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OPR1000 Control Rod Drop Accident Simulation using the SPACE Code

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1. Introduction

The Korea nuclear industry has developed a best-estimated two-phase three-filed thermal-hydraulic analysis code, SPACE (Safety and Performance Analysis Code for Nuclear Power Plants), for safety analysis and design of a PWR (Pressurized Water Reactor). As the first phase, the demo version of the SPACE code was released in March 2010. The code has been verified and improved according to the Validation and Verification (V&V) matrix prepared for the SPACE code as the second phase of the development.

In this study, a Control Rod Drop accident has been simulated using the SPACE code as one aspect of the V&V work. The results from this test were compared with tests of the RETRAN and CESEC codes.

2. Control Rod Drop Accident Modeling

2.1 Control Rod Drop Accident Description

To begin with, a Control Rod Drop accident is classified as an ANS condition II event. A Control Rod Drop accident initiated by an electrical or mechanical failure can result in one or more control rods from the same group of a given group dropping to the bottom of the core. The negative reactivity insertion from the dropped control rod causes a prompt reduction in nuclear power followed by a decrease in Reactor Coolant System (RCS) pressure and hot leg temperature. According to the amount of dropped rod worth, a direct reactor trip could occur following the dropped rod event. If a reactor trip does not occur, the initial nuclear power could be restored by reactivity feedback or bank withdrawal. The drop of a single full length CRA (Control Rod Assembly) into the core reduces the fission power in the vicinity of the dropped CRA and adds negative reactivity on a core-wide basis. The negative reactivity addition causes a prompt drop in core power and heat flux. The magnitude of this power decrease (~4 to 20%) depends on the worth of the dropped Control Rod. With the turbine runback feature inoperative, the turbine continues to demand the same power it did prior to the CRA drop. This results in a power mismatch between the primary and secondary system that leads to a cooldown of the RCS. In the presence of a negative MTC (Moderator Temperature Coefficient) and DTC (Doppler Temperature Coefficient), the decreasing average coolant and fuel temperatures add positive reactivity.

As the coolant temperature decreases, the pressurizer control systems (i.e., heaters, sprays, and charging pumps) act to maintain the pressurizer pressure and level. After approximately 30 seconds, the radial and axial power distributions begin to shift in response to the reactivity feedback effects and neutron flux redistribution caused by the dropped CRA. An asymmetry in the radial power distribution occurs and within a few minutes a new tilted asymptotic state is gradually reached with higher radial peaks (this is termed the post-drop distribution). If the event is not terminated by then, xenon redistribution occurs, which causes further tilting and increases the radial peaks by approximately 5% within one hour. The positive reactivity addition from MTC and DTC feedback effects is eventually sufficient to compensate for the negative reactivity added by the dropped rod. The core subsequently restablizes, with the core power returning to the initial pre-drop power level and coolant temperature that is slightly reduced.

2.2 Steady-state modeling for Control Rod Drop Accident using the SPACE code

At first, the SPACE code deck for calculation of the control Rod Drop accident was made using the initial conditions of the RETRAN code deck, which used the OPR1000 safety analysis project for SPACE code capability evaluation. All initial conditions and assumptions used in RETRAN code were equally adapted to the Control Rod Drop accident SPACE input deck.

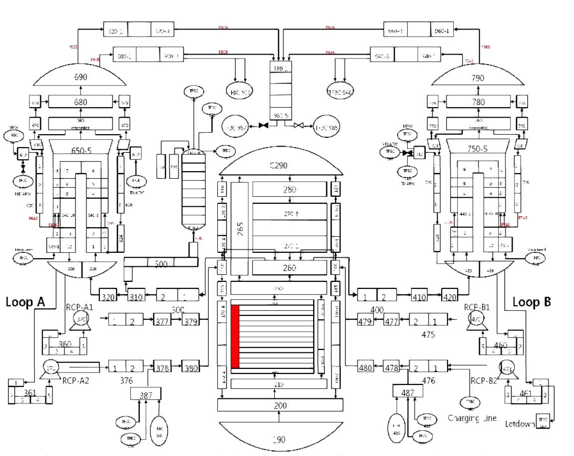

Fig. 1. SPACE Nodal Diagram for Control Rod Drop Accident.

For the conservatism, the SPACE input deck for the Control Rod Drop accident was not made at 100%

power condition but at 102% power condition. The SPACE input deck for the Control Rod Drop was run from 0 seconds to 500 seconds for steady-state confirmation.

Table I : Control Rod Drop Accidents Initial Conditions

Parameter	SPACE	RETRAN
Primary Coolant System		
Mass flow rate (10^6 lbm/hr)	112.0	112.0
Core inlet temperature (K)	588.86	587.79
Hot Leg Temperature (K)	604.85	603.53
Cold Leg Temperature (K)	572.90	572.04
Reactor Vessel		
Power level (MWt)	2871.3	2871.3
Core flow (kg/s)	14111.8	14111.76
Pressurizer		
Pressure (psia)	2000	2000
Water level (%)	52.6	52.6
Steam Generator Secondary Side		
Pressure (psia)	1131.0	1131.0
Mass flow rate (kg/s)	819.25	819.68
SG wide water level (%)	79.0	78.9
SG narrow water level (%)	44.01	44.0
Kinetic parameters		
Axial Shape Index	-0.3	-0.3
Dropped Rod Worth	-0.0006	-0.0006
MTC (pcm/F)	-35	-35

The major parameters are presented in the following figures, from Fig. 2 to Fig. 7.

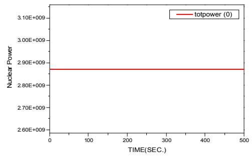

Fig. 2. Core Power

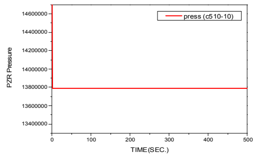

Fig. 3. PZR Pressure

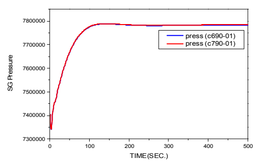

Fig. 4. SG Pressure

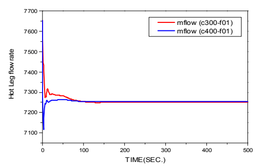

Fig. 5. Hot Leg flow

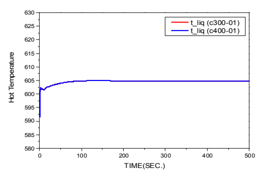

Fig. 6. Hot Leg Temp.

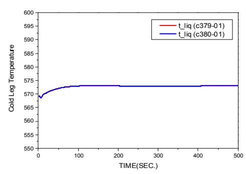

Fig. 7. Cold Leg Temp.

2.3 Transient modeling for Control Rod Drop accident using the SPACE code

The SPACE transient input deck of the Control Rod Drop accident was made based on the steady-state deck of the RETRAN code. For verification of the SPACE code, the basic assumptions and conditions used in the RETRAN and CESEC codes were identically adopted to the transient SPACE input deck.

The transient simulation was performed during 400 seconds after steady-state run. The major parameters are presented in the following figures, from Fig. 8 to Fig. 11.

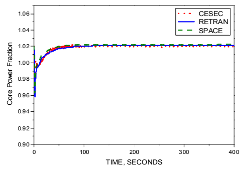

Fig. 8. Core Power

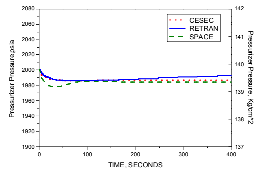

Fig. 9. PZR Pressure

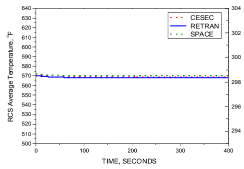

Fig. 10. RCS Avg. Temp.

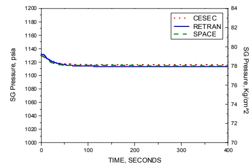

Fig. 11. SG Pressure

3. Conclusions

The Korean nuclear industry has been developing the SPACE code for safety analysis and design of a PWR. A Control Rod Drop accident has been simulated for the SPACE code V&V. The results have been compared with those for the RETRAN and CESEC codes.

Through this evaluation of a Control Rod Drop accident using the SPACE code, it is concluded that the SPACE code has the capability to predict the system response caused by a Control Rod Drop accident.

Acknowledgements

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