PLANNING OF EXPERIMENTAL STUDIES WITH SIMULATION OF PHENOMENA OCCURRING IN SFR UNDER SEVERE ACCIDENT CONDITIONS

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CONTENTS

INTRODUCTION (1/3)

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 large-size sodium cooled fast reactor (SFR) BN-1200 is under development.

BN-1200 reactor would meet the requirements (including those on safety) imposed to the 4th generation reactors.

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

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

INTRODUCTION (2/3)

In this view, the following goals are set for the specialists involved in the development and justification of the BN-1200 design:

- ***Carrying out analytical studies of severe beyond design basis accidents in BN-1200 and evaluation of radioactivity release to the environment (giving necessary recommendations on possible ways of mitigation of accident consequences, if necessary);***
- ***Development of technical decisions eliminating the possibility of radioactivity propagation outside NPP site in the amount exceeding permissible value for the population in case of severe beyond design basis accidents, including ULOF accident;***
- ***Development of the new generation computer codes for the analysis and justification of SFR safety in cases of severe beyond design basis accidents and their verification on the basis of experimental data;***
- ***Creation of experimental facilities for obtaining deficient experimental data and carrying out related studies.***

INTRODUCTION (3/3)

In view of limited amount of experimental data on severe beyond design basis accidents in SFR, FTP implies upgrading of the experimental infrastructure of the nuclear power industry for the purpose of obtaining necessary experimental data for verification computer codes used for analysis of severe accidents in SFR.

In particular, in the State Scientific Center of the Russian Federation – Institute for Physics and Power Engineering (SSC RF - IPPE) some experimental facilities are planned to be upgraded for the purpose of:

- ***Justification of the BN-1200 safety under conditions of severe accidents (ULOF, FSA cross-section blockage etc);***
- ***Verification of computer codes, including COREMELT computer code developed for the analysis of severe beyond design basis accident ULOF.***

ULOF ACCIDENT - PHYSICAL PHENOMENA (1/4)

The following processes may occur in the large size SFR during ULOF accident:

- ***Sodium boiling;***
- ***Melting and displacement of cladding and fuel material.***

The large size SFR is characterized by positive value of sodium void reactivity effect (SVRE).

So, methods of decreasing SVRE value down to the acceptable level are under study.

The ultimate goal is to eliminate, by decreasing SVRE, large-scale sodium boiling in SFR core that can lead to extensive damage of the core structural elements.

The “flattened” core design with sodium cavity was chosen for decreasing SVRE value in the large size SFR.

ULOF ACCIDENT - PHYSICAL PHENOMENA (2/4)

Calculations have confirmed effectiveness of sodium cavity concept:

- ***After sodium boiling onset coolant is partially removed from the area at the top of the fuel pins bundle.***
- ***Since sodium void reactivity effect is negative in this area, reactor power starts to decrease causing decrease of sodium boiling intensity.***
- ***Finally, the mode of periodical sodium boiling onsets with decreasing amplitude of reactor power, coolant flow rate and reactivity fluctuations is realized on the background of general power decrease.***

Apparently, vapor content in sodium cavity has strong effect 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.

ULOF ACCIDENT - PHYSICAL PHENOMENA (3/4)

It is obvious that the mode of two-phase flow in core sodium cavity significantly influences ULOF accident dynamics.

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

As regards studies on sodium boiling processes, it is also important to carry out experimental studies on sodium boiling caused by the accident with blockage of SA cross section.

Both nature and degree of the effect of blockage location and its size on the scale and mode of boiling should be studied and time available before accident propagation to the adjacent fuel subassemblies should be evaluated.

ULOF ACCIDENT - PHYSICAL PHENOMENA (4/4)

As it was mentioned above, melting and relocation of cladding and fuel materials may occur during ULOF accident.

Therefore, justification of SFR safety requires carrying out experiments with simulation of processes caused by cladding and fuel melting and molten materials interaction with coolant under ULOF accident conditions.

The most important characteristics of the above physical processes are as follows:

- ***Pressure in the area of interaction of molten core materials with sodium;***
- ***Degree of fuel dispersion;***
- ***Mechanical energy release as a result of molten materials interaction with sodium (coefficient of conversion of thermal energy of interacting materials into mechanical energy of liquid metal coolant movement).***

COREMELT COMPUTER CODE (1/4)

Set of computer codes capable of analyzing all types of severe accidents and all their stages was developed at the SSC RF–IPPE for the analysis of severe beyond design accidents in SFR.

The universal code package COREMELT is now under development on the basis of several codes used for modeling accidents accompanied by phase change in the core components (coolant boiling and cladding and fuel melting).

COREMELT code is designed for modeling all stages of ULOF type severe beyond design accident up to possible core disrupture:

- ***Coolant boiling;***
- ***Cladding and fuel melting;***
- ***Their relocation and interaction with coolant.***

COREMELT COMPUTER CODE (2/4)

COREMELT code package is capable of making connected 3D calculations on neutronics and thermal hydraulics transients in SFR.

Current version of COREMELT-2D code includes:

- ***Neutronics module RADAR***
- ***Thermal-hydraulics module COREMELT.***

In RADAR module, multi-group neutron diffusion equation is solved in R-Z and X-Y geometry. TRIGEX code modified for the purpose of this problem solution with built-in CONSYST code connected to ABBN-93 nuclear data library are used as a block for the preparation of dynamic neutron data.

COREMELT COMPUTER CODE (3/4)

In COREMELT module a multi-component multi-phase mathematical model of thermal hydraulics in R-Z geometry in porous body approximation is realized.

All components are conventionally broken down into two groups:

- ***Moving components***
- ***Stationary (structural) components.***

As regards moving components, the complete set of mass, momentum and energy preservation differential equations is solved.

Stationary (structural) components simulating various structural elements of the core and reactor vessel, as well as fuel and steel scales frozen on their surface are described by mass and energy preservation differential equations.

COREMELT COMPUTER CODE (4/4)

The number of the components may vary depending on complexity of the problem to be solved.

All moving components are connected mechanically to each other and to the channel walls (structural components).

Heat transfer between all the components is described by the corresponding relationships closing basic set of differential equations.

In the multi-component flow model, there are descriptions of phase transitions, such as evaporation-condensation and melting-freezing.

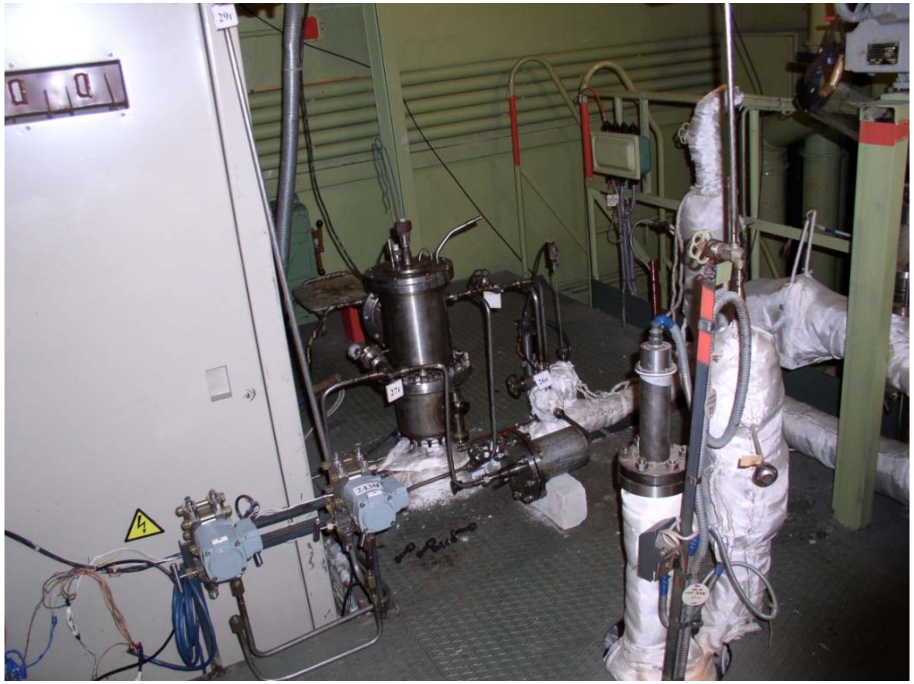
UPGRADING IPPE EXPERIMENTAL BASE

There is an extensive experimental infrastructure at the SSC RF - IPPE, which can be used for verification of computer codes developed for justification of the new SFR designs.

In particular, it is planned to use PLUTON and AR-1 test facilities for experimental studies on various phenomena, which may occur in case of severe beyond design basis accidents in SFR.

These test facilities are currently upgrading for the sake of simulation of the processes caused by severe beyond design basis accidents in SFR.

PLUTON TEST FACILITY (1/2)



PLUTON Test Facility

Purpose

–Studies on processes of material movement caused by interaction of uranium-containing corium simulators with sodium in SA simulators of various designs;
– Experimental determination of thermal-to-mechanical energy conversion coefficients in case of molten fuel interaction with coolant.

Main characteristics

Coolant	Na
Sodium inventory, kg	100
Max temperature, °C	550
Max input power, kW	150
Max pressure, MPa	0.8
Material	Cr18N10Ti s.s.

PLUTON TEST FACILITY (2/2)

Experimental studies are planned to carry out on PLUTON test facility with modeling of processes causing fuel element failures, their melting and interaction with coolant.

Now this test facility upgrading is underway in order to fulfill stated tasks.

Experimental studies using fuel pin mock-ups are planned.

One of the most important characteristics under study is the fraction of thermal energy converted into mechanical energy.

AR-1 TEST FACILITY (1/5)

Test facility "AR-1"

Purpose

–Studies on thermal processes in SFR elements under start-up, operation transient and accident conditions;
– Studies on stability of flow and heat transfer in case of liquid metal coolant boiling.

Main characteristics

Coolant	NaK	Na
Pressure, MPa	0.6	1.0
Temperature, °C	900	900
Flow rate, m^3/hour	10	10
Electric power, kW	100	100

AR-1 TEST FACILITY (2/5)

AR-1 test facility is used for upgrading of working section for experimental studies of sodium boiling modes in SFR fuel subassembly.

Experimental fuel subassembly design having geometry and main features of SA of advanced SFR is under development.

The main mode parameters simulated in the experiments (sodium velocity and temperature in SA mock-up and heat flux from the fuel pin mock-up to coolant) were also chosen on condition of max degree of approximation to reactor conditions.

AR-1 TEST FACILITY (3/5)

In the first stage it is planned to conduct experiments in single subassembly to study mechanisms of sodium evaporation and condensation in core sodium cavity.

Program of the first series of experiments was worked out.

This program implies carrying out studies on steady-state and transient sodium boiling inside one SA containing 7 fuel element mock-ups.

So, the activities planned in the first stage are aimed at:

- ***Studies on the boundaries of stable liquid metal boiling in the core of fast reactor under transient and accident conditions;***
- ***Studies on dynamic boiling caused by the abrupt change of parameters (power, flow rate and pressure) with the purpose of development of analytical methods and verification of computer codes;***
- ***Diagnostics of liquid metal boiling onset in the pin bundles for the sake of accident detection.***

AR-1 TEST FACILITY (4/5)

It is expected that this approach would facilitate more comprehensive studies of sodium boiling processes occurring both in pin bundle and outside this bundle (in core sodium cavity up to upper sodium plenum).

In two-phase models describing flow in core sodium cavity, there are many uncertain parameters influencing calculation result.

Therefore, experiments with sodium cavity boiling are considered as:

- ***Model tests aimed at the studies on sodium boiling as physical phenomenon;***
- ***Applied studies for substantiation of safety of the large size SFR under ULOF accident conditions.***

AR-1 TEST FACILITY (5/5)

Data obtained in the experiments will permit to:

- ***Verify closing relationships in the two-phase flow models as applied to geometry of sodium cavity and fuel elements bundle for various coolant flow modes;***
- ***Correct mode maps of the COREMELT code;***
- ***Perform additional verification of the COREMELT code.***

At the next stage it is expedient to carry out experiments with sodium boiling in parallel channels in the natural flow mode.

Thank you

for your attention !