Analysis of Core Disruptive Accidents in a Small Sodium Fast Reactor

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1. Introduction

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Analysis of core disruptive accidents (CDA) starts with liquid fuel interspersed with void spaces left in the core when the sodium coolant is expelled. As temperature rises, the voids are filled with the expanded liquid, thus producing saturated vapor pressure. If the liquid reaches the threshold energy to fill the voids completely, pressure begins to rise rapidly. In this study, the equation of state for the fuel vapor pressure developed recently by Joseph *et al.*[1] was cross-checked and used in this study.

A set of core disassembly analyses was subsequently performed for the sodium-voided core of the KALIMER-150 design[2] by using the VENUS-II code[3] for the various reactivity insertion rate up to 100 \$/s , which had been assumed to set the upper-bound design limits of containment systems in early safety studies.

2. Fuel-Vapor Pressure

The EOS for the widely used uranium oxide fuel is relatively well known but only a limited amount of experimental data and theoretical models are currently available for the metallic fuel. Regarding the U-Pu-Zr alloy, no experimental data is currently available but an EOS was developed based on general theoretical models. Using the principle of corresponding states (PCS) method, Joseph *et al.*[1] developed the following expression of vapor pressure for the metallic alloy (70% U, 20 % Pu and 10 % Zr, by wt.%),

$$\log P = 8.58 - 22{,}379/T - 0.946 \log T \qquad (1)$$

where pressure is in MPa and temperature is in K.

As part of an effort to test the reliability of the above relationship, the data for vapor pressure of each element of the alloy was searched to calculate and compare the vapor pressures for the alloy. A number of handbooks of chemistry and physics were reviewed for vapor pressures of the elements of the fuel alloy. For uranium, for instance, the data from Reference 4 was in reasonable agreement with Rau and Thorn's data[5] within the order of magnitude. The EOS of the metal alloy with the same weight fraction of the elements as the reference alloy was subsequently calculated using the data of vapor pressure of each element as listed in Reference 4.

Figure 1 shows the saturated vapor pressures as a function of temperature for the U-Pu-Zr alloy and each element of the alloy. It is noted that the vapor pressure of the metal alloy developed by Joseph *et al.* , given in Eq. (1), is in fair agreement with the one that is calculated in this study based on the data of the elements. Consequently, Eq.(1) was used in our CDA analysis . The specific heat used for the fuel alloy to convert the relationship of internal energy and temperature is about 0.22 J/g.K.

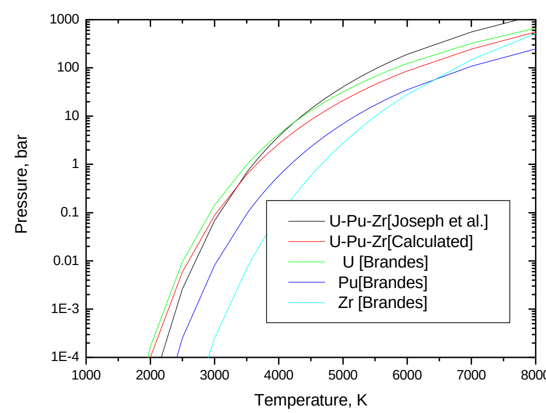

Fig.1. Relationship of vapor pressure and temperature of U-Pu-Zr fuel alloy and each element

3. Analysis Results

KALIMER-150 is a pool-type sodium cooled prototype reactor that uses metallic U-Pu-Zr alloy, generating 392MWt of power. The reference 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. The fuel pins are made of sealed HT-9 tubing containing metal fuel slug of U-Pu-10%Zr in columns[2]. The core is radially divided into 5 regions, with internal blankets and driver fuels alternately loaded in the two –dimensional (r-z) geometrical mockup in the VENUS-II code[3].

Figure 2 shows the power history during the various excursions. For the reactivity insertion rate of 100$/s, core power reaches its maximum at 3,140Gw at 3.4ms, which is about 800 times the initial power. Energy released during the power excursion amounts to 5,900 MJ. With the reduced rate of reactivity insertion, the peak reactivity and power decrease. As a result, the amounts of energy generation in the core during the power excursions also decrease. In the case of the reactivity insertion rate of 20 $/s, the maximum core power is 264 GW, which is about 70 times the initial power. Energy released during the power excursion amounts to 3,200 MJ..

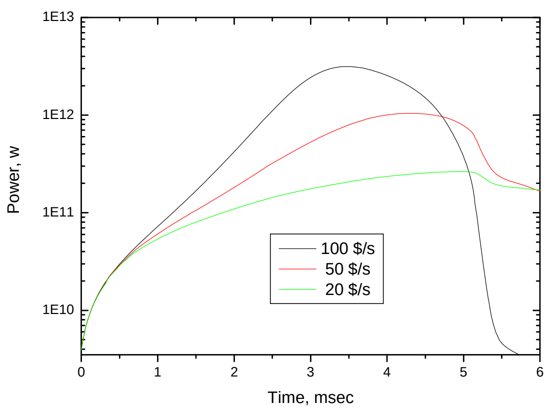

Fig.2. Power change during the power excursion of various reactivity insertion rates

The Peak and average temperatures in each region of the core are listed in Table 1 for various rates of the reactivity insertion into the sodium-voided core. With the reactivity insertion rates of 20$/s and 50$/s, the average temperatures of the inner blanket assemblies remain below the melting temperature of the fuel during the excursions. Even for the reactivity insertion rate of 100$, the average temperatures of the blanket assemblies slightly go over the melting temperature but are too low to generate the damaging work energy. It may be assumed, therefore, that the blanket assemblies would not contribute to generating the mechanical work energy that potentially threatens the reactor vessel or internal structures up to the reactivity insertion of 100 $/s.

4. Conclusion

It is observed that the amount of power rise becomes significant with the increase of the rate of reactivity insertion, but that the amount of energy release is not as much sensitive to the rate of reactivity insertion. This is because of the two compensating effects related to the rates of reactivity insertion, that is, the earlier power rise and the period of time of the power excursions. For the case of the reactivity insertion rate of 100 $/s, the maximum core power and total energy released during the power excursion amounts to 3,140 GW and 5,900 MJ, respectively.

Table 1.Regionwise Average Temperature for Various Reactivity Insertion Rates

Ramp Rate ($/s) / Temperature(K)	20	50	100
Inner Driver Fuel			
-Peak Temperature	4,610	5,130	7,000
-Mean Temperature	3,830	4,260	5,750
Outer Driver Fuel			
-Peak Temperature	3,850	4,260	5,760
-Mean Temperature	3,010	3,360	4,560
Inner Blanket(Inside)			
-Peak Temperature	1,670	1,680	1,920
-Mean Temperature	1,490	1,530	1,690
Inner Blanket(Outside)			
-Peak Temperature	1,600	1,670	1,680
-Mean Temperature	1,330	1,390	1,530

Acknowledgements

This work was performed under ‘the Long-Term Nuclear Energy Research and Development Program‘, sponsored by the Ministry of Education, Science and Technology of the Republic of Korea.

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