Development of The Built-In Primary Sodium Purification System for The Advanced BN-1200 Reactor Plant

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Abstract. To purify primary sodium in the advanced BN-1200 reactor plant, a purification system with cold traps has been used that are located in the reactor vessel (in-built purification system). Such decision has excluded external communications of the auxiliary system with radioactive sodium and respectively a possibility that sodium will outflow to compartments outside the reactor.

The sizes of cold traps located in the reactor are small that has limited the sodium flowrate through them, impurity storage capacity, and has made it necessary to replace traps in the course of reactor plant operation. Cold traps include such main components of the conventional external purification system as sodium communications, a portion of the cooling circuit, flow meter devices, and electromagnetic devices (a pump and throttle pump) to ensure sodium circulation and to control the sodium flowrate. In the course of development, options have been considered to cool traps with argon, liquid sodium, and gallium.

To validate operation of electromagnetic devices for the cold trap, a package of research activities and R&D activities has been done:

- thermal irradiation studies have been done of sample electrotechnical materials intended for the electromagnetic pump and throttle pump.
- mockups of the electromagnetic pump and throttle pump have been manufactured and tested.

Key Words: Cold Trap, Electromagnetic Device, R&D Activity

1. Introduction

The BN-1200 reactor plant uses sodium as a primary coolant.

In the reactor plant operation process various impurities, which dissolve in sodium, come into the circuit. Oxygen and hydrogen are basic impurities dissolved in sodium and affecting reactor plant operation.

If content of impurities in sodium is considerable, their impact on circuit element conditions is negative. Oxygen and, to some less degree, hydrogen cause increased corrosion of structural materials of reactor core and equipment. Also, deposition of impurities on low-temperature portions of the sodium circuit is possible, and it could lead to reduction of flow areas up to clogging. To prevent consequences of impurity deposition a purification system is provided in the reactor plant.

2. Development of Primary Purification System Concept

The cold purification method, which is based on decrease of impurity solubility when it temperature decreases, is used for sodium purification in sodium-cooled fast reactor plants [1].

There are two primary sodium purification systems which are different in principle. They are a built-in purification system and a remote system.

The both options of the primary sodium purification system, the remote one and that, in which cold traps are incorporated in the reactor vessel, have advantages and disadvantages.

In the majority of Russian and foreign reactor plants, including reactors with the integral layout, the primary sodium purification system is located beyond the reactor boundaries. This location of the purification system has the following advantages:

- quite simple design of cold traps;
- simple maintenance of the system;
- wide range for selection of cooling agent to cool cold traps (in particular, application of air makes the circuit cheap in production and simple and easy in operation);
- quite simple repair operations in cases of failures of system elements because these elements are accessible;
- majority of purification system element failures have no direct impact on reactor operation.

Disadvantages of the external location of the purification system are the following:

- specially equipped rooms are required for system arrangement, and it increases plant construction costs;
- presence of sodium circuit beyond the boundaries of the reactor and rooms for reactor location, each of which is a barrier for radioactive substances, decreases reactor plant safety;
- large surfaces of equipment and primary sodium communications also decreases safety because increase probability of their depressurization.

Purification system arrangement with primary cold trap location in the reactor vessel is associated with advantages of the integral reactor layout, which are the following:

- plant construction cost reduces because there are no rooms occupied by the external system;
- reactor plant safety increases because barriers on the way of radioactive substances propagation are compact due to the fact that there is no sodium circuit beyond the reactor and special rooms for reactor location;
- probability of radioactive sodium leakages into the process rooms beyond the reactor boundaries is eliminated.

Disadvantages of the built-up purification system are the following:

- complex design of the cold trap because its casing encompasses all elements of purification system sodium circuit and the cooling circuit element, which removes heat directly from sodium to be purified;
- difficult maintenance because of high-level requirements imposed for keeping temperature conditions of cold trap operation to prevent clogging of its sodium communications by impurities; and difficult repair because the structural elements are hard to access (majority of elements could be accessible only when the cold trap is withdrawn from the reactor and dismounted);
- possible direct effect of failures of purification system elements, in particular, of cooling circuit elements, on reactor operation, which makes high requirements for their reliability necessary;
- necessary large scope of research and developmental activities caused by cold trap design novelty and increased requirements for its component reliability, which is proved by cold trap

development experience of the Super Phenix plant (the only plant in the world where the built-up purification system was implemented in practice [2]).

Because of high-level requirements for the BN-1200 design aimed at improvement of technical and economical indices and safety, to purify primary circuit sodium the BN-1200 reactor plant applies the purification system with cold traps located in the reactor vessel (built-up purification system) [3].

3. Cold Trap of BN-1200 Reactor Plant

3.1. Cold trap development

The following was considered under development of the BN-1200 cold trap:

- built-up cold trap, considering its location in the reactor, should include all basic elements of traditional external purification system: pipelines, devices providing circulation and control of sodium flow rate, a recuperator, flow metering devices, etc.;

- considering high-density configuration of the reactor, the overall dimensions of the cold trap were highly restricted and, consequently, capacity with respect to impurities was restricted;

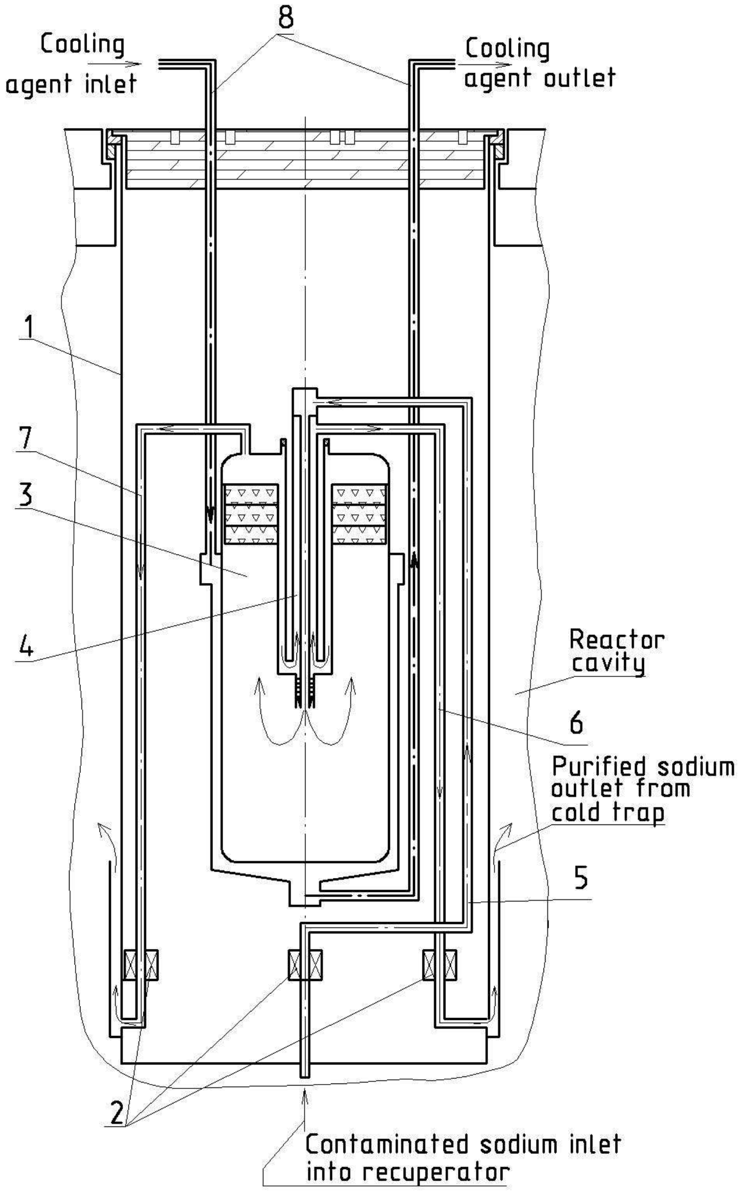
- optimum sodium velocity through the cold trap should be provided;

- cold trap arrangement in the reactor made it necessary to determine a cooling agent type, as air is impossible to use because of active interaction between sodium and air in case of depressurization of cooling elements within cold trap boundaries.

The developed cold trap design is a vessel, where the following elements are located in a single casing:

- working cavity;
- recuperator;
- pipeline of contaminated sodium supply to the recuperator;
- pipeline of purified sodium discharge from the recuperator;
- pipeline of discharge bypass of purified sodium from the working cavity;
- electromagnetic devices, intended to provide sodium circulation through the cold traps and to distribute purified sodium flow between paths of the recuperator and the bypass pipeline depending on reactor operation mode;
- pipelines of cooling agent supply and discharge.

The built-up purification system of BN-1200 primary sodium consists of three cold traps, which schematic diagram is given in Fig. 1.



1 - casing of built-up cold trap; 2 – electromagnetic devices; 3 - working cavity of cold trap; 4 – recuperator; 5 - pipeline of contaminated sodium supply to recuperator; 6 - pipeline of purified sodium discharge from recuperator; 7 - pipeline of purified sodium bypass from working cavity; 8 - pipelines of cooling agent supply and discharge

FIG. 1 – The cold trap schematic diagram.

Limited overall dimensions of the cold trap and, consequently, its working cavity, resulted in necessity to replace the cold trap upon the expiry of life time for accumulation of the ultimate quantity of impurities.

4. Selection of Cooling Agent Type

4.1. A cooling agent type for the cold trap is selected considering the following main factors: reactor plant safety, satisfactory physical and chemical properties of the cooling agent, cost of cooling system implementation.

Three types of cooling agent were chosen: pressurized argon, sodium and gallium.

To compare a coolant types a R&D complex was developed, and taking into account advantages and disadvantages of the cooling options, the option of argon cooling of the cold trap was selected.

5. Justification of Cold Trap Operability

5.1. The cold trap consists of an electromagnetic pump (EMP) and electromagnetic pumps-throttles (EMPT).

This equipment is subjected to thermal-radiation impact during operation.

Thus, it was required to justify experimentally operability EMP and EMPT, as elements affecting purification system operability.

5.2. To justify EMP and EMPT operability a R&D complex was developed, which included the following stages:

- manufacture and tests of EMP and EMPT mockup test samples;
- thermal-radiation tests of specimens of electro-technical materials intended to use in EMP and EMPT.

5.2.1. Manufacture and Tests of EMP and EMPT mockup test samples

5.2.1.1. To justify operability of standard EMPs and EMPTs, their mockup test samples were manufactured. Their structural layout is given in Fig. 2.

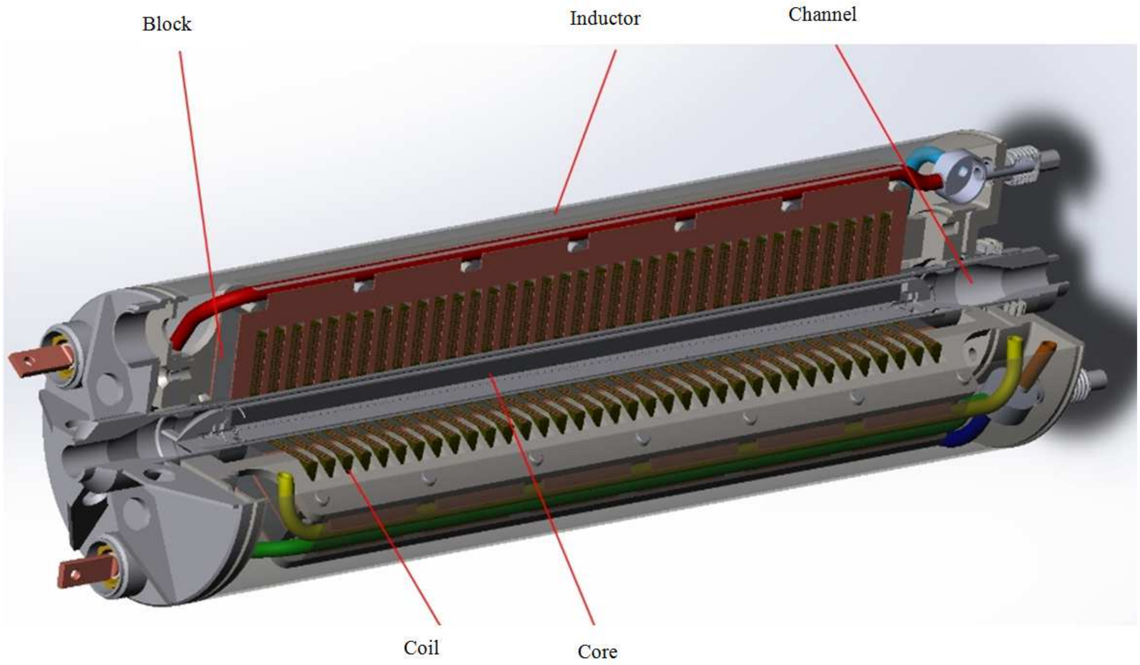


FIG. 2 - EMP (EMPT) structural layout.

The EMP operation principle is based on interaction of a travelling electromagnetic field, generated by the inductor winding, with currents induced by this field in liquid sodium, filling an annular gap of a channel. Their interaction resulted in electromagnetic force, providing motion of liquid sodium. The EMP is cooled by cooling agent circulating over the coiled pipe, arranged inside the EMP.

The EMP consists of a channel and an inductor.

The channel is an annular-section flow path; it is arranged between two cylinders. The outer cylinder is a channel shell, to which adaptors are welded for joining with circuit pipeline.

The inner cylinder is a shell with flow streamers (confusor and diffusor), which form core casing, in which leak-tight volume a magnetic core is located.

The inductor consists of two main elements: a magnetic core and an excitation winding. The magnetic core is an assembly of three blocks gathered of electric steel sheets. The excitation winding, consisting of ring-type coils is placed in block slots. The EMP cooling system is attached to blocks.

To manufacture coils the thermal-resistant winding wire with bimetallic conductor and high-temperature insulation having no organic components was used for the first time in the world experience.

The EMPT structural layout is similar to that of the EMP.

5.2.1.2. For EMP and EMPT tests, the test facility consisting of a sodium circuit and a cooling circuit, simulating operation conditions of standard EMPs and EMPTs (except radiation impact) was made.

At the test facility tests of the idle run (dependence of magnet field inductance value on excitation winding current) were performed, and operating head and rate of working travel was determined.

Test results justified EMP and EMPT applicability indices and confirmed correctness of engineering solutions.

5.2.2. Thermal-radiation tests of specimens of electro-technical materials intended to use in EMP and EMPT

Different electro-technical materials (winding wire insulation, current lead insulators) are used in EMP and EMPT.

Operability of these materials under the conditions of thermal-radiation impact required experimental justification.

The experiment was aimed to determine electro-technical characteristics (electrical resistance and breakdown voltage) of electro-technical materials (ETM) in the process in which they are affected by fast neutron flux, temperature and pressure of gas fluid, simulating operation conditions of cold trap EMP and EMPT.

The experiment was performed at the research reactor BOR-60, located at territory of Scientific Research Institute of Atomic Reactors.

Large preparatory work to provide simulation of design operation conditions preceded the tests. For this purpose, the experiment to determine neutron flux density gradient along the channel height was performed in the vertical experimental channel of the BOR-60 reactor. The results of this experiment were necessary to select place for ETM location during tests.

Channel irradiation devices with electrical heaters and high-voltage lines were developed.

A testing module, represented and placed in the channel irradiation device was developed to test specimens of electro-technical materials.

This module is a cylinder of dielectric material, in which a test specimen is installed between electrodes.

The module with ETM specimen was located in the channel irradiation device and then –into the vertical experimental channel of the BOR-60 reactor.

In the reactor, electrical resistance and breakdown voltage of ETM specimens under direct thermal-radiation impact were measured.

The experiment results were used to justify selection of ETM for EMPs and EMPTs.

6. Conclusion

Application of built-up sodium purification system instead of the external purification system increases plant safety, which is one of the main priorities in the current nuclear industry.

Acronyms

NPP – nuclear power plant
R&D – research and development
EMP – electromagnetic pump
EMPT – electromagnetic pump-throttle
ETM – electro-technical materials

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