MONITORING OF TECHNICAL CONDITION OF THE CORE IN THE BN-1200 ADVANCED COMMERCIAL SODIUM-COOLED REACTOR

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Abstract. The paper considers the BN-1200 fuel cladding tightness monitoring systems and other available fuel cladding tightness monitoring systems of fast reactors and discusses possibilities to apply their development and operation experience for development of the BN-12000 fuel cladding tightness monitoring system.

Key Words: NPP, BN, cladding tightness monitoring, fuel rod.

1 Introduction

The most important criteria of NPP functioning is to ensure nuclear safety, which, to great extent, is determined by non-exceeding of design limits for the degree of fuel cladding tightness determined by regulatory documents. Normal operation limits for fuel element damage of BN-reactors are:

- Gas-leakage type defects - not more than 0.1% of total quantity of fuel elements in the core;
- Direct contact of nuclear fuel with coolant - not more than 0.01% of total quantity of fuel elements in the core.

An operational limit value is half as many. Besides, the specified limits for fast reactors are much more conservative as compared with limits determined for other reactor types.

Fuel cladding tightness monitoring (CTM) at an NPP is performed by a set of operative and non-operative systems on activity of process media of the primary circuit.

Set points of emergency and warning system actuation are determined based on the assigned limits. The quantitative values of set points are assigned by an analytical method considering operation experience of similar systems on BN-600 и BN-800 reactors.

Efficiency of CTM system is confirmed by Russian and foreign reactor operation experience. Application of CTM system permits to enhance safety of reactor plant operation and spent fuel storage, and contributes to achievement of high operation indices of the power unit.

2 Operative CTM systems

2.1 The CTM System Based on Delayed Neutron (SCTMSS) [1-5]

One of the main operative systems, continuously monitoring fuel cladding tightness during reactor power operation is the delayed neutron based CTM system.

This system operation principle is based on recording of neutron radiation of short-lived fuel fission products, which are precursors of delayed neutrons. In case of fuel element depressurization, delayed neutron precursors come to the coolant and then they are transported with sodium flow to the area of detecting units, which are placed in the reactor cavity opposite inlet ports of intermediate heat exchangers. These detecting units include suspensions of ionization chambers, which register neutron radiation of delayed neutron precursors from the coolant volume.

The task to detect and localize (identify approximately a location place) fuel assemblies with leaky fuel elements in the core is solved based on readings of different suspensions of ionization chambers of the sector CTM system.

At the BN-1200 reactor the sector CTM system has been designed considering design and operation experience of the sector CTM system of BN-600 and BN-800 reactors.

In the BN-1200 design there were implemented design improvements in the detecting unit arrangement. To enhance fail safety three independent recording branches for signals from delayed neutron precursors with a majority decision scheme of emergency signal generation to the reactor control and protection system are used.

The main differences of the detecting unit *(see Figure 1)* of the BN-1200 sector CTM system from that of the BN-600 reactor are the following:

- increase of mass and overall dimension characteristics to optimize arrangement of ionization chamber suspensions;
- increase of quantity of ionization chamber suspensions to be located in each detecting unit (from 2 to 3);
- installation of a thermal couple to record the temperature in the detecting unit;
- decrease of neutron background on ionization chamber suspensions due to application of a filter of borated polyethylene.

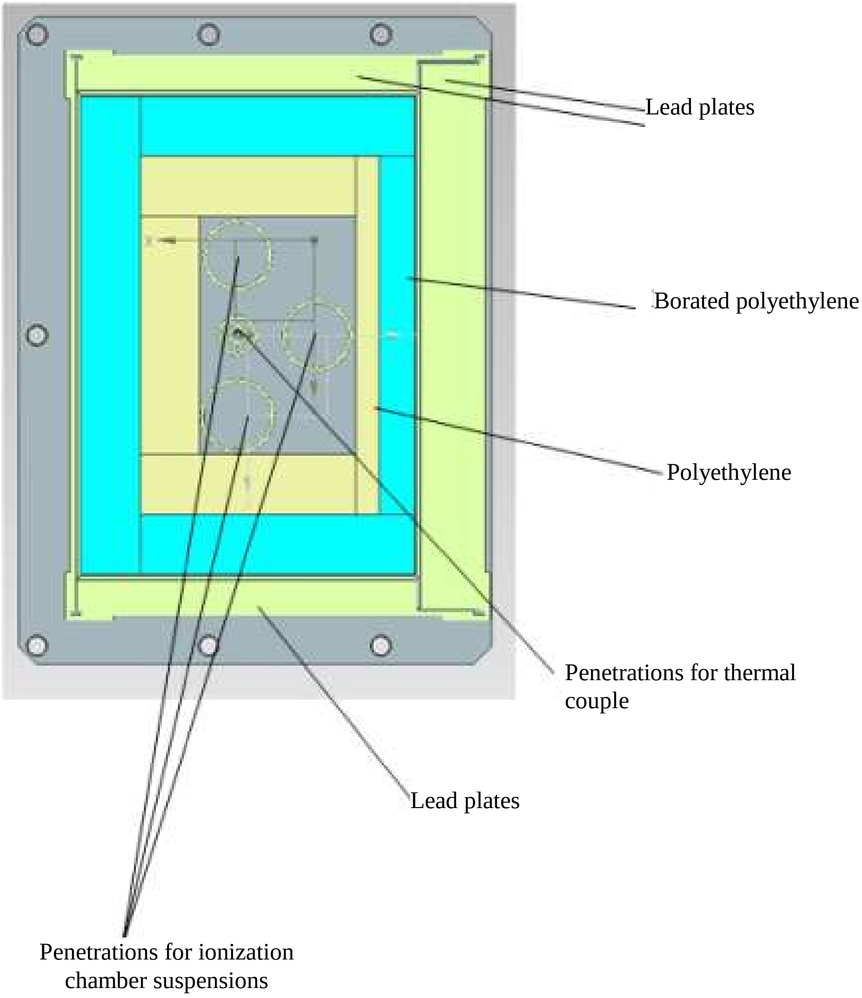

Figure 1. –The detecting unit of the sector CTM system

2.2 Gas CTM System (GCTMS) [1, 6]

A gas-based monitoring system of fuel element cladding tightness functions at reactor power operation and intended for:

- recording of fuel element depressurization by change of activity of reactor protective gas;
- determination of isotope composition of gamma-active nuclides in protective gas.

In the course of this system development for the BN-1200 reactor the available designs of gas CTM systems of BN-600 and BN-800 reactors *(see Figure 2)* were analyzed, and this system operation experience at the BN-600 reactor was considered.

As a result of the performed analysis it was decided to detach the gas CTM system as a separate system independent from a system of blow-off and holding of active argon. This decision makes it possible to increase this system efficiency considerably due to reduction of length of pipelines from the reactor gas cavity to recording instrumentation, which reduces time of sample transportation to measuring instrumentation.

The basic scheme of gas supply to the measuring portion was adopted from the gas CTM system of the BN-600 reactor. Gas is taken from the in-vessel gas collector, then supplied to sodium vapor traps by pipelines and come to suction of micro-pumps, and then it pumped through a measuring portion to measure total volume activity and to make gas spectrometry. After the measuring portion gas returns to the reactor by gas compensation pipeline.

The gas CTM system structure of the BN-1200 reactor uses a unique detecting unit for gas volume activity based on an ionization chamber of a special design. This unit was successfully tested as a part of the gas CTM system of the BN-600 reactor and put into experimental operation. In contrast to detecting units used at present time the developed device allows prompt measurements of total volume reactor gas activity in the entire range of expected values and effective detection of gas leak at early stages.

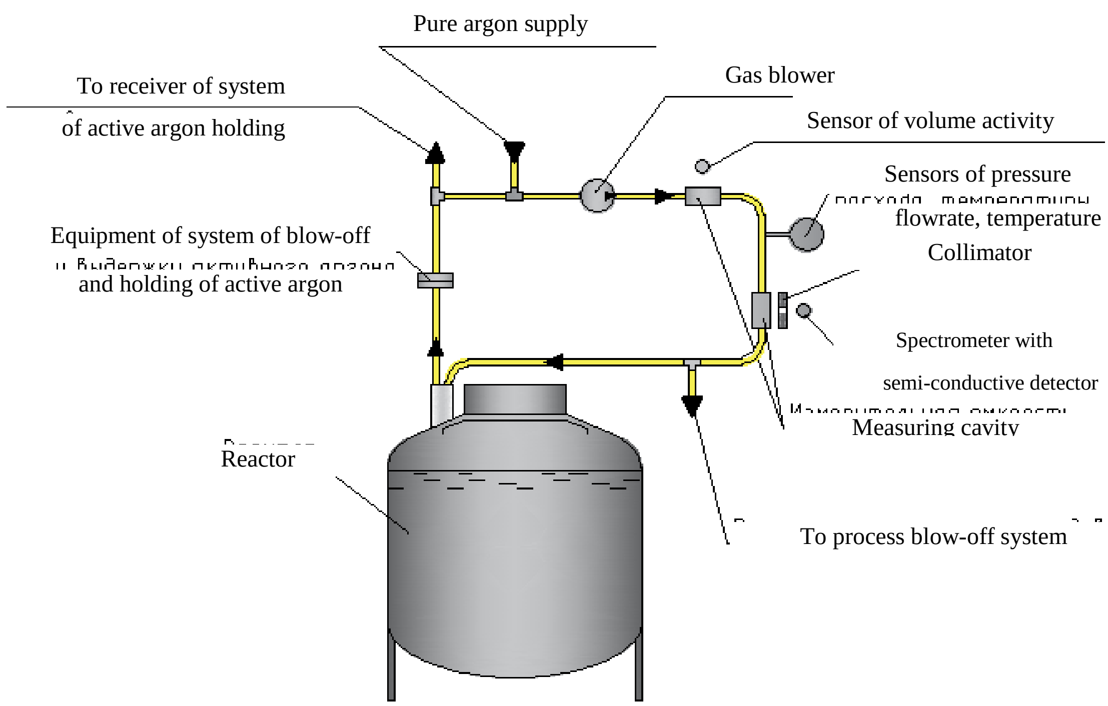

Figure 2. The scheme of the gas CTM system

2.3 Sodium CTM system [1, 5-8]

The specific feature of sodium CTM system (SoCTMS) is that this system, in addition to fuel cladding tightness monitoring, allows prompt monitoring of the process of primary circuit (coolant and equipment) contamination with fission products, in particular, with cesium, in presence of leaky fuel elements in the core. The sodium CTM system is used in all operation modes of the unit, in which the primary circuit system functions.

The BN-1200 basic concept eliminates the possibility to output the primary coolant beyond the reactor vessel boundaries. Because of this limitation, it is impossible to apply development experience of sodium CTM systems of BN-600 and BN-800 reactor plants in a full scope. As a new design decision it was proposed to arrange a technological (sampling) portion of SoCTMS in in-vessel equipment of the reactor, and to arrange an automated portion in rooms adjacent to the reactor cavity.

It is supposed that the BN-1200 SoCTMS sampling portion will be made in the form of a technological channel of an annular tube design. This structure will be used to arrange sodium supply to the spectrometry sector and to discharge it from this sector. This structure *(see Figure 3)* includes the following devices:

- throttle device to provide required flowrate through the spectrometry sector;
- flow meter to measure rate of flow of an adsorber;
- temperature sensor;
- graphite adsorber, located in the top part of the channel.

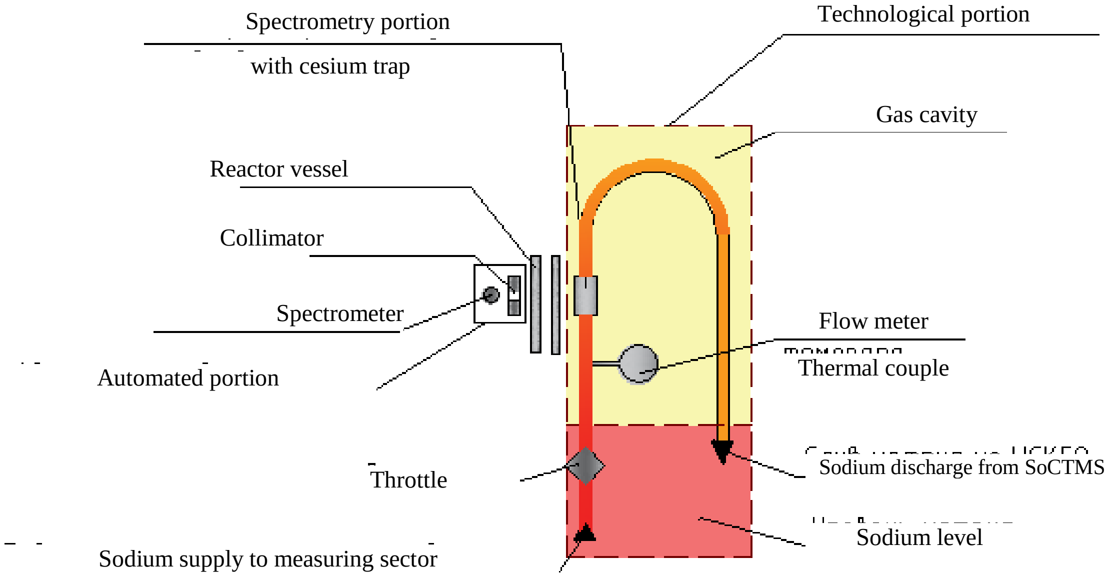

Figure 3. The BN-1200 sodium CTM system

The main element of the sodium CTM system is a graphite adsorber *(see Figure 4)*, intended to monitor cesium isotope content in coolant during reactor power operation.

The system is based on the property of carbon-bearing materials to sorb fission products, mainly cesium, from sodium. Reactor graphite is used as sorbent which provides high sorption capacity enough to monitor cesium isotope activity and high stability in sodium coolant flow.

Graphite adsorber application to monitor cesium isotope content in the primary sodium was proved by operation experience of the BN-600 sodium CTM system. A graphite adsorber of a similar design is applied at the BN-800 reactor.

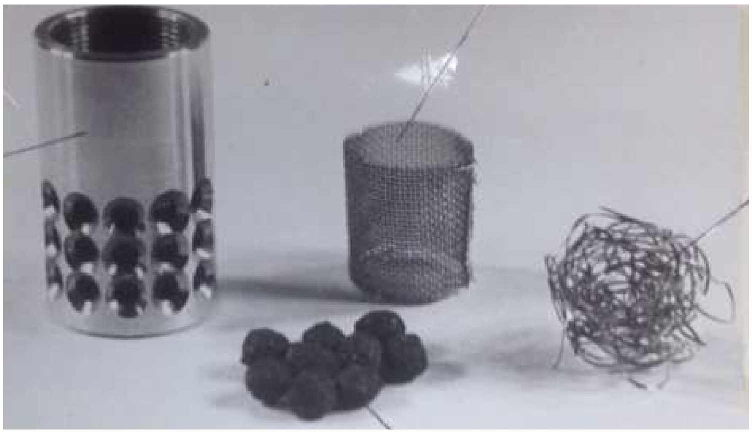

Figure 4. Graphite adsorber elements

To justify selected design operability and to measure BN-1200 sodium CTM system efficiency the following design and analytical work was made:

- operation experience of the BN-600 sodium CTM system was analyzed;
- design analysis of the in-vessel sodium CTM system efficiency during monitoring tightness of core fuel elements was made;
- technological channel strength (vibration strength) was estimated.

The obtained results confirm possibility in principle to arrange the technological (sampling) portion of the sodium CTM system in reactor in-vessel equipment.

3 Non-operative CTM systems [9-11]

Non-operative CTM systems compromise two systems:

- defect assembly detection system – reactor (DADS-R);
- defect assembly detection system in a washing seat (DADS-WS).

Handling technology for leaky spent fuel assemblies of the BN-1200 power unit has been realized successfully at the BN-600 power unit for 30 years. Operation experience of BN-600 DADS-R and DADS-WS shows their high efficiency and reliability in detection of defect assemblies.

These systems at the BN-1200 reactor are similar in design and operation principles to those of BN-600 and BN-800 reactors.

3.1 Defect Assembly Detection System – Reactor

The reactor system of detection of defect fuel assemblies (DADS-R) *(see Figure 5)* is intended to detect fuel assemblies with leaky fuel elements at a shutdown reactor. Fuel assemblies with leaky fuel elements are detected to unload them timely to provide further reactor operation within the assigned limits of parameters associated with fuel element damage.

The design is based on recording of activity of fission gases coming out through a defect in a damaged fuel element cladding into a sampler volume. To intensify fission gas release from fuel a fuel assembly is placed into sampler gas medium and held in it for a certain time to heat fuel by residual heat.

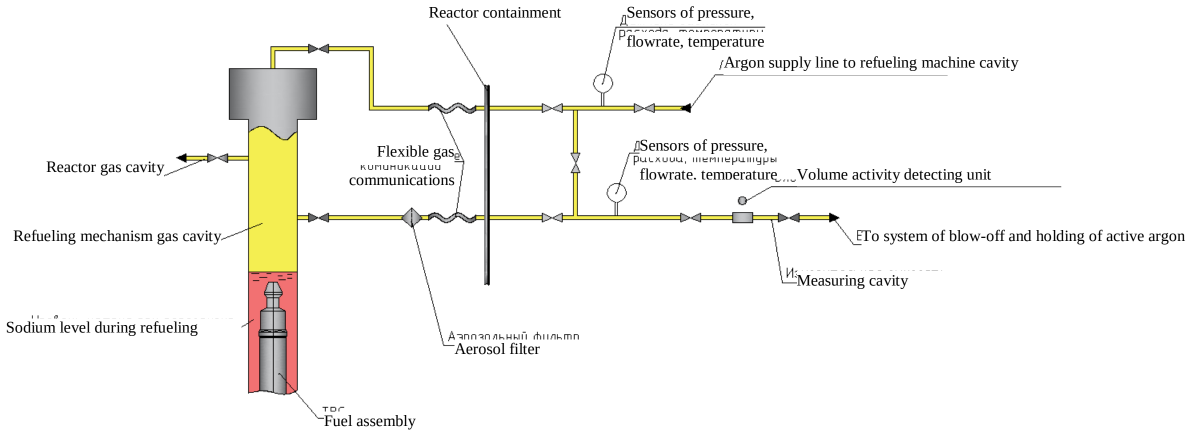

Figure 5. The DADS-R process flow diagram

3.2 Defect Assembly Detection System in a Washing Seat (DADS-WS)

At the BN-1200 reactor the defect assembly detection system in washing seats *(see Figure 6)* monitors fuel element cladding tightness during washing of all spent fuel assemblies in washing seats. As a rule, monitoring is performed after steam-water washing. Exceptions are spent fuel assemblies which are identified by the sector CTM system and the DADS-R as fuel assemblies with “direct fuel contact with coolant” defect: their first monitoring stage is performed before washing.

The DADS-WS is built-in in the system of spent fuel assembly washing in washing seats and monitors tightness of spent fuel assemblies into two stages. At the first stage a washing seat with a fuel assembly being in it is filled with nitrogen, the spent fuel assembly is heated and fission gases being under claddings begin to come out through cladding defects. After holding, nitrogen from the washing seat is begun to release to special ventilation by controlled flowrate. Sampling for the measuring sector is made from the gas discharge pipeline. Tightness of fuel element claddings of the inspected spent fuel assembly is estimated by readings of activity sensors.

Spent fuel assemblies which appeared to be leaky by the results of the first monitoring stage pass the second stage of monitoring.

At the second stage a washing seat with a fuel assembly being in it is filled with pure water which, having achieved a certain level, overflows in an overflow collector, near which a semi-conductive gamma spectrometer sensor is installed. Fission fragments come out from the fuel assemblies with “direct fuel contact with coolant” defect to water. Radioactive substances from leak-tight fuel assemblies and from fuel assemblies with “gas leakage” defect do not come into water.

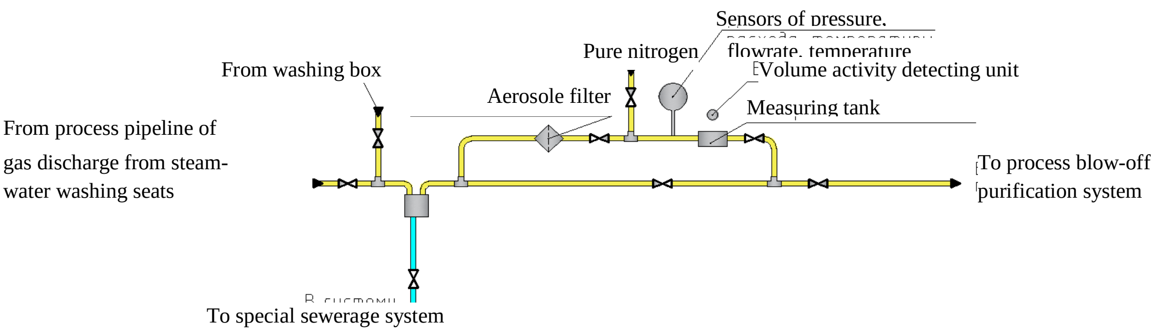

Figure 6. The DADS-WS process flow diagram

4 Conclusion

Radiation monitoring systems of fission products in the primary coolant are one of the most important components to provide physical safety barriers at the BN-1200 reactor.

Operation experience of CTM systems at BN-600, BN-800 reactors, which showed high efficiency and reliability of these systems, was considered in development of BN-1200 CTM systems.

Schemes of sector, gas CTM systems, and DADS-R and DADS-WS are mainly adopted from BN-600 and BN-800 reactors with some insignificant design modifications aimed at increase of efficiency of these systems. Adoption of schemes of operating plants allows making conclusion on high efficiency and reliability of the above-mentioned systems in their application at the BN-1200 reactor.

The main innovation for the BN-1200 reactor is a fundamentally new monitoring system and a unique design of sodium CTM system, eliminating primary coolant output beyond the reactor vessel boundaries.

To justify efficiency and reliability of application of the new scheme of the sodium CTM system the similar system operation experience at the BN-600 reactor and preliminary design analysis were performed. The results of performed analysis and calculations confirm possibility in principle to arrange the technological portion of the sodium CTM system in reactor in-vessel equipment. Application of one of the main elements of the BN-1200 sodium CTM system (graphite adsorber) has been proved by long-term operation experience at the BN-600 reactor.

To justify operability of the proposed design of the sodium CTM system more completely, to measure its efficiency, to solve system calibration problems it is necessary to perform a set of calculation-experimental and analytical studies.

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