HEAT TRANSFER DURING BOILING OF A LIQUID
METAL DURING EMERGENCY COOLDOWN OF A
FAST-NEUTRON REACTOR

A. P. Sorokin, A. D. Efanov,
E. F. Ivanov, D. E. Martsinyuk,
G. P. Bogoslovskaya, K. S. Rymkevich,
and V. L. Mal'kov

The physics of the processes, the characteristics, and the stability of different regimes of boiling (nucleate, projectile, disperse-ring), which are observed in experiments investigating the boiling of liquid-metal coolant in a model of a fuel assembly for a fast-neutron reactor in the emergency cooldown regime with low circulation velocity, are analyzed. The experimental setup, the methods for performing measurements, and the experimental data on the boiling of a liquid metal are described. A mathematical model of the process of boiling of a liquid-metal coolant in a natural-circulation loop is described, and the results of test calculations for regimes with an increase in heating and with sharp pressure drop are presented. 7 figures, 12 references.

A great deal of attention has been devoted during the last thirty years on the boiling of alkali metals [1, 2]. Heat emission, flow regimes, the hydraulic resistance, the crisis of heat transfer, the initial overheating, and the mechanism and stability of boiling have been studied. The results of these investigations show that compared with water the boiling of liquid metals exhibits certain peculiarities, including the following:

- under real conditions the interaction of individual factors is so complicated that the initial overheating for boiling up of liquid metals is difficult to predict accurately;
- in alkali metals, large bubbles form on a limited number of centers of vaporization, and most of the bubble formation cycle falls within the waiting time period;
- the growth of a vapor bubble of alkali metal is explosive, occurring at the rate \( \approx 10 \text{ m/sec} \);
- the main flow regimes for two-phase flows of alkali metals are the same as for ordinary coolants: near atmospheric pressure a disperse-ring regime predominates;
- a phase transition in a disperse-ring flow of alkali metals in channels occurs, as a rule, by evaporation from the surface of a liquid metal film on the wall without the formation of bubbles (boiling) on the wall: the effective heat-transfer coefficient in this case reaches hundreds of kW/m².

The present investigations are concerned primarily with the analysis of transient and emergency regimes caused by a sharp increase in the power and different blockages of the flow-through section of the core, stoppage of a circulation pump (with and without run-out of the rotor). There are few data on boiling in bundles in regimes with a low coolant flow velocity with natural convection.

Experimental Model. The setup for performing the investigations of boiling of a eutectic sodium-potassium alloy (22% Na + 78% K) under natural convection conditions (Fig. 1) contains two 3-m high vertical channels, connected with one another at the top and bottom and forming, respectively, the down and up branches of the circulation loop. A working section containing a seven-rod assembly of fuel-element simulators is located at the bottom of the up channel. The assembly consists of seven simulators and 12 displacement rods, arranged in a triangular lattice with a relative step of 1.185 and placed in a 50 x 1.5 mm and 3-m long stainless-steel pipe.

The fuel-element simulators consist of 8 mm in diameter and 1-mm thick factory-made, Kh18N10 stainless-steel, graduated pipes, into which spiral heaters made of 1-mm in diameter molybdenum wire were inserted. The coil was 4 mm in diameter and 420 mm long. The gap between the heaters and the jackets of the simulators was filled with fused magnesium oxide powder. The model assembly is equipped with a large number of measuring channels containing different primary transducers (sensors), which made it possible to obtain extensive experimental data for investigating the boiling of a liquid-metal coolant in an assembly of electrically heated to fuel-element simulators.

**Experimental Investigations.** A series of experiments was performed to investigate the boiling of a eutectic sodium-potassium alloy in a model of a fuel assembly of a fast-neutron reactor in a natural-convection regime with different mass flow velocities obtained by varying the hydraulic resistance of the circulation loop using a throttle. In the experimental procedure, the thermal power of the fuel assembly with stationary coolant present in the loop was increased and natural motion of the coolant commenced. As the thermal power increased, the coolant temperature increased until the saturation temperature was reached in the heating zone and boiling commenced (Fig. 2). Three boiling regimes were observed:

- Nucleate boiling at the initial stage of the process; the characteristic feature of this regime is a stable coolant temperature in the simulators, a pressure drop on the assembly, coolant flow at the entrance and exit from the heating zone; an increase in heating resulted in a transition of nucleate boiling to projectile boiling;

- Projectile boiling, with heat flux density from 125 to 170 kW/m²; a characteristic feature of this regime is its pulsational character; the formation of large vapor bubbles (projectiles) every 40 or more seconds, which at the moment of rising caused a sharp increase in the flow rate of the coolant at the entrance and strong oscillations of the measured parameters, was observed; the oscillations of the parameters were of the hydrodynamic nature and were determined not only directly by the boiling of the coolant in the fuel assembly but also by a system processes occurring in the assembly and in the circulation loop; the temperature of the jackets of the fuel-element simulators did not exceed the saturation temperature, attesting to the presence of a liquid film on the surface of the simulators; increasing the power of the assembly increased the rate of formation of projectiles and decreased the amplitude of the temperature pulsations: for a heat flux from 210 to 230 kW/m² a transition from the projectile to the disperse-ring regime was observed;

- Disperse-ring regime, characterized by stable behavior of the measured parameters; evaporation of liquid and removal of drops from the surface of the simulators resulted in drying of the surface – a crisis of heat transfer, melting of the jacket of the simulators, and a transition to a serious accident: for this reason the disperse-ring regime is the limiting regime of boiling, which provides adequate cooling of a fuel assembly.