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Research of structural-phase state of natural corium in fast power reactors

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A B S T R A C T

The paper presents results of material testing of the full-scale corium (melt of fuel and structural materials of the reactor core), obtained in the in-pile experimental device. Tests were carried out in the research reactor IGR (Impulse Graphite Reactor) at simulation of the final stage of severe accident of the fast power reactor with sodium coolant. The investigations include metallographic analysis of structure condition of corium ingot fragments. They are partly supplemented by the results of X-ray phase analysis of the powders made from those fragments.

1. Introduction

Development of a molten fuel pool in the power fast neutron reactor core is being considered as the most serious failure in fast reactors [1,2]. It can lead to the critical conditions for neutron multiplication due to high fuel enrichment (the phenomenon of re-criticality). Re-criticality, in its turn, can lead to further overheating of the damaged reactor and massive output of radioactivity out of protective barriers. Hence, rigorous studies of the fast reactor severe accident processes are so important. Structurally problem can be solved, for example, by application specially designed removing channels. Such channels enables early withdrawal of the molten corium outside of the reactor core and eliminate the possibility of re-criticality. That is why one of the main results of studies [3,4] is an experimental confirmation of possibility to create fast reactor core using inner ducts in the construction of fuel assemblies (FAs). Such solution provides directed (controlled) movement of the molten corium.

There are numerous studies about structural and phase condition of material testing of prototype (produced out-of-pile conditions) and full-scale (produced in-pile conditions) corium in light-water power reactors [5–7]. It is because this studies has been conducted for a long time. They have been started since the accident at TMI-2 reactor in the US in 1979. Similar studies of prototype, especially full-scale corium of the fast power reactors, are rare. Therefore the materials behavior of the full-scale corium melt of the fast reactor at severe accident have not been studied sufficiently and obtained data of material testing of such corium condition currently are new.

Results of post-reactor material testing of solidified full-scale corium are demanded and irreplaceable at describing of corium melt behavior in order to define possible processes that occurred in damaged reactors.

Moreover additional works of the behavior of the fast power reactor fuel under severe accident condition were carried out at the Institute of Atomic Energy of the National Nuclear Center of the Republic of Kazakhstan on the IGR reactor (Impulse Graphite Reactor) [8–10].

The goal of this work is to study the structure condition of the corium fragments produced in-pile conditions. The experiment simulates final stage of severe accident with loss of coolant (LOCA) of the fast power reactor with sodium coolant.

2. Corium producing and method of its research

In order to conduct simulating test for study mechanisms of materials melting of model fuel assembly (FA) and movement of

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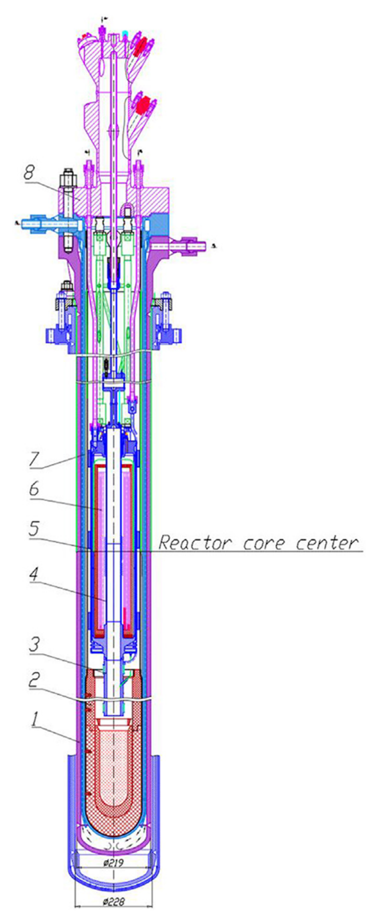
the corium melt in the IGR reactor in-pile, experimental device (ED) was designed and produced. Scheme of the experimental device is presented in Fig. 1. ED consists of following basic elements:

- FA casing with fuel elements from the BN-350 reactor - fuel rods are inserted inside it and melted in the curse of IGR reactor start-up in order to obtain a melt mixture of uranium dioxide (fuel) and stainless steel (fuel claddings); main features of the BN-350 reactor fuel elements used in the experiment are presented in Table 1.
- Inner duct - discharges the melt out of FA casing cavity into melt trap after penetration of its wall.
- Melt trap - provides melt reception from FA casing cavity during experiment.
- Pressure vessel - provides safe condition for conduction of experiment.
- Measuring equipment for parameters of the experiment.

Concept of the experiment conducted on the IGR reactor was based on simulation of accident on the fast neutron reactor with sodium coolant where the following sequence of events was realized:

- Placement of the experimental device (ED) in the experimental canal of the IGR reactor complex and subsequently its connection with the technological systems of IGR.
- Preheating of materials and coolant of FA model up to the temperature corresponding to normal operating temperatures of the fast reactor. Preheating system provides heating FA materials to a temperature up to 673 K for 3–4 h with constant monitoring and controlling the heating process. Materials were preheated with using electric heaters, that were made from cables with an outer diameter of 1.5 mm. Heaters were wound on the fuel assemblies casing. They were connected in series with each other and connected to the power supply system bench of reactor.
- Obtaining of corium melt pool with preset mass ratio in the cavity of the fuel assembly casing of the ED through radiation of model FA by neutron flux of the IGR reactor; Preparation of the melt pool at the bottom of the test section is carried out by heating the fuel assembly. Heating was conducted by exposing the experimental device to neutron flux, on a given diagram of the energy output of the reactor.
- Penetration of the steel inner duct by corium melt.
- Movement of the melt to cavity of discharge duct and then to the melt trap of experimental device.
- Solidification of melt in ED melt trap.

Preparation of metallographic test of solidified corium melt in the ED melt trap (Fig. 2) was conducted in three main stages. At the preliminary stage experimental device was held in radiation protective chamber. Such treatment reduced radioactivity of corium to the allowable level for working with samples without time limits.



1 – pressure vessel, 2 – melt trap, 3 – discharge duct, 4 – inner duct, 5 – fuel assembly casing, 6 – fuel assembly, 7 – lid of fuel assembly, 8 – lid of experimental device.

Fig. 1. Scheme of longitudinal section of the in-pile experimental device.