NEUTRON-PHYSICAL CHARACTERISTICS OF BLANKET OF HYBRID FUSION NEUTRON SOURCE BASED ON SOLUTION OF THORIUM NITRATE AND MINOR ACTINIDES IN HEAVY WATER

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1. INTRODUCTION

The Russian program for the development of new-generation nuclear energy technologies includes the creation of fusion neutron sources [1]. The use of neutron sources for burning minor actinides (MA) and producing fuel for nuclear power is considered in Russia as one of the promising ways to obtain faster returns from research in the field of controlled thermonuclear fusion and the use of energy in real conditions for practical demonstration of the energy potential of thermonuclear reactions. In the Russian Federation, the Kurchatov Institute considers the Tokamak T-15MD as a prototype source of thermonuclear neutrons [2].

2. PURPOSE AND OBJECTIVES OF STUDY

The main purpose of the research is to study the possibilities of transmutation of minor actinides (MA) and the production of nuclear fuel (uranium–233 and tritium) in a fusion neutron source (FNS) blanket from a solution of thorium nitrate in heavy water.

To achieve this goal, the following tasks were identified within the framework of this study: substantiation of the use of thorium nitrate solution in heavy water as a FNS blanket material, creation of a three-dimensional neutron-physical model of FNS with the aqueous blanket using thorium nitrate to perform Monte Carlo calculations, comparison of calculated neutron-physical characteristics of the heavy-water blanket with dioxide thorium and blanket with thorium nitrate, calculation of the production of nuclear fuel (uranium-233 and tritium) in the FNS model when loading minor actinides, calculation of the transmutation of minor actinides in the aqueous blanket.

The calculations were performed using the Monte Carlo method by the use of the MCNP-4 code with a library of nuclear data from ENDF/B-VII files. The calculation results are presented in the Table 1.

3. RESULTS

A comparison of the neutron-physical characteristics of the heavy-water blanket with a solution of thorium nitrate and a suspension of thorium dioxide shows that thorium nitrate enriched with the isotope ^{15}N is able to successfully replace thorium dioxide, which has a high abrasiveness.

The production of uranium-233 and tritium in FNS with the solution of thorium nitrate and minor actinides in the deep subcritical state of the blanket (keff ~ 0.95) makes it possible to achieve fuel self-sufficiency. At k_{eff} ~ 0.95, the machine has an electrical power of about 80~130 MW, which corresponds to the parameters of a low-power reactor.

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Transmutation of MA in the FNS energy spectrum with a high proportion of thermal neutrons makes it possible to completely burn the loading of neptunium-237 and americium isotopes in a safe mode (k_{eff} ~ 0.95) in 1.5–2 years. The values improve if the enrichment of the blanket with uranium-233 is increased. The ^{244}Cm isotope does not completely burn up. In the thermal spectrum, the ^{244}Cm load can be burned by 65%. As a result of α-decay with a $T_{1/2}$ period of 18.1 years, ^{244}Cm turns into plutonium, which can be returned to the fuel cycle.

The utilization of MA in a hybrid thermonuclear plant makes it possible to successfully burn actinides due to the high density of the thermal neutron flux, which can be changed by varying the power of thermonuclear fusion. It is also possible to regulate the energy spectrum of neutrons by changing the ratio of fuel and moderator in the blanket. The state of the blanket (core) is controlled not by delayed neutrons, but by neutrons emitted by the plasma, which eliminates the loss of control over the reactivity of the blanket. During the burning of MA, isotopes valuable in industry and medicine are formed in the radiative capture reaction (n,γ). There are many fissionable ones among them, which can be burned by recycling.

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REFERENCES

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TABLE 1. PRODUCTION OF NUCLEAR FUEL AND TRANSMUTATION OF MINOR ACTINIDES IN $^{232}TH(NO_3)_4$ HEAVY-WATER BLANKET DEPENDING OF ^{233}U ENRICHMENT FOR 1 YEAR (365 DAYS) OF MACHINE OPERATION AT NEUTRON SOURCE POWER OF 5 MW (1,775×10^{18} N/S)

The mass of minor actinides in a thorium blanket with a total load of 21 kg is ^{237}Np – 9.345 kg, ^{241}Am – 10.214 kg, ^{243}Am – 1.281 kg, ^{243}Cm – 4.2×10^{-3} kg, ^{244}Cm – 1.554×10^{-1} kg					
Material of the aqueous blanket		$^{232}Th(NO_3)_4$ (61,43 g) + D_2O (100 g)			
Volume of the aqueous blanket, m^3		15.6987			
Total amount of ^{6}Li, kg		341.255			
^{233}U enrichment (wt. %)		0	1.6	1.7	1.8
Loading of ^{232}Th, kg		5.095×10^3	5.014×10^3	5.009×10^3	5.004×10^3
Loading of ^{233}U, kg		0	8.153×10^1	8.662×10^1	9.172×10^1
k_{eff}		0.004	0.926	0.952	0.983
Reactivity $\rho = (k_{eff} - 1)/k_{eff}$		—	–0.079	–0.050	–0.017
Neutron yield per 1 fission of the ^{233}U nucleus		—	2.498	2.498	2.498
Burning of minor actinides, %	^{237}Np	7.353	51.29	82.10	208,2
	^{241}Am	28.48	194.9	311.7	790,6
	^{243}Am	6.603	55.28	89.38	228,1
	^{243}Cm	27.09	178.4	284.8	720,2
	^{244}Cm	1.466	14.46	25.45	65,12
^{233}U production, kg/year		1.588×10^1	1.097×10^2	1.755×10^2	4.449×10^2
^{233}U consumption, kg/year		0	1.087×10^2	1.842×10^2	4.926×10^2
Reproduction rate of ^{233}U		0	1.009	0.953	0.903
^{3}H production, kg/year		0.188	0.417	0.553	1.117
^{3}H consumption, kg/year		~3.000×10^{-1}	~3.000×10^{-1}	~3.000×10^{-1}	~3.000×10^{-1}
Reproduction rate of ^{3}H		0.627	1.390	1.843	3.273
Thermal power of the ^{232}Th blanket, MW		1.931	2.442×10^2	4.123×10^2	1.100×10^3
Electrical power, MW		6.437×10^{-1}	8.141×10^1	1.374×10^2	3.667×10^2
Thermal power density, MW/m^3		1.230×10^{-1}	1.556×10^1	2.626×10^1	7.007×10^1
Maximum statistical uncertainty, %		0.1	0.8	1	3