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Analysis of the ULOF event for the KALIMER-150 by using SAS4A/SASSYS-1

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1. Introduction

In this study, the analysis of ATWS for the KALIMER-150 was conducted using the SAS4A/SASSYS-1 code to predict and evaluate the system response by nuclear kinetic and thermal hydraulic effects that involve inherently shutting the core down to acceptable power levels, and preclude a coolant boiling and fuel damage. The accident was assumed to occur by an ULOF (unprotected loss of flow), which is one of ATWS (anticipated transients without scram) events [1].

In the KALIMER-150 design, the coolant pumps are specified as an electromagnets (EM) design equipped with synchronous motor-generator (MG) sets to provide inertia for flow coast down. Power to the MG sets is provided by a source external to the unit. The initiator for the ULOF accident is assumed to be a failure of the normal power supply for the primary and intermediate loops coolant pumps. The offsite power supply for the EM pump is not a safety-grade system, thus a loss of flow event is of high probability to be considered “anticipated” in the KALIMER design.

The SAS4A/SASSYS-1 code was used as an analysis tool. The SAS4A code system is a tool for analyzing the initial phase of hypothetical core disruptive accidents (HCDAs) up to gross melting or failures of the subassembly wall [2]. SAS4A contains detailed mechanistic models of transient thermal, hydraulic, neutronic, and mechanical phenomena to describe the response of the reactor core, its coolant, fuel elements, and structural members to accident conditions. The core models in SAS4A provide the capability to analyze the initial phase of core disruptive accidents through coolant heatup and boiling, fuel element failure, and fuel melting and relocation. Originally developed to analyze oxide fuel clad with stainless steel, the models in SAS4A were extended to metallic fuel.

2. Analysis

The reduced primary coolant flow normally leads to a reactor scram due to a high flux-to-flow ratio. For this event to be interested, it is assumed that the RPS fails to detect the mismatch or that the control rods fail to insert. The ULOF is assumed to start with a trip of forced coolant flow in a reactor operating initially at full power. Power level is determined by inherent reactivity feedbacks and GEM during the entire transient.

A loss of power supply to all primary pumps may occur while the reactor is operating in the power mode. Then the flow rate in the primary loop coasts down while the forced circulating flow in the intermediate loop maintains. The normal heat removal through the IHXs and SGs is available in this event. Also the natural circulation in the PHTS (primary heat transport system) in conjunction with the PSDRS (passive shutdown decay heat removal system) effectively removes the core decay heat.

For a loss of flow accident, the power to flow ratio is the key parameter that determines the consequences of the accident. As long as enough coolant flow is available to remove the generated heat, the fuel temperature can be maintained at acceptable levels. Therefore the generated heat, the fuel temperature can be maintained at acceptable levels. Therefore the pump coastdown plays an important role for the plant safety and depends on the capacity of the pump synchronous generator. Since the detailed design data for the KALIMER EM pumps was not available to date, the EM pumps modes provided by the SAS4ASASSYS-1 code could not be used in this analysis. Instead the coastdown curve of the KALIMER EM pump was directly used as input data in the tabular format of flow vs. time. Therefore the pump flow rate behaves the coastdown characteristic curves after the pump trip.

3. Results

Fig. 1 shows theat the reactor power level decreases with the flow rate during the initial 600 seconds. Trip of the primary pumps at 0 seconds causes a rapid flow reduction with a decrease of reactor power level. The coastdown flow rate gradually decays following pump trip during the initial 100 seconds. Over the longer term, the core flow is driven by natural circulation in the PHTS. The natural circulation flow rate by SAS4A/SASSYS-1 is 4.74% of the rated flow at 600 seconds. The power immediately begins to drop and reaches day heat level by about 100 seconds since there is enough negative reactivity insertion due to GEMs. In the KALIMER-150 desing, the six GEM subassemblies are located in a high leakage region on the core. The power lovel drops to 2.37% of the nominal power by the end of 600 seconds.

The changes in the reactivity by SAS4A/SASSYS-1 are shown in Fig. 2. The GEM reactivity clearly overwhelms all otehr reactivity effects and provides a negative shutdown margin. The GEMs reach their full worth at about -2.26$ in about 100 seconds, and the worth remains throughout the entire transient. The fast insertion of negative reactivity reduces the power keeping the power-to-flow ratio faorable. At the end of 600 seconds, the net reactivities predicted by SAS4A/SASSYS-1 is -1.79$. During the first 600 seconds of the event, the positivie feedbacks are offset by the GEM negative feedback and the core maintains a subcritical shutdown.

The ULOF condition indicates the core is over-cooled compared to the reference temperature at the nominal operating condition. The maximum average fuel, cladding and coolant temperatures at steady state are 877, 816 and 810K, respectively. And all of the values decrease to about 743K at 600 seconds as shown in Fig. 3. The Doppler feedback shows a positive response because the fuel actually cools down. Doppler feedback is the fastest acting feedback mechanism. The usual positive reactivity feedback from sodium density becomes negative after about 150 seconds into the transient because of core over-cooling by GEMs. The control rod expansion reactivity feedback is slightly negative in the early transient but soon becomes positive since slightly positive due to vessel expansion. The reactivity feedbacks for the axial and radial expansion are slightly negative in the early transient but they soon become positive since their temperatures become lower than the reference ones.

Fig.3 shows the maximum average temperatures of coolant, cladding and fuel, respectively. The rapid insertion of the negative reactivity reduces the power, keeping the power-to-flow ratio favorable, so that the heat generated in the fuel can be removed without damageing the fuel. The rapid increase of the fuel temperature in the first few seconds is attributed to the power-to-flow mismatch, and subsequent rapid drops of those temperature result from the quick negative feedback of the GEMs. The fuel temperature rise again due to the power-to-flow mismatch and reach in the equilibrium condition when the natural circulation flow is established at the decay heat power level.

The highest peak fuel temperatue at the beginning of the transient is 900.7K at 10 seconds. It is below the melting temperature of fuel (1343K). There is substantial safety margin for the ULOF event. The peak cladding temperature is 849K and it is substantially below the threshold for eutectic formation (1063K). The duration of the elevated temperatures are lower than 10 seconds. This provides a enough safety margin and no cladding damage is expeted. The peak sodium temperature is 826.6K and it is also below its boiling point which is 1224K at core outlet.

4. Conclusion

The analysis of ATWS induced by ULOF was conducted for the KALIMER-150 by using the SAS4A/SASSYS-1 code . It was found that the fast insertion of negative reactivity through GEM reduces the power and offsets other positive feedbacks. The temperatures of fuel, cladding and coolant are shown to be lower than their limit of melting, eutectic formation and boiling point, respectively. It can be concluded from this result that a large safety margin and no cladding damage are expected during ULOF event.

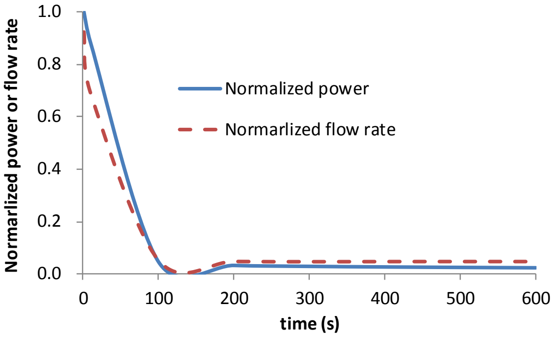

Fig. 1. Normalized power and flow rate

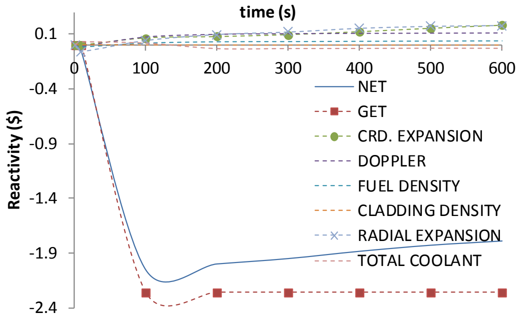

Fig. 2. Reactivity feedback components

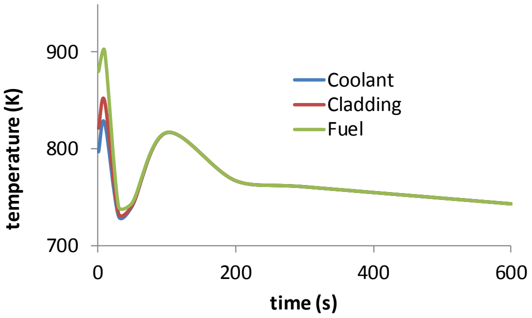

Fig. 3. Temperatures of coolant, cladding and fuel

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