Experimental study of the molten metal relocation on the surface of the heated rod

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Abstract. The investigation of the liquid metal melt flow along the surface of a heated rod is carried out. Experimental studies were provided in a seven-rod assembly. In this series of experiments, only the central rod of the assembly was heated. All rods of the assembly were in a stream of the heated argon. Aluminum and zinc were used as the material of the model cladding of the rods. The dynamics of temperature and the movement of the molten cladding along the surface of the heated rod were studied. Obtained results may be useful for validating computer codes to simulate beyond design accidents in nuclear power plants.

1. Introduction
One of the most clean energy sources is nuclear energy. The main barrier hindering its further development is the serious consequences resulting in severe accidents with the destruction of the core. In the world, several severe accidents, leading to the melting of fuel elements, core degradation and the extensive release of radioactive substances into the environment occurred during operation of reactor facilities.

The motion and heat transfer of the melt during thermal destruction of the fuel rods are very important for a detailed understanding of the accidents in nuclear power plants. Investigation of the melt behavior is also important for determining the range of applicability of existing and developed numerical codes to justify the safety of nuclear power facilities. To perform a numerical analysis of the behavior of a reactor during a severe accident, and therefore, to reduce the damage caused to the environment, careful adjustment of the calculation codes describing such phenomena is required. Verification of such codes requires experimental data.

In the case of a severe accident of a reactor unit cooled by liquid sodium with a loss of coolant flow (LOF and ULOF), coolant boiling will occur at a temperature much lower than the melting point of the fuel cell claddings. In this case, the melting of the cladding of the fuel rods will occur in a flow of boiling sodium. Presumably, the speed of their movement can reach about 150 m/s. The study of such processes directly in the reactor is impossible due to the safety reasons; therefore, the problem arises to investigate the processes taking place on the special experimental facilities in order to obtain information about the melting dynamics, the velocity of the molten cladding relocation in the gas flow,
and the regimes of the melt flow. Therefore, some experiments were carried out recently with low-melting metals and model substrates [1-4].

The program of experiments is a transition from simple to complex. At first, a facility to study the formation of droplets of liquid metal on the surface of quartz glass in the air atmosphere was constructed [5]. Experiments in an inert gas atmosphere (argon) were conducted [5]. Also formation and movement of liquid metal droplets in high-speed (up to 10 m/s) argon flow were studied [6]. Then a facility was constructed to investigate molten cladding relocation in a 7-pin assembly in a hot argon flow (this study).

2. Experimental facility
An experimental facility was created. The geometrical parameters of the facility were close to the geometry of the fuel assemblies of the fast breeder reactor. The scheme and photograph of the experimental facility are shown in figure 1. Test part contained a bundle of 7 rods simulating a fuel assembly. Processes of melting and relocation of the melt were studied on a central fuel element. The rod bundle was flushed with argon flow. Argon was preheated in a heat exchanger. Due to the change in the power of the heat exchanger, the argon temperature at the inlet to the experimental model was varied. Outside, the bundle was enclosed in a quartz shell. Argon was fed to the lower part of the experimental facility through the cavities of the peripheral fuel rod simulators.

Six peripheral fuel rod simulators were made of stainless steel. They had a diameter of 12 mm and a wall thickness of 1 mm. The central rod was a heated stainless steel rod with a diameter of 10 mm. A model cladding of aluminum or zinc was deposited on the surface of the rod. This tube was used to simulate the fuel column. The central rod was connected to an adjustable laboratory current source (LATR) with a maximum power of 2000 W. It allows the heating of the outer surface of the tube up to the melting temperature of aluminum (about 600°C). The experimental setup was installed in a special chemical box. Video registration and thermocouple measurements were used as the research methods.

![Figure 1](image.png)

Figure 1. The scheme (a) and the photograph of the experimental setup.

3. Experimental results
Experiments in the 7-rods bundle were performed. The analysis of temperature evolution and melting fragment dynamics were carried out. Video shooting of the melting process was performed for aluminum and zinc model cladding. Simultaneously with this, the melt flow of the model shell was visualized (figure 2 (a, b)). To improve the quality of images, the peripheral tubes were painted black. After the end of the experiment and the cooling of the experimental model, it was disassembled and distribution of the frozen cladding fragments was analyzed (figure 2 c).
Three thermocouples were installed in the shell material. The location of the thermocouples is shown in the diagram (figure 3a). The temporal evolution of the temperature of the aluminum model cladding is shown in the graph (figure 3b). In the region, where melting takes place, there is a known phenomenon of stopping the rise in temperature during melting. It was registered by a central thermocouple (TC2). For other two thermocouples, the melting curve was not recorded.

![Figure 2](image2.png)

**Figure 2.** The photographs of the experimental model at the beginning (a) and end of the experiment (b) and the post test analysis (c).

![Figure 3](image3.png)

**Figure 3.** The temperature evolution on the surface of the aluminum cladding model.

**Conclusions**
Experimental investigation of the fuel pin model melting in 7-rods bundle was performed. The analysis of temperature evolution and melting fragment dynamics were carried out. The obtained results may be useful for understanding of the melt motion during severe accidents in nuclear power plant. Also the results are very important to develop models and to understand the processes that take place during the accidents in the core of nuclear power plants. Further development of the
experimental facility is planned. For example, it is necessary to investigate melting of all 7 rods of the assembly simultaneously. Also, it is necessary to provide researches with different values of the temperature and flow rate of argon. And it would be better to conduct high-speed shooting of the melting process.

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