Analysis of severe accident induced by UTOP for the KALIMER-150 by using SAS4A/SASSYS-1

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1. Introduction

In this study, the analysis of severe accidents 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 UTOP (unprotected transient overpower), which was one of ATWS (anticipated transients without scram) events.

The SAS4A/SASSYS-1 code was used as an analysis tool. The SAS4A and SASSYS-1 computer codes were developed at Argonne National Laboratory in the integral fast reactor (IFR) program for transient analysis of liquid metal cooled reactors (LMRs). The SAS4A code was developed to analyze severe core disruptive accidents resulting from undercooling or overpower initiating accidents [1]. 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 cald with stainless steel, the models in SAS4A were extended to metallic fuel. The SASSYS-1 code, originally developed to address the consequences of loss of decay heat removal accidents, was evolved into a tool to analyze passive safety response mechanisms in ATWS, and as a margin assessment tool for design basis accidents (DBAs). To fulfill this role, the SASSYS-1 code contains the same models as SAS4A for fuel element heat transfer and single and two-phase coolant hydraulics. In addition, it had the capability to provide a detailed thermal-hydraulic simulation of the primary and secondary sodium coolant circuits, as well as the balance-of-plant (BOP) steam / water circuit [1].

2. Analysis and Results

The ATWS events are an extremely unlikely event category in the KALIMER-150 design, however, they were considered in establishing the design bases for KALIMER-150. Among the several ATWS events, UTOP, ULOF (unprotected loss-of flow) and ULOHS (unprotected loss-of-heat-sink), which were the most relevant for an evaluation of the passive safety design features, only the UTOP was considered in this study.

It was assumed that the UTOP occurred when a positive reactivity was inadvertently inserted in the core and the reactor protection system (RPS) completely failed. Beginning with the steady state, the code computed increase of an external reactivity up to the given value. Two cases of UTOP were analyzed. The UTOP was described to insert 2 cents per second for 15 seconds based on the maximum withdrawal rate of the KALIMER shim motor in case 1 [3]. And the reactivity increase rate was assumed to be 6.67 cents per second until it reached 1.0 dollar in 15 seconds, considering an extremely severe situation in case 2.

The SAS4A predictions for progression of the accidents were as follows. In the SAS4A/SASSYS-1 analysis, the initial reactivity insertion leads to a power increase, which raises the fuel, coolant, and structural temperatures.

The power transients during the initial 600 seconds for the two cases are shown in Fig. 1. The reactor powers reached peaks of 1.5- and 3.1-times the rated power at 15.0 seconds for cases 1 and 2, respectively. And the powers slowly decreased to equilibrium with the available heat sink provided by the heat capacity of coolant and the heat rejection by the steam generators in both cases.

Fig. 2 shows the maximum coolant, cladding and fuel temperatures in the hottest fuel element channels of the two cases. Their peak coolant temperature results were shown to be 610 and 849℃ at 15 seconds, respectively. Both results were lower than the sodium boiling temperature (1070℃). The peak cladding temperatures of cases 1 and 2 were shown to be 619 and 869℃ at 15.0 seconds, respectively. The result of case 1 was found to be below the threshold for eutectic formation (790℃) and provided a large safety margin. But the result of case 2 exceeded the eutectic formation temperature. Therefore, cladding damage was expected during UTOP of case 2. The peak fuel temperatures of the cases 1 and 2 were shown to be 781 and 1137℃ at 15.0 seconds, respectively. Though the peak fuel temperatue of case 1 was lower than the fuel melting temperature (1070℃), that of the case 2 exceeded the fuel temperature critera. Therefore, fuel melting is expected during a UTOP of case 2.

The increase of temperature in the fuel, coolant, and structures brings reactivity feedback due to the Doppler effect, fuel and cladding axial thermal expansion, coolant density decrease, radial core dilation by structural thermal expansion at the above-core load pad (ACLP) plane and thermal expansion of the control rod drivelines [4]. Figures 3 and 4 showed the evolution of these reactivities of cases 1 and 2, respectively. The net reactivities, which were the sum of the assumed reactivity insertion and the feedback, increased initially with the inserted reactivities, but soon peaked and fell as the negative feedback countered only the positive feedback from the coolant density decrease in both cases. The net reactivities of both cases eventually decreased to near zero in about 100 seconds.

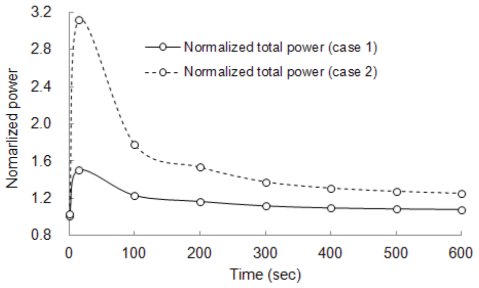

Fig. 1. Normalized powers

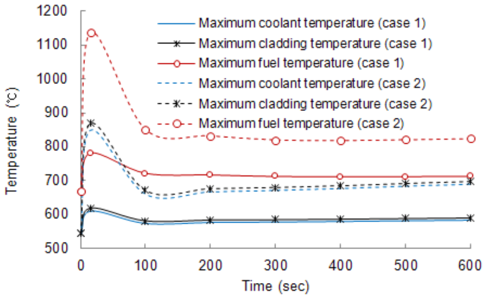

Fig. 2. Temperatures of coolant, cladding and fuel

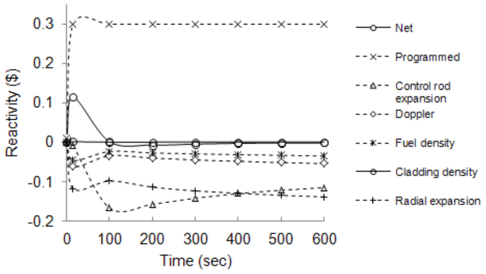

Fig. 3. Reactivity feedback components of case 1.

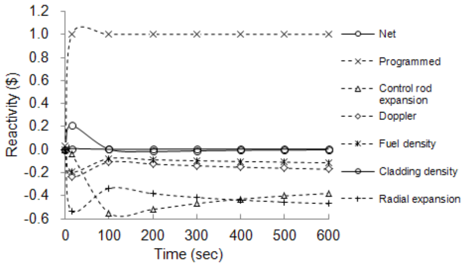

Fig. 4. Reactivity feedback components of case 2.

3. Conclusions

The analysis results showed that the KALIMER-150 design had inherent safety characteristics and was capable of accommodating UTOP when a positive reactivity insertion rate was assumed to be 2 cents per second for 15 seconds in case 1, and this assumption was based on the maximum withdrawal rate of the KALIMER-150 shim motor [3]. The passive safety mechanism in the KALIMER-150 design made the core shutdown with sufficient margin and the passive removal of decay heat and matching power to the heat sink by passive self-regulation was successful. The self-regulation of power without scram was mainly due to the inherent and passive reactivity feedback. However, cladding and fuel melting temperatures exceeded their melting values when the external reactivity insertion was assumed to reach 1.0 dollar in 15 seconds in case 2.

The SAS4A/SASSYS-1 analysis of these extremely unlikely sequences was conducted to examine the tendency of metal fuel to act as a fuse, to avoid an energetic accident sequence that challenges containment integrity [5]. Further study will be conducted to an analysis of other extremely sever accident cases and core melting phenomena.

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