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Molten Pool Behavior in KALIMER-600

S.D. Suk and C.H. Cho
Korea Atomic Energy Research Institute, 150 Dukjin dong.,Yuseong,Daejeon,Korea 305-353
sdsuk@kaeri.re.kr

1. Introduction

Safety studies of the KALIMER-600 design have shown that the design has inherent safety characteristics and is capable of accommodating double fault initiators such as ATWS events without boiling coolant or melting fuel [1]. For the future design of liquid metal reactor, however, the evaluation of the safety performance may be required for such tripe-fault accident sequences as unprotected transient overpower or loss of flow accidents that lead to fuel melting. For any postulated accident sequence which leads to core melting, in-vessel retention of the core debris will be one of the important issues for the future design of SFR[2].

The cooling mechanism of the particulate debris bed in sodium is heat removal by conduction, single-phase convection, boiling or radiation. With serious core degradation, conduction and single-phase convection through the bed may be inadequate to remove the decay heat from the debris. In such a case, boiling of the coolant will occur. As long as boiling is adequate to remove the heat from the bed, the temperature in the debris will remain at or below the boiling of the coolant and there would be no thermal reaction on supporting structures or plate. If the decay heat generation rate is beyond dryout inception in the debris bed, however, a stable dryout layer may be formed. At positions in dryout layer where temperatures exceed the melting point of the fuel particles, a molten layer of the particles may be developed and propagate to form a molten pool of the debris bed[3].

In this study, scoping analyses were carried out to evaluate the coolability of the molten pool of the core debris bed accumulated in the lower support plate below the core, during the unprotected loss-of-flow accidents or transient overpower in the KALIMER-600.

2. Analysis Methods

The molten pool is treated as consisting of an upper sublayer of the frozen crust with pure conduction, just below the overlying sodium pool, and main pool of the melt with natural ,convection placed on the support plate. For the analysis of the coolability of the molten pool, a series of the heat transfer processes must be considered. Starting from the top of the pool downward, the following processes of one dimensional heat transfer are considered in this study:

1) Heat transfer from the upper surface of the frozen melt crust to the overlying sodium is calculated based on the correlation developed by McDonald and Connolly[4]
2) Heat transfer through the frozen melt crust by conduction is calculated using a constant value of thermal conductivity of the melt. The temperature of the lower surface above the pool is assumed to remain constant at the eutectic temperature of the melt.
3) Heat transfer from the peak temperature of the melt pool to the upper crust is calculated using the same correlation used for the heat transfer from the upper surface of the frozen melt crust to the overlying sodium.

The heat transfer downward from the peak temperature in the pool to the support plate was neglected in this study for the sake of simplicity of the calculations. The support plate of the lower plenum or core catcher of KALIMER 600 is thick enough to limit downward heat transfer to a small fraction of the upward heat transfer to the overlying sodium pool.

Marching downward from the bulk temperature of the overlying sodium pool, the temperature at the interface of the molten pool and support plate is calculated considering the heat flow processes described above. If the pool-plate interface temperature remains below the eutectic temperature of the melt and steel plate(about 1,000 K), then the support plate is assumed to stay intact and the molten pool is assumed coolable in this study.

3. Analysis Results

Figure 1shows the temperature rises above the sodium bulk temperature at the pool-plate interface for three cases of the extent of core melting; just melting of 114 assemblies of inner driver fuels, more extensive melting of 228 inner/middle driver fuels, or whole core melting. The sodium bulk temperature was assumed to be 818 K, which is the core out let temperature of the KALIMER-600 design. It means that temperature rise should be less than about 180 K for the pool to be coolable.

It may be seen that the molten pool resulting from the accumulation of the melt of the inner driver fuels becomes coolable in an hour. It takes relatively long hours (about 3,000 hours) for the melt of the inner/middle driver fuels to get coolable. In the case of the whole core melting, the pool-plate interface temperature never reaches down the eutectic temperature.

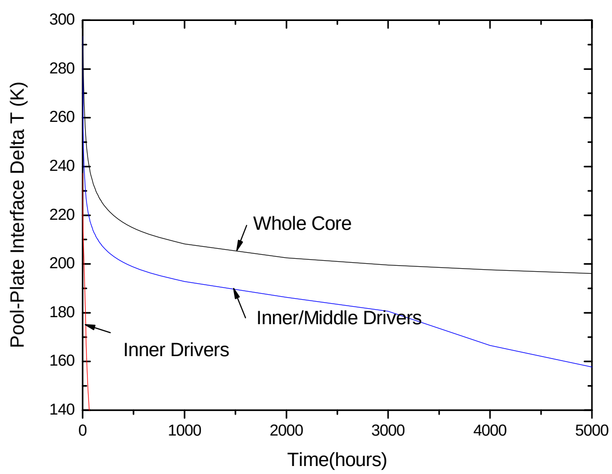

Fig.1 Temperature rise at the pool-plate interface for three cases of core melting

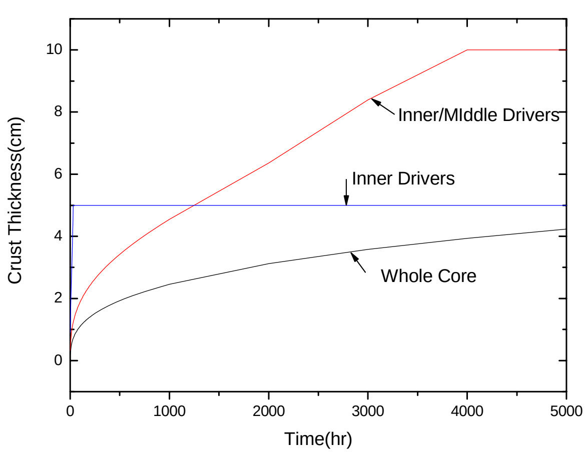

Fig. 2 Growth of crust thickness above the melt pool for three cases of core melting

The behavior of the pool noted above can also be observed in the growth of thickness of the frozen fuel crust. Figure 2 illustrates the growth of the frozen crust thickness at the top of the pool. It may be noted that the pool becomes the crust in an hour staying coolable for the case of the melting of the inner driver fuels. It takes about 4,000 hours for the pool to become totally crusted. The molten pool consisting of the whole core is only partly crusted..

3. Conclusion

A simple calculation shows that the molten pool of the core debris may be cooled by natural circulation inside the pool and heat transfer to the overlying sodium pool if 114 subassemblies of the inner driver fuels are molten and uniformly distributed on the plate of the core catcher of the KALIMER-600 system. For the case of a more extensive core melting including the fuel assemblies of the inner and middle driver fuels or the whole core melting, the integrity of the support plate is not warranted.

Acknowledgements

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