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Analysis of a Transient Over-Power in KALIMER-600

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1. Introduction

KALIMER-600 [1] is designed to satisfy the safety principle of defense-in-depth and also the safety design objectives which have been established to implement the safety principle in the design. The most important two primary safety design objectives are the accident resistance and the accident mitigation. The main purpose of these objectives is to detect any failure threatening the safety functions and to control the accidents within the design basis by maintaining the required fundamental safety functions.

Highly reliable diversified shutdown mechanisms are equipped for the reactivity control function during an accident or abnormal transients in KALIMER-600. The reactivity is also controlled by the inherent reactivity feedback mechanisms incorporated in the design. In addition, a uniquely designed passive decay heat removal circuit provides the heat removal function. Due to these passive and inherent safety characteristics, the safety of KALIMER-600 is much improved than the existing PWR designs. Therefore, the events whose frequencies are higher than 10^{-7} per reactor-year are categorized as design basis events (DBEs).

A transient over-power (TOP) is one of the most important DBEs in the design of a liquid metal-cooled reactor. A TOP event is initiated by an inadvertent withdrawal of one or more control rods from the initial inserted position due to a malfunction of the drive motor systems. The rod control system of KALIMER-600 allows only one rod to move at a time, thus, a failure in shim motor control results in a maximum reactivity insertion at the maximum shim motor speed. The TOP postulates that a malfunction in the reactivity controller causes the shim motor to continue to withdraw the control rods to the top of active core.

Single rod withdrawal is the most likely rod withdrawal accident, but it is assumed that the limiting postulated DBE TOP is the withdrawal of all primary control rods at the maximum shim motor speed. This event bounds other reactivity insertion events considered as potential DBEs. When the reactor power reaches the high neutron flux trip setpoint, the reactor trip occurs. The high core outlet temperature trip is the other competing reactor trip mechanism.

The acceptance criteria for the safety analysis are determined to guarantee the public safety by assuring the integrity of fuel rod and primary structures. The integrity of the vessel structures and boundaries is assured by limiting their average core exit temperatures. The clad temperature is limited to exclude the stress rupture and the eutectic formation between the metallic fuel and the fuel. The criteria for the fuel and the coolant are the fuel solidus temperature and the sodium boiling temperature.

2. Methods of Analysis

The TOP event is assumed to initiate at a full power and the quantity of reactivity insertion is determined to be 0.98$ for 46.7 seconds. The reactivity insertion of 0.98$ is obtained considering the initial position of control rods inserted for the compensation of burnup reactivity swing. The corresponding initial location of control rod is 140.1 mm from the core top. The maximum shim motor speed is assumed to be 3 mm/s, thus, the time of reactivity insertion is about 46.7 second.

For the analysis of a TOP event, some design variables are applied to be conservative. The fuel conductivity is assumed to be reduced to 92% of the maximum value based on the MACSIS calculation, which shows that the conductivity is reduced with the increase of fuel burnup. The decay heat from the reactor core is also assumed as 110 % of the normal decay curve.

The effect of uncertainties is evaluated by the sensitivity studies on the control rod worth, Doppler coefficient, and the sodium void worth. Sensitivity studies for the reactor power, primary flow rate, and the core inlet temperature are also performed to find the most conservative condition of initial operating variables.

It is assumed that the high neutron flux trip is activated at 115% of the rated power and the core exit temperature trip at 560 ^{o}C including the uncertainties. The reactor trip at higher power or at higher core exit temperature delays the trip signal, thus, results in more conservative consequences.

The accident consequence for the TOP is analyzed with the SSC-K computer code [2] for the evaluation of the integrity of fuel, cladding, structure and coolant during the transient. The SSC-K is a best-estimate system code for analyzing a variety of off-normal conditions or accidents of a pool-type sodium-cooled fast reactor. The SSC-K is developed at KAERI on the basic framework of SSC-L [3], which was originally developed at Brookhaven National Laboratory to analyze loop-type liquid metal reactor transients. The SSC-K code accommodates new models for the pool thermal hydraulics and major components, reactivity feedback effects for the metallic fuel [4], and PDRC [5].

3. Analysis Results

The results of sensitivity study shows that more conservative peak fuel temperature and coolant temperature are predicted with a lower control rod worth, higher Doppler coefficient, and lower sodium void worth. The most important factor governing the peak temperatures is the reactor trip time. A higher peak temperature is predicted if the reactor trip is delayed. The results also show that the peak fuel and coolant temperatures are determined by the combined effect of reactor power, flow rate, and the core inlet temperature. Generally, higher peak temperatures are obtained with higher power, lower flow rate, and higher core inlet temperature condition.

The most conservative results are obtained for the case in which the reactor power is 104% of the rated power, the primary flow rate is 100%, and the core inlet temperature is 395 °C. The predicted peak fuel temperature and the clad temperature are 743 °C and 599 °C, which satisfy the safety limit of 955 °C and 700 °C, respectively.

Fig. 1 shows the trend of reactor power and primary flow rate for the most conservative case of TOP. The power peaks to 116% at 8.6 seconds after the initiation of rod withdrawal, and then it decreases drastically due to the reactor trip. The primary pump trip is assumed to occur at 3 seconds after the reactor trip followed by the pump coastdown. Fig. 2 depicts the peak fuel temperature change and also the cladding temperature at the same location.

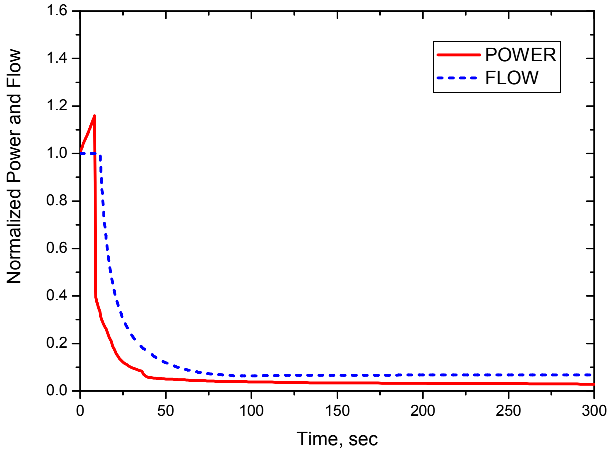

Figure 1. Reactor power and flow rate for a TOP transient

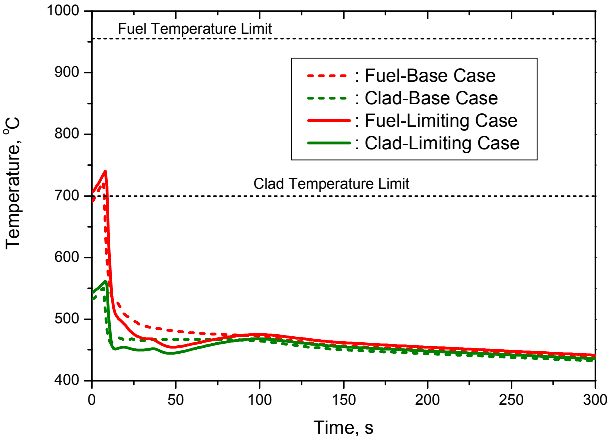

Figure 2. Peak fuel and clad temperatures for TOP transients

4. Conclusion

The safety analysis has been performed for the TOP event which is a DBE in KALIMER-600. The analysis results show that the fuel, clad, and the coolant temperatures are well within the safety limit temperatures. Therefore, the KALIMER-600 design fulfills the design basis safety criteria with no fuel damage and no threat to the structural integrity during the transient.

Through the analysis of TOP, it is clearly shown that the KALIMER-600 design maintains its safety functions required for the mitigation of the accidents with an appropriate margin because enough conservatisms are imposed in the analysis. Therefore, it is concluded that the KALIMER-600 breakeven core design ensures safety margins for TOP DBE.

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