Transactions of the Korean Nuclear Society Spring Meeting
Gyeongju, Korea, May 29-30, 2008

Post Accident Heat Removal in KALIMER-600

S.D. Suk and Y.B.Lee
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 and the determination of containment requirements may require consideration of 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 is one of the important issues for the future design of LMR.

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

2. Transient Phase of Accident Sequences

The current KALIMER-600 design features a continuation of pin geometry below and above the active core as in the KALIMER-150 design. A previous study indicated that the coolant channels would be plugged by the freezing molten fuel in the inlet, lower shield region with its length about 112 cm as well as in the outlet, fission-gas-plenum region for the KALIMER-600 design for a sudden loss-of-flow transient[2]. The melt will most probably emerge from the assembly by meltthrough of the assembly. It will take some time for the melt to reach the core support structures. Thus, the amount of decay heat to be assumed in considerations of fuel coolability would be reduced for the KALIMER-600 design. The melt containing considerable amount of steel should gradually enter the sodium pool below. The particle size and shape of the fragments of the molten core, the porosity of the bed, and the degree of subsequent spreading in the sodium pool are among the important parameters to determine to evaluate the debris coolability.

3. Analysis Methods and Results

3.1 Analysis Methods

The cooling mechanism of the particulate debris bed in sodium is heat removal by conduction, single-phase convection (natural circulation without boiling), 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.

Because of the high porosity of the debris beds of metal fuel, there may be a possibility of debris coolability with the heat removal by conduction and/or by single-phase convection. A simple calculation shows, however, that the debris bed of the KALIMER-600, which is assumed to be uniformly spread across the lower core support plate, is not coolable by conduction alone.

The method for calculating the coolability of debris bed by single-phase natural convection is based on the modified Ergun equation [3], which relates the friction factor for the packed bed to the Reynolds number. From a fluid mechanics point of view, the most important parameter to determine for the coolability is the pressure drop required for the liquid to flow through the bed at a specified flow rate. The pressure gradient is caused by buoyancy resulting from the temperature difference across the bed. Hardee and Nilson [4] have shown that the temperature difference driving natural circulation is proportional to the actual temperature difference between the overlying sodium and the bottom surface of the bed. Once the pressure gradient is known as a function of the temperature difference across the bed, the relationship may be developed for the superficial velocity in terms of the bed properties including particle diameter, decay heat, bed height and porosity, among others, by using the Ergun equation along with the heat balance in the bed. Subsequently, the temperature drop across the bed can be determined from the velocity using the heat balance in the bed. If the sodium temperature above the bed is below the boiling point, then the debris bed is assumed coolable by single-phase natural convection in this study.

3.2 Analysis Results

Figure 1 shows the temperature difference between the sodium above the bed and the bottom surface of the support plate as a function of decay heat, when the whole core of the KALIMER-600 reactor is molten and uniformly spread on the lower plenum. It was assumed in this calculation that the particle diameter is 1 mm and porosity of the bed is 0.9. The temperature of the bottom surface of the plate was assumed to be 500 ^{o}C. As can be seen in the figure, the debris bed is coolable when the decay heat is below 1.4 % or so, meaning that the coolabilty of the bed depends on how long it takes the fuel melt to reach the lower structure below the core.

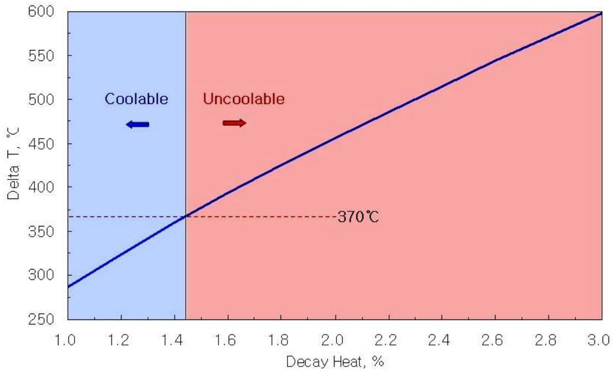

Figure 1. Temperature difference across the debris bed as a function of decay heat for whole core melting

The magnitudes of temperature drop across the bed for three cases of the core melting are listed in Table 1. The level of decay heat is estimated to be less than 2 % for the representative sequence of loss of flow, should it occur in the KALIMER-600 core. Hence the debris bed composed of the inner driver fuels only should be coolable for the reference sequence of the accidents.

Table 1. Temperature difference across the bed for each case of the regional core melting (K)

Decay Heat (%)	Inner Fuel Drivers (114 Assays)	Inner/Middle Drivers (228Assays)	Whole Core Melting (336 Assays)
1.0	156	241	287
2.0	248	383	456
3.0	325	501	598

3. Conclusion

The analysis results predict that the core debris bed may be cooled by natural circulation without boiling if 114 subassemblies of the inner driver fuels are molten and uniformly distributed on the lower plenum structure below the core during the reference sequence of loss-of-flow accident. For the case of more extensive core melting including the fuel assemblies of the inner and middle driver fuels or the whole core melting, the coolability of the bed is estimated to depend on the specific sequence of the accidents.

Acknowledgements

This work was performed under 'the Long-term Nuclear R&D Program' sponsored by the Ministry of Science and Technology of the Republic of Korea.

REFERENCES

[1] D. Hahn et al,"Design Features of Advanced Sodium-Cooled Fast Reactor KALIMER-600,"Paper 4327, *Proceedings of ICAPP'04,* Pittsburgh, PA, USA, June 13-17, 2004
[2] S. D. Suk, Y. B. Lee," Molten Fuel Relocation Behavior during a Severe Accident in KALIMER-600, " *Proceedings of Korea Nuclear Society Fall Meeting,* Kyungju, Korea, November 2-3, 2006
[3] S. Ergun, "Fuel Flow through Packed Columns," *Chem. Eng. Prog.* , 48, 89-94, 1952
[4] H. C. Hardee, R. H. Nilson," Natural Convection in Porous Media with Heat Generation," *Nucl. Sci. Eng.*, 8, 369, 1960