Sensitivity analysis on the control rod withdrawal accident (CRW) ATWS with GAMMA+

Seyun Kim[a*], Sang Jun Ha[a], Nam-il Tak[b], Hong Sik Lim[b]
[a]Korea Electric Power Research Institute, Munji-ro 65, Yuseong, Daejeon, Korea, 305-380
[b]Korea Atomic Energy Research Institute, Dukjin-dong 150, Yuseong, Daejeon, Korea, 305-353
[*]Corresponding author: seyunkim@kepri.re.kr

1. Introduction

A modular gas-cooled reactor has inherent safety characteristics with its large heat capacity and low power density of the core when compared with conventional light water reactors. To understand the safety features of the designed reactor, analyses for the RCCS performance in various accident conditions are required. A control rod withdrawal (CRW) without a reactor scram is one of the key safety demonstration issues of the VHTR design. To investigate the safety characteristics of a GCR under the accidental scenarios, sensitivity studies are carried out.

2. Sensitivity study

2.1 Analysis condition and method

A prismatic core gas-cooled reactor with the core exit helium temperature of 950° C was used in the analysis and the multi-dimensional GAs Multicomponent Mixture Analysis (GAMMA+) code was adopted to analyze the thermal hydraulic characteristics in a GCR [1]. For a safety analysis, an analysis model of a reactor coolant system and cavity cooling system is presented in Figure 1.

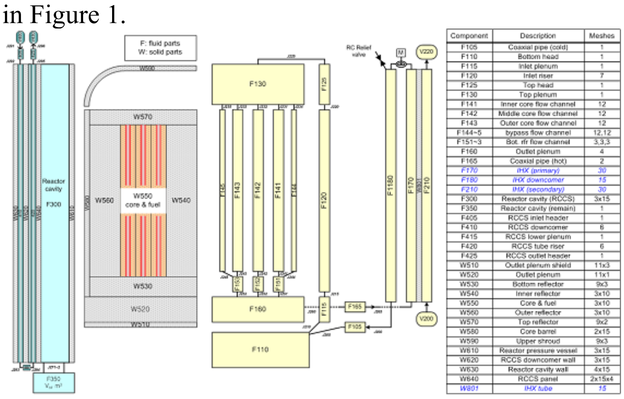

Fig. 1 Schematic of modular gas-cooled reactor

The behavior of the reactor core is simulated with point-kinetic equations with six-group delayed neutrons, by considering the reactivity changes due to the effects of a core temperature variation, xenon transients and reactivity insertions [1]. The total fraction of delayed neutrons is 0.00541 and effective prompt neutron lifetime is 3.23×10^{-4} seconds. The reactivity of the moderator, reflector and fuel are functions of temperature as shown in Figure 2.

2.2 Analysis results in reference condition

In the present postulated accident sequences, reactivity insertion by control rod withdrawal is assumed as 5×10^{-3} Δk/k in 130 seconds. The circulator head decreases linearly 60 seconds after the reactor trip signal generated. The mass flowrates of core flow paths are depicted in Figure 3, the natural circulation due to temperature difference between paths attenuates with time.

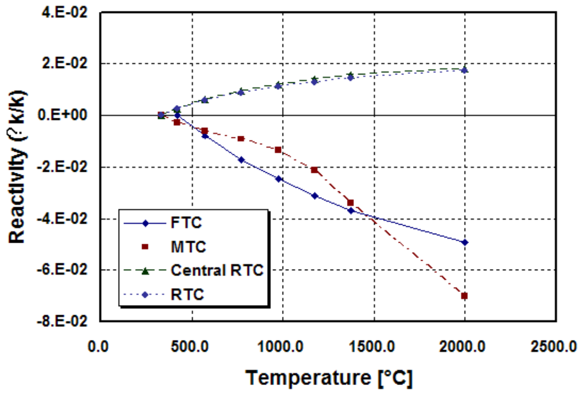

Fig. 2 Reactivity of fuel, moderator and reflector

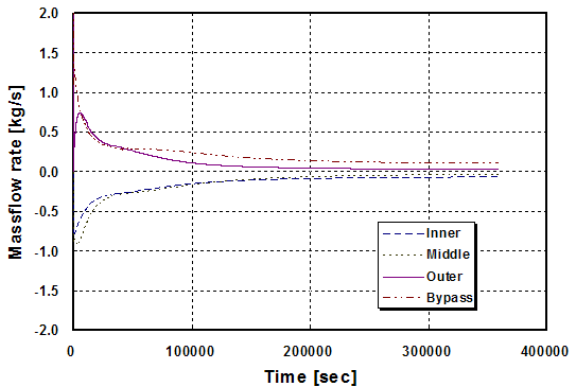

Fig. 3 Heat transfer characteristics in depressurized LOFC with RCCS failure without insulation

Figure 4 shows the net reactivity behavior including the reactivity feedback effects of the fuel, moderator and reflector temperature, xenon concentration and the control rod. The reactor core reaches a re-critical condition about 4×10^{4} seconds and the reactivities of the graphite moderator and xenon density mainly contribute to the net reactivity behavior [2]. The transient behavior of normalized power is presented in Figure 5 for 7×10^{4} seconds. The reactor power reaches 115% overpower in 14.7 seconds due to the positive reactivity insertion and reactor trip signal is generated.

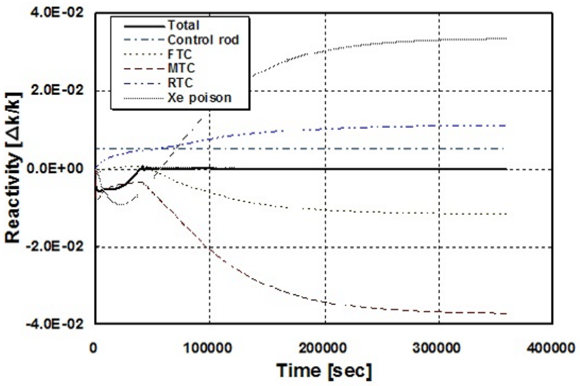

Fig. 4 Reactivity transient in CRW-ATWS

The circulator is switched off in 15.7 seconds and the coastdown of the circulator is started. After the re-criticality power peak occurs at 4.21×10^4 seconds with 2.6% of initial power, the power oscillates due to reactivity feedback.

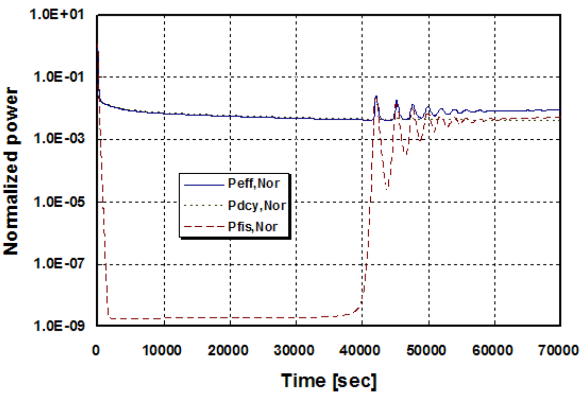

Fig. 5 Reactor power transient in CRW-ATWS

2.3 Sensitivity analysis

For a sensitivity analysis, the coastdown of the circulator is assumed to continue for 30, 60 and 120 seconds. Because of the variation of the massflow rate of the primary coolant in early period of accident, the maximum temperature of fuel, moderator and reflector are changed. However, the temperature variation is below 1% of reference condition. The effect of coastdown curve of circulator in the reactor transient behavior is negligible.

In CRW-ATWS, the insertion reactivity is one of the significant parameter[3]. For 3×10^{-3}, 5×10^{-3} and 7×10^{-3} Δk/k, the transient behavior of reactor is analyzed. In the view point of reactivity, the reactivity changes due to the FTC, RTC and Xe density are relatively small and the MTC and control rod effect is dominant. According to the variation of reactivity insertion, the re-criticality point varies about 5000 seconds. However, the magnitudes of the re-criticality power peaks are similar and the difference in the converged magnitude of power is less than several percent of the reference case as shown in Figure 7.

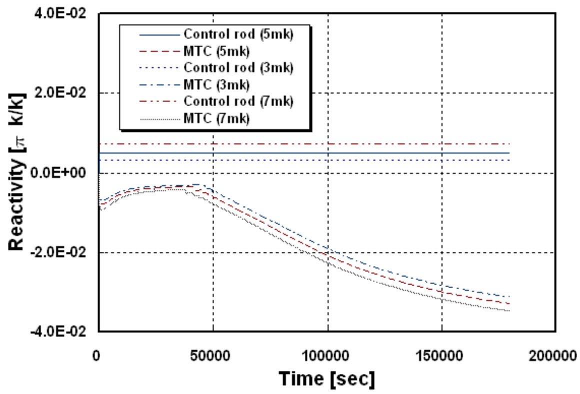

Fig. 6 Reactivity transient in CRW-ATWS with variation of insertion reactivity

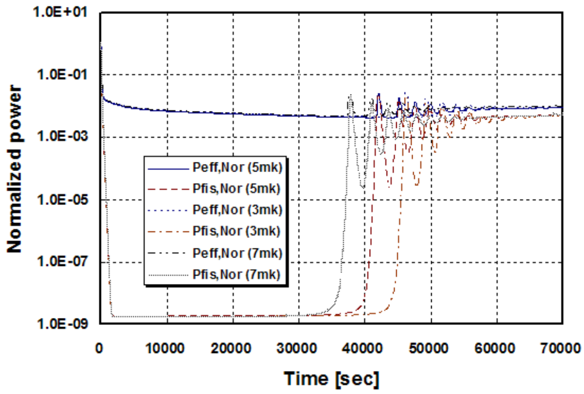

Fig. 7 Reactor power transient in CRW-ATWS with variation of insertion reactivity

3. Conclusions

Sensitivity study on the transient behavior of the reactor for CRW-ATWS was carried out. Generally, the variation of coastdown period of circulator has negligible impact on the transient behavior of the reactor. When the insertion reactivity varied, re-criticality point is shifted and the maximum temperature also varied about 3% from the reference value. However, the code shows the limited performance due to the use of point kinetics for the reactor core.

REFERENCES

[1] H.S. Lim and H.C. No, Transient multicomponent mixture analysis based on ICE numerical scheme for predicting an air ingress phenomena in an HTGR, NURETH-10, Seoul, Korea, October 5-9, 2003

[2] Ji Su Jun, Hong Sik Lim, Jae Man Noh, and Won-Jae Lee, The GAMMA Code Assessment of the HTR-10 Safety Demonstration Experiments-CRW ATWS, Transaction of KNS spring meeting, May, 2008

[3] W.J. Lee, Screening of Gas-Cooled Reactor Thermal-Hydraulic and Safety Analysis Tools and Experiment Database, KAERI/RR-2761, 2006