.0	10.0-8.0	8.0-6.0	6.0-4.0	4.0-3.0	3.0-2.0	2.0-1.0	1.0-0.5	0.5-0.0
^{242m}Am (2.2 MeV)	8.61E+13	3.53E+14	1.63E+15	6.73E+15	8.35E+15	1.44E+16	2.16E+16	1.21E+16	8.60E+15
^{242m}Am (.048 MeV)	1.57E-01	6.43E-01	2.97E+00	1.25E+01	2.09E+01	4.06E+01	4.65E+01	2.35E+01	1.70E+01
^{250}Cm	3.78E+06	2.16E+07	1.33E+08	7.31E+08	1.11E+09	2.23E+09	3.91E+09	2.48E+09	1.91E+09
^{249}Bk	6.05E+01	3.34E+02	1.98E+03	1.05E+04	1.54E+04	3.02E+04	5.14E+04	3.16E+04	2.38E+04
^{249}Cf	6.95E+00	2.14E+01	7.90E+01	4.76E+02	1.35E+03	2.00E+03	1.42E+03	5.31E+02	3.73E+02
^{250}Cf	3.91E+07	1.17E+08	4.18E+08	1.34E+09	1.41E+09	2.15E+09	2.87E+09	1.48E+09	9.95E+08
^{252}Cf	8.36E+09	2.44E+10	8.53E+10	2.66E+11	2.73E+11	4.10E+11	5.36E+11	2.71E+11	1.80E+11
^{254}Cf	4.59E+12	1.32E+13	4.54E+13	1.40E+14	1.41E+14	2.10E+14	2.70E+14	1.35E+14	8.86E+13
^{253}Es	1.11E+06	3.25E+06	1.14E+07	4.03E+07	4.68E+07	6.67E+07	7.90E+07	3.85E+07	2.55E+07
^{254}Es	2.77E+04	8.11E+04	2.86E+05	1.19E+06	1.63E+06	2.20E+06	2.28E+06	1.04E+06	6.90E+05
^{254m}Es	7.78E+10	2.28E+11	7.98E+11	2.50E+12	2.57E+12	3.87E+12	5.07E+12	2.57E+12	1.71E+12