LEAD COOLANT FOR FAST REACTOR-BURNER WITH HARD NEUTRON SPECTRUM

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ABSTRACT

The purpose of paper is the search of a technique for hardening the fast reactor neutron spectrum and by this way, increasing the burning of Np-237, Am-243, and other minor actinides (MA) fissionable preferentially under hard neutron spectrum. The main concern is for using lead isotope, Pb-208, as a reactor coolant instead of natural lead, Pb-nat, which is the mixture of isotopes. Pb-208 has the high inelastic scattering threshold of 2.61 MeV. So, it slowly moderates the fission spectrum.

The contribution of liquid metal coolants: sodium, Pb-nat, and Pb-208, minor actinides: Np-237, Am-241, and Am-243, elements of structural materials: Fe, Cr, Ni, etc, to the fast-reactor neutron spectrum for a blanket is analyzed. For this calculation using Monte-Carlo Code "MMKFK" is conducted. As a result, it is shown that the incineration of MA in the blanket is increased from 18 to 26 percent when one uses Pb-208 as a coolant instead of the usual natural lead.

I. INTRODUCTION

The incineration of long-lived radioactive wastes is one of the important problems in the development of the future power engineering. This problem was considered systematically by experts from many countries. Many international conferences are devoted to this problem (see Proceedings of GLOBAL-93, 95, 97). The strategy of the nuclear transmutation is following.

Neptunium is included in the U-Pu fuel and then, it is transmuted in a fast reactor core. Americium has to be converted by its disposing in special targets inside the blanket of fast reactors or accelerator-driven reactors. The fission and neutron capture cross-sections of MA for fast and thermal neutrons are listed in Table 1. These data are taken from JENDL-3.2 library[1].

One can distinguish two groups of MA in Table 1. The first group consists of Pu-238, Pu-239, Pu-241, and Cm-245 having high fission cross-sections in the thermal Maxwellian spectrum of neutrons. Therefore, a thermal reactor is suitable for incinerating these MA. The second group includes Np-237, Pu-240, Pu-242, and Am-243, which are fissionable when neutrons are above the some energy threshold. It requires a fast reactor-burner with hard neutron spectrum for such the MA incineration.

Table 1. The neutron cross-sections of MA for thermal and fast fission spectra, barns

Nuclide	Thermal Maxwellian spectrum		Fast fission spectrum	
	Capture	Fission	Capture	Fission
Np-237	144.0	0.02	0.18	1.32
Pu-238	457.9	15.2	0.10	1.98
Pu-239	274.8	699.0	0.05	1.80
Pu-240	263.8	0.05	0.10	1.34
Pu-241	326.3	938.7	0.12	1.65
Pu-242	16.8	0.002	0.09	1.12
Am-241	532.1	2.71	0.24	1.36
Am-243	70.5	0.10	0.20	1.07
Cm-244	13.4	0.91	0.14	1.55
Cm-245	287.2	1673.0	0.07	1.74

II. "MMKFK" SIMULATION

The use of coolants with low moderating properties is one of the ways to get the hard neutron spectrum in the fast reactor. In this paper, the stable lead isotope, Pb-208, which 52.3 percent are contained in natural lead of, is proposed as the one of such coolants. The neutron inelastic scattering cross-section of Pb-208 is 3.0–3.5 times less than the one for other lead isotopes. These data are taken from JENDL-3.2 library[1] and given in Table 2.

Table 2. Neutron inelastic scattering cross-sections of natural lead and his stable isotopes, averaged up on fission neutron spectrum, barns

Nuclide	Pb-204	Pb-206	Pb-207	Pb-208	Pb-nat
Cross-section, σ_{in}	1.325	1.316	1.265	0.361	0.804

Calculation of the MA transmutation rates in the fast reactor with different coolants is performed by Monte-Carlo method using Code "MMKFK"[2]. Such the simulation reproduces a broad class of parameters at operation of the standard BN-type fast reactor. The analysis of obtained results for burning neptunium and americium in the blanket having thickness of 50 cm was carried out in this paper. Six (6) various models are simulated here for the fast reactor blanket with different kinds of fuel and coolant. The composition of this blanket is listed in Table 3.

Table 3. The composition of fast reactor blanket for different models of (MA + coolant), nuclides$\cdot 10^{-20}/cm^3$

Nuclide	Model 1 (Np+Na)	Model 2 (Np+Pb-nat)	Model 3 (Np+Pb-208)	Model 4 (Am+Na)	Model 5 (Am+Pb-nat)	Model 6 (Am+Pb-208)
Np-237	12.6	12.6	12.6	0.0	0.0	0.0
Am-241	0.0	0.0	0.0	11.4	11.4	11.4
Am-243	0.0	0.0	0.0	4.0	4.0	4.0
O	25.2	25.2	25.2	23.6	23.6	23.6
Na	103.0	0.0	0.0	103.0	0.0	0.0
Pb-nat	0.0	143.0	0.0	0.0	143.0	0.0
Pb-208	0.0	0.0	143.0	0.0	0.0	143.0

The composition of structural materials is the same for all the models. The values of nuclear concentration for elements of structural materials used in homogeneous blanket are listed in Table 4.

Table 4. The nuclear concentration of structural materials in homogeneous blanket model, nuclides$\cdot 10^{-20}/cm^3$

Nuclide	Model 1–6
Fe	140.0
Cr	30.8
Ni	16.8
Mo	2.4
Mn	1.6
Zr	21.6
C	21.6

The weight and volume portions of the main material constituents used in the “MMKFK” calculation are summarized in Table 5. One can see that the volume portions of main materials in all the models are following: 7.13–9.54 % for the fuel, 54.16–57.00 % for the coolant, and 35.06–37.17 % for structural materials. It is important to note that the volume share of the coolant is large for changing the neutron spectrum in the blanket.

Table 5. Weight and volume composition of materials of the blanket models (MA + coolant) for "MMKFK" calculation

Model	Fuel		Coolant		Structural materials	
	Weight, %	Volume, %	Weight, %	Volume, %	Weight, %	Volume, %
1. (Np+Na)	18.12	7.39	12.66	55.44	69.22	37.17
2. (Np+Pb-nat)	7.37	7.14	64.45	56.90	28.12	35.95
3. (Np+Pb-208)	7.35	7.13	64.54	57.00	28.11	35.87
4. (Am+Na)	21.10	9.54	12.20	54.16	66.70	36.31
5. (Am+Pb-nat)	8.78	9.23	63.47	55.62	27.75	35.15
6. (Am+Pb-208)	8.76	9.21	63.56	55.73	27.68	35.06

III. RESULTS

The objective for simulating the considered system is the establishment of difference between a neutron temperature in the blanket charged with various metal coolants: sodium, Pb-nat, and Pb-208. Results of "MMKFK" calculation include the values for combined collision, capture of neutrons, and fission of MA. The "MMKFK" runs above 10^6 particles are taken into account for the blanket area. The incident particle energy corresponded to the reactor core spectrum. In order to show the results, the neutron temperature as a ratio of the fission cross-section to the sum of that and the cross-section of neutron capture, $\sigma_{fis}/(\sigma_{fis}+\sigma_{cap})$ is used, due to monotonous dependence of this ratio on the neutron energy over the MA threshold. The higher value of the ratio, the harder neutron spectrum is. The obtained values of this ratio are listed in Table 6.

Table 6. The fission portion in summarized cross-section of neutron capture and fission for neptunium and americium in the fast reactor with different coolants, $\sigma_{fis}/(\sigma_{fis}+\sigma_{cap})$

MA	Sodium	Pb-nat	Pb-208
Np-237	0.200	0.210	0.265
Am-241	0.177	0.175	0.215
Am-243	0.217	0.226	0.280

As the data of Table 6 suggests, the fast reactor with natural-lead coolant practically does not differ from the reactor with sodium coolant relative to MA incineration. The use of Pb-208 as a coolant in the fast reactor results in increasing incineration of MA from 18 to 26 % in comparison with a usual fast reactor. For maximum hardening the neutron spectrum, the heavy lead isotope as a coolant is necessary.

IV. CONCLUSIONS

The opportunity of low moderating isotopic tailored coolant (100 percent of molten lead isotope, Pb-208) for increasing the incineration of minor actinides in the fast reactor is considered.

Indeed, the "MMKFK" simulation by Monte-Carlo method has shown that Pb-208 used in the fast reactor results in hardening the neutron spectrum and increasing the incineration of Np-237, Am-241, and Am-243 from 18 to 26 % in comparison with the effect of natural lead in the same reactor.

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