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SIMPLIFIED BENCHMARK SPECIFICATION BASED ON #2670 ISTC VVER PIE

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ABSTRACT

In the paper a simplified specification of the calculational benchmark based on the #2670 ISTC project providing VVER-440 PIE data for 8 samples cut out of 4 fuel pins of the Novovoronezh NPP fuel assembly (FA) No. D26135 of 38.5 MWd/kgU av. burnup is described.

INTRODUCTION

The #2670 ISTC project was in progress in 2003-5. Measurements of 8 samples cut out of 4 fuel pins of the Novovoronezh NPP FA No. D26135 were performed in RIAR Dimitrovgrad, Rusia, the final project report is accessible via Internet /1a/. The concrete D26135 FA examined in #2670 ISTC project and presented in the following benchmark specification underwent 4-cycle campaign of totally 1109 days in the core of VVER-440 unit 4 of the Novovoronezh NPP and reached average burnup 38.5 MWd/kgU. The four cycles of the FA irradiation were adequate the 15th, 16th, 17th and 18th cycles of the Novovoronezh Unit 4 operation.

The benchmark structure is similar to the second phase of the VVER-440 burnup credit benchmark /2/ (CB2) where depletion of a standard VVER-440 FA of 3.6 wt. % enrichment and burnup up to 40 MWd/kgU was specified for calculation but no measured data were available for a comparison where. The following specification of the simplified benchmark should enables to simulate the irradiation of the D26135 FA based on **operational history by means of values calculated with the Russian operational codes** /1a/. The related burnups B_C can be seen the 4th column in Table 4 below.

In addition to this, the benchmark participants are encouraged to calculate the individual sample cases also using the **measured burnup values** (B_F, B_M - see the columns 2 and 3 in Table 4). In such a case, the participants are asked for description of their approach to an operation history approximation as the detailed operation data provided by RIAR resulted from operational code calculations so they refer to the calculated burnup values (B_C). The prospective approaches taken by the participants will be compared when evaluating the results of the benchmark.

BENCHMARK OBJECTIVE

- to use different calculational methodologies for nuclide inventory prediction to simulate the depletion of the D26135 FA up to discharge according to the specified data (based on the #2670 ISTC project final report /1a/) of the fuel, fuel pins and fuel assembly as well as the operation history in the course of D26135 irradiation in the VVER-440 unit 4 of the Novovoronezh NPP

- to intercompare the nuclide concentrations calculated with different methodologies for the actinides and fission products measured in #2670 ISTC project

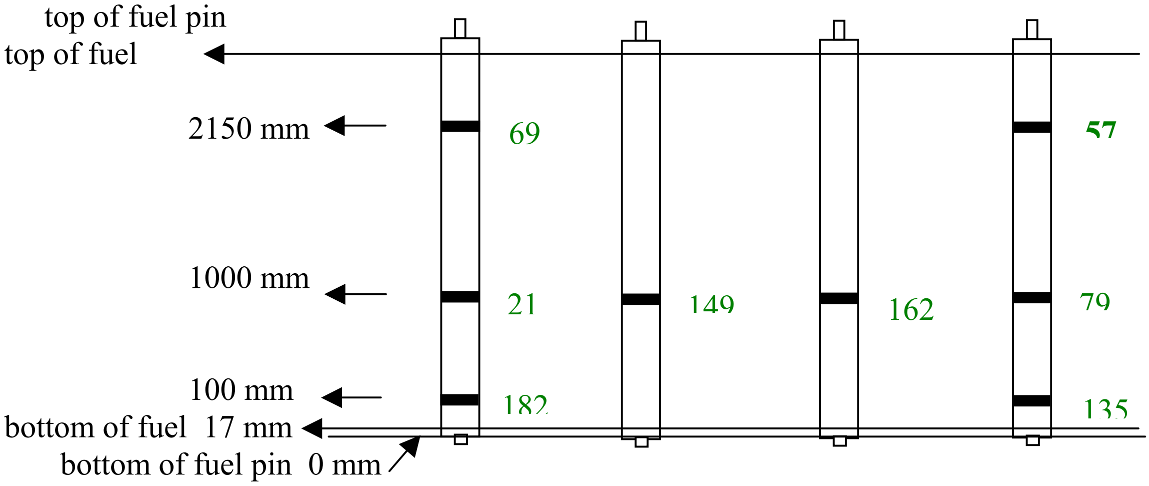
- to compare the result of the calculated nuclide concentration evaluation with the measured data /1a/

SPECIFICATION

In the following tables, the numbers of fuel samples and pins as numbered in the #2670 ISTC project final report /1a/ will be used to be connected with the original description in /1a/. The sample layers of 10 mm were marked and located as follows (according to /1a/):

pin No:	65	67	68	69
alias pin No:	16	54	82	116

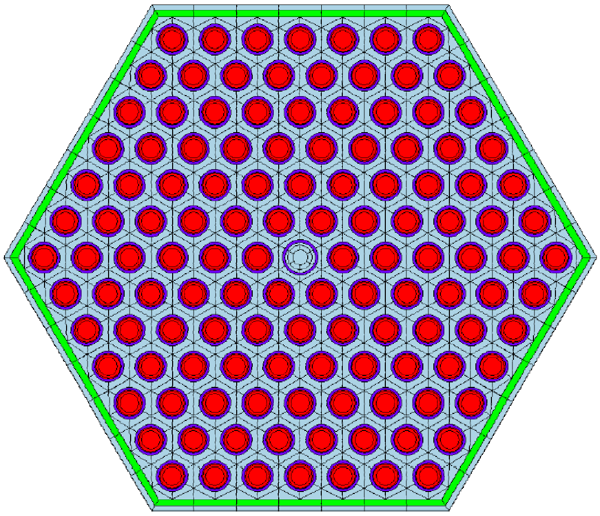
Sample numbers and the lower coordinate of the sample positions along the fuel pins (no scale) (/1/ a, page 196-7) :



The positions of the fuel pins within the investigated fuel assembly as well as the positions of all the FAs in the core during the 4 cycles of irradiation are described in details in /1a/. As the data connected with the FA operational pre-history are not available in /1a/ the following specification will use partly the real operation history data but mostly the results of the Russian pre-calculations related to the sample positions - from this point of view it is the most simplified depletion approach for the benchmark calculations.

Parameter		**Data**
<u>Fuel Assembly Data</u>		
Lattice		hexagonal, pitch 14.7 cm
Moderator	av. temperature, K	see Table 7-14 below
	pressure	12.26 MPa
Soluble boron content		see Table 2 below
Number of fuel rods		126
Number of central tubes		1
Shroud		
Wrench dimensions:		
	inner size	14.02 cm
	outer size	14.42 cm

Material	2.5% wt. Nb, 97.47% wt. Zr, 0.03% wt. Hf, ρ = 6.44 g/cm^3
Spacer grid (10 spacers along the fuel column)	
Material	1% wt. Nb, 98.97% wt. Zr, 0.03% wt. Hf, ρ = 6.44 g/cm^3
Mass (for spacer smearing)	99 g/pc x 10 pcs/ass. = 990 g/ass.



VVER-440 assembly, 3.6 % U-235.

Fuel / Fuel Rod Data

U-235 mass fraction in the mixture of uranium isotopes, %	3.6
U-236 mass fraction in uranium, %	0.1
U-234 mass fraction in uranium, % /1 e/	0.033
Mass fraction of impurities with reference to uranium, % :	
Nitrogen	0.02
Boron	0.00004
Iron	0.06
Silicon	0.025
Manganese	0.002
Copper	0.005
Nickel	0.015
Carbon	0.01
Fluorine	0.005
Chromium	0.01
Pellet density, g/cm^3	10.0037
Rod pitch, cm	1.22
Rod outer diameter, cm	0.91
Pitch in FA, cm	1.22
Cladding inner diameter, cm	0.772
Pellet diameter, cm	0.7565
Pellet central hole diameter, cm	0.12

Helium pressure in fuel rod, MPa	0.6
Active fuel length (hot), cm	244
Effective fuel temperature, K	see Table 7-14 below
Clad temperature, K	see Table 7-14 below
material	1% wt. Nb, 98.97% wt. Zr, 0.03% wt. Hf, $\rho = 6.44\ g/cm^3$

Central Instrumental Tube Data

Inner radius, cm	0.440
Outer radius, cm	0.515
Material	1% wt. Nb, 98.97% wt. Zr, 0.03% wt. Hf, $\rho = 6.44\ g/cm^3$

Operation History Data

Linear Power at Sample Positions [W/cm]	see Tables 7-14 below
Boron Content (av.) [g $_{H3BO3}$ /kg $_{H2O}$]	see Table 2 below
Number of cycles	4
Cooling Time	see: the measurement date / end of irradiation (Table 5)

Table 1 Cycle Durations /1c/

cycle No.	uptime [effective days]	downtime [calendar days] between the cycles
15	296	67
16	390	32
17	98	70
18	325	sample cooling time: see the measurement date / end of irradiation (Table 5)
total	1109	

Table 2 Boron Content History

cycle No.	Successive Time Intervals [day]	Av. Boron Content [g $_{H3BO3}$ /kg $_{H2O}$]	Boron Fraction [%]
15	100	4.22	1
	100	2.11	0.50
	61	0.56	0.13
	35	0	0
16	100	5.97	1.42
	100	3.76	0.89
	143	1.32	0.31
	47	0	0
17	95	0.87	0.21
	3	0	0
18	100	5.06	1.20
	100	2.95	0.70
	107	0.96	0.23
	18	0	0

Average burnups /1a/

Average burnup of D26135 FA : 38.5 MWd/kgU_{ini}

Table 3 Average burnups of the examinated fuel pins

Fuel pin No.	av. B [MWd/kgU_{ini}]
65	36.4
67	37.6
68	39.3
69	42.2

Table 4 Information on sample burnups (derivation from FPs measurement / reactor record calculations)

sample No.	av.*) B_F [kgFPs/tU$_{ini}$] /1a/	B_M [GWd/tU$_{ini}$] recalculated from av. B_F by SCALE and *(the value according to /4/)*	B_C [GWd/tU$_{ini}$] as based on lin. power calculated at sample position /1a/ from 15th to 18th cycle	$(B_C - B_M)/B_M$ [%]
182	22.86	22.18 *(22.09)*	6.68	17
			9.45	
			2.70	
			7.04	
			total: 25.86	
21	41.50	40.48 *(40.11)*	12.78	9
			16.23	
			3.97	
			11.10	
			total: 44.08	
69	31.32	30.46 *(30.27)*	8.43	5
			11.28	
			2.77	
			9.62	
			total: 32.09	
149	41.90	40.94 *(40.50)*	13.51	12
			16.78	
			4.13	
			11.39	
			total : 45.80	
162	44.20	43.22 *(42.72)*	14.34	7
			17.40	
			4.26	
			11.69	
			total: 46.23	
135	29.90	29.04 *(28.90)*	8.37	6
			11.02	
			3.17	
			8.07	
			total: 30.65	
79	46.30	45.25 *(44.75)*	15.53	11
			18.29	
			4.42	
			11.96	
			total: 50.20	
57	36.20	35.32 *(34.99)*	10.19	5
			12.86	
			3.10	
			10.83	
			total: 36.99	

*) 'av.' means the value averaged over the results of three measurement methods /1a/

Table 5 Inventory results of measurements /1a, 1c / for the individual samples [kg FP/tU$_{initial}$]

sample	**21**	**149**	**162**	**79**	**57**	**135**	**182**	**69**
isotope								
u235	7.65	6.99	6.12	4.13	9.52	12.87	16.06	11.77
u236	5.19	5.29	5.37	5.26	4.85	4.42	4.06	4.69
u238	931.19	931.99	930.45	930.32	937.4	943.11	947.45	940.14
cooling time for isotopes above	**4525**	**4529**	**4543**	**4554**	**4613**	**4613**	**4627**	**4627**
u234	0.189	0.189	0.188	0.094	0.105	0.24	0.135	0.172
cooling time	**data related to the end of irradiation**							
np237	1.43	1.46	1.49	1.59	1.11	0.78	0.71	1.03
cooling time	**data related to the end of irradiation**							
pu238	0.22	0.206	0.253	0.3	0.148	0.08	0.066	0.129
pu239	6.741	6.246	6.019	5.785	6.019	5.315	5.769	6.408
pu240	2.885	2.87	2.93	3.046	2.379	1.888	1.599	2.164
pu241	1.02	0.988	0.99	0.972	0.827	0.621	0.5	0.76
pu242	0.778	0.83	0.928	0.965	0.557	0.314	0.188	0.413
cooling time	**4525**	**4529**	**4543**	**4556**	**4610**	**4610**	**4627**	**4627**
am241	0.803	0.856	0.825	0.847	0.71	0.525	0.443	0.658
am242m	0.001248	0.001457	0.00114	0.001013	0.00108	0.000834	0.000982	0.001096
am243	0.16	0.19	0.21	0.266	0.103	0.041	0.024	0.07
cooling time	**4529**	**4530**	**4544**	**4554**	**4919**	**4615**	**4628**	**4628**
cm244	0.04494	0.05489	0.07464	0.1176	0.3003	0.0084	0.0042	0.0139
cm245	0.00473	0.00378	0.00722	0.01056	0.00135	0.00052	0.00025	0.00131
cm246	0.000414	0.00045	0.00056	0.000597	-	0.000061	0.000021	0.000132
cooling time	**4511**	**4511**	**4526**	**4556**	**4586**	**4586**	**4608**	**4607**
nd142	0.0294	0.0318	0.0339	0.0386	0.0206	0.0155	0.0078	0.0131
nd143	0.965	0.969	0.981	0.992	0.864	0.779	0.618	0.797
nd144	1.677	1.722	1.811	2.002	1.402	1.148	0.84	1.21
nd145	0.898	0.912	0.937	0.986	0.777	0.665	0.506	0.692
nd146	0.821	0.84	0.874	0.947	0.695	0.579	0.43	0.608
nd148	0.473	0.482	0.499	0.523	0.4	0.336	0.252	0.354
nd150	0.228	0.232	0.241	0.246	1.187	0.157	0.116	0.166
cooling time	**4529**	**4530**	**4544**	**4554**	**4615**	**4615**	**4628**	**4628**
cs133	1.328	1.416	1.471	1.462	1.253	1.078	0.848	1.11
cs134	0.00292	0.00238	0.00317	0.00313	0.00211	0.0014	0.00108	0.00172
cs135	0.476	0.488	0.48	0.46	0.449	0.415	0.389	0.46
cs137	1.122	2.202	1.26	1.263	0.993	0.826	0.637	0.883
cooling time	**4531**	**4530**	**4543**	**4556**	**4610**	**4610**	**4627**	**4627**
ce140	1.54	1.558	1.64	1.729	1.285	1.095	0.832	1.149
ce142	1.407	1.423	1.498	1.585	1.178	1.004	0.764	1.053
cooling time	**4536**	**4537**	**4544**	**4556**	**4614**	**4614**	**4630**	**4629**
sm147	0.2776	0.298	0.2882	0.2804	0.2692	0.2565	0.2543	0.263
sm148	0.1932	0.2103	0.2208	0.2315	0.1551	0.1178	0.0896	0.1272
sm149	0.00305	0.00319	0.00312	0.00294	0.00304	0.00299	0.00309	0.00306
sm150	0.3399	0.3686	0.3777	0.3878	0.2907	0.2405	0.2053	0.2544
sm151	0.0104	0.0112	0.0106	0.0102	0.0104	0.01	0.0102	0.0103
sm152	0.1148	0.124	0.1237	0.1243	0.1039	0.0922	0.0852	0.096
sm154	0.0435	0.0472	0.049	0.0507	0.0362	0.087	0.0233	0.0306
eu151	0.0002	0.000642	0.000324	0.000152	0.000384	0.00043	0.00133	0.000593
eu153	0.0222	0.0214	0.0205	0.0152	0.0217	0.0224	0.0199	0.0222
eu154	0.00188	0.00168	0.00156	0.00119	0.00156	0.00137	0.0012	0.00167
eu155	0.000262	0.00024	0.000191	0.000179	0.000256	0.000222	0.000203	0.00023

cooling time	**4536**	**4537**	**4545**	**4557**	**4616**	**4616**	**4631**	**4631**
mo95	0.92	0.93	0.97	1.01	0.78	0.69	0.53	0.72
tc99	0.96	0.96	1	1.02	0.82	0.72	0.55	0.75
cooling time	**4527**	**4532**	**4547**	**4558**	**4619**	**4619**	**4633**	**4633**
ru101	0.98	0.99	1.04	1.08	0.82	0.7	0.53	0.73
gd155	0.00134	0.0014	0.00143	0.00142	0.00114	0.00096	0.00075	0.001
cooling time	**4533**	**4538**	**4549**	**4560**	**4622**	**4622**	**4634**	**4634**
pd105	0.529	0.552	0.59	0.58	0.439	0.348	0.261	0.364
pd108	0.147	0.155	0.171	0.166	0.115	0.091	0.064	0.099
ag109	0.054	0.054	0.055	0.051	0.046	0.038	0.03	0.041
cooling time	**4538**	**4539**	**4550**	**4561**	**4623**	**4623**	**4635**	**4635**

Table 6 Errors of the measured values /1a/ for the individual isotopes and samples [the last one or two digits of the measured value of Table 5]

sample **isotope**	**21**	**149**	**162**	**79**	**57**	**135**	**182**	**69**
u234	47	47	46	68	47	38	36	46
u235	28	94	19	19	47	19	19	28
u236	28	94	19	19	19	96	19	95
u238	37	38	35	35	40	42	42	42
pu238	24	23	28	33	16	88	73	14
pu239	14	9	8	7	8	10	9	11
pu240	10	9	12	13	15	16	8	13
pu241	12	20	20	12	12	5	6	12
pu242	5	9	12	14	9	4	85	11
np237	10	10	10	11	78	56	50	71
am241	17	14	61	81	28	19	27	24
am242 E3	10	10	6	10	8	5	10	10
am243	87	90	63	13	52	20	12	42
cm244	36	44	61	94	24	67	33	11
cm245 E2	9	7	14	21	3	1	5	3
cm246 E4	4	4	6	6		7	2	13
nd142	9	9	9	9	6	5	23	5
nd143	9	9	9	10	8	8	6	8
nd144	10	11	11	13	8	7	5	7
nd145	9	9	9	9	8	6	5	7
nd146	8	8	8	9	7	6	4	6
nd148	5	5	5	5	4	3	2	3
nd150	2	2	2	2	2	15	1	2
cs133	46	50	51	50	43	38	34	36
cs134	6	7	6	6	6	7	5	8
cs135	19	19	18	16	16	17	16	17
cs137	50	50	50	67	53	44	40	47
ce140	50	50	51	60	53	44	40	46
ce142	50	50	60	61	50	50	38	53
ce144	51	52	55	56	50	37	35	38
sm147	50	52	52	51	50	47	46	47
sm148	33	38	41	42	28	25	16	23
sm149	10	13	10	10	10	11	11	10
sm150	55	66	60	70	50	40	37	46
sm151	25	22	22	20	22	20	20	21

sm152	20	22	22	22	18	16	15	17
sm154	22	24	26	25	20	15	12	17
eu151	12	12	10	6	14	16	18	16
eu153	11	11	10	7	11	11	10	11
eu154	21	21	21	16	19	18	14	18
eu155	11	11	10	7	11	12	11	12
mo95	17	17	17	18	14	12	96	13
tc99	17	17	18	18	15	13	10	14
ru101	18	18	19	19	15	13	96	13
pd105	96	99	11	11	79	63	47	66
pd108	26	28	31	30	21	16	12	17
ag109	15	15	16	14	13	11	84	11
gd155	12	13	13	13	97	82	63	85

Table 7 Irradiation history data of **sample 69** - values of linear power [W/cm] , av. T_{mod} [°K] /3/, av.T_{clad} [°K] /1a/ and av.T_{fuel} [°K] /3/ in the course of irradiation

CYCLE 15	duration [days]	linear power at sample position [W/cm]	specific power *) [MW/ass]	T fuel [K] /3/	Tmoderator [K] /3/	T cladding [K] /1/
phase 1	100	91.6	2.82	763	576	594
phase 2	100	109.3	3.36	803	575	597
phase 3	61	119.5	3.67	825	575	599
phase 4	35	143.5	4.41	880	571	600
CYCLE 16						
phase 1	100	91.1	2.80	762	573	592
phase 2	100	107.2	3.30	798	572	594
phase 3	143	117.6	3.62	821	572	595
phase 4	47	142.6	4.38	878	567	596
CYCLE 17						
phase 1	95	108.1	3.32	800	571	593
phase 2	3	119.5	3.67	825	570	594
CYCLE 18						
phase 1	100	101.9	3.13	786	567	588
phase 2	100	114.3	3.51	814	567	590
phase 3	107	120.1	3.69	827	566	590
phase 4	18	139.4	4.29	871	564	592

*) specific power [MW/ass] as the previous column value *244 {FA height}*126 {number of pins} usable for the simplified 1D depletion calculation, otherwise see /1a/ more detailed description and data

Table 8 Irradiation history data of **sample 21** - values of linear power [W/cm], av. T_{mod} [°K] /3/, av. T_{clad} [°K] /1a/ and av. T_{fuel} [°K] /3/ in the course of irradiation

CYCLE 15	duration [days]	linear power at sample position [W/cm]	specific power *) [MW/ass]	T fuel [K] /3/	Tmoderator [K] /3/	T cladding [K] /1/
phase 1	100	175.8	5.40	953	555	591
phase 2	100	166.2	5.11	932	555	589
phase 3	61	162.2	4.99	923	555	588
phase 4	35	143.6	4.42	880	553	582
CYCLE 16						
phase 1	100	175.9	5.41	953	554	590
phase 2	100	164.2	5.05	927	552	586
phase 3	143	155.7	4.79	908	551	583
phase 4	47	129.8	3.99	849	549	576
CYCLE 17						
phase 1	95	157.2	4.79	911	552	584
phase 2	3	151.1	4.61	897	551	581
CYCLE 18						
phase 1	100	132.7	4.08	856	550	577
phase 2	100	132.6	4.08	855	550	577
phase 3	107	130.6	4.01	851	549	576
phase 4	18	121.7	3.74	831	549	573

Table 9 Irradiation history data of **sample 182** - values of linear power [W/cm] , av. T_{mod} [°K] /3/, av.T_{clad} [°K] /1a/ and av.T_{fuel} [°K] /3/ in the course of irradiation

CYCLE 15	duration [days]	linear power at sample position [W/cm]	specific power *) [MW/ass]	T fuel [K] /3/	Tmoderator [K] /3/	T cladding [K] /1/
phase 1	100	85.0	2.61	749	546	563
phase 2	100	87.6	2.69	755	545	563
phase 3	61	91.5	2.81	763	545	564
phase 4	35	80.6	2.48	740	545	561
CYCLE 16						
phase 1	100	90.3	2.78	760	544	563
phase 2	100	93.4	2.87	767	544	563
phase 3	143	97.7	3.01	777	544	563
phase 4	47	84.3	2.59	748	543	560
CYCLE 17						
phase 1	95	106.1	3.26	795	543	565
phase 2	3	100.8	3.10	784	543	563
CYCLE 18						
phase 1	100	76.0	2.34	729	544	559
phase 2	100	84.1	2.58	747	543	560
phase 3	107	89.2	2.74	758	543	561
phase 4	18	83.7	2.57	746	542	559

Table 10 Irradiation history data of **sample 149** - values of linear power [W/cm], av. T_{mod} [°K] /3/, av.T_{clad} [°K] /1a/ and av.T_{fuel} [°K] /3/ in the course of irradiation

CYCLE 15	duration [days]	linear power at sample position [W/cm]	specific power *) [MW/ass]	T fuel [K] /3/	Tmoderator [K] /3/	T cladding [K] /1/
phase 1	100	185.5	5.70	974	553	591
phase 2	100	175.9	5.41	953	553	589
phase 3	61	171.8	5.28	944	553	588
phase 4	35	152.1	4.68	899	551	582
CYCLE 16						
phase 1	100	181.8	5.59	966	553	590
phase 2	100	169.6	5.21	939	551	586
phase 3	143	161.1	4.95	920	550	583
phase 4	47	134.4	4.13	860	548	576
CYCLE 17						
phase 1	95	162.1	4.98	922	551	584
phase 2	3	155.9	4.79	908	550	581
CYCLE 18						
phase 1	100	135.9	4.18	863	550	577
phase 2	100	135.9	4.18	863	550	577
phase 3	107	133.9	4.12	858	549	576
phase 4	18	125.0	3.84	838	548	574

Table 11 Irradiation history data of **sample 162** - values of linear power [W/cm], av. T_{mod} [°K] /3/, av.T_{clad} [°K] /1a/ and av.T_{fuel} [°K] /3/ in the course of irradiation

CYCLE 15	duration [days]	linear power at sample position [W/cm]	specific power *) [MW/ass]	T fuel [K] /3/	Tmoderator [K] /3/	T cladding [K] /1/
phase 1	100	196.4	6.04	997	551	591
phase 2	100	187.0	5.75	977	551	589
phase 3	61	182.6	5.61	968	551	588
phase 4	35	161.2	4.96	920	549	582
CYCLE 16						
phase 1	100	189.3	5.82	982	551	590
phase 2	100	176.1	5.41	954	550	586
phase 3	143	166.6	5.12	932	549	583
phase 4	47	138.7	4.27	869	548	576
CYCLE 17						
phase 1	95	167.3	5.14	934	550	584
phase 2	3	160.6	4.94	919	549	581
CYCLE 18						
phase 1	100	139.4	4.29	871	549	577
phase 2	100	139.4	4.29	871	548	577
phase 3	107	137.2	4.22	866	548	576
phase 4	18	127.6	3.92	844	548	573

Table 12 Irradiation history data of **sample 57** - values of linear power [W/cm], av. T_{mod} [°K] /3/, av.T_{clad} [°K] /1a/ and av.T_{fuel} [°K] /3/ in the course of irradiation

CYCLE 15	duration [days]	linear power at sample position [W/cm]	specific power *) [MW/ass]]	T fuel [K] /3/	Tmoderator [K] /3/	T cladding [K] /1/
phase 1	100	109.4	3.36	803	572	594
phase 2	100	132.0	4.06	854	570	597
phase 3	61	144.7	4.45	883	569	599
phase 4	35	177.1	5.44	954	565	600
CYCLE 16						
phase 1	100	104.1	3.20	791	571	592
phase 2	100	122.5	3.77	832	569	594
phase 3	143	133.8	4.11	858	568	595
phase 4	47	163.3	5.02	924	563	596
CYCLE 17						
phase 1	95	121.1	3.72	829	569	593
phase 2	3	133.6	4.11	858	567	594
CYCLE 18						
phase 1	100	115.8	3.56	817	565	588
phase 2	100	128.8	3.96	847	564	590
phase 3	107	134.4	4.13	859	563	590
phase 4	18	154.9	4.76	906	561	592

Table 13 Irradiation history data of **sample 79** - values of linear power [W/cm] , av. T_{mod} [°K] /3/, av.T_{clad} [°K] /1a/ and av.T_{fuel} [°K] /3/ in the course of irradiation

CYCLE 15	duration [days]	linear power at sample position [W/cm]	specific power *) [MW/ass]	T fuel [K] /3/	Tmoderator [K] /3/	T cladding [K] /1/
phase 1	100	212.4	6.53	1031	548	591
phase 2	100	203.0	6.24	1012	548	589
phase 3	61	197.8	6.08	1000	548	588
phase 4	35	174.3	5.36	949	547	582
CYCLE 16						
phase 1	100	200.1	6.15	1005	549	590
phase 2	100	185.5	5.70	974	548	586
phase 3	143	174.5	5.36	950	548	583
phase 4	47	144.2	4.43	882	546	576
CYCLE 17						
phase 1	95	173.6	5.34	948	549	584
phase 2	3	166.2	5.11	931	548	581
CYCLE 18						
phase 1	100	143.4	4.41	880	548	577
phase 2	100	142.7	4.39	878	548	577
phase 3	107	140.4	4.32	873	547	576
phase 4	18	130.5	4.01	851	547	573

Table 14 Irradiation history data of **sample 135** - values of linear power [W/cm], av. T_{mod} [°K] /3/, av.T_{clad} [°K] /1a/ and av.T_{fuel} [°K] /3/ in the course of irradiation

CYCLE 15	duration [days]	linear power at sample position [W/cm]	specific power *) [MW/ass]	T fuel [K] /3/	Tmoderator [K] /3/	T cladding [K] /1/
phase 1	100	106.5	3.27	796	541	563
phase 2	100	110.0	3.38	804	541	563
phase 3	61	114.6	3.52	815	541	564
phase 4	35	101.1	3.11	785	540	561
CYCLE 16						
phase 1	100	105.6	3.25	794	541	563
phase 2	100	109.2	3.36	802	541	563
phase 3	143	113.9	3.50	813	540	563
phase 4	47	98.1	3.02	778	540	560
CYCLE 17						
phase 1	95	124.7	3.83	837	539	565
phase 2	3	117.8	3.62	822	539	563
CYCLE 18						
phase 1	100	87.7	2.70	755	541	559
phase 2	100	96.8	2.98	775	541	560
phase 3	107	102.0	3.14	786	540	561
phase 4	18	95.5	2.94	772	540	559

BENCHMARK RESULTS

Participants are requested to calculate sample compositions and report calculated isotopic concentrations for the isotopes measured under the #2670 ISTC project and provided in /1a /, see Table 5.

General data:

Date
Institute
Participants
Computer code and data library identification**)
Notes

Please, forward the results by e-mail to NRI (mar@nri.cz).

**) The data specified and listed above create a set of the data values which can enter as input data for calculations. Please, make a note on the level of simplification of the depletion model as embodied by the code used for the calculation in case the code is country specific/no publicly known (at sending the results).

REFERENCES

/1/ Documents describing the #2670 PIE performance and results from the measurement:

a. L. J. Jardine: Radiochemical Assays of Irradiated VVER-440 Fuel for Use in Spent Fuel Burnup Credit Activities, Lawrence Livermore National Laboratory, UCRL-TR-212202, April 2005, http://www.llnl.gov/tid/lof/documents/pdf/319467.pdf
b. Data notes and additions 1 of A.Chetverikov, the RIAR email of August 23, 2006
c. Data notes and additions 2 of A.Chetverikov, the RIAR email of December 13, 2006
d. Data notes and additions 3 of A.Chetverikov, the RIAR email of December 27, 2006
e. Personal communication with A.Chetverikov, Jan. 19, 2007 and letter of Feb.12,2007

/2/ Markova L., Calculational Burnup Credit Benchmark Proposal, 6th AER Symposium on VVER Reactor Physics and Reactor Safety, Kirkkonummi, Finland, Sept. 23-26, 1996

/3/ I.Tinka, J. Kratochvil: Aproximace strednich teplot paliva v aktivni zone VVER 440 [Approximation of Average Fuel Temperature for VVER-440 Core], in Czech, 'Jaderna Energie' Journal, Vol. 34, No.2, 1988

/4/ A. Chetverikov, RIAR Dimitrovgrad - personal communication on burnup unit recalculation formula used in Russia for the given fuel design / enrichment/ burnup: $B[MWd/kg_{Uinit}]=(0.965\div0.968) *B_F[kg_{FPs}/t_{Uinit}]$

/5/ SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation, NUREG/CR-0200, Rev.4 (ORNL/NUREG/CSD-2/R6), Vols. I,II, and III (Dec. 1999). Version 4.4a , RSIC code package CCC-545/17.