Transactions of the Korean Nuclear Society Virtual spring Meeting

May 13-14, 2021

Methodology for MAAP5 to Track RELAP5 Results for an Application of a Severe Accident Module in Nuclear Power Plant Simulators

Keo-hyoung Lee [a*], Kyeong-min Kim [b], Joo-youl Lee [b], Jong-beom Lee [b]
[a]*FNC Technology Co., Ltd., 32 Fl., 13 Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggi-do, Korea*
[b]*KHNP Central Research Institute, 1312-gil, Yuseong-daero, Yuseong-gu, Daejeon, Korea*
[*]*Corresponding author: khlee@fnctech.com*

1. Introduction

The Korean regulatory authority has declared an amendment of the "Nuclear Safety Act" to strengthen the legal framework of the severe accident management strategies. In accordance with this amendment, it was required to expand the simulation capability of the Nuclear Power Plant (NPP) simulators which are mainly used for training operators and licensing. As the result, the accident range that should be analyzed by simulators in Korea has been extended from Design-Basis Accidents (DBA) to severe accidents.

In order to apply a severe accident module in NPP simulators, various element technologies are required. Because the DBA analysis code and the severe accident analysis code for the NPP simulators are different from each other, the development of a methodology for tracking between computational codes is an essential and important technology among them. This paper addressed the technical background and major logic of the tracking methodology and the analysis results when the methodology is applied.

2. Backgrounds

The thermal-hydraulic behavior of the Reactor Coolant System (RCS) and Steam Generator (SG) of the Pressurized Water Reactor (PWR) type simulators in Korea is simulated with RELAP5 [1]. This computational code has excellent thermal-hydraulic capability for analyzing NPPs, but it is limited in simulating severe accidents in which the core is severely damaged. Thus, MAAP5 [2] is used to analyze the phenomena of severe accidents after core damage which is limited to being interpreted by RELAP5. MAAP5 is a useful tool for analyzing the consequences of a wide range of postulated plant transients including severe accidents.

Since the analysis capability of RELAP5 before core damage is superior to MAAP5, the behavior of the plant before core damage is predicted by RELAP5. And, the results analyzed by MAAP5 are utilized after the core damage. For the same scenario, if RELAP5 and MAAP5 derive perfectly the same analysis results, it is enough to change the data assigned to the simulator from the RELAP5 analysis result to the MAAP5 analysis result. However, unfortunately, even in the same scenario, each code can derive somewhat different analysis results due to the differences in the various thermal-hydraulic models and calculation methods included in each code. Therefore, it is necessary to apply the logic that MAAP5 tracks RELAP5 so that similar results can be derived from the two codes during the transition. Then transition between RELAP5 and MAAP5 can be performed seamlessly.

3. Methodology

In this section, the major logic applied to the tracking methodology is described. Prior to the description of the tracking methodology, the interface method between the simulator and the thermal-hydraulic computational code such as RELAP5 and MAAP5 was introduced first. And, the transition method from RELAP5 to MAAP5 after tracking RELAP5 by MAAP5 is described last.

3.1 The Interface Method

The thermal-hydraulic phenomena analyzed by the computational code are closely interfaced to the simulator. The loss of the pressure boundary of the RCS, the safety injection into the RCS, the main steam discharged from the SG, the feedwater into the SG, etc. are determined by interfacing between the simulator and the computational code. Figure 1 shows how RELAP5 and the simulator are interfaced with each other.

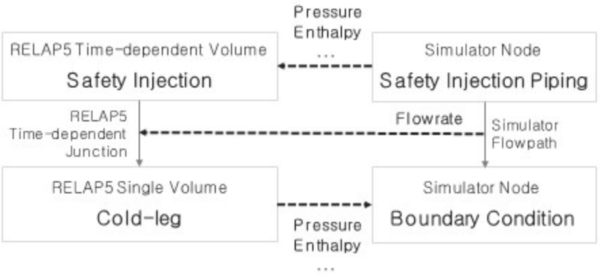

Fig. 1. A diagram of safety injection interface between RELAP5 and the simulator.

The thermal-hydraulic conditions such as pressure and enthalpy of the cold-leg calculated by RELAP5 during transient assign to the boundary condition node of the simulator. Accordingly, the fluid analysis module of the simulator can calculate the safety injection flowrate based on the differential pressure between the nodes for the safety injection piping and the boundary condition that refers to the condition of the cold-leg. The pressure and enthalpy conditions of the safety injection piping node are transferred to the time-dependent volume for safety injection of RELAP5, and the safety injection flow calculated by the fluid analysis module of the simulator assigns to the time-dependent junction of RELAP5. Then the safety injection is simulated in RELAP5. This interface method is similarly applied to simulate the RCS break, the main steam discharge, the feedwater, and so on.

The interface method between MAAP5 and the simulator is not the same as that of RELAP5 due to the differences in the characteristics of each computational code, but the basic concept is similar as shown in Fig. 2.

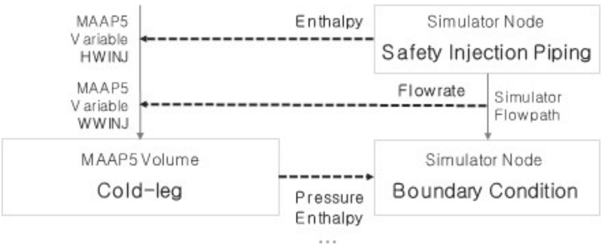

Fig. 2. A diagram of safety injection interface between MAAP5 and the simulator.

In MAAP5, instead of the concept such as the time-dependent volume and the time-dependent junction of RELAP5, the safety injection is simply simulated with two variables - HWINJ and WWINJ. The condition of the safety injection water is defined only by HWINJ (enthalpy), and the safety injection flowrate is defined by WWINJ. Although slight difference in physical characteristics may occur, this interface method applied to MAAP5 is reasonable enough.

3.2 The Tracking Methodology

RELAP5 and the simulator are interfaced with each other to simulate the behavior of the NPP. MAAP5 also simulates the same boundary conditions in parallel. However, only the results analyzed by RELAP5 are assigned to the simulator before the core damage. As an example, the following conditions determined by the simulator during the transient due to a Loss-Of-Coolant Accident (LOCA) are equally applied to RELAP5 and MAAP5,

(1) the break area,
(2) the temperature of the safety injection water,
(3) the flowrate of the safety injection,
(4) the discharge flowrate of the main steam,
(5) the temperature of the feedwater,
(6) the flowrate of the feedwater, etc.

Since the boundary conditions are completely same, the analysis results of the two computational codes can be expected to be same. However, the two codes do not lead to the same results due to the differences in the various thermal-hydraulic models and calculation methods included in each code. Therefore, the methodology to track RELAP5 is applied to the severe accident module for the NPP simulators. The major RCS and SG conditions that MAAP5 tracks RELAP5 are as follows;

(1) the pressurizer water level,
(2) the pressurizer pressure,
(3) the SG water level, and
(4) the SG pressure.

MAAP5 has no function of the water injection and suction into the pressurizer directly. The water injection may be possible through the pressurizer backup spray function. However, since the spray can affect the pressurizer pressure, it is not utilized to track the pressurizer water level. Thus, a method of the water injection and suction into the hot-leg connected to the pressurizer surge-line is applied. That is, if the pressurizer water level calculated by MAAP5 is smaller than that of RELAP5, water is injected into the hot-leg, and if the result is opposite, logic of the water suction is implemented.

This method is appropriate when the RCS except the pressurizer is filled with water, but there is a limitation as the tracking logic of the pressurizer water level when steam exists in the hot-leg during transient. Thus, additional logic to control the form loss of the pressurizer surge-line was applied. If the pressurizer water level analyzed by MAAP5 is larger than that of RELAP5, the surge-line form loss is reduced so that the pressurizer water flows more easily into the hot-leg.

In the case of pressurizer pressure, RELAP5 results can be tracked through the pressurizer normal spray and the pressurizer heater, which are the original function of the pressurizer. In the steady-state or the mild transient, it is possible to track the pressurizer pressure only with these functions, but there is a limit to apply these functions during transient such as a LOCA. Thus, additional logic to control the break area of the RCS is applied. Since RELAP5 and MAAP5 differ in the application method of the critical flow model that calculates the break flowrate, this logic for controlling the break area is necessary to track the pressurizer pressure.

The SG water level was tracked by the water injection and suction into the SG. And, the method to track the SG pressure is the evaporation of the SG water or the condensation of the SG steam. Since MAAP5 does not have functions to evaporate water or condensate steam directly, the evaporation is simulated by water suction from the SG while injecting water into the SG, and the condensation is implemented by reversing it.

3.3 The Transition from RELAP5 to MAAP5

RELAP5 and MAAP5 show considerably similar thermal-hydraulic behavior, when MAAP5 tracks successfully the conditions of the pressurizer and SG calculated by RELAP5. If the analysis results of the two codes are similar, it is possible to transit the computational code that provides the conditions of the

RCS and SG. Although MAAP5 tracks the results of REALP5, the results of the two codes are not perfectly same. Therefore, there may be a discontinuous tendency in the case of instantaneous transition at a specific point in time. In order to avoid this situation, a seamless transition was made based on the fuel cladding temperature. When the fuel cladding temperature is 800 K or less, only the results analyzed by RELAP5 are transferred to the simulator, and when the temperature is over 1,000 K, only the results analyzed by MAAP5 are assigned. When the fuel cladding temperature is between 800 K and 1,000 K, the REALP5 analysis results was gradually transited to the MAAP5 results according to the weighting factor based on the fuel cladding temperature calculated by RELAP5.

4. Results

The methodology for MAAP5 to track RELAP5 results can be applied not only in the transient, but also in the steady-state. In the case of the steady-state, the simulation was performed at the 100% power status in Advanced Power Reactor 1,400 MWe (APR1400). And, the transient calculation was presented based on a scenario in which a Large Break (LB) LOCA occurs and the safety injection system is failed.

4.1 The Steady-state Calculation

Even if the initial conditions of RELAP5 and MAAP5 are similar, some oscillation is inevitable before maintaining the steady-state. As shown from Fig. 3 through Fig. 5, the pressurizer and SG conditions analyzed by MAAP5 maintained the steady-state at around 1,000 seconds after the application of the tracking logic begins. And, RELAP5 and MAAP5 leaded to the identical results after 1,000 seconds.

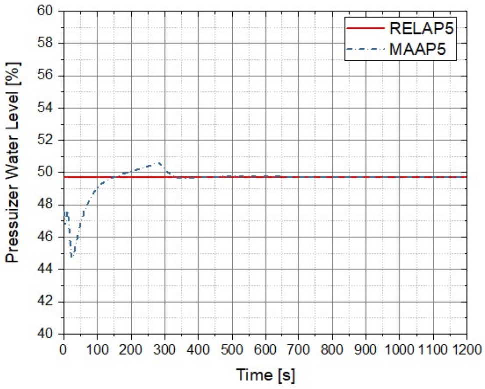

Fig. 3. The behavior of the pressurizer water level of RELAP5 and MAAP5 during steady-state.

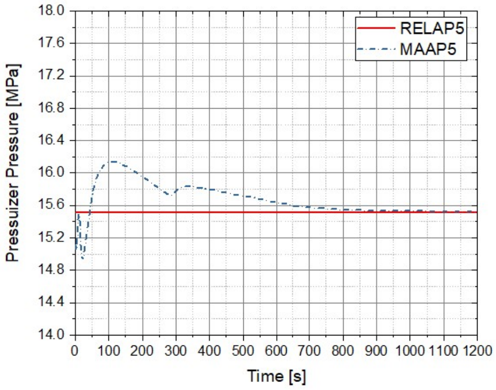

Fig. 4. The behavior of the pressurizer pressure of RELAP5 and MAAP5 during steady-state.

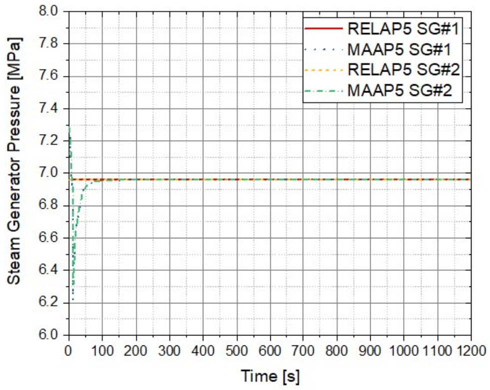

Fig. 5. The behavior of the SG pressure of RELAP5 and MAAP5 during steady-state.

4.2 The Transient Calculation

A cold-leg break with the area corresponding to 10% of the cross-sectional area of the cold-leg occurred about 30 seconds after the start of the calculation. The progressing speed of LBLOCA with safety injection failure was quite fast. As shown in Fig. 6, the temperature of the fuel cladding started to exceed 800 K at 350 seconds after the calculation. And it exceeded 1,000 K at 425 seconds. Accordingly, the transition from REALP5 to MAAP5 started at 350 seconds, and ended at 425 seconds.

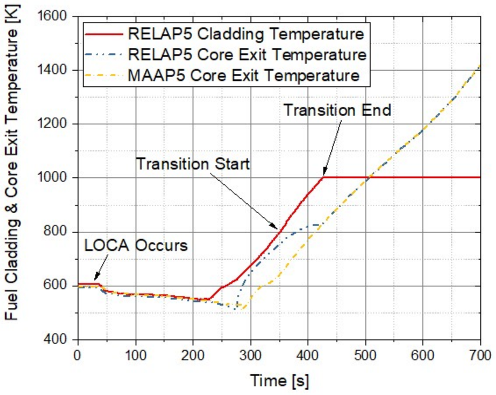

Fig. 6. The behavior of the fuel cladding and core exit temperature of RELAP5 and MAAP5 during steady-state.

As shown in Fig. 7 through Fig. 10, MAAP5 successfully tracked the pressurizer and SG conditions of RELAP5 up to 350 seconds. Since the MAAP5 and RELAP5 analysis results at 350 seconds were similar, the information assigned to the simulator could be smoothly converted during the transition period between 350 and 425 seconds.

Even if the pressurizer and SG conditions between the two codes showed quite similarly, there was some difference in the trends of the Core Exit Temperature (CET) according to Fig. 6. Both codes predicted similarly the time to increase the CET as around 275 seconds. However, it was found that a difference of about 100 K of the CET at 350 seconds when the transition started. This difference in CET gradually decreased based on the weighting factor during the transition from RELAP5 to MAAP5. As a result, the CET became the same at 425 seconds when the transition ended. And, the running of RELAP5 was stopped when the transition to MAAP5 was completed. Thus, there is no change in the fuel cladding temperature calculated by RELAP5 after 425 seconds as shown in Fig. 6.

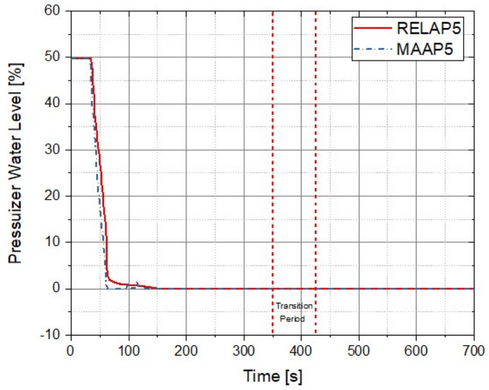

Fig. 7. The behavior of the pressurizer water level of RELAP5 and MAAP5 during transient.

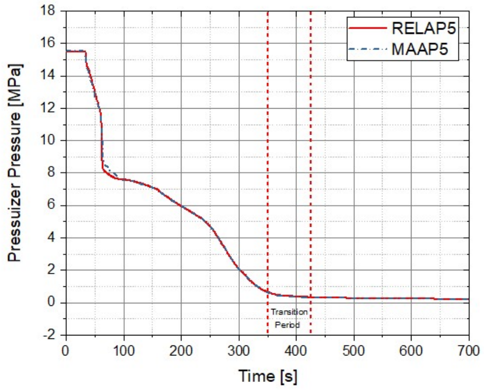

Fig. 8. The behavior of the pressurizer pressure of RELAP5 and MAAP5 during transient.

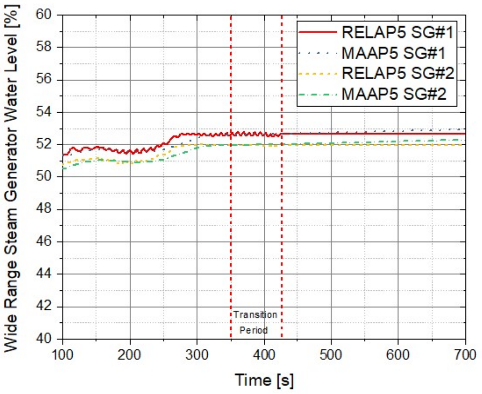

Fig. 9. The behavior of the wide range SG water level of RELAP5 and MAAP5 during transient.

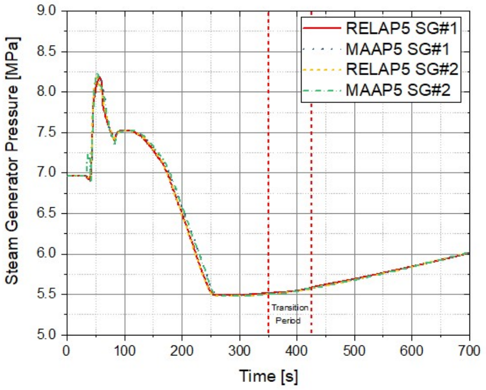

Fig. 10. The behavior of the SG pressure of RELAP5 and MAAP5 during transient.

5. Conclusions

The accident range that can be analyzed by simulators in Korea has been extended to severe accidents by application of the severe accident module. For the severe accident module, a tracking methodology was developed that MAAP5 tracks the thermal-hydraulic behaviors analyzed by RELAP5. This methodology is based on the logic that tracks the conditions of the pressurizer and SG, and according to the simulation results, the transition between RELAP5 and MAAP5 can be performed seamlessly.

This tracking methodology is developed for the purpose of improving the capability of the NPP simulator, but it is also meaningful in terms of providing an advanced method of the safety analysis. The RCS and SG behavior before the core damage is analyzed through RELAP5, and the behavior after core damage is calculated by MAAP5 with the seamless transition of the two computational codes. This analysis technique is expected to contribute to the improvement of the safety analysis capability of the NPPs.

REFERENCES

[1] K. E. Carlson and the RELAP5-3D Code Development Team, "RELAP5-3D Code Manual Volume 1: Code Structure,

System Models, and Solution Methods", Idaho National Engineering and Environmental Laboratory, INEEL-EXT-98-00834, 2005.
[2] Electric Power Research Institute, "Modular Accident Analysis Program (MAAP5.0.5)," Fauske & Associates, LLC, Vol. 1~4, 2019.