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Sensitive Analysis for Core Disassembly Accidents in KALIMER-150

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1. Introduction

In this study, a sensitive study for core disassembly accidents in the sodium-voided core of the KALIMER-150 was performed using the VENUS-II code[1] modified for the analysis of metal-fuelled core. Parametric studies were performed to investigate the sensitivity of the analysis results to the variations of the initial conditions of major uncertainties such as the power level and temperature distributions in the core.

Calculation results show that only some of the driver fuels at the inner ring of the core would vaporize generating modest work energy in the case of a few tens of dollars per second reactivity insertion rate, which is presumed to be theoretically possible when fuel slumping starts in the core disruptive accident initiated by an abrupt loss of flow without scram.

2. Analysis Methods and Reactor Modeling

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 the KALIMER-150 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

KALIMER-150 is a 150 MWe pool-type sodium cooled prototype reactor that uses metallic U-Pu-Zr alloy, which brings potential benefits over the oxide fuel in an improved inherent safety, reduced burdens on nuclear waste, and a unique proliferation resistance. The KALIMER-150 core system is designed to generate 392MWt of power. The reference core utilizes a heterogeneous core configuration with driver fuel and internal blanket zones alternately loaded in the radial direction.

The two –dimensional (r-z) geometrical mockup used for KALIMER-150 is shown in Figure 1. The core is modeled with seven regions as indicated by the solid lines. At the start of the core disassembly analysis, the core is assumed to be at prompt critical and its thermal power assumed to be fifty 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.

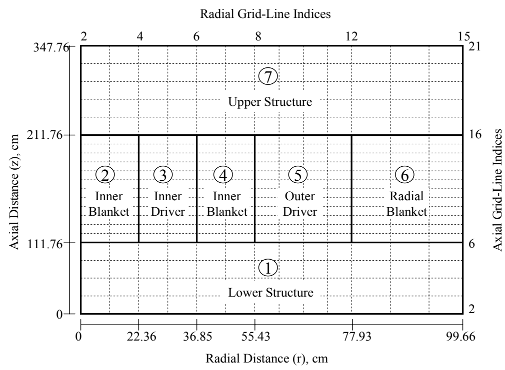

Figure 1. KALIMER-150 model

The initial conditions at prompt critical would be dependent on the specifics of the various possible sequences at the initiating phase of loss of flow accidents. Parametric studies are carried out in this study, therefore, to investigate the sensitivity of the calculations to the initial power level and temperature distributions, which are among the major initial conditions of uncertainties expected to influence the analysis results.

3. Analysis Results

Presented in Figure 2 and Table 1 are the results obtained by varying the initial power from ten times to one hundred times the normal power (indicated as P_s in the figure and table) , which are presumed to be an adequate range of the power level for the core disruptive accidents initiated by an abrupt loss of flow. It can be seen that an increase of the initial power increases the peak power, energy release and core temperature. But the peak reactivity and ratio of the peak to initial power decrease as the initial power increases. It may be observed that the results of energy release or core temperature are not much sensitive to the initial power level assumed, to the extent that the energy released increases less than 10 % with the ten-time increase of the initial power.

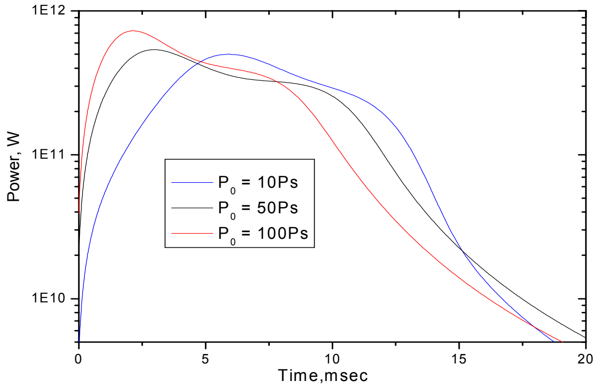

Figure 2. Power changes with different initial power levels assumed during 20$/s power excursion

Table 1. Variations in initial power level during 20$/s power excursion

Initial Power, P_0	$P_0 = 10P_s$	$P_0 = 50P_s$	$P_0 = 100P_s$
P_p,Peak power,GW	500	538	*727*
P_p / P_0	128	27	*19*
Energy release, MJ	3,870	4,200	*4,480*
Peak temperature,K	*5,170*	*5,430*	*5,650*

For the cases of reactivity insertion at the rate of a few tens of dollars per second, the peak temperatures in the driver fuels located in the outer ring of the core go up slightly above the boiling point. The driver fuels loaded in the central part of the core are expected to generate some work energy since their mean temperatures are above the boiling temperature. The work done by fuel vapor isentropically expanding down to a final pressure of 1atm is estimated to be modest in the order of a few tens of mega joules.

The variations of initial temperatures in each region of the core were also made in this study. The temperatures at the driver fuel regions were increased to 500 K or decreased by 200 K from the reference values. Results are that the amount of energy release and temperatures are not sensitive at all to the variations of the core temperature in the case of the lower ramp rates of reactivity insertion.

3. Conclusion

A number of calculations have been performed 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. For the case of the reactivity insertion at ramp rates of a few tens of dollars per second(10-30$/s), the mean temperature of the driver fuels located in the inner ring of the core goes slightly over the vaporization temperature but most of the driver fuels in the outer ring remain below the boiling temperature. Some of the driver fuels at the inner ring of the core would vaporize and gradually disperse resulting in modest work energy generated.

Parametric studies were also performed to investigate the sensitivity of the core meltdown energetics to the variations of the initial conditions of the major uncertainties, including the power level and temperature distributions in the core. An increase of the initial power increases the peak power, energy release and core temperatures in the case of the reactivity insertion at the rate of 10 to 20 $/s but the results of energy release or core temperature were not much sensitive to the initial power level assumed.

Acknowledgements

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[2] D.Hahn et al., "KALIMER Preliminary Conceptual D esign Report," KAERI/TR-2204/2002, 2002