

Integrated R&D to Validate Innovative Emergency Heat Removal System for BN-1200 Reactor

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Abstract. Decay heat removal from fast reactor BN-1200 to atmosphere air is provided by passive emergency heat removal system (EHRS). Development of EHRS involved the following innovations:

- passive check valve at the outlet of decay heat exchanger (DHX);
- application of outlet damper of air heat exchanger (AHX) with passive elements;
- natural circulation in all EHRS circuits.

The following experiments were conducted using test facilities with water and sodium:

- hydraulic testing of several options of DHX check valve are performed using scaled-down mockup;
- hydraulic testing of full-scale mockup of check valve;
- in the closed position of check valve diffusion like process was investigated (long-term testing);
- experimental studies of thermohydraulic characteristics are performed using scaled-down reactor model with one EHRS loop.

Comprehensive calculation justification of EHRS efficiency was performed using a new generation calculation code SOKRAT-BN.

Key Words: Decay Heat Removal, Mockup, Check Valve, Verification.

1. Introduction

Decay heat removal from BN-1200 reactor, in case when cooling through steam generators is not possible, is provided using EHRS. This system consists of four independent loops each including three heat transfer circuits: primary (in reactor), intermediate and air circuits.

There are four DHX installed in reactor. One of the innovative solutions introduced in EHRS of BN-1200 reactor is a passive check valve at the outlet of DHX. During power operation of the reactor this valve is closed and in case of switching into cooling mode in the process of main circulation pumps rundown the DHX check valves open in passive mode and coolant comes inside of fuel subassemblies (SA).

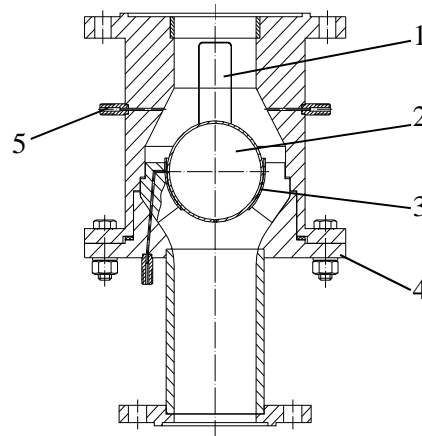
In similar EHRS loops of foreign reactors (for example, EFR, PFBR, CEFBR [1]) the mentioned valve is not used and the coolant from DHX goes back into the upper plenum (UP) of the reactor and further into the space between SA wrapper tubes, i.e. inter-wrapper space [2].

The design of the outlet damper of AHX also includes innovative solution which comprises application of passively actuating flaps that are hold in closed position by means of electric magnet. In case of beyond-design-basis accident with blackout, the electric magnet is de-energized and the flap turns by gravity and opens channel for air circulation through AHX.

To validate EHRS efficiency, JSC “Afrikantov OKBM” and JSC “SSC RF-IPPE” conducted comprehensive research and development activities.

2. Hydraulic Testing of Check Valve Mockups

Hydraulic testing of down scaled mockups of the check valve (simplified design with scale of 1:5) was conducted using water test facility at JSC “Afrikantov OKBM” [3]. The sketch of this mockup is given below in Fig. 1.



1 – window; 2 – locking element; 3 – supporting bowl; 4 – body; 5 – pressure sampling tubes

FIG. 1 – Mockup of the check valve.

Several mockups of the check valve were tested: one with ball type locking element, located, in the initial state, in the supporting bowl (see Fig. 2a) or the other one using the thin wall ribs (see Fig. 2b) as well as the third one with hemisphere type locking element connected with the guiding rod (see Fig. 2c).

During testing the following parameters were measured: flowrate and temperature of water in several points of the check valve, position and velocity of the locking element (throughout special windows in the body of the mockup using high speed digital videocamera).

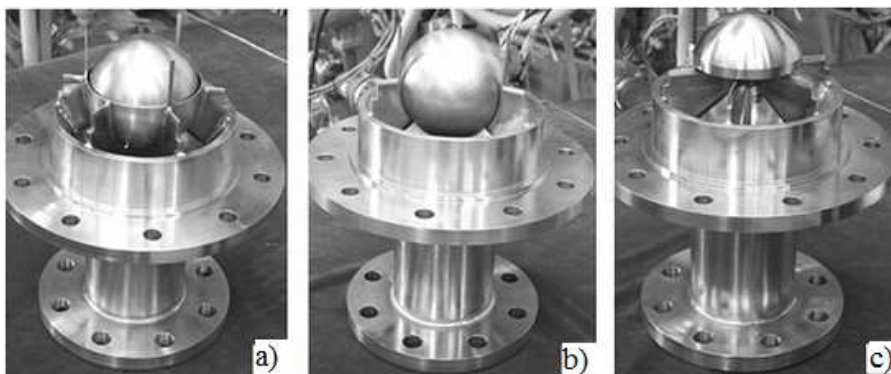
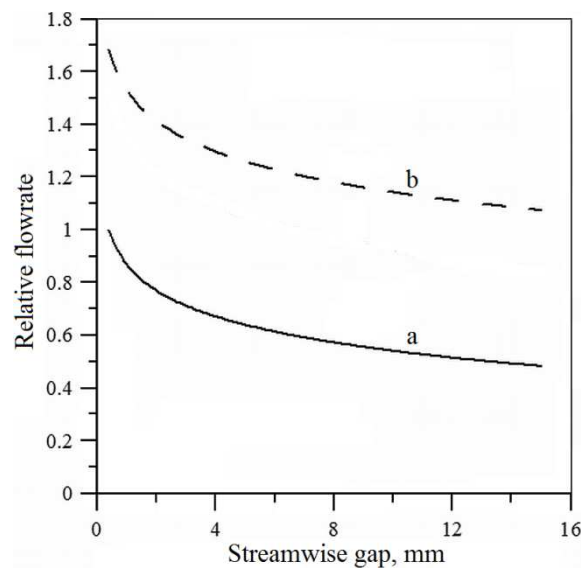


FIG. 2 – Tested mockups of the check valve.

The following data was received during the testing:

- dependence of the check valve ‘closing flowrate’ on the gap between the locking element and the supporting bowl (see Fig. 3);
- velocity of the locking element collision with the seat when closing of the valve and time of closing with various mass of locking element;
- pressure and pressure drop in the check valve.



a – “light” ball; *b* – “heavy” ball

FIG. 3 – ‘Closing flowrate’ of the check valve mockup depending on the streamwise gap (size between the locking element and the supporting bowl) and ball mass.

Based on the results of tests and calculations the type of check valve with ball locking element located on the supporting bowl, having sufficient gap, was selected for further development. The gap size was chosen by design requirements considering results of the tests.

3. Hydraulic Tests of the Full Scale Check Valve Mockup

Testing of the full scale check valve mockup was performed at JSC “Afrikantov OKBM” using the water test facility presented in Fig. 4. In order to simulate flow pattern inside the valve a section of bottom part of DHX was integrated into the testing stand.

The performed testing confirmed operability of the check valve with flowrates corresponding to the standard values of actual coolant in the EHRS. The following characteristics of the valve were obtained:

- hydraulic resistance of the check valve mockup while transferring into standby mode (primary pump acceleration stage until closing of the check valves) and in the decay heat removal mode;
- ‘closing flowrate’ of the check valve mockup;
- flowrate of leakage through the closed check valve into standby mode;
- pressure variation in the test facility caused by high local accelerations of liquid occurring in the course of the check valve closing;
- information about influence of the locking element mechanical hit upon the valve seat on the state of its components (on the results of resource testing).

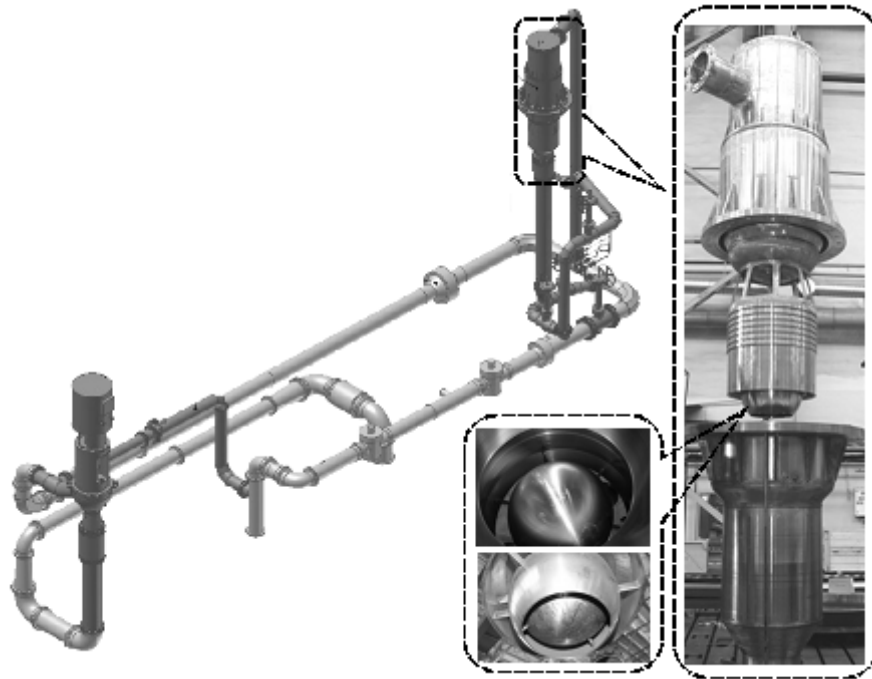


FIG. 4 – Test facility and mockup of the check valve.

Check valve mockup operating values obtained in the course of experimental activities were compared with values obtained in calculations using Russian CFD code FlowVision [4].

This comparison showed that calculated values for the valve ‘closing flowrate’ exceed the values obtained during the experimental research by 8-17% depending on the weight of the locking element.

The analysis of this phenomenon allows proposition that the result is significantly influenced by the factor of instability of the real closing process of the valve which was not considered in the calculation methodologies.

The hydraulic resistance of the check valve in experiments and in code calculations coincided with accuracy of 1% (for the check valve) and up to 10% (for the complete experimental section that includes the check valve and the DHX section).

Fig. 5 gives pressure distribution obtained through the calculation using CFD code FlowVision. Water flow through the check valve from top downward occurs in the decay heat removal mode, the water flow from bottom upward occurs while transferring into standby mode.

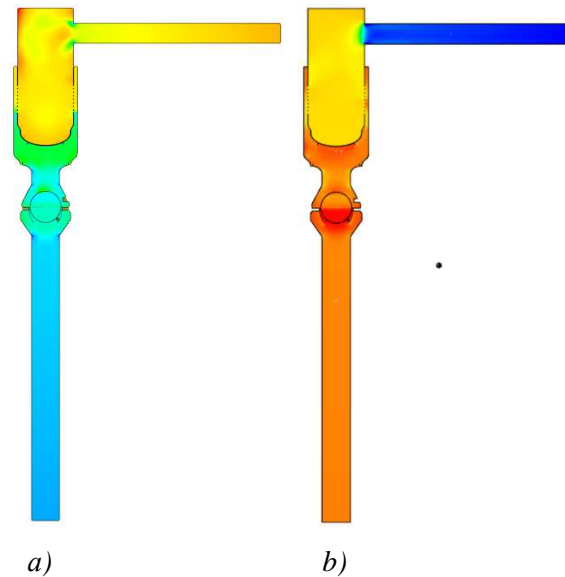


FIG. 5 – Calculated pressure distribution with flow direction: a – downward; b – upward.

4. Static Testing for Self-adhering of Check Valve Components

Static testing for self-adhering was performed at JSC “SSC RF-IPPE” using the sodium test facility stand. The testing was aimed at studying processes undergoing in the contact point of the locking element and the valve seat. The testing was conducted under standard conditions (sodium temperature and compressing force of the locking element of the valve seat) common for reactor power operation.

The testing showed no self-adhering of the locking element and the valve seat. No diffusion like process was observed during visual inspection of the components (see Fig. 6).

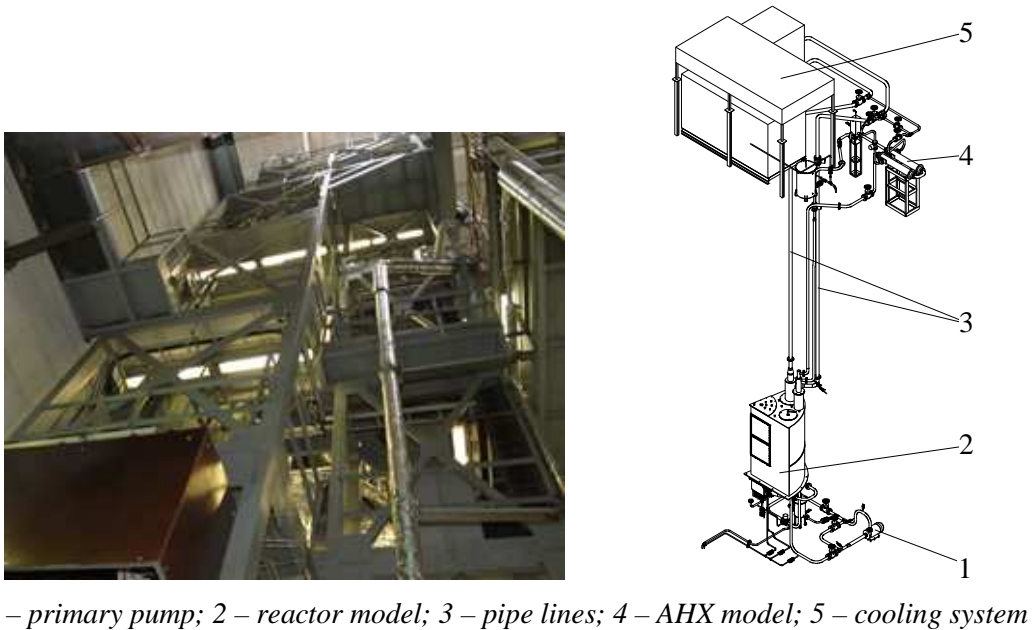


FIG. 6 – Segment of the locking element after testing.

5. Testing for Thermal Hydraulic Characterization Using the Downscaled Model of BN-1200 Reactor With EHRS Loop

Testing aimed at identification of thermal hydraulic characteristics of BN-1200 reactor with EHRS loop was performed in JSC “Afrikantov OKBM” using the water test facility “TISEY” [5]. The test facility includes a closed loop of 1/4 of BN-1200 reactor with intermediate circuit and a single EHRS loop (air loop is not simulated).

Main overall dimensions (exterior outlines and elevations of the equipment) are downscaled by 5 times as compared to the actual reactor. Maximum power of the core model in the simulated power mode of operation is 350 kW and in the cooling mode 70 kW. Total height of the test facility is 21 m. The overview is given in Fig. 7.



1 – primary pump; 2 – reactor model; 3 – pipe lines; 4 – AHX model; 5 – cooling system

FIG. 7 – Overview of “TISEY” test facility.

The test facility has over 500 thermocouples, seven flow meters, three pressure sensors, ten pressure drop sensors, three level meters, six watts transducers.

Power operation of reactor was simulated using the facility as well as cooling modes through EHRS loop. Totally there were over 40 stationary and dynamic modes tested using the facility.

The following parameter zone were examined simulating the power modes (calculated using typical size and speed in UP of the reactor model): as for Reynolds number 13,900 – 75,500, as for Peclet number 47,800 – 233,500, as for Richardson number 0 – 78, as for Prandtl number 3.0 – 3.7. The following results were achieved:

- the influence of the above core structure design on speed and temperature fields in the reactor model was analyzed;
- the effect of EHRS efficiency along with number of operating dummy SA and water levels on characteristics of the reactor model and EHRS loop was examined;
- database for verification of CFD codes was generated.

The following may be noted based on the analysis of modes that simulate cooling through the EHRS:

- the efficiency of innovative EHRS loop with check valve was experimentally validated using the test facility;
- passive opening of the DHX check valve, development of natural circulation in reactor model and EHRS circuit were demonstrated;
- characteristics for alternative options of EHRS design were obtained;

- the influence of primary pump valve position and water level on natural circulation development in reactor model was examined;
- the influence of EHRS switching delay on the cooling process was investigated;
- database for verification of CFD codes was generated.

Fig. 8 shows temperature fields in the UP of the reactor model based on results of testing with simulation of cooling through EHRS.

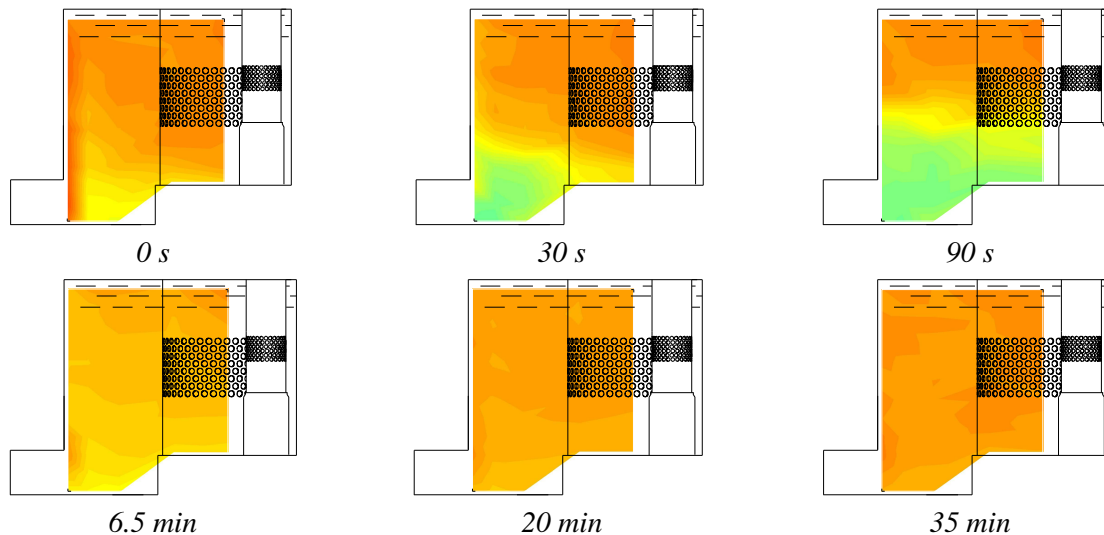


FIG. 8 – Water temperature fields in the UP of the reactor model from results of testing with simulation of decay heat removal mode (time after scram).

As per the obtained experimental data, the approach to calculation analysis of BN-1200 thermal hydraulic processess was verified using the CFD code FlowVision (relating to physical models, numerical scheme, and actual design simplifications applied in the CFD code).

Fig. 9 gives distribution of excess temperature of water across the height of the reactor model UP during cooling simulation based on results of testing and verification calculations.

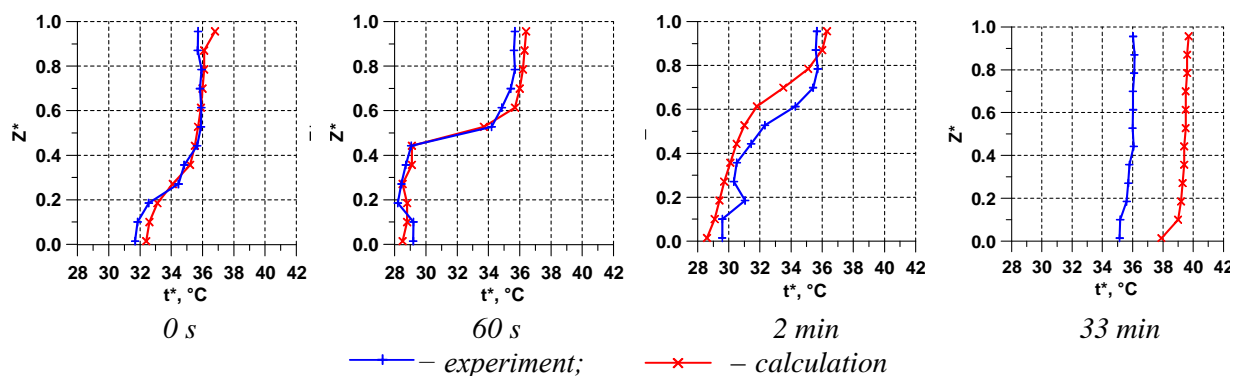
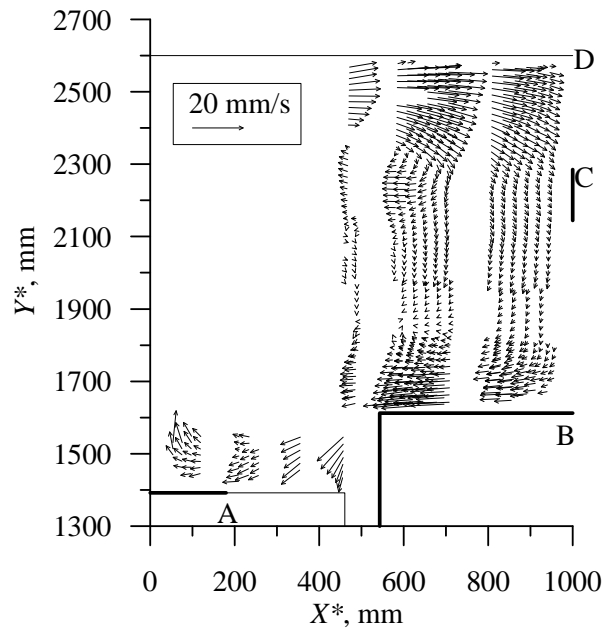


FIG. 9 – Distribution of excess temperature of water across the height of the reactor model UP during cooling simulation through EHRS.

Using special Particle Image Velocimetry (PIV) system, developed by the Institute of Applied Physics of Russian Academy of Sciences, considering peculiarities of the test facility, in the UP measurements of two components of water velocity fields were performed. The graph of velocity field vector in DHX direction in the decay heat removal mode is given in Fig. 10.



A – outlet of the electrically heated SA, B – supporting belt, C – inlet window of DHX, D – water level

FIG. 10 – Vector velocity field in DHX direction in decay heat removal mode.

6. Calculation Justification of EHRS Efficiency Using New Generation Code SOKRAT-BN

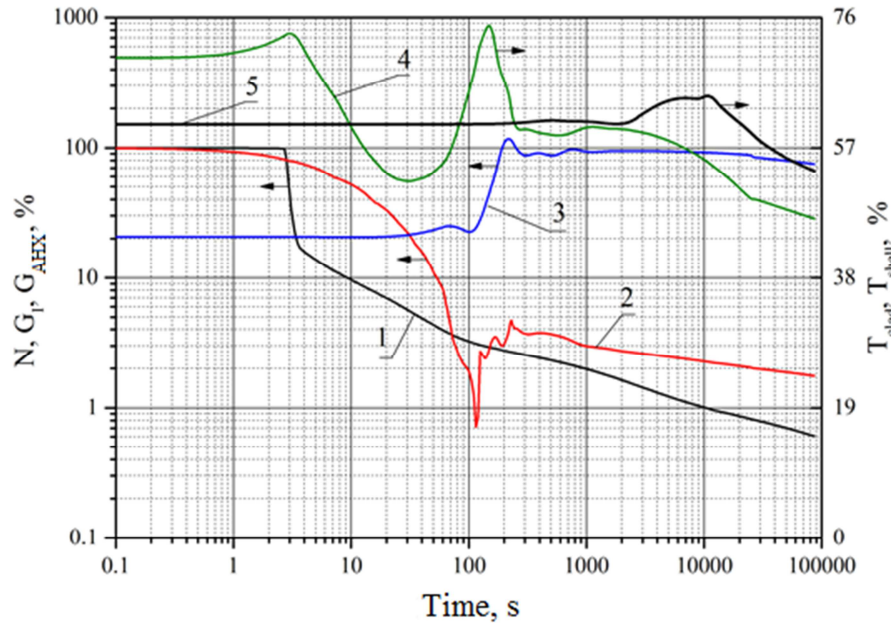
Calculation examination of BN-1200 decay heat removal modes through EHRS was performed using SOKRAT-BN code [6]. Reactor cooling through EHRS is possible in case of forced circulation loss in primary and secondary circuits. In the process of primary pump rundown check valves of DHX and dampers of AHX open. As a consequence, coolant natural circulation develops in all EHRS circuits. Cooling through EHRS is considered conservatively proceeding from operation of only two of four independent EHRS loops.

Verification of SOKRAT-BN code with respect to simulation of thermohydraulic processes with natural circulation of coolant is performed on the basis of experimental data obtained using BN-600 reactor. The results of verification conformed adequacy of the mentioned processes simulation using the SOKRAT-BN code [7].

The calculation model of reactor plant describes main primary equipment, secondary pipelines and equipment as well as EHRS pipelines and equipment [8].

Results of calculation using SOKRAT-BN code showed sustainable natural circulation development in reactor and EHRS (see Fig 11). During cooling down, normal operation limit relating to temperature of fuel rod cladding and reactor vessel is not exceeded (see Fig. 11).

The calculations performed using SOKRAT-BN code confirmed efficiency of EHRS application in the process of BN-1200 reactor cooldown.



1 – reactor power (N); 2 – flowrate through the core (G_1); 3 – flowrate in the intermediate circuit of EHRs (G_{AHX}); 4 – relation of fuel rod cladding temperature to the acceptable value (T_{clad}); 5 – relation of reactor vessel temperature to the acceptable value (T_{shell})

FIG. 11 – Basic parameters of reactor in the process of decay heat removal.

7. Conclusion

A vast scope of calculation and experimental activities was performed with regard to innovative passive component of EHRs, i.e. DHX check valve. Those activities resulted in design selection and identification of check valve mockup characteristics. Operability of that valve was also confirmed during those experiments.

The downscaled model ensured identification of thermohydraulic characteristics of BN-1200 reactor with EHRs loop. Experimentally efficiency of the innovative EHRs with check valve was confirmed and characteristics of alternative options of EHRs design were obtained.

The calculations performed using SOKRAT-BN code confirmed efficiency of EHRs application in the process of BN-1200 reactor cooldown.

The performed R&D enabled to substantiate EHRs efficiency and safety of the BN-1200 reactor.

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