LOW-ACTIVATION LEAD COOLANT FOR ADVANCED SMALL MODULAR NPP

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ABSTRACT

The purpose of the paper is in studying perspectives of a new heavy liquid metal coolant for a small fast reactor (FR) concept. To reduce the post irradiation activity of the coolant the using of lead isotope, Pb-206, instead of natural lead , Pb-nat, is offered. In this case the accumulation of such hazardous radionuclides, as Po-210, Bi-208, Bi-207, essentially decreases. The interval of the lead-206 coolant cost which does not exceed 20% of the overall FR cost is estimated. The possibility of lead-206 obtaining for FR needs with the centrifugal separation technique is pointed out.

INTRODUCTION

Now the same attention is given to the development of small nuclear engineering based on nuclear reactors with the power up to 300 MW [1]. For example, the policy of the Ministry of Russian Federation for Atomic Energy in the field of nuclear engineering [2] includes the creation of small nuclear power plants (NPP) for remote regions of Russia in 2001-2010 years. IAEA elaborates a development program of small nuclear engineering for developing countries. According to this program the need for small NPP will be 70-80 units for the next decade, and after 2015 the annual need for them will be up to 10-50 units [3].

In modern projects of perspective NPP the preference is given to fast reactors with heavy liquid metal coolants. Internal self-hardening, absence of poisoning effects, compensation of uranium fuel burn-out by produced plutonium fuel and other positive features of FR will enable in future to lengthen operating campaign of the reactor till 10-12 years, and service life of FR - till 30-60 years [4,5].

CALCULATION RESULTS AND DISCUSSION

As it known, the coolant, circulating through the core of FR, is activated and accumulates long-lived radionuclides. Taking in account the masses of coolant materials in considered FR (20-200 tons) and the scales of introduction of small NPP in the future, we can have problems with handling completed coolant after FR removal from exploitation and during repair and emergency works. So it is desirable to have a low-activation coolant with low content of long-lived radionuclides - products of nuclear reactions. In paper [6], presented at the GLOBAL'99 conference, it was offered to use lead enriched with isotope Pb-206 as a low-activation coolant for FRs. Its content in a natural mixture of lead isotopes is 24 %, and the demanded enrichment of isotope does not exceed 95-98 %.

In Fig 1 resalts of calculations of the operative activity induced in Pb-nat and lead stable isotopes placed in the BOR-60 FR core spectrum is given. It can be seen that operative activity does not depend on irradiation time and is equal to $1 \cdot 10^{14}$ Bq/kg for Pb-nat. It consists mostly of short-lived lead isotopes, Pb-207m(~76%), Pb-204m(~12%) and Pb-209(~11%). Lead stable isotope, Pb-206, gives a relatively small contribution to summary operative activity of Pb-nat.

Short-lived radioisotope, Pb-209, is responsible for generation of many long-lived and radiotoxic nuclides. Stable bismuth isotope, Bi-209, is produced via fast beta decay of Pb-209. Concentration of stable bismuth in Pb-nat is increasing year by year with a rate of 0.1 gram/kg/year. Time dependent production of Bi-209 for Pb-nat and lead stable isotopes irradiated in a FR is shown in Fig.2. Bismuth production is maximum for lead isotope, Pb-208. Stable bismuth, . Bi-209, is a source of generation such its radioisotopes, as Bi-207 and Bi-208, via ^{209}Bi(n,3n)^{207}Bi and ^{209}Bi(n,2n)^{208}Bi reactions. In Fig.3 and Fig.4 activity of produced Bi-207 and Bi-208 is represented. Both of these nuclides are long-lived and hazardous enough. Bi-207 decay half-time is equal to 32.2 years and its gamma radiation mean energy approaches to 1.5 MeV. Bi-208 is a very long-lived isotope

($T_{1/2}$=3.68·10^5 years) and its gamma radiation mean energy is equal to 2.7 MeV. That is why their clearance level for regulatory control is equal to 10^4 Bq/kg. These clearance levels can be exceeded by Pb-nat after 2 years irradiation in a FR. As concerns Pb-206, activity of Bi-207 and Bi-208 induced in it does not reach the clearance level at all.

Another hazardous radionuclide induced in Pb-nat is alpha-active polonium isotope,. Po-210. Its generation is also connected with bismuth production in lead. As it is clear from Fig.5, activity of Po-210 reaches a very high level of 10^9-10^{10} Bq/kg in a relatively short irradiation time. When lead isotope, Pb-206, is used instead of Pb-nat, production of Po-210 is decreased by 4 orders of magnitude.

By the present time a number of the projects of small NPIs with a lead-bismuth coolant for remote regions of Russia is designed. There are reactor installations (RI) such as ANGSTROM, SVBR-75, BRUS-150 and others, designed in SSC RF IPPE, Obninsk, and EDO "Gidropress", Podolsk, Russia. Their basic power and cost characteristics, and also specific coolant demands are listed in Table 1.

Table 1.

Basic Power and Cost Characteristics of the Small NPPs.

The naming of NPI Basic characteristics of NPI	ANGSTROM modular arrangement [4] [7]	SVBR-75 modular arrangement [5] [8]	SVBR-75 monoblock [5] [8]	BRUS - 150 monoblock [4] [7]
Thermal capacity, MW	30	265	265	500
Thermal supply capacity, MW	14			
Electric capacity, MW	6	90	90	170
Coolant weight, tons	40	80	190	350
Specific demand for coolant, tons/MW (therm.)	1.3	0.3	0.7	0.7
NPP cost oriented, million of dollars USA	20	180	200	340
Coolant cost limited, million of dollars USA	4	36	40	68
Enriched lead-206 price limited, USD/kg	100	450	210	200

From the Table 1 follows, that the specific costs for creation of NPP are 2 million dollars USA for 1 MW (el.), and the approximate cost of single (100 MW_{el}) small NPP is not less than 200 million dollars. In the reviewed projects we used the lead-bismuth coolant having good thermal and physical properties and low melting point (125°C). However the lead-bismuth coolant is characterized by the high induced radioactivity, which leads to the losses of valuable non-ferrous metal after FR removal from exploitation [9]. Besides, for reliable localization of radioactive coolant, in some projects of small NPPs the additional intermediate circuit with heavy metal coolant is envisioned. Usage of low-activation enriched lead-206 in the NPP will allow to avoid problems connected with the induced activity of the coolant. However, the fact, that the cost of such coolant should not exceed 20 % from overall costs of NPP, bounds the possibility of using enriched lead-206 in NPP. As follows from the Table 1, the maximum acceptable price of lead-206 should not be higher than 200 USD/kg, then NPP will be able to compete to other sources of electric power and heat. At the favorable scenario of development of nuclear engineering and the annual creation of 10 units of small NPPs, the general demands for lead-206 with enrichment C=95% can be about 1-2 thousand tons per year after 2015.

Large-scale stable isotope separation has become practicable after an appropriate up-to-date gas centrifuge had been devised.

The cost of enriched lead-206 is determined by the price of initial actuating substance and costs of the enriching process.. The current price of 95% enriched lead-206 is close to 10 thousand dollars/kg while the price of natural lead is only ~1 dollar/kg. The cost of lead enrichment with isotope Pb-206 is relatively low due to the high content of lead-206 in natural lead and demanded final level of enrichment (C≈95 %).

In the future, the price of the product lead-206 can be furtherly decreased at the expense of the following factors:

- reaching an industrial level with production of several tons of enriched lead-206 per year,
- developing the cheap know-how of obtaining the actuating substance - tetramethyl lead,
- usage of initial actuating substance and separating power for attendant obtaining other stable lead isotopes, for example Pb-208, which is also demanded for nuclear technology in large volumes [10].

CONCLUSION

- To solve the problems of handling nuclear radiowaste, it is proposed to use lead enriched with lead isotope, Pb-206, as a low-activation heavy liquid metal coolant for the small nuclear power plant ($P_{thermal}$<300 MW) containing 20-2000 tons of coolant material.
- It is shown, that lead enriched with lead isotope, Pb-206, up to C≈95 % can be demanded for nuclear power engineering, if its price is below 200 USD/kg.
- Under a favorable scenario of developing small nuclear power plants, after 2015 the need for cheap isotopically tailored lead can be of 1-2 thousand tons per year.

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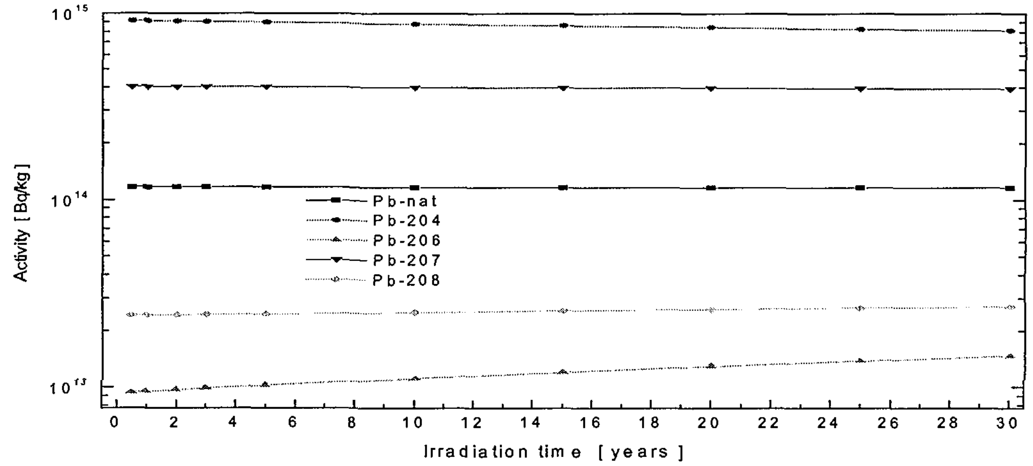

Fig.1. Operative activity of lead placed in a FR BOR-60 core.

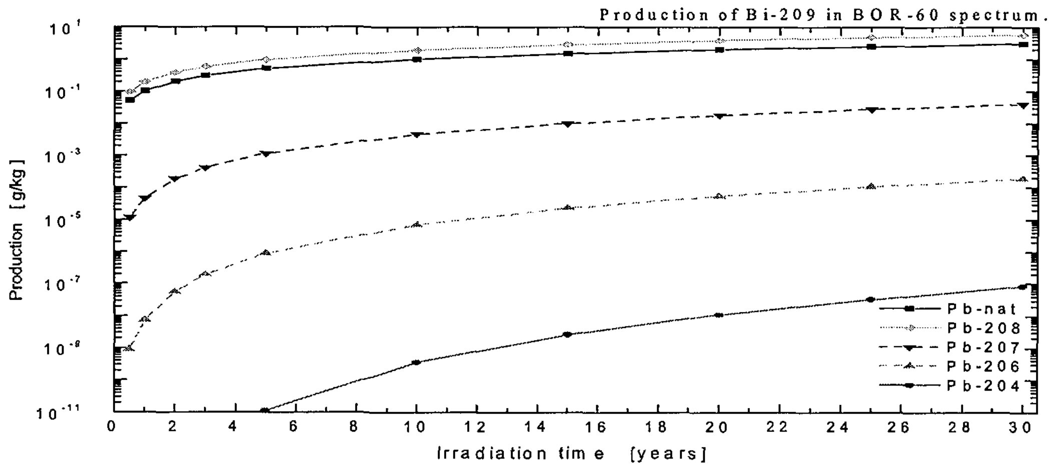

Fig .2. Production of stable bismuth, Bi-209, in lead placed in a FR BOR-60 core.

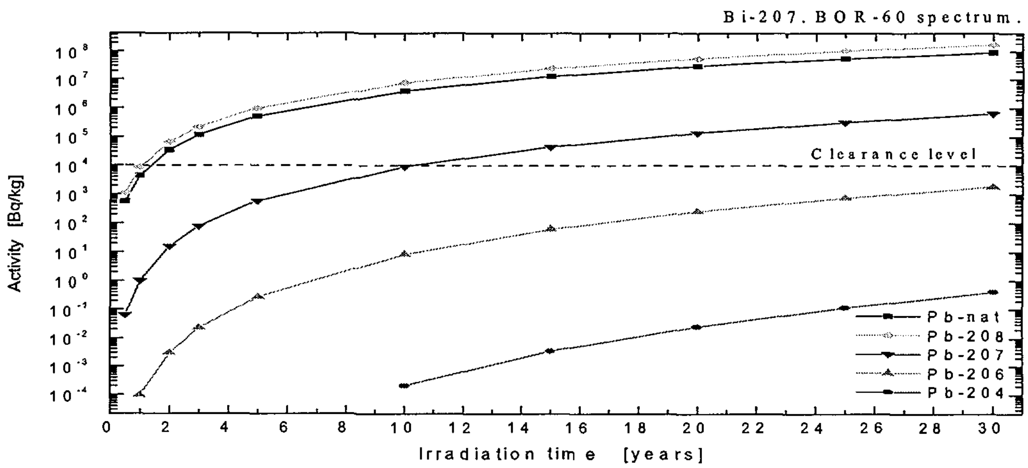

Fig.3. Activity of Bi-207 induced in lead placed in a FR BOR-60 core.

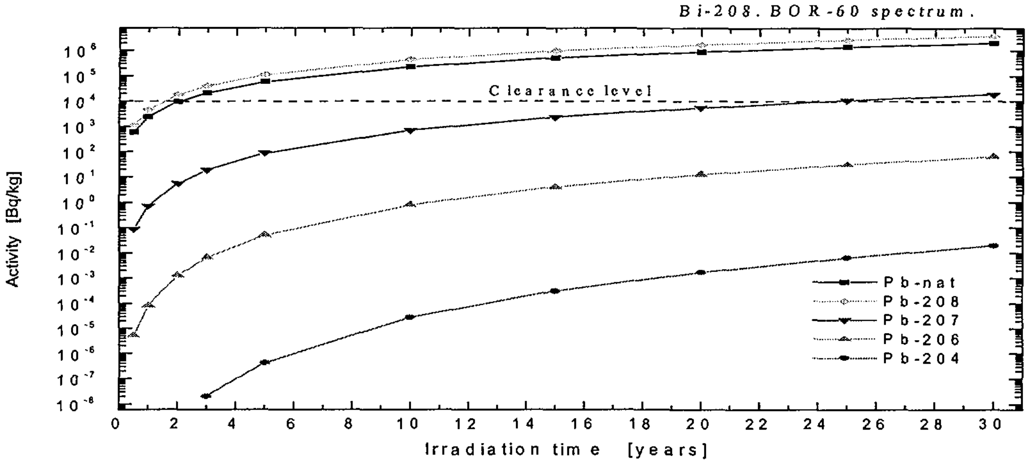

Fig.4. Activity of Bi-208 induced in lead.

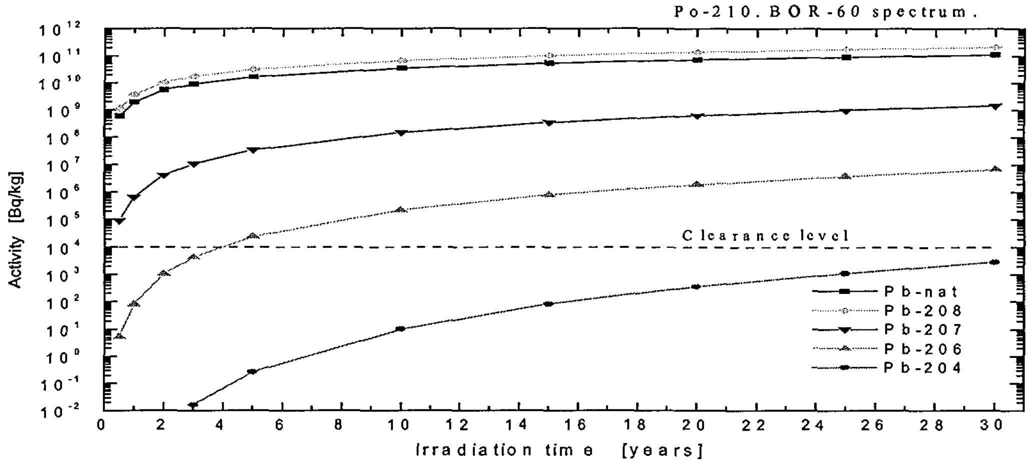

Fig.5. Activity of Po-210 induced in lead.