LMR Core Disassembly Calculation using the VENUS-II Code

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1. Introduction

In this study , core disassembly analysis in the sodium-voided core of the KALIMER were performed using the VENUS-II code[1] for various reactivity insertion rates up to 100 $/s, which has been widely considered to be the upper limit of ramp rates due to fuel compaction. The VENUS-II code is a two-dimensional coupled neutronics-hydrodynamics program that calculates the dynamic behavior of an LMFR during a prompt critical excursion.

Core disruptive accidents have been investigated at Korea Atomic Energy Research Institute(KAERI) as part of the work to demonstrate the inherent and ultimate safety of conceptual design of the Korea Advanced Liquid Metal Reactor(KALIMER), a pool-type sodium cooled prototype fast reactor that uses U-TRU-Zr metallic fuel[2]. Results of previous scoping studies using a modified Bethe-Tait methods showed that the core disruptive power excursions are terminated without any significant pressure rise or energy release to threaten the integrity of the reactor system[3,4].This study is a continual to the previous scoping studies, analyzing core disruptive accidents in more detail using the VENUS-II code.

2. Methods and Results

2.1 Analysis Methods

The VENUS-II code was developed by ANL to simulate the dynamic behavior of oxide fueled core of liquid metal reactors during a super-prompt critical power excursion induced by the reactivity insertion[1]. The power level and nuclear energy deposition are calculated using a standard point kinetics equation. The reactivity used to drive the point-kinetics calculation is a combination of reactivity insertion and feedback effects due to Doppler broadening and material motion. The energy deposited in the core is converted to temperature by using a simple adiabatic model. The corresponding internal pressures are then found by the equation of state options provided in the code.

Some of the major changes made in this study to apply the VENUS-II code to the CDA analysis of KALIMER include reactivity feedback models and the equations of state of pressure-energy density relationship for metallic fuel. The equations of state were derived for the saturated-vapor as well as the single-phase liquid of metallic uranium fuel. A vapor pressure equation for uranium is given by Raugh and Thorn[5] as,

$$\log p = 5.702 - (\frac{23,300}{T}) \qquad (1)$$

where pressure is in atmosphere and temperature in K.

Meanwhile, for the single-phase liquid region, an equation of state was developed in a linear threshold type. Use was made of the equation-of-state data calculated by Brout[6]. The result of our fitting is

$$p = 11,000(E - 1.10)\text{, for } \rho = 9.92\text{g/ cm}^3 \qquad (2)$$

$$p = 5,940(E - 1.44)\text{, for } \rho = 7.44\text{g/cm}^3 \qquad (3)$$

where the pressure is measured in MPa and the liquid energy in KJ/g.

2.2 KALIMER Core Configuration

The reference system of analysis is the KALIMER breakeven core designed to generate 392MWt of power. The core utilizes a heterogeneous core configuration with driver fuel and internal blanket zones alternately loaded in the radial direction.. There are no upper or lower axial blankets surrounding the core. The reference core has an active core height of 100 cm and a radial equivalent diameter(including control rods and radial blankets) of about 100cm[2].The fuel temperature (Doppler) coefficients are estimated to vary as -0.081 $T^{-1.45}$ for the sodium-voided case, whereas it varies as -0.083 $T^{-1.41}$ in the case of the sodium-flooded core. The Doppler coefficient does not show any substantial change with burnup[7].

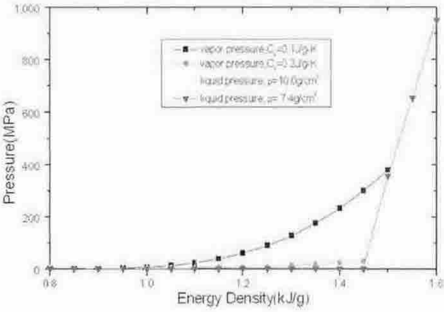

Figure 1.Energy- Pressure Relationship EOS.

2.3 Results

Figure 2 shows the core power during prompt critical power excursion driven by the 100$/s reactivity insertion with failure to scram. Power oscillates once due to the Doppler feedback effect and eventually drops down when the core comes to subcritical with the core disassembly.

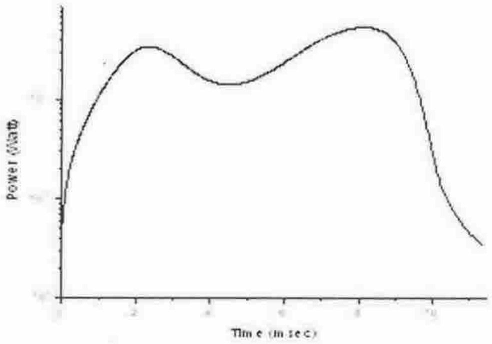

Figure 2.Powerfor 100$/s reactivity insertion

Figure 3 illustrates the time history of energy generated in the core for the 100$/s reactivity insertion. It can be seen that the amount of energy generated saturates to 3,000 MJ. This value may be converted to the average energy density of around 0.6 KJ/g of fuel, which is below the fuel boiling point.

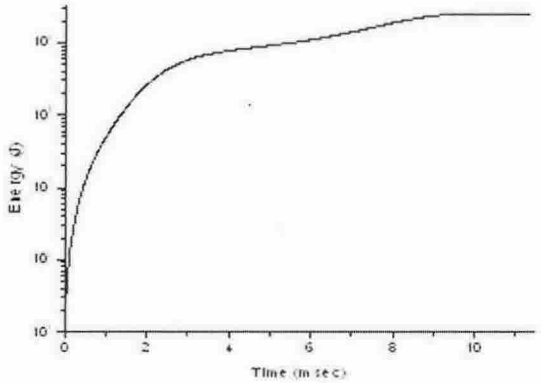

Figure 3. Energy deposition for 100$/s excursion

In the mean time, the code predicts that the core peak temperature amounts to about 6,000 K, which is above the fuel boiling temperature(about 4,500 K).

3. Conclusion

For the upper-limit case of the reactivity insertion rate of 100$/s, the energy density at the peak location of the core goes over the boiling point but the rest of the core stays in the solid liquid region. It is estimated that the power excursion may well be terminated by a gradual fuel dispersion.

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