Application of Equation of State for SFR Core Disassembly Analysis

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1. Introduction

In this study, a core disassembly analysis in the sodium-voided core of the KALIMER-150 (Hahn *et al.,* 2002) was performed using the VENUS-II code [1] for the reactivity insertion rates of 100 $/s, which has been widely considered to be the upper limit of the ramp rates due to a fuel compaction. This extreme case of the reactivity insertion rate also serves to test the applicability of the density-dependent equation of state of pressure-energy relationship utilized in this study for the single phase liquid region far above the melting temperature of the uranium.

The density-dependent equations of state of pressure-energy density relationship developed for the metallic fuel were implemented into the VENUS-II code, which was originally developed for analyzing the core disruptive accident(CDA) of the oxide-fueled SFR core. The equations of state for the single-phase liquid of the metallic uranium fuel derived based on the van der Waals model are used in this study , while a correlation for fuel vapor pressure as given by Raugh and Thorn[2] is used when the fuel is in the two-phase region.

The VENUS-II code is a two-dimensional coupled neutronics-hydrodynamics program that calculates the dynamic behavior of a sodium fast reactor(SFR) during a prompt-critical power excursion. 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 the 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.

The reference system investigated in this study is the KALIMER-150 core, which is a pool-type sodium cooled prototype fast reactor that uses U-TRU-Zr metallic fuel 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[3].

2. Equation of State

The equation of state plays an important role in calculations of the course of a hypothetical fast reactor excursion, for it serves as the link between the neutronic relations and dynamic behavior of a core which leads to ultimate shutdown. The principal relation necessary for such calculations are the pressure as a function of energy and volume for hydrodynamic calculations. There exist, however, considerable uncertainties in our knowledge of the equation of state as well as material properties at extreme conditions of the temperature and pressure, occurring during the power excursion of fast reactors. Resort has therefore been made to theory and correlation for the estimation of these physical properties at extreme conditions.

Figure 1 is a plot of density dependent energy-pressure relationship implemented into the VENUS-II code for the equation of state for the uranium fuel. The smoothly varying lower portion of the plot is the fuel vapor pressure as given by the correlation developed by Raugh and Thorn. This pressure function is used when the fuel is in the two-phase domain. The steep linear portions of the curve for the various densities are the single-phase pressure relationship developed based on van der Waals model.

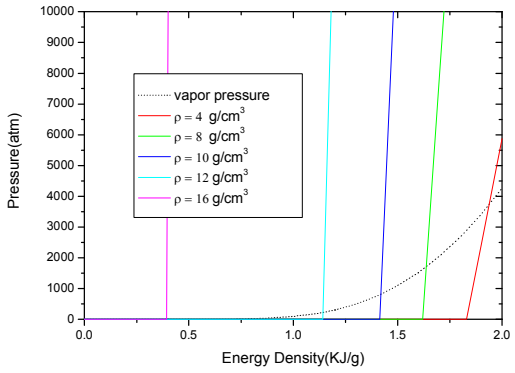

Fig. 1 Equation of state of pressure-energy-density relationship for uranium

3. Analysis Results

Pressure develops during an excursion as a result of heating or compressing the reactor materials. These pressures, along with the temperature and density of the material, must be estimated in order to calculate the resulting material motions during disassembly. Figures 2 and 3 illustrate the changes of the pressures and densities at the four locations of the core. The radial mesh nimber 4 indicates the inner driver fuel assemblies located at the central part of the core, representing the most reactive fuel assemblies in the core. The radial mesh 8 represents the outer driver fuels located at the peripheral side of the core.

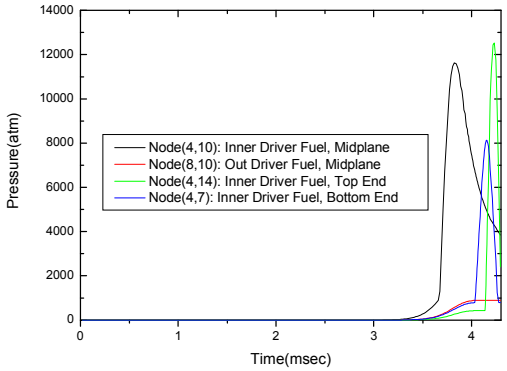

Fig. 2 Pressure changes during 100$/s power excursion

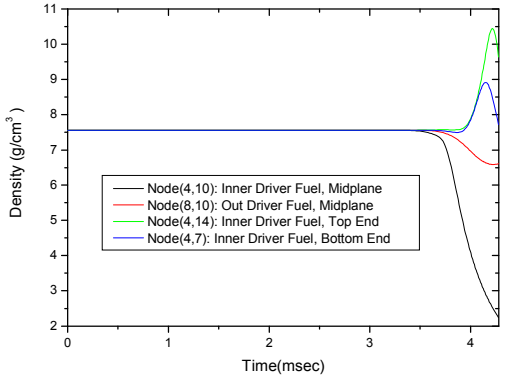

Fig. 3 Density changes during 100$/s power excursion

As can be seen in Figure 2, pressure rises first at the mesh cell number (4,10) located at the axial mid-plane of the inner driver fuel assemblies , where the peak power occurs. The pressure at the cell jumps up from 890 to 1300 atm at about 3.68 ms, rapidly reaches its maximum to 11,600 atm (at 3.82 ms) and eventually drops down. Explaining the situation in terms of the equation of state of the pressure-energy-density relationship, as depicted in Figure 1, the pressure first gradually increases in the two-phase fuel vapor region up to 890 atm by 3.68 ms, when the fuel vapor disappear and the fuel becomes a single phase liquid. As a consequence, the nodal pressure steeply increases, reaching its peak. Then it drops down as the fuel density rapidly decreases as may be noted in Figure 3.

Subsequently, the local pressures also increase significantly near the axial ends of the inner driver fuel assemblies. At the cell number (4,7), which is located at one mesh up of the bottom end of the fuel, the pressure begins to steeply rise at about 4.0 ms and reaches its maximum to 8,100 atm at 4.16 ms into the excursion. The cell density first decreases a bit as the temperature increases. But from about 3.87 ms on, the cell density begins to rise because of the rapid compression due to the motion of the mesh cells from the axial mid-plane. This high density makes the pressure steeply rise at the bottom node. There is no pressure buildup at the inner blanket assemblies during the power excursion.

4. Conclusion

Calculations have been made to analyze the core disruptive accidents initiated by fuel slumping in the KALIMER-150 reactor, using the VENUS-II code modified for the analysis of a metal-fueled core in this study. It was observed that the density-dependent equation of state used in this study predicted in a reasonable and consistent way the behavior of the pressure-density-energy (or temperature) of the core during the extreme power excursion

Acknowledgements

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References

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