Safety Analysis of Anticipated Transient without Scram (ATWS) events for the Prototype GEN-IV SFR (PGSFR) using MARS-LMR

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1. Introduction

A safety analysis of ATWS for the recently designed Prototype GEN-IV Sodium Cooled Fast Reactor (PGSFR) was conducted. The MARS-LMR code is used as a safety analysis tool, which was developed with new coolant properties and heat transfer and pressure drop correlations for liquid metals [1]. Three events including Unprotected Transient Over-Power (UTOP), Unprotected Loss OF Flow (ULOF), and Unprotected Loss Of Heat Sink (ULOHS) are selected as representative events for the ATWS. In an unprotected condition, the power in the core is only controlled by reactivity feedbacks, which is interacted with thermal-hydraulic characteristics of components in the plant. Heat is removed by the steam generator (SG) and decay heat removal system (DHRS). Therefore, the major objectives of the safety analysis of ATWS events are to investigate the thermal hydraulic characteristics of DHRS and SGs, neutron kinetic characteristics of reactivity feedback, and interaction between neutron kinetics and thermal-hydraulics during the events.

2. Safety Analysis of ATWS

2.1 Basic analysis parameters

The reactor is modeled with 6 channels i.e., inner, outer, hot, control rods, reflector, and in-vessel storage (IVS) assemblies. A coolant flow is driven by two primary mechanical pumps, and passed by the core region though the inlet plenum. The primary heat transport system (PHTS) is divided into cool and hot

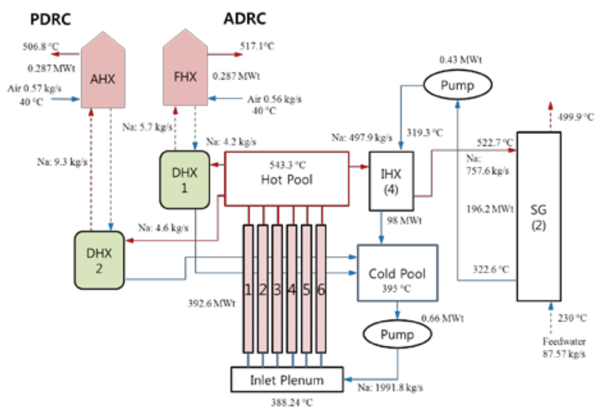

Fig. 1 Schematics of the calculated steady state conditions

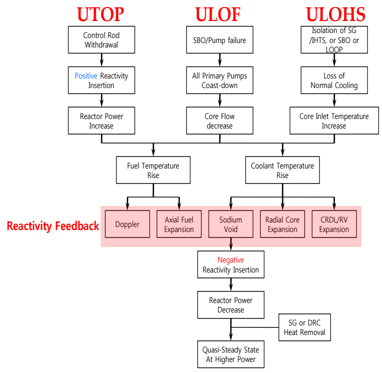

Fig. 2 Procedures of ATWS events with reactivity feedbacks

pools based on the core. Heat is removed by two steam generators, which are connected by two intermediate heat exchangers (IHXs) with one pump for each loop, which is called an intermediate heat transport system (IHTS). The DHRS consists of passive DRC and active DRC, which have two loops with DHX and air-sodium heat exchangers by each.

The total power in the core is 392.6 MWt, the total dissipation heats in the pumps of PHTS and IHTS are 1.3 MWt and 0.87 MWt, repectively. The heat removal rate in the SG is 393.6 MWt. The heat removal rate in the single DHRS loop is 5 MWt, so the total heat removal rate of DHRS is 20MWt for four loops. Based on the design values, the steady state result was obtained, as shown in Fig.1, which will be used as the initial condition for an ATWS event analysis.

2.2 Reactivity feedback models

In an unprotected event, the major key parameter is the reactivity feedback, which controls the behavior of the power generation in the core with neutron kinetics. Five reactivity feedback models are considered for an ATWS event in the MARS-LMR. The Doppler and sodium density was originally embedded in the MARS code and thermal structural expansion related models including fuel axial expansion, core radial expansion, and control rod/reactor vessel expansion were recently added [2]. The reactivity feedback models were prepared based on the reactivity coefficients [3].

2.3 Results

The UTOP event is initiated with 30 cents reactivity insertion at 10 seconds for 15 seconds. All events are

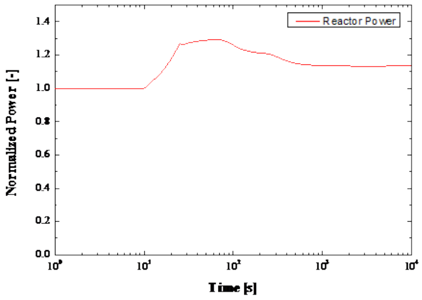

Fig. 3 Normalized power during the UTOP event.

calculated for 10^4 seconds except the ULOHS event, because the long-term (10^5 seconds) cooling performance test is necessary for the ULOHS. It is assumed that the DHRS is activated at 5 seconds after events for all ATWS events. The power is increased due to inserted reactivity, and a new thermal equilibrium is then established by the reactivity feedback, especially a negative radial expansion component. The newly saturated power is 1.29 times the rated power, as shown in Fig. 3.

The ULOF assumes that the primary and secondary pumps are tripped at 10 seconds. The coastdown halving times of the pumps in PHTS and IHTS are 8 and 4 seconds, respectively. The power is reduced due to negative reactivity feedbacks corresponding to rising temperatures. The dominant reactivity feedback component is the radial expansion. The most important parameter in a ULOF is the power-to-flow ratio, which is usually a reactor trip signal in a LOF event. This ratio reaches about 6, and then the fuel and cladding temperatures represent higher peak values. However, the power-to-flow ratio is highly dependent on the coastdown curve in the pump. Fig. 4 shows results of sensitivity test of two pump types with four different halving times. It is found that the pump coastdown characteristic is a critical parameter in the ULOF event. The pump design in the PGSFR is still developing, and after finalization of the details of the pumps, the estimation of the ULOF event will be achieved again.

The ULOHS assumes that SGs are failed at 10 seconds. Therefore, the heat rejection is accomplished by only DHRS. The heat is decreased to a decay heat level after about 1000 seconds due to the negative reactivity feedback, as shown in Fig. 5. The coolant, fuel, and cladding temperatures are continuously

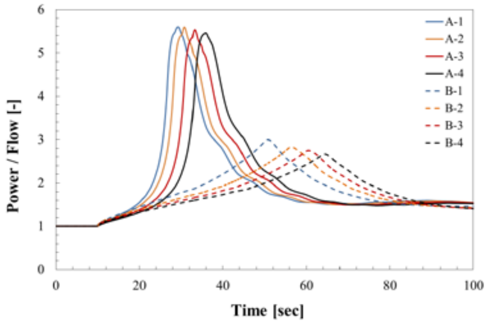

Fig. 4 Power-to-flow ratio for different halving times.

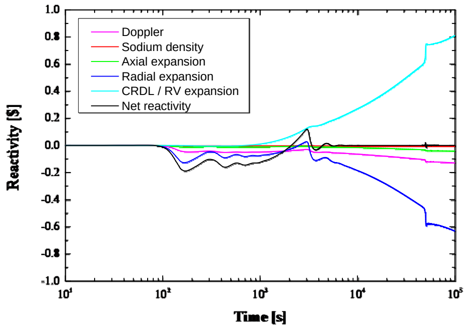

Fig. 5 Reactivity components during the ULOHS event.

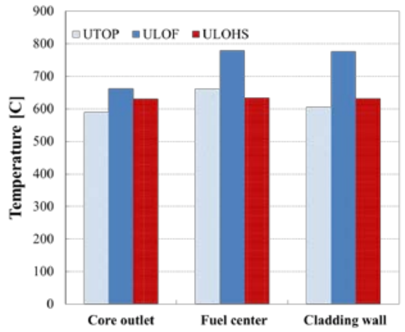

Fig. 6 Coolant, fuel, and cladding temperatures during ATWS.

increased due to a mismatched heat balance between DHRS and decay heat in the core, though reactivity reaches new equilibrium. After 10^5 seconds, the heat balance is almost achieved, because the heat removal capacity is also improved as the coolant temperature is increased. The coolant, fuel, and cladding temperatures for all ATWS events are satisfied with the temperature limits as shown in Fig. 6.

3. Conclusions and Further Works

The safety analyses for an ATWS event: UTOP, ULOF, and ULOHS are carried out with the MARS-LMR code. Based on the interaction between the neutron kinetics in the reactivity feedback components and thermal-hydraulics in the DHRS, all ATWS events are passively established in a new equilibrium state satisfying the temperature limits. The details of the pump design for the ULOF and intensive sensitivity test for the ULOHS are necessary to evaluate the accurate safety behavior. In addition, the validation for reactivity feedback models is critical for an unprotected transient analysis. Additional validation and modification will be achieved soon.

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