Comparative Analysis of the KALIMER ATWS by Using SSC-K and SAS4A/SASSYS-1

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1. Introduction

Results from the comparative analysis of the KALIMER-150 conceptual design using SSC-K[1] and SAS4A/SASSYS-1[2] are presented. Three ATWS events as the most relevant for an evaluation of the passive safety design features are selected. These are an unprotected transient overpower (UTOP), an unprotected loss-of-flow (ULOF), and an unprotected loss-of-heat-sink (ULOHS). By completing the code-to-code comparison analysis, a prediction performance of the SSC-K code is evaluated.

2. Comparison of Analysis Results

It is assumed that no plant protection system action including a reactor scram is taken during the ATWS events, so that the power level is changed in response to the thermal reactivity feedbacks. The main concern of the ATWS analyses is to evaluate the system response by nuclear-kinetic and thermal-hydraulic effects that involve inherently shutting the core down to acceptable power levels, which precludes a coolant boiling and fuel damage.

2.1 UTOP

One of the traditional accidents that has been analyzed is the unprotected transient overpower (UTOP) and this event results when a positive reactivity is inadvertently inserted into the core and there is a complete failure of the reactor protection system (RPS). In this analysis, the UTOP is assumed to insert 2 cents per second for 15 seconds based on the maximum withdrawal rate of the KALIMER shim motor.

The power and flow transients during the initial 600 seconds are shown in Fig. 1. Their peak powers calculated by the two codes are almost same. SSC-K predicts that the power reaches a peak of 1.48 times the rated power at 16.0 seconds into the transient and begins to level off at 1.08 times the rated power by 400 seconds. While the peak power by SAS4A/SASSYS-1 increases to 1.50 times the rated power at 15.0 seconds and later stabilizes at 1.05 times the rated power after 600 seconds. The observed discrepancy in the power is mainly the result of the different rates of reactivity change during the first 15 seconds, and the power varies slowly thereafter.

A large difference in the peak fuel temperature is noted. The peak fuel centerline temperature predicted by SAS4A/SASSYS-1 reaches 1057 K (783.9 °C), while the peak temperature by SSC-K reaches 1126.2 K (853.1 °C). The discrepancy of 69.2 K in the peak fuel temperature is considered to result from the different fuel model and physical properties; however the two prediction results are below the melting temperature of the fuel (1070 °C). There is a substantial safety margin for the UTOP event.

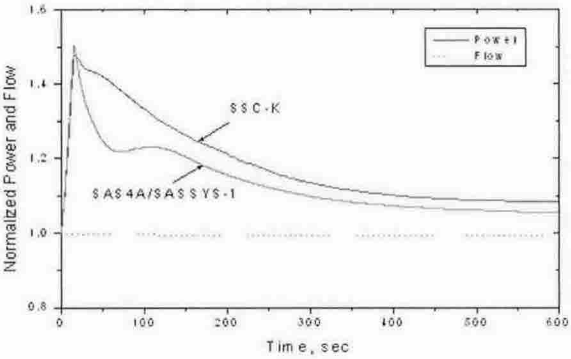

Figure 1. Normalized power and flow (UTOP)

2.2 ULOF

The Unprotected Loss of Flow (ULOF) accident is assumed to start with a trip and coastdown of all of the primary pumps. The normal heat removal through the IHXs and SGs is available in this event. Also the natural circulation in the PHTS in conjunction with the PSDRS effectively removes the core decay heat. The power level is determined by the inherent reactivity feedbacks and GEM during the entire transient.

Figure 2 shows that the reactor power level decreases with the flow rate during the initial 600 seconds. A trip of the primary pumps at 0 seconds causes a rapid flow reduction with a decrease of the reactor power level. The natural circulation flow rate by SAS4A/SASSYS-1 is 4.9 % of the rated flow at 600 seconds, while the one by SSC-K is 6.7% of the rated flow. The two code calculations show a 1.8% difference in the natural circulation flow rate; however, the power levels predicted by them are very close. The power immediately begins to drop and reaches a decay heat level by about 90 seconds since there is enough negative reactivity insertion due to the GEMs. The power level drops to about 2.8% of the nominal power by the end of 600 seconds.

The highest peak fuel temperatures at the beginning of the transient predicted by SAS4A/SASSYS-1 and SSC-K are 949 K (675.8 °C) at 5 seconds and 1017.2 K (744 °C) at 11 seconds, respectively. However the two prediction results are below the melting temperature of the fuel (1343 K). There is a substantial safety margin for the ULOF event. The temperatures of the clad and sodium coolant predicted by both codes are very close and they are about 814.7 K (541.5 °C) and 807.6 K (534.4 °C), respectively. Both temperatures are substantially below the threshold for an eutectic formation (1063 K) and the duration of the elevated temperature is very short. It provides a large safety margin and no cladding damage is expected.

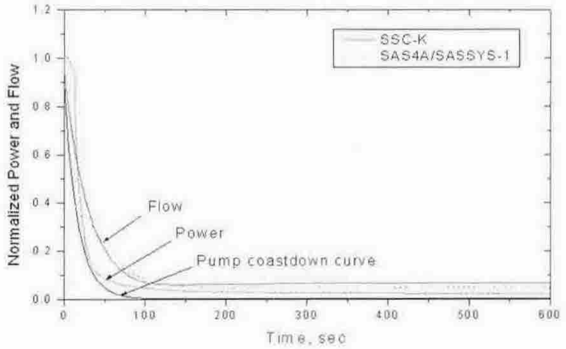

Figure 2. Normalized power and flow (ULOF)

2.3 ULOHS

The ULOHS is assumed to start with a loss of heat rejection capability at all of the steam generators, with the primary and intermediate loop pumps continuing to run. The only heat removal is conducted by the passive heat removal system of the PSDRS. The ULOHS tends to be a longer-term transient than the others, because it does not end until the system temperatures have increased to the point where the fission process is shut down, leaving only the decay heat generated in the core, and where the decay heat generation rate is within the capability of the PSDRS.

The power history plot in Figure 3 indicates that the negative reactivity associated with the inlet temperature rise is sufficient enough to reduce the reactor power to a decay heat level within the first hour of the accident.

SAS4A/SASSYS-1 predicts that the peak transient coolant temperature in the ULOHS accident is 890 K (617 °C) at 2400 seconds and the temperature converges to about 888 K (615 °C) after that. SSC-K predicts almost the same converged temperature but the temperature behavior during an early transient is significantly different. Both temperatures predicted by the two codes are nearly 300 °C below the sodium boiling temperature, and more than 150 °C below the temperature which could cause a long-term damage to the full element integrity.

During the initial period, the sodium pool heat sink absorbs the decay heat that exceeds the capacity of the PSDRS, without reaching temperatures that damage the core. KALIMER eventually cools until it becomes neutronically critical again, at a power matched to the capacity of the PSDRS.

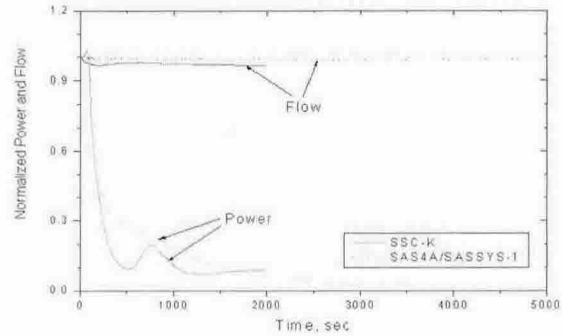

Figure 3. Normalized power and flow (ULOHS)

3. Conclusion

The peak temperatures of the fuel, clad and sodium in the hottest assembly, and the average temperature at the core outlet for UTOP, ULOF and ULOHS are summarized in Figure 4, in which the temperature limits determined for the KALIMER-150 safety are also shown.

The results of the code-to-code comparison analyses indicate that the SAS4A/SASSYS-1 calculation agrees in general with the SSC-K calculation. Since the reactivity feedback has a dominant effect on the ATWS consequence, most of the differences between the two calculations may result from the differences in the reactivity feedback calculations. The thermal-hydraulic behaviors calculated by the two codes during the ATWS events show relatively good agreements.

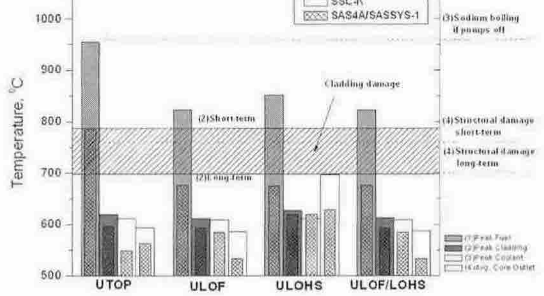

Figure 4. Temperature limits for KALIMER safety

REFERENCES

[1] W.P. Chang, Y.M. Kwon, Y.B. Lee, D. Hahn, "Model Development for Analysis of the Korea Advanced Liquid Metal Reactor," Nucl. Eng. Des., Vol.217, 63-80, 2002.

[2] J. E. Cahalan, et al., "Advanced LMR Safety Analysis Capabilities in the SASSYS-1 and SAS4A Computer Codes," Proceedings of the Int. Topical Meeting on ARS, Pittsburgh, Pennsylvania, 17-21 April, ANS, 1994.