Overall Consideration to Flood Liquid Gallium in Reactor Cavity for IVR-ERVC

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1. Introduction

When core melts and deposits on the bottom of the reactor vessel, In-Vessel corium retention by external reactor vessel cooling (IVR-ERVC) strategy begins to flood the reactor cavity to remove the decay heat through the wall of the reactor vessel. A few investigations have been performed to evaluate and increase the coolability of ERVC with limited [1, 2, 3, 4, 5]. The APR-1400 reactor is first reactor applied with ERVC strategy as high power reactor compared with the AP-600 and the AP-1000. It is not certain that the ERVC strategy provides sufficient thermal margin for large reactors like the APR-1400 reactor. The recommendations to enhance the thermal margin for ERVC include coating some materials on the vessel outer surface, increasing the reactor cavity flood level and streamlining the gap between the vessel and the vessel insulation [6]. In this work, a new type of approach was studied to lead a successful ERVC strategy by replacing the flooding material from present borated water to a liquid metal. There are some discussions about the proper section of a liquid metal, the position of storage tank for a liquid metal. And the issue of the ultimate heat removal was also treated in detail. Finally, the problems to apply the ERVC strategy using a liquid metal were discussed in a view of the subject on the material and the economics.

2. Discussion

2.1 Liquid Metals for IVR-ERVC

Table 1 shows the thermal properties of the liquid metal in a state of a pure and an alloy. The first priority to apply a liquid metal in ERVC strategy is that a liquid metal has the low melting temperature and the high boiling temperature. The other requirement is physically and chemically stable. The gallium metal is considered as flooding material. The gallium has the proper temperature condition in listed candidates. The overall thermal properties of Na are far more superior to the properties of gallium heat transport. But there are no tremendous reactions between the gallium and the water.

Table I: Thermal properties of liquid metals

	Na	Pb	LBE	Ga
Atomic Weight	22.997	207.21	208	69.723
Melting Point (°C)	97.8	327.4	123.5	29.76
Boiling Point (°C)	892	1737	1670	2204
Density (kg/m3)	880	10500	10300	6095
Specific Heat (J/kg-K)	1300	160	146	381.5
Thermal Conductivity (W/m-K)	76	16	11	29
Viscosity (cP)	0.34	2.25	1.7	1.810

2.2 Storage Tank in Containment

A liquid metal should be stored to maintain a liquid state in the storage tank which has heating/heat shield system. The location of the storage tank is important in ERVC strategy. The following requirements related to the storage tank could be described.

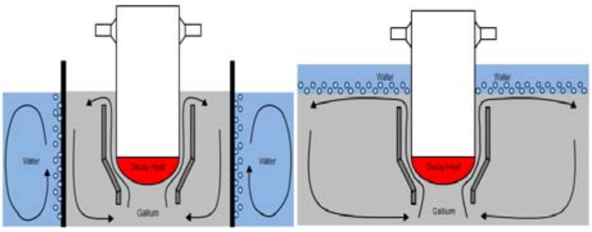
- The Storage Tank should be located near the reactor.
- The Storage Tank should in a higher position than a reactor cavity.
- The dimension of the storage tank should be designed in a minimum capacity for flooding the reactor cavity with a liquid metal.

2.3 Ultimate Heat Sink

In present ERVC system, the ultimate heat sink is the borated water which is the coolant. The decay heat generated in corium is removed on the reactor vessel outer wall by the boiling. The heat removal on the reactor vessel outer wall is restricted by thermal limit called by critical heat flux (CHF). The space which has the direct contact with the reactor vessel outer wall is filled with a liquid metal to avoid the thermal limit that occurs in water. The one of main functions of the gallium in ERVC system is to perform the heat transfer medium only between the reactor vessel and the ultimate heat sink. The other main function is to store the heat by the specific heat capacity of a liquid metal before the heat is transferred to the ultimate heat sink. This function makes it possible to have more time to flood the cavity with the borated water. It leads to have the potential uses of the borated water before flooding.

2.3 Configuration with Liquid Metal and Borated Water

The decay heat generated in corium is transferred through the contact part between the reactor vessel and the liquid metal. Then the heat was ultimately dissipated by the boiling in the surface facing the borated water. Because the heat transfer mechanisms are formed, the heat removal capacity depends on the relative configuration between the liquid metal and the borated water. The configuration of both the gallium and the borated water could be divided to two types depending on whether or not the direct contact with each other. This concepts show in Fig 1. First configuration which called as a side cooling in this work is that two fluids were separated by the block structure. The sufficient heat transfer area between the liquid metal and the borated water could be served. Additionally, the area can enlarge by attaching the fins on the block structure surface. It leads to ensure the safety of the reactor vessel and to decrease the temperature of the liquid metal under ERVC strategy. Other configuration which called as an upper cooling in this work is to flood the cavity with both the borated water and the gallium in the same reactor cavity space which is not separated. As the result of that, two layers of the fluids were naturally formed by the different density. It makes to simplify the application of a liquid metal in ERVC strategy.

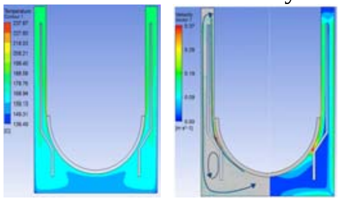


(a) Side cooling concept (b) Upper cooling concept
Fig. 1. Configuration with liquid metal and borated water

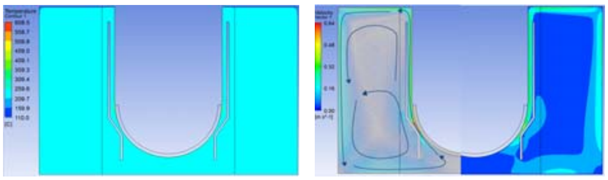
2.5 Thermal Analytic Approaches using CFD

When a side cooling concept was applied, the CFD analysis results shows in Fig 2. The natural circulation flow was formed in the gallium analysis region. The dimension of the block structure and the geometry of the insulation are main parameter to affect the state of a natural circulation. The maximum temperature in the analysis region is 237 degree Celsius which is under the gallium boiling temperature (2200 degree Celsius). It is expected that the stable natural circulation would be continually formed.

When an upper cooling concept was applied, the CFD analysis results shows in Fig 3. The natural circulation flow was formed in the gallium analysis region. The dimension of the cavity and the geometry of the insulation are main parameter to affect the state of a natural circulation. The maximum temperature in the analysis region is 605 degree Celsius which is under the gallium boiling temperature (2200 degree Celsius). Although the temperature in the analysis region was formed at a high level, it is expected that the stable natural circulation would be continually formed.



(a) (b)
Fig. 2. (a) Temperature & (b) Velocity distribution in the gallium in side cooling case



(a) (b)
Fig. 3. (a) Temperature & (b) Velocity distribution in the gallium in upper cooling case

3. Conclusions

The following results are obtained.
- The gallium liquid metal is a superior candidate to flood the reactor cavity with the proper melting/boiling temperature.
- The configurations with both the gallium and the borated water determine the cooling capacity in the ERVC strategy.
- The additional cooling could be obtained by changing the geometry of the insulation, the block structure and the cavity.

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