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Activities on Experimental Substantiation of SFR Safety in Accidents with Sodium Boiling

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Introduction (1/3)

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Within the framework of the Federal Target Program “Nuclear Power Technologies of a New Generation for Period of 2010-2015 and with Outlook to 2020” (FTP) the design of a large-size sodium-cooled fast reactor (SFR) BN-1200 is under development.

The BN-1200 reactor would meet safety requirements imposed to the 4^{th} generation reactor facilities.

One of the key safety requirements imposed to the 4^{th} generation NPPs is assurance of their resistance to any severe accident that may occur during reactor operation in order to eliminate the necessity of evacuation of population living in the vicinity of the NPP.

The most unfavorable beyond design basis accident for SFR is ULOF accident with loss of grid and emergency power supplies and failure of all reactivity control devices.

Introduction (2/3)

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The following goals are set for development and justification of the BN-1200 design:

- *Development of the new generation computer codes for the analysis and justification of SFR safety under conditions of severe beyond design basis accidents and their verification on the basis of experimental data;*
- *Construction of experimental facilities for obtaining required experimental data and carrying out related studies*
- *Carrying out analytical studies of severe beyond design basis accidents in the BN-1200 by means of the computational codes developed and verified on the basis of the experimental data and evaluation of radioactivity release to the environment*
- *Development of technical solutions eliminating the possibility of radioactivity propagation outside NPP site in the amount exceeding permissible value for the inhabitants in case of severe beyond design basis accidents, including ULOF accident.*

Introduction (3/3)

In view of limited amount of experimental data on severe beyond design basis accidents in SFR, the FTP implies updating of the experimental infrastructure of the nuclear power industry for the purpose of obtaining required experimental data.

COREMELT computer code is developed in the SSC RF-IPPE for the analysis of the severe beyond design basis accidents which can occur in the SFR.

A specific program of sodium boiling tests is under development to provide experimental data required for verification and validation of the COREMELT code regarding sodium boiling modes.

For this purpose it is planned to update the AR-1 test facility located in the SSC RF–IPPE.

Experimental program envisages study of sodium boiling modes that can arise in the BN-1200 reactor under conditions of the ULOF severe beyond design basis accident and of the design basis accident with fuel subassembly (FSA) cross-section blockage.

Analysis of phenomena arising in SFR under severe accidents (1/3)

Phenomena of sodium coolant boiling that can arise under the ULOF accident and under conditions of the accident with FSA cross-section blockage are considered.

A large-size SFR is usually characterized by positive value of sodium void reactivity effect (SVRE) and sodium boiling will strongly effect on ULOF accident consequences and it may cause melting and displacement of cladding and fuel materials under certain conditions.

The concept of the "flattened" core design (with decreased core height/diameter ratio) and with sodium cavity located above the core is applied for decreasing SVRE value in the BN-1200.

Coolant boiling appears in the upper core section under ULOF accident and it may propagate to the central core region in the course of the accident development.

With sodium cavity, sodium boiling starts in the upper core section and it first propagates to the sodium cavity volume.

Analysis of phenomena arising in SFR under severe accidents (2/3)

Preliminary calculations have confirmed that upon sodium boiling onset coolant is partially removed from the area at the top part of the fuel pins bundle.

Since SVRE is negative in this area, reactor power starts to reduce causing decrease of sodium boiling intensity.

Finally, the mode of periodical sodium onsets with decreasing amplitude of reactor power, coolant flow rate and reactivity fluctuations is realized on the background of general power decrease.

These fluctuations can continue for several dozen seconds.

However, the abrupt stability loss may occur in some channels with coolant flow rate decrease down to zero, this being accompanied by the increase of temperature of fuel pin claddings in related channels in the area of DNB appearance.

Stable sodium boiling continues in the other channels (no DNB) with the decrease of reactor power.

Analysis of phenomena arising in SFR under severe accidents (3/3)

Thus, vapor content in sodium cavity strongly effects on the rate of reactor power decrease.

In turn, reactor power decrease results in the decrease of fuel pins temperature and, hence, more intensive vapor condensation.

Obvious feedback is visible when the mode of two-phase flow in sodium cavity significantly influences the ULOF accident dynamics.

Therefore, it is important to carry out experimental studies on sodium boiling modes in both fuel pin bundle and FSA sodium cavity, including conditions of sodium natural flow in the parallel channels system.

Nature and scale of sodium boiling mode under conditions of blockage of the FSA cross-section will be significantly dependent on the size of the blockage and its location.

An accident with total blockage of the FSA cross-section is the most dangerous.

It is planned to model the blockage of the FSA cross-section at the AR-1 test facility by means of decrease of coolant flow rate through the test assembly.

Description of the COREMELT code

COREMELT code is now under development that is designated to model severe accidents in the SFR core.

As regards ULOF accident, COREMELT code permits to model all stages of the accident including coolant boiling, cladding and fuel melting, their relocation and interaction with coolant:

- *COREMELT code is capable of making 3D coupled calculations of neutronic and thermal-hydraulic transients in the SFR*

Current COREMELT-2D code version includes:

- *Neutronic module RADAR and*
- *Thermal-hydraulic module COREMELT.*

AR-1 test facility

AR-1 test facility is applied for investigation of:

- *Thermal hydraulic processes in the SFR elements under start-up, operation transient and accident conditions*
- *Flow stability and heat transfer characteristics under liquid metal coolant boiling modes.*

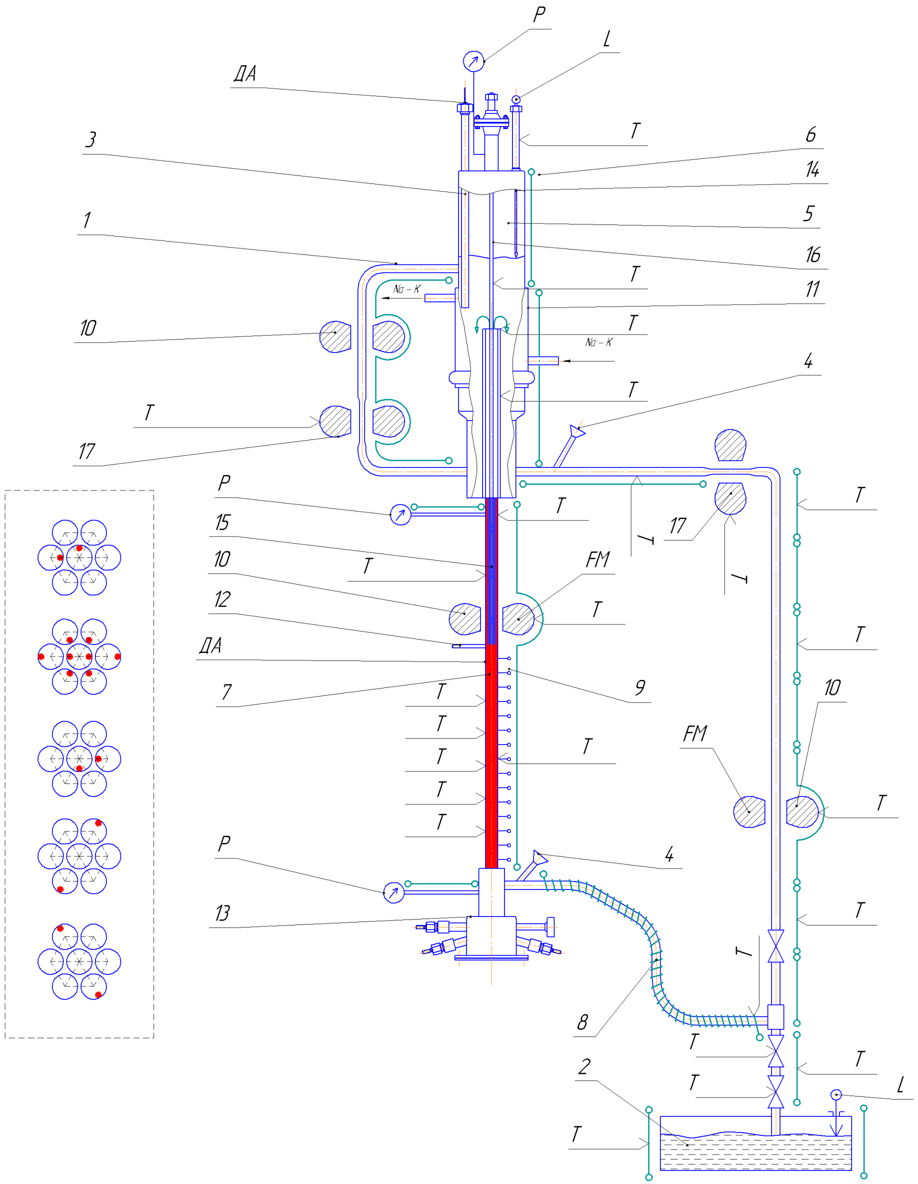
The AR-1 test facility consists of two loops:

- *Test sodium loop and*
- *Auxiliary loop with sodium-potassium alloy as a coolant.*

Main characteristics

Coolant	Sodium-potassium	Sodium
Pressure, MPa	0.6	1.0
Temperature, °C	900	900
Flowrate, m^3/h	10	10
Electric power, kW	100	100

Experimental sodium loop



1 – bypass line
2 – sodium tank
3 – acoustic sensor
4 – thermocouple sleeves
5 – gas cavity
6 – expansion tank
7 – subassembly model
8 – additional heater
9 – potentiometer sensor taps
10 – flowmeters
11 – sodium-to-sodium-potassium heat-exchanger
12 – current lead
13 – electrical connections unit
14 – sodium level meter
15 – restriction area
16 – restrictors rod
17 – electromagnetic pumps

AR-1 test facility

The following parameters can be measured in tests:

- *Electrical power of pin simulators*
- *Coolant flow rate and its oscillations in the test loop*
- *Coolant pressure at the inlet and outlet of the test FSA model, pressure oscillations, gas cavity pressure*
- *Distribution of fuel pin simulator surface temperature along the height of a heating zone*
- *Coolant temperature in various points of the test loop, including the heated zone*
- *Registration of the presence of vapor phase along the height of the test FSA model*
  - Potentiometric sensors are used for this purpose with electrodes located along all the height of the simulator heating zone, which allow to register a depth of penetration of vapor phase downwards test assembly.

The test FSA model has a geometry similar to the FSA of the BN-1200 reactor including:

- *Active part*
- *Sodium cavity*
- *Top shielding layer etc.*

The FSA model design provides possibility of change of the sodium plenum height by means of withdrawal of the displacers simulating absorber elements.

Experimental program of sodium boiling tests (1/2)

The purpose of upgrading AR-1 test facility is modeling of coolant boiling processes that can occur in the SFR core under conditions of the ULOF beyond design basis accident and design basis accident with the FSA cross-section blockage.

Therefore, the main mode parameters simulated in the tests are chosen from point of view of max degree of approximation of reactor conditions:

- *Sodium velocity*
- *Sodium temperature*
- *Heat flux from the fuel pin simulators to the coolant*

First stage of tests:

- *Stationary and non-stationary tests on investigation of sodium vaporization and condensation modes in the area of the core and sodium cavity of a single test subassembly*
  - The first series of tests on sodium boiling in the single test FSA with 7 fuel pin simulators
  - The second series of tests on sodium boiling in the single test FSA with 19 fuel pin simulators

The instrumentation for measurements permits to investigate sodium boiling process both within the bundle of fuel pin simulators and outside of it (in the sodium cavity up to the expansion tank).

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Experimental program of sodium boiling tests (2/2)

In stationary tests the sodium boiling mode is provided by means of step-by-step increase of power of the heaters with the subsequent stabilization of sodium parameters at each power level.

Tests are scheduled to be carried out for both sodium forced flow mode through test subassembly and sodium natural circulation mode.

In non-stationary tests it is planned to model conditions characteristic for investigated accidents:

- *For ULOF transient it is envisaged initially to rich a steady state mode of the AR-1 facility operation, and then to provide reduction of the power released in the fuel pin simulators and decrease of sodium flow rate through the test subassembly in accordance with the preliminary set dependences*
- *Modeling sodium boiling mode caused by the FSA cross-section blockage is provided by means of total stop of the coolant flow rate through the test subassembly with the constant power of heaters.*

The program of tests envisages investigation of degree and specific features of influence of value of the height of the sodium cavity over the core on accident transient conditions, in particular, on behavior and parameters of sodium boiling mode.

Second stage of tests:

- *Investigation of stability of sodium boiling in parallel channels under coolant natural circulation mode.*

Conclusion

- Within the framework of the BN-1200 design development and its safety substantiation an implementation of sodium boiling tests at the AR-1 test facility updated for this purpose in the SSC RF-IPPE is planned.
- The main objective of these tests consists in acquisition of the experimental data required for upgrading and verification of the COREMELT code models used for simulation of coolant boiling in the SFR core under conditions of severe accidents.
- Tests on sodium boiling will permit to enhance reliability and validity of computational substantiation of the BN-1200 self-protection against such accidents as ULOF accident and accident with blockage of the FSA cross-section.

Thank you
for your attention !