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VVER In-Core Self-Powered Neutron Detector Calculational Benchmark

FINAL SPECIFICATIONS

English - Or. English

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Final Specification for the VVER in-Core Self-Powered Neutron Detector Calculational Benchmark

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Introduction

- **Systems to be calculated are as follows:** Absorbers (BA) rods (UGd);
  Profiled MOX fuel assembly with 12 U-Gd Burnable Absorber (BA) rods (MOXGd) and rhodium self-powered neutron detector (SP
- Uniform LEU fuel assembly with 12 U-Gd Burnable ND)
- Model SPND with prescribed neutron capture rate distribution inside Rh emitter.

Results to be provided are in the two computer files:

1. EXCEL file with numerical results;
2. WORD file with information about the calculational scheme used.

All the results obtained with the MCU code after the Draft Specification of this benchmark was issued are available to participants in Appendix 4. Please provide any comments using the following e-mail:

Sergey Gorodkov: ssg@adis.vver.kiae.ru

Content of this document

1. Material specification

Table 1 Material description

Material Name	Comment *)	Isotopic content, (atoms/barn cm3)			
Fuel materials, *T=1027K*					
U1	LEU fuel of 3.7 w/o enrichment	^{235}U	8.6264E-4	^{16}O	4.6063E-2
		^{238}U	2.2169E-2		
PU1	MOX fuel with 2.0 w/o of fissile Pu	^{235}U	4.2672E-5	^{239}Pu	4.2414E-4
		^{238}U	2.1025E-2	^{240}Pu	2.7250E-5
		^{16}O	4.3047E-2	^{241}Pu	4.5228E-6
PU2	MOX fuel with 3.0 w/o of fissile Pu	^{235}U	4.2209E-5	^{239}Pu	6.3621E-4
		^{238}U	2.0797E-2	^{240}Pu	4.0875E-5
		^{16}O	4.3045E-2	^{241}Pu	6.7842E-6
PU3	MOX fuel with 4.2 w/o of fissile Pu	^{235}U	4.1652E-5	^{239}Pu	8.9071E-4
		^{238}U	2.0522E-2	^{240}Pu	5.7225E-5
		^{16}O	4.3043E-2	^{241}Pu	9.4980E-6
GD1	LEU fuel of 3.6 w/o of ^{235}U containing 4 w/o of Gd_2O_3	^{235}U	7.2875E-4	^{155}Gd	1.8541E-4
		^{238}U	1.9268E-2	^{156}Gd	2.5602E-4
		^{16}O	4.1854E-2	^{157}Gd	1.9480E-4
		^{152}Gd	2.5159E-6	^{158}Gd	3.0715E-4
		^{154}Gd	2.7303E-5	^{160}Gd	2.6706E-4
Non-fuel materials					
CL1	Zirconium alloy T=575K	Zr Nb	4.259E-2 4.225E-4	Hf	6.597E-6
MOD	Moderator, 0.6 g/kg of boron, T_m=575K, γ= 0.7235 g/cm^3 in operating poisoned state	H ^{16}O	4.843E-2 2.422E-2	^{10}B ^{11}B	4.794E-6 1.942E-5
RH	SPND rhodium wire, T=575K, γ= 12.4 g/cm^3	^{103}Rh	7.257E-02		
INS	Aluminium oxide SPND insulator Al T=575K, γ= 3.9 g/cm^3	Al	4.607E-02	^{16}O	6.911E-02
COL	SPND nickel collector (sheath) T=575K, γ= 8.71g/cm^3	Ni	8.936E-02		

*) The information in this column is given only as a comment. For the calculations the data from the "Isotopic content" column should be used.

2. Geometry description

Let us specify the following geometric objects :

- *Cn* - *n*-zones elementary cell;
- *K1* - uniform assembly with 12 Gd pins (331 elementary cells of 4 types)
- *K2* - profiled assembly with 12 Gd pins (331 elementary cells of 6 types)

n-zones elementary cell ***Cn*** *inside* ***K1 / K2*** *Assembly*:

1-st zone - Cyl($\boldsymbol{r_0},\boldsymbol{r_1}$) ;

j-th zone - Cyl($\boldsymbol{r_0},\boldsymbol{r_1}$) \ Cyl($\boldsymbol{r_0},\boldsymbol{r_{1-1}}$) , j=1,..n-1;

n-th zone - Hex($\boldsymbol{r_0}$,***h=1.275 cm***) \ Cyl($\boldsymbol{r_0},\boldsymbol{r_{n-1}}$) ;
where Cyl($\boldsymbol{r_0},r_j$) - cylinder of radius r_j with center at point $\boldsymbol{r_0}$;
Hex($\boldsymbol{r_0}$,***h=1.275 cm***) - hexagon with center at point $\boldsymbol{r_0}$ and across flats dimension *h=**1.275 cm***.

Assembly K1 ***(uniform assembly containing 12 Gd BA rods)*** **:**
It is a "container" Hex($\boldsymbol{r_0}$,***H=23.6 cm***), which contains 331 elementary cells *Cn* of 4 types (see Figure 1).

Assembly ***K2 (profiled assembly containing 12 Gd BA rods)*** :
It is a "geometric container" Hex($\boldsymbol{r_0}$,***H=23.6 cm***), which contains 331 elementary cells *Cn* of 6 types (see Figure 2).

Table 2 Description of cell types geometry

Cell geometry	Comment	Total zones number	Cylindrical zones outer radius (cm)
Cn	Fuel cell	3	R_1 = **0.386** R_2 = **0.4582**
Cn	Central tube cell with SPND	16	R_1 = **7.9056937E-03** R_2 = **1.1180339E-02** R_3 = **1.3693063E-02** R_4 = **1.5811387E-02** R_5 = **1.7677668E-02** R_6 = **1.9364916E-02** R_7 = **2.0916499E-02** R_8 = **2.2360679E-02** R_9 = **2.3717081E-02** R_{10} = **0.025** R_{11} = **0.03679** R_{12} = **0.05** R_{13} = **0.075** R_{14} = **0.48** R_{15} = **0.5626**
Cn	Guide tube cell	3	R_1 = **0.545** R_2 = **0.6323**

All cells of all types have the same outer dimension *h=**1.275 cm***. Fuel cell may contain one of the following materials: PU1, PU2, PU3 or GD1

3. Neutronic calculations

3.1 *K1* and *K2* assemblies state to be calculated

Calculations of the assembly neutronic parameters should be performed for single state, with fuel temperature at ***1027 K*** and all other material temperatures at ***575 K***.

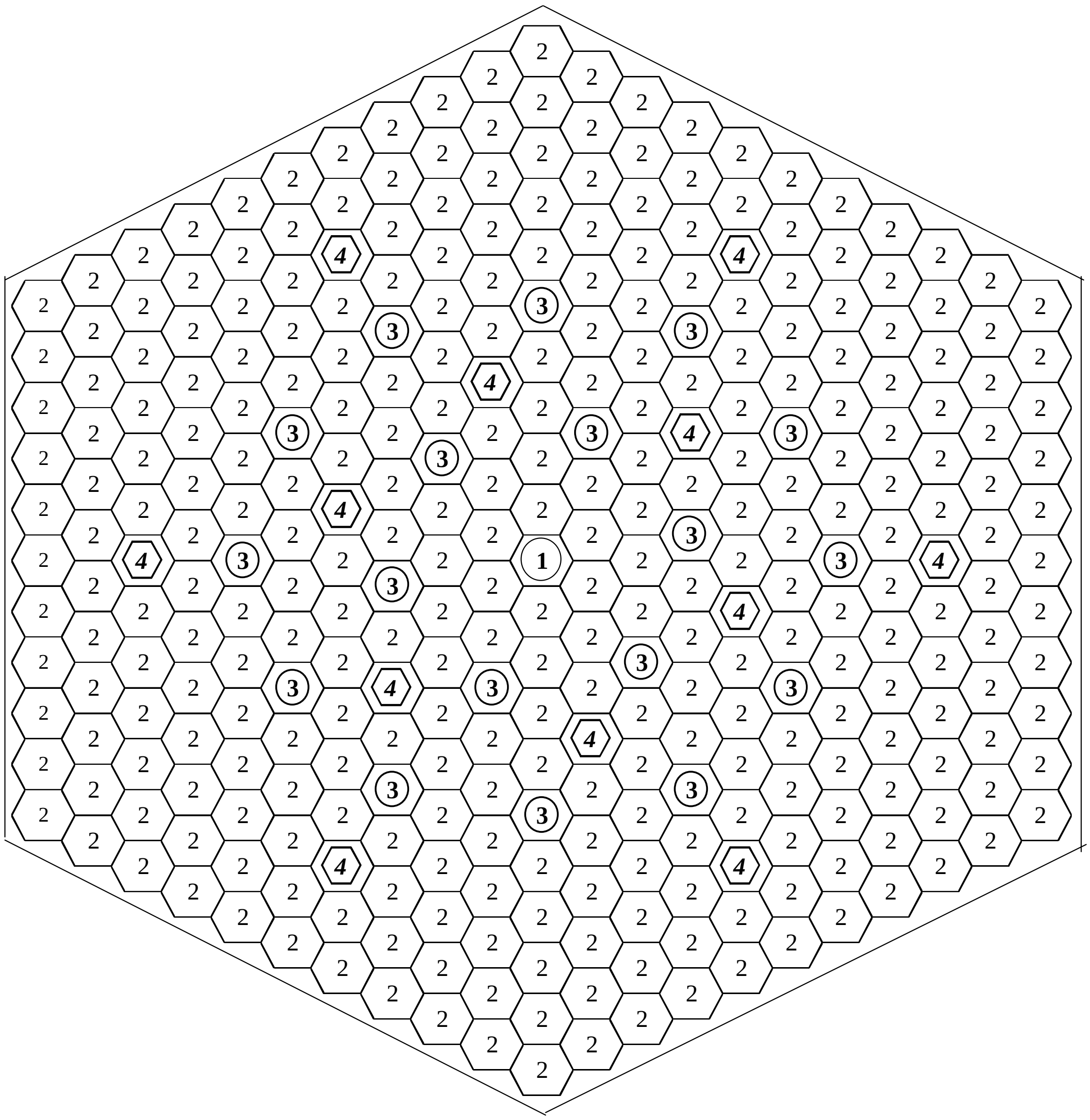
^{135}Xe and ^{149}Sm concentrations in fuel zones in zero burnup point (B=0) are equal to 0, and in the others burnup points are equal to equilibrium values.

Burnup calculation (with power density equaled to ***108 MWt/m³ or 0.3567 kW/cm³ fuel***) should be performed. All calculations should be performed with zero current on assembly side and zero axial leakage (infinite lattice of assemblies).

3.2 Assemblies material structure (Table 4)

General geometry type	Cell type	Zone number	Zone material
K1	1 – Central tube cell with SPND	1-10	RH
		11-12	INS
		13	COL
		14	MOD
		15	CL1
		16	MOD
	2 – Fuel cell (with U1)	1	U1
		2	CL1
		3	MOD
	3 – Guide tube cell	1	MOD
		2	CL1
		3	MOD
	4 – Fuel cell (with GD1)	1	GD1
		2	CL1
		3	MOD
K2	1 – Central tube cell with SPND	Same as in *K1* assembly	
	2 – Fuel cell (with PU3)	1	PU3
		2	CL1
		3	MOD
	3 – Guide tube cell	1	MOD
		2	CL1
		3	MOD
	4 – Fuel cell (with PU2)	1	PU2
		2	CL1
		3	MOD
	5 – Fuel cell (with PU1)	1	PU1
		2	CL1
		3	MOD
	6 – Fuel cell (with GD1)	1	GD1
		2	CL1
		3	MOD

Figure 1 Cartogram of the Uniform LEU fuel assembly with 12 Gd BA rods

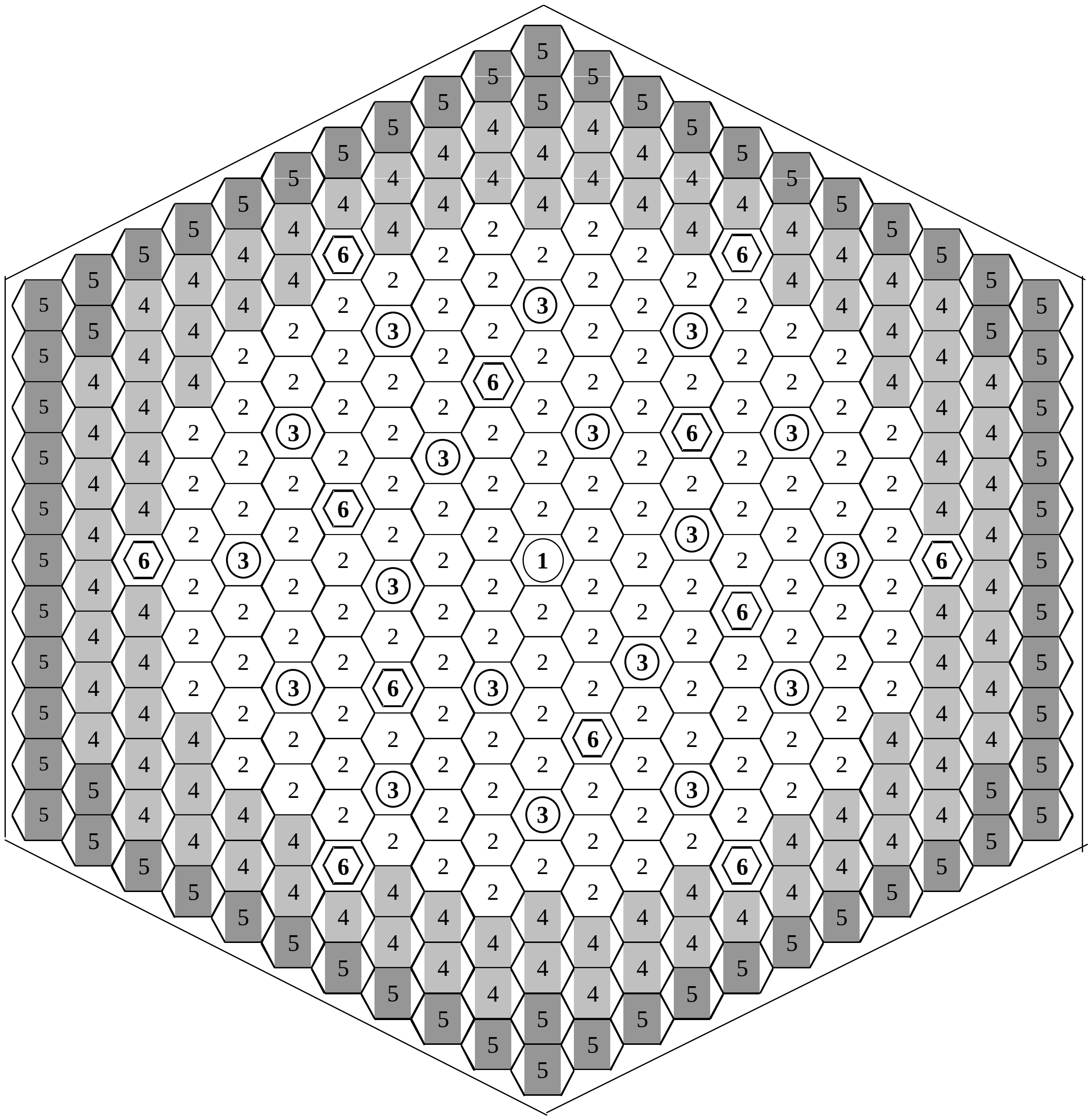


Cell types:

1. Central tube cell
2. Fuel cell (with U1)
3. Guide tube cell
4. Fuel cell (with GD1)

1322.20 g of fissile metal per 1 cm height segment of assembly

Figure 2. Cartogram of the Profiled MOX fuel assembly with 12 Gd BA rods.
Assembly type K2. Variant MOXGd



Cell types:

1. Central tube cell
2. Fuel cell (with PU3)
3. Guide tube cell
4. Fuel cell (with PU2)
5. Fuel cell (with PU1)
6. Fuel cell (with GD1)

1239.16 g of fissile metal per 1 cm height segment of assembly

3.3 Functionals to be calculated

In the course of the neutronic calculations the following parameters should be calculated as a function of assembly average burnup for the following burnup points: **0, 10, 20, 30, 40, 50, 60 MWd/kg HM:**

- power of the 6 central pins surrounding the detector.
- distributions of neutron absorption rate through ten equivolume concentric zones of the emitter.
- distributions of Rh nuclear density through ten equivolume concentric zones of the emitter.

Tables and forms for submitting the results are presented in Appendix 1.

It should be noted, that ^{135}Xe and ^{149}Sm concentrations in the fuel zones at zero burnup (B=0) are equal to 0, and at the others burnup points are equal to equilibrium values.

4. Electron-photon calculations.

4.1 Model detector problem

Only electrons and photons from rhodium neutron capture must be considered. The in-core photons contribution to the detector signal is to be neglected.

The electric charge absorbed in the insulator is assumed to have uniform spatial distribution. So the radius of the cylindrical surface, splitting the insulator into two parts, is chosen in such a way, that the electric charge absorbed in the inner part of the insulator will flow to the emitter.

The SPND surface is considered to be black for all outcoming particles.

This and the previous approximation may be verified in the course of benchmark solution.

4.2 Model detector material structure (Table 5)

General geometry type	Cell type	Zone number	Zone material
MD	Model SPND	1	RH
		2	RH
		3	RH
		4	RH
		5	RH
		6	RH
		7	RH
		8	RH
		9	RH
		10	RH
		11	INS
		12	INS
		13	COL

4.3 Functionals to be calculated

In the course of the electron-photon calculations the following parameters should be calculated :

- Partial detector signals ***J (i)*** (*i=1,2,. . .10*) , due to single neutron absorption, uniformly distributed inside ***i***-th emitter zone, are to be calculated.

- After that SPND electrical signal ***J*** can be calculated at each emitter burnup step using the formula:

$$J = \sum_{i=1}^{10} J(i)\, R_{Rh}^{a}\,(i)$$

where $R_{Rh}^{a}\,(i)$ is neutron absorption rate distribution through the emitter zones.
When using this formula, we assume, that depleted ^{103}Rh is replaced by ^{104}Pd, which has practically the same properties with respect to electrons and photons, as ^{103}Rh.

Tables and forms for results are presented in Appendix 1.

Appendix 1

- Results to be reported
- Preferred format is EXCEL
- The file with the results should be an EXCEL Workbook containing 18 sheets. Each shee to contain one table.

Table 6. ^{103}Rh nuclide concentrations (in atoms/barn*cm) in the radial zones of the emitter versus *K1* assembly burnup

Zone No	Assembly burnup, MWd/kgHM						
	0	10	20	30	40	50	60
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

Table 7. ^{103}Rh neutron absorption rate in radial zones of a 1 cm long emitter segment (in abs/sec/cm) versus *K1* assembly burnup

Zone No	Assembly burnup, MWd/kgHM						
	0	10	20	30	40	50	60
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

Table 8. Power of the 6 central pins and the SPND electrical signal (per 1 cm height of assembly) versus *K1* assembly burnup.

Assembly burnup MWd/kgHM	Pins power KW/cm	SPND current μA/cm
0		
10		
20		
30		
40		
50		
60		

Tables 9 – 11 for *K2* assembly are similar to those for the *K1* assembly

Table 12. Partial detector signals due to single neutron absorption, uniformly distributed inside *i*-th emitter zone (per 1 cm long emitter segment)

Emitter zone No	Partial detector signal in Coulomb/cm
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Appendix 2

Details to be provided about the calculational scheme used.
Preferred format is WORD.

1. name of participant;
2. establishment of participant;
3. name of computer code(s) used including reference and short description of method;
4. basic data library version;
5. data processing code/method used to obtain the cross-section data used;
6. spectral calculations and data reduction methods used;
7. number of groups(fast, thermal)/continuous energy;
8. assumptions made for some cross-sections such as (n,2n);
9. self-shielding and mutual resonance shielding applied to which nuclides;
10. cell, lattice, etc. calculation methods used;
11. other information that would be helpful to identify possible sources of discrepancies, especially deviations (possibly none) from the specification.

Appendix 3

Schedule

September 2004	Distribution of the draft specification
End of November 2005	Distribution of the final specification
Month before the next meeting	Gathering of first results from participants by RRC KI: *Sergey Gorodkov: ssg@adis.vver.kiae.ru*
Next meeting	Presentation of the results and preliminary analysis

Appendix 4

SPND benchmark results obtained with MCU code

These results were obtained quite recently after thorough recalculation. The difference with those presented in Paris in June 2005 is of minor significance. Their presentation is intended for those participants, who intend to solve only one part of this benchmark problem, either the one relative to neutronics or to electron-photon.

Table 13. Partial detector signals due to single neutron absorption, uniformly distributed inside *i*-th emitter zone (per 1 cm long emitter segment)

Emitter zone No	Partial detector signal in Coulomb/cm
1	-3.843E-14
2	-4.290E-14
3	-4.763E-14
4	-5.248E-14
5	-5.780E-14
6	-6.347E-14
7	-6.941E-14
8	-7.610E-14
9	-8.338E-14
10	-9.183E-14

Table 14. ^{103}Rh nuclide concentrations (in atoms/barn*cm) in the radial zones of the emitter versus *K1* assembly burnup

Zone	Assembly burnup, MWd/kgHM						
No	0	10	20	30	40	50	60
1	0.07257	0.06533	0.05832	0.05137	0.04450	0.03794	0.03142
2	0.07257	0.06518	0.05813	0.05110	0.04386	0.03734	0.03094
3	0.07257	0.06496	0.05772	0.05060	0.04338	0.0369	0.03030
4	0.07257	0.06483	0.05741	0.05016	0.04284	0.03624	0.02951
5	0.07257	0.06462	0.05706	0.04953	0.04204	0.03513	0.02847
6	0.07257	0.06431	0.05646	0.04874	0.04108	0.03409	0.02752
7	0.07257	0.06393	0.05577	0.04791	0.03988	0.03270	0.02615
8	0.07257	0.06336	0.05479	0.04655	0.03843	0.03090	0.02448
9	0.07257	0.06255	0.05346	0.04459	0.03626	0.02889	0.02240
10	0.07257	0.06112	0.05095	0.04160	0.03330	0.02608	0.01978

Table 15. ^{103}Rh neutron absorption rate in radial zones of a 1 cm long emitter segment (in abs/sec/cm) versus *K1* assembly burnup

Zone	Assembly burnup, MWd/kgHM						
No	0	10	20	30	40	50	60
1	6.643E+10	6.069E+10	6.403E+10	6.219E+10	6.112E+10	5.900E+10	5.725E+10
2	7.027E+10	6.167E+10	6.411E+10	6.430E+10	6.088E+10	5.839E+10	5.573E+10
3	7.061E+10	6.265E+10	6.479E+10	6.373E+10	6.074E+10	5.910E+10	5.622E+10
4	7.230E+10	6.553E+10	6.712E+10	6.689E+10	6.212E+10	6.135E+10	5.578E+10
5	7.564E+10	6.825E+10	6.821E+10	6.878E+10	6.440E+10	6.304E+10	5.578E+10
6	7.952E+10	7.102E+10	7.070E+10	6.966E+10	6.464E+10	6.309E+10	5.665E+10
7	8.127E+10	7.378E+10	7.327E+10	7.379E+10	6.693E+10	6.412E+10	5.453E+10
8	8.734E+10	7.902E+10	7.705E+10	7.507E+10	6.955E+10	6.243E+10	5.310E+10
9	9.564E+10	8.531E+10	8.175E+10	7.784E+10	7.017E+10	6.176E+10	5.204E+10
10	1.122E+11	9.640E+10	8.669E+10	7.784E+10	6.979E+10	6.074E+10	5.041E+10

Table 16. ^{103}Rh nuclide concentrations (in atoms/barn*cm) in the radial zones of the emitter versus *K2* assembly burnup

Zone	Assembly burnup, MWd/kgHM						
No	0	10	20	30	40	50	60
1	0.07257	0.06764	0.06234	0.05707	0.05130	0.04566	0.03977
2	0.07257	0.06751	0.06215	0.05668	0.05097	0.04531	0.03917
3	0.07257	0.06734	0.06185	0.05613	0.05034	0.04438	0.03818
4	0.07257	0.06719	0.06151	0.05564	0.04976	0.04353	0.03725
5	0.07257	0.06696	0.06113	0.05518	0.04909	0.04256	0.03632
6	0.07257	0.06666	0.06062	0.05439	0.04819	0.04158	0.03521
7	0.07257	0.06629	0.05998	0.05341	0.04691	0.04018	0.03383
8	0.07257	0.06577	0.05896	0.05209	0.04535	0.03848	0.03197
9	0.07257	0.06504	0.05766	0.05048	0.04330	0.03621	0.02966
10	0.07257	0.06366	0.05534	0.04743	0.03974	0.03267	0.02621

Table 17. ^{103}Rh neutron absorption rate in the radial zones of a 1 cm long emitter segment (in abs/sec/cm) versus *K2*assembly burnup

Zone	Assembly burnup, MWd/kgHM						
No	0	10	20	30	40	50	60
1	4.577E+10	4.888E+10	5.134E+10	5.609E+10	5.376E+10	5.843E+10	5.651E+10
2	4.674E+10	4.830E+10	5.239E+10	5.445E+10	5.371E+10	6.052E+10	5.695E+10
3	4.726E+10	5.032E+10	5.492E+10	5.553E+10	5.440E+10	6.141E+10	5.608E+10
4	4.811E+10	5.205E+10	5.609E+10	5.711E+10	5.707E+10	6.146E+10	5.629E+10
5	5.041E+10	5.222E+10	5.553E+10	5.902E+10	6.069E+10	6.162E+10	5.805E+10
6	5.364E+10	5.444E+10	5.936E+10	6.014E+10	6.213E+10	6.251E+10	5.925E+10
7	5.590E+10	5.675E+10	6.281E+10	6.266E+10	6.386E+10	6.413E+10	5.953E+10
8	6.024E+10	6.116E+10	6.721E+10	6.583E+10	6.733E+10	6.538E+10	5.887E+10
9	6.729E+10	6.932E+10	7.179E+10	7.110E+10	6.941E+10	6.465E+10	6.008E+10
10	8.298E+10	8.119E+10	7.950E+10	7.613E+10	7.313E+10	6.444E+10	5.788E+10

Table 18. . Power of the 6 central pins and the SPND electrical signal (per 1 cm height of assembly) versus *K1* assembly burnup.

Assembly burnup MWd/kgHM	Pins power KW/cm	SPND current μA/cm
0	1.072	0.05213
10	1.047	0.04643
20	1.042	0.04546
30	1.036	0.04407
40	1.030	0.04068
50	1.026	0.03797
60	1.022	0.03346

Table 19 Power of the 6 central pins and the SPND electrical signal (per 1 cm height of assembly) versus *K2* assembly burnup.

Assembly burnup MWd/kgHM	Pins power KW/cm	SPND current μA/cm
0	1.130	0.03615
10	1.119	0.03698
20	1.110	0.03907
30	1.107	0.03920
40	1.098	0.03902
50	1.089	0.03882
60	1.074	0.03590