Self-Power-Regulating Characteristics of the KALIMER-150 Core during Unscrammed Accidents

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1. Introduction

A liquid metal fast reactor has the potential of enhanced safety utilizing inherent safety characteristics, transuranics reduction and resolving spent fuel storage problems through proliferation-resistant actinide recycling. The Korea Atomic Energy Research Institute has developed the conceptual design of KALIMER-150 [1], the design target of which is to have the features of being economically competitive, inherently safe, environmentally friendly, and proliferation-resistant.

The KALIMER-150 design highly emphasizes inherent safety, which maintains the core power reactivity coefficient to be negative during all modes of the plant status and under accidental conditions as well. These effects result from either the law of nature, or both the law of nature and core design. In this paper, investigated is the self-power regulation features due to reactivity feedback effects for the unprotected transient analysis results.

2. Inherent Safety Characteristics

The safety systems of KALIMER-150 are based on a passive system and do not require active components in coping with accidents. It improves the reliability of the KALIMER-150 safety function. KALIMER-150 accommodates unprotected anticipated transients without scram (ATWS) events without operator action, and without the support of active shutdown, shutdown heat removal, or any automatic system without damage to the plant and without jeopardizing public safety. Neither operator action nor offsite support is required for at least three days without violating core protection limits at an accident. The inherent core safety is ensured by the following reactivity feedback effects during the transients.

Figures 1 through 3 are the reactivity feedback components predicted by SSC-K code [2] during unprotected transient overpower (UTOP), unprotected loss of heat sink (ULOHS), and unprotected loss of flow (ULOF) event, respectively. The net reactivity for ATWS events maintains negative value during the early transient (about 10 minutes) and the value eventually goes to near zero after then by a thermal balance in the core.

2.1 Doppler Feedback

Doppler is the direct result of the laws of nature. As the fuel temperature rises, more neutrons are parasitically absorbed in the resonance energy range. This has the effect of removing active neutrons from the core and reducing reactivity. Doppler feedback is the fastest acting feedback mechanism. Fuel temperature is instantly affected by the core power level and is a practically instantaneous indicator of the power excursion. Doppler feedback removes the reactivity as the temperature rises and can thus help limit the extent of the power-increase excursion.

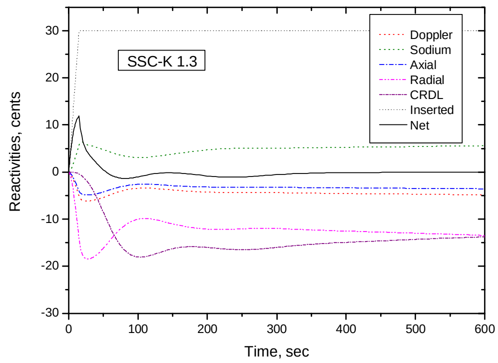

Figure 1. Reactivity feedback during KALIMER-150 UTOP

2.2 Sodium Density/Void

Thermal expansion of the sodium results in fewer sodium atoms being within the core so fewer neutrons are parasitically captured by the coolant, which results in a positive reactivity feedback effect. Off-setting this effect leads to increased leakage of neutrons from the core because there are fewer sodium atoms to scatter them back into the core. Reduced neutron collision with the sodium atoms also tends to harden the neutrons energy spectrum. For the small KALIMER-150 core, the neutron leakage effect is more dominant than the neutron spectrum hardening. For a sodium-cooled, mixed plutonium-uranium core, the net feedback effect from the coolant thermal expansion is positive. As long as the sodium is subcooled, this contribution is modest; however, in the extremely unlikely event that the sodium is voided from the entire core, this feedback effect is significant.

2.3 Axial Fuel Expansion

Metallic fuel expands significantly as it heats. Radial fuel slug expansion is accommodated within the pin and the fuel bundle lattice and does not affect the reactivity. Then the axial expansion is controlled by the expansion of the cladding, since the metallic fuel has little strength. Axial fuel expansion increases the core height and primarily decreases the effective density of the core materials by increasing the core surface area. The axial expansion increases the probability that a neutron will escape the core, giving a significant negative reactivity feedback. While the geometric change also affects neutron captures within the core, the overall effect is a rapid negative reactivity feedback contribution from the fuel temperature increase.

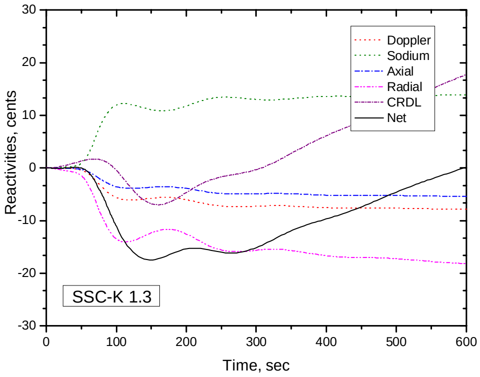

Figure 2. Reactivity feedback during KALIMER-150 ULOHS

2.4 Radial Core Dilation

Thermal expansion of the core structures is a result of both the laws of nature and the particular core design. It causes negative feedback for temperature increases by the combination of increased core volume captures and increased core surface leakage. The feedback is slow the coolant must then transport the heat to the load pad planes and heat the ducts/load pads. The heat capacities of the materials and the sodium transit times thus cause the feedback to be delayed by roughly a minute. The radial dimension of the core is determined largely by the assembly spacing, which is determined by the grid plate at the bottom of the core and by the above core load pad (ACLP).

The radial power profile across the core gives a tendency of temperature decrease in the radial direction. The side of the assembly duct facing the core center is hotter than the side away from the core center, so the differential thermal expansion of the duct tends to cause the assembly to take a shape that is convex to the core centerline. Interactions between adjacent assemblies and the core restraint boundaries force the core to deflect outwardly and spoil the neutronic efficiency of the core. Since the duct region is heated and bowing is in and above the core and the duct is thin and has a small heat capacity, bowing feedback tends to occur within a few seconds of the start of the transient.

The effect of such a growth in the volume and outer surface area of the active fuel region of the core is not only to increase the parasitic neutron captures in the extra coolant with the core volume but also to increase the loss of neutrons from the core region through the surface area.

2.5 Control Rod Driveline and Reactor Vessel Expansion

During the temperature increase transient, the hot sodium discharged into the reactor upper plenum heats and extends the length of the driveline. The expansion will cause the control absorber bundle to move toward the core mid-plane, which by itself gives a negative feedback. Since the control rod drives attach to the top of the reactor vessel and the core attaches to the bottom of the vessel, the expansion of the reactor vessel as it heats pulls the control rods out of the core somewhat. This results in a positive feedback. The net feedback due to this mechanism may be either positive or negative depending on the particular transient. This effect is not a safety factor early in a transient since its time constant is relatively large.

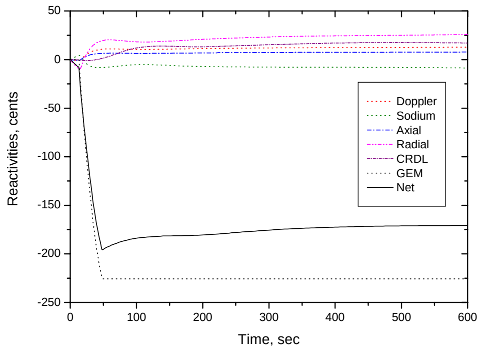

Figure 3. Reactivity feedback during KALIMER-150 ULOF

3. Conclusion

The SSC-K calculations for the typical ATWS events in KALIMER-150 were carried out to investigate the inherent safety features. The characteristics of the KALIMER-150 core were discussed with respect to the reactivity feedback effects on the core power regulation. The self-regulation of power without scram is mainly due to the inherent and passive reactivity feedback. The GEM effect during unprotected loss of flow appeared to be highly effective, but detailed discussion is not presented herein. It should be noted that safety margins of the KALIMER-150 appeared to be significant for all ATWS events.

Acknowledgement

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REFERENCES

[1] D. Hahn, Y. M. Kwon et al., KALIMER Conceptual Design Report, KAERI/TR-2204/2002. KAERI, 2002.
[2] Y. M. Kwon et al., SSC-K Code Users Manual, Rev.1, KAERI/TR-2014/2002, KAERI, 2002.