Fuel Melting Behavior in KALIMER-600

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1. Introduction

KALIMER-600 is a sodium-cooled, pool-type reactor with electrical capacity of 600MWe. The development of the reactor system was made to satisfy the design targets of enhanced safety, competitive economics, proliferation resistance and environmental friendliness. The reactor core is breakeven and consists of metal fuel with no radial and axial blanket[1,2].

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[3,4]. For the future design of sodium fast reactor(SFR), however, the evaluation of the safety performance may be required for such tripe-fault accident sequences as unprotected transient overpower (UTOP)or loss of flow accidents(ULOF) that lead to fuel melting.

In this study, a scoping analysis was carried out using the MELT-III code [5] to evaluate the early phase of the core melting accident, during the unprotected transient overpower initiated by the reactivity insertion rate of 50 cents/s in the KALIMER-600. The MELT-III code is a multichannel, neutronics, thermal-hydraulics program developed to investigate the transient behavior of the UTOP accidents in SFR.

2. Accident Sequences

For the coolant boiling and subsequent fuel melting to be initiated in the KALIMER reactor core, a third fault initiator must be assumed. Such multiple fault initiators have extremely low probability of occurrence, however. Most likely candidates identified for the accident initiators leading to energetic core disruption are the essentially unlimited rod bank runout unprotected transient overpower and the abrupt unprotected loss of flow[3].

The unlimited rod bank runout UTOP can be caused , for instance, by a cluster of control rods withdraw , resulting in the addition of large amount of reactivity enough to bring about fuel melting. As reactivity increases, the core power and temperature rise. The increasing temperature generates reactivity feedback in opposition to the power increase, but continued addition of reactivity from the withdrawing control rods increases the reactor power to the point where the coolant at core exit is approaching boiling.

At the same time, temperatures in fuel pins are at or above the fuel melting point, while still below the clad melting temperature. The combination of Doppler and axial expansion feedback and the negative feedback associated with the in-pin fuel relocation prevents the reactivity from reaching prompt critical. The peak temperature of the cladding takes place toward the core outlet because the sodium continues to flow, carrying heat from the lower portion of the fuel along with it, and because of the high thermal conductivity and efficient heat transfer characteristics of sodium[6,7].

3. Analysis Results

Figure 1 shows the core reactivity changes during the UTOP initiated by the reactivity insertion rate of 50 cents/s in the KALIMER-600. The effects of the reactivity feedback considered in this study include the Doppler effect, axial fuel expansion, sodium density, and ejection of molten fuel into the gas plenum above the fuel.

It may be seen in Figure 1 that the core net reactivity linearly increases early of the transient with almost the same rate of increase as the insertion rate. As the fuel expansion effect becomes sizable, however, the rate of increase of net reactivity gradually decreases. Fuel melting takes place at the center of the upper part of fuel in the inner driver region at about 1.90 s after the initiation of the transient. Fuel melt front propagates afterwards.

At 2.05 s into the transient, the mass fraction of the molten fuel amounts to as much as 18 % and the top of the fuel reaches the melting point of the metal fuel alloy, which is assumed 1,380 K. It is assumed in this study that as the melt front reaches the top node of the fuel, molten fuel begins to eject into the gas plenum above the fuel column. It may be noted in the figure that, the net reactivity drops down at 2.05 ms into the transient as a result of fuel ejection into the gas plenum.

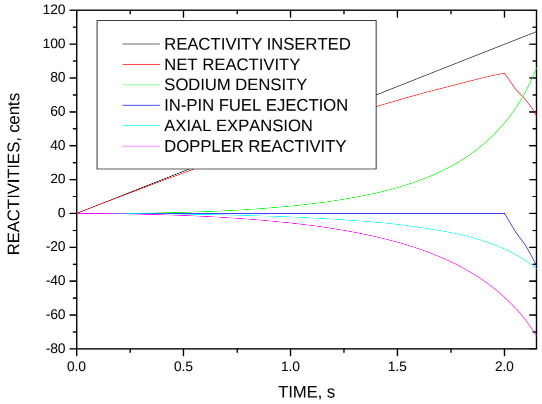

Fig.1 Reactivity Change during 50cent/s UTOP Accident in KALIMER-600

Figure 2 shows the axial temperature distributions of the fuel pin and coolant at 2.05 s into the transient. It is seen that the top of the fuel begins reaches the melting point at the centerline and the peak fuel temperature is about 1,700 K at the centerline of the upper part of the fuel.

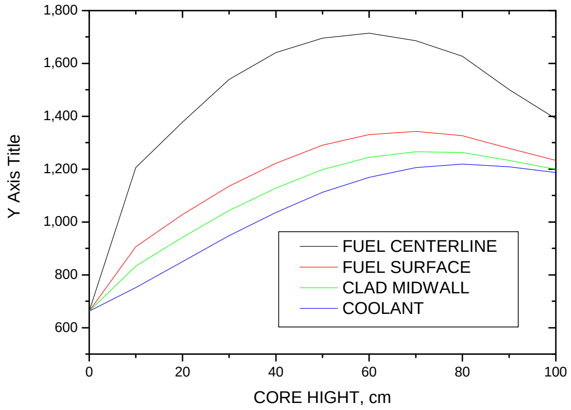

Fig. 2 Axial Temperature Distributions along Fuel pin and Coolant during 50cents/s UTOP in KALIMER-600

Calculations showed that core power reaches its maximum at about 76,300 Mw, which is about 50 times the initial power. The total energy released during the excursion amounts to 2,000 MJ.

4. Conclusion

An effort was made to simulate the early phase of the triple-fault UTOP accident initiated by the reactivity insertion rate of 50 cents/s in the KALIMER-600. Results show that the fuel melting accident may well be terminated by fuel ejection into the gas plenum above the core before fuel pin failure. A more detailed study should be carried out to investigate the phenomena related to the fuel clad failure as well as in-pin fuel motion before the fuel failure.

Acknowledgements

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