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Analysis of HCDA Power Excursions in KALIMER-150

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1. Introduction

A number of calculations have been performed to analyze the hypothetical super-prompt-critical power excursion of KALIMER-150 for various reactivity insertion rates, ranging from 10$/s up to 100$/s, using the VENUS-II code modified for the analysis of a metal-fueled core[1]. Parametric studies were also carried out in this study 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

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. Reactor Modeling

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[2].

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. It is seen that the regionwise Doppler weighting factors for the blanket regions are larger when compared to their volume fractions. This means that the blanket regions are more important in terms of the Doppler feedback effect. The regionwise average temperature is assumed to be 1,400 K in the driver fuels located in the inner ring of the core . Its peak temperature is assumed to be 1,700 K. It is roughly that about a half of the region is molten. Meanwhile, the average and peak temperatures of the driver fuels in the outer ring of the core are assumed to be 1,250 K and 1,500 K. About a quarter of the region is molten. It is assumed that the inner blankets and radial blankets are not initially molten[3].

Table 1. Initial conditions in fueled regions

Region .	Inner Blanket (inside)	Driver Fuel (inside)	Inner Blanket (outside)	Driver Fuel (outside)
Volume Fraction	0.050	0.087	0.173	0.302
Power Fraction	0.030	0.220	0.081	0.615
Density (g/cm^3)	9.50	7.56	9.50	7.56
Doppler weighting	0.12	0.11	0.33	0.25
Average Temperature (K)	1,200	1,400	1,100	1,250

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3. Analysis Results

In Figure 1 are compared the power histories for the excursions initiated by various reactivity insertion rates.

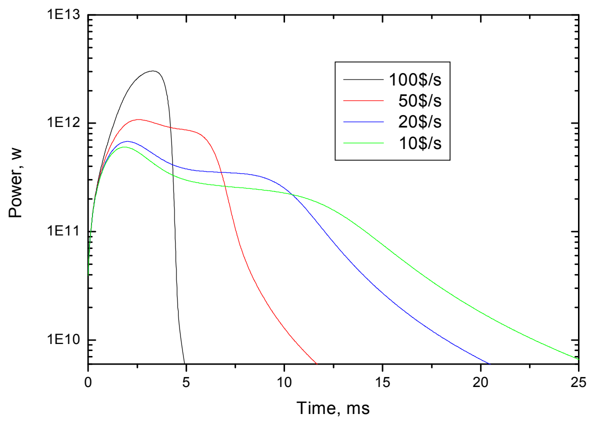

Figure 1. Power changes with different initial power levels assumed during 20$/s power excursion

The peak power ranges from about 600 GW for the case of the reactivity insertion rate of 10$/s to 3,000 GW with the ramp rate of 100$/s. It may be noted from the figure that somewhat different modes of the power histories exist. In the case of the power excursions initiated by the low rates of the reactivity insertion, the powers rapidly increase to the peaks and decline a bit to the plateaus and then slowly decrease, and eventually drop down below the initial value. The plateau effects are more pronounced with the excursions initiated by the low rates of the reactivity insertion. The plateau effects are due to the balance between the positive ramp rates and the negative Doppler reactivity effects.

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..

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 in the table that work energy should be generated only in the driver fuels loaded inside the core, 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.

Using the average temperatures listed in Table 2, the work energy arising from fuel vapor expansion is calculated to be about 350 MJ for the excursion caused by the 100 $/s reactivity insertion rate. This is below the structural design limit of the reactor vessel of KALIMER-150, which is set to be 500MJ. In the case of the reactivity insertion rates below 20 $/s, the average temperature of the driver fuels located in the inner ring of the core go slightly over the vaporization temperature but most of the driver fuels in the outer ring would remain below the boiling temperature. It would be that the inner ring of the driver fuels boil and gradually disperse with an insignificant amount of work energy generated.

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 much sensitive to the variations of the core temperature, as shown in Table 3 for the case of the lower ramp rates of reactivity insertion.

Table 3. Regionwise average temperature for various initial temperature distributions(20$/s)

Core Temperature, K	T_0 - 200	T_0	T_0 + 500
Inner Driver, K	4,590	4,490	4,850
Outer Driver, K	3,650	3,670	3,840
Inner Blanket, K	1,690	1,600	2,020
Outer Blanket, K	1,500	1,450	1,800
Energy Release, MJ	4,430	4,200	3,820

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 shown that the work energy generated during and after power excursions are below the structural design criteria of the reactor system of the KALIMER-150.

Acknowledgements

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