Analysis of Core Meltdown Accidents in KALIMER-150

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1. Introduction

In this study, a core disassembly analysis in the sodium-voided core of the KALIMER-150 was performed using the VENUS-II code [1] for various reactivity insertion rates up to 100 $/s. 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.

The calculation results show that the mechanical work energy arising from the fuel vaporization after the power excursion is less than the structural design criteria of the reactor vessel, even for the extreme case of the reactivity insertion rate of 100 $/s, which has been widely considered to be the upper limit of the ramp rates due to a fuel compaction.

2. Methods and Results

2.1 Analysis Methods

The VENUS-II code was developed to simulate the dynamic behavior of the oxide fueled core of liquid metal reactors during a super-prompt critical power excursion induced by a 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 the reactivity feedback models and the equations of state of pressure-energy density relationship for the metallic fuel. The equations of state were derived for the saturated-vapor as well as the single-phase liquid of the metallic uranium fuel.

2.2 KALIMER Core Configuration and Model

The reference system of analysis is the KALIMER breakeven core designed to generate 392MWt of power. The core utilizes a heterogeneous core configuration with the driver fuel and internal blanket zones alternately loaded in the radial direction., as shown in Figure 1. 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].

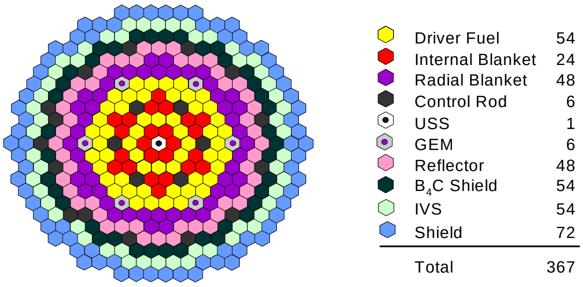

Figure 1. KALIMER-150 Core configuration

The two –dimensional (r-z) geometrical mockup used for KALIMER-150 is shown in Figure 2. The core is modeled with seven regions as indicated by the solid lines.

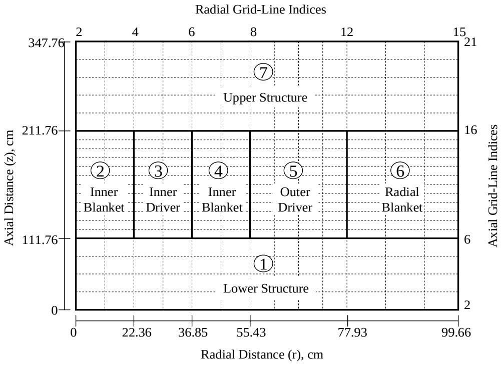

Figure 2. KALIMER-150 model

At the start of the core disassembly analysis, the core is assumed to be at prompt critical and its thermal power is one hundred times the normal power (392 MW). The value used for the total delayed neutron fraction and prompt neutron lifetime are 0.00358 and 0.3 μs , respectively. Table 1 shows the various initial parameters for each fueled region of the core, including the volume fraction, power fraction, nodal density, Doppler weighting and the average temperatures.

Table 1. Initial conditions in fueled regions

Region No.	2	3	4	5	6
Volume Fraction	0.050	0.087	0.173	0.302	0.388
Power Fraction	0.030	0.220	0.081	0.615	0.032
Density (g/cm^3)	9.50	7.56	9.50	7.56	9.50
Doppler weighting	0.12	0.11	0.33	0.25	0.19
Average Temperature (K)	1,200	1,400	1,100	1,250	900

2.3 Results

A number of calculations have been performed to analyze the hypothetical super-prompt-critical power excursion of KALIMER for various reactivity insertion rates, using the VENUS-II code modified for the analysis of a metal-fueled core and the reactor parameters listed in the previous section. The amounts of energy generation in the core during the power excursions range from about 4,400 MJ with the ramp rates of 10$/s, up to 7,300 MJ for the case of the 100 $/s insertion rate, as shown in Figure 3.

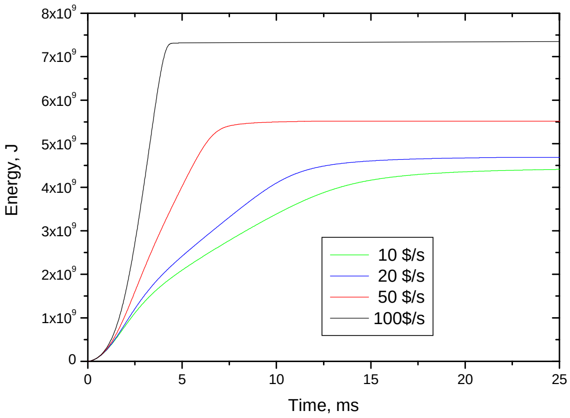

Figure 3. Energy deposition for the power excursions induced by various reactivity insertion rates

The average temperatures in each region of the core are listed in Table 2 for various rates of the reactivity insertion into the sodium-voided core. It is seen that the average temperatures of the radial blanket assemblies remain below the melting temperature of the fuel (,which is assumed to be about 1,400 K in this study) during the excursions. The peak temperatures of the radial blanket assemblies are also below the melting point of the fuel.

Table 2. Regionwise average temperature for various reactivity insertion rates

Ramp Rate ($/s) / Temperature(K)	10	20	50	100
Driver Fuel (In)	4,500	4,670	5,260	6,550
Driver Fuel(Out)	3,660	3,800	4,290	5,330
InnerBlanket (In)	1,600	1,630	1,720	1,920
Radial Blanket	1,000	1,010	1,020	1,060

It may be noted from the temperatures of the driver fuels listed in Table 2 that a sizable amount of work energy should be generated only for the excursions initiated by the reactivity insertion rates higher than 50 $/s, since any significant amount of work would be produced only above the fuel vaporization temperature, which is assumed to be 4,300 K in this study. The work energy amounts to 350 MJ for the excursion caused by the reactivity insertion rate of 100 $/s, satisfying the design criteria (500 MJ).

3. Conclusion

For the upper-limit case of the reactivity insertion rate of 100$/s, the work energy generated by the fuel vaporization in the core of KALMER-150 is estimated to be less than the structural design criteria of the reactor system.

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] J.F.Jackson and R.B.Nicholson, "VENUS-II, An LMFBR Disassembly Program,"ANL-7951, Argonne National Laboratory,1972
[2] D.Hahn et al., "KALIMER Preliminary Conceptual Design Report," KAERI/TR-2204/2002, 2002