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Analysis of Power Excursion 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

Sodium fast reactors(SFRs) can be very sensitive to dimensional changes or relocation of materials since the intact SFR core is not in its most reactive configuration. Therefore it is theoretically possible that a rearrangement of the geometry can lead to prompt-critical reactivity excursions and to a hydrodynamic disassembly of the reactor resulting in a sizable energy release to the reactor system.

In this study, a core disassembly analysis in the sodium-voided core of the KALIMER-600 [1]was performed using the VENUS-II code [2] for the extremely large reactivity insertion rate of 100 $/s. The core kinetics and hydraulic behavior of the KALIMER is followed over the period of the super-prompt critical power excursion induced by the ramp reactivity insertion, starting at the time that the sodium-voided core reaches the melting temperature of the metallic fuels. For this purpose, the equations of state of pressure-energy density relationship were derived for the saturated- vapor as well as the solid liquid of metallic fuel, and implemented into the formulations of the disassembly reactivity in the VENUS code.

2. Reactor Model

The Reference core is KALIMER-600 breakeven core loaded with U-TRU-10%Zr ternary alloy fuel, generating 1,523 MWt. The homogeneous core comprises 114 inner driver fuel assemblies, 114 middle driver fuel assemblies, 108 outer dirver fuel assemblies, 12 control rods, 1 ultimate shutdown system (USS) assembly. The core is surrounded with 72 reflector assemblies, 168 B_4C shield assemblies, and 114 in-vessel storages (IVSs).

The two –dimensional (r-z) geometrical mockup used for KALIMER-600 is shown in Figure 1. The core is modeled with six regions as indicated by the heavier lines. Lower shield and fission gas plenum below and above the core, respectively, are also included in the analyses.

It is assumed that the core including the driver fuels are completely voided of sodium during the excursion. However, sodium is assumed to be present in the reflector assemblies and axial structural regions. At the start of the core disassembly analysis, the core is assumed to be at prompt critical. The core thermal power at prompt critical is assumed to be 15,240 MW, which is ten times the steady state power. The mean temperatures of the driver fuel regions are assumed to be above the melting temperature of the fuel (1,550K).

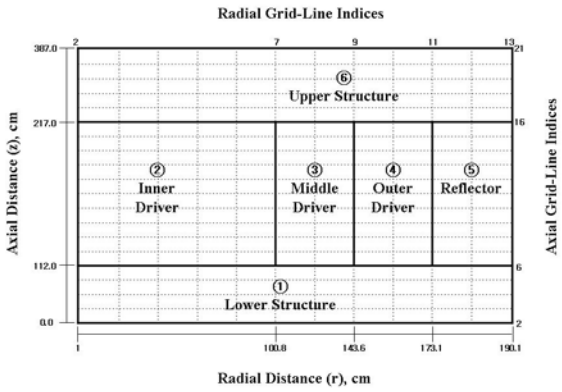

Fig. 1 KALIMER-600 Core Nodalization Scheme

2. Analysis Methods

The principal relation necessary for the CDA analysis is the pressure as a function of energy and volume for hydrodynamic calculations. The initial configuration of sodium-voided core is such that liquid fuel above the melting point is interspersed with void spaces left in the core when the coolant is expelled. As the temperature rises, the voids are filled with the expanded liquid thus producing saturated vapor pressure. If the liquid reaches the threshold energy to fill the voids completely, the pressure begins to rise rapidly.

Some of the major changes made in this study to apply the VENUS-II code to the CDA analysis of KALIMER-600 include the equations of state of pressure-energy density relationship for the U-Pu-Zr metallic fuel. The equations of state for the single-phase liquid of the metallic fuel were derived based on the van der Waals model [3], while a correlation for the fuel vapor pressure developed by Joseph *et al.*[4] was used when the fuel is in

the two-phase region. Most of the data for the thermodynamic properties of the U-TRU-Zr fuel are not currently available to the authors. Under the circumstances, the material properties of the U-Pu-Zr alloy were used instead in this study.

3. Analysis Results

Figure 2 shows the reactivity feedback due to the Doppler effect and core disassembly as well as the change of the net reactivity above prompt critical, for the power excursion initiated by the reactivity insertion rate of 100$/s. As can be seen in the figure, the net reactivity increases first, but it begins to decrease from 2.85 millisecond into the excursion as the Doppler effect becomes sizable. The core reactivity drops down below prompt critical at about 4.42 ms, as the reactivity feedback due to core disassembly becomes significant.

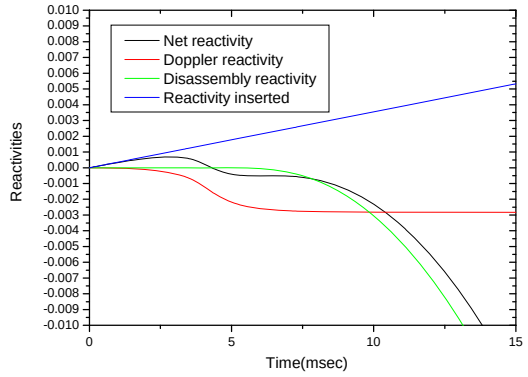

Fig. 2 Reactivites during 100$/s power excursion

Figure 3 shows the power history during the excursion. Core power reaches its maximum at 6,140 Gw at 4.25 ms, which is about 400 times the initial power. The total energy released during the excursion amounts to 1,5400MJ.

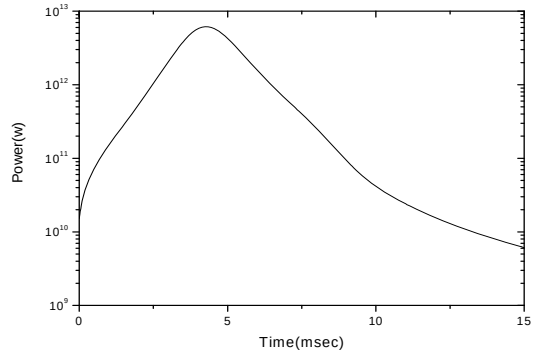

Fig. 3 Power changes during 100$/s power excursion

Temperature rises up to 4,230 K at the axial midplane of the inner driver fuel, where the peak power occurs representing the most reactive fuel assemblies in the core. This level of temperature is far below the set point for the fuel to reach the single liquid phase. The peak pressure also remains below 10 atm. The power excursion is terminated at 7.5 ms as the negative reactivity feedback brings the core reactivity far below critical state.

4. Conclusion

Calculations have been made to analyze the supercritical power excursion initiated by a reactivity insertion at the rate of 100 $/s into the KALIMER-600 core, using the equations of state for pressure-energy relationship for U-Pu –Zr metal alloy. It was observed that the core remains below the solid liquid region so that the power excursion is terminated without an extreme pressure or temperature rise.

Acknowledgements

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