Russian Research Center "Kurchatov Institute"

RBEC-M Lead-Bismuth Cooled Fast Reactor Benchmarking Calculations

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In RBEC-M benchmark, three different depletion problems are specified for the benchmark as follows:

Mode.1: Burn-up cycle consists of 1800 effective full-power days

Mode.2: Burn-up cycle consists of 900 effective full-power days

Mode.3: Fuel cycle consists of six partial fuel cycles of 300 effective full-power days each. Reactor is shut down for refuelling for 60 days. During refuelling, 1/6 volume part of fuel and fission products in core and blanket zones is removed and fresh fuel composition is added.

The requested functionals are as follows:

- For reactor depletion Modes 1 and 2;
  - k_{eff}
  - axial and radial power distributions in the core*
  - power peaking factors in the core zones
  - volume averaged neutron spectra in the core zones
  - k_{inf} in the core central zone.

- For depletion Mode 3:
  - k_{eff}
  - axial and radial power distributions in the core*
  - power peaking factors in the core zones
  - volume averaged neutron spectra in the core zones
  - k_{inf} in the core central zone

* Radial power distributions are to be calculated in two planes: in the core mid-plane and near the core top (45cm above the core mid-plane). Axial power distributions are to be calculated in the radial centre of each core zone.

Number of energy group: Pointwise cross-section data

Use codes: Processing evaluated data into a format appropriate for MCNP: NJOY99
Critical calculations: MCNP5
Fuel cycle analysis: ISTAR-2

Use nuclear data set: ENDF/B-VI, JENDL-3.2/3.3 and JEF-3.1

Methods used for criticality calculations and fuel cycle analysis are described in Appendix.

Benchmarking results

Some calculational investigations were performed at the beginning of the work to define the appropriate parameters of Monte Carlo simulation process and obtain good results for reasonable time.
So, the criticality calculations were performed with following parameters:

Neutron histories $N = 2 \cdot 10^6$;
Neutrons per generation M = 4000;
Active neutron generations NG = 500;
Skipped generations NS = 30.

With these parameters an estimated standard deviation of k_{eff} was about ±0.0003, and 99 percent confidence interval for k_{eff} was about ±0.0008.

Table.1 shows k_{eff} value at the beginning of the cycle (BOC).

Table.1 BOC k_{eff} value

BOC k_{eff}	
Codes	k_{eff} value
MCNP5	1.0038±0.0003

Calculated neutron multiplication factor of infinite medium with Core-1 composition at BOC:

$K_{inf} = 1.1660 \pm 0.0002$.

Mode.1 **Single Cycle Analysis for 1800 Effective Full Power Days**

Table.2 shows the evolution of the multiplication factor. The depletion calculations were performed with 2 subintervals (900 days).

Table.2 k_{eff} by time step

Mode.1	
Day	k_{eff} for 900MW, 1800 days cycle
0	1.0038±0.0003
900	1.0122±0.0003
1800	1.0102±0.0003

As can be seen in Table 2, multiplication factor increases during the first time subinterval and then decreases slightly to the end of cycle. As it is shown below, this decrease is connected with growing neutron capture in fission products and with redistribution of power generation between cores and blankets.

Tables 3, 4 and 5 show neutron balances in cores at the beginning, midpoint and end of cycle. Neutron generation rate is practically the same in cores and during cycle. In each core capture in fission products grows with fission product accumulation, but capture in heavy nuclides decreases, so neutron absorption rate does not change. At BOC capture in heavy nuclides for Core-1, Core-2 and Core-3 is about 92%, 93% and 95% of total neutron absorption. It is connected with more fuel volume fractions in peripheral cores.

Table.3 Neutron balance in Core-1 (Mode.1)

For 1000 fissions in Core-1 at BOC			
Fission neutrons	2884	Capture in heavy nuclides	1315
(n,2n) neutrons	4	Capture in fission products	
(n,3n) neutrons		Absorption in construction materials	67
		Absorption in coolant	48
Total neutron generation	2888	Total neutron absorption	1430
For 1000 fissions in Core-1 after 900 days burnup (Mode.1)			
Fission neutrons	2889	Capture in heavy nuclides	1232
(n,2n) neutrons	3	Capture in fission products	87
(n,3n) neutrons		Absorption in construction materials	67
		Absorption in coolant	47
Total neutron generation	2892	Total neutron absorption	1433
For 1000 fissions in Core-1 after 1800 days burnup (Mode.1)			
Fission neutrons	2892	Capture in heavy nuclides	1191
(n,2n) neutrons	3	Capture in fission products	165
(n,3n) neutrons		Absorption in construction materials	67
		Absorption in coolant	48
Total neutron generation	2895	Total neutron absorption	1471

Table.4 Neutron balance in Core-2 (Mode.1)

For 1000 fissions in Core-2 at BOC			
Fission neutrons	2882	Capture in heavy nuclides	1249
(n,2n) neutrons	4	Capture in fission products	
(n,3n) neutrons		Absorption in construction materials	60
		Absorption in coolant	36
Total neutron generation	2886	Total neutron absorption	1345
For 1000 fissions in Core-2 after 900 days burnup (Mode.1)			
Fission neutrons	2885	Capture in heavy nuclides	1205
(n,2n) neutrons	4	Capture in fission products	60
(n,3n) neutrons		Absorption in construction materials	60
		Absorption in coolant	36
Total neutron generation	2889	Total neutron absorption	1361
For 1000 fissions in Core-2 after 1800 days burnup (Mode.1)			
Fission neutrons	2888	Capture in heavy nuclides	1179
(n,2n) neutrons	4	Capture in fission products	115
(n,3n) neutrons		Absorption in construction materials	60
		Absorption in coolant	37
Total neutron generation	2892	Total neutron absorption	1391

Table.5 Neutron balance in Core-3 (Mode.1)

For 1000 fissions in Core-3 at BOC			
Fission neutrons	2880	Capture in heavy nuclides	1239
(n,2n) neutrons	5	Capture in fission products	
(n,3n) neutrons		Absorption in construction materials	50
		Absorption in coolant	21
Total neutron generation	2885	Total neutron absorption	1310
For 1000 fissions in Core-3 after 900 days burnup (Mode.1)			
Fission neutrons	2882	Capture in heavy nuclides	1216
(n,2n) neutrons	5	Capture in fission products	34
(n,3n) neutrons		Absorption in construction materials	51
		Absorption in coolant	21
Total neutron generation	2887	Total neutron absorption	1322
For 1000 fissions in Core-3 after 1800 days burnup (Mode.1)			
Fission neutrons	2883	Capture in heavy nuclides	1194

(n,2n) neutrons	5	Capture in fission products	67
(n,3n) neutrons		Absorption in construction materials	51
		Absorption in coolant	21
Total neutron generation	2888	Total neutron absorption	1333

Table 6 shows region powers and power peaking factors at the beginning and end of 1800-day cycle. Core powers decrease to EOC. In this model it is connected with breeding in blankets and growing of blanket powers, so core powers decrease to keep total power at level 900 MW.

Table.6 Region powers and power peaking factors

Mode.1					
	ZONE	Power(Watts)	Power Density	Peak Density	Peak to Average
			(Watts/cm^3)	(Watts/cm^3)	Power Density
BOC	Core1	3.42E+08	1.47E+02	1.98E+02	1.35E+00
	Core2	3.98E+08	1.27E+02	1.94E+02	1.52E+00
	Core3	1.48E+08	9.98E+01	1.54E+02	1.55E+00
EOC	Core1	3.20E+08	1.37E+02	1.82E+02	1.32E+00
	Core2	3.72E+08	1.19E+02	1.76E+02	1.48E+00
	Core3	1.44E+08	9.74E+01	1.44E+02	1.48E+00

Figure.1 depicts radial power density profiles at the core mid-plane for the beginning and end of cycle. Spatial variations of the power distribution can be observed. As can be seen in Figure.1 power peaking appears at the boundaries between zones of different fuel loading. Figure.2 depicts axial power profiles in the center of reactor.

Table 15 shows radial power distributions in the mid-plane of core and lateral blanket for 3 reference points of the reactor campaign: fresh fuel, end of 900-day cycle and end of 1800-day cycle.
Table 16 shows axial power distributions in the center of the core and axial blankets blanket for 3 reference points of the reactor campaign: fresh fuel, end of 900-day cycle and end of 1800-day cycle.

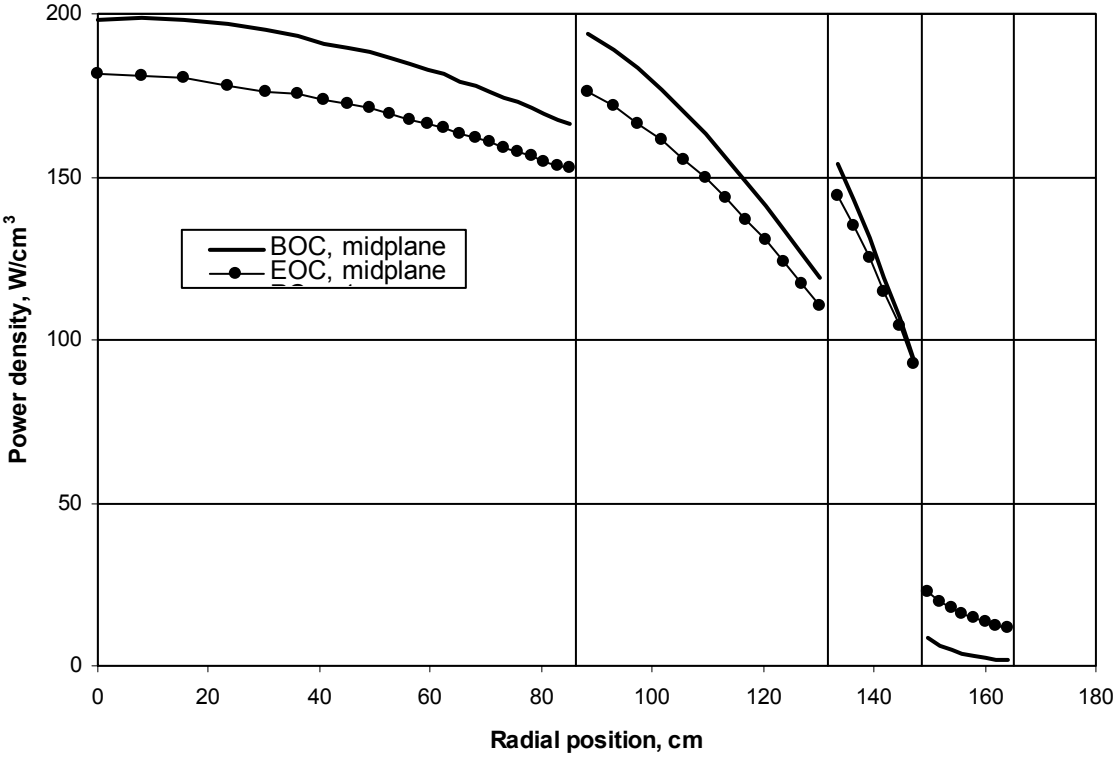

Fig.1 Radial power profiles in the core and lateral blanket (Mode.1)

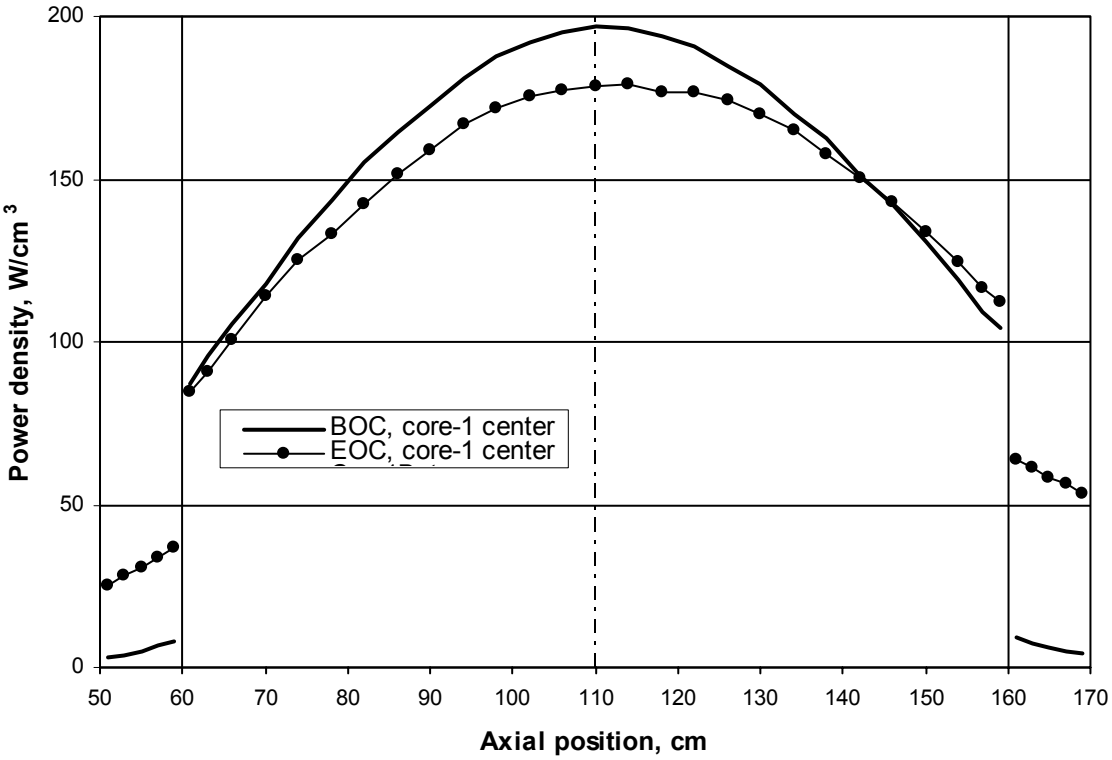

Fig.2 Axial power profiles in the Core-1 and axial blankets (Mode.1)

Volume averaged neutron flux in the core zones was obtained at BOC and EOC in XMAS structure (172 groups) and ANL structure (33 groups). Tables 7.1 and 7.2 provide flux values for each energy group.

Table.7.1 Volume averaged neutron spectra in the core in XMAS structure, 172 groups

Mode.1							
		BOC			EOC		
Group number	Top energy, eV	Core.1	Core.2	Core.3	Core.1	Core.2	Core.3
1	1.964E+07	2.26E+08	7.43E+08	5.41E+08	8.34E+08	1.47E+09	4.38E+07
2	1.733E+07	2.87E+09	3.07E+09	1.98E+09	3.31E+09	2.97E+09	4.13E+09
3	1.492E+07	9.00E+09	5.06E+09	4.36E+09	6.43E+09	5.48E+09	6.85E+09
4	1.384E+07	5.62E+10	4.40E+10	3.26E+10	5.06E+10	4.57E+10	3.11E+10
5	1.162E+07	1.56E+11	1.34E+11	1.00E+11	1.42E+11	1.23E+11	8.90E+10
6	1.000E+07	6.24E+11	5.48E+11	3.73E+11	6.13E+11	4.86E+11	3.55E+11
7	8.187E+06	1.73E+12	1.44E+12	9.45E+11	1.59E+12	1.38E+12	9.42E+11
8	6.703E+06	1.50E+12	1.30E+12	8.39E+11	1.43E+12	1.18E+12	8.05E+11
9	6.065E+06	2.03E+12	1.70E+12	1.13E+12	1.86E+12	1.57E+12	1.09E+12
10	5.488E+06	6.23E+12	5.25E+12	3.48E+12	5.84E+12	4.97E+12	3.46E+12
11	4.493E+06	1.01E+13	8.49E+12	5.48E+12	9.48E+12	7.90E+12	5.49E+12
12	3.679E+06	1.52E+13	1.26E+13	7.88E+12	1.44E+13	1.18E+13	7.99E+12
13	3.012E+06	2.18E+13	1.76E+13	1.06E+13	2.06E+13	1.65E+13	1.05E+13
14	2.466E+06	1.40E+13	1.11E+13	6.51E+12	1.32E+13	1.05E+13	6.53E+12
15	2.231E+06	1.69E+13	1.33E+13	7.72E+12	1.57E+13	1.25E+13	7.84E+12
16	2.019E+06	3.95E+13	3.09E+13	1.78E+13	3.77E+13	2.93E+13	1.77E+13
17	1.653E+06	4.77E+13	3.67E+13	2.05E+13	4.53E+13	3.49E+13	2.04E+13
18	1.353E+06	2.75E+13	2.11E+13	1.17E+13	2.64E+13	2.02E+13	1.17E+13
19	1.225E+06	3.25E+13	2.48E+13	1.34E+13	3.11E+13	2.35E+13	1.35E+13
20	1.108E+06	3.53E+13	2.66E+13	1.46E+13	3.32E+13	2.50E+13	1.44E+13
21	1.003E+06	3.91E+13	2.95E+13	1.59E+13	3.70E+13	2.78E+13	1.60E+13
22	9.072E+05	4.31E+13	3.26E+13	1.78E+13	4.08E+13	3.07E+13	1.78E+13
23	8.209E+05	1.64E+14	1.23E+14	6.64E+13	1.54E+14	1.15E+14	6.60E+13
24	6.081E+05	6.60E+13	4.90E+13	2.62E+13	6.21E+13	4.59E+13	2.62E+13
25	5.502E+05	6.75E+13	4.97E+13	2.69E+13	6.30E+13	4.67E+13	2.68E+13
26	4.979E+05	6.95E+13	5.13E+13	2.78E+13	6.49E+13	4.79E+13	2.77E+13
27	4.505E+05	6.51E+13	4.82E+13	2.62E+13	6.10E+13	4.50E+13	2.61E+13
28	4.076E+05	2.19E+14	1.61E+14	8.76E+13	2.05E+14	1.51E+14	8.71E+13
29	3.020E+05	7.40E+13	5.37E+13	2.88E+13	6.96E+13	5.09E+13	2.88E+13
30	2.732E+05	7.56E+13	5.55E+13	3.03E+13	7.10E+13	5.23E+13	3.03E+13
31	2.472E+05	2.00E+14	1.46E+14	8.07E+13	1.89E+14	1.39E+14	7.99E+13
32	1.832E+05	2.68E+14	1.96E+14	1.08E+14	2.53E+14	1.85E+14	1.07E+14
33	1.228E+05	6.56E+13	4.76E+13	2.63E+13	6.19E+13	4.49E+13	2.60E+13
34	1.111E+05	1.61E+14	1.17E+14	6.52E+13	1.52E+14	1.11E+14	6.48E+13

35	8.230E+04	1.14E+14	8.34E+13	4.70E+13	1.07E+14	7.86E+13	4.63E+13
36	6.738E+04	1.07E+14	7.64E+13	4.24E+13	1.00E+14	7.22E+13	4.18E+13
37	5.517E+04	1.38E+14	9.88E+13	5.63E+13	1.29E+14	9.30E+13	5.52E+13
38	4.087E+04	4.36E+13	3.09E+13	1.75E+13	4.05E+13	2.90E+13	1.70E+13
39	3.698E+04	7.83E+13	5.56E+13	3.20E+13	7.23E+13	5.21E+13	3.11E+13
40	2.928E+04	8.65E+12	6.15E+12	3.61E+12	8.08E+12	5.81E+12	3.55E+12
41	2.739E+04	4.30E+13	3.11E+13	1.84E+13	3.97E+13	2.91E+13	1.79E+13
42	2.479E+04	1.49E+14	1.04E+14	5.79E+13	1.37E+14	9.62E+13	5.59E+13
43	1.662E+04	2.74E+13	1.91E+13	1.09E+13	2.51E+13	1.78E+13	1.05E+13
44	1.503E+04	7.17E+13	4.94E+13	2.82E+13	6.53E+13	4.58E+13	2.72E+13
45	1.114E+04	3.97E+13	2.69E+13	1.53E+13	3.59E+13	2.48E+13	1.46E+13
46	9.119E+03	2.47E+13	1.68E+13	9.77E+12	2.24E+13	1.55E+13	9.34E+12
47	7.466E+03	3.90E+13	2.62E+13	1.52E+13	3.49E+13	2.41E+13	1.44E+13
48	5.531E+03	1.21E+13	8.01E+12	4.56E+12	1.07E+13	7.30E+12	4.35E+12
49	5.005E+03	3.44E+13	2.25E+13	1.28E+13	3.02E+13	2.04E+13	1.21E+13
50	3.527E+03	4.42E+12	2.86E+12	1.64E+12	3.85E+12	2.59E+12	1.53E+12
51	3.355E+03	2.52E+13	1.62E+13	9.30E+12	2.15E+13	1.44E+13	8.62E+12
52	2.249E+03	5.70E+12	3.61E+12	2.03E+12	4.79E+12	3.14E+12	1.86E+12
53	2.035E+03	1.28E+13	8.01E+12	4.64E+12	1.05E+13	6.89E+12	4.19E+12
54	1.507E+03	1.77E+12	1.10E+12	6.44E+11	1.42E+12	9.27E+11	5.67E+11
55	1.434E+03	4.33E+12	2.73E+12	1.62E+12	3.45E+12	2.23E+12	1.40E+12
56	1.234E+03	4.00E+12	2.45E+12	1.50E+12	3.12E+12	2.04E+12	1.29E+12
57	1.010E+03	1.53E+12	9.66E+11	6.05E+11	1.19E+12	7.74E+11	5.10E+11
58	9.142E+02	2.16E+12	1.37E+12	8.78E+11	1.65E+12	1.08E+12	7.12E+11
59	7.485E+02	1.02E+12	6.29E+11	3.96E+11	7.64E+11	4.89E+11	3.17E+11
60	6.773E+02	2.36E+12	1.42E+12	9.50E+11	1.64E+12	1.04E+12	7.41E+11
61	4.540E+02	6.02E+11	3.61E+11	2.68E+11	3.64E+11	2.34E+11	1.90E+11
62	3.717E+02	3.42E+11	2.07E+11	1.61E+11	2.05E+11	1.28E+11	1.16E+11
63	3.043E+02	4.05E+11	2.35E+11	2.13E+11	2.18E+11	1.31E+11	1.30E+11
64	2.040E+02	1.27E+11	7.52E+10	8.57E+10	6.08E+10	3.59E+10	4.28E+10
65	1.486E+02	2.20E+10	1.23E+10	1.63E+10	1.02E+10	6.53E+09	7.63E+09
66	1.367E+02	5.14E+10	3.12E+10	5.02E+10	2.33E+10	1.47E+10	1.99E+10
67	9.166E+01	1.25E+10	6.16E+09	1.12E+10	3.09E+09	2.21E+09	3.94E+09
68	7.567E+01	5.04E+09	2.02E+09	3.97E+09	1.03E+09	7.88E+08	2.20E+09
69	6.790E+01	4.67E+09	2.21E+09	4.70E+09	1.45E+09	8.32E+08	1.29E+09
70	5.560E+01	1.74E+09	9.54E+08	1.93E+09	5.63E+08	3.90E+08	3.22E+08
71	5.158E+01	1.15E+09	4.30E+08	1.91E+09	4.61E+08	1.17E+08	5.01E+08
72	4.825E+01	1.19E+09	5.90E+08	1.49E+09	1.46E+08	2.25E+08	6.19E+08
73	4.552E+01	2.39E+09	1.46E+09	3.21E+09	1.45E+08	3.03E+08	6.65E+08
74	4.017E+01	1.32E+09	4.15E+08	1.40E+09	1.04E+07	1.66E+07	3.43E+08
75	3.727E+01	2.71E+08	4.34E+08	7.37E+08	1.66E+08	6.73E+07	8.70E+07

76	3.372E+01	6.73E+08	5.92E+08	1.40E+09	2.09E+08	1.32E+08	4.39E+08
77	3.051E+01	8.25E+08	7.93E+08	2.33E+09	1.05E+08	2.15E+08	1.10E+09
78	2.761E+01	1.15E+09	6.20E+08	1.30E+09	2.10E+08	1.43E+08	8.78E+08
79	2.498E+01	1.09E+09	5.21E+08	2.19E+09	3.21E+08	2.24E+08	7.05E+08
80	2.260E+01	5.39E+08	2.35E+08	7.97E+08	8.04E+07	1.81E+07	2.33E+08
81	1.945E+01	4.16E+08	2.68E+08	9.54E+08	6.54E+07	3.37E+07	1.42E+08
82	1.593E+01	3.25E+08	2.74E+08	4.34E+08	3.12E+06	3.35E+07	1.05E+08
83	1.371E+01	5.36E+08	2.89E+08	7.97E+08	1.74E+07	7.25E+07	3.13E+08
84	1.122E+01	2.78E+08	7.70E+07	2.82E+08	2.09E+07	0.00E+00	7.07E+07
85	9.906E+00	2.83E+08	1.73E+08	4.12E+08	8.55E+07	2.55E+06	5.70E+07
86	9.190E+00	3.55E+08	2.59E+08	6.38E+08	5.04E+07	1.04E+07	1.10E+08
87	8.315E+00	2.62E+08	1.84E+08	3.45E+08	1.23E+06	1.34E+06	1.73E+07
88	7.524E+00	1.30E+08	4.49E+07	3.27E+06	0.00E+00	0.00E+00	1.00E+07
89	6.160E+00	6.24E+07	4.29E+06	0.00E+00	7.15E+06	0.00E+00	0.00E+00
90	5.346E+00	1.46E+08	4.96E+07	0.00E+00	3.81E+06	0.00E+00	0.00E+00
91	5.043E+00	3.36E+08	7.23E+07	0.00E+00	0.00E+00	0.00E+00	5.43E+07
92	4.129E+00	1.08E+08	0.00E+00	3.14E+07	0.00E+00	0.00E+00	0.00E+00
93	4.000E+00	5.26E+08	1.07E+08	2.20E+08	0.00E+00	0.00E+00	4.47E+07
94	3.381E+00	2.95E+07	4.36E+06	3.96E+07	0.00E+00	0.00E+00	1.21E+07
95	3.300E+00	2.19E+08	9.80E+07	2.77E+08	2.25E+08	3.43E+07	8.36E+07
96	2.768E+00	2.53E+07	0.00E+00	2.11E+07	0.00E+00	0.00E+00	0.00E+00
97	2.720E+00	6.37E+06	0.00E+00	4.47E+06	0.00E+00	3.69E+06	9.49E+06
98	2.600E+00	0.00E+00	4.88E+06	5.24E+06	0.00E+00	5.10E+06	0.00E+00
99	2.550E+00	6.79E+07	1.82E+08	7.82E+07	0.00E+00	2.29E+07	0.00E+00
100	2.360E+00	8.36E+07	8.38E+07	8.41E+07	9.44E+06	6.02E+07	8.12E+05
101	2.130E+00	1.62E+07	6.21E+05	1.02E+07	0.00E+00	1.06E+08	1.06E+07
102	2.100E+00	5.58E+07	8.72E+07	7.97E+06	3.72E+07	2.57E+07	6.27E+07
103	2.020E+00	7.22E+06	3.43E+07	3.02E+07	7.04E+07	3.04E+07	4.22E+07
104	1.930E+00	7.01E+07	6.21E+07	1.18E+08	0.00E+00	1.91E+07	1.37E+07
105	1.840E+00	2.15E+07	1.50E+07	4.57E+07	0.00E+00	9.05E+07	0.00E+00
106	1.755E+00	4.50E+07	2.63E+07	4.67E+07	0.00E+00	1.48E+07	0.00E+00
107	1.670E+00	1.78E+07	8.30E+06	2.27E+07	0.00E+00	2.42E+07	4.45E+06
108	1.590E+00	1.53E+07	0.00E+00	4.88E+06	1.93E+07	7.37E+06	1.09E+08
109	1.500E+00	5.79E+06	0.00E+00	4.86E+07	0.00E+00	0.00E+00	0.00E+00
110	1.475E+00	4.22E+06	0.00E+00	4.78E+07	0.00E+00	0.00E+00	2.88E+07
111	1.445E+00	2.13E+07	3.45E+07	1.84E+07	0.00E+00	2.24E+05	3.48E+07
112	1.370E+00	9.01E+06	3.56E+06	0.00E+00	0.00E+00	1.34E+07	2.24E+07
113	1.338E+00	5.61E+06	2.95E+06	1.11E+07	0.00E+00	0.00E+00	0.00E+00
114	1.300E+00	0.00E+00	0.00E+00	1.00E+07	8.12E+05	0.00E+00	6.42E+07
115	1.235E+00	4.13E+06	0.00E+00	9.68E+06	0.00E+00	0.00E+00	7.02E+06
116	1.170E+00	3.22E+06	4.00E+05	4.41E+06	0.00E+00	0.00E+00	0.00E+00

117	1.150E+00	1.03E+06	0.00E+00	2.31E+06	0.00E+00	0.00E+00	0.00E+00
118	1.125E+00	0.00E+00	0.00E+00	4.51E+05	0.00E+00	0.00E+00	0.00E+00
119	1.110E+00	1.15E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
120	1.097E+00	7.42E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
121	1.071E+00	2.31E+05	9.21E+04	7.84E+05	0.00E+00	0.00E+00	0.00E+00
122	1.045E+00	0.00E+00	0.00E+00	0.00E+00	1.38E+05	0.00E+00	0.00E+00
123	1.035E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
124	1.020E+00	0.00E+00	0.00E+00	1.00E+05	0.00E+00	0.00E+00	0.00E+00
125	9.960E-01	3.45E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
126	9.860E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
127	9.720E-01	2.35E+06	0.00E+00	1.21E+07	0.00E+00	0.00E+00	0.00E+00
128	9.500E-01	0.00E+00	0.00E+00	1.77E+06	0.00E+00	0.00E+00	0.00E+00
129	9.300E-01	0.00E+00	1.23E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
130	9.100E-01	0.00E+00	4.59E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
131	8.600E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
132	8.500E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
133	7.900E-01	0.00E+00	3.36E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
134	7.800E-01	3.95E+07	0.00E+00	6.03E+07	0.00E+00	0.00E+00	0.00E+00
135	7.050E-01	4.33E+07	1.19E+07	1.11E+06	0.00E+00	0.00E+00	0.00E+00
136	6.250E-01	5.73E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.85E+07
137	5.400E-01	0.00E+00	1.00E+07	1.54E+07	0.00E+00	0.00E+00	0.00E+00
138	5.000E-01	4.30E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
139	4.850E-01	0.00E+00	0.00E+00	2.39E+07	0.00E+00	0.00E+00	0.00E+00
140	4.330E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
141	4.000E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
142	3.910E-01	7.99E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
143	3.500E-01	7.29E+06	5.04E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
144	3.200E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
145	3.145E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
146	3.000E-01	0.00E+00	0.00E+00	1.12E+04	0.00E+00	0.00E+00	0.00E+00
147	2.800E-01	0.00E+00	0.00E+00	6.55E+06	0.00E+00	0.00E+00	0.00E+00
148	2.480E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
149	2.200E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	1.890E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
151	1.800E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
152	1.600E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
153	1.400E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
154	1.340E-01	0.00E+00	0.00E+00	6.26E+06	0.00E+00	0.00E+00	0.00E+00
155	1.150E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
156	1.000E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
157	9.500E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

158	8.000E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
159	7.700E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
160	6.700E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
161	5.800E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
162	5.000E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
163	4.200E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
164	3.500E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
165	3.000E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
166	2.500E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
167	2.000E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
168	1.500E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
169	1.000E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
170	6.900E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
171	5.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
172	3.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total		2.85E+15	2.07E+15	1.15E+15	2.66E+15	1.94E+15	1.14E+15

Table.7.2 Volume averaged neutron spectra in the core in ANL structure, 33 groups

Mode.1							
		BOC			EOC		
Group number	Top energy, eV	Core.1	Core.2	Core.3	Core.1	Core.2	Core.3
1	1.41E+07	2.16E+11	1.80E+11	1.34E+11	1.94E+11	1.71E+11	1.22E+11
2	1.00E+07	3.85E+12	3.27E+12	2.15E+12	3.62E+12	3.03E+12	2.10E+12
3	6.07E+06	1.83E+13	1.54E+13	1.01E+13	1.72E+13	1.44E+13	1.00E+13
4	3.68E+06	5.11E+13	4.14E+13	2.51E+13	4.82E+13	3.89E+13	2.51E+13
5	2.23E+06	1.05E+14	8.13E+13	4.63E+13	9.93E+13	7.72E+13	4.62E+13
6	1.35E+06	1.77E+14	1.34E+14	7.33E+13	1.68E+14	1.27E+14	7.31E+13
7	8.21E+05	2.98E+14	2.21E+14	1.20E+14	2.79E+14	2.08E+14	1.19E+14
8	4.98E+05	3.54E+14	2.61E+14	1.42E+14	3.31E+14	2.44E+14	1.41E+14
9	3.02E+05	3.51E+14	2.56E+14	1.40E+14	3.30E+14	2.43E+14	1.39E+14
10	1.83E+05	3.34E+14	2.43E+14	1.34E+14	3.14E+14	2.30E+14	1.33E+14
11	1.11E+05	2.75E+14	2.00E+14	1.12E+14	2.58E+14	1.89E+14	1.11E+14
12	6.74E+04	2.45E+14	1.75E+14	9.86E+13	2.29E+14	1.65E+14	9.70E+13
13	4.09E+04	1.74E+14	1.24E+14	7.15E+13	1.61E+14	1.16E+14	6.96E+13
14	2.48E+04	1.77E+14	1.23E+14	6.93E+13	1.63E+14	1.15E+14	6.68E+13
15	1.50E+04	1.11E+14	7.57E+13	4.32E+13	1.01E+14	7.01E+13	4.15E+13
16	9.12E+03	6.37E+13	4.29E+13	2.50E+13	5.73E+13	3.96E+13	2.38E+13
17	5.53E+03	5.08E+13	3.33E+13	1.90E+13	4.46E+13	3.02E+13	1.79E+13
18	3.36E+03	3.08E+13	1.98E+13	1.13E+13	2.63E+13	1.76E+13	1.05E+13
19	2.04E+03	1.91E+13	1.20E+13	6.98E+12	1.56E+13	1.02E+13	6.24E+12

20	1.23E+03	7.58E+12	4.72E+12	2.94E+12	5.87E+12	3.84E+12	2.47E+12
21	7.49E+02	3.38E+12	2.05E+12	1.35E+12	2.41E+12	1.53E+12	1.06E+12
22	4.54E+02	9.46E+11	5.68E+11	4.30E+11	5.70E+11	3.63E+11	3.07E+11
23	3.04E+02	5.29E+11	3.09E+11	2.97E+11	2.77E+11	1.65E+11	1.72E+11
24	1.49E+02	7.41E+10	4.43E+10	6.73E+10	3.39E+10	2.14E+10	2.78E+10
25	9.17E+01	1.76E+10	8.18E+09	1.52E+10	4.13E+09	3.01E+09	6.16E+09
26	6.79E+01	1.11E+10	5.65E+09	1.32E+10	2.77E+09	1.87E+09	3.37E+09
27	4.02E+01	5.35E+09	3.38E+09	9.38E+09	1.02E+09	7.99E+08	3.58E+09
28	2.26E+01	1.30E+09	7.77E+08	2.17E+09	1.49E+08	8.53E+07	4.80E+08
29	1.37E+01	1.44E+09	7.93E+08	2.13E+09	1.74E+08	8.54E+07	5.51E+08
30	8.32E+00	1.04E+09	3.60E+08	3.79E+08	1.22E+07	1.34E+06	8.17E+07
31	3.99E+00	1.36E+09	7.76E+08	1.24E+09	3.63E+08	4.58E+08	5.69E+08
32	5.41E-01	4.30E+06	1.00E+07	3.93E+07	0.00E+00	0.00E+00	0.00E+00
33	4.14E-01	1.53E+07	5.04E+05	1.28E+07	0.00E+00	0.00E+00	0.00E+00
	Total	2.85E+15	2.07E+15	1.15E+15	2.66E+15	1.94E+15	1.14E+15

In both structures for energy group ratio flux-to-lethargy was obtained as follows: total volume averaged neutron flux in zone was normed by 1 and group component was divided by group width in lethargy units. Figure 3 illustrates a histogram of the ratio of flux-to-lethargy versus neutron energy at BOC for Core-1.

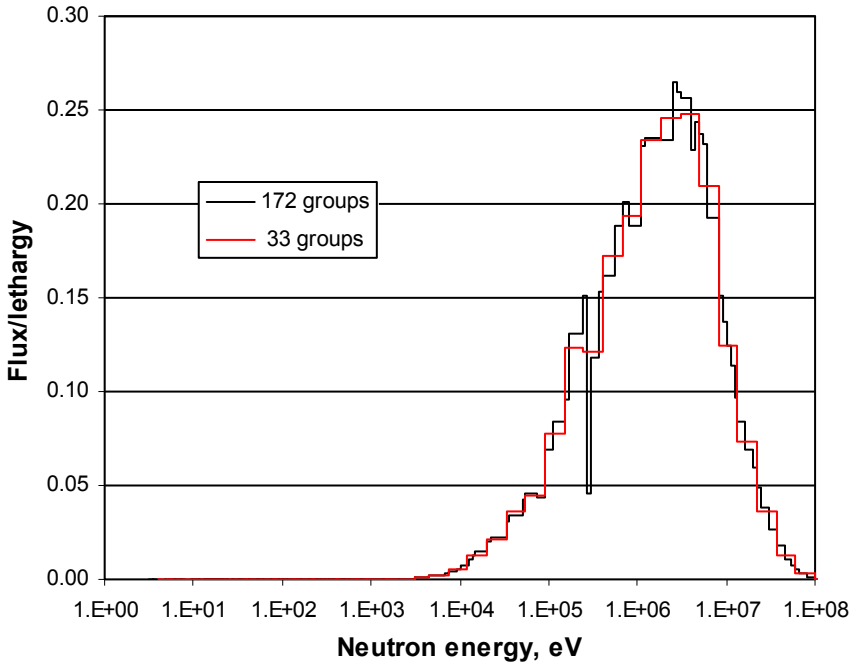

Fig.3 Flux/lethargy vs. neutron energy in Core-1 at BOC (Mode.1)

Figures 4 and 5 illustrate histograms of the ratio of flux-to-lethargy versus neutron energy at BOC and EOC for reactor cores. It can be seen that neutron spectra are practically the same in cores and during cycle.

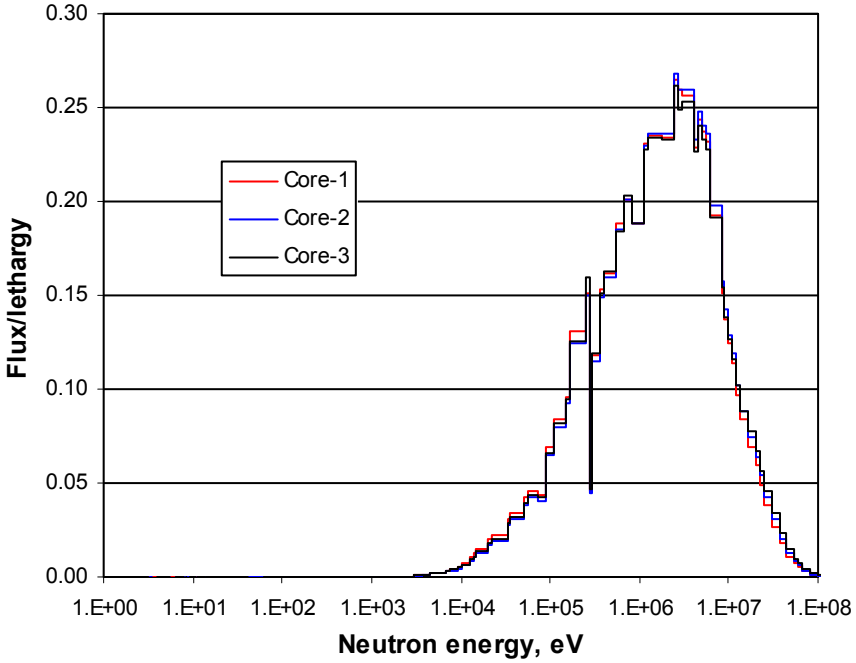

Fig.4 Flux/lethargy vs. neutron energy at BOC (Mode.1)

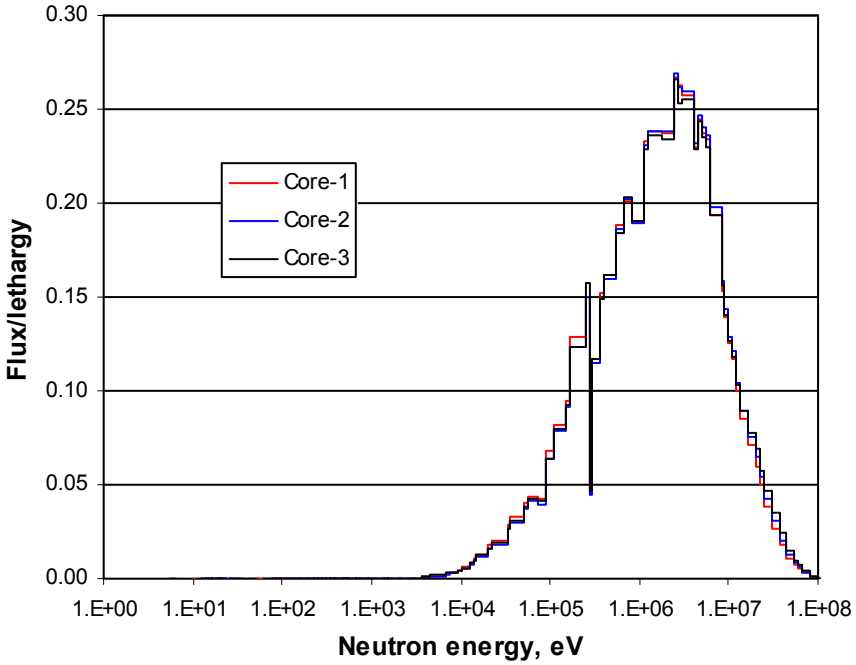

Fig.5 Flux/lethargy vs. neutron energy at EOC (Mode.1)

Mode.2 **Single Cycle Analysis for 900 Effective Full Power Days**

Table.8 shows the evolution of the multiplication factor. The depletion calculations were performed with 1 subinterval (900 days).

Table.8 k_{eff} by time step

Mode.2	
Day	k_{eff} for 900MW, 900 days cycle
0	1.0038±0.0003
900	1.0122±0.0003

As can be seen in Table 8, multiplication factor increases during cycle. It is connected with growing plutonium generation in fuelled zones.
Tables 9, 10 and 11 show neutron balances in cores at the beginning and end of cycle. Neutron generation rate is practically the same in cores and during cycle. In each core capture in fission products grows with fission product accumulation, but capture in heavy nuclides decreases, so neutron absorption rate does not change. At BOC capture in heavy nuclides for Core-1, Core-2 and Core-3 is about 92%, 93% and 95% of total neutron absorption. It is connected with more fuel volume fractions in peripheral cores.

Table.9 Neutron balance in Core-1 (Mode.2)

For 1000 fissions in Core-1 at BOC			
Fission neutrons	2884	Capture in heavy nuclides	1315
(n,2n) neutrons	4	Capture in fission products	
(n,3n) neutrons		Absorption in construction materials	67
		Absorption in coolant	48
Total neutron generation	2888	Total neutron absorption	1430
For 1000 fissions in Core-1 after 900 days burnup (Mode.2)			
Fission neutrons	2889	Capture in heavy nuclides	1232
(n,2n) neutrons	3	Capture in fission products	87
(n,3n) neutrons		Absorption in construction materials	67
		Absorption in coolant	47
Total neutron generation	2892	Total neutron absorption	1433

Table.10 Neutron balance in Core-2 (Mode.2)

For 1000 fissions in Core-2 at BOC			
Fission neutrons	2882	Capture in heavy nuclides	1249
(n,2n) neutrons	4	Capture in fission products	
(n,3n) neutrons		Absorption in construction materials	60
		Absorption in coolant	36
Total neutron generation	2886	Total neutron absorption	1345

For 1000 fissions in Core-2 after 900 days burnup (Mode.2)			
Fission neutrons	2885	Capture in heavy nuclides	1205
(n,2n) neutrons	4	Capture in fission products	60
(n,3n) neutrons		Absorption in construction materials	60
		Absorption in coolant	36
Total neutron generation	2889	Total neutron absorption	1361

Table.11 Neutron balance in Core-3 (Mode.2)

For 1000 fissions in Core-3 at BOC			
Fission neutrons	2880	Capture in heavy nuclides	1239
(n,2n) neutrons	5	Capture in fission products	
(n,3n) neutrons		Absorption in construction materials	50
		Absorption in coolant	21
Total neutron generation	2885	Total neutron absorption	1310
For 1000 fissions in Core-3 after 900 days burnup (Mode.2)			
Fission neutrons	2882	Capture in heavy nuclides	1216
(n,2n) neutrons	5	Capture in fission products	34
(n,3n) neutrons		Absorption in construction materials	51
		Absorption in coolant	21
Total neutron generation	2887	Total neutron absorption	1322

Table 12 shows region powers and power peaking factors at the beginning and end of 900-day cycle. Core powers decrease to EOC. In this model it is connected with breeding in blankets and growing of blanket powers, so core powers decrease to keep total power at level 900 MW.

Table.12 Region powers and power peaking factors

Mode.2					
	ZONE	Power(Watts)	Power Density	Peak Density	Peak to AVG.
			(Watts/cm^3)	(Watts/cm^3)	Power Density
BOC	Core1	3.42E+08	1.47E+02	1.98E+02	1.35E+00
	Core2	3.98E+08	1.27E+02	1.94E+02	1.52E+00
	Core3	1.48E+08	9.98E+01	1.54E+02	1.55E+00
EOC	Core1	3.39E+08	1.45E+02	1.95E+02	1.34E+00
	Core2	3.79E+08	1.21E+02	1.85E+02	1.52E+00
	Core3	1.42E+08	9.58E+01	1.46E+02	1.52E+00

Figure.6 depicts radial power density profiles at the core mid-plane for the beginning and end of cycle. Spatial variations of the power distribution can be observed. As can be seen in Figure.6 power peaking appears at the boundaries between zones of different fuel loading. Figure.7 depicts axial power profiles in the center of reactor.

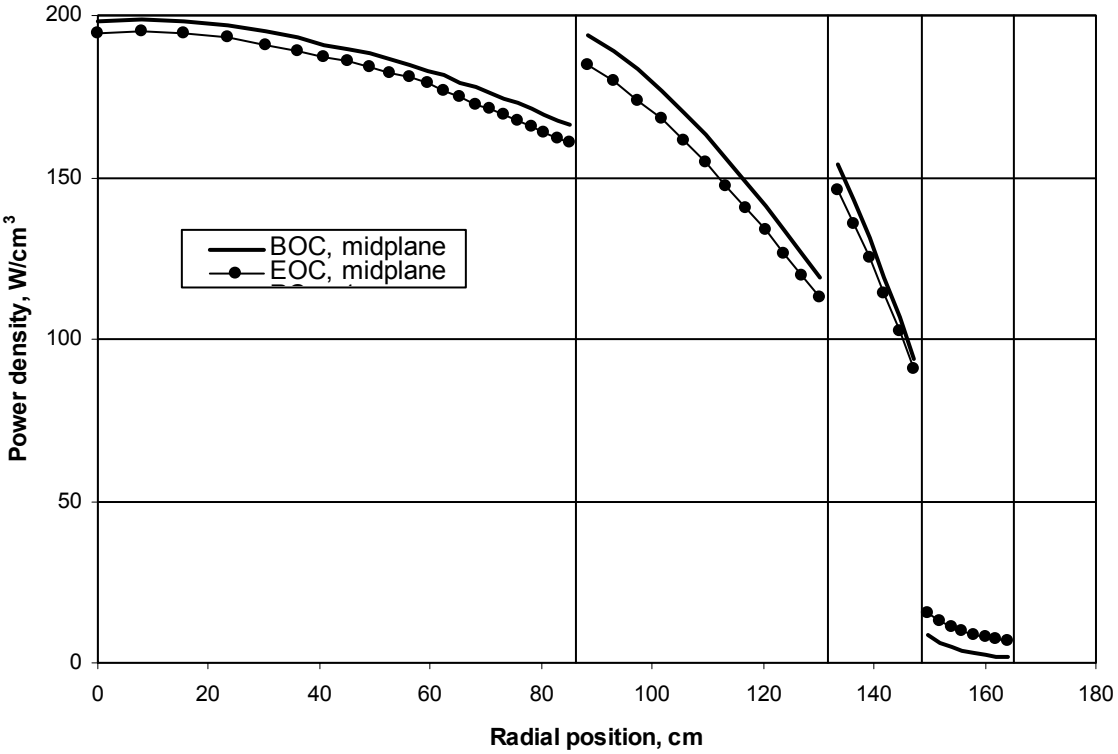

Fig.6 Radial power profiles in the cores and lateral blanket (Mode.2)

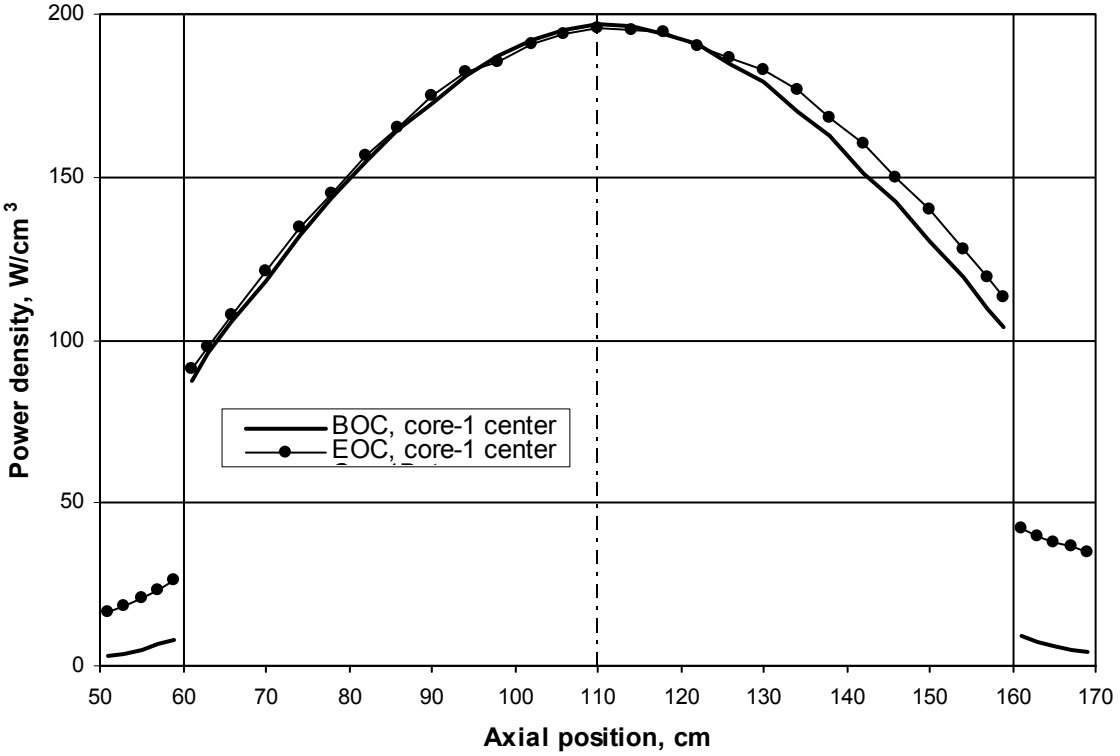

Fig.7 Axial power profiles in the Core-1 and axial blankets (Mode.2)

Volume averaged neutron flux in the core zones was obtained at BOC and EOC in XMAS structure (172 groups) and ANL structure (33 groups). Tables 13.1 and 13.2 provide flux values for each energy group.

Table.13.1 Volume averaged neutron spectra in the core in XMAS structure, 172 groups

Mode.2							
		BOC			EOC		
Group number	Top energy, eV	Core.1	Core.2	Core.3	Core.1	Core.2	Core.3
1	1.964E+07	2.26E+08	7.43E+08	5.41E+08	2.38E+09	0.00E+00	1.09E+09
2	1.733E+07	2.87E+09	3.07E+09	1.98E+09	3.22E+09	4.19E+09	4.31E+09
3	1.492E+07	9.00E+09	5.06E+09	4.36E+09	1.03E+10	5.90E+09	1.98E+09
4	1.384E+07	5.62E+10	4.40E+10	3.26E+10	5.55E+10	4.82E+10	2.55E+10
5	1.162E+07	1.56E+11	1.34E+11	1.00E+11	1.69E+11	1.15E+11	7.99E+10
6	1.000E+07	6.24E+11	5.48E+11	3.73E+11	6.23E+11	5.36E+11	3.11E+11
7	8.187E+06	1.73E+12	1.44E+12	9.45E+11	1.70E+12	1.35E+12	9.35E+11
8	6.703E+06	1.50E+12	1.30E+12	8.39E+11	1.47E+12	1.15E+12	8.68E+11
9	6.065E+06	2.03E+12	1.70E+12	1.13E+12	2.00E+12	1.62E+12	1.08E+12
10	5.488E+06	6.23E+12	5.25E+12	3.48E+12	6.20E+12	5.02E+12	3.44E+12
11	4.493E+06	1.01E+13	8.49E+12	5.48E+12	9.85E+12	7.91E+12	5.31E+12
12	3.679E+06	1.52E+13	1.26E+13	7.88E+12	1.51E+13	1.20E+13	7.75E+12
13	3.012E+06	2.18E+13	1.76E+13	1.06E+13	2.18E+13	1.69E+13	1.05E+13
14	2.466E+06	1.40E+13	1.11E+13	6.51E+12	1.40E+13	1.06E+13	6.35E+12
15	2.231E+06	1.69E+13	1.33E+13	7.72E+12	1.65E+13	1.25E+13	7.69E+12
16	2.019E+06	3.95E+13	3.09E+13	1.78E+13	3.88E+13	2.95E+13	1.73E+13
17	1.653E+06	4.77E+13	3.67E+13	2.05E+13	4.74E+13	3.49E+13	1.97E+13
18	1.353E+06	2.75E+13	2.11E+13	1.17E+13	2.75E+13	2.04E+13	1.13E+13
19	1.225E+06	3.25E+13	2.48E+13	1.34E+13	3.23E+13	2.36E+13	1.31E+13
20	1.108E+06	3.53E+13	2.66E+13	1.46E+13	3.49E+13	2.53E+13	1.39E+13
21	1.003E+06	3.91E+13	2.95E+13	1.59E+13	3.87E+13	2.80E+13	1.56E+13
22	9.072E+05	4.31E+13	3.26E+13	1.78E+13	4.31E+13	3.09E+13	1.73E+13
23	8.209E+05	1.64E+14	1.23E+14	6.64E+13	1.63E+14	1.17E+14	6.40E+13
24	6.081E+05	6.60E+13	4.90E+13	2.62E+13	6.50E+13	4.68E+13	2.52E+13
25	5.502E+05	6.75E+13	4.97E+13	2.69E+13	6.61E+13	4.77E+13	2.59E+13
26	4.979E+05	6.95E+13	5.13E+13	2.78E+13	6.82E+13	4.91E+13	2.67E+13
27	4.505E+05	6.51E+13	4.82E+13	2.62E+13	6.33E+13	4.63E+13	2.52E+13
28	4.076E+05	2.19E+14	1.61E+14	8.76E+13	2.15E+14	1.54E+14	8.46E+13
29	3.020E+05	7.40E+13	5.37E+13	2.88E+13	7.26E+13	5.12E+13	2.81E+13
30	2.732E+05	7.56E+13	5.55E+13	3.03E+13	7.48E+13	5.31E+13	2.94E+13
31	2.472E+05	2.00E+14	1.46E+14	8.07E+13	1.98E+14	1.40E+14	7.88E+13
32	1.832E+05	2.68E+14	1.96E+14	1.08E+14	2.64E+14	1.87E+14	1.05E+14
33	1.228E+05	6.56E+13	4.76E+13	2.63E+13	6.45E+13	4.55E+13	2.52E+13
34	1.111E+05	1.61E+14	1.17E+14	6.52E+13	1.59E+14	1.11E+14	6.29E+13

35	8.230E+04	1.14E+14	8.34E+13	4.70E+13	1.12E+14	7.92E+13	4.54E+13
36	6.738E+04	1.07E+14	7.64E+13	4.24E+13	1.05E+14	7.30E+13	4.13E+13
37	5.517E+04	1.38E+14	9.88E+13	5.63E+13	1.35E+14	9.41E+13	5.40E+13
38	4.087E+04	4.36E+13	3.09E+13	1.75E+13	4.25E+13	2.94E+13	1.70E+13
39	3.698E+04	7.83E+13	5.56E+13	3.20E+13	7.62E+13	5.27E+13	3.10E+13
40	2.928E+04	8.65E+12	6.15E+12	3.61E+12	8.46E+12	5.88E+12	3.53E+12
41	2.739E+04	4.30E+13	3.11E+13	1.84E+13	4.18E+13	2.95E+13	1.78E+13
42	2.479E+04	1.49E+14	1.04E+14	5.79E+13	1.44E+14	9.73E+13	5.54E+13
43	1.662E+04	2.74E+13	1.91E+13	1.09E+13	2.65E+13	1.80E+13	1.05E+13
44	1.503E+04	7.17E+13	4.94E+13	2.82E+13	6.90E+13	4.66E+13	2.69E+13
45	1.114E+04	3.97E+13	2.69E+13	1.53E+13	3.78E+13	2.53E+13	1.45E+13
46	9.119E+03	2.47E+13	1.68E+13	9.77E+12	2.37E+13	1.59E+13	9.28E+12
47	7.466E+03	3.90E+13	2.62E+13	1.52E+13	3.71E+13	2.45E+13	1.44E+13
48	5.531E+03	1.21E+13	8.01E+12	4.56E+12	1.14E+13	7.54E+12	4.37E+12
49	5.005E+03	3.44E+13	2.25E+13	1.28E+13	3.25E+13	2.11E+13	1.21E+13
50	3.527E+03	4.42E+12	2.86E+12	1.64E+12	4.10E+12	2.68E+12	1.53E+12
51	3.355E+03	2.52E+13	1.62E+13	9.30E+12	2.32E+13	1.50E+13	8.75E+12
52	2.249E+03	5.70E+12	3.61E+12	2.03E+12	5.22E+12	3.30E+12	1.89E+12
53	2.035E+03	1.28E+13	8.01E+12	4.64E+12	1.16E+13	7.24E+12	4.30E+12
54	1.507E+03	1.77E+12	1.10E+12	6.44E+11	1.58E+12	9.88E+11	5.88E+11
55	1.434E+03	4.33E+12	2.73E+12	1.62E+12	3.87E+12	2.39E+12	1.51E+12
56	1.234E+03	4.00E+12	2.45E+12	1.50E+12	3.47E+12	2.19E+12	1.36E+12
57	1.010E+03	1.53E+12	9.66E+11	6.05E+11	1.32E+12	8.29E+11	5.16E+11
58	9.142E+02	2.16E+12	1.37E+12	8.78E+11	1.87E+12	1.19E+12	7.31E+11
59	7.485E+02	1.02E+12	6.29E+11	3.96E+11	8.75E+11	5.42E+11	3.28E+11
60	6.773E+02	2.36E+12	1.42E+12	9.50E+11	1.90E+12	1.18E+12	7.62E+11
61	4.540E+02	6.02E+11	3.61E+11	2.68E+11	4.82E+11	2.73E+11	1.96E+11
62	3.717E+02	3.42E+11	2.07E+11	1.61E+11	2.57E+11	1.55E+11	1.17E+11
63	3.043E+02	4.05E+11	2.35E+11	2.13E+11	2.74E+11	1.80E+11	1.40E+11
64	2.040E+02	1.27E+11	7.52E+10	8.57E+10	7.01E+10	4.69E+10	6.02E+10
65	1.486E+02	2.20E+10	1.23E+10	1.63E+10	1.01E+10	7.82E+09	1.30E+10
66	1.367E+02	5.14E+10	3.12E+10	5.02E+10	3.11E+10	2.15E+10	3.22E+10
67	9.166E+01	1.25E+10	6.16E+09	1.12E+10	5.10E+09	3.60E+09	5.78E+09
68	7.567E+01	5.04E+09	2.02E+09	3.97E+09	1.14E+09	1.34E+09	2.53E+09
69	6.790E+01	4.67E+09	2.21E+09	4.70E+09	1.34E+09	1.20E+09	3.51E+09
70	5.560E+01	1.74E+09	9.54E+08	1.93E+09	6.36E+08	2.00E+08	1.44E+09
71	5.158E+01	1.15E+09	4.30E+08	1.91E+09	6.56E+08	9.42E+07	1.96E+09
72	4.825E+01	1.19E+09	5.90E+08	1.49E+09	7.38E+08	2.57E+08	7.49E+08
73	4.552E+01	2.39E+09	1.46E+09	3.21E+09	9.79E+08	4.98E+08	1.15E+09
74	4.017E+01	1.32E+09	4.15E+08	1.40E+09	7.36E+07	2.26E+08	6.09E+08
75	3.727E+01	2.71E+08	4.34E+08	7.37E+08	6.56E+08	7.13E+05	6.23E+07

76	3.372E+01	6.73E+08	5.92E+08	1.40E+09	1.20E+09	7.87E+07	9.34E+08
77	3.051E+01	8.25E+08	7.93E+08	2.33E+09	2.16E+09	3.37E+08	1.02E+08
78	2.761E+01	1.15E+09	6.20E+08	1.30E+09	4.43E+08	6.51E+08	1.21E+09
79	2.498E+01	1.09E+09	5.21E+08	2.19E+09	4.17E+08	1.42E+08	3.03E+08
80	2.260E+01	5.39E+08	2.35E+08	7.97E+08	3.64E+08	1.84E+08	4.27E+07
81	1.945E+01	4.16E+08	2.68E+08	9.54E+08	0.00E+00	0.00E+00	2.93E+08
82	1.593E+01	3.25E+08	2.74E+08	4.34E+08	2.82E+07	2.48E+08	7.51E+07
83	1.371E+01	5.36E+08	2.89E+08	7.97E+08	5.95E+06	2.78E+07	3.10E+07
84	1.122E+01	2.78E+08	7.70E+07	2.82E+08	1.12E+07	2.57E+07	3.13E+08
85	9.906E+00	2.83E+08	1.73E+08	4.12E+08	0.00E+00	3.54E+07	2.05E+07
86	9.190E+00	3.55E+08	2.59E+08	6.38E+08	5.78E+07	4.37E+07	1.11E+08
87	8.315E+00	2.62E+08	1.84E+08	3.45E+08	0.00E+00	0.00E+00	2.47E+08
88	7.524E+00	1.30E+08	4.49E+07	3.27E+06	0.00E+00	0.00E+00	8.34E+06
89	6.160E+00	6.24E+07	4.29E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	5.346E+00	1.46E+08	4.96E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
91	5.043E+00	3.36E+08	7.23E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
92	4.129E+00	1.08E+08	0.00E+00	3.14E+07	0.00E+00	0.00E+00	0.00E+00
93	4.000E+00	5.26E+08	1.07E+08	2.20E+08	0.00E+00	0.00E+00	0.00E+00
94	3.381E+00	2.95E+07	4.36E+06	3.96E+07	0.00E+00	0.00E+00	0.00E+00
95	3.300E+00	2.19E+08	9.80E+07	2.77E+08	0.00E+00	0.00E+00	6.43E+08
96	2.768E+00	2.53E+07	0.00E+00	2.11E+07	0.00E+00	0.00E+00	0.00E+00
97	2.720E+00	6.37E+06	0.00E+00	4.47E+06	0.00E+00	0.00E+00	0.00E+00
98	2.600E+00	0.00E+00	4.88E+06	5.24E+06	0.00E+00	0.00E+00	0.00E+00
99	2.550E+00	6.79E+07	1.82E+08	7.82E+07	0.00E+00	0.00E+00	0.00E+00
100	2.360E+00	8.36E+07	8.38E+07	8.41E+07	8.44E+06	0.00E+00	1.88E+08
101	2.130E+00	1.62E+07	6.21E+05	1.02E+07	0.00E+00	0.00E+00	0.00E+00
102	2.100E+00	5.58E+07	8.72E+07	7.97E+06	0.00E+00	0.00E+00	0.00E+00
103	2.020E+00	7.22E+06	3.43E+07	3.02E+07	0.00E+00	0.00E+00	0.00E+00
104	1.930E+00	7.01E+07	6.21E+07	1.18E+08	0.00E+00	0.00E+00	3.93E+08
105	1.840E+00	2.15E+07	1.50E+07	4.57E+07	0.00E+00	1.19E+08	9.48E+07
106	1.755E+00	4.50E+07	2.63E+07	4.67E+07	0.00E+00	1.72E+06	1.38E+08
107	1.670E+00	1.78E+07	8.30E+06	2.27E+07	0.00E+00	0.00E+00	1.11E+08
108	1.590E+00	1.53E+07	0.00E+00	4.88E+06	0.00E+00	2.35E+06	3.96E+08
109	1.500E+00	5.79E+06	0.00E+00	4.86E+07	0.00E+00	0.00E+00	0.00E+00
110	1.475E+00	4.22E+06	0.00E+00	4.78E+07	0.00E+00	0.00E+00	2.36E+07
111	1.445E+00	2.13E+07	3.45E+07	1.84E+07	1.44E+07	0.00E+00	2.50E+08
112	1.370E+00	9.01E+06	3.56E+06	0.00E+00	0.00E+00	3.50E+07	1.91E+08
113	1.338E+00	5.61E+06	2.95E+06	1.11E+07	0.00E+00	1.29E+06	4.76E+07
114	1.300E+00	0.00E+00	0.00E+00	1.00E+07	0.00E+00	0.00E+00	0.00E+00
115	1.235E+00	4.13E+06	0.00E+00	9.68E+06	0.00E+00	0.00E+00	0.00E+00
116	1.170E+00	3.22E+06	4.00E+05	4.41E+06	0.00E+00	0.00E+00	0.00E+00

117	1.150E+00	1.03E+06	0.00E+00	2.31E+06	0.00E+00	0.00E+00	0.00E+00
118	1.125E+00	0.00E+00	0.00E+00	4.51E+05	0.00E+00	0.00E+00	0.00E+00
119	1.110E+00	1.15E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
120	1.097E+00	7.42E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
121	1.071E+00	2.31E+05	9.21E+04	7.84E+05	0.00E+00	0.00E+00	0.00E+00
122	1.045E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
123	1.035E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
124	1.020E+00	0.00E+00	0.00E+00	1.00E+05	0.00E+00	0.00E+00	0.00E+00
125	9.960E-01	3.45E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
126	9.860E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
127	9.720E-01	2.35E+06	0.00E+00	1.21E+07	0.00E+00	0.00E+00	0.00E+00
128	9.500E-01	0.00E+00	0.00E+00	1.77E+06	0.00E+00	0.00E+00	0.00E+00
129	9.300E-01	0.00E+00	1.23E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
130	9.100E-01	0.00E+00	4.59E+06	0.00E+00	0.00E+00	0.00E+00	8.47E+07
131	8.600E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
132	8.500E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
133	7.900E-01	0.00E+00	3.36E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
134	7.800E-01	3.95E+07	0.00E+00	6.03E+07	0.00E+00	0.00E+00	0.00E+00
135	7.050E-01	4.33E+07	1.19E+07	1.11E+06	0.00E+00	0.00E+00	0.00E+00
136	6.250E-01	5.73E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
137	5.400E-01	0.00E+00	1.00E+07	1.54E+07	0.00E+00	0.00E+00	0.00E+00
138	5.000E-01	4.30E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
139	4.850E-01	0.00E+00	0.00E+00	2.39E+07	0.00E+00	0.00E+00	0.00E+00
140	4.330E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
141	4.000E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
142	3.910E-01	7.99E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
143	3.500E-01	7.29E+06	5.04E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
144	3.200E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
145	3.145E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
146	3.000E-01	0.00E+00	0.00E+00	1.12E+04	0.00E+00	0.00E+00	0.00E+00
147	2.800E-01	0.00E+00	0.00E+00	6.55E+06	0.00E+00	0.00E+00	0.00E+00
148	2.480E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
149	2.200E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	1.890E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
151	1.800E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
152	1.600E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
153	1.400E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
154	1.340E-01	0.00E+00	0.00E+00	6.26E+06	0.00E+00	0.00E+00	0.00E+00
155	1.150E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
156	1.000E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
157	9.500E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

158	8.000E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
159	7.700E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
160	6.700E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
161	5.800E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
162	5.000E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
163	4.200E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
164	3.500E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
165	3.000E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
166	2.500E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
167	2.000E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
168	1.500E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
169	1.000E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
170	6.900E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
171	5.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
172	3.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total		2.85E+15	2.07E+15	1.15E+15	2.79E+15	1.97E+15	1.11E+15

Table.13.2 Volume averaged neutron spectra in the core in ANL structure, 33 groups

Mode.2							
		BOC			EOC		
Group number	Top energy, eV	Core.1	Core.2	Core.3	Core.1	Core.2	Core.3
1	1.41E+07	2.16E+11	1.80E+11	1.34E+11	2.07E+11	1.59E+11	1.18E+11
2	1.00E+07	3.85E+12	3.27E+12	2.15E+12	3.81E+12	3.10E+12	2.05E+12
3	6.07E+06	1.83E+13	1.54E+13	1.01E+13	1.82E+13	1.46E+13	9.78E+12
4	3.68E+06	5.11E+13	4.14E+13	2.51E+13	5.08E+13	3.95E+13	2.45E+13
5	2.23E+06	1.05E+14	8.13E+13	4.63E+13	1.04E+14	7.78E+13	4.48E+13
6	1.35E+06	1.77E+14	1.34E+14	7.33E+13	1.75E+14	1.28E+14	7.09E+13
7	8.21E+05	2.98E+14	2.21E+14	1.20E+14	2.92E+14	2.11E+14	1.16E+14
8	4.98E+05	3.54E+14	2.61E+14	1.42E+14	3.48E+14	2.48E+14	1.37E+14
9	3.02E+05	3.51E+14	2.56E+14	1.40E+14	3.46E+14	2.45E+14	1.36E+14
10	1.83E+05	3.34E+14	2.43E+14	1.34E+14	3.28E+14	2.32E+14	1.30E+14
11	1.11E+05	2.75E+14	2.00E+14	1.12E+14	2.70E+14	1.90E+14	1.08E+14
12	6.74E+04	2.45E+14	1.75E+14	9.86E+13	2.39E+14	1.67E+14	9.52E+13
13	4.09E+04	1.74E+14	1.24E+14	7.15E+13	1.69E+14	1.18E+14	6.86E+13
14	2.48E+04	1.77E+14	1.23E+14	6.93E+13	1.72E+14	1.16E+14	6.64E+13
15	1.50E+04	1.11E+14	7.57E+13	4.32E+13	1.06E+14	7.15E+13	4.10E+13
16	9.12E+03	6.37E+13	4.29E+13	2.50E+13	6.09E+13	4.06E+13	2.36E+13
17	5.53E+03	5.08E+13	3.33E+13	1.90E+13	4.78E+13	3.13E+13	1.80E+13
18	3.36E+03	3.08E+13	1.98E+13	1.13E+13	2.86E+13	1.83E+13	1.07E+13
19	2.04E+03	1.91E+13	1.20E+13	6.98E+12	1.73E+13	1.09E+13	6.42E+12

20	1.23E+03	7.58E+12	4.72E+12	2.94E+12	6.64E+12	4.15E+12	2.59E+12
21	7.49E+02	3.38E+12	2.05E+12	1.35E+12	2.83E+12	1.71E+12	1.19E+12
22	4.54E+02	9.46E+11	5.68E+11	4.30E+11	7.23E+11	4.21E+11	3.58E+11
23	3.04E+02	5.29E+11	3.09E+11	2.97E+11	3.62E+11	2.05E+11	2.06E+11
24	1.49E+02	7.41E+10	4.43E+10	6.73E+10	4.66E+10	2.96E+10	4.37E+10
25	9.17E+01	1.76E+10	8.18E+09	1.52E+10	7.72E+09	5.36E+09	9.90E+09
26	6.79E+01	1.11E+10	5.65E+09	1.32E+10	4.19E+09	3.09E+09	7.06E+09
27	4.02E+01	5.35E+09	3.38E+09	9.38E+09	2.08E+09	2.10E+09	3.25E+09
28	2.26E+01	1.30E+09	7.77E+08	2.17E+09	2.69E+08	2.92E+08	5.31E+08
29	1.37E+01	1.44E+09	7.93E+08	2.13E+09	1.63E+08	3.17E+08	7.31E+08
30	8.32E+00	1.04E+09	3.60E+08	3.79E+08	3.71E+07	6.32E+07	1.08E+08
31	3.99E+00	1.36E+09	7.76E+08	1.24E+09	1.35E+09	4.95E+08	1.08E+09
32	5.41E-01	4.30E+06	1.00E+07	3.93E+07	0.00E+00	0.00E+00	1.58E+07
33	4.14E-01	1.53E+07	5.04E+05	1.28E+07	0.00E+00	0.00E+00	0.00E+00
	Total	2.85E+15	2.07E+15	1.15E+15	2.79E+15	1.97E+15	1.11E+15

In both structures for energy group ratio flux-to-lethargy was obtained as follows: total volume averaged neutron flux in zone was normed by 1 and group component was divided by group width in lethargy units. Figure 8 illustrates a histogram of the ratio of flux-to-lethargy versus neutron energy at EOC for Core-1.

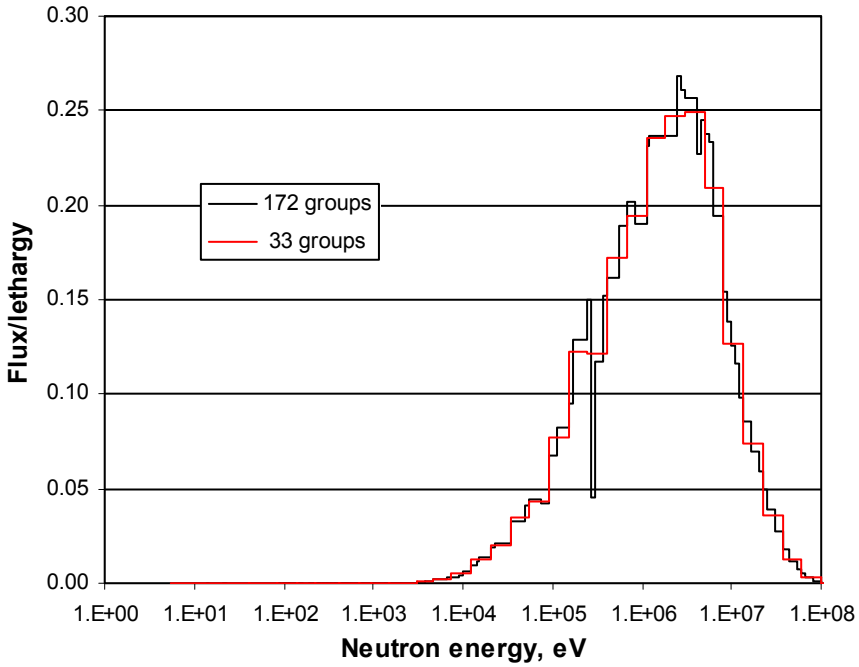

Figure.8 Flux/lethargy vs. neutron energy for Core-1 at EOC (Mode.2)

Figures 9 and 10 illustrate histograms of the ratio of flux-to-lethargy versus neutron energy at BOC and EOC for reactor cores. It can be seen that neutron spectra are practically the same in cores and during cycle.

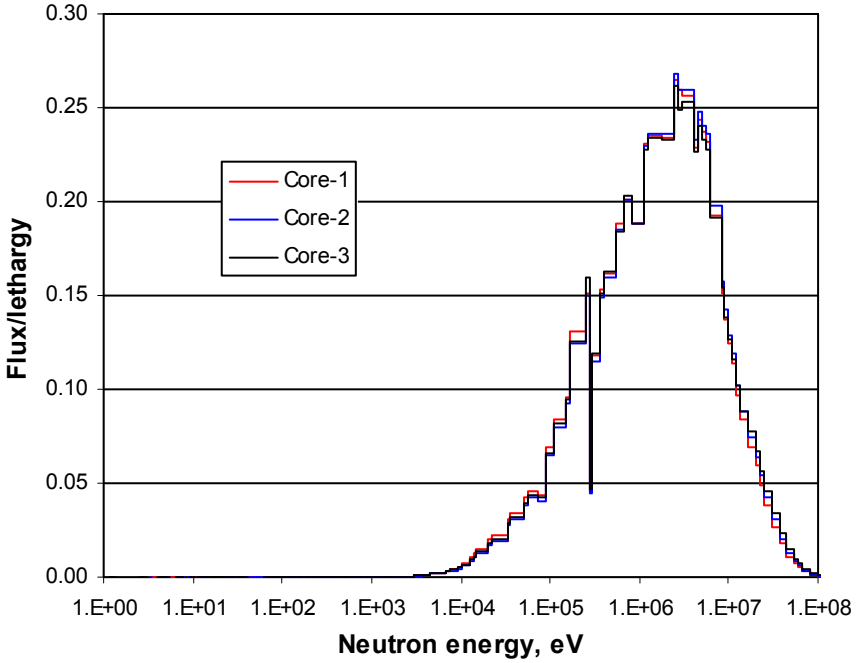

Figure.9 Flux/lethargy vs. neutron energy at BOC (Mode.2)

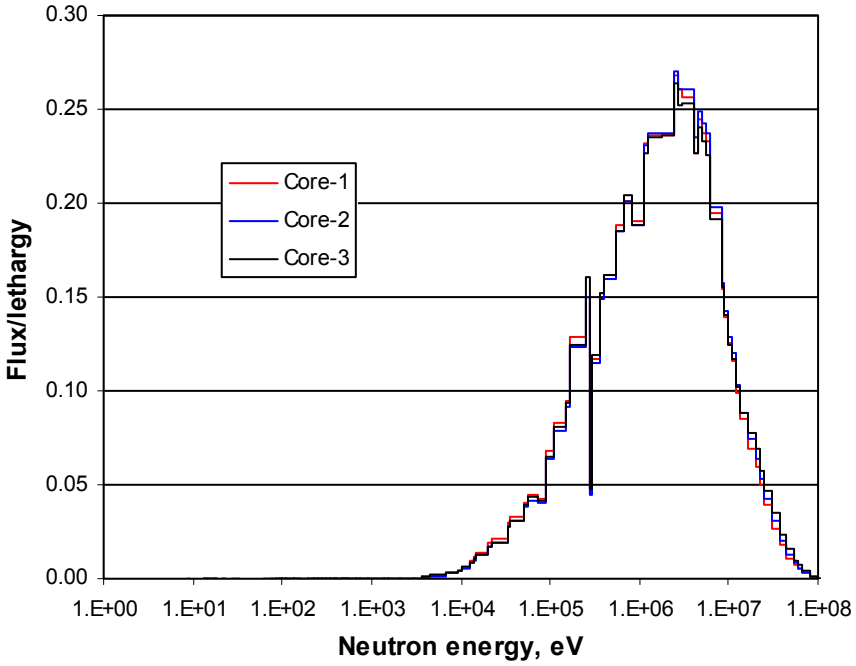

Figure.10 Flux/lethargy vs. neutron energy at EOC (Mode.2)

Mode.3 **Fuel Cycle Consists of Six Partial Fuel Cycles of 300 Effective Full Power Days Each**

Table 14 and Figure 11 provide the effective multiplication factor evolution with time.

Table.14 k_{eff} by time step (Mode.3)

Mode.3	
k_{eff} Evolution for 900MW, 6 Cycles	
day	Code
	MCNP5
0	1.0038±0.0003
300	1.0068±0.0003
360	1.0070±0.0003
660	1.0084±0.0003
720	1.0084±0.0003
1020	1.0094±0.0003
1080	1.0095±0.0003
1380	1.0098±0.0003
1440	1.0097±0.0003
1740	1.0098±0.0003
1800	1.0091±0.0003
2100	1.0093±0.0003

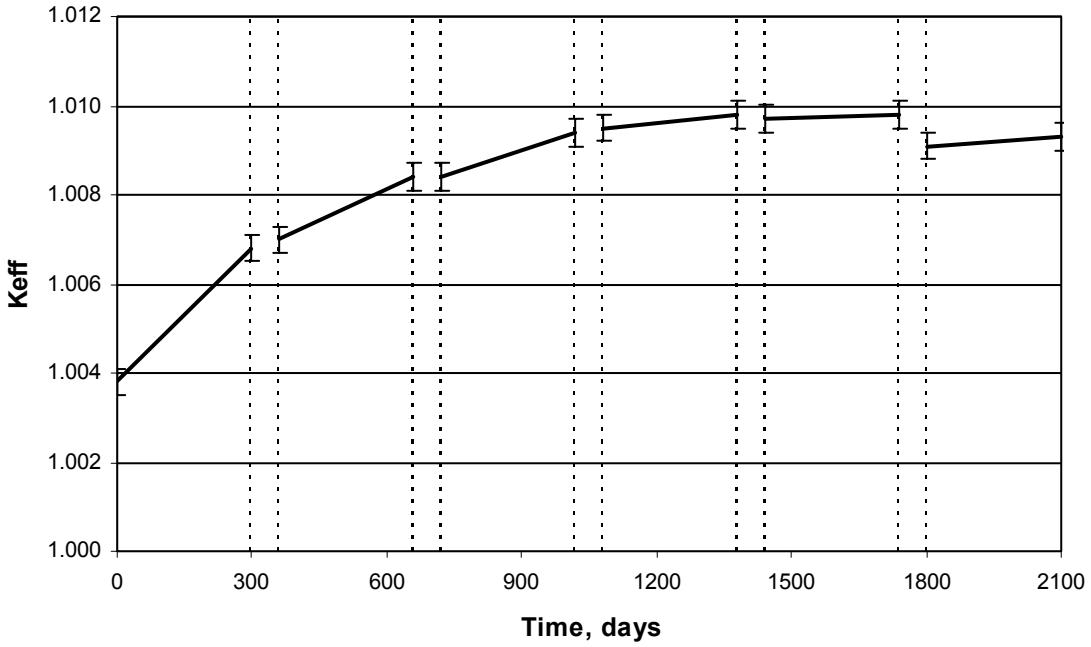

Fig.11 Evolution of k_{eff} for 900MW, 6 Cycles (Mode.3)

As can be observed from Figure 11, the effective multiplication factor is increasing during the 300-day irradiation period. The core is then cooled and reloaded. In first cycles, k_{eff} does not decrease after reload. With time, the time change in reactivity becomes smaller for the irradiation period. After last reload k_{eff} decreases, but the change is practically within estimated standard deviation. Several additional cycles are needed to define either reactivity reaches a steady state or k_{eff} decrease becomes.

Figures from 12 to 16 depict diagrams of heavy nuclides nuclear densities in Core-1 at 4 points of each sub-cycle: beginning of irradiation, beginning of cooling, before and after reload. The main heavy nuclides are U-235, U-238, Pu-238, Pu-239, Pu-240, Pu-241, Am-241 and Am-243. Nuclear density of Pu-242 changes slightly in sub-cycles and is not shown on diagrams.

Figures 17 and 18 depict diagrams of fission products nuclear densities in Core-1 at 4 points of each sub-cycle: beginning of irradiation, beginning of cooling, before and after reload. The main fission products with neutron capture more than 5% of total fission products capture are Ru-101, Rh-103, Pd-105, Tc-99, Pd-107 and Cs-133.

Figures from 19 to 23 depict diagrams of heavy nuclides nuclear densities in Lateral blanket at 4 points of each sub-cycle: beginning of irradiation, beginning of cooling, before and after reload. The main heavy nuclides are U-235, U-238, Pu-238, Pu-239, Pu-240, Pu-241, Am-241 and Am-243.

Figures 24 and 25 depict diagrams of fission products nuclear densities in Lateral blanket at 4 points of each sub-cycle: beginning of irradiation, beginning of cooling, before and after reload. The main fission products with neutron capture more than 5% of total fission products capture are Ru-101, Rh-103, Pd-105, Tc-99, Cs-133 and Sm-149.

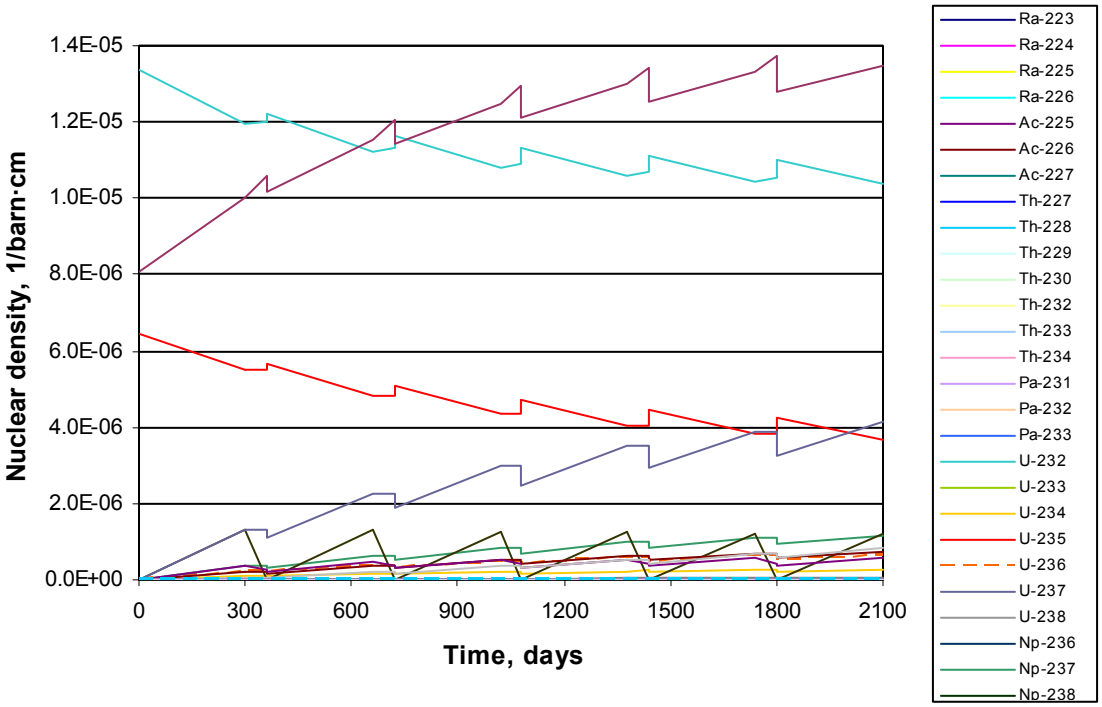

Figure.12 Core-1: heavy nuclide densities in 6 cycles (Mode.3)

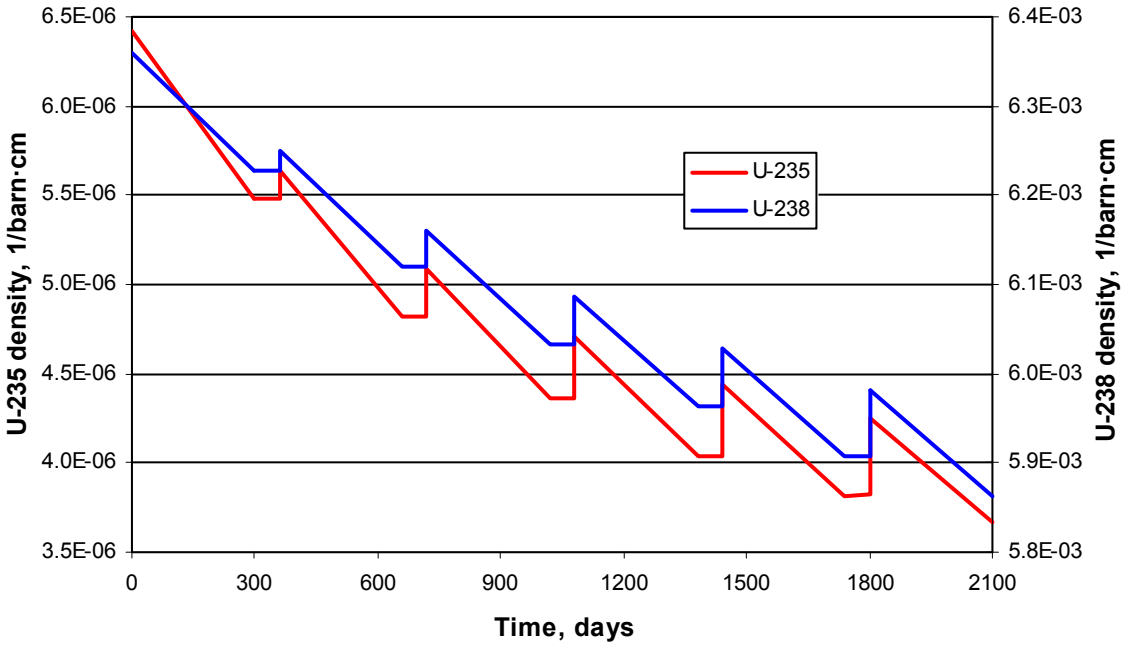

Figure.13 Core-1: U-235 and U-238 nuclear density in 6 cycles (Mode.3)

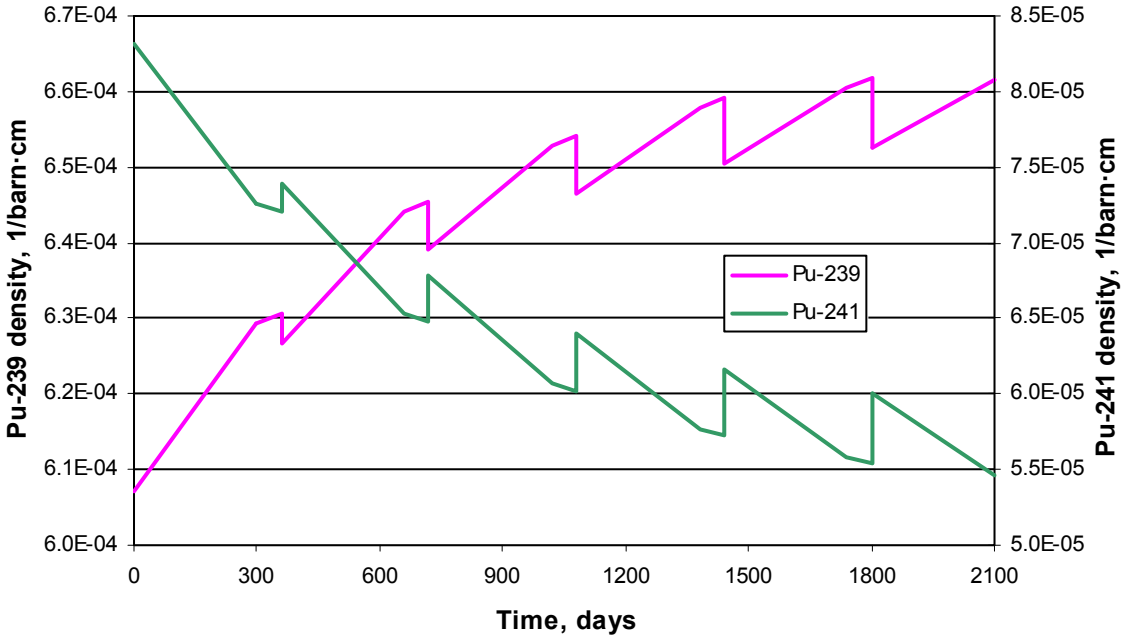

Figure.14 Core-1: Pu-239 and Pu-241 nuclear density in 6 cycles (Mode.3)

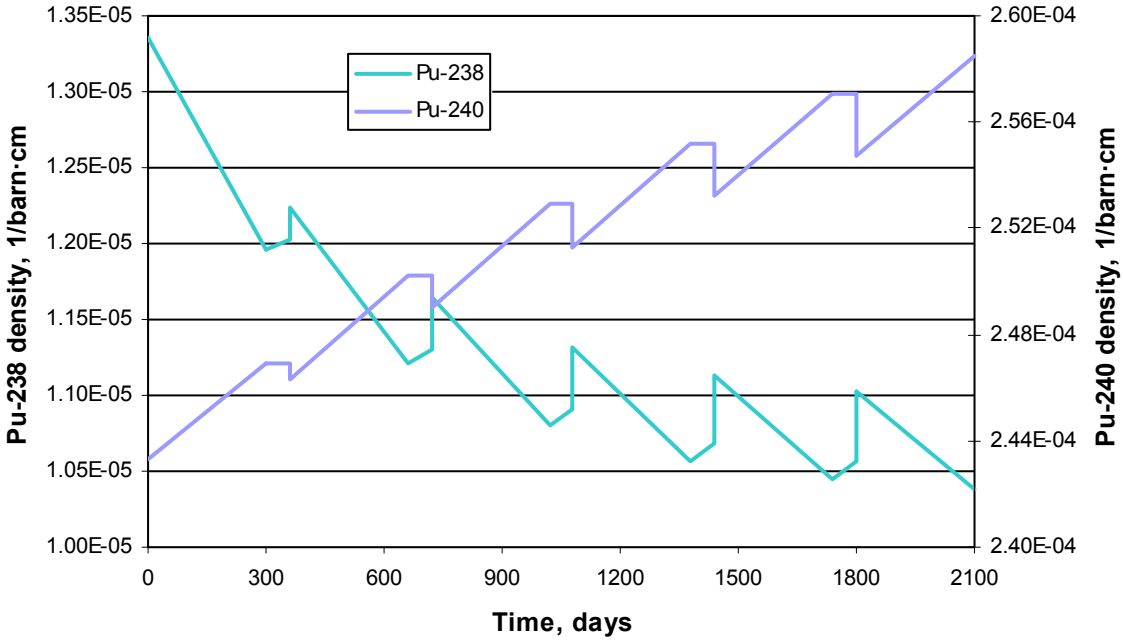

Figure.15 Core-1: Pu-238 and Pu-240 nuclear density in 6 cycles (Mode.3)

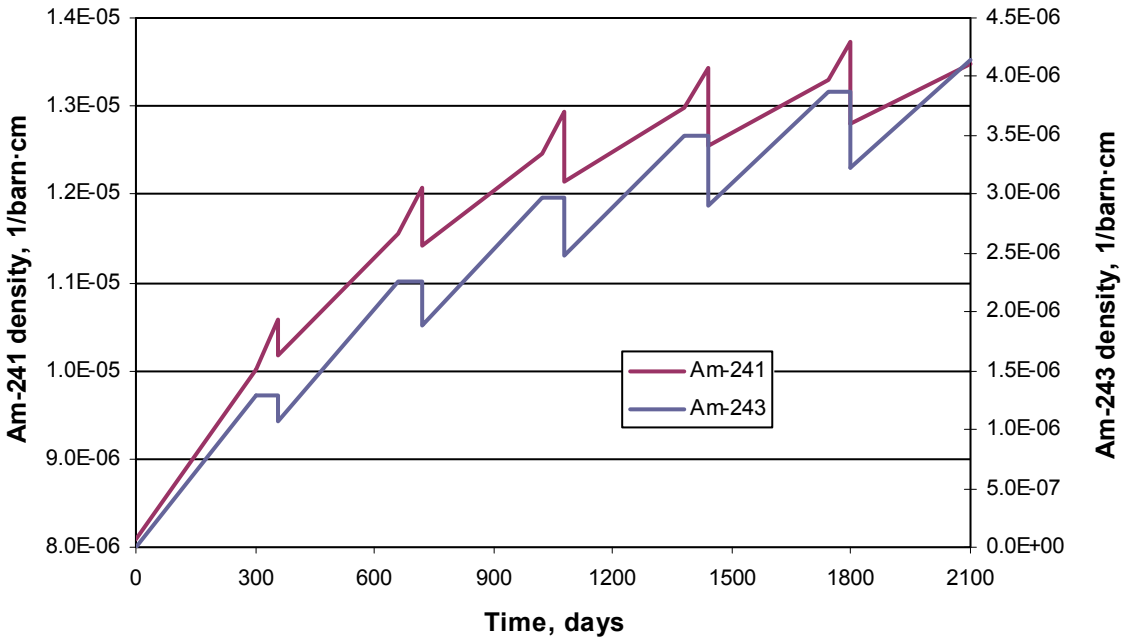

Figure.16 Core-1: Am-241 and Am-243 nuclear density in 6 cycles (Mode.3)

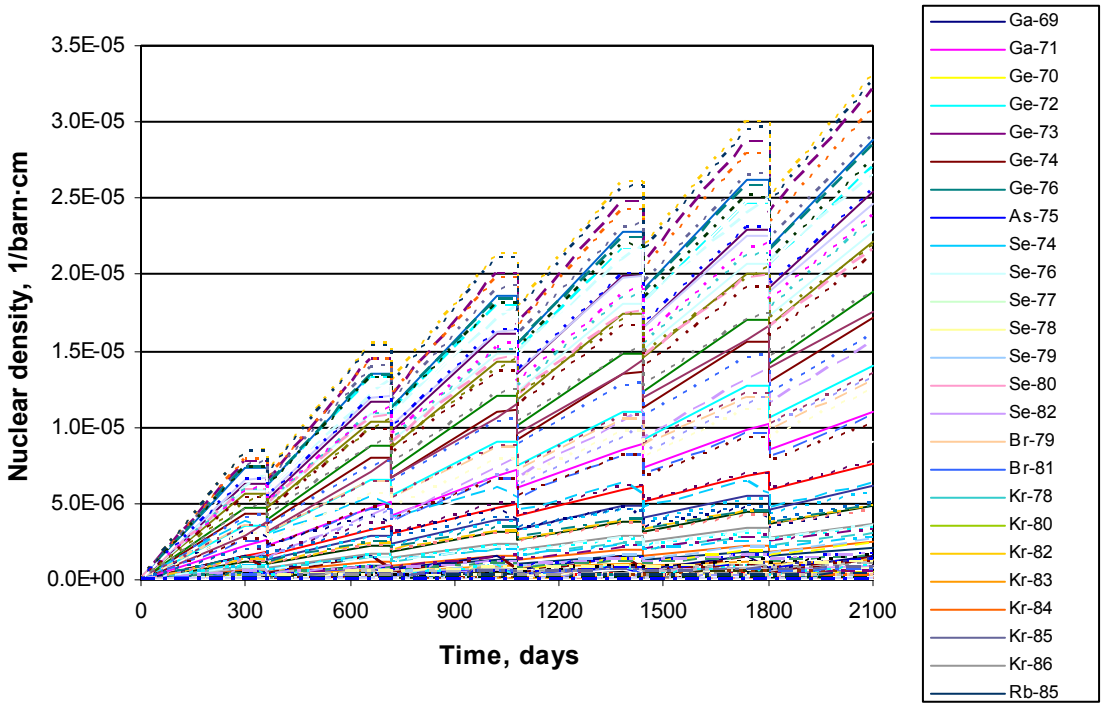

Figure.17 Core-1: Fission product densities in 6 cycles (Mode.3)

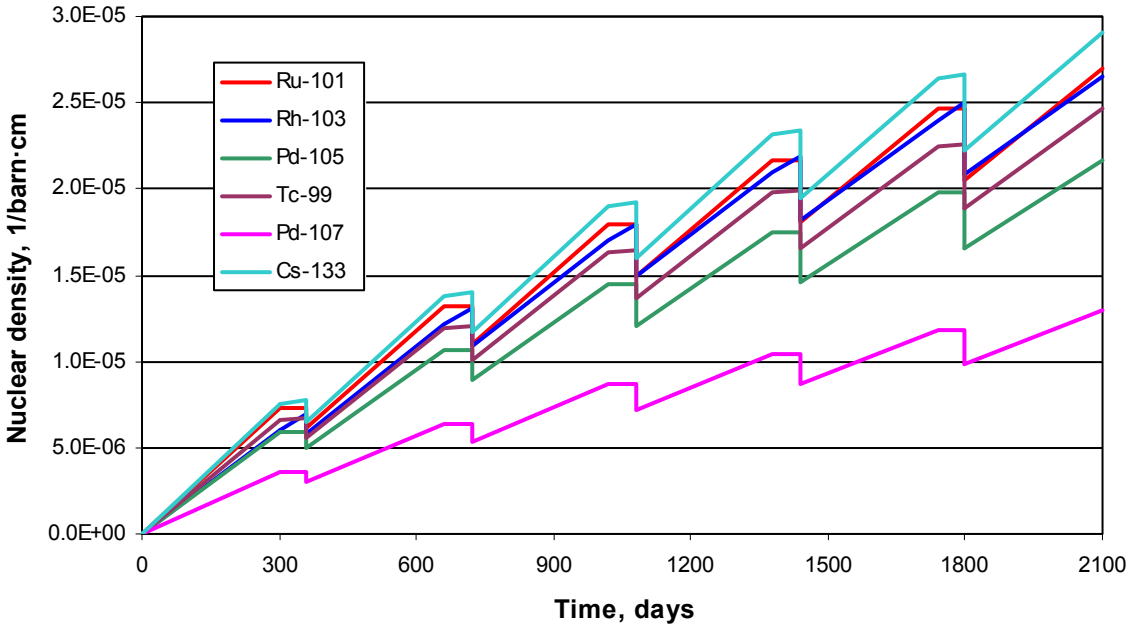

Figure.18 Core-1: main fission products density in 6 cycles (Mode.3)

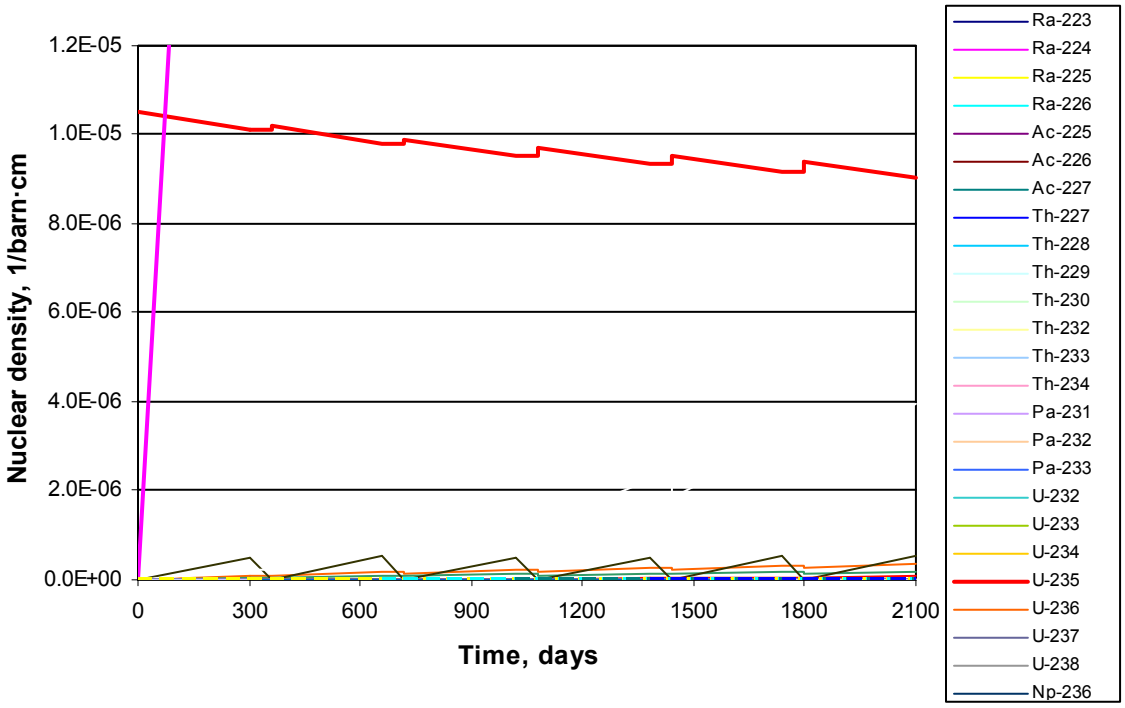

Figure.19 Lateral blanket: heavy nuclide densities in 6 cycles (Mode.3)

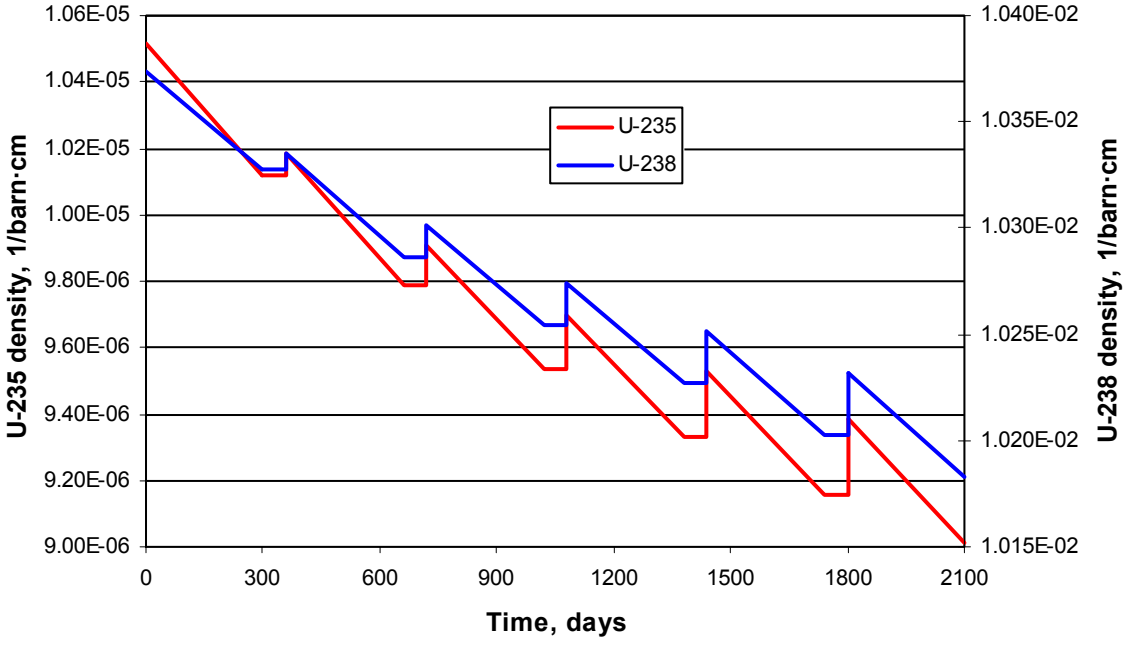

Figure.20 Lateral blanket: U-235 and U-238 nuclear density in 6 cycles

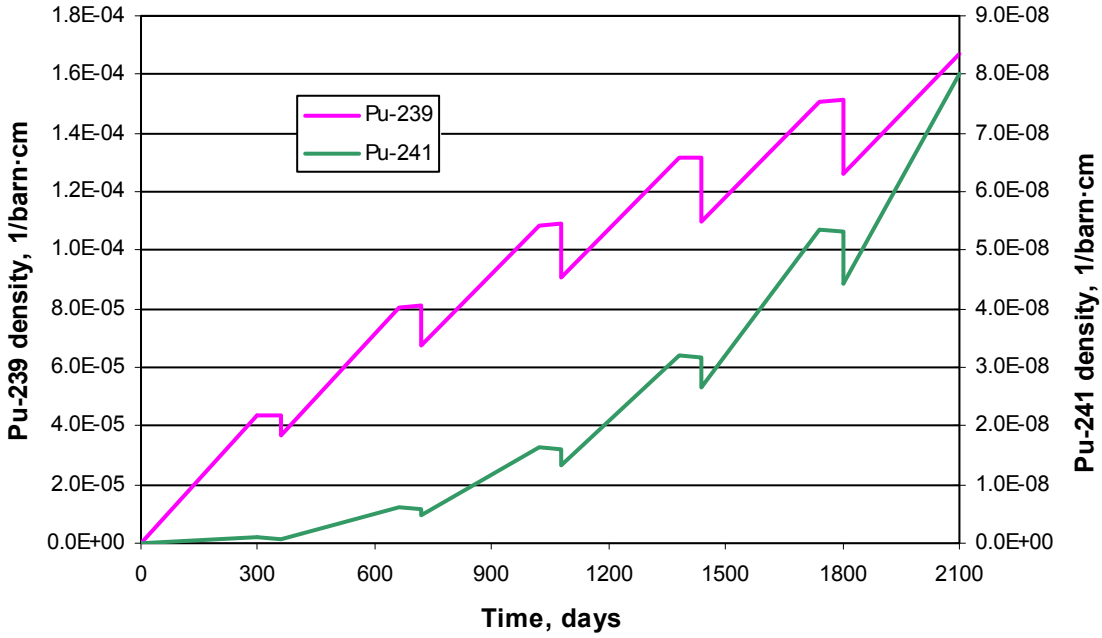

Figure.21 Lateral blanket: Pu-239 and Pu-241 nuclear density in 6 cycles

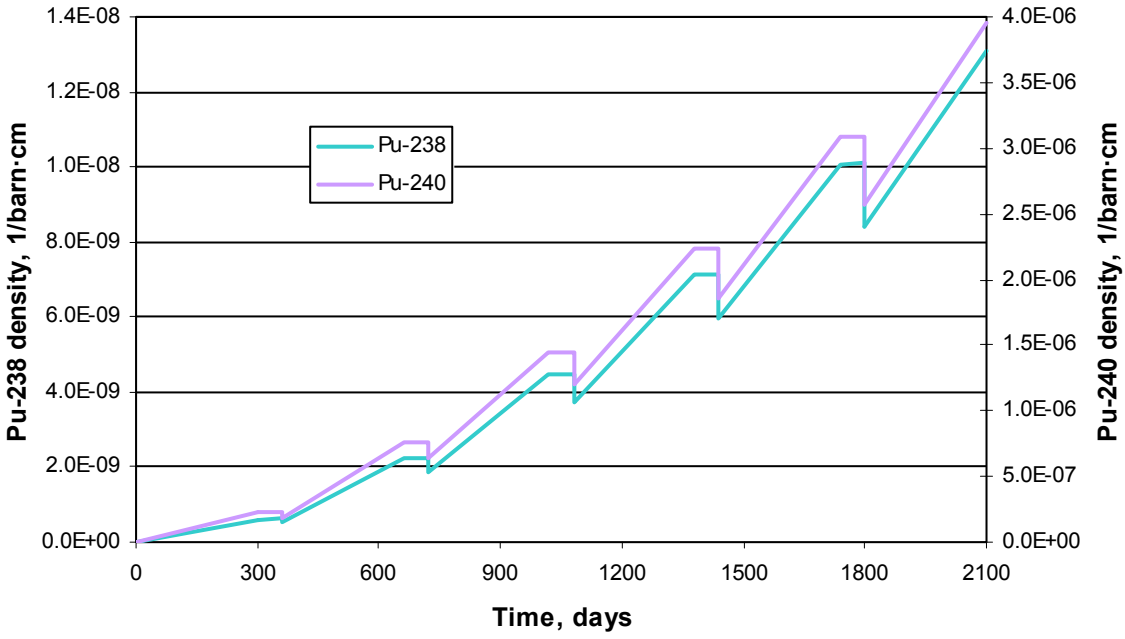

Figure.22 Lateral blanket: Pu-238 and Pu-240 nuclear density in 6 cycles

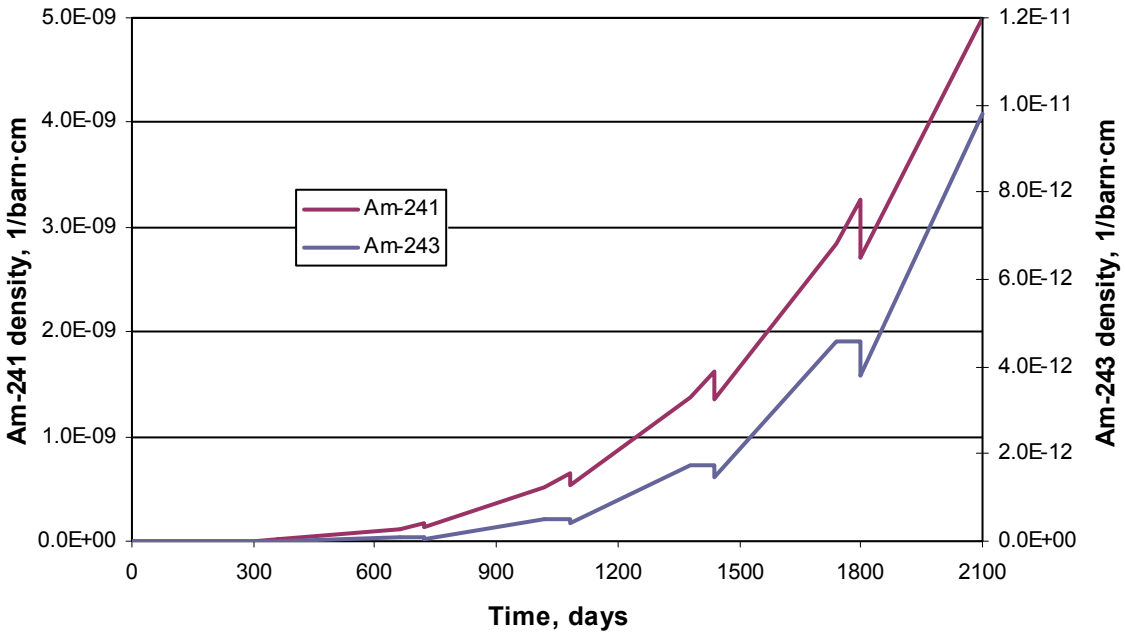

Figure.23 Lateral blanket: Am-241 and Am-243 nuclear density in 6 cycles

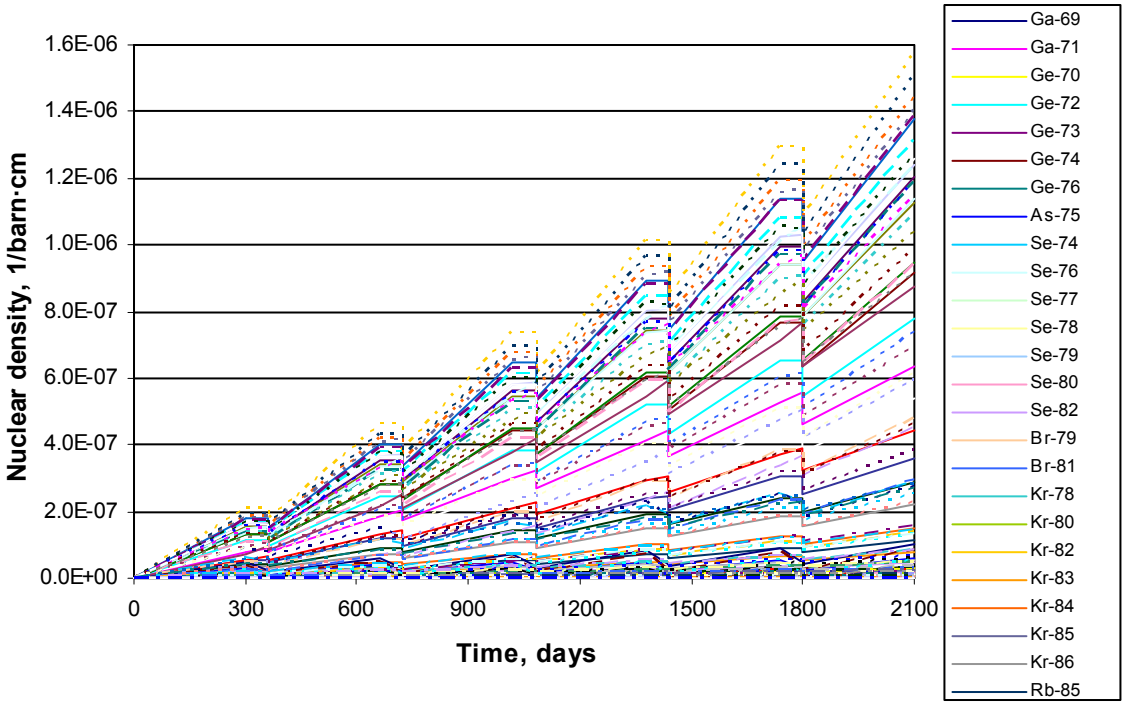

Figure.24 Lateral blanket: fission products nuclear densities in 6 cycles

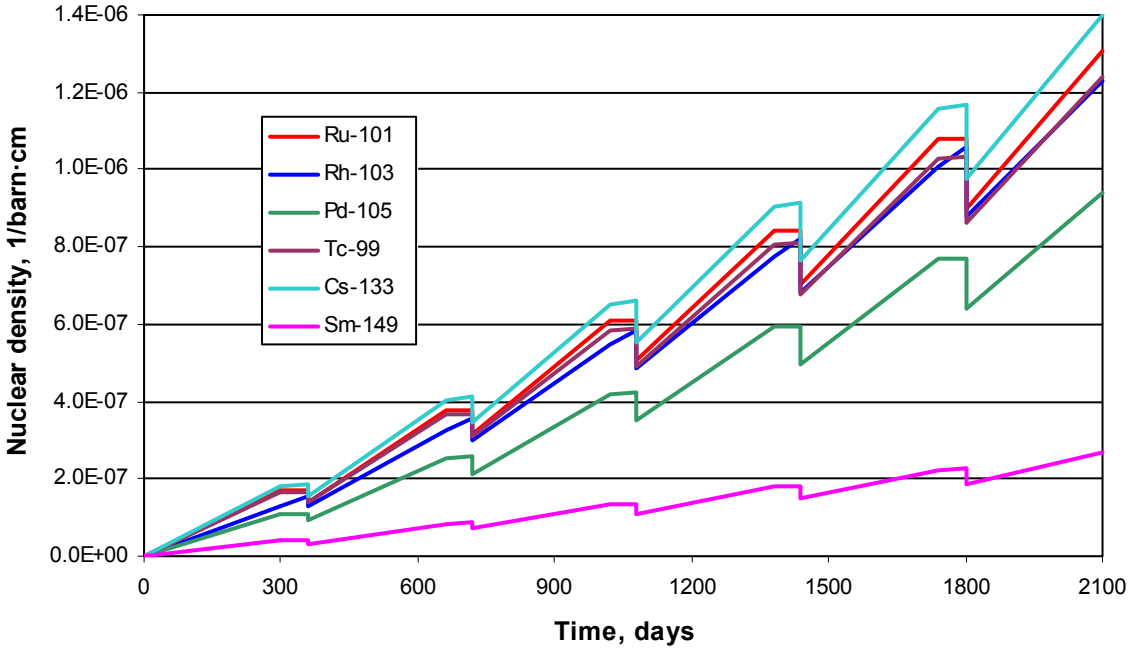

Figure.24 Lateral blanket: main fission products nuclear densities in 6 cycles

Benchmarking Summary

The RBEC-M benchmark problem defined in the IAEA CRP on "Small Reactors without On-site Refueling" was investigated. Analysis of three different reactor operational modes with various edits at the beginning and end of the specified cycles was performed. The results for all three modes of reactor operation were obtained and discussed; i.e., criticality calculation, axial and radial power profiles, neutron spectra, power peaking factors, k-infinity and neutron balances in the cores.

Table.15 Radial power distributions in the mid-plane of core and lateral blanket, W/cm^3

Region	R, cm	Beginning of the cycle	End of 900-day cycle	End of 1800-day cycle
Core-1	0.000	1.98E+02	1.95E+02	1.82E+02
	7.906	1.99E+02	1.95E+02	1.81E+02
	15.349	1.98E+02	1.94E+02	1.80E+02
	23.597	1.97E+02	1.93E+02	1.78E+02
	30.463	1.95E+02	1.91E+02	1.76E+02
	36.045	1.93E+02	1.89E+02	1.75E+02
	40.871	1.91E+02	1.87E+02	1.74E+02
	45.184	1.90E+02	1.86E+02	1.72E+02
	49.120	1.88E+02	1.84E+02	1.71E+02
	52.764	1.87E+02	1.82E+02	1.69E+02
	56.171	1.85E+02	1.81E+02	1.68E+02
	59.384	1.83E+02	1.79E+02	1.66E+02

	62.431	1.81E+02	1.77E+02	1.65E+02
	65.336	1.79E+02	1.75E+02	1.63E+02
	68.118	1.78E+02	1.73E+02	1.62E+02
	70.790	1.76E+02	1.71E+02	1.61E+02
	73.365	1.74E+02	1.69E+02	1.59E+02
	75.853	1.73E+02	1.67E+02	1.58E+02
	78.261	1.71E+02	1.66E+02	1.56E+02
	80.598	1.69E+02	1.64E+02	1.55E+02
	82.869	1.68E+02	1.62E+02	1.54E+02
	85.079	1.66E+02	1.61E+02	1.52E+02
Core-2	88.538	1.94E+02	1.85E+02	1.76E+02
	93.106	1.89E+02	1.80E+02	1.72E+02
	97.460	1.83E+02	1.74E+02	1.66E+02
	101.628	1.77E+02	1.68E+02	1.61E+02
	105.631	1.70E+02	1.61E+02	1.55E+02
	109.488	1.63E+02	1.54E+02	1.50E+02
	113.214	1.56E+02	1.48E+02	1.43E+02
	116.821	1.49E+02	1.41E+02	1.37E+02
	120.320	1.41E+02	1.33E+02	1.31E+02
	123.720	1.34E+02	1.27E+02	1.24E+02
	127.029	1.26E+02	1.20E+02	1.17E+02
	130.254	1.19E+02	1.13E+02	1.11E+02
Core-3	133.319	1.54E+02	1.46E+02	1.44E+02
	136.235	1.43E+02	1.36E+02	1.35E+02
	139.090	1.31E+02	1.25E+02	1.25E+02
	141.888	1.19E+02	1.14E+02	1.15E+02
	144.631	1.07E+02	1.02E+02	1.04E+02
	147.324	9.38E+01	9.07E+01	9.28E+01
Lateral blanket	149.831	8.40E+00	1.55E+01	2.29E+01
	152.003	6.17E+00	1.30E+01	1.99E+01
	154.003	4.75E+00	1.13E+01	1.78E+01
	156.003	3.79E+00	9.97E+00	1.61E+01
	158.003	3.01E+00	8.78E+00	1.45E+01
	160.003	2.40E+00	7.94E+00	1.33E+01
	162.003	1.92E+00	7.27E+00	1.23E+01
	164.175	1.58E+00	6.73E+00	1.15E+01

Table.16 Axial power distributions in the center of the core and axial blankets, W/cm^3

Region	Z, cm	Beginning of the cycle	End of 900-day cycle	End of 1800-day cycle
Bottom axial blanket-1	51	3.03E+00	1.65E+01	2.54E+01
	53	3.78E+00	1.85E+01	2.82E+01
	55	4.98E+00	2.09E+01	3.07E+01
	57	6.52E+00	2.34E+01	3.34E+01
	59	7.81E+00	2.64E+01	3.65E+01
Core-1	61	8.72E+01	9.11E+01	8.46E+01
	63	9.59E+01	9.76E+01	9.06E+01
	66	1.06E+02	1.07E+02	1.01E+02
	70	1.18E+02	1.21E+02	1.14E+02
	74	1.32E+02	1.35E+02	1.25E+02
	78	1.44E+02	1.45E+02	1.33E+02
	82	1.55E+02	1.57E+02	1.42E+02
	86	1.64E+02	1.65E+02	1.52E+02
	90	1.73E+02	1.75E+02	1.59E+02
	94	1.81E+02	1.82E+02	1.67E+02
	98	1.87E+02	1.85E+02	1.72E+02
	102	1.92E+02	1.91E+02	1.75E+02
	106	1.95E+02	1.94E+02	1.77E+02
	110	1.97E+02	1.96E+02	1.79E+02
	114	1.96E+02	1.95E+02	1.79E+02
	118	1.94E+02	1.94E+02	1.77E+02
	122	1.91E+02	1.90E+02	1.77E+02
	126	1.85E+02	1.87E+02	1.74E+02
	130	1.79E+02	1.83E+02	1.70E+02
	134	1.70E+02	1.77E+02	1.65E+02
	138	1.63E+02	1.68E+02	1.58E+02
	142	1.51E+02	1.60E+02	1.50E+02
	146	1.42E+02	1.50E+02	1.43E+02
	150	1.30E+02	1.40E+02	1.33E+02
	154	1.19E+02	1.28E+02	1.25E+02
	157	1.09E+02	1.20E+02	1.17E+02
	159	1.04E+02	1.13E+02	1.13E+02
Top axial blanket-1	161	9.28E+00	4.20E+01	6.38E+01
	163	7.12E+00	4.00E+01	6.11E+01
	165	6.04E+00	3.77E+01	5.85E+01
	167	4.68E+00	3.64E+01	5.65E+01
	169	4.29E+00	3.48E+01	5.35E+01

Appendix

RBEC-M Lead-Bismuth Cooled Fast Reactor Benchmarking Calculations

1. Analysis Methods

In RRC KI suite of neutron-physical codes was used to analyze the benchmark problems. Criticality calculations were performed with the MCNP5 Monte Carlo code [1]. Neutron data for MCNP5 were obtained using code system NJOY99 (version 99.90) [2, 3, 4] from libraries of evaluated nuclear data files ENDF/B, JEFF and JENDL. For each nuclide the set of data for required temperatures was generated with tolerance 0.005. The nuclides and libraries used are listed in Tables A1, A2 and A3. Fuel cycle analyses were performed with the ISTAR-2 code system, developed in RRC KI.

Fuel cycle analysis

The fuel cycle analyses were performed using the ISTAR-2 code system developed for analysis of fuel cycles of multi-component nuclear power systems with advanced reactors. Code system has abilities to perform equilibrium or non-equilibrium cycle calculations for the set of processes – reactors, reactor zones, cooling, reprocessing (with or without neutron flux) – and nuclide streams between them. The radioactive decay is also taken into account.
Non-equilibrium cycle analyses were performed for the benchmark problems. Each of core and blanket zones was represented as a single depletion zone. In each depletion zone the isotope kinetics problem was solved for united vector of heavy nuclides (Table A5) and fission products (Table A6).
The volume averaged neutron cross-sections were obtained and transported to electronic table from the criticality calculations with the MCNP5 code – for heavy nuclides $\sigma(n, \gamma)$, $\sigma(n, fission)$, $\sigma(n, 2n)$, $\sigma(n, 3n)$, $\sigma(n, n'+\alpha)$, ν_{total}; and for fission products $\sigma(n, \gamma)$.
Parameters for radioactive nuclides decay – α, β^-, β^-+n, β^- with daughter nuclide in 1st exited state, β^+ or EC, isomer transition from 1st exited state to ground state, isomer transition from 2nd exited state to 1st exited state, spontaneous fission – were obtained and transported to electronic table from ENDF/B-6 decay data library [5] and Table of Isotopes CD ROM [6]. In general, any other decay type can be included into electronic table.
Parameters for fission products generation were obtained from ENDF/B-6 fission product yield sublibraries [7]. Special investigations were performed [8] to reduce the size of fission products yield vector from 1325 to 1098, and data for seven nuclides from JENDL-3.2 library was added, thus the resulting nuclide of decay or (n, γ) reaction belongs to the same fission products vector.
Energy per fission for certain actinides (recommended by Monteburns 2.0 manual) is listed in Table A4. For others 200 MeV per fission is adopted.
Probability of Np-236m production in Np-237(n, 2n) reaction [9] averaged by reactor core spectrum is adopted 0.644.
Probability of Am-242m production in Am-241(n, γ) reaction [10] averaged by reactor core spectrum is adopted 0.25.

With this data code system ISTAR-2 generates the matrix of isotope kinetics problem and uses LSODES code [11] to solve this problem for given burnup interval.
To increase the accuracy of the burnup calculations the standard “mid-step” methodic was used. With the MCNP5 code for each region (cores and blankets) volume averaged one-group cross-sections for heavy nuclides and fission products were calculated. In the same calculation the contribution of each region to fission (thermal) power was obtained. Then the beginning of time step (BOTS) neutron fluxes were computed in the assumption that the cross-sections don’t

change during burnup step and region energy production during time step corresponds to region power at the BOTS. With this data isotope kinetics problem was solved for region and end of time step (EOTS) nuclear densities was obtained. With MCNP5 code EOTS thermal power of region was calculated and mid-step region power was obtained and mid-step neutron flux was computed. Then isotope kinetics problem once more was solved for region and final EOTS nuclear densities were obtained. This procedure was used for next time step and so on.

In the Mode.1 and Mode.2 calculations the employed burnup interval was 900 days for the first and second problems. At the BOTS volume averaged one-group cross-sections for all nuclides were recalculated. Some calculations show that cross-sections vary slowly during 100 day burnup, so 200-days and 300-days burnup intervals can be used in the later analysis.

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Table.A1 List of heavy nuclides neutron data used in criticality calculations

Number	Nuclide	Library	Revision	Date	Number	Nuclide	Library	Revision	Date
1	**Ra-223**	JENDL-3.2		Sep-89	34	**Pu-241**	ENDF/B-VI	2	19950911
2	**Ra-224**	JENDL-3.2		Sep-89	35	**Pu-242**	ENDF/B-VI		19900206
3	**Ra-225**	JENDL-3.2		Sep-89	36	**Pu-243**	ENDF/B-VI	1	19930930
4	**Ra-226**	JENDL-3.2	2	Nov-93	37	**Pu-244**	ENDF/B-VI		19900206
5	**Ac-225**	JENDL-3.2		Sep-89	38	**Am-241**	ENDF/B-VI	2	19950911
6	**Ac-226**	JENDL-3.2		Sep-89	39	**Am-242**	ENDF/B-VI	1	19910806
7	**Ac-227**	JENDL-3.2		Sep-89	40	**Am-242m**	ENDF/B-VI	1	19910806
8	**Th-227**	JENDL-3.2	2	Jun-94	41	**Am-243**	ENDF/B-VI	1	19981007
9	**Th-228**	JENDL-3.2	2	Jun-94	42	**Am-244**	JENDL-3.2		Sep-89
10	**Th-229**	JENDL-3.2	2	Jun-94	43	**Am-244m**	JENDL-3.2		Sep-89
11	**Th-230**	ENDF/B-VI		19900202	44	**Cm-241**	ENDF/B-VI		19900206
12	**Th-232**	ENDF/B-VI		19900205	45	**Cm-242**	ENDF/B-VI		19900206
13	**Th-233**	JENDL-3.2	2	Jun-94	46	**Cm-243**	ENDF/B-VI		900206
14	**Th-234**	JENDL-3.2	2	Jun-94	47	**Cm-244**	ENDF/B-VI		19900206
15	**Pa-231**	ENDF/B-VI		19900205	48	**Cm-245**	ENDF/B-VI	1	930603
16	**Pa-232**	JENDL-3.2	2	Jun-94	49	**Cm-246**	ENDF/B-VI	1	930526
17	**Pa-233**	ENDF/B-VI		19900202	50	**Cm-247**	ENDF/B-VI	1	19930930
18	**U-232**	ENDF/B-VI		19900205	51	**Cm-248**	ENDF/B-VI		19900206
19	**U-233**	ENDF/B-VI		19900205	52	**Cm-249**	JENDL-3.2	2	Sep-92
20	**U-234**	ENDF/B-VI		19900206	53	**Cm-250**	JENDL-3.2	2	Jun-94
21	**U-235**	ENDF/B-VI	5	19981109	54	**Bk-247**	JEFF-3.1		041027
22	**U-236**	ENDF/B-VI		19900205	55	**Bk-249**	ENDF/B-VI		19900205
23	**U-237**	ENDF/B-VI	1	19930930	56	**Bk-250**	JENDL-3.2		Sep-89
24	**U-238**	ENDF/B-VI	3	19981007	57	**Cf-249**	JENDL-3.2		Sep-89
25	**Np-236**	JENDL-3.3	2	20020222	58	**Cf-250**	ENDF/B-VI	1	19930930
26	**Np-237**	ENDF/B-VI	1	19910806	59	**Cf-251**	ENDF/B-VI	1	19930930
27	**Np-238**	ENDF/B-VI	1	19930930	60	**Cf-252**	ENDF/B-VI	2	19930930
28	**Np-239**	ENDF/B-VI		19900111	61	**Cf-253**	ENDF/B-VI	1	19930930
29	**Pu-236**	ENDF/B-VI		19970220	62	**Cf-254**	JENDL-3.2	2	Jun-94
30	**Pu-237**	ENDF/B-VI		19900206	63	**Es-253**	ENDF/B-VI		19900206
31	**Pu-238**	ENDF/B-VI		19900205	64	**Es-254**	JENDL-3.2		Jun-94
32	**Pu-239**	ENDF/B-VI	2	19981007	65	**Es-255**	JENDL-3.2		Jun-94
33	**Pu-240**	ENDF/B-VI	2	19930930					

Table.A2 List of fission products neutron data used in criticality calculations

Number	Nuclide	Library	Revision	Date	Number	Nuclide	Library	Revision	Date
1	**Ga-69**	JENDL-3.3	2	20020208	41	**Zr-94**	ENDF/B-VI		19900126
2	**Ga-71**	JENDL-3.3	2	20020208	42	**Zr-95**	ENDF/B-VI		19900126
3	**Ge-70**	JENDL-3.3	2	20010713	43	**Zr-96**	ENDF/B-VI		19900126
4	**Ge-72**	ENDF/B-VI		19900124	44	**Nb-93**	ENDF/B-VI	2	19990803
5	**Ge-73**	ENDF/B-VI	1	19930930	45	**Nb-94**	ENDF/B-VI		19900126
6	**Ge-74**	ENDF/B-VI		19900124	46	**Nb-95**	ENDF/B-VI		19900126
7	**Ge-76**	ENDF/B-VI		19900124	47	**Mo-92**	JENDL-3.3	4	20010904
8	**As-75**	ENDF/B-VI		19900124	48	**Mo-94**	ENDF/B-VI		19900129
9	**Se-74**	ENDF/B-VI		19900124	49	**Mo-95**	ENDF/B-VI		19900129
10	**Se-76**	ENDF/B-VI		19900124	50	**Mo-96**	ENDF/B-VI		19900129
11	**Se-77**	ENDF/B-VI		19900124	51	**Mo-97**	ENDF/B-VI		19900129
12	**Se-78**	ENDF/B-VI		19900124	52	**Mo-98**	JENDL-3.3	4	20010904
13	**Se-79**	JENDL-3.3	2	20020222	53	**Mo-99**	ENDF/B-VI		19900129
14	**Se-80**	ENDF/B-VI		19900124	54	**Mo-100**	JENDL-3.3	4	20010904
15	**Se-82**	ENDF/B-VI		19900124	55	**Tc-99**	ENDF/B-VI		19900129
16	**Br-79**	ENDF/B-VI		19900124	56	**Ru-96**	ENDF/B-VI		19900129
17	**Br-81**	ENDF/B-VI		19900124	57	**Ru-98**	ENDF/B-VI		19900129
18	**Kr-78**	ENDF/B-VI		19900124	58	**Ru-99**	ENDF/B-VI		19900129
19	**Kr-80**	ENDF/B-VI		19900124	59	**Ru-100**	ENDF/B-VI		19900129
20	**Kr-82**	ENDF/B-VI		19900124	60	**Ru-101**	ENDF/B-VI	1	19930930
21	**Kr-83**	ENDF/B-VI		19900124	61	**Ru-102**	ENDF/B-VI	1	19930930
22	**Kr-84**	ENDF/B-VI		19900124	62	**Ru-103**	ENDF/B-VI		19900129
23	**Kr-85**	ENDF/B-VI		19900124	63	**Ru-104**	ENDF/B-VI		19900129
24	**Kr-86**	ENDF/B-VI		19900124	64	**Ru-105**	ENDF/B-VI		19900129
25	**Rb-85**	ENDF/B-VI		19900124	65	**Ru-106**	ENDF/B-VI		19900129
26	**Rb-86**	ENDF/B-VI		19900124	66	**Rh-103**	ENDF/B-VI		19900129
27	**Rb-87**	ENDF/B-VI		19900124	67	**Rh-105**	ENDF/B-VI		19900129
28	**Sr-84**	ENDF/B-VI		19900125	68	**Pd-102**	ENDF/B-VI		19981007
29	**Sr-86**	ENDF/B-VI		19900125	69	**Pd-104**	ENDF/B-VI		19981007
30	**Sr-87**	ENDF/B-VI		19900125	70	**Pd-105**	ENDF/B-VI		19981007
31	**Sr-88**	ENDF/B-VI		19900125	71	**Pd-106**	ENDF/B-VI		19981007
32	**Sr-89**	ENDF/B-VI		19900125	72	**Pd-107**	ENDF/B-VI		19900111
33	**Sr-90**	ENDF/B-VI		19900125	73	**Pd-108**	ENDF/B-VI		19981007
34	**Y-89**	ENDF/B-VI	1	19970220	74	**Pd-110**	ENDF/B-VI		19981007
35	**Y-90**	ENDF/B-VI		19900125	75	**Ag-107**	ENDF/B-VI		19900129
36	**Y-91**	ENDF/B-VI		19900125	76	**Ag-109**	ENDF/B-VI		19900130
37	**Zr-90**	ENDF/B-VI		19900126	77	**Ag-110m1**	JENDL-3.2		19940901
38	**Zr-91**	ENDF/B-VI		19900126	78	**Ag-111**	ENDF/B-VI		19900129
39	**Zr-92**	ENDF/B-VI		19900126	79	**Cd-106**	ENDF/B-VI	2	19970220
40	**Zr-93**	ENDF/B-VI		19900126	80	**Cd-108**	ENDF/B-VI	2	19970220

Table.A2 List of fission products neutron data used in criticality calculations (cont.)

Number	Nuclide	Library	Revision	Date	Number	Nuclide	Library	Revision	Date
81	**Cd-110**	ENDF/B-VI	3	19970220	121	**I-130**	ENDF/B-VI		19900131
82	**Cd-111**	ENDF/B-VI		19950911	122	**I-131**	ENDF/B-VI		19900131
83	**Cd-112**	ENDF/B-VI	2	19970220	123	**I-135**	ENDF/B-VI		19900131
84	**Cd-113**	ENDF/B-VI		19950911	124	**Xe-124**	ENDF/B-VI		19900131
85	**Cd-114**	ENDF/B-VI	2	19970220	125	**Xe-126**	ENDF/B-VI		19900131
86	**Cd-115m1**	ENDF/B-VI		19900130	126	**Xe-128**	ENDF/B-VI		19900131
87	**Cd-116**	ENDF/B-VI	2	19970220	127	**Xe-129**	ENDF/B-VI		19900131
88	**In-113**	ENDF/B-VI		19000000	128	**Xe-130**	ENDF/B-VI		19900131
89	**In-115**	JENDL-3.3	3	20020222	129	**Xe-131**	ENDF/B-VI		19900131
90	**Sn-112**	ENDF/B-VI	1	19910806	130	**Xe-132**	ENDF/B-VI		19900131
91	**Sn-114**	ENDF/B-VI	1	19910806	131	**Xe-133**	ENDF/B-VI		19900131
92	**Sn-115**	ENDF/B-VI		19900130	132	**Xe-134**	ENDF/B-VI		19900131
93	**Sn-116**	ENDF/B-VI		19900130	133	**Xe-135**	ENDF/B-VI		19900131
94	**Sn-117**	ENDF/B-VI		19900130	134	**Xe-136**	ENDF/B-VI		19900131
95	**Sn-118**	ENDF/B-VI		19900130	135	**Cs-133**	ENDF/B-VI		20000628
96	**Sn-119**	ENDF/B-VI		19900130	136	**Cs-134**	ENDF/B-VI		20000628
97	**Sn-120**	JENDL-3.3	2	20020222	137	**Cs-135**	ENDF/B-VI		20000628
98	**Sn-122**	JENDL-3.3	2	20020222	138	**Cs-136**	ENDF/B-VI		19900131
99	**Sn-123**	ENDF/B-VI		19900130	139	**Cs-137**	ENDF/B-VI		19900131
100	**Sn-124**	JENDL-3.3	3	20020222	140	**Ba-132**	JENDL-3.2		19940901
101	**Sn-125**	ENDF/B-VI		19900130	141	**Ba-134**	ENDF/B-VI		20000628
102	**Sn-126**	ENDF/B-VI		19900130	142	**Ba-135**	ENDF/B-VI		19900111
103	**Sb-121**	ENDF/B-VI		19900130	143	**Ba-136**	ENDF/B-VI		19900111
104	**Sb-123**	ENDF/B-VI		19900130	144	**Ba-137**	ENDF/B-VI		19900111
105	**Sb-124**	ENDF/B-VI		19900130	145	**Ba-138**	ENDF/B-VI	1	19950911
106	**Sb-125**	ENDF/B-VI		19900130	146	**Ba-140**	ENDF/B-VI		19950911
107	**Sb-126**	ENDF/B-VI		19900130	147	**La-138**	JENDL-3.2		19940901
108	**Te-120**	ENDF/B-VI		19900130	148	**La-139**	ENDF/B-VI	1	19910806
109	**Te-122**	ENDF/B-VI		19900130	149	**La-140**	ENDF/B-VI		19900131
110	**Te-123**	ENDF/B-VI		19900130	150	**Ce-140**	ENDF/B-VI		19900131
111	**Te-124**	ENDF/B-VI		19900130	151	**Ce-141**	ENDF/B-VI		19900131
112	**Te-125**	ENDF/B-VI		19900130	152	**Ce-142**	ENDF/B-VI		19900131
113	**Te-126**	ENDF/B-VI		19900130	153	**Ce-143**	ENDF/B-VI		19900131
114	**Te-127m1**	ENDF/B-VI		19900130	154	**Ce-144**	ENDF/B-VI		19900131
115	**Te-128**	ENDF/B-VI		19900130	155	**Pr-141**	ENDF/B-VI		20000628
116	**Te-129m1**	ENDF/B-VI		19900130	156	**Pr-142**	ENDF/B-VI		19900131
117	**Te-130**	ENDF/B-VI		19900130	157	**Pr-143**	ENDF/B-VI		19900131
118	**Te-132**	ENDF/B-VI		19900130	158	**Nd-142**	ENDF/B-VI		19900131
119	**I-127**	ENDF/B-VI		19930930	159	**Nd-143**	ENDF/B-VI	1	19930930
120	**I-129**	ENDF/B-VI		19900131	160	**Nd-144**	ENDF/B-VI		19900131

Table.A2 List of fission products neutron data used in criticality calculations (cont.)

Number	Nuclide	Library	Revision	Date	Number	Nuclide	Library	Revision	Date
161	**Nd-145**	ENDF/B-VI	1	19930930	183	**Eu-154**	ENDF/B-VI	1	20000628
162	**Nd-146**	ENDF/B-VI		19900131	184	**Eu-155**	ENDF/B-VI		20000628
163	**Nd-147**	ENDF/B-VI	1	19910806	185	**Eu-156**	ENDF/B-VI		19900201
164	**Nd-148**	ENDF/B-VI		19900131	186	**Eu-157**	ENDF/B-VI		19900201
165	**Nd-150**	ENDF/B-VI		19900131	187	**Gd-152**	ENDF/B-VI		19970220
166	**Pm-147**	ENDF/B-VI	1	19910806	188	**Gd-154**	ENDF/B-VI		19970220
167	**Pm-148**	ENDF/B-VI		19900201	189	**Gd-155**	ENDF/B-VI		19900201
168	**Pm-148m1**	ENDF/B-VI		19900201	190	**Gd-156**	ENDF/B-VI		19900201
169	**Pm-149**	ENDF/B-VI		19900201	191	**Gd-157**	ENDF/B-VI		19900201
170	**Pm-151**	ENDF/B-VI		19900201	192	**Gd-158**	ENDF/B-VI		19900201
171	**Sm-144**	ENDF/B-VI	1	19950911	193	**Gd-160**	ENDF/B-VI		19900201
172	**Sm-147**	ENDF/B-VI		19900119	194	**Tb-159**	ENDF/B-VI		19900201
173	**Sm-148**	ENDF/B-VI		19900201	195	**Tb-160**	ENDF/B-VI		19900201
174	**Sm-149**	ENDF/B-VI		20000628	196	**Dy-160**	ENDF/B-VI		20000628
175	**Sm-150**	ENDF/B-VI	1	19930930	197	**Dy-161**	ENDF/B-VI		20000628
176	**Sm-151**	ENDF/B-VI	1	19910806	198	**Dy-162**	ENDF/B-VI		20000628
177	**Sm-152**	ENDF/B-VI	1	19930930	199	**Dy-163**	ENDF/B-VI		20000628
178	**Sm-153**	ENDF/B-VI		19900201	200	**Dy-164**	ENDF/B-VI		20000628
179	**Sm-154**	ENDF/B-VI		19900201	201	**Ho-165**	ENDF/B-VI	1	19981007
180	**Eu-151**	ENDF/B-VI		19891221	202	**Er-166**	ENDF/B-VI		19900111
181	**Eu-152**	ENDF/B-VI		19900111	203	**Er-167**	ENDF/B-VI		19900111
182	**Eu-153**	ENDF/B-VI		20000628					

Table.A3 List of other materials neutron data used in criticality calculations

Number	Nuclide	Library	Release	Revision	Date
1	**B-10**	ENDF/B-VI		1	19910806
2	**B-11**	ENDF/B-VI			19900123
3	**N-14**	ENDF/B-VI	6	3	19990803
4	**N-15**	ENDF/B-VI			19900507
5	**C-nat**	ENDF/B-VI		2	19990803
6	**Si-nat**	ENDF/B-VI			19000000
7	**V-nat**	ENDF/B-VI			19900125
8	**Cr-50**	ENDF/B-VI	6	3	19990902
9	**Cr-52**	ENDF/B-VI	6	2	19990803
10	**Cr-53**	ENDF/B-VI	6	2	19990803
11	**Cr-54**	ENDF/B-VI	6	3	19990902
12	**Mn-55**	ENDF/B-VI	6	1	19990907
13	**Fe-54**	ENDF/B-VI	6	3	19990902
14	**Fe-56**	ENDF/B-VI	6	2	19990803
15	**Fe-57**	ENDF/B-VI	6	2	19990803
16	**Fe-58**	ENDF/B-VI	6	2	19990907
17	**Ni-58**	ENDF/B-VI	6	2	19990803
18	**Ni-60**	ENDF/B-VI	6	2	19990803
19	**Ni-61**	ENDF/B-VI	6	3	19990803
20	**Ni-62**	ENDF/B-VI	6	3	19990902
21	**Ni-64**	ENDF/B-VI	6	2	19990803
22	**Nb-93**	ENDF/B-VI	6	2	19990803
23	**Mo-nat**	ENDF/B-VI			19900129
24	**W-nat**	ENDF/B-VI		1	19910806
25	**Pb-206**	ENDF/B-VI	6	1	19990803
26	**Pb-207**	ENDF/B-VI	6	2	19990803
27	**Pb-208**	ENDF/B-VI	6	2	19990803
28	**Bi-209**	ENDF/B-VI			20000628

Table.A4 Energy per fission for certain actinides

Number	Nuclide	Q, MeV	Number	Nuclide	Q, MeV	Number	Nuclide	Q, MeV
1	**Th-227**	180.86	12	**U-238**	203.5	23	**Am-243**	213.7
2	**Th-229**	184.94	13	**Np-237**	201.46	24	**Cm-242**	211.66
3	**Th-232**	191.46	14	**Np-238**	203.5	25	**Cm-243**	213.7
4	**Pa-231**	189.42	15	**Pu-238**	203.5	26	**Cm-244**	215.74
5	**Pa-233**	197	16	**Pu-239**	208.7	27	**Cm-245**	217.78
6	**U-232**	191.06	17	**Pu-240**	207.58	28	**Cm-246**	219.82
7	**U-233**	197.62	18	**Pu-241**	210.72	29	**Cm-248**	223.9
8	**U-234**	195.48	19	**Pu-242**	211.66	30	**Cm-249**	225.92
9	**U-235**	200	20	**Am-241**	210.26	31	**Cf-251**	230.02
10	**U-236**	199.46	21	**Am-242**	212.18	32	**Es-254**	236.14
11	**U-237**	201.48	22	**Am-242m**	212.18			

Table.A5 List of heavy nuclides used in isotope kinetics calculations

Number	Nuclide	Number	Nuclide	Number	Nuclide	Number	Nuclide
1	**Rn-216**	32	**Th-230**	63	**Np-240**	94	**Cm-246**
2	**Rn-217**	33	**Th-231**	64	**Pu-234**	95	**Cm-247**
3	**Rn-218**	34	**Th-232**	65	**Pu-235**	96	**Cm-248**
4	**Rn-219**	35	**Th-233**	66	**Pu-236**	97	**Cm-249**
5	**Rn-220**	36	**Th-234**	67	**Pu-237**	98	**Cm-250**
6	**Rn-222**	37	**Th-235**	68	**Pu-238**	99	**Cm-251**
7	**Fr-219**	38	**Pa-229**	69	**Pu-239**	100	**Bk-243**
8	**Fr-220**	39	**Pa-230**	70	**Pu-240**	101	**Bk-245**
9	**Fr-221**	40	**Pa-231**	71	**Pu-241**	102	**Bk-246**
10	**Fr-222**	41	**Pa-232**	72	**Pu-242**	103	**Bk-247**
11	**Fr-223**	42	**Pa-233**	73	**Pu-243**	104	**Bk-248**
12	**Ra-220**	43	**Pa-234**	74	**Pu-244**	105	**Bk-249**
13	**Ra-221**	44	**Pa-235**	75	**Pu-245**	106	**Bk-250**
14	**Ra-222**	45	**U-230**	76	**Pu-246**	107	**Bk-251**
15	**Ra-223**	46	**U-231**	77	**Am-239**	108	**Cf-247**
16	**Ra-224**	47	**U-232**	78	**Am-240**	109	**Cf-248**
17	**Ra-225**	48	**U-233**	79	**Am-241**	110	**Cf-249**
18	**Ra-226**	49	**U-234**	80	**Am-242**	111	**Cf-250**
19	**Ra-227**	50	**U-235**	81	**Am-242m**	112	**Cf-251**
20	**Ra-228**	51	**U-236**	82	**Am-243**	113	**Cf-252**
21	**Ac-223**	52	**U-237**	83	**Am-244**	114	**Cf-253**
22	**Ac-224**	53	**U-238**	84	**Am-244m**	115	**Cf-254**
23	**Ac-225**	54	**U-239**	85	**Am-245**	116	**Cf-255**
24	**Ac-226**	55	**U-240**	86	**Am-246**	117	**Es-250**
25	**Ac-227**	56	**Np-234**	87	**Cm-239**	118	**Es-252**
26	**Ac-228**	57	**Np-235**	88	**Cm-240**	119	**Es-253**
27	**Th-225**	58	**Np-236**	89	**Cm-241**	120	**Es-254**
28	**Th-226**	59	**Np-236m**	90	**Cm-242**	121	**Es-255**
29	**Th-227**	60	**Np-237**	91	**Cm-243**	122	**Es-256**
30	**Th-228**	61	**Np-238**	92	**Cm-244**	123	**Fm-255**
31	**Th-229**	62	**Np-239**	93	**Cm-245**	124	**Fm-256**

Table.A6 List of fission products used in isotope kinetics calculations

Number	Nuclide	Number	Nuclide	Number	Nuclide	Number	Nuclide
1	**Fe-68**	51	**Zn-75**	101	**Ge-80**	151	**Se-85**
2	**Co-66**	52	**Zn-76**	102	**Ge-81**	152	**Se-86**
3	**Co-67**	53	**Zn-77**	103	**Ge-82**	153	**Se-87**
4	**Co-68**	54	**Zn-78**	104	**Ge-83**	154	**Se-88**
5	**Co-69**	55	**Zn-79**	105	**Ge-84**	155	**Se-89**
6	**Co-72**	56	**Zn-80**	106	**Ge-85**	156	**Se-90**
7	**Co-73**	57	**Zn-81**	107	**Ge-86**	157	**Se-91**
8	**Co-74**	58	**Zn-82**	108	**Ge-87**	158	**Se-92**
9	**Co-75**	59	**Zn-83**	109	**Ge-88**	159	**Se-93**
10	**Ni-66**	60	**Ga-66**	110	**As-69**	160	**Br-75**
11	**Ni-67**	61	**Ga-67**	111	**As-71**	161	**Br-77**
12	**Ni-68**	62	**Ga-68**	112	**As-72**	162	**Br-77m1**
13	**Ni-69**	63	**Ga-69**	113	**As-73**	163	**Br-78**
14	**Ni-71**	64	**Ga-70**	114	**As-74**	164	**Br-79**
15	**Ni-72**	65	**Ga-71**	115	**As-75**	165	**Br-79m1**
16	**Ni-73**	66	**Ga-72**	116	**As-76**	166	**Br-80**
17	**Ni-74**	67	**Ga-72m1**	117	**As-77**	167	**Br-80m1**
18	**Ni-75**	68	**Ga-73**	118	**As-78**	168	**Br-81**
19	**Ni-76**	69	**Ga-74**	119	**As-79**	169	**Br-82**
20	**Ni-77**	70	**Ga-74m1**	120	**As-80**	170	**Br-82m1**
21	**Ni-78**	71	**Ga-75**	121	**As-81**	171	**Br-83**
22	**Cu-66**	72	**Ga-76**	122	**As-82**	172	**Br-84**
23	**Cu-67**	73	**Ga-77**	123	**As-82m1**	173	**Br-84m1**
24	**Cu-68**	74	**Ga-78**	124	**As-83**	174	**Br-85**
25	**Cu-68m1**	75	**Ga-79**	125	**As-84**	175	**Br-86**
26	**Cu-69**	76	**Ga-80**	126	**As-84m1**	176	**Br-87**
27	**Cu-70**	77	**Ga-81**	127	**As-85**	177	**Br-88**
28	**Cu-70m1**	78	**Ga-82**	128	**As-86**	178	**Br-89**
29	**Cu-71**	79	**Ga-83**	129	**As-87**	179	**Br-90**
30	**Cu-72**	80	**Ga-84**	130	**As-88**	180	**Br-91**
31	**Cu-73**	81	**Ga-85**	131	**As-89**	181	**Br-92**
32	**Cu-74**	82	**Ge-66**	132	**As-90**	182	**Br-93**
33	**Cu-75**	83	**Ge-67**	133	**Se-72**	183	**Br-94**
34	**Cu-76**	84	**Ge-68**	134	**Se-73**	184	**Br-95**
35	**Cu-77**	85	**Ge-69**	135	**Se-73m1**	185	**Br-96**
36	**Cu-78**	86	**Ge-70**	136	**Se-74**	186	**Kr-77**
37	**Cu-79**	87	**Ge-71**	137	**Se-75**	187	**Kr-78**
38	**Cu-80**	88	**Ge-71m1**	138	**Se-76**	188	**Kr-79**
39	**Cu-81**	89	**Ge-72**	139	**Se-77**	189	**Kr-79m1**
40	**Zn-66**	90	**Ge-73**	140	**Se-77m1**	190	**Kr-80**
41	**Zn-67**	91	**Ge-73m1**	141	**Se-78**	191	**Kr-81**
42	**Zn-68**	92	**Ge-74**	142	**Se-79**	192	**Kr-81m1**
43	**Zn-69**	93	**Ge-75**	143	**Se-79m1**	193	**Kr-82**
44	**Zn-69m1**	94	**Ge-75m1**	144	**Se-80**	194	**Kr-83**
45	**Zn-70**	95	**Ge-76**	145	**Se-81**	195	**Kr-83m1**
46	**Zn-71**	96	**Ge-77**	146	**Se-81m1**	196	**Kr-84**
47	**Zn-71m1**	97	**Ge-77m1**	147	**Se-82**	197	**Kr-85**
48	**Zn-72**	98	**Ge-78**	148	**Se-83**	198	**Kr-85m1**
49	**Zn-73**	99	**Ge-79**	149	**Se-83m1**	199	**Kr-86**
50	**Zn-74**	100	**Ge-79m1**	150	**Se-84**	200	**Kr-87**

Table.A6 List of fission products used in isotope kinetics calculations (cont.)

Number	Nuclide	Number	Nuclide	Number	Nuclide	Number	Nuclide
201	**Kr-88**	251	**Sr-96**	301	**Zr-98**	351	**Mo-94**
202	**Kr-89**	252	**Sr-97**	302	**Zr-99**	352	**Mo-95**
203	**Kr-90**	253	**Sr-98**	303	**Zr-100**	353	**Mo-96**
204	**Kr-91**	254	**Sr-99**	304	**Zr-101**	354	**Mo-97**
205	**Kr-92**	255	**Sr-100**	305	**Zr-102**	355	**Mo-98**
206	**Kr-93**	256	**Sr-101**	306	**Zr-103**	356	**Mo-99**
207	**Kr-94**	257	**Sr-102**	307	**Zr-104**	357	**Mo-100**
208	**Kr-95**	258	**Sr-103**	308	**Zr-105**	358	**Mo-101**
209	**Kr-96**	259	**Sr-104**	309	**Zr-106**	359	**Mo-102**
210	**Kr-97**	260	**Y-85**	310	**Zr-107**	360	**Mo-103**
211	**Kr-98**	261	**Y-87**	311	**Zr-108**	361	**Mo-104**
212	**Rb-79**	262	**Y-88**	312	**Zr-109**	362	**Mo-105**
213	**Rb-81**	263	**Y-89**	313	**Nb-89**	363	**Mo-106**
214	**Rb-83**	264	**Y-89m1**	314	**Nb-90**	364	**Mo-107**
215	**Rb-84**	265	**Y-90**	315	**Nb-91**	365	**Mo-108**
216	**Rb-85**	266	**Y-90m1**	316	**Nb-92**	366	**Mo-109**
217	**Rb-86**	267	**Y-91**	317	**Nb-93**	367	**Mo-110**
218	**Rb-86m1**	268	**Y-91m1**	318	**Nb-93m1**	368	**Mo-111**
219	**Rb-87**	269	**Y-92**	319	**Nb-94**	369	**Mo-112**
220	**Rb-88**	270	**Y-93**	320	**Nb-94m1**	370	**Mo-113**
221	**Rb-89**	271	**Y-93m1**	321	**Nb-95**	371	**Mo-114**
222	**Rb-90**	272	**Y-94**	322	**Nb-95m1**	372	**Mo-115**
223	**Rb-90m1**	273	**Y-95**	323	**Nb-96**	373	**Tc-93**
224	**Rb-91**	274	**Y-96**	324	**Nb-97**	374	**Tc-95**
225	**Rb-92**	275	**Y-96m1**	325	**Nb-97m1**	375	**Tc-95m1**
226	**Rb-93**	276	**Y-97**	326	**Nb-98**	376	**Tc-97**
227	**Rb-94**	277	**Y-97m1**	327	**Nb-98m1**	377	**Tc-97m1**
228	**Rb-95**	278	**Y-98**	328	**Nb-99**	378	**Tc-98**
229	**Rb-96**	279	**Y-98m1**	329	**Nb-99m1**	379	**Tc-99**
230	**Rb-97**	280	**Y-99**	330	**Nb-100**	380	**Tc-99m1**
231	**Rb-98**	281	**Y-100**	331	**Nb-100m1**	381	**Tc-100**
232	**Rb-99**	282	**Y-101**	332	**Nb-101**	382	**Tc-101**
233	**Rb-100**	283	**Y-102**	333	**Nb-102**	383	**Tc-102**
234	**Rb-101**	284	**Y-103**	334	**Nb-102m1**	384	**Tc-102m1**
235	**Rb-102**	285	**Y-104**	335	**Nb-103**	385	**Tc-103**
236	**Sr-83**	286	**Y-105**	336	**Nb-104**	386	**Tc-104**
237	**Sr-84**	287	**Y-106**	337	**Nb-104m1**	387	**Tc-105**
238	**Sr-85**	288	**Y-107**	338	**Nb-105**	388	**Tc-106**
239	**Sr-85m1**	289	**Zr-87**	339	**Nb-106**	389	**Tc-107**
240	**Sr-86**	290	**Zr-88**	340	**Nb-107**	390	**Tc-108**
241	**Sr-87**	291	**Zr-89**	341	**Nb-108**	391	**Tc-109**
242	**Sr-87m1**	292	**Zr-90**	342	**Nb-109**	392	**Tc-110**
243	**Sr-88**	293	**Zr-90m1**	343	**Nb-110**	393	**Tc-111**
244	**Sr-89**	294	**Zr-91**	344	**Nb-111**	394	**Tc-112**
245	**Sr-90**	295	**Zr-92**	345	**Nb-112**	395	**Tc-113**
246	**Sr-91**	296	**Zr-93**	346	**Mo-90**	396	**Tc-114**
247	**Sr-92**	297	**Zr-94**	347	**Mo-91**	397	**Tc-115**
248	**Sr-93**	298	**Zr-95**	348	**Mo-92**	398	**Tc-116**
249	**Sr-94**	299	**Zr-96**	349	**Mo-93**	399	**Tc-117**
250	**Sr-95**	300	**Zr-97**	350	**Mo-93m1**	400	**Tc-118**

Table.A6 List of fission products used in isotope kinetics calculations (cont.)

Number	Nuclide	Number	Nuclide	Number	Nuclide	Number	Nuclide
401	**Ru-95**	451	**Rh-114**	501	**Ag-109m1**	551	**Cd-121**
402	**Ru-96**	452	**Rh-115**	502	**Ag-110**	552	**Cd-121m1**
403	**Ru-97**	453	**Rh-116**	503	**Ag-110m1**	553	**Cd-122**
404	**Ru-98**	454	**Rh-117**	504	**Ag-111**	554	**Cd-123**
405	**Ru-99**	455	**Rh-118**	505	**Ag-111m1**	555	**Cd-124**
406	**Ru-100**	456	**Rh-119**	506	**Ag-112**	556	**Cd-125**
407	**Ru-101**	457	**Rh-120**	507	**Ag-113**	557	**Cd-126**
408	**Ru-102**	458	**Rh-121**	508	**Ag-113m1**	558	**Cd-127**
409	**Ru-103**	459	**Rh-122**	509	**Ag-114**	559	**Cd-128**
410	**Ru-104**	460	**Rh-123**	510	**Ag-115**	560	**Cd-129**
411	**Ru-105**	461	**Pd-99**	511	**Ag-115m1**	561	**Cd-130**
412	**Ru-106**	462	**Pd-101**	512	**Ag-116**	562	**Cd-131**
413	**Ru-107**	463	**Pd-102**	513	**Ag-116m1**	563	**Cd-132**
414	**Ru-108**	464	**Pd-103**	514	**Ag-117**	564	**In-107**
415	**Ru-109**	465	**Pd-104**	515	**Ag-117m1**	565	**In-109**
416	**Ru-109m1**	466	**Pd-105**	516	**Ag-118**	566	**In-111**
417	**Ru-110**	467	**Pd-106**	517	**Ag-118m1**	567	**In-112**
418	**Ru-111**	468	**Pd-107**	518	**Ag-119**	568	**In-112m1**
419	**Ru-112**	469	**Pd-107m1**	519	**Ag-120**	569	**In-113**
420	**Ru-113**	470	**Pd-108**	520	**Ag-120m1**	570	**In-113m1**
421	**Ru-114**	471	**Pd-109**	521	**Ag-121**	571	**In-114**
422	**Ru-115**	472	**Pd-109m1**	522	**Ag-122**	572	**In-114m1**
423	**Ru-116**	473	**Pd-110**	523	**Ag-122m1**	573	**In-115**
424	**Ru-117**	474	**Pd-111**	524	**Ag-123**	574	**In-115m1**
425	**Ru-118**	475	**Pd-111m1**	525	**Ag-124**	575	**In-116**
426	**Ru-119**	476	**Pd-112**	526	**Ag-125**	576	**In-116m1**
427	**Ru-120**	477	**Pd-113**	527	**Ag-126**	577	**In-116m2**
428	**Rh-99**	478	**Pd-114**	528	**Ag-127**	578	**In-117**
429	**Rh-101**	479	**Pd-115**	529	**Ag-128**	579	**In-117m1**
430	**Rh-101m1**	480	**Pd-116**	530	**Cd-105**	580	**In-118**
431	**Rh-102**	481	**Pd-117**	531	**Cd-106**	581	**In-118m1**
432	**Rh-102m1**	482	**Pd-118**	532	**Cd-107**	582	**In-118m2**
433	**Rh-103**	483	**Pd-119**	533	**Cd-108**	583	**In-119**
434	**Rh-103m1**	484	**Pd-120**	534	**Cd-109**	584	**In-119m1**
435	**Rh-104**	485	**Pd-121**	535	**Cd-110**	585	**In-120**
436	**Rh-104m1**	486	**Pd-122**	536	**Cd-111**	586	**In-120m1**
437	**Rh-105**	487	**Pd-123**	537	**Cd-111m1**	587	**In-120m2**
438	**Rh-105m1**	488	**Pd-124**	538	**Cd-112**	588	**In-121**
439	**Rh-106**	489	**Pd-125**	539	**Cd-113**	589	**In-121m1**
440	**Rh-106m1**	490	**Pd-126**	540	**Cd-113m1**	590	**In-122**
441	**Rh-107**	491	**Ag-103**	541	**Cd-114**	591	**In-122m1**
442	**Rh-108**	492	**Ag-105**	542	**Cd-115**	592	**In-122m2**
443	**Rh-108m1**	493	**Ag-105m1**	543	**Cd-115m1**	593	**In-123**
444	**Rh-109**	494	**Ag-106**	544	**Cd-116**	594	**In-123m1**
445	**Rh-109m1**	495	**Ag-106m1**	545	**Cd-117**	595	**In-124**
446	**Rh-110**	496	**Ag-107**	546	**Cd-117m1**	596	**In-124m1**
447	**Rh-110m1**	497	**Ag-107m1**	547	**Cd-118**	597	**In-125**
448	**Rh-111**	498	**Ag-108**	548	**Cd-119**	598	**In-125m1**
449	**Rh-112**	499	**Ag-108m1**	549	**Cd-119m1**	599	**In-126**
450	**Rh-113**	500	**Ag-109**	550	**Cd-120**	600	**In-126m1**

Table.A6 List of fission products used in isotope kinetics calculations (cont.)

Number	Nuclide	Number	Nuclide	Number	Nuclide	Number	Nuclide
601	**In-127**	651	**Sn-136**	701	**Te-126**	751	**Xe-125**
602	**In-127m1**	652	**Sb-113**	702	**Te-127**	752	**Xe-125m1**
603	**In-128**	653	**Sb-115**	703	**Te-127m1**	753	**Xe-126**
604	**In-128m1**	654	**Sb-117**	704	**Te-128**	754	**Xe-127**
605	**In-129**	655	**Sb-118**	705	**Te-129**	755	**Xe-127m1**
606	**In-129m1**	656	**Sb-118m1**	706	**Te-129m1**	756	**Xe-128**
607	**In-130**	657	**Sb-119**	707	**Te-130**	757	**Xe-129**
608	**In-130m1**	658	**Sb-120**	708	**Te-131**	758	**Xe-129m1**
609	**In-130m2**	659	**Sb-120m1**	709	**Te-131m1**	759	**Xe-130**
610	**In-131**	660	**Sb-121**	710	**Te-132**	760	**Xe-131**
611	**In-131m1**	661	**Sb-122**	711	**Te-133**	761	**Xe-131m1**
612	**In-132**	662	**Sb-122m1**	712	**Te-133m1**	762	**Xe-132**
613	**In-133**	663	**Sb-123**	713	**Te-134**	763	**Xe-133**
614	**In-134**	664	**Sb-124**	714	**Te-135**	764	**Xe-133m1**
615	**Sn-111**	665	**Sb-124m1**	715	**Te-136**	765	**Xe-134**
616	**Sn-112**	666	**Sb-124m2**	716	**Te-137**	766	**Xe-134m1**
617	**Sn-113**	667	**Sb-125**	717	**Te-138**	767	**Xe-135**
618	**Sn-113m1**	668	**Sb-126**	718	**Te-139**	768	**Xe-135m1**
619	**Sn-114**	669	**Sb-126m1**	719	**Te-140**	769	**Xe-136**
620	**Sn-115**	670	**Sb-126m2**	720	**Te-141**	770	**Xe-137**
621	**Sn-116**	671	**Sb-127**	721	**Te-142**	771	**Xe-138**
622	**Sn-117**	672	**Sb-128**	722	**I-121**	772	**Xe-139**
623	**Sn-117m1**	673	**Sb-128m1**	723	**I-123**	773	**Xe-140**
624	**Sn-118**	674	**Sb-129**	724	**I-125**	774	**Xe-141**
625	**Sn-119**	675	**Sb-130**	725	**I-126**	775	**Xe-142**
626	**Sn-119m1**	676	**Sb-130m1**	726	**I-127**	776	**Xe-143**
627	**Sn-120**	677	**Sb-131**	727	**I-128**	777	**Xe-143m1**
628	**Sn-121**	678	**Sb-132**	728	**I-129**	778	**Xe-144**
629	**Sn-121m1**	679	**Sb-132m1**	729	**I-130**	779	**Xe-145**
630	**Sn-122**	680	**Sb-133**	730	**I-130m1**	780	**Xe-146**
631	**Sn-123**	681	**Sb-134**	731	**I-131**	781	**Xe-147**
632	**Sn-123m1**	682	**Sb-134m1**	732	**I-132**	782	**Cs-127**
633	**Sn-124**	683	**Sb-135**	733	**I-132m1**	783	**Cs-129**
634	**Sn-125**	684	**Sb-136**	734	**I-133**	784	**Cs-131**
635	**Sn-125m1**	685	**Sb-137**	735	**I-133m1**	785	**Cs-132**
636	**Sn-126**	686	**Sb-138**	736	**I-134**	786	**Cs-133**
637	**Sn-127**	687	**Sb-139**	737	**I-134m1**	787	**Cs-134**
638	**Sn-127m1**	688	**Te-115**	738	**I-135**	788	**Cs-134m1**
639	**Sn-128**	689	**Te-117**	739	**I-136**	789	**Cs-135**
640	**Sn-128m1**	690	**Te-118**	740	**I-136m1**	790	**Cs-135m1**
641	**Sn-129**	691	**Te-119**	741	**I-137**	791	**Cs-136**
642	**Sn-129m1**	692	**Te-120**	742	**I-138**	792	**Cs-136m1**
643	**Sn-130**	693	**Te-121**	743	**I-139**	793	**Cs-137**
644	**Sn-130m1**	694	**Te-121m1**	744	**I-140**	794	**Cs-138**
645	**Sn-131**	695	**Te-122**	745	**I-141**	795	**Cs-138m1**
646	**Sn-131m1**	696	**Te-123**	746	**I-142**	796	**Cs-139**
647	**Sn-132**	697	**Te-123m1**	747	**I-143**	797	**Cs-140**
648	**Sn-133**	698	**Te-124**	748	**I-144**	798	**Cs-141**
649	**Sn-134**	699	**Te-125**	749	**I-145**	799	**Cs-142**
650	**Sn-135**	700	**Te-125m1**	750	**Xe-124**	800	**Cs-143**

Table.A6 List of fission products used in isotope kinetics calculations (cont.)

Number	Nuclide	Number	Nuclide	Number	Nuclide	Number	Nuclide
801	**Cs-144**	851	**La-151**	901	**Pr-158**	951	**Sm-143m1**
802	**Cs-145**	852	**La-152**	902	**Pr-159**	952	**Sm-144**
803	**Cs-146**	853	**La-153**	903	**Nd-140**	953	**Sm-145**
804	**Cs-147**	854	**La-154**	904	**Nd-141**	954	**Sm-146**
805	**Cs-148**	855	**La-155**	905	**Nd-142**	955	**Sm-147**
806	**Cs-149**	856	**Ce-135**	906	**Nd-143**	956	**Sm-148**
807	**Cs-150**	857	**Ce-137**	907	**Nd-144**	957	**Sm-149**
808	**Ba-129**	858	**Ce-138**	908	**Nd-145**	958	**Sm-150**
809	**Ba-131**	859	**Ce-139**	909	**Nd-146**	959	**Sm-151**
810	**Ba-132**	860	**Ce-139m1**	910	**Nd-147**	960	**Sm-152**
811	**Ba-133**	861	**Ce-140**	911	**Nd-148**	961	**Sm-153**
812	**Ba-134**	862	**Ce-141**	912	**Nd-149**	962	**Sm-154**
813	**Ba-135**	863	**Ce-142**	913	**Nd-150**	963	**Sm-155**
814	**Ba-135m1**	864	**Ce-143**	914	**Nd-151**	964	**Sm-156**
815	**Ba-136**	865	**Ce-144**	915	**Nd-152**	965	**Sm-157**
816	**Ba-136m1**	866	**Ce-145**	916	**Nd-153**	966	**Sm-158**
817	**Ba-137**	867	**Ce-146**	917	**Nd-154**	967	**Sm-159**
818	**Ba-137m1**	868	**Ce-147**	918	**Nd-155**	968	**Sm-160**
819	**Ba-138**	869	**Ce-148**	919	**Nd-156**	969	**Sm-161**
820	**Ba-139**	870	**Ce-149**	920	**Nd-157**	970	**Sm-162**
821	**Ba-140**	871	**Ce-150**	921	**Nd-158**	971	**Sm-163**
822	**Ba-141**	872	**Ce-151**	922	**Nd-159**	972	**Sm-164**
823	**Ba-142**	873	**Ce-152**	923	**Nd-160**	973	**Sm-165**
824	**Ba-143**	874	**Ce-153**	924	**Nd-161**	974	**Eu-147**
825	**Ba-144**	875	**Ce-154**	925	**Pm-141**	975	**Eu-149**
826	**Ba-145**	876	**Ce-155**	926	**Pm-143**	976	**Eu-151**
827	**Ba-146**	877	**Ce-156**	927	**Pm-144**	977	**Eu-152**
828	**Ba-147**	878	**Ce-157**	928	**Pm-145**	978	**Eu-152m1**
829	**Ba-148**	879	**Pr-139**	929	**Pm-146**	979	**Eu-152m2**
830	**Ba-149**	880	**Pr-140**	930	**Pm-147**	980	**Eu-153**
831	**Ba-150**	881	**Pr-141**	931	**Pm-148**	981	**Eu-154**
832	**Ba-151**	882	**Pr-142**	932	**Pm-148m1**	982	**Eu-154m1**
833	**Ba-152**	883	**Pr-142m1**	933	**Pm-149**	983	**Eu-155**
834	**La-133**	884	**Pr-143**	934	**Pm-150**	984	**Eu-156**
835	**La-135**	885	**Pr-144**	935	**Pm-151**	985	**Eu-157**
836	**La-137**	886	**Pr-144m1**	936	**Pm-152**	986	**Eu-158**
837	**La-138**	887	**Pr-145**	937	**Pm-152m1**	987	**Eu-159**
838	**La-139**	888	**Pr-146**	938	**Pm-152m2**	988	**Eu-160**
839	**La-140**	889	**Pr-147**	939	**Pm-153**	989	**Eu-161**
840	**La-141**	890	**Pr-148**	940	**Pm-154**	990	**Eu-162**
841	**La-142**	891	**Pr-148m1**	941	**Pm-154m1**	991	**Eu-163**
842	**La-143**	892	**Pr-149**	942	**Pm-155**	992	**Eu-164**
843	**La-144**	893	**Pr-150**	943	**Pm-156**	993	**Eu-165**
844	**La-145**	894	**Pr-151**	944	**Pm-157**	994	**Gd-147**
845	**La-146**	895	**Pr-152**	945	**Pm-158**	995	**Gd-149**
846	**La-146m1**	896	**Pr-153**	946	**Pm-159**	996	**Gd-151**
847	**La-147**	897	**Pr-154**	947	**Pm-160**	997	**Gd-152**
848	**La-148**	898	**Pr-155**	948	**Pm-161**	998	**Gd-153**
849	**La-149**	899	**Pr-156**	949	**Pm-162**	999	**Gd-154**
850	**La-150**	900	**Pr-157**	950	**Sm-143**	1000	**Gd-155**

Table.A6 List of fission products used in isotope kinetics calculations (cont.)

Number	Nuclide	Number	Nuclide
1001	**Gd-156**	1051	**Ho-164m1**
1002	**Gd-157**	1052	**Ho-165**
1003	**Gd-158**	1053	**Ho-166**
1004	**Gd-159**	1054	**Ho-166m1**
1005	**Gd-160**	1055	**Ho-167**
1006	**Gd-161**	1056	**Ho-168**
1007	**Gd-162**	1057	**Ho-169**
1008	**Gd-163**	1058	**Ho-170**
1009	**Gd-164**	1059	**Ho-170m1**
1010	**Gd-165**	1060	**Ho-171**
1011	**Tb-151**	1061	**Ho-172**
1012	**Tb-153**	1062	**Er-161**
1013	**Tb-155**	1063	**Er-162**
1014	**Tb-156**	1064	**Er-163**
1015	**Tb-156m1**	1065	**Er-164**
1016	**Tb-157**	1066	**Er-165**
1017	**Tb-158**	1067	**Er-166**
1018	**Tb-158m1**	1068	**Er-167**
1019	**Tb-159**	1069	**Er-167m1**
1020	**Tb-160**	1070	**Er-168**
1021	**Tb-161**	1071	**Er-169**
1022	**Tb-162**	1072	**Er-170**
1023	**Tb-163**	1073	**Er-171**
1024	**Tb-164**	1074	**Er-172**
1025	**Tb-165**	1075	**Tm-165**
1026	**Dy-155**	1076	**Tm-166**
1027	**Dy-156**	1077	**Tm-167**
1028	**Dy-157**	1078	**Tm-168**
1029	**Dy-158**	1079	**Tm-169**
1030	**Dy-159**	1080	**Tm-170**
1031	**Dy-160**	1081	**Tm-171**
1032	**Dy-161**	1082	**Tm-172**
1033	**Dy-162**	1083	**Yb-166**
1034	**Dy-163**	1084	**Yb-167**
1035	**Dy-164**	1085	**Yb-168**
1036	**Dy-165**	1086	**Yb-169**
1037	**Dy-165m1**	1087	**Yb-169m1**
1038	**Dy-166**	1088	**Yb-170**
1039	**Dy-167**	1089	**Yb-171**
1040	**Dy-168**	1090	**Yb-172**
1041	**Dy-169**	1091	**Lu-169**
1042	**Ho-159**	1092	**Lu-169m1**
1043	**Ho-159m1**	1093	**Lu-171**
1044	**Ho-161**	1094	**Lu-171m1**
1045	**Ho-161m1**	1095	**Lu-172**
1046	**Ho-162**	1096	**Lu-172m1**
1047	**Ho-162m1**	1097	**Hf-171**
1048	**Ho-163**	1098	**Hf-172**
1049	**Ho-163m1**		