ISSUES OF LEAD COOLANT TECHNOLOGY

Yu.I. ORLOV, P.N. MARTYNOV, V.A. GULEVSKY

STATE SCIENTIFIC CENTER OF RUSSIAN FEDERATION (SSC RF)
INSTITUTE FOR PHYSICS AND POWER ENGINEERING (IPPE)
OBNINSK, RUSSIAN FEDERATION

Abstract

Starting from 1989 with the BREST-OD-300 reactor design development, some experimental studies related to lead coolant have been performed to provide feasibility of using liquid lead as a coolant in the closed circuit. Further comprehensive analytical and experimental studies are required to develop lead coolant technology for the BREST-OD-300 reactor design. General work program for justification of lead coolant technology are planned aiming at not only getting the information on the components required for the technology realization and their design features but also revealing the possibility of use of data obtained in the course of lead-bismuth circuit operation for the lead circuits. The main results performed so far for justification of BREST-OD-300 reactor coolant technology are presented in this paper. The results confirmed the possibility of using the experience gained on lead-bismuth coolant justification on the stage of the BREST-OD-300 reactor design development. In addition, the results provided directions for further justification of lead coolant technology based on experience gained on lead-bismuth coolant.

1. INTRODUCTION

Requirement of improvement of nuclear reactor safety and reliability impels the designers to look for the advanced coolants as compared to traditional cooling media (water, sodium, etc). Among such coolants liquid lead is considered. Below are described lead coolant properties making it attractive for use in the reactor heat removal system.

Lead has appropriate neutronic characteristics. Its capture cross section is low, so it can be used as a coolant for either intermediate or fast neutron reactors. Activation of lead in reactor is low, and it is explosion–proof media. It has low vapor pressure and high boiling point (~ 1750^{o}C), thus assuring low pressure in the primary circuit of the reactor. Lead is comparatively cheap, so it can be produced on a large scale.

Besides, physical and chemical properties of lead are close to those of lead–bismuth eutectic alloy, which for many years has been successfully used as a coolant of propulsion reactors. Large scope of information has been gained on physical, chemical, thermophysical and other properties of the alloy. Technology of this coolant has been developed as well as devices for its implementation. Methodology and experimental base is available which can be used for justification of lead as a coolant of power reactors.

2. DEVELOPMENT OF LEAD COOLANT TECHNOLOGY

On the basis of the considerations mentioned above, development of BREST–OD–300 reactor design was initiated under ENTEK management with the broad circle of specialists from different research centers being involved.

On the other hand, use of lead as a coolant for the BREST–OD–300 reactor requires development of lead coolant technology conformably to specific design and parameters of nuclear reactor. This is because of the following reasons:

– Physical and chemical properties of lead are quite different from those of coolants used on the wide scale in the nuclear power (water and alkali metals), for which technologies were mainly developed;

- There is no experience gained anywhere in the world on the use of lead and its alloys in the facilities of size comparable to that of BREST–OD–300 reactor or having similar design life; lead–bismuth coolant was used in comparatively small size facilities with heat removal system design quite different from that of BREST–OD–300 reactor.

It should be noted that starting from 1989, in the course of work performed under the assignment by ENTEK within the framework of BREST reactor design development, some processes related to lead coolant (such as hydrogen regeneration, oxygen enrichment, etc) were used on test facilities of the Institute for Physics and Power Engineering (IPPE) and some other organizations, which will probably be the integral parts of lead coolant technology of the BREST–OD–300 reactor. However, the main efforts in the process of this work were aimed at proving feasibility of liquid lead use as a coolant in the closed circuit, development of filling, start–up and operation modes of test facilities and studies of mass transfer processes (mainly corrosion) in the circuit. Temperature conditions and design characteristics of test facility components were far from those of the BREST–OD–300 reactor.

It follows from the above considerations that comprehensive analytical and experimental studies are required in order to develop technology of BREST–OD–300 reactor lead coolant. These studies should be carried out with maximum effectiveness in order to get information on the components required for this technology realization and their design features as soon as possible.

It has been already determined on the basis of the work performed that lead coolant technology should for sure include the following procedures:

- Hydrogen reduction of lead from its oxides;
- Control of the coolant quality using $Ar–H_2O–H_2$ ternary mixtures and mass exchangers with solid phase oxide filling agent;
- Coolant purification by filtering from solid phase mixtures which cannot be reduced.

Results of studies (both already completed and planned) are required primarily for experimental confirmation of feasibility of use of the above mentioned systems and equipment as well as their effective operation.

Another important goal of studies is the analysis and comparison of mass transfer processes in the circuits with lead and lead–bismuth coolants considered for two different conditions:

- Coolant technology systems are in operation;
- No coolant technology systems are used.

Results of these studies are needed for revealing the possibility of use of data obtained in the course of lead–bismuth circuit operation, for the lead circuits.

Below presented are the main stages of the general work program of justification of lead coolant technology, planned for the nearest three years:

- Determination of optimum thermodynamic conditions of liquid metal circuit in order to minimize intensity of mass transfer processes and assurance of corrosion resistance of structural materials;
- Studies on the process of slag formation in different operating modes of the primary circuit of the BRIEST–OD–300 reactor, such as circuit filling, repair and maintenance,

core refueling, leaks in the circuit and in the steam generator;

- Tests and improvement of technology of the circuit surface cleaning by providing coolant–gas two–component flow;
- Development of methods and devices for coolant filtering;
- Development of methods and devices for gas purification and BREST–OD–300 reactor gas communications protection against material corrosion products and lead vapors;
- Development of methods and means required for the primary circuit surface protection against corrosion;
- Development of methods and devices for control of condition of the coolant and internal surfaces of the primary circuit;
- Experimental and methodological support (as far as coolant technology is concerned) of tests of the fuel elements for the BREST–OD–300 reactor, using lead channel of the BOR–60 reactor;
- Studies on the environmental issues related to heavy metal coolant in case of design basis and beyond design accidents of the BREST–OD–300 reactor;
- Development and justification of input data for designing coolant technology system of the BREST–OD–300 reactor and its operating rules.

3. THE MAIN RESULTS OF WORK PERFORMED IN 1999 ON JUSTIFICATION OF BREST–OD–300 REACTOR LEAD COOLANT TECHNOLOGY

Followings are the works that were performed in 1999 to justify the lead coolant technology for the BREST–OD–300 reactor:

- Justification of the option of heavy metal coolant technology system and the main requirements to this system made on the basis of experience gained on operation of lead and lead-bismuth circuits;
- Experimental confirmation of serviceability of proposed technology system of heavy metal coolant under the temperature conditions of the BREST–OD–300 reactor;
- Revealing the increase of oxide dissolving contribution to the general hydrogen regeneration process of the coolant (as compared to that of lead-bismuth circuits);
- Revealing the possibility of decreasing hydrogen content down to the lower limit of explosion safety and fire safety ($CH_2 < 4 - 5$ vol.%) in the process of regeneration;
- Development of immersed mass exchanger design with solid phase filling agent for dissolved oxygen supply to the melt in the course of passivation protection of structural materials;
- Development of technology of production of solid phase oxide filling agent of mass exchanger;
- Experimental confirmation of mass exchanger serviceability in the course of passivation protection of materials under conditions of intensive provocation of corrosion;
- Development of concept of gas route protection against structural material corrosion products and lead vapors;
- Justification of filtering materials (MFVE–3 glass paper, etc) for purification of cover gas of the BREST–OD–300 reactor at the temperature up to 150^{o}C;
- Confirmation of serviceability and thermal resistance of MKTT–2.2A filtering material at T = 420^{o}C (for 1000 hours as a reference time period);
- Confirmation of possibility of non–isoconcentration distribution of dissolved oxygen under BREST–OD–300 reactor temperature conditions.

The main results of the above works are:

- Closeness of qualitative and quantitative characteristics of the main physical and chemical processes in lead and lead–bismuth coolant circuits was experimentally confirmed. This confirms the possibility of using experience gained on lead-bismuth coolant justification on the stage of BREST–OD–300 reactor design development;
- Directions of further justification of lead coolant technology were finally determined on the basis of experience gained on lead–bismuth coolant bringing to use.

On the other hand, further realization of the program of justification of lead coolant use in the BREST–OD–300 reactor would require considerable material expenses and strenuous experimental and analytical studies.