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INVESTIGATION OF GEOMETRY AND FUEL COMPOSITION IN TWO-ZONE SUBCRITICAL RESEARCH REACTOR FOR NUCLEAR WASTE TRANSMUTATION

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The investigations directed to optimization of fuel compositions for two-zone subcritical reactor is considered in present paper. The study of two-zone subcritical reactor with heterogeneous fuel regard to geometrical, material and economical characteristics was carried out within the scope of this paper. The calculations of transmutation characteristics for main isotopes regard to radioactive waste from conventional nuclear reactors was carried out. There is a possibility for selection of material and geometrical characteristics of two-zone subcritical system in such a way as to satisfy the objectives for development of subcritical reactor in relation to the magnitude of the neutron flux, the transmutation parameters and the cost of system.

INTRODUCTION

Further progress of nuclear energy in the world is impossible without the development of new types of research reactors, otherwise it is impossible to obtain new experimental data for benchmark calculations, verification of new software codes, etc.

One of the greatest challenges for nuclear energy is highly radioactive waste generated during irradiation in nuclear reactors. Most of the radioactive hazard from irradiated nuclear fuel originates from only a few chemical elements: plutonium, neptunium, americium, curium and some long-lived fission products such as iodine and technetium. These radioactive by-products, although present at very low concentrations in the waste fuel. As such, it requires isolation from environment in stable deep geological formations for long periods of time. Partitioning and transmutation (P&T) [1] technology is considered as an instrument of reducing the burden on a geological disposal. As plutonium and the minor actinides (MA) are mainly responsible for the long-term radiotoxicity, when these nuclides are first removed from the irradiated fuel (partitioning) and then fragmented by fission (transmutation), the remaining waste loses most of its long-term radiotoxicity.

Accelerator driven systems (ADS) are advanced nuclear systems, which are particularly suitable for transmutation objectives. Such a nuclear reactor may be employed to address several missions, for example transmutation and generate electricity. ADS presents several benefits: more flexible with respect to fuel composition and potentially raised safety.

As the issue of spent fuel management is one of the most important of the future nuclear power development in the world, the study of transmutation possibilities also relevant. There are many international projects in this way, for example: MYRRHA [2], YALINA [3], SAD etc., and Ukraine is no exception. We have already built a subcritical system with an electron accelerator in Kharkiv [4], and in the nearly future, it is planned to be launched.

In this work, the authors' main focus on investigation of two-zone subcritical reactor driven by high-intensity neutron generator.

1. MODELING SCHEME AND CALCULATION METHODS

The presented subcritical system has two zones with different neutron spectrum. A graphite moderator was added to arrange the thermal neutron spectrum in the outer zone. The scheme with light water moderator and coolant is used, was not considered due to the risk of light water getting into the inner zone during an emergency and a significant splash of reactivity, as a result. Helium was selected to be a coolant in the internal and external zones [5].

The geometric and material characteristics of the WWER-1000 reactor fuel rods were used in the fuel cell model development for the subcritical reactor both zones. The fuel in fuel cells is uranium dioxide at different uranium-235 enrichment: *System I* (in the internal enrichment zone – 10%, in the external enrichment zone – 5%); *System II* (in the internal enrichment zone – 15%, in the external enrichment zone – 3%). The fuel density is 10.96 g/cm^3, the fuel rod's shell is zirconium+1% of niobium, the fuel cell diameter is 0.786 cm, the fuel rod's shell diameter is 0.91 cm, the fuel rods step in the inner zone is 1.275 cm. The fuel rod placement square grid was selected for the subcritical reactor both zones. The uranium dioxide enrichment in the inner zone at the level of 10…15% was selected based on the IAEA recommendations on reducing the uranium-235 enrichment level in the subcritical research reactors projects [6].

Fuel rods in the outer zone are located for the step of 5 cm. There is the space of the helium coolant to dissipate heat, which is equivalent to the space in the inner zone with the fuel rods step of 1.275 cm, around each fuel rod.

The Monte-Carlo Serpent 2.1.26 code was used for the neutron modeling in the calculations described below [7]. This code is used successfully both for the traditional nuclear reactors calculation and innovative reactors [8–11] and for other applications [12, 13]. The ENDF/B-VII library has been used as the evaluated nuclear data library for all presented calculations [14].

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2. SERPENT MODELING RESULTS

2.1. NEUTRON AND ECONOMIC PARAMETERS CALCULATION OF SYSTEM WITH HETEROGENEOUS FUEL COMPOSITION

The first step in the subcritical systems with heterogeneous fuel composition study was to model the change in the internal zone volume with fixed fuel composition of both zones (for *Systems I* and *II*) and with a fuel rod in the external zone fixed step of 5 cm. The cross section of the subcritical reactor typical two-zone model designed by Serpent code is shown in Fig. 1. Fig. 2 shows the "mesh" image of the subcritical reactor both zones cross-section. As indicated in the Serpent code description concerning the "mesh" images: "... the color scheme is divided into "hot" shades of red and yellow, representing the relative divisions power in the system, and "cold" shades of blue, representing the relative heat flux (the flow below 0.625 eV)". Presented Figs. 1 and 2 belong to *System I* with the inner zone radius of 10.5 cm.

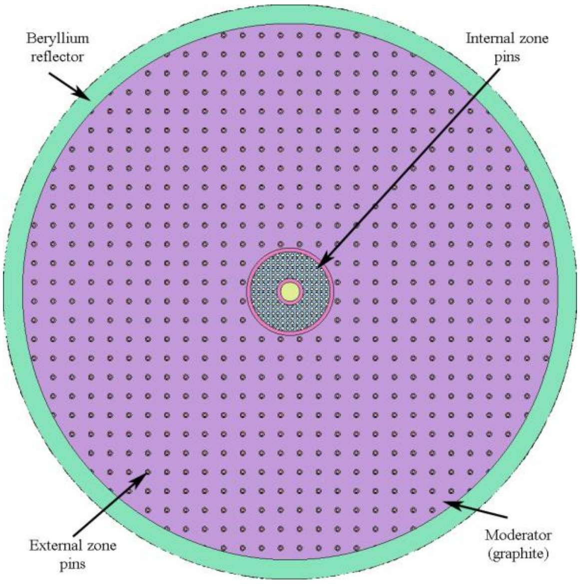

Fig. 1. A subcritical reactor typical model scheme (cross-section)

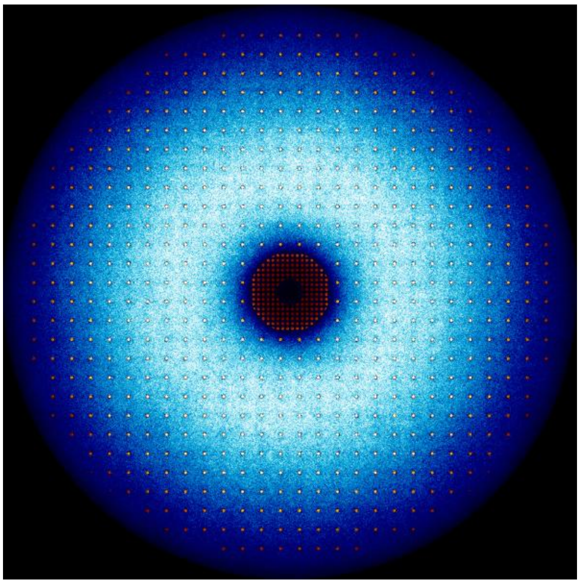

Fig. 2. Mesh image of the subcritical reactor (cross-section)

System I was modeled to change the inner zone radius (and consequently the inner zone volume) in the range from 10.5 to 43.5 cm, and *System II* was modeled to change the inner zone radius in the range from 10.5 to 50.5 cm. The neutron fluxes normalized to one neutron of an external source for internal and external zones and for the entire subcritical system were counted. The main Serpent modeling neutron, geometric and economic characteristics for *System I* are presented in Tabl. 1, for *System II* – in Tabl. 2. The main modeling parameters were similar to those described in the previous article (homogeneous model calculation) [19] in the "1.3 Modeling scheme" section and selected on the basis of the author's previous works [15–20].

The designations in Tables 1 and 2 include the following values: R_{int} – the inner zone radius, cm; V_{ext}/V_{int} – ratio of external and internal zones volumes; F_{int} – the neutron flux in the inner zone in relation to an external source one neutron; F_{ext} – the neutron flux in the external zone in relation to an external source one neutron; F_{sum} – the total neutron flux in the entire subcritical system in relation to an external source one neutron; C_{int} – estimated fuel cost in the inner zone, mln Euro; C_{ext} – estimated fuel cost in the external zone, mln Euro; C_{sum} – estimated fuel cost in the entire subcritical system, mln Euro. The fuel cost estimate was based on the current point price of uranium dioxide plus the uranium-235 enrichment cost.

Table 1

The Serpent modeling of a two-zone subcritical model with heterogeneous fuel composition results (*System I*)

R_{int}, cm	V_{ext}/V_{int}	F_{int}	F_{ext}	F_{sum}	C_{int}, mln Euro	C_{ext}, mln Euro	C_{sum}, mln Euro
1	2	3	4	5	6	7	8
10.50	49.51	7.01	221.03	228.03	0.35	0.54	0.89
11.50	40.71	8.32	218.76	227.08	0.43	0.54	0.97
12.50	34.24	9.74	216.42	226.15	0.52	0.55	1.07
13.50	29.34	11.06	215.67	226.73	0.62	0.56	1.18
14.50	25.26	12.68	213.25	225.93	0.73	0.57	1.29
15.50	22.18	14.19	210.38	224.57	0.85	0.58	1.42
16.50	19.60	15.61	208.51	224.11	0.97	0.59	1.56
17.50	17.51	17.04	206.75	223.78	1.11	0.60	1.70
18.50	15.85	18.55	204.87	223.42	1.26	0.61	1.87

1	2	3	4	5	6	7	8
19.50	14.35	20.20	203.06	223.26	1.41	0.62	2.03
20.50	13.02	21.84	200.63	222.47	1.57	0.63	2.21
21.50	11.91	23.52	199.18	222.69	1.75	0.64	2.39
22.50	11.04	24.75	198.33	223.08	1.94	0.66	2.60
23.50	10.13	26.65	195.47	222.12	2.14	0.67	2.80
24.50	9.40	28.29	193.10	221.39	2.35	0.68	3.03
25.50	8.75	29.99	191.47	221.45	2.57	0.69	3.26
26.50	8.18	31.37	189.41	220.77	2.80	0.71	3.51
27.50	7.66	33.13	188.31	221.44	3.05	0.72	3.77
28.50	7.19	34.90	186.80	221.70	3.31	0.73	4.04
29.50	6.77	36.33	184.97	221.30	3.58	0.75	4.32
30.50	6.39	38.16	182.24	220.40	3.86	0.76	4.62
31.50	6.04	39.79	180.86	220.64	4.16	0.77	4.93
32.50	5.73	41.49	179.14	220.63	4.47	0.79	5.26
33.50	5.44	43.29	177.35	220.64	4.79	0.80	5.59
34.50	5.15	45.06	175.11	220.17	5.12	0.81	5.93
35.50	4.89	46.86	173.02	219.88	5.46	0.82	6.29
36.50	4.66	48.69	171.55	220.23	5.83	0.83	6.66
37.50	4.45	50.34	170.29	220.62	6.21	0.85	7.06
38.50	4.27	51.59	168.63	220.21	6.61	0.87	7.47
39.50	4.08	53.56	166.02	219.58	7.01	0.88	7.89
40.50	3.91	55.45	164.29	219.74	7.43	0.89	8.33
41.50	3.74	57.30	162.59	219.89	7.87	0.91	8.78
42.50	3.62	58.55	162.27	220.82	8.35	0.93	9.28
43.50	3.47	60.65	159.76	220.41	8.80	0.94	9.74

It can seen from Tabl. 1 that with increasing the inner zone volume, the neutron flux in the inner zone increases significantly (by almost 9 times), and the neutron flux in the outer zone decreases by 40%, while the total neutron flux in both zones remains almost the same. During the economic characteristics analysis the fuel cost in the inner zone is seen to increase by about 25 times, the fuel cost in the external zone – by 43% and the fuel cost of the whole subcritical system – by almost 11 times. From these results, we can conclude that in order to create favorable conditions for investigating the transmutation of minor actinides in the inner zone rapid spectrum, it is necessary to increase the more enriched fuel volume significantly and as a consequence, the cost of the entire subcritical system increases significantly.

It can be seen from Tabl. 2 that using more enriched fuel in the inner zone allows to get higher neutron fluxes in the thermal zone, but at the same time the cost of the entire subcritical system increases due to more expensive enrichment to 15% by uranium-235. Using less enriched fuel in the thermal zone allows to increase the thermal zone size but then the cost of fuel in the thermal zone increases.

Table 2

The Serpent modeling of a two-zone subcritical model with heterogeneous fuel composition results (*System II*)

R_{int}, cm	V_{ext}/V_{int}	F_{int}	F_{ext}	F_{sum}	C_{int}, mln Euro	C_{ext}, mln Euro	C_{sum}, mln Euro
1	2	3	4	5	6	7	8
10.50	73.42	6.82	265.36	272.18	0.55	0.73	1.28
11.50	59.76	8.28	262.39	270.67	0.67	0.73	1.40
12.50	49.48	9.71	258.73	268.44	0.80	0.73	1.53
13.50	41.73	11.23	255.58	266.81	0.94	0.72	1.67
14.50	35.69	12.84	251.93	264.77	1.10	0.72	1.82
15.50	30.86	14.70	248.46	263.15	1.27	0.72	1.98
16.50	26.93	16.37	244.30	260.67	1.44	0.71	2.16
17.50	23.58	18.56	240.23	258.79	1.63	0.71	2.34
18.50	20.90	20.50	236.54	257.03	1.83	0.70	2.53
19.50	18.72	22.25	233.07	255.32	2.04	0.70	2.75
20.50	16.78	24.42	229.14	253.55	2.27	0.70	2.97
21.50	15.12	26.45	225.10	251.55	2.50	0.69	3.19
22.50	13.66	28.73	220.86	249.59	2.74	0.69	3.43
23.50	12.42	31.02	216.96	247.98	3.00	0.68	3.68
24.50	11.32	33.27	212.73	246.00	3.27	0.68	3.94
25.50	10.35	35.59	208.38	243.97	3.54	0.67	4.22
26.50	9.49	38.15	203.71	241.85	3.83	0.67	4.50

1	2	3	4	5	6	7	8
27.50	8.73	40.24	200.16	240.40	4.13	0.66	4.79
28.50	8.07	42.67	196.24	238.92	4.45	0.66	5.11
29.50	7.48	45.07	191.80	236.87	4.78	0.66	5.43
30.50	6.92	47.68	187.48	235.16	5.11	0.65	5.76
31.50	6.42	49.84	183.48	233.32	5.46	0.64	6.10
32.50	5.98	52.62	179.25	231.87	5.82	0.64	6.46
33.50	5.56	55.18	174.71	229.88	6.19	0.63	6.82
34.50	5.19	57.34	171.01	228.34	6.57	0.63	7.20
35.50	4.84	59.99	166.38	226.37	6.96	0.62	7.58
36.50	4.53	62.62	162.66	225.28	7.37	0.61	7.99
37.50	4.27	64.83	159.30	224.13	7.81	0.61	8.42
38.50	4.01	67.45	155.11	222.56	8.25	0.61	8.85
39.50	3.75	69.99	151.06	221.05	8.68	0.60	9.28
40.50	3.53	72.28	147.34	219.62	9.14	0.59	9.73
41.50	3.33	75.05	143.17	218.22	9.62	0.59	10.21
42.50	3.12	77.61	139.28	216.89	10.09	0.58	10.67
43.50	2.95	79.91	135.34	215.25	10.59	0.57	11.17
44.50	2.78	82.60	131.42	214.02	11.10	0.57	11.67
45.50	2.63	84.88	128.01	212.90	11.64	0.56	12.20
46.50	2.47	87.35	124.14	211.49	12.16	0.55	12.71
47.50	2.33	90.06	120.39	210.45	12.70	0.54	13.25
48.50	2.21	92.23	116.90	209.13	13.28	0.54	13.82
49.50	2.09	94.50	113.20	207.71	13.85	0.53	14.38
50.50	1.99	96.71	110.26	206.97	14.47	0.53	14.99

2.2. CALCULATION OF A SYSTEM WITH A HETEROGENEOUS FUEL COMPOSITION TRANSMUTATIONAL CHARACTERISTICS

Since one of the main presented subcritical reactor assignments is the radioactive waste transmutation study, a number of studies have been carried out to determine the main transmutation characteristics. Such Serpent simulations results are presented in Tabl. 3 *for System I* and Tabl. 4 *for System II*. The Np-237 and Am-243 radioactive isotopes were selected from the minor actinides group and I-129 and Tc-99 were selected from the long-lived fission products group for the subcritical system transmutation characteristics study [21].

Table 3

Transmutation characteristics of a two-zone subcritical model with heterogeneous fuel composition (*System I*)

R_{int}, cm	$\sigma_f^{Np\text{-}237}$, barn	$\sigma_f^{Am\text{-}243}$, barn	$\sigma_c^{Np\text{-}237}$, barn	$\sigma_c^{Am\text{-}243}$, barn	$\alpha^{Np\text{-}237}$	$\alpha^{Am\text{-}243}$	$\sigma_c^{I\text{-}129}$, barn	$\sigma_c^{Tc\text{-}99}$, barn
1	2	3	4	5	6	7	8	9
10.50	0.4992	0.3654	12.3855	24.9477	24.81	68.28	5.2583	15.7608
11.50	0.4945	0.3566	11.3526	23.0604	22.96	64.66	5.2351	15.7291
12.50	0.4900	0.3502	10.9041	22.0777	22.25	63.04	5.2259	15.7262
13.50	0.4833	0.3427	10.2751	20.7755	21.26	60.62	5.2176	15.7207
14.50	0.4826	0.3401	9.6706	19.5964	20.04	57.62	5.2081	15.6873
15.50	0.4749	0.3302	8.9985	18.2190	18.95	55.18	5.1764	15.7013
16.50	0.4700	0.3246	8.4686	17.2603	18.02	53.18	5.1607	15.6795
17.50	0.4692	0.3227	8.2013	16.4375	17.48	50.94	5.1597	15.6779
18.50	0.4656	0.3185	7.9632	16.5041	17.10	51.81	5.1434	15.6900
19.50	0.4614	0.3136	7.5949	15.3214	16.46	48.86	5.1328	15.6732
20.50	0.4587	0.3101	7.2880	14.9243	15.89	48.12	5.1162	15.6655
21.50	0.4552	0.3059	6.8847	14.1817	15.12	46.36	5.1140	15.6528
22.50	0.4506	0.3011	6.7580	13.6573	15.00	45.36	5.1157	15.6690
23.50	0.4472	0.2974	6.6177	12.9505	14.80	43.55	5.0968	15.6560
24.50	0.4448	0.2950	6.3249	12.7432	14.22	43.19	5.0815	15.6372
25.50	0.4416	0.2914	6.0863	12.1703	13.78	41.76	5.0736	15.6698
26.50	0.4379	0.2876	5.8645	11.8307	13.39	41.14	5.0558	15.6278
27.50	0.4341	0.2844	5.8405	11.6339	13.45	40.90	5.0628	15.6506
28.50	0.4332	0.2833	5.6817	11.3048	13.11	39.91	5.0560	15.6309
29.50	0.4278	0.2784	5.5146	10.9821	12.89	39.44	5.0520	15.6327
30.50	0.4269	0.2767	5.2857	10.3033	12.38	37.24	5.0328	15.6043
31.50	0.4237	0.2739	5.1828	10.1327	12.23	36.99	5.0279	15.5983

1	2	3	4	5	6	7	8	9
32.50	0.4221	0.2724	5.1477	10.1250	12.19	37.17	5.0208	15.6141
33.50	0.4200	0.2703	5.0033	9.8747	11.91	36.53	5.0146	15.6037
34.50	0.4180	0.2682	4.8613	9.3366	11.63	34.81	5.0075	15.5863
35.50	0.4158	0.2661	4.7311	8.9581	11.38	33.67	4.9905	15.5917
36.50	0.4135	0.2642	4.6836	8.9224	11.33	33.78	4.9867	15.5795
37.50	0.4119	0.2625	4.5949	8.8349	11.16	33.66	4.9935	15.5878
38.50	0.4089	0.2603	4.5487	8.7098	11.12	33.46	4.9828	15.6036
39.50	0.4077	0.2589	4.3694	8.3748	10.72	32.35	4.9626	15.5735
40.50	0.4062	0.2572	4.3097	8.0917	10.61	31.46	4.9543	15.5708
41.50	0.4036	0.2553	4.2586	8.0849	10.55	31.67	4.9556	15.5610
42.50	0.4018	0.2535	4.2029	7.7776	10.46	30.68	4.9604	15.5654
43.50	0.4009	0.2529	4.1368	7.6835	10.32	30.38	4.9456	15.5897

Table 4

Transmutation characteristics of a two-zone subcritical model with heterogeneous fuel composition (*System II*)

R_{int}, cm	σ_f^{Np-237}, barn	σ_f^{Am-243}, barn	σ_c^{Np-237}, barn	σ_c^{Am-243}, barn	α^{Np-237}	α^{Am-243}	σ_c^{I-129}, barn	σ_c^{Tc-99}, barn
1	2	3	4	5	6	7	8	9
10.50	0.5341	0.3852	10.0698	20.2898	18.85	52.68	6.5009	15.7011
11.50	0.5288	0.3763	9.0191	18.1078	17.06	48.12	6.4658	15.6882
12.50	0.5247	0.3700	8.4916	17.3700	16.18	46.95	6.4441	15.6604
13.50	0.5189	0.3633	8.0888	16.9456	15.59	46.64	6.4124	15.6805
14.50	0.5134	0.3561	7.5780	15.6143	14.76	43.85	6.3895	15.6573
15.50	0.5094	0.3502	7.1034	14.5061	13.95	41.42	6.3622	15.6550
16.50	0.5049	0.3445	6.6933	13.6417	13.26	39.60	6.3347	15.6299
17.50	0.5024	0.3410	6.3384	12.8949	12.62	37.82	6.3095	15.6308
18.50	0.4976	0.3360	6.0730	12.2299	12.20	36.40	6.2808	15.6225
19.50	0.4934	0.3308	5.8314	11.6141	11.82	35.11	6.2497	15.6016
20.50	0.4895	0.3263	5.5606	10.9183	11.36	33.46	6.2278	15.5818
21.50	0.4870	0.3230	5.3144	10.6487	10.91	32.97	6.1952	15.5762
22.50	0.4829	0.3193	5.1392	10.1364	10.64	31.75	6.1676	15.5817
23.50	0.4804	0.3164	4.9452	9.6248	10.29	30.42	6.1385	15.5640
24.50	0.4774	0.3133	4.7966	9.2815	10.05	29.63	6.1184	15.5571
25.50	0.4749	0.3099	4.6047	8.8945	9.70	28.70	6.0831	15.5593
26.50	0.4717	0.3072	4.4137	8.5807	9.36	27.93	6.0485	15.5449
27.50	0.4686	0.3039	4.3355	8.2401	9.25	27.12	6.0238	15.5351
28.50	0.4672	0.3023	4.2592	8.2904	9.12	27.42	5.9917	15.5302
29.50	0.4638	0.2995	4.1091	8.0165	8.86	26.77	5.9576	15.5198
30.50	0.4617	0.2971	3.9327	7.2707	8.52	24.47	5.9271	15.4959
31.50	0.4587	0.2945	3.8905	7.2487	8.48	24.62	5.9032	15.4882
32.50	0.4585	0.2940	3.8242	7.2105	8.34	24.52	5.8773	15.4663
33.50	0.4549	0.2901	3.7054	6.8724	8.15	23.69	5.8303	15.4657
34.50	0.4527	0.2885	3.6180	6.7184	7.99	23.29	5.7983	15.4582
35.50	0.4512	0.2866	3.4957	6.4257	7.75	22.42	5.7573	15.4628
36.50	0.4495	0.2850	3.4347	6.3602	7.64	22.32	5.7348	15.4267
37.50	0.4478	0.2836	3.4046	6.2396	7.60	22.00	5.7106	15.4377
38.50	0.4451	0.2811	3.3658	6.0308	7.56	21.45	5.6692	15.4060
39.50	0.4426	0.2788	3.2409	5.8611	7.32	21.02	5.6294	15.3977
40.50	0.4421	0.2780	3.1696	5.6236	7.17	20.23	5.5841	15.3929
41.50	0.4411	0.2773	3.1047	5.4582	7.04	19.69	5.5476	15.3609
42.50	0.4393	0.2756	3.0641	5.4124	6.97	19.64	5.5217	15.3763
43.50	0.4379	0.2743	3.0098	5.2986	6.87	19.31	5.4693	15.3646
44.50	0.4362	0.2726	2.9317	5.1045	6.72	18.72	5.4240	15.3168
45.50	0.4349	0.2718	2.8825	5.0096	6.63	18.43	5.3911	15.3075
46.50	0.4329	0.2698	2.8513	4.8816	6.59	18.09	5.3456	15.2828
47.50	0.4320	0.2690	2.8021	4.8333	6.49	17.97	5.3140	15.3056
48.50	0.4316	0.2685	2.7554	4.6937	6.38	17.48	5.2667	15.2789
49.50	0.4304	0.2675	2.7065	4.6015	6.29	17.20	5.2037	15.2456
50.50	0.4300	0.2668	2.6749	4.4728	6.22	16.76	5.1687	15.2293

The designations in Tables 3 and 4 include the following values: R_{int} – the inner zone radius, cm; $\sigma_f^{Np\text{-}237}$ – the microscopic cross-section of the fission reaction for Np-237 in the inner zone, barn; $\sigma_f^{Am\text{-}243}$ – the microscopic cross-section of the fission reaction for Am-243 in the inner zone, barn; $\sigma_c^{Np\text{-}237}$ – the microscopic cross-section of the capture reaction for Np-237 in the inner zone, barn; $\sigma_c^{Am\text{-}243}$ – the microscopic cross-section of the capture reaction for Am-243 in the inner zone, barn; $\alpha^{Np\text{-}237}$ – the microscopic cross-section of the capture reaction ratio to the microscopic cross-section of the fission reaction for Np-237 in the inner zone [22]; $\alpha^{Am\text{-}243}$ – the microscopic cross-section of the capture reaction ratio to the microscopic cross-section of the fission reaction for Am-243 in the inner zone; $\sigma_c^{I\text{-}129}$ – microscopic cross-section of the capture reaction for I-129 in the outer zone, barn; $\sigma_c^{Tc\text{-}99}$ – microscopic cross-section of the capture reaction for Tc-99 in the outer zone, barn. Microscopic cross-sections are calculated as averaged over the specified zones entire volume. From Tabl. 3 for *System I*, it is clearly seen that with increasing the inner zone volume, the transmutation characteristics of the system for minor actinides considerably improve. It can be seen that parameter α decreases by almost 2.4 times for Np-237 and for Am-243 parameter α decreases by almost 2.23 times. At the same time the transmutation characteristics for long-lived fission products are reduced slightly (up to 6% for I-129). From Tabl. 4 for *System II*, the same is seen with increasing the inner zone volume: the transmutation characteristics of the system for minor actinides considerably improve; parameter α decreases by almost 3 times for Np-237 and for Am-243 parameter α decreases by almost 3.15 times. At the same time the microscopic cross-sections of the capture reaction for long-lived fission products decrease slightly for the thermal zone.

Comparing the *System I* and *Systems II* transmutation characteristics, the following can be noted: a) the division cross-sections for minor actinides are higher for *System II*; b) the capture cross-sections for minor actinides are lower also for *System II*; c) as a consequence, the α parameter for *System II* is much better than for *System I*, which allows us to conclude that fuel with 15% enrichment creates better conditions for minor actinides transmutation than fuel with a 10% enrichment; d) *System II* has a higher capture cross-section than *System I* for iodine and a bit lower for technetium. Summing up the comparison of the presented systems, it can be concluded that *System II* has better transmutation characteristics for both minor actinides and for long-lived fission products (iodine-129).

These results give an opportunity to select the geometric and material characteristics of the research two-zone subcritical reactor in such a way that neutron and transmutation parameters meet the purposes of creating this reactor.

CONCLUSIONS

A two-zone subcritical reactor model with fast neutron spectra and the thermal one in the internal and external zones was developed using Serpent code. At the same time the uranium-235 enrichment maximum level did not exceed 10…15% which complies with the IAEA recommendations for new subcritical reactors projects [6].

An optimization modeling of the two-zone subcritical system main neutron, economic and transmutation characteristics for various geometric parameters was carried out.

It was shown that it is possible to choose the two-zone subcritical system fuel composition and geometry in such a way that the system transmutation and neutron characteristics and the fuel cost fulfill the purposes of creating a research subcritical reactor.

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ИССЛЕДОВАНИЕ ГЕОМЕТРИИ И ТОПЛИВНОГО СОСТАВА ДВУХЗОННОГО ПОДКРИТИЧЕСКОГО ЯДЕРНОГО РЕАКТОРА ДЛЯ ТРАНСМУТАЦИИ ЯДЕРНЫХ ОТХОДОВ

Д.О. Шеляговский, В.И. Гулик, А.В. Носовский

Представлены результаты исследований, направленных на оптимизацию топливного состава двухзонного подкритического ядерного реактора. В рамках данной работы были выполнены исследования двухзонного подкритического реактора с гетерогенным составом топлива в отношении геометрических, материальных и экономических параметров рассмотренной системы. Также был выполнен расчет трансмутационных характеристик системы для основных изотопов, которые относятся к проблемным элементам радиоактивных отходов действующих ядерных реакторов. Было показано, что можно подобрать материальные и геометрические характеристики двухзонной подкритической системы таким образом, чтобы это удовлетворяло целям создания подкритического реактора в отношении величины потока нейтронов, трансмутационных параметров и стоимости системы.

ДОСЛІДЖЕННЯ ГЕОМЕТРІЇ І ПАЛИВНОГО СКЛАДУ ДВОЗОННОГО ПІДКРИТИЧНОГО ЯДЕРНОГО РЕАКТОРА ДЛЯ ТРАНСМУТАЦІЇ ЯДЕРНИХ ВІДХОДІВ

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Представлені результати досліджень, спрямованих на оптимізацію паливного складу двозонного підкритичного ядерного реактора. В рамках даної роботи були виконані дослідження двозонного підкритичного реактора з гетерогенним складом палива відносно геометричних, матеріальних і економічних параметрів розглянутої системи. Також було виконано розрахунок трансмутаційних характеристик системи для основних ізотопів, які відносяться до проблемних елементів радіоактивних відходів діючих ядерних реакторів. Було показано, що можна підібрати матеріальні і геометричні характеристики двозонної підкритичній системи таким чином, щоб це задовольняло цілям створення підкритичного реактора щодо величини потоку нейтронів, трансмутаційних параметрів і вартості системи.