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BR-1 Reactor Spectral Indices Benchmarks

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Dave Heinrichs
Nuclear Criticality Safety Division

Lawrence Livermore National Laboratory, 7000 East Avenue, P.O. Box 808, L-198, Livermore, California, 94551, 0808, USA

Auspices

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Introduction:

Cross section (reaction rate) ratios were measured in the core center of the BR-1 Fast Spectrum Assembly, which was put into operation at the Institute for Physics and Power Engineering (IPPE) in Obninsk, Russia, in 1955. Benchmark values for these ratios, or spectral indices, were published in the "International Handbook of Evaluated Criticality Safety Benchmark Experiments," NEA No. 7520, Nuclear Energy Agency, Organisation for Economic Co-operation and Development, Volume IX, "Fundamental Physics Measurements Supporting Nuclear Criticality Safety," Evaluation No. FUND-IPPE-FR-MULT-RRR-001, "Cross Section Ratios Measured in the Core Center of the BR-1 Fast Spectrum Assembly," Yuri Khomyakov, Yevgeniy Rozhikhin, September 30, 2009.

Methodology:

The relevant details of the benchmark model provided in the Handbook are given in the sections on **Dimensions** (with additional annotations) and **Materials** (used "as is") in developing the benchmark model for the COG11.3 code.

Each spectral index is calculated as the ratio of the reaction rate (<RR>) of interest relative to the U-235 fission reaction rate. The reaction rate is simply the flux within a radius of 0.46 cm and height of 1 cm at the midplane of the Pu rods (at Z=0.0) weighted by the reaction cross section used as a detector response function, which in no way perturbs the flux.

Therefore, two detectors are used to calculate a spectral index. In all cases, a reaction detector (e.g., number=#0000052 for radiative capture in ^{197}Au) is used to score a reaction rate (<RR>) of interest averaged over all energies, and another (e.g., number=#0000010) is used to score the fission reaction rate in ^{235}U over all energies:

```
number=#0000052 title="BR-1 spectrum averaged Au-197(n,g) r-r" reaction 5 0.664761 drf-e neutron r-rate 42 46
number=#0000010 title="BR-1 spectrum averaged U-235(n,f)    r-r" reaction 5 0.664761 drf-e neutron r-rate 10 15
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The spectral index (in this case for radiative capture in ^{197}Au relative to ^{235}U fission) is then just the ratio of the two (reaction rate) detector results.

Note that "r-rate" corresponds to a reaction number for a material specified using the nlib parameter in the MIX block; e.g., nlib=ENDFB8R0. This library corresponds to a complete library suitable for particle transport. COG11.3 also provides a doslib parameter; e.g., doslib=IRDFF-II. In this case "irdff-r-r" is used to specify reaction rates from an incomplete library of partial (dosimetry) reactions.

Results:

COG11.3 calculation results using ENDF/B-VIII.0 for both particle transport and reaction rate ratios are provided in Table 1. Results using ENDF/B-VIII.0 for particle transport and IRDFF-II for reaction rate ratios are given in Table 2 except note that IRDFF-1.05 is used for the ^{60}Co(n,g) reaction rate. Results using JEFF-3.3 for both particle transport and reaction rate ratios are provided in Table 3. Table 4 identifies the libraries which produced reliable results, i.e., with $|C/E-1| \leq 3\sigma$.

A sample COG11.3 input listing is provided in the Appendix.

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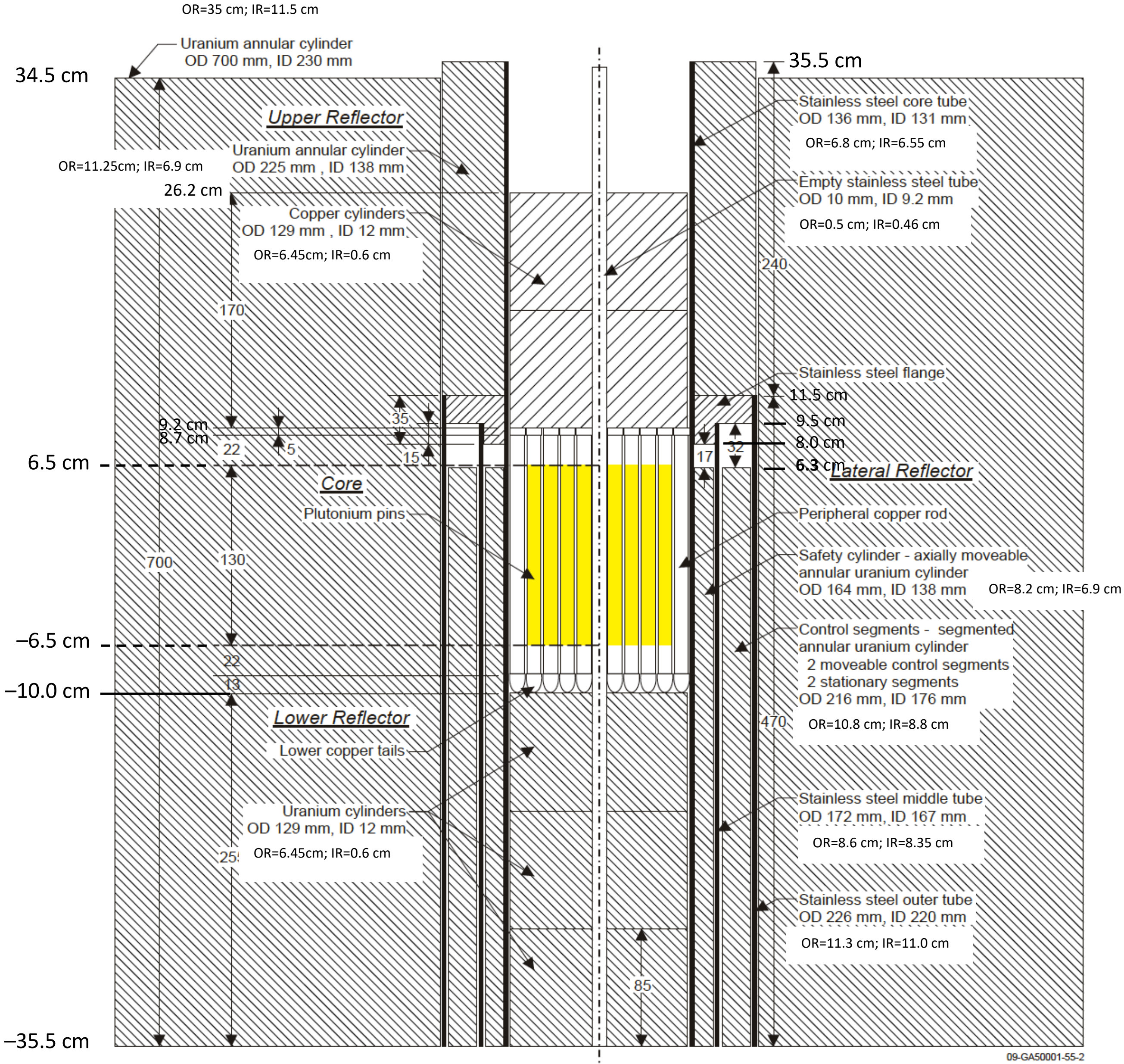
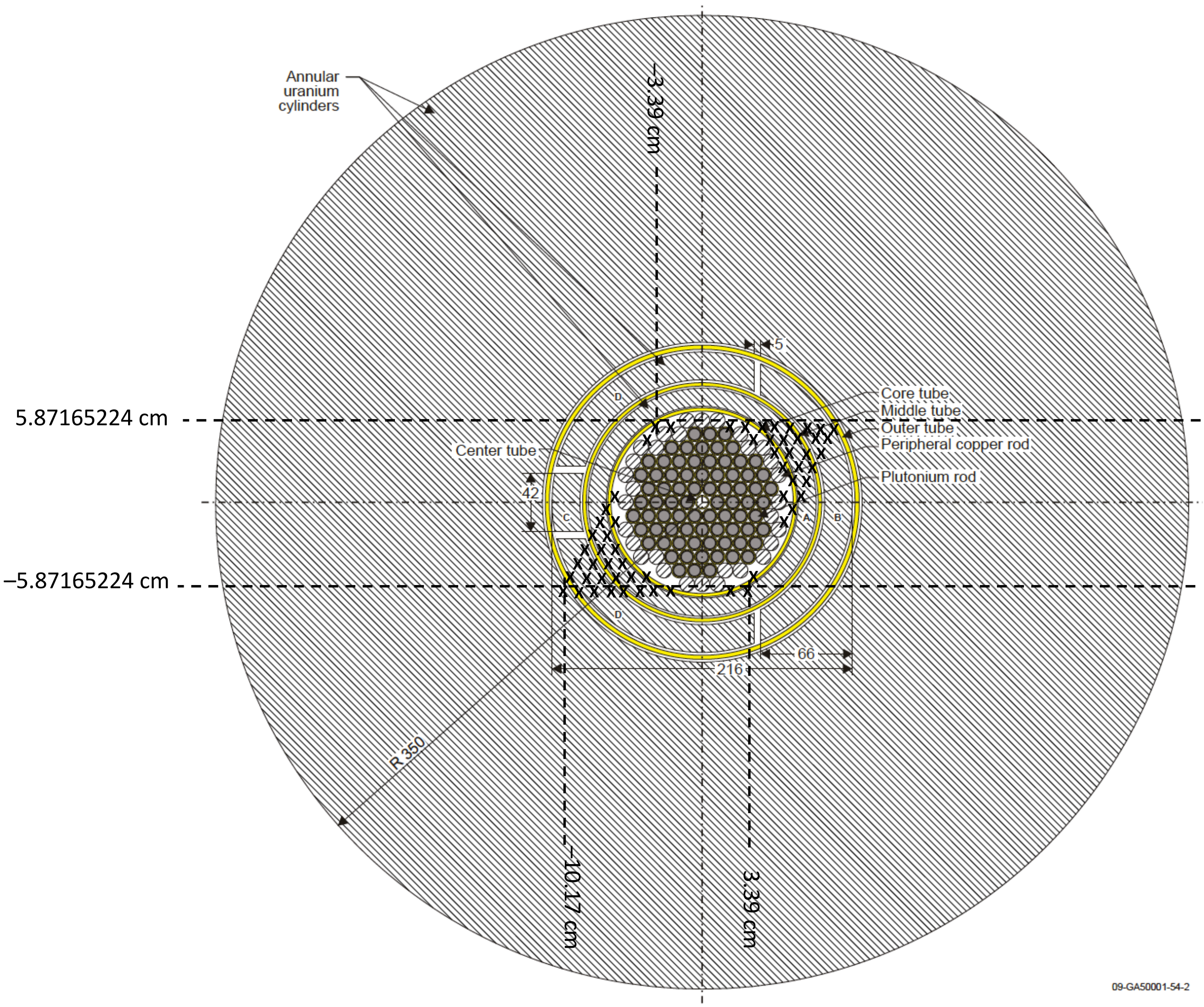
Dimensions: Axial view



Dimensions: Plane view (pitch = 1.13 cm)



A. - Safety Cylinder.
B. - Big Safety Segment (Shim Rod).
C. - Small Safety Segment (Control Rod).
D. - Stationary Segments.

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Dimensions: Pu and Copper Rods

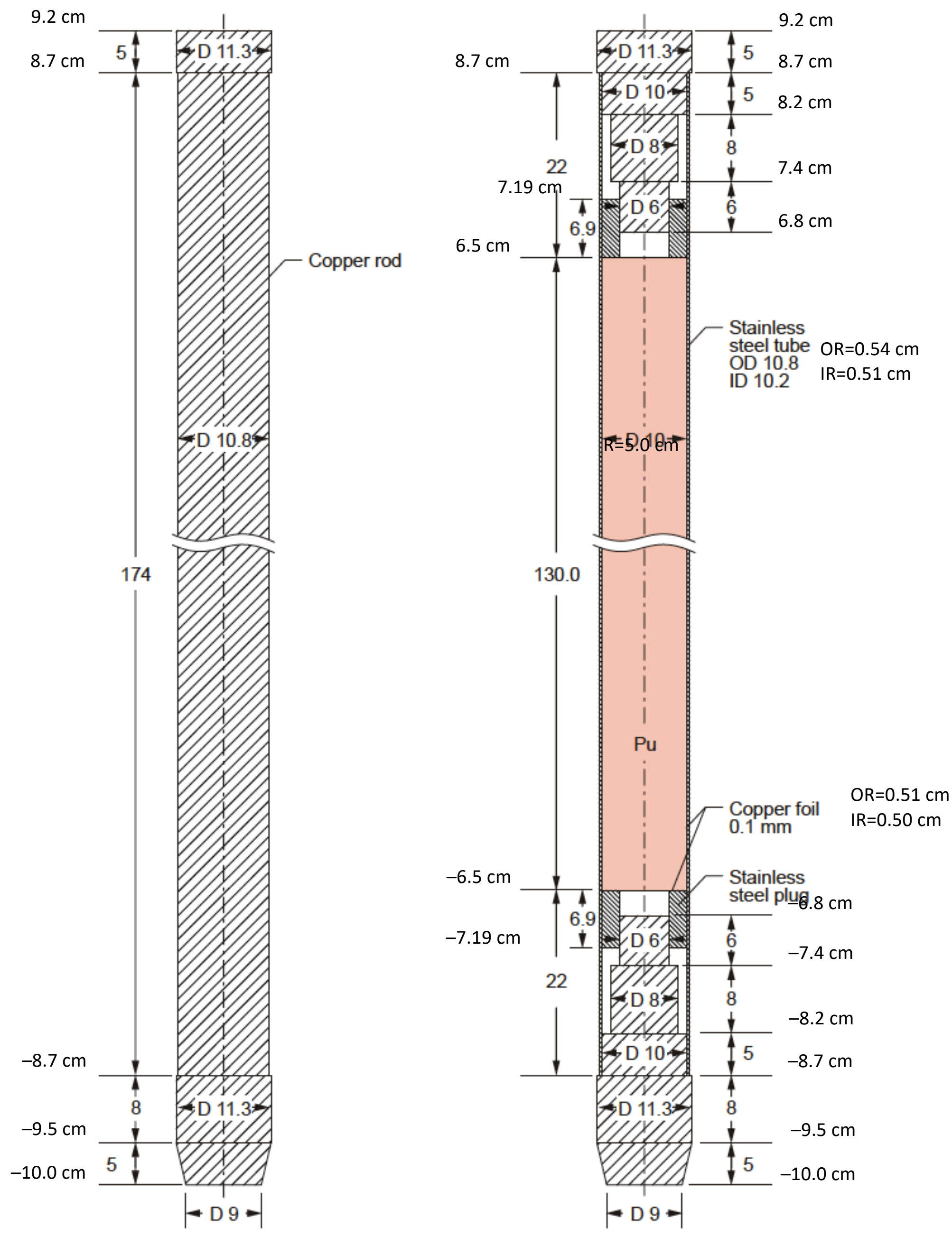

Figure 8. Model of Rods (dimensions in mm).

Materials:

Table 13. Atom Densities of Materials (atoms/barn-cm).

Material	Structural Element	Density (g/cm^3)	Nuclide or Isotope	Atomic Density
Plutonium Metal	Fuel Pins	15.5629049 [(a)]	^{238}Pu	1.9260E-05
			^{239}Pu	3.7610E-02
			^{240}Pu	8.8210E-04
			^{241}Pu	7.7039E-06
			Ga	2.3389E-03
Copper	Foil, Copper Rods, Fuel Pin Tails	8.9	Cu	8.4343E-02
Stainless-Steel	Cans, Plugs, Tubes, Flange	7.93	Fe	5.9986E-02
			Cr	1.5724E-02
			Ni	8.5030E-03
			Mn	1.0431E-03
			Si	8.5018E-04
			Ti	4.7376E-04
			C	4.1748E-04
Depleted Uranium Metal	Reflector, Control Segments, Safety Cylinder	18.9	^{235}U	2.0404E-04
			^{238}U	4.7248E-02
			Fe	3.2608E-04
			C	5.6857E-03

(a) The number of digits shown does not indicate accuracy of the data but is to maintain consistency between the benchmark model and experimental data.

FUND-IPPE-FR-MULT-RRR-001

Results: ENDF/B-VIII.0

Table 1. Benchmark-Model and Calculated* Reaction Rate Ratios: COG11.3 with ENDF/B-VIII.0 used for both particle transport and reaction rate ratios.

Reaction Ratio	Benchmark-Model	Calculated	C/E
Th232(n,f)/U235(n,f)	0.043 ± 0.0013	(9.3143E-4 ± 1.1%)/(2.3189E-2 ± 0.6%) = 0.0402 ± 1.3%	0.934 ± 3.3%
U233(n,f)/U235(n,f)	1.54 ± 0.03	(3.6267E-2 ± 0.6%)/(2.3189E-2 ± 0.6%) = 1.5640 ± 0.8%	1.016 ± 1.5%
U234(n,f)/U235(n,f)	0.790 ± 0.024	(1.6961E-2 ± 0.7%)/(2.3189E-2 ± 0.6%) = 0.7314 ± 0.9%	**0.926** ± 2.0%
U236(n,f)/U235(n,f)	0.333 ± 0.010	(7.4679E-3 ± 0.9%)/(2.3189E-2 ± 0.6%) = 0.3220 ± 1.1%	0.967 ± 3.2%
U238(n,f)/U235(n,f)	0.165 ± 0.005	(3.8368E-3 ± 1.0%)/(2.3189E-2 ± 0.6%) = 0.1655 ± 1.2%	1.003 ± 3.2%
Np237(n,f)/U235(n,f)	0.771 ± 0.023	(1.8907E-2 ± 0.8%)/(2.3189E-2 ± 0.6%) = 0.8153 ± 1.0%	1.058 ± 3.1%
Pu239(n,f)/U235(n,f)	1.33 ± 0.04	(3.1631E-2 ± 0.6%)/(2.3189E-2 ± 0.6%) = 1.3641 ± 0.8%	1.026 ± 3.1%
Pu240(n,f)/U235(n,f)	0.877 ± 0.026	(1.9120E-2 ± 0.7%)/(2.3189E-2 ± 0.6%) = 0.8245 ± 0.9%	0.940 ± 3.1%
Pu241(n,f)/U235(n,f)	1.29 ± 0.04	(3.0582E-2 ± 0.6%)/(2.3189E-2 ± 0.6%) = 1.3188 ± 0.8%	1.022 ± 3.2%
Pu242(n,f)/U235(n,f)	0.658 ± 0.020	(1.5926E-2 ± 0.8%)/(2.3189E-2 ± 0.6%) = 0.6868 ± 1.0%	1.044 ± 3.2%
Am241(n,f)/U235(n,f)	0.825 ± 0.025	(1.8063E-2 ± 0.8%)/(2.3189E-2 ± 0.6%) = 0.7789 ± 1.0%	0.944 ± 3.2%
Th232(n,g)/U235(n,f)	0.109 ± 0.004	(2.3601E-3 ± 0.8%)/(2.3189E-2 ± 0.6%) = 0.1018 ± 1.1%	0.934 ± 3.8%
U236(n,g)/U235(n,f)	0.123 ± 0.006	(2.7510E-3 ± 0.8%)/(2.3189E-2 ± 0.6%) = 0.1186 ± 1.1%	0.964 ± 5.0%
U238(n,g)/U235(n,f)	0.077 ± 0.003	(1.8097E-3 ± 2.5%)/(2.3189E-2 ± 0.6%) = 0.0780 ± 2.6%	1.014 ± 4.7%
Np237(n,g)/U235(n,f)	0.240 ± 0.012	(6.8327E-3 ± 1.1%)/(2.3189E-2 ± 0.6%) = 0.2947 ± 1.3%	**1.228** ± 5.2%
Th232(n,2n)/U235(n,f)	0.00924 ± 0.00050	(2.6791E-4 ± 6.3%)/(2.3189E-2 ± 0.6%) = 0.0116 ± 6.3%	1.250 ± 8.3%
U238(n,2n)/U235(n,f)	0.00916 ± 0.00050	(2.3225E-4 ± 5.6%)/(2.3189E-2 ± 0.6%) = 0.0100 ± 5.6%	1.093 ± 7.8%
Nb93(n,2n)/U235(n,f)	0.000293 ± 0.000010	(2.1407E-5 ± 18.7%)/(2.3189E-2 ± 0.6%) = 9.22E-4 ± 18.7%	**3.147** ± 19.0%
Al27(n,a)/U235(n,f)	0.00043 ± 0.00002	(1.1146E-5 ± 6.1%)/(2.3189E-2 ± 0.6%) = 0.00048 ± 6.1%	1.118 ± 7.7%
Fe54(n,a)/U235(n,f)	0.00050 ± 0.00002	(1.0739E-5 ± 3.7%)/(2.3189E-2 ± 0.6%) = 0.00046 ± 3.7%	0.926 ± 5.5%
Co59(n,a)/U235(n,f)	0.000095 ± 0.000004	(2.3715E-6 ± 5.8%)/(2.3189E-2 ± 0.6%) = 0.000102 ± 5.8%	1.077 ± 7.2%
Mo92(n,a)/U235(n,f)	0.000055 ± 0.000005	(2.0511E-6 ± 3.7%)/(2.3189E-2 ± 0.6%) = 8.845E-5 ± 3.7%	**1.608** ± 9.7%
Nb93(n,a)/U235(n,f)	0.0000159 ± 0.0000009	(1.3970E-6 ± 2.4%)/(2.3189E-2 ± 0.6%) = 6.024E-5 ± 2.5%	**3.789** ± 6.2%
Mg24(n,p)/U235(n,f)	0.00090 ± 0.00004	All results were zero	
Al27(n,p)/U235(n,f)	0.00221 ± 0.00015	(5.1323E-5 ± 2.4%)/(2.3189E-2 ± 0.6%) = 0.00221 ± 2.5%	1.001 ± 7.2%
Ti46(n,p)/U235(n,f)	0.0066 ± 0.0003	All results were zero	
Ti47(n,p)/U235(n,f)	0.0097 ± 0.0005	All results were zero	
Ti48(n,p)/U235(n,f)	0.00018 ± 0.000008	All results were zero	
Fe54(n,p)/U235(n,f)	0.0447 ± 0.0015	(9.6559E-4 ± 1.5%)/(2.3189E-2 ± 0.6%) = 0.04164 ± 1.6%	0.932 ± 3.7%
Fe56(n,p)/U235(n,f)	0.00061 ± 0.00002	(1.5881E-5 ± 4.4%)/(2.3189E-2 ± 0.6%) = 0.00068 ± 4.4%	1.123 ± 5.5%
Ni58(n,p)/U235(n,f)	0.055 ± 0.003	All results were zero	
Co59(n,p)/U235(n,f)	0.00084 ± 0.00004	All results were zero	
Mo92(n,p)/U235(n,f)	0.00388 ± 0.00015	All results were zero	
Cr50(n,g)/U235(n,f)	0.0557 ± 0.0005	(1.0810E-4 ± 4.6%)/(2.3189E-2 ± 0.6%) = 0.00466 ± 4.6%	**0.084** ± 4.7%
Mn55(n,g)/U235(n,f)	0.00297 ± 0.00015	(8.8540E-5 ± 3.1%)/(2.3189E-2 ± 0.6%) = 0.00382 ± 3.2%	**1.286** ± 6.0%
Fe58(n,g)/U235(n,f)	0.00228 ± 0.00009	(8.1525E-5 ± 5.7%)/(2.3189E-2 ± 0.6%) = 0.00352 ± 5.7%	**1.542** ± 7.0%
Co59(n,g)/U235(n,f)	0.0064 ± 0.0003	(1.2344E-4 ± 2.0%)/(2.3189E-2 ± 0.6%) = 0.00532 ± 2.1%	**0.832** ± 6.0%
Ni64(n,g)/U235(n,f)	0.00185 ± 0.00008	(6.0794E-4 ± 1.1%)/(2.3189E-2 ± 0.6%) = 0.00262 ± 1.3%	**1.417** ± 4.5%
Cu63(n,g)/U235(n,f)	0.0114 ± 0.0005	(2.7291E-4 ± 1.3%)/(2.3189E-2 ± 0.6%) = 0.01177 ± 1.4%	1.032 ± 4.6%
Cu65(n,g)/U235(n,f)	0.0076 ± 0.0006	(1.5087E-4 ± 1.4%)/(2.3189E-2 ± 0.6%) = 0.00651 ± 1.5%	0.856 ± 8.0%
Mo98(n,g)/U235(n,f)	0.0193 ± 0.0008	(6.3102E-4 ± 1.9%)/(2.3189E-2 ± 0.6%) = 0.02721 ± 2.0%	**1.410** ± 4.6%
Zr94(n,g)/U235(n,f)	0.0064 ± 0.0004	(2.2119E-4 ± 1.2%)/(2.3189E-2 ± 0.6%) = 0.00954 ± 1.3%	**1.490** ± 6.4%
Zr96(n,g)/U235(n,f)	0.00306 ± 0.00015	(1.4081E-4 ± 0.8%)/(2.3189E-2 ± 0.6%) = 0.00607 ± 1.0%	**1.984** ± 5.0%
Au197(n,g)/U235(n,f)	0.105 ± 0.005	(2.3184E-3 ± 1.4%)/(2.3189E-2 ± 0.6%) = 0.09998 ± 1.5%	0.952 ± 5.0%
In115(n,ng)/U235(n,f)	0.102 ± 0.006	(1.1583E-2 ± 1.0%)/(2.3189E-2 ± 0.6%) = 0.49950 ± 1.2%	**4.757** ± 6.0%

*Calculated at midplane of Pu rods in a radius of 0.46 cm and height of 1 cm. File: BR1-2. Results in **RED** have |C/E-1|>3σ.

Results (continued): IRDFF-II

Table 2. Benchmark-Model and Calculated* Reaction Rate Ratios: COG11.3 with ENDF/B-VIII.0 used for particle transport and IRDFF-II for the reaction rate ratios (except IRDFF1.05 used for In115(n,ng))

Reaction Ratio	Benchmark-Model	Calculated	C/E
Th232(n,f)/U235(n,f)	0.043 ± 0.0013	(9.6130E-4 ± 1.1%)/(2.3149E-2 ± 0.7%) = 0.0415 ± 1.3%	0.966 ± 3.3%
U233(n,f)/U235(n,f)	1.54 ± 0.03	Not Available	
U234(n,f)/U235(n,f)	0.790 ± 0.024	Not Available	
U236(n,f)/U235(n,f)	0.333 ± 0.010	Not Available	
U238(n,f)/U235(n,f)	0.165 ± 0.005	(3.7648E-3 ± 1.0%)/(2.3149E-2 ± 0.7%) = 0.1626 ± 1.2%	0.986 ± 3.3%
Np237(n,f)/U235(n,f)	0.771 ± 0.023	(1.8992E-2 ± 1.4%)/(2.3149E-2 ± 0.7%) = 0.8204 ± 1.6%	1.064 ± 3.4%
Pu239(n,f)/U235(n,f)	1.33 ± 0.04	(3.1693E-2 ± 2.3%)/(2.3149E-2 ± 0.7%) = 1.3691 ± 2.4%	1.029 ± 3.9%
Pu240(n,f)/U235(n,f)	0.877 ± 0.026	Not Available	
Pu241(n,f)/U235(n,f)	1.29 ± 0.04	Not Available	
Pu242(n,f)/U235(n,f)	0.658 ± 0.020	Not Available	
Am241(n,f)/U235(n,f)	0.825 ± 0.025	(1.8179E-2 ± 0.8%)/(2.3149E-2 ± 0.7%) = 0.7853 ± 1.1%	0.952 ± 3.2%
Th232(n,g)/U235(n,f)	0.109 ± 0.004	(2.3382E-3 ± 0.8%)/(2.3149E-2 ± 0.7%) = 0.1010 ± 1.1%	0.927 ± 3.8%
U236(n,g)/U235(n,f)	0.123 ± 0.006	Not Available	
U238(n,g)/U235(n,f)	0.077 ± 0.003	(1.7699E-3 ± 1.0%)/(2.3149E-2 ± 0.7%) = 0.0765 ± 1.2%	0.993 ± 4.1%
Np237(n,g)/U235(n,f)	0.240 ± 0.012	Not Available	
Th232(n,2n)/U235(n,f)	0.00924 ± 0.00050	Not Available	
U238(n,2n)/U235(n,f)	0.00916 ± 0.00050	(2.3170E-4 ± 5.8%)/(2.3149E-2 ± 0.7%) = 0.0100 ± 5.8%	1.093 ± 8.0%
Nb93(n,2n)/U235(n,f)	0.000293 ± 0.000010	Not Available	
Al27(n,a)/U235(n,f)	0.00043 ± 0.00002	Not Available	
Fe54(n,a)/U235(n,f)	0.00050 ± 0.00002	Not Available	
Co59(n,a)/U235(n,f)	0.000095 ± 0.000004	Not Available	
Mo92(n,a)/U235(n,f)	0.000055 ± 0.000005	Not Available	
Nb93(n,a)/U235(n,f)	0.0000159 ± 0.0000009	Not Available	
Mg24(n,p)/U235(n,f)	0.00090 ± 0.00004	(2.2499E-5 ± 5.7%)/(2.3149E-2 ± 0.7%) = 0.00097 ± 5.7%	1.080 ± 7.3%
Al27(n,p)/U235(n,f)	0.00221 ± 0.00015	(4.7480E-5 ± 2.6%)/(2.3149E-2 ± 0.7%) = 0.00205 ± 2.7%	0.928 ± 7.3%
Ti46(n,p)/U235(n,f)	0.0066 ± 0.0003	(1.3836E-4 ± 2.8%)/(2.3149E-2 ± 0.7%) = 0.00598 ± 2.9%	0.906 ± 5.4%
Ti47(n,p)/U235(n,f)	0.0097 ± 0.0005	(2.1141E-4 ± 1.3%)/(2.3149E-2 ± 0.7%) = 0.00913 ± 1.5%	0.942 ± 5.4%
Ti48(n,p)/U235(n,f)	0.00018 ± 0.000008	(4.3657E-6 ± 5.5%)/(2.3149E-2 ± 0.7%) = 0.00019 ± 5.5%	1.048 ± 7.1%
Fe54(n,p)/U235(n,f)	0.0447 ± 0.0015	(8.9128E-4 ± 1.6%)/(2.3149E-2 ± 0.7%) = 0.03850 ± 1.7%	**0.861** ± 3.8%
Fe56(n,p)/U235(n,f)	0.00061 ± 0.00002	(1.4958E-5 ± 4.5%)/(2.3149E-2 ± 0.7%) = 0.00065 ± 4.6%	1.059 ± 5.6%
Ni58(n,p)/U235(n,f)	0.055 ± 0.003	(1.2317E-3 ± 1.4%)/(2.3149E-2 ± 0.7%) = 0.05321 ± 1.6%	0.967 ± 5.7%
Co59(n,p)/U235(n,f)	0.00084 ± 0.00004	(1.7127E-5 ± 2.7%)/(2.3149E-2 ± 0.7%) = 0.00074 ± 2.8%	0.881 ± 5.5%
Mo92(n,p)/U235(n,f)	0.00388 ± 0.00015	Not Available	
Cr50(n,g)/U235(n,f)	0.0557 ± 0.0005	Not Available	
Mn55(n,g)/U235(n,f)	0.00297 ± 0.00015	(8.6878E-5 ± 2.9%)/(2.3149E-2 ± 0.7%) = 0.00375 ± 3.0%	**1.264** ± 5.9%
Fe58(n,g)/U235(n,f)	0.00228 ± 0.00009	(5.5704E-5 ± 4.6%)/(2.3149E-2 ± 0.7%) = 0.00241 ± 4.7%	1.055 ± 6.1%
Co59(n,g)/U235(n,f)	0.0064 ± 0.0003	(1.3755E-4 ± 3.7%)/(2.3149E-2 ± 0.7%) = 0.00594 ± 3.8%	0.928 ± 6.0%
Ni64(n,g)/U235(n,f)	0.00185 ± 0.00008	Not Available	
Cu63(n,g)/U235(n,f)	0.0114 ± 0.0005	(2.7693E-4 ± 2.0%)/(2.3149E-2 ± 0.7%) = 0.01196 ± 2.1%	1.049 ± 4.9%
Cu65(n,g)/U235(n,f)	0.0076 ± 0.0006	Not Available	
Mo98(n,g)/U235(n,f)	0.0193 ± 0.0008	Not Available	
Zr94(n,g)/U235(n,f)	0.0064 ± 0.0004	Not Available	
Zr96(n,g)/U235(n,f)	0.00306 ± 0.006	Not Available	
Au197(n,g)/U235(n,f)	0.105 ± 0.005	(2.2966E-3 ± 1.1%)/(2.3149E-2 ± 0.7%) = 0.09921 ± 1.3%	0.945 ± 4.9%
In115(n,ng)/U235(n,f)	0.102 ± 0.006	(2.3029E-3 ± 0.9%)/(2.3149E-2 ± 0.7%) = 0.99482 ± 1.1%	0.975 ± 6.0%

*Calculated at midplane of Pu rods in a radius of 0.46 cm and height of 1 cm. Files: BR1-0 and BR1-1. Results in **RED** have |C/E-1|>3σ.

Table 3. Benchmark-Model and Calculated* Reaction Rate Ratios: COG11.3 with JEFF-3.3 used for both particle transport and reaction rate ratios.

Reaction Ratio	**Benchmark-Model**	**Calculated**	**C/E**
Th232(n,f)/U235(n,f)	0.043 ± 0.0013	(9.2174E-4 ± 1.1%)/(2.2914E-2 ± 0.6%) = 0.0402 ± 1.3%	0.935 ± 3.3%
U233(n,f)/U235(n,f)	1.54 ± 0.03	(3.5650E-2 ± 0.6%)/(2.2914E-2 ± 0.6%) = 1.5558 ± 0.8%	1.010 ± 1.5%
U234(n,f)/U235(n,f)	0.790 ± 0.024	(1.6928E-2 ± 0.7%)/(2.2914E-2 ± 0.6%) = 0.7388 ± 0.9%	0.935 ± 2.0%
U236(n,f)/U235(n,f)	0.333 ± 0.010	(7.3178E-3 ± 0.9%)/(2.2914E-2 ± 0.6%) = 0.3194 ± 1.1%	0.959 ± 3.2%
U238(n,f)/U235(n,f)	0.165 ± 0.005	(3.7416E-3 ± 1.0%)/(2.2914E-2 ± 0.6%) = 0.1633 ± 1.2%	0.990 ± 3.2%
Np237(n,f)/U235(n,f)	0.771 ± 0.023	(1.8906E-2 ± 0.8%)/(2.2914E-2 ± 0.6%) = 0.8251± 1.0%	1.070 ± 3.1%
Pu239(n,f)/U235(n,f)	1.33 ± 0.04	(3.1473E-2 ± 0.6%)/(2.2914E-2 ± 0.6%) = 1.3735 ± 0.8%	1.033 ± 3.1%
Pu240(n,f)/U235(n,f)	0.877 ± 0.026	(1.9485E-2 ± 0.7%)/(2.2914E-2 ± 0.6%) = 0.8504 ± 0.9%	0.970 ± 3.1%
Pu241(n,f)/U235(n,f)	1.29 ± 0.04	(3.0637E-2 ± 0.6%)/(2.2914E-2 ± 0.6%) = 1.3370 ± 0.8%	1.036 ± 3.2%
Pu242(n,f)/U235(n,f)	0.658 ± 0.020	(1.6205E-2 ± 0.8%)/(2.2914E-2 ± 0.6%) = 0.7072 ± 1.0%	1.075 ± 3.2%
Am241(n,f)/U235(n,f)	0.825 ± 0.025	(1.8253E-2 ± 0.8%)/(2.2914E-2 ± 0.6%) = 0.7966 ± 1.0%	0.966 ± 3.2%
Th232(n,g)/U235(n,f)	0.109 ± 0.004	(2.3389E-3 ± 0.8%)/(2.2914E-2 ± 0.6%) = 0.1018 ± 1.1%	1.021 ± 3.8%
U236(n,g)/U235(n,f)	0.123 ± 0.006	(2.2529E-3 ± 0.9%)/(2.2914E-2 ± 0.6%) = 0.0983 ± 1.1%	**0.799** ± 5.0%
U238(n,g)/U235(n,f)	0.077 ± 0.003	(1.6992E-3 ± 1.0%)/(2.2914E-2 ± 0.6%) = 0.0742 ± 1.2%	0.963 ± 4.1%
Np237(n,g)/U235(n,f)	0.240 ± 0.012	(6.7204E-3 ± 1.1%)/(2.2914E-2 ± 0.6%) = 0.2933 ± 1.3%	**1.222** ± 5.2%
Th232(n,2n)/U235(n,f)	0.00924 ± 0.00050	(2.5498E-4 ± 6.7%)/(2.2914E-2 ± 0.6%) = 0.0111 ± 6.7%	1.204 ± 8.6%
U238(n,2n)/U235(n,f)	0.00916 ± 0.00050	(2.2408E-4 ± 5.9%)/(2.2914E-2 ± 0.6%) = 0.00978 ± 5.9%	1.068 ± 8.1%
Nb93(n,2n)/U235(n,f)	0.000293 ± 0.000010	(1.7076E-5 ± 16.7%)/(2.2914E-2 ± 0.6%) = 7.45E-4 ± 16.7%	**2.543** ± 17.1%
Al27(n,a)/U235(n,f)	0.00043 ± 0.00002	(1.0646E-5 ± 6.2%)/(2.2914E-2 ± 0.6%) = 0.00046 ± 6.2%	1.080 ± 7.8%
Fe54(n,a)/U235(n,f)	0.00050 ± 0.00002	(7.1518E-6 ± 5.1%)/(2.2914E-2 ± 0.6%) = 0.00031± 5.1%	**0.624** ± 6.5%
Co59(n,a)/U235(n,f)	0.000095 ± 0.000004	(2.2016E-6 ± 5.5%)/(2.2914E-2 ± 0.6%) = 9.608E-5 ± 5.5%	1.011 ± 7.0%
Mo92(n,a)/U235(n,f)	0.000055 ± 0.000005	(1.3839E-6 ± 4.5%)/(2.2914E-2 ± 0.6%) = 6.040E-5 ± 4.5%	1.098 ± 10.2%
Nb93(n,a)/U235(n,f)	0.0000159 ± 0.0000009	(1.0249E-6 ± 3.4%)/(2.2914E-2 ± 0.6%) = 4.473E-5 ± 3.4%	**2.813** ± 6.6%
Mg24(n,p)/U235(n,f)	0.00090 ± 0.00004	All results were zero	
Al27(n,p)/U235(n,f)	0.00221 ± 0.00015	(4.8945E-5 ± 2.5%)/(2.2914E-2 ± 0.6%) = 0.00214 ± 2.6%	0.966 ± 7.3%
Ti46(n,p)/U235(n,f)	0.0066 ± 0.0003	All results were zero	
Ti47(n,p)/U235(n,f)	0.0097 ± 0.0005	All results were zero	
Ti48(n,p)/U235(n,f)	0.00018 ± 0.000008	All results were zero	
Fe54(n,p)/U235(n,f)	0.0447 ± 0.0015	(8.4458E-4 ± 1.5%)/(2.2914E-2 ± 0.6%) = 0.03686 ± 1.6%	**0.825** ± 3.7%
Fe56(n,p)/U235(n,f)	0.00061 ± 0.00002	(1.5044E-5 ± 4.4%)/(2.2914E-2 ± 0.6%) = 0.00066 ± 4.4%	1.076 ± 5.5%
Ni58(n,p)/U235(n,f)	0.055 ± 0.003	All results were zero	
Co59(n,p)/U235(n,f)	0.00084 ± 0.00004	All results were zero	
Mo92(n,p)/U235(n,f)	0.00388 ± 0.00015	All results were zero	
Cr50(n,g)/U235(n,f)	0.0557 ± 0.0005	(1.2134E-4 ± 5.6%)/(2.2914E-2 ± 0.6%) = 0.00530 ± 5.6%	**0.095** ± 5.7%
Mn55(n,g)/U235(n,f)	0.00297 ± 0.00015	(8.6686E-5 ± 2.9%)/(2.2914E-2 ± 0.6%) = 0.00378 ± 3.0%	**1.274** ± 5.9%
Fe58(n,g)/U235(n,f)	0.00228 ± 0.00009	(6.0388E-5 ± 6.5%)/(2.2914E-2 ± 0.6%) = 0.00264 ± 6.5%	1.156 ± 7.6%
Co59(n,g)/U235(n,f)	0.0064 ± 0.0003	(1.3148E-4 ± 2.0%)/(2.2914E-2 ± 0.6%) = 0.00574 ± 2.1%	0.897 ± 6.0%
Ni64(n,g)/U235(n,f)	0.00185 ± 0.00008	(7.5009E-5 ± 1.4%)/(2.2914E-2 ± 0.6%) = 0.03274 ± 1.5%	**17.69** ± 4.6%
Cu63(n,g)/U235(n,f)	0.0114 ± 0.0005	(2.8039E-4 ± 1.9%)/(2.2914E-2 ± 0.6%) = 0.01224 ± 2.0%	1.073 ± 4.8%
Cu65(n,g)/U235(n,f)	0.0076 ± 0.0006	(1.7398E-4 ± 1.7%)/(2.2914E-2 ± 0.6%) = 0.00759 ± 1.8%	0.999 ± 8.1%
Mo98(n,g)/U235(n,f)	0.0193 ± 0.0008	(4.3376E-4 ± 1.2%)/(2.2914E-2 ± 0.6%) = 0.01893 ± 1.3%	0.981 ± 4.4%
Zr94(n,g)/U235(n,f)	0.0064 ± 0.0004	(1.4125E-4 ± 3.7%)/(2.2914E-2 ± 0.6%) = 0.00616 ± 3.7%	0.963 ± 7.3%
Zr96(n,g)/U235(n,f)	0.00306 ± 0.00015	(1.5856E-4 ± 2.7%)/(2.2914E-2 ± 0.6%) = 0.00692 ± 2.8%	**2.261** ± 5.6%
Au197(n,g)/U235(n,f)	0.105 ± 0.005	(2.2640E-3 ± 1.0%)/(2.2914E-2 ± 0.6%) = 0.09869 ± 1.2%	0.940 ± 4.9%
In115(n,ng)/U235(n,f)	0.102 ± 0.006	(1.2793E-2 ± 1.0%)/(2.2914E-2 ± 0.6%) = 0.55830 ± 1.2%	**5.474** ± 6.0%

*Calculated at midplane of Pu rods in a radius of 0.46 cm and height of 1 cm. File: BR1-2. Results in **RED** have |C/E-1|>3σ.

FUND-IPPE-FR-MULT-RRR-001

Conclusion: The following COG11.3 cross-section libraries produce calculated results consistent with BR-1 benchmark values.

Table 4. Recommended Libraries for Reaction Rate Calculations

Th232(n,f)	IRDFF-II ENDFB8R0
U233(n,f)	JEFF3.3 ENDFB8R0
U234(n,f)	JEFF3.3* ENDFB8R0*
U236(n,f)	ENDFB8R0
U238(n,f)	IRDFF-II ENDFB8R0
Np237(n,f)	ENDFB8R0 IRDFF-II
Pu239(n,f)	ENDFB8R0 IRDFF-II
Pu240(n,f)	JEFF3.3 ENDFB8R0
Pu241(n,f)	ENDFB8R0
Pu242(n,f)	ENDFB8R0
Am241(n,f)	JEFF3.3 IRDFF-II ENDFB8R0

Th232(n,g)	JEFF3.3 ENDFB8R0 IRDFF-II
U236(n,g)	ENDFB8R0
U238(n,g)	IRDFF-II ENDFB8R0
Np237(n,g)	None

Th232(n,2n)	ENDFB8R0
U238(n,2n)	JEFF3.3 ENDFB8R0
Nb93(n,2n)	None

Al27(n,a)	JEFF3.3 ENDFB8R0
Fe54(n,a)	ENDFB8R0
Co59(n,a)	JEFF3.3 ENDFB8R0
Mo92(n,a)	JEFF3.3
Nb93(n,a)	None

Mg24(n,p)	IRDFF-II
Al27(n,p)	ENDFB8R0 IRDFF-II
Ti46(n,p)	IRDFF-II
Ti47(n,p)	IRDFF-II
Ti48(n,p)	IRDFF-II
Fe54(n,p)	ENDFB8R0
Fe56(n,p)	IRDFF-II ENDFB8R0
Ni58(n,p)	IRDFF-II
Co59(n,p)	IRDFF-II JEFF3.3
Mo92(n,p)	IRDFF-II

Cr50(n,g)	None
Mn55(n,g)	None
Fe58(n,g)	IRDFF-II JEFF3.3
Co59(n,g)	IRDFF-II
Ni64(n,g)	None
Cu63(n,g)	ENDFB8R0 IRDFF-II
Cu65(n,g)	JEFF3.3 ENDFB8R0
Mo98(n,g)	JEFF3.3
Zr94(n,g)	JEFF3.3
Zr96(n,g)	None
Au197(n,g)	ENDFB8R0 IRDFF-II JEFF3.3

In115(n,ng)	IRDFF1.05

* In these cases, |C/E-1| > 3σ (slightly).

Appendix

COG11.3 Sample Input Listing

```
FUND-IPPE-FR-MULT-RRR-001: BR-1 with detectors for spectral indices calculation
basic
  neutron delayedn CM URRPT
criticality
  npart=5000 nbatch=1050 sdt=0.0001 nfirst=51 norm=1. nsource=1 0 0 0
mix nlib=ENDFB8R0 ptlib=PT.ENDFB8R0.ACE sablib=T.ENDFB8R0
  mat=1  bunches pu238 1.9260-5 pu239 3.7610-2 pu240 8.8210-4 pu241 7.7039-6 ga 2.3389-3 $ Plutonium
  mat=2  bunches    cu 8.4343-2                                                         $ Copper
  mat=3  bunches    fe 5.9986-2    cr 1.5724-2    ni 8.5030-3    mn 1.0431-3 si 8.5018-4 $ Stainless
                    ti 4.7376-4     c 4.1748-4                                          $  Steel
  mat=4  bunches  u235 2.0404-4  u238 4.7248-2    fe 3.2608-4     c 5.6857-3            $ Depleted U

  mat=10 bunches  u235 1.0 $ This and the following isotopes are at 1 atom/b.cm
  mat=11 bunches th232 1.0
  mat=12 bunches  u233 1.0
  mat=13 bunches  u234 1.0
  mat=14 bunches  u236 1.0
  mat=15 bunches  u238 1.0
  mat=16 bunches np237 1.0
  mat=17 bunches pu239 1.0
  mat=18 bunches pu240 1.0
  mat=19 bunches pu241 1.0
  mat=20 bunches pu242 1.0
  mat=21 bunches am241 1.0
  mat=22 bunches  nb93 1.0
  mat=23 bunches  al27 1.0
  mat=24 bunches  fe54 1.0
  mat=25 bunches  co59 1.0
  mat=26 bunches  mo92 1.0
  mat=27 bunches  mg24 1.0
  mat=28 bunches  ti46 1.0
  mat=29 bunches  ti47 1.0
  mat=30 bunches  ti48 1.0
  mat=31 bunches  fe56 1.0
  mat=32 bunches  ni58 1.0
  mat=33 bunches  cr50 1.0
  mat=34 bunches  mn55 1.0
  mat=35 bunches  fe58 1.0
  mat=36 bunches  ni64 1.0
  mat=37 bunches  cu63 1.0
  mat=38 bunches  cu65 1.0
  mat=39 bunches  mo98 1.0
  mat=40 bunches  zr94 1.0
  mat=41 bunches  zr96 1.0
  mat=42 bunches au197 1.0
  mat=43 bunches in115 1.0
assign-m  5 0                                  $ Void in detector region
assign-mc 1 red 2 yellow 3 gray 4 brown 5 pink $ Color assignments
geometry

   sector 5 void  -12 -13         $ Detector region
   sector 3 SST    13 -14         $ SST central tube
   sector 2 Cu     15 -16         $ Cu  upper axial cylinders
   sector 4 DU     15 -17         $ DU  lower axial cylinders
 use unit 3 Core   14  16  17 -20 $ Rod lattice
   sector 3 SST    20 -21         $ SST core tube

   sector 4 DU     30 -31            $ DU  safety cylinder
   sector 3 SST    32 -33            $ SST middle tube
   sector 4 DU     34 -35            $ DU  control cylinder
   sector 3 SST    36 -37            $ SST outer tube
   sector 3 SST    30 -32 -41        $ SST flange
   sector 3 SST    30  33 -36 41 -42 $ SST flange
   sector 4 DU     30  42 -44        $ DU  annular cylinder
   sector 4 DU     45 -46            $ DU  large radial reflector
   boundary vacuum 49


define unit 1 $ Pu rod
```

```
   sector 2 Cu     -1                    $ Cu  bottom plug
   sector 3 SST     1  3 -4              $ SST bottom plug
   sector 1 Pu     -6                    $ Pu
   sector 2 Cu      4  5  6 -7           $ Cu  foil
   sector 3 SST     2  3 -5              $ SST top plug
   sector 2 Cu     -2                    $ Cu  top plug
   sector 3 SST     1  2  4  5  7  8 -9 $ SST tube
define unit 2 $ Cu rod
   sector 2 Cu    -11
define unit 3 $ 13x13 tri-x lattice
   {tri-x
     -3.39  5.87165224
    -10.17 -5.87165224
      3.39 -5.87165224
     13 13
      1 -99.9  99.9
     1001 2001 3001 4001
     fill
                - - 2 2 2 - - - - - - - - -
               - 2 2 1 1 1 2 - - - - - - -
              2 2 1 1 1 1 1 2 2 - - - -
             2 1 1 1 1 1 1 1 1 2 - - -
            2 1 1 1 1 1 1 1 1 1 2 - -
           - 2 1 1 1 1 1 1 1 1 1 - -
          - 2 1 1 1 1 - 1 1 1 1 2 -
         - - 1 1 1 1 1 1 1 1 1 2 -
        - - 2 1 1 1 1 1 1 1 1 1 2
       - - - 2 1 1 1 1 1 1 1 1 2
      - - - - 2 2 1 1 1 1 1 1 2
     - - - - - - 2 1 1 1 2 2 -
    - - - - - - - - 1 1 1 - - }
picture cs sector   color -36 0 36 -36  0 -36 36  0 -36 title="axial view"
picture cs material color -36 0 36 -36  0 -36 36  0 -36 title="axial view"
picture cs material color  -7 0 10  -7  0 -11  7  0 -11 title="axial detail of the lattice region"
picture cs material color  -7 7  0  -7 -7   0  7 -7   0 title="plane detail of the lattice region"
picture cs material color  -2 0  8  -2  0   6  2  0   6 title="axial detail of Pu rod bottom"
picture cs material color  -2 0 -6  -2  0 -11  2  0 -11 title="axial detail of Pu rod bottom"
volume
  material -9 -9 -9  9 -9 -9 -9  9 -9 18 18 18
surfaces
$ --- Pu rod
  1 revolution 9 -10.0 0.45 -9.5 0.565 -8.7 0.565 -8.7 0.5 -8.2 0.5 -8.2 0.4 -7.4 0.4  -7.4 0.3 -6.8 0.3
      tr 0 0 0 0 0 1 0 1 0 $ Copper bottom plug
  2 revolution 8   6.8 0.3   7.4 0.3    7.4 0.4    8.2 0.4  8.2 0.5  8.7 0.5  8.7 0.565 9.2 0.565
      tr 0 0 0 0 0 1 0 1 0 $ Copper top plug
  3 c z 0.3              $ SST plugs, inner
  4 c z 0.51 -7.19 -6.5  $ SST bottom plug
  5 c z 0.51  6.5   7.19 $ SST top    plug
  6 c z 0.50 -6.49  6.49 $ Cu  foil,  inner
  7 c z 0.51 -6.5   6.5  $ Cu  foil,  outer
  8 c z 0.51 -8.7   8.7  $ SST tube,  inner
  9 c z 0.54 -8.7   8.7  $ SST tube,  outer
$ --- Cu rod
 11 revolution 7 -10.0 0.45 -9.5 0.565 -8.7 0.565 -8.7 0.54 8.7 0.54 8.7 0.565 9.2 0.565
      tr 0 0 0 0 0 1 0 1 0 $ Copper rod
$ --- SST central SST tube
 12 c z  0.46  -0.5   0.5 $ Detector region
 13 c z  0.46             $ SST central core tube, inner
 14 c z  0.5  -35.5  35.5 $ SST central core tube, outer
$ --- Cu upper and DU lower cylinders
 15 c z  0.6              $ Cu and DU,     inner
 16 c z  6.45   9.2  26.2 $ Cu  cylinders, upper
 17 c z  6.45 -35.5 -10.0 $ DU  cylinders, lower
$ --- SST core tube
 20 c z  6.55 -35.5  35.5 $ SST core tube, inner
 21 c z  6.8  -35.5  35.5 $ SST core tube, outer
$ --- DU safety and control cylinders; SST middle and outer tubes
 30 c z  6.9              $ DU  safety cylinder, inner
 31 c z  8.2  -35.5   6.3 $ DU  safety cylinder, outer
 32 c z  8.35             $ SST middle tube, inner
 33 c z  8.6  -35.5   9.5 $ SST middle tube, outer
 34 c z  8.8              $ DU  control cylinder, inner
 35 c z 10.8  -35.5   6.3 $ DU  control cylinder, outer
 36 c z 11.0              $ SST outer tube, inner
```

```
 37 c z 11.3  -35.5  11.5 $ SST outer tube, outer
$ --- SST flange
 41 c z  8.2    8.0   9.5 $ SST flange
 42 c z 10.8    9.5  11.5 $ SST flange
$ --- DU annular cylinder and large radial reflector
 44 c z 11.25  11.5  35.5 $ DU  annular cylinder
 45 c z 11.5              $ DU  large radial reflector, inner
 46 c z 35.0  -35.5  34.5 $ DU  large radial reflector, outer
 49 c z 35.0  -35.5  35.5 $ BCD

detector
 number=#0000000 title="BR-1 spectrum flux at center"            reaction 5 0.664761 drf-e neutron number-flux
 number=#0000010 title="BR-1 spectrum averaged U-235(n,f)    r-r" reaction 5 0.664761 drf-e neutron r-rate 10 15
 number=#0000011 title="BR-1 spectrum averaged Th-232(n,f)   r-r" reaction 5 0.664761 drf-e neutron r-rate 11 15
 number=#0000012 title="BR-1 spectrum averaged U-233(n,f)    r-r" reaction 5 0.664761 drf-e neutron r-rate 12 15
 number=#0000013 title="BR-1 spectrum averaged U-234(n,f)    r-r" reaction 5 0.664761 drf-e neutron r-rate 13 15
 number=#0000014 title="BR-1 spectrum averaged U-236(n,f)    r-r" reaction 5 0.664761 drf-e neutron r-rate 14 15
 number=#0000015 title="BR-1 spectrum averaged U-238(n,f)    r-r" reaction 5 0.664761 drf-e neutron r-rate 15 15
 number=#0000016 title="BR-1 spectrum averaged Np-237(n,f)   r-r" reaction 5 0.664761 drf-e neutron r-rate 16 15
 number=#0000017 title="BR-1 spectrum averaged Pu-239(n,f)   r-r" reaction 5 0.664761 drf-e neutron r-rate 17 15
 number=#0000018 title="BR-1 spectrum averaged Pu-240(n,f)   r-r" reaction 5 0.664761 drf-e neutron r-rate 18 15
 number=#0000019 title="BR-1 spectrum averaged Pu241(n,f)    r-r" reaction 5 0.664761 drf-e neutron r-rate 19 15
 number=#0000020 title="BR-1 spectrum averaged Pu242(n,f)    r-r" reaction 5 0.664761 drf-e neutron r-rate 20 15
 number=#0000021 title="BR-1 spectrum averaged Am241(n,f)    r-r" reaction 5 0.664761 drf-e neutron r-rate 21 15

 number=#0000022 title="BR-1 spectrum averaged Th-232(n,g)   r-r" reaction 5 0.664761 drf-e neutron r-rate 11 46
 number=#0000023 title="BR-1 spectrum averaged U-236(n,g)    r-r" reaction 5 0.664761 drf-e neutron r-rate 14 46
 number=#0000024 title="BR-1 spectrum averaged U-238(n,g)    r-r" reaction 5 0.664761 drf-e neutron r-rate 15 46
 number=#0000025 title="BR-1 spectrum averaged Np-237(n,g)   r-r" reaction 5 0.664761 drf-e neutron r-rate 16 46

 number=#0000026 title="BR-1 spectrum averaged Th-232(n,2ng) r-r" reaction 5 0.664761 drf-e neutron r-rate 11 12
 number=#0000027 title="BR-1 spectrum averaged U-238(n,2ng)  r-r" reaction 5 0.664761 drf-e neutron r-rate 15 12
 number=#0000028 title="BR-1 spectrum averaged Nb-93(n,2ng)  r-r" reaction 5 0.664761 drf-e neutron r-rate 22 12

 number=#0000029 title="BR-1 spectrum averaged Al-27(n,ag)   r-r" reaction 5 0.664761 drf-e neutron r-rate 23 45
 number=#0000030 title="BR-1 spectrum averaged Fe-54(n,ag)   r-r" reaction 5 0.664761 drf-e neutron r-rate 24 45
 number=#0000031 title="BR-1 spectrum averaged Co-59(n,ag)   r-r" reaction 5 0.664761 drf-e neutron r-rate 25 45
 number=#0000032 title="BR-1 spectrum averaged Mo-92(n,ag)   r-r" reaction 5 0.664761 drf-e neutron r-rate 26 45
 number=#0000033 title="BR-1 spectrum averaged Nb-93(n,ag)   r-r" reaction 5 0.664761 drf-e neutron r-rate 22 45

 number=#0000034 title="BR-1 spectrum averaged Mg-24(n,pg)   r-r" reaction 5 0.664761 drf-e neutron r-rate 27 82
 number=#0000035 title="BR-1 spectrum averaged Al-27(n,pg)   r-r" reaction 5 0.664761 drf-e neutron r-rate 23 82
 number=#0000036 title="BR-1 spectrum averaged Ti-46(n,pg)   r-r" reaction 5 0.664761 drf-e neutron r-rate 28 82
 number=#0000037 title="BR-1 spectrum averaged Ti-47(n,pg)   r-r" reaction 5 0.664761 drf-e neutron r-rate 29 82
 number=#0000038 title="BR-1 spectrum averaged Ti-48(n,pg)   r-r" reaction 5 0.664761 drf-e neutron r-rate 30 82
 number=#0000039 title="BR-1 spectrum averaged Fe-54(n,pg)   r-r" reaction 5 0.664761 drf-e neutron r-rate 24 82
 number=#0000040 title="BR-1 spectrum averaged Fe-56(n,pg)   r-r" reaction 5 0.664761 drf-e neutron r-rate 31 82
 number=#0000041 title="BR-1 spectrum averaged Ni-58(n,pg)   r-r" reaction 5 0.664761 drf-e neutron r-rate 32 82
 number=#0000042 title="BR-1 spectrum averaged Co-59(n,pg)   r-r" reaction 5 0.664761 drf-e neutron r-rate 25 82
 number=#0000043 title="BR-1 spectrum averaged Mo-92(n,pg)   r-r" reaction 5 0.664761 drf-e neutron r-rate 26 82

 number=#0000044 title="BR-1 spectrum averaged Cr-50(n,g)    r-r" reaction 5 0.664761 drf-e neutron r-rate 33 46
 number=#0000045 title="BR-1 spectrum averaged Mn-55(n,g)    r-r" reaction 5 0.664761 drf-e neutron r-rate 34 46
 number=#0000046 title="BR-1 spectrum averaged Fe-58(n,g)    r-r" reaction 5 0.664761 drf-e neutron r-rate 35 46
 number=#0000047 title="BR-1 spectrum averaged Co-59(n,g)    r-r" reaction 5 0.664761 drf-e neutron r-rate 25 46
 number=#0000048 title="BR-1 spectrum averaged Ni-64(n,g)    r-r" reaction 5 0.664761 drf-e neutron r-rate 36 46
 number=#0000049 title="BR-1 spectrum averaged Cu-63(n,g)    r-r" reaction 5 0.664761 drf-e neutron r-rate 37 46
 number=#0000050 title="BR-1 spectrum averaged Cu-65(n,g)    r-r" reaction 5 0.664761 drf-e neutron r-rate 38 46
 number=#0000051 title="BR-1 spectrum averaged Mo-98(n,g)    r-r" reaction 5 0.664761 drf-e neutron r-rate 39 46
 number=#0000052 title="BR-1 spectrum averaged Zr-94(n,g)    r-r" reaction 5 0.664761 drf-e neutron r-rate 40 46
 number=#0000052 title="BR-1 spectrum averaged Zr-96(n,g)    r-r" reaction 5 0.664761 drf-e neutron r-rate 41 46
 number=#0000052 title="BR-1 spectrum averaged Au-197(n,g)   r-r" reaction 5 0.664761 drf-e neutron r-rate 42 46

 number=#0000053 title="BR-1 spectrum averaged In-115(n,ng)  r-r" reaction 5 0.664761 drf-e neutron r-rate 43 11
end
```