

Concerning advantages in using ^{208}Pb as such a FR coolant

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Abstract. In the paper cores of two fast reactors with heavy liquid metal coolant are considered. The first object, RBETS-M, is a project of a medium power, 900 MW, reactor cooled with lead-bismuth. The second object, BRUTS, is a project of an ultra-small power, 0.5 MW, reactor cooled with lead. The results of replacement of their standard coolants with the lead coolant enriched up to 100% with ^{208}Pb are presented. In the RBETS-M core having a large coolant volume share this replacement results in sufficient increasing the share of ^{238}U involved in the fission process and respective decreasing the share of ^{239}Pu and ^{241}Pu burning.

1. Introduction

Presently, several projects dedicated to fast reactors (FRs) with heavy liquid metal coolant (HLMC) are in progress in Russia. Two projects among them are considered in this paper. The first is a medium power reactor, RBETS-M, proposed by the Moscow Kurchatov Institute since 2000 [1] and developed in the frame of international collaboration. Innovation of this reactor lies in using gas lifting and lead-bismuth for core cooling. The second reactor considered is BRUTS, an ultra-small power reactor proposed by the Obninsk Institute for Nuclear Power Engineering in 2015 [2]. Innovation of BRUTS lies in using a coolant from natural lead, $^{\text{nat}}\text{Pb}$, and a core with a stock of reactivity less than beta effective that makes this reactor safe and suitable for education purposes. Earlier, in 2013, a project of ELECTRA, a lead cooled reactor for training and education was published in Ref. 3. The goal of the present paper is to estimate the advantages which can be achieved in these two above mentioned reactors in the case of replacement of their standard coolants, Pb-Bi and $^{\text{nat}}\text{Pb}$, with a coolant from ^{208}Pb which is expensive enough but is possessed of unique consuming properties [4-10].

2. Description of reactor's main parameters

In Table 1 several BRUTS and RBETS-M core parameters are given.

3. Method of calculations

In this work densities of neutron flux in the central parts of BRUTS and RBETS-M cooled with $^{\text{nat}}\text{Pb}/^{208}\text{Pb}$ and Pb-Bi/ ^{208}Pb , respectively, were calculated using Monte Carlo code. On this base, several neutron and physical characteristics: mean neutron energy, share of fast neutrons with $E_n > 0.8$ MeV, shares of fissile and low fissile nuclides involved in the fission process were calculated.



Table 1. Main standard core parameters of the reactors BRUTS and RBETS.

Parameter core's value	BRUTS's value	RBETS-M inner
Thermal power [MW]	0.5	900
Fuel	UO ₂	(Pu+U)N
Fuel enrichment [%]	19.7 of ²³⁵ U	13.7 of power grade Pu
Coolant	^{nat} Pb	Pb-Bi
Core diameter [cm]	62	86
Core height [cm]	62	100
Coolant volume share [%]	25.5	62.5

4. Results

In Table 2 the results of calculations are presented.

Table 2. Core neutron and physical characteristics of the reactors BRUTS and RBETS-M cooled with ^{nat}Pb and Pb-Bi (thin lettering) and ²⁰⁸Pb (bold lettering).

Parameter inner core's	BRUTS's value	RBETS-M value
Mean neutron energy [MeV]	0.5650 / 0.5543	0.4226 / 0.3992
Variation of mean neutron energy [%]	+ 1.9304	+ 5,8617
Share of fast neutrons with E _n >0.8 MeV [%]	0.1869 / 0.1832	0.1438 / 0.1293
Variation of share of fast neutrons [%]	+ 2.0197	+ 11.2142
²³⁵ U share in total number of fissions [%]	86.0610 / 86.5368	
²³⁷ Np share in total number of fissions [%]		0.0236 / 0.0227
²³⁸ U share in total number of fissions [%]	13.9390 / 13.4632	16.6218 / 14.0162
²³⁸ Pu share in total number of fissions [%]		0.8599 / 0.8713
²³⁹ Pu share in total number of fissions [%]		69.0942 / 71.7217
²⁴⁰ Pu share in total number of fissions [%]		5.5982 / 5.4488
²⁴¹ Pu share in total number of fissions [%]		5.9602 / 6.1699
²⁴¹ Am share in total number of fissions [%]		1.0825 / 1.0210
²⁴² Pu share in total number of fissions [%]		0.7594 / 0.7283

From Table 2 follows that using a coolant from ²⁰⁸Pb instead of standard coolants from ^{nat}Pb or Pb-Bi leads to the following results:

- Increasing the mean neutron energy;
- Increasing the share of fast neutrons;
- Decreasing ²³⁵U share in total number of fissions in BRUTS;
- Increasing ²³⁸U share in total number of fissions in BRUTS;
- Increasing ²³⁷Np share in total number of fissions in RBETS-M;
- Increasing ²³⁸U share in total number of fissions in RBETS-M;
- Decreasing ²³⁸Pu share in total number of fissions in RBETS-M;
- Decreasing ²³⁹Pu share in total number of fissions in RBETS-M;
- Increasing ²⁴⁰Pu share in total number of fissions in RBETS-M;
- Decreasing ²⁴¹Pu share in total number of fissions in RBETS-M;
- Increasing ²⁴¹Am share in total number of fissions in RBETS-M;
- Increasing ²⁴²Pu share in total number of fissions in RBETS-M.

The profit in using ²⁰⁸Pb as such a coolant increases with increasing a volume share of coolant in the core. For medium and high power FRs, the typical coolant volume share in the core is of 60-70%. For

the RBETS-M inner core it is equal to 62.5%, for the small-power reactor BRUTS it is equal to 25.5%.

In Fig.1 shares of ^{238}U and power grade Pu nuclides related to the total number of fissions in RBETS-M inner core cooled with Pb-Bi/ ^{208}Pb are presented.

Figure 1 demonstrates the advantages in using ^{208}Pb as such a coolant:

- Increase of low fissile nuclides: ^{237}Np , ^{238}U , $^{240,242}\text{Pu}$, ^{241}Am burning;
- Decrease of valuable fissile nuclides: $^{238, 239, 241}\text{Pu}$ burning.

Another advantage of ^{208}Pb consists in its low neutron absorbing ability. As it was shown in Ref. 10, one-group cross-section of neutron radiation capture by ^{208}Pb in RBETS-M inner core cooled with ^{208}Pb is equal to 0.93 mbarn, while one-group cross-section of neutron radiation capture by the mix Pb-Bi in the inner core of RBETS-M cooled with Pb-Bi is equal to 3.71 mbarn.

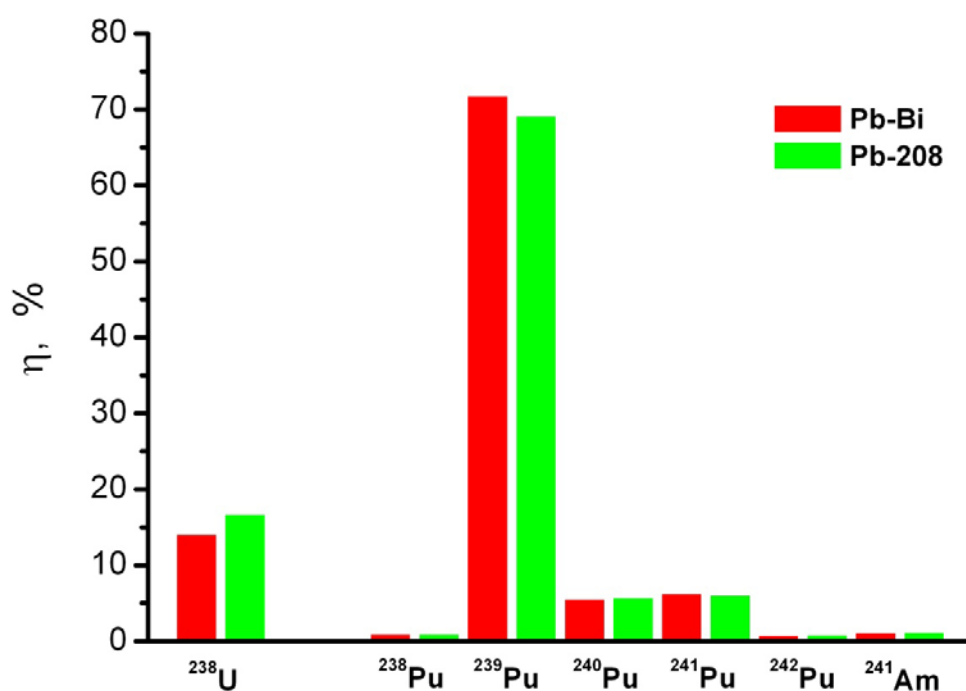


Figure 1. Shares of ^{238}U and power grade Pu nuclides related to the total number of fissions in RBETS-M inner core cooled with Pb-Bi/ ^{208}Pb .

5. Conclusion

On the base of the paper's results, it can be expected that in small-sized small power (100 MW electric) FR fueled with metallic uranium and power grade plutonium and cooled with innovative coolant from ^{208}Pb (about 150 tons) further increasing core's mean neutron energy and, respectively, increasing shares of ^{238}U , ^{237}Np , $^{240,242}\text{Pu}$ and ^{241}Am fissions in the total fission process can be acquired.

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