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On the Possibility of Perfection of Reactors' Passive Heat Removal Systems by the Use of an Ebullience Channel

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Abstract—The possibility is considered of creating a passive heat removal system with an ebullience channel and natural circulation of coolers, in which the residual heat release could be directed not only upward but also downward from the source to the final absorber. Experimental results on the properties of the system in the static and dynamic regimes and examples of its possible application are presented.

Keywords: passive heat removal systems, emergency cooling of nuclear reactors, natural circulation, flashing two-phase flows

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Passive heat removal systems (PHRS) are destined for long-term removal of residual heat released by the core through the steam generator to the final absorber in cases of accidents beyond the design basis when all sources of electric power supply are lost. The existing PHRS employ the natural circulation of coolers of the first and second reactor circuits. In this case, heat is transferred to the final absorber only upward, e.g., to water in the tank of the emergency cooling system, which boils out for a definite time [1, 2]. Therefore, the duration of action of such systems in the passive regime is bounded and active measures are required for maintaining its operation and replenishment of water.

If the final absorber is air, then, due to a small efficiency of heat transfer to it, high-power atomic plants require large heat transfer surfaces installed above the reactor [3, 4]. For a ship with an atomic plant or a floating nuclear power plant, this can lead to a danger of overturning.

The use of an ebullience channel gives new properties to a PHRS: it becomes possible to remove the heat released by the source to the final absorber not only upward but downward as well. The final absorber situated below may be water in a tank or a pool, and it can be connected with a basin or the sea. This makes it possible to remove most of the released heat through a heat-exchange unit situated below the heat source and cooled by water, whose amount is unlimited [5], i.e., the duration of action of the PHRS in the passive regime during accidents with a total blackout of an atomic plant, is also unlimited.

The scheme of a PHRS with an ebullience channel and heating of the intermediate heat exchanger by steam from the steam generator is shown in Fig. 1. In the vertical ebullience channel incorporated into the PHRS and situated above the heat source, the water temperature t_{in} at the input is below the saturation temperature at the pressure at the input to the channel. As water moves upward in the channel, its pressure decreases and, therefore, the saturation temperature corresponding to this pressure decreases too. At a certain height in the channel, the saturation temperature becomes equal to the water temperature. Above this place in the channel, there is a water ebullience zone.

Figure 2 shows the beginning of the ebullience process as water moves upward in a transparent channel. The water pressure decreases, and the mass and volume of steam content increase. In the ebullience zone, the water temperature decreases to the temperature t_{in} at the input to the channel to the saturation temperature $t_{w.sat}$ at the pressure p in the separator. The arising steam phase reduces the density of the medium in the ascending section of the circulation duct, which produces an increased moving head of natural circulation in the closed circulation circuit. This makes it possible to install, in the descending section of the circulation circuit, heat exchanger *6* (see Fig. 1) below the heat source and remove through it most of the thermal power Q_s. Steam produced on the ebullience is condensed in the heat exchange and condensation unit. Since the mass steam content of a boiling up flow does not exceed approximately 1.5%, $Q_{he.c}$ is significantly smaller than $Q_{l.he}$.

The ebullience channel, which produces a moving head in the PHRS, may be considered—by analogy with a circulation pump—as a conditional pump (schematically shown on the right in Fig. 1) with its characteristics and properties. A distinctive feature of such a conditional pump is that, at the input, it receives water heated to the ebullience and, at the output, it has a steam–water mixture. The moving head of natural circulation in the circulation circuit of the cooling system is produced mainly due to the cooler