Verification of DICE Physical Module Integrity by SBLOCA Calculation

Hyunjoon Jeong[*], Jonghyun Kim[**], Gyunyoung Heo[***], Taewan Kim[†]
Department of Safety Engineering, Incheon National University, 119 Academy-ro, Yeonsu-gu, Incheon, 22012, Republic of Korea[*,†]
Department of Nuclear Engineering, Chosun University, 309 Pilmun-daero, Dong-gu, Gwangju, 61452, Republic of Korea[**]
Department of Nuclear Engineering, Kyunghee University, 1732 Deokyoung-daero, Giheung-gu, Yongin, 17104 Republic of Korea[***]

hj_jeong@inu.ac.kr[*], jonghyun.kim@chosun.ac.kr[**], gheo@khu.ac.kr[***], taewan.kim@inu.ac.kr[†]

1. Introduction

The conventional deterministic safety analysis (DSA) and probabilistic safety assessment (PSA) methodology have a limitation in considering the time-dependent interactions of system process, equipment performance, and operator actions. [1] In order to reflect those dynamic interactions to the safety evaluation, dynamic probabilistic safety assessment (D-PSA) has been developed as an integrated safety assessment methodology combining DSA and PSA. [2,3] In this study, a D-PSA tool, namely Dynamic Integrated Condition Evaluation (DICE), has been developed based on dynamic event tree (DET) method. Through the following chapters, specific features of the DICE will be introduced, and comparison of small break loss of coolant accident (SBLOCA) analysis results between DICE and MARS-KS 1.5 will be shown.

2. Methodology and Feature of DICE model

2.1 Methodology

D-PSA is an integrated safety analysis method that models physical behavior of plant system, equipment state and operator action under NPPs accident conditions based on real-time interaction among them. As such, it is possible to model the process probabilistic event and change of system behavior. One of the methods for implementing the D-PSA methodology is the DET methodology. Starting with the initial event, the DET methodology is able to create branches based on real-time interaction between physical and equipment/ operator models, as show in Fig.1 to draw a variety of accident scenarios that could not be considered in the static event tree.

2.2 Feature of DICE model

DICE is graphic user interface based computational tool based on the DET methodology and runs under the Microsoft window environment. The DICE consists of physical module simulating the physical behavior of the system, automatic diagnostic module to judge the branching condition of main safety variable of the NPPs,

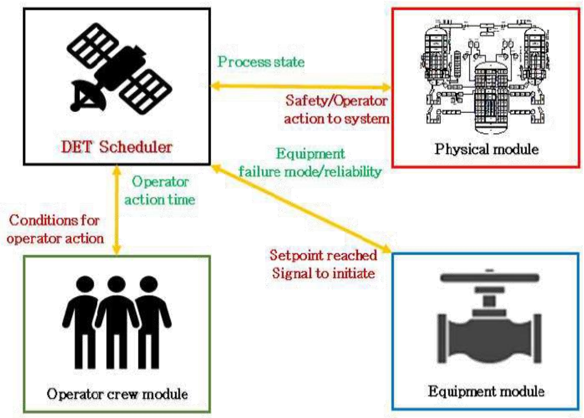

Fig. 1. Interaction between individual modules of DET Tool

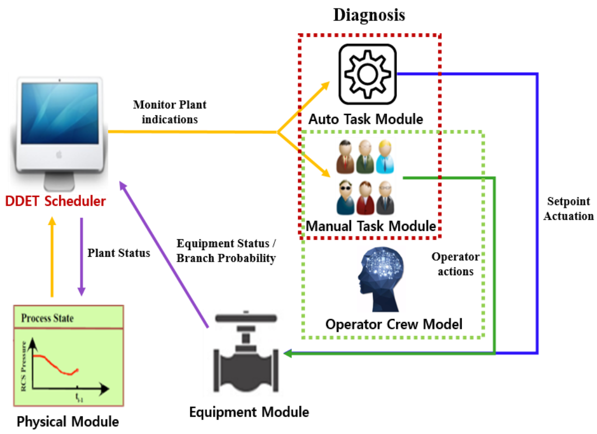

Fig. 2. Interaction between individual modules of DICE Tool

manual diagnostic module simulating operator's decision, equipment reliability module implemented from the diagnostic module's evaluation, and scheduler module that manages the information exchange and the overall interpretation between each module, as shown in Fig.2. The physical module has been developed using a regulatory verification system safety code in Korea, MARS-KS 1.5 [4], and has been completed the connection with scheduler and other modules have been developed from scratch for DICE.

3. Calculation of SBLOCA

This chapter shows the performance of SBLOCA (2inch break) calculations using MARS-KS and DICE. The plant input model used for the calculation is selected the Westinghouse 3-loop NPPs and using kori 3/4 model input deck [5]. The integrity of the DICE through steady-state calculation and coupling with DICE physical module and scheduler has been verified the technical report [6]. So, steady-state calculation results be briefly described, and explain the results of transient state calculated using MARS-KS and DICE.

3.1 Steady-state calculation

It was confirmed that the steady-state calculated values of the MARS-KS 1.5 stand-alone and DICE have no significant difference when compared to the design values, and that there is no error in the steady-state calculated values between the two codes, the steady state calculation result is shown in Table. I.

Table I: Steady state calculation data of MARS-KS and DICE

Parameter	Design	Calculation MARS-KS / DICE	Error MARS-KS / DICE
Core Power	2775 MWt	2775 MWt / 2775 MWt	0.0 % / 0.0 %
1^{st} Pressure	155.13 MPa	15.513 MPa / 15.513 MPa	0.0 % / 0.0 %
2^{nd} Pressure	66.3 MPa	6.648 MPa / 6.648 MPa	-0.27 % / -0.27 %
PZR Level	58.0 %	58.37 % / 58.37 %	-0.64 % / -0.64 %
SG Level	50.0 %	49.86 % / 49.86 %	0.28 % / 0.28 %
Hot leg Temp	598.15 K	599.77 K / 599.77 K	-0.27 % / -0.27 %
Cold leg Temp	565.15 K	565.19 K / 565.19 K	-0.01 % / -0.01 %
MFW Flow	516.0 kg/s	519.18 kg/s / 519.18 kg/s	-0.61 % / -0.61 %
Steam Flow	516.1 kg/s	519.26 kg/s / 519.26 kg/s	-0.61 % / -0.61 %

3.2 Transient Calculation

In this section, additional transient calculation of 10000s was performed based on the results of steady-state calculation, and during the first 20sec, null-transient calculation is conducted to check system stability state due to restart. 2 inch break in a loop 2 cold leg is implemented by using valve component, and after 20sec the accident is initiated by opening the break valve. At the beginning of the accident, the pressure of pressurizer decreases rapidly and generates pressurizer low pressure signal and reactor trip. After the accident, the pressure of the primary system decreases rapidly as shown in Fig.3. When the pressure of the primary system reaches below 12.514MPa, low pressurizer pressure (LPP) signal induces safety injection actuation signal at 61.7sec. The main feedwater is isolated as the safety injection signal is generated, and the auxiliary feedwater system is activated to supply water to the steam generator. In this calculation, only the motor driven pump has been actuated and the trip logic has been added to stop injection of the auxiliary feedwater if the level of the steam generator exceeds 50%, as shown in Fig.4,5.

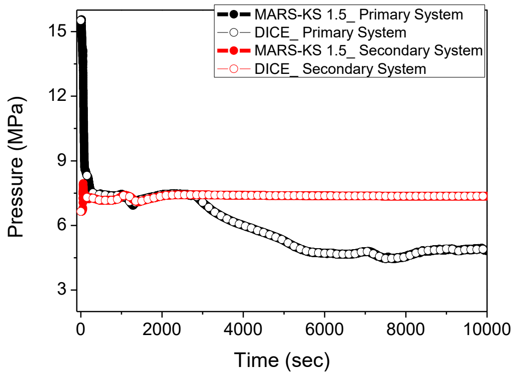

Fig. 3. Pressure behavior of pressurizer and main steam line of transient calculation

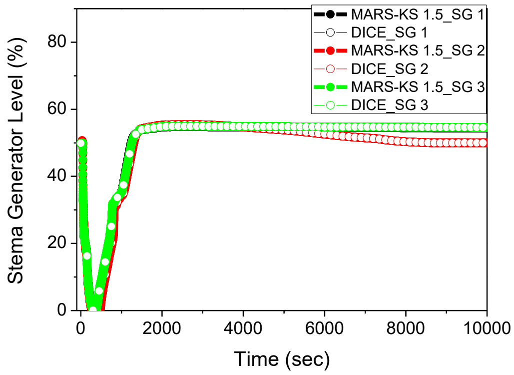

Fig. 4. Steam generator level of transient calculation

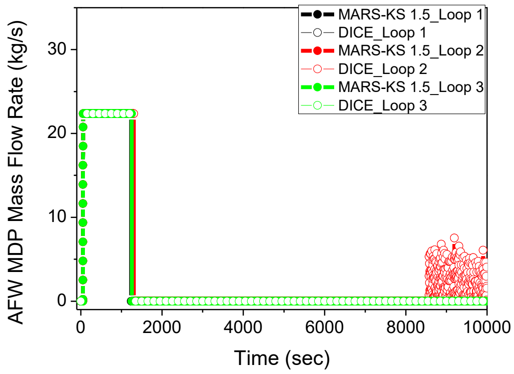

Fig. 5. Auxiliary feed water motor driven pump mass flow rate of transient calculation

As shown in Figure 6, MSIV is isolated according to the steam line low pressure signal, and when the secondary pressure exceeded the setting of the safety valve, steam generator PORV and MSSV are used to calculate the steam to be released into the atmosphere. Fig.7 and Fig.8 show the reactor core collapsed water level and peak cladding temperature, and core level is decreased to approximately 2709.5sec before recovery. At this time, PCT shows the maximum valve, and this phenomenon appears as a loop seal that causes water to enter the steam generator u-tube to block the flow path of steam. Approximately 2643.5sec later, loop seal clearing occurs and the pressure on the primary side becomes lower than the secondary side, accompanying recovery of the core level. Until the end of calculation, high pressure safety injection (HPSI) system 1 train was used only for safety injection considering single failure. However, low pressure safety injection (LPSI) system is not actuated since the primary system pressure is not depressurized below LPSI actuation condition. Then, until end of the calculation, the accident is terminated without further rise of peak cladding temperature and the chronology of SBLOCA is shown in Table. II.

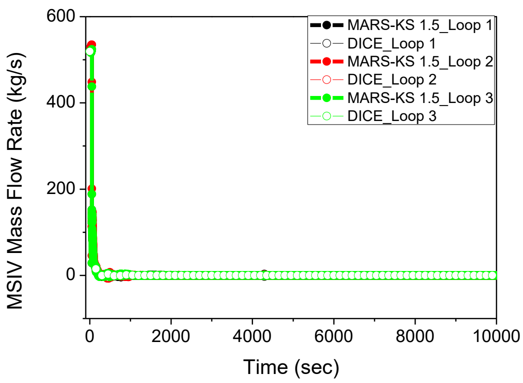

Fig. 6. MSIV mass flow rate of transient calculation

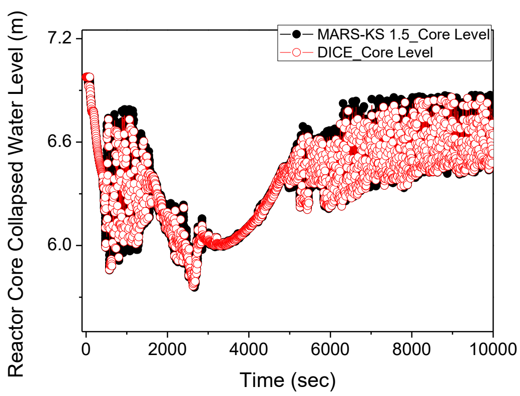

Fig. 7. Reactor Core Collapsed water level of transient calculation

Table II: Chronology of SBLOCA

Event	Time (sec)	Remark
Break valve open	20.1	2 inch break
PZR Low pressure	50.36	P < 13.514MPa
Reactor Trip	50.36	
LPP signal	61.7	P < 12.514MPa
Safety Injection	61.7	
MFW Isolation	61.7	
AFW Actuation	61.7	
MSIV Isolation	211.0	SL Low Pressure signal
Loop seal clearing	2643.5	
Max. PCT	2709.5	597.97K
End	10000.0	

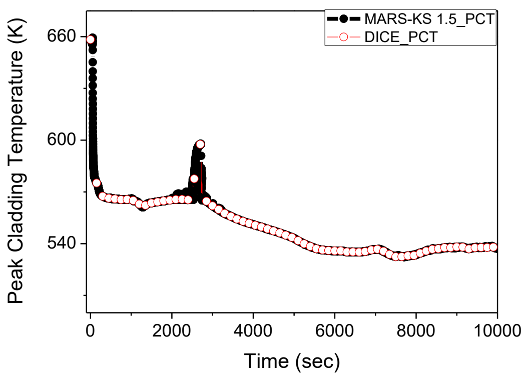

Fig. 8. Peak cladding temperature of transient calculation

4. Result

To demonstrate the integrity of the DICE physical module, MARS-KS 1.5 stand-alone and a comparative calculation of the DICE steady state and transient were performed through a reference plant [5], and the calculation results were shown in Fig.3 to Fig.8 by screening the essential thermal hydraulic variables. It was confirmed that the calculation information between the two codes for the primary and secondary system pressure and the water level of the pressurizer and steam generator were not different, and the results of comparing the main steam flow rate of the secondary steam generator and the steam flow rate in the steam pipe were also not different. In addition, the sequence of accident progression according to the transient calculation and operation of the main safety equipment were also not different from the two codes.

5. Conclusions

SBLOCA calculation was performed using the physical module of DICE and MARS-KS 1.5 stand-alone. Both codes show the same value for the steady state as well as the transient, which means that the two codes have the same interpretation ability from the initial initialize step to the iterative calculation process to the calculation end step. Therefore, it can be concluded that there is no difference from the existing single MARS-KS 1.5 code calculation result, which proves that there is no problem in terms of the integrity of the MARS-KS 1.5 code coupled in DICE.

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