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MODELING OF THE CORIUM AND METALS – COOLERS INTERACTION IN A CORE CATCHER OF A LIGHT WATER REACTOR

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МОДЕЛИРОВАНИЕ ВЗАИМОДЕЙСТВИЯ КОРИУМА С МЕТАЛЛАМИ – ОХЛАДИТЕЛЯМИ В ЛОВУШКЕ РАСПЛАВА ЛЕГКОВОДНОГО РЕАКТОРА

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Аннотация. *В настоящей работе мы провели моделирование взаимодействия кориума с легкоплавкими металлами - охладителями. Моделирование осуществлялось с помощью программного комплекса ANSYS. В результате проведенной работы определено время, за которое каждый из рассматриваемых металлов - охладителей достигнет точек фазовых переходов плавления и кипения. Анализ результатов позволил сделать соответствующие выводы об возможности их использования при локализации тяжелой аварии с расплавлением активной зоны.*

Introduction. The main elements of the gravitational inversion concept in a core catcher are sacrificial materials used due to the fact that, according to some researches, corium is a system of two immiscible liquid phases – oxide and metal [1]. Due to the difference in the densities of the two systems, the metallic part of the corium is located above the oxide. If water is supplied to the metal part for cooling, then with the active interaction between water and metal part of the corium, there is a possibility of the formation of a critical concentration of hydrogen. Additional difficulties are created by the fact that, according to some scenarios, corium leaves the reactor vessel not as a single mass, but in portions for some time while creating the threat of a steam explosion when a high-energy melt falls into a container filled with water [2].

The experiments showed that mutual dissolution of the sacrificial material and the melt occurs at a rate sufficient to implement the inversion of the oxide and metal layers in <1 h [3]. After the inversion of the corium components, water is supplied to the surface of the melt bath. However, its implementation takes a certain amount of time. Thus, when the melt is localized in the core catcher, there is a small period of time when cooling of the corium surface is not organized. In this regard, there is a risk that the system will go beyond the permissible limits (the beginning of the uranium dioxide boiling) due to decay heat in the corium [4].

Based on the foregoing, methods of melt cooling become highly relevant, excluding the direct supply of water to the surface while portioned escape of corium and until completion of the gravitational inversion of the corium parts. In this regards, we proposed an idea [5] to use low-melting metals (*further in the text - metal-coolers*) in the specified period of time to provide extra-cooling of the corium surface in order to increase the efficiency of corium localization during a severe accident. The proposed concept is based on the idea that when the corium enters the trap, the cooling material will move to its surface due to the density difference and will remove heat from the corium during a period when water supply to the corium is undesirable. After the corium left the reactor in full mass and inversion of its layers is completed, water will be supplied to its surface, and the selected material should pass a phase transition of boiling and leave the trap.

Research methods. The objective of this research is to determine a time required for a metal-cooler to reach the points of phase conversions (melting and boiling) and a nature of its interaction with corium under severe accident condition. Development and calculations of the thermal state of the thermophysical model were performed using the ANSYS software [6].

A two-dimensional computational domain was chosen for modeling of a heat transfer in the core catcher due to symmetry of the melt trap relative to the central axis. Figure 1 shows the computational domain of the core catcher.

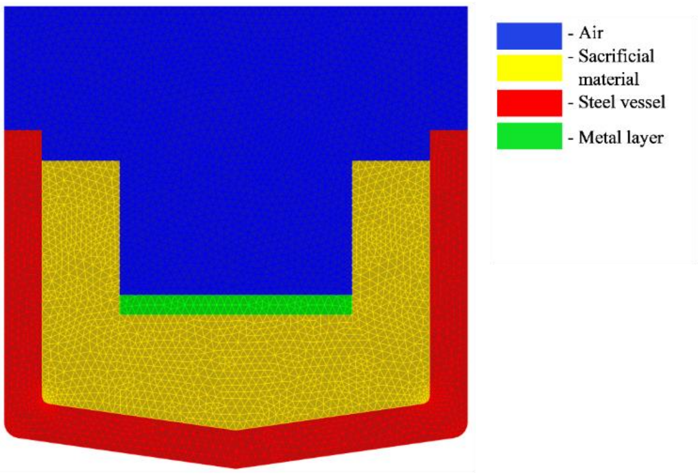

Fig. 1. The computational model of corium interaction with metals-coolers in the core catcher

To compare the heat removal from corium using different metals-coolers, each calculation has an equivalent:

- Initial conditions (initial corium temperature 2500 °C);
- Mass of corium;
- Mass of metal-coolers.

Results. The numerical calculations showed that the melting of metals-coolers implements in a short period of time (the maximum time is ~ 5.5 s for manganese). The analysis of temperature variation in metals-coolers with time shows that zinc and magnesium will fully transfer into steam while the boiling of antimony is likely to be local in a certain volume of liquid metal. Manganese most likely will not reach the boiling point and will be in the system in a liquid state and will enter into various chemical interactions.

Based on the modeling results, it was concluded that in case of the proposed approach, it is possible that corium surface will not be cooled because metals-coolers are melted in a short period of time. At such result of events, an option was considered when a metal-cooler enters into the core catcher after corium leaves the reactor vessel. This approach will allow providing the heat removal directly on the corium surface. Zinc was considered as a metal-cooler in this calculation. The calculation results show that when zinc is used as metal-cooler, zinc transfers into a steam during a time sufficient to complete this process within a set interval of time according to the proposed concept.

Conclusion. The computer modeling of the interaction between corium and candidate metals-coolers in the core catcher of a light water reactor was conducted in the ANSYS FLUENT software. The calculations were conducted under the same initial conditions to compare selected candidate metals-coolers to justify their use in the core catcher in the case of a severe accident with core melting and corium escaping beyond the reactor vessel.

Based on the computer modeling and analysis of the obtained results, it is possible to draw conclusions about the possible practical implementation of the proposed corium cooling method. Next, it is necessary to conduct a series of experimental studies of corium interaction with the selected materials to study issues related to the nature of interaction of cooling metals with corium in a severe accident with core melting.

REFERENCES

1. Sidorov, A.S., Nosenko, G.E., Granovsky, V.S., et al. (2001) The containment protection system of a water-cooled reactor plant. RF Patent, No. 2165108, 10 p.
2. Morozov, A.V., Remizov, O. V. (2012) Severe accidents at nuclear power plants with VVER, p.136.
3. Asmolov, V.G. et al. (2002) Choice of Buffer Material for the Containment Trap for WWER -1000 Core Melt. Atomic Energy, Vol. 92, pp. 5-14
4. Sehgal, B.R. et al. (2000) Melt-Structure-Water Interactions During Severe Accident in LWRs. NPSD, Royal Institute of Technology, Annual Report, Sweden
5. Skakov, M., Toleubekov, K., Baklanov, V., et al. (2022) The method of corium cooling in a core catcher of a light-water nuclear reactor. Eurasian Physical Technical Journal, no. 19(3(41), pp. 69-77. doi.org/10.31489/2022No3/69-77
6. ANSYS Fluent Tutorial Guide, 2022, from https://forum.ansys.com/uploads/846/SCJEU0NN8IHX.pdf