Numerical Investigation of Thermal-Hydraulic Phenomena for SBLOCA in SMART-ITL

S. J. An, Y. J. Lee, Y. J. Chung, S. W. Lim, H. Bae

Introduction

An integral-effect test loop for SMART (SMART-ITL) was designed for various tests to understand the integral thermal-hydraulic behavior expected to occur in SMART. The SMART-ITL is equipped with passive safety injection system (PSIS) and passive residual heat removal system (PRHRS) and containment pressure and radioactivity suppression system (CPRSS). The obtained experimental data is also used to validate the performance of the thermal-hydraulic code for the safety analysis.

In the present study, an attempt was made to numerically predict the thermal-hydraulic phenomena in SMART-ITL. For this purpose, TASS/SMR-S code which is a one-dimensional thermal-hydraulic code for the safety and performance analysis was used. The simulation was performed for the small break loss of coolant accident (SBLOCA) on the safety injection (SI) line. The predicted results were compared with the experimental data.

Governing equations

▣ One-dimensional multi-phase Navier-Stokes equations

$$AL\frac{\partial \rho_m}{\partial t^*}+AL\frac{\partial \rho_m}{\partial t}+L\frac{\partial}{\partial x}\left[(1-\alpha)\rho_l u_l A+\alpha\rho_g u_g A\right]=0$$

$$AL\frac{\partial}{\partial t^*}\left[(1-\alpha)\rho_l\right]+AL\frac{\partial}{\partial t}\left[(1-\alpha)\rho_l\right]+L\frac{\partial}{\partial x}\left[(1-\alpha)\rho_l u_l A\right]=\Gamma$$

$$AL\frac{\partial}{\partial t^*}(\alpha\rho_n)+AL\frac{\partial}{\partial t}(\alpha\rho_n)+L\frac{\partial}{\partial x}(\alpha\rho_n u_g A)=0$$

$$AL\frac{\partial}{\partial t^*}(\rho_m u_m)+AL\frac{\partial}{\partial t}(\rho_m u_m)+L\frac{\partial}{\partial x}\left[(1-\alpha)\rho_l u_l u_l A+\alpha\rho_g u_g u_g A\right]=-AL\frac{\partial P}{\partial x}-F_{fric}-F_{form}-F_{grav}$$

$$AL\frac{\partial}{\partial t^*}(\rho_m e_m)+AL\frac{\partial}{\partial t}(\rho_m e_m)+L\frac{\partial}{\partial x}\left[(1-\alpha)\rho_l h_l u_l A+\alpha\rho_g h_g u_g A\right]=\dot{Q}_w$$

$$AL\frac{\partial}{\partial t^*}(\alpha\rho_g e_g)+AL\frac{\partial}{\partial t}(\alpha\rho_g e_g)+L\frac{\partial}{\partial x}(\alpha\rho_g h_g u_g A)+ALP\frac{\partial \alpha}{\partial t}=\dot{Q}_g-\Gamma h_s$$

▣ Chexal-Lellouche drift-flux model

▣ IAPWS-IF97 formula

Numerical methods

▣ Staggered grid concept

▣ Segregated algorithm

▣ Semi-implicit method

▣ Upwind discretization method for convection terms

▣ Approximated Jacobian

▣ Dual time stepping

Nodalization for SMART-ITL

The reactor coolant system (RCS), secondary system for the feedwater control valves to the turbine stop valves, safety injection tanks (SITs), core makeup tanks (CMTs), and the PRHRS are modeled. The entire computational domain is consisted of 406 nodes and 461 paths.

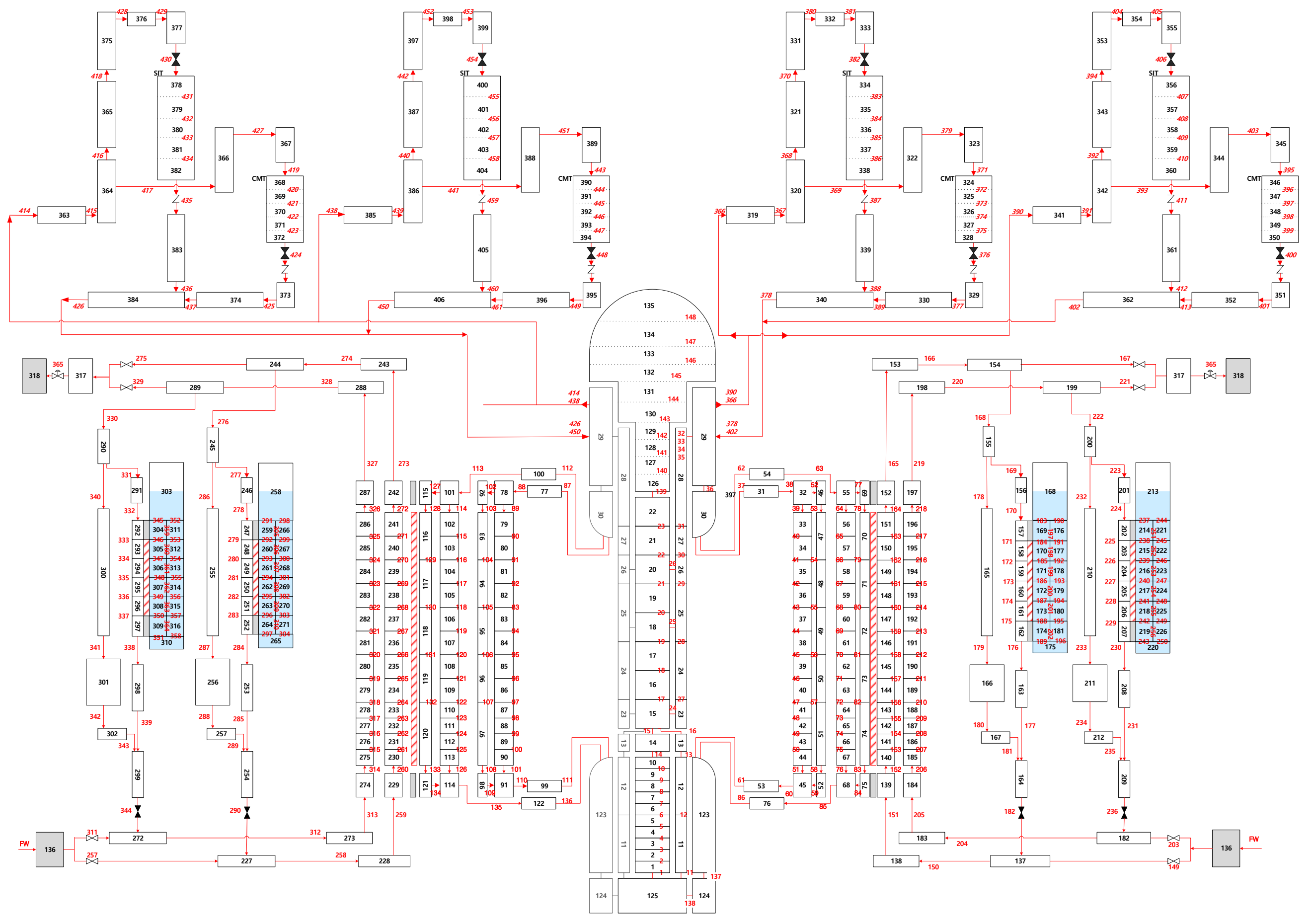

Figure 1. Nodalization for SMART-ITL

Results and discussions

▣ The SBLOCA occurs at t = 0 sec, and the pressure decreases and reaches setpoint of reactor trip.

▣ As the PRHR actuation signal is generated by the low feedwater flow rate, the PRHRS isolation valves are opened. After that, the safety injection water is supplied to recover the water level of the reactor pressure vessel.

▣ In Fig. 2 ~7, the core power, break flow rate, pressurizer (PZR) pressure, temperature at core inlet and outlet, and water level in the CMT and the reactor pressure vessel are presented.

▣ Predicted results are reasonably agreed with the experiment except the water level in reactor pressure vessel (RPV).

▣ Numerical studies to improve the prediction results for the water level in RPV are being conducted additionally.

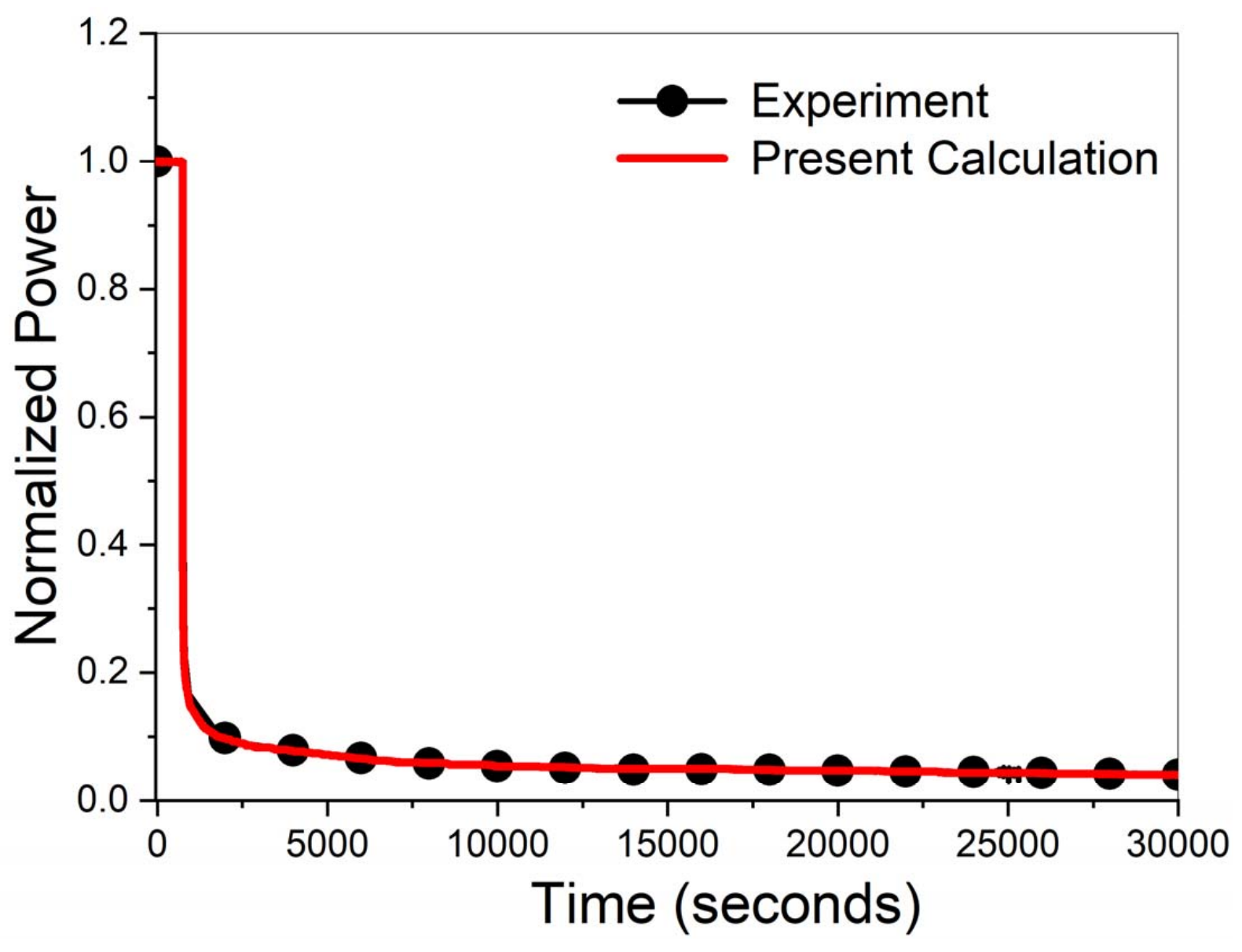

Figure 2. Power

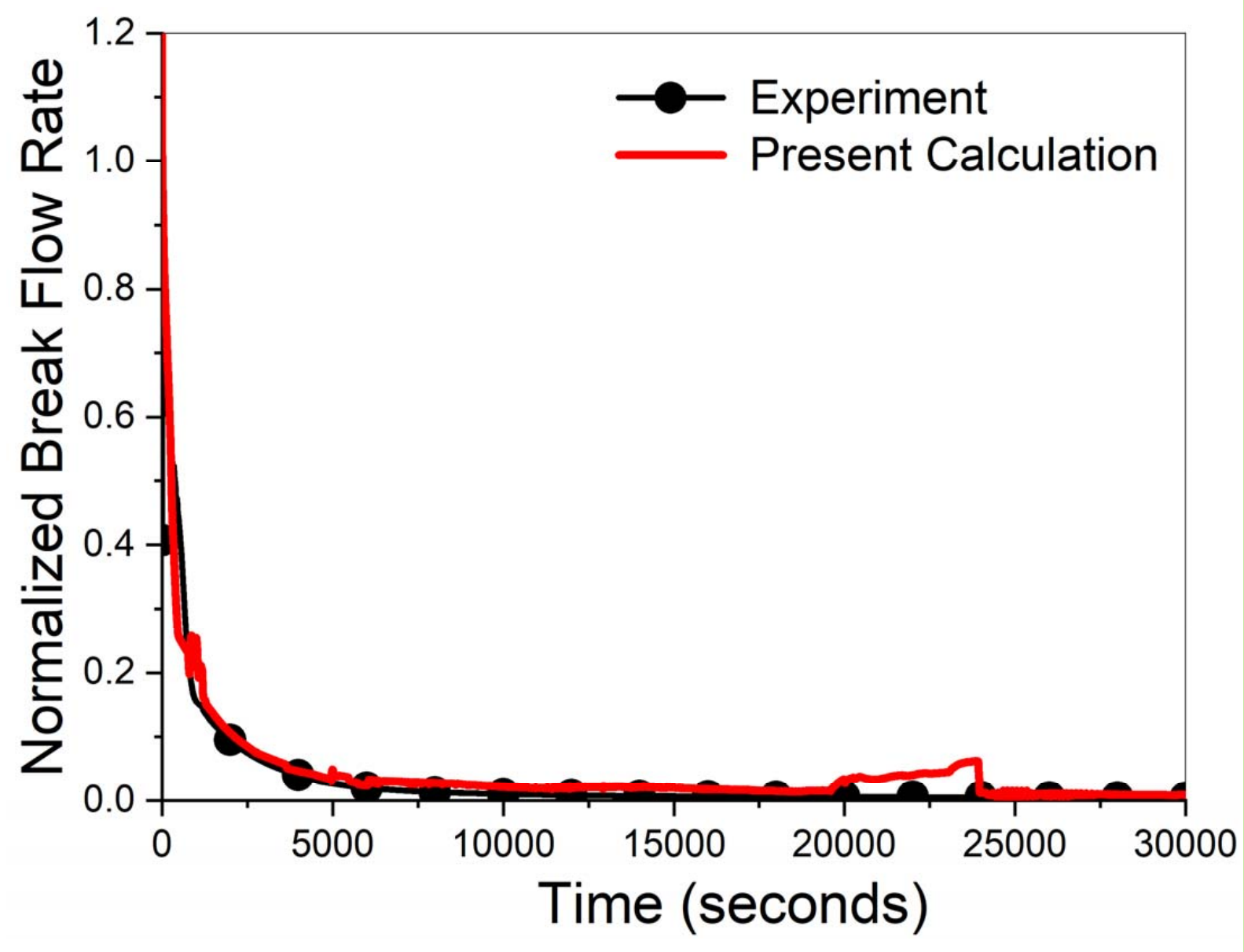

Figure 3. Break Flow Rate

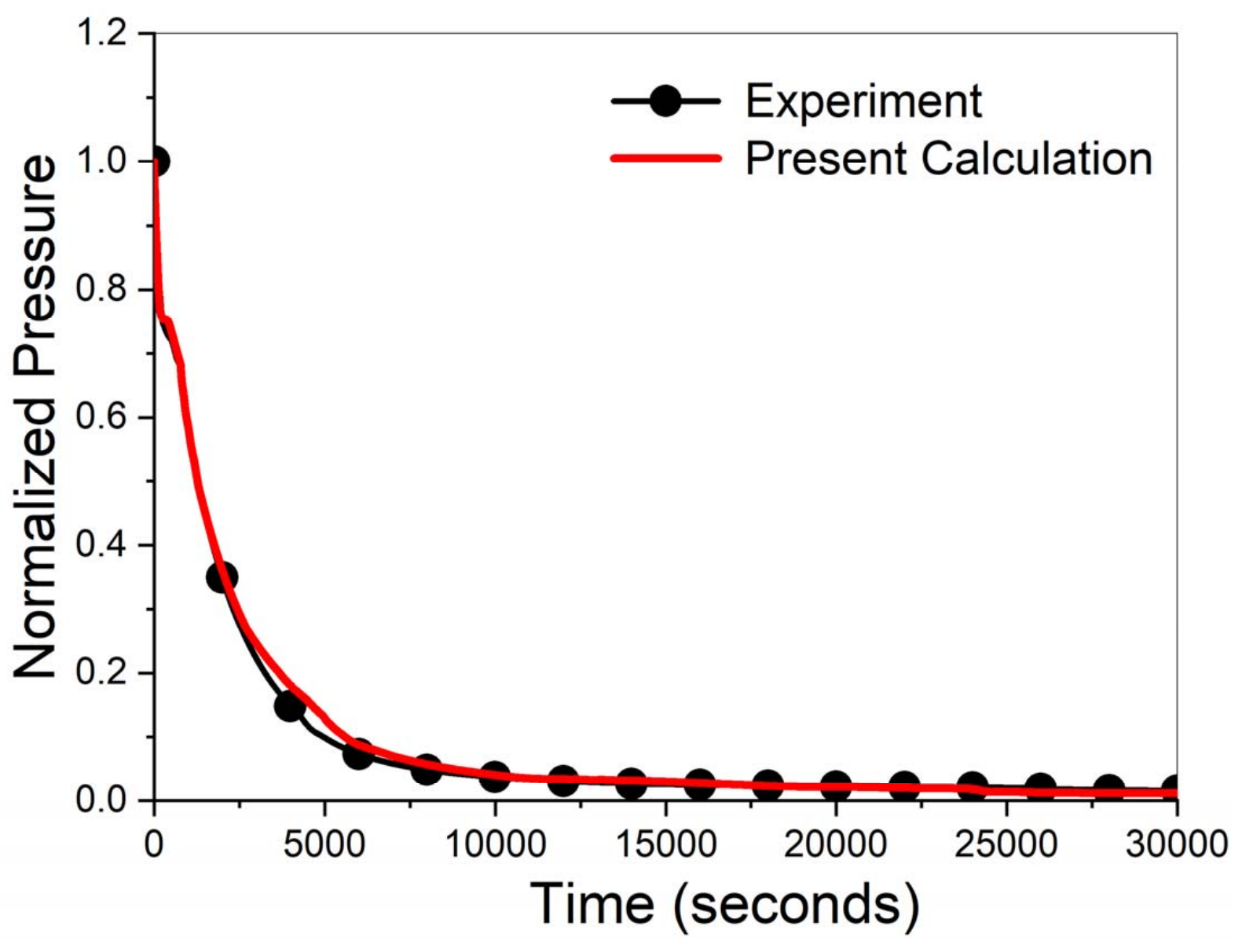

Figure 4. Pressurizer Pressure

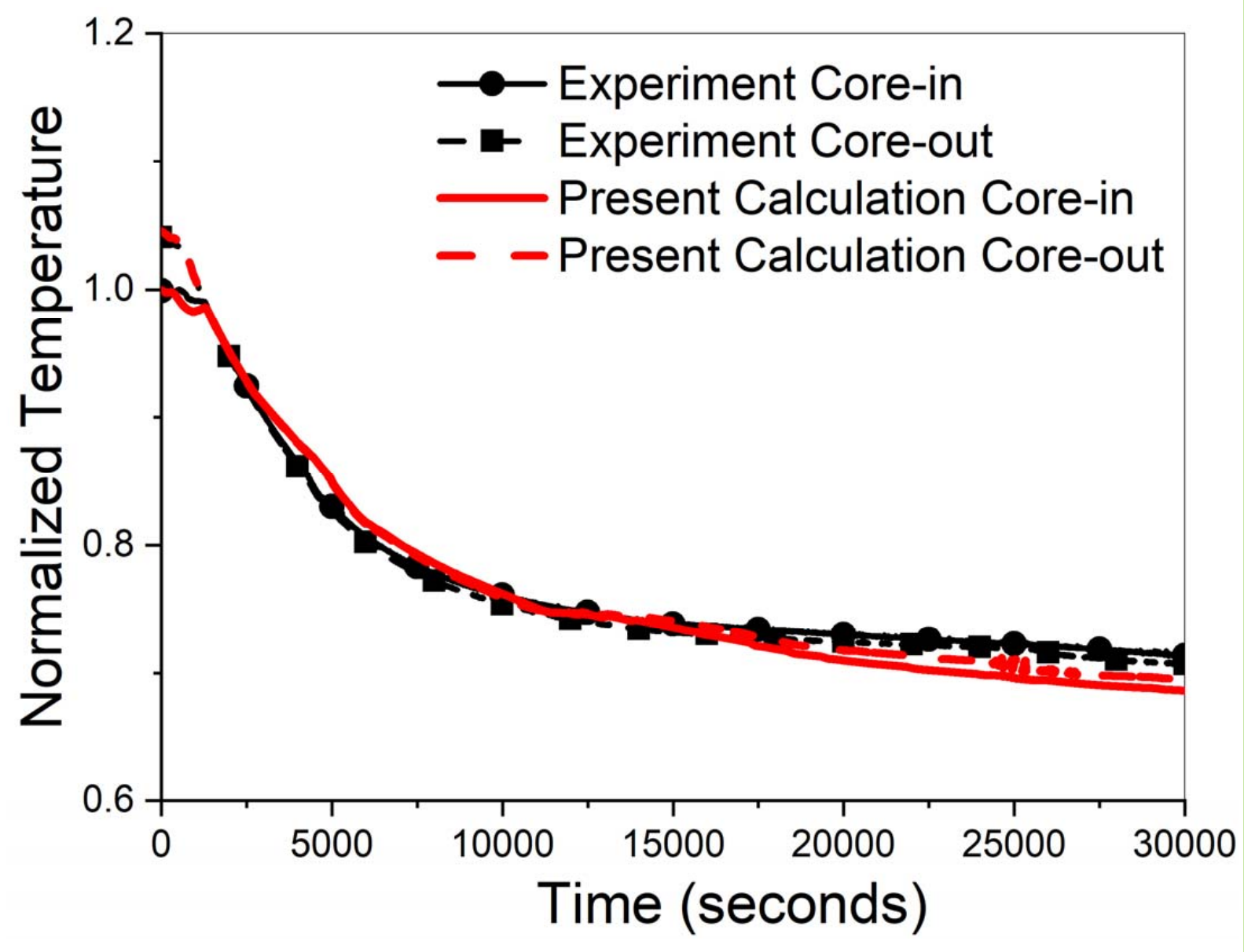

Figure 5. Temperature at Core Inlet and Outlet

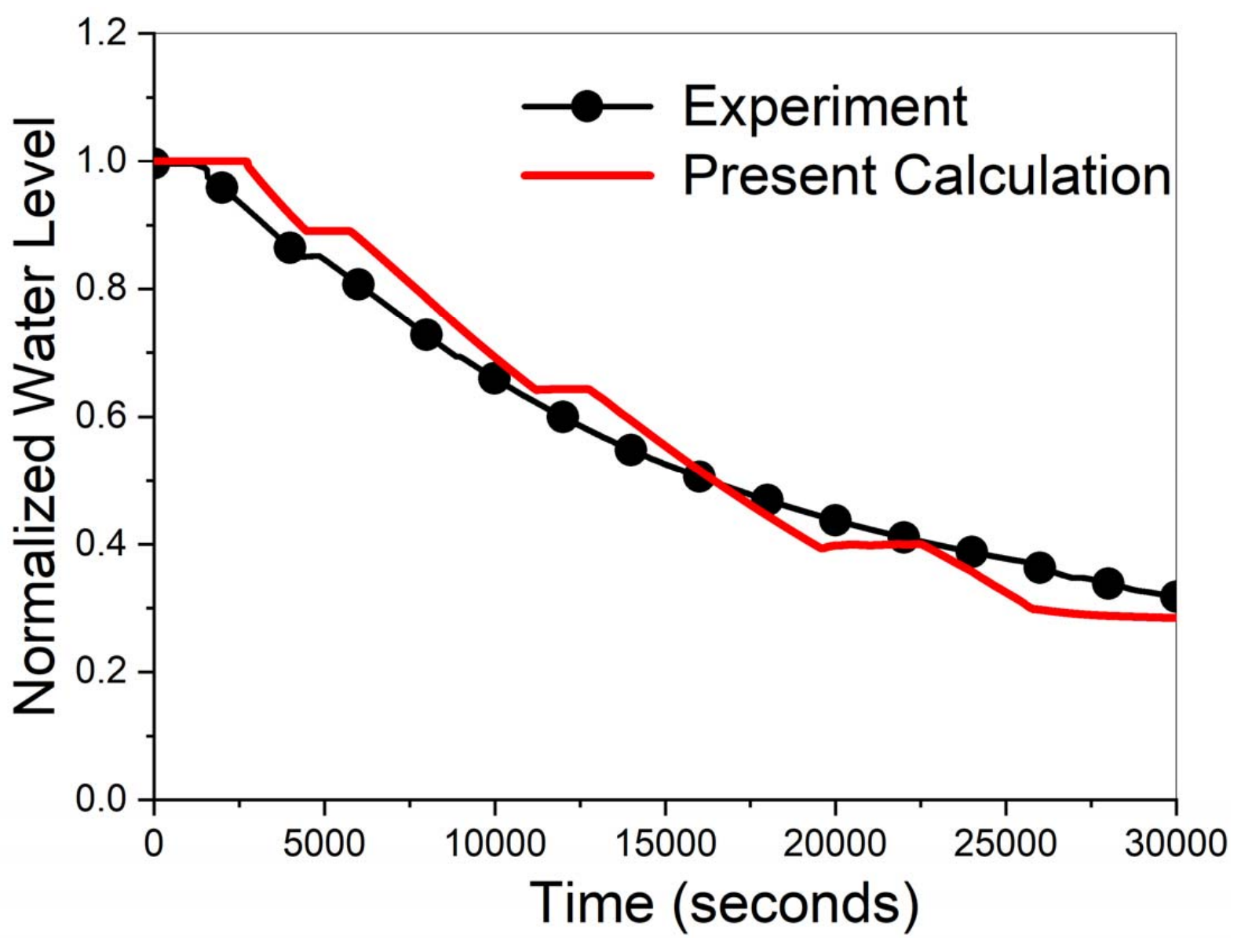

Figure 6. Water Level in CMT

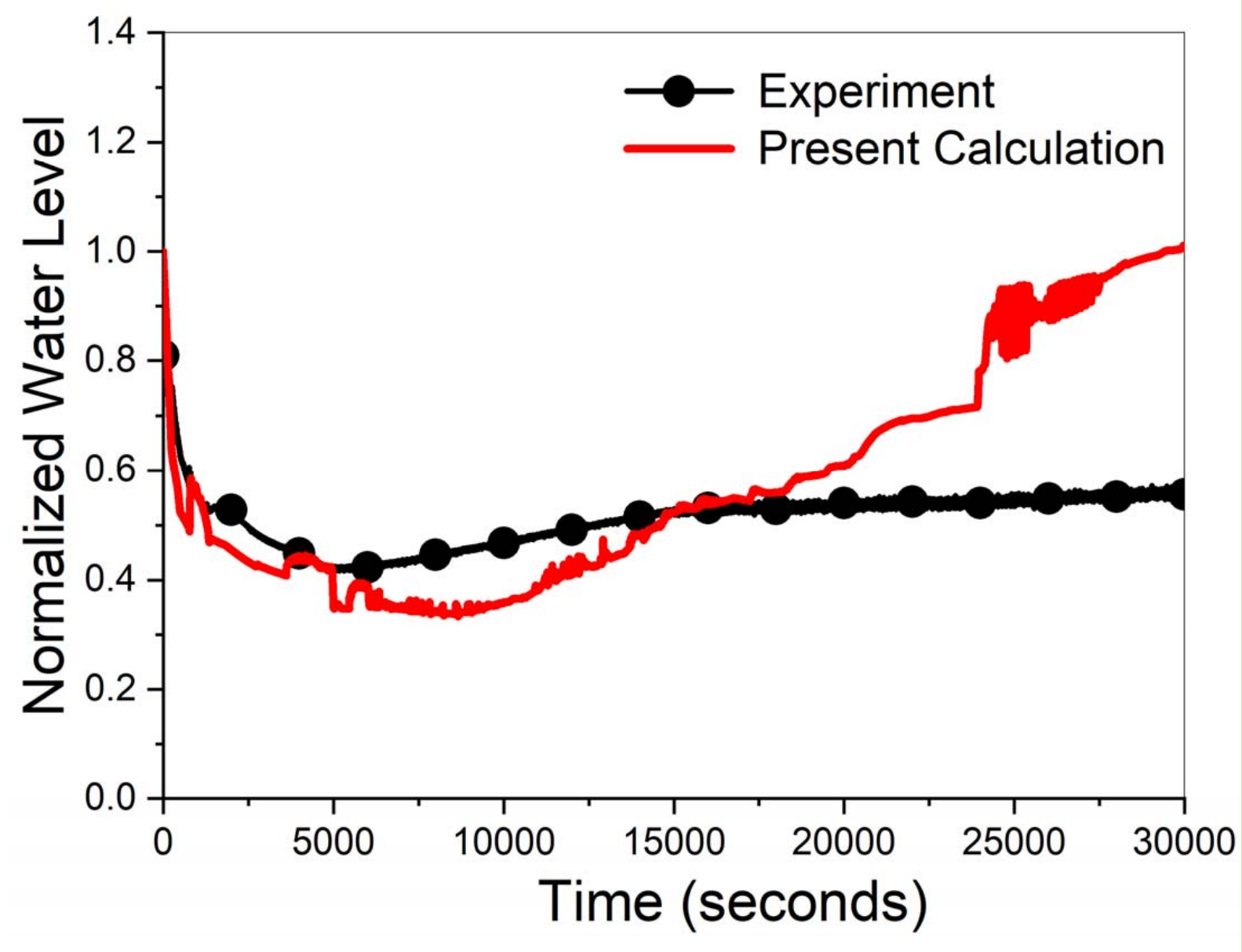

Figure 7. Water Level in Reactor Pressure Vessel

Concluding remarks

In the present study, a numerical simulation was carried out to predict the thermal-hydraulic phenomena for SBLOCA in SMART-ITL. For this purpose, the TASS/SMR-S code was used. The calculation was made for the SI line break SBLOCA with the operation of PSIS. It was shown that the agreement between the prediction and test is reasonably good for the core power, break flow rate, and PZR pressure.

Korea Atomic Energy Research Institute (KAERI)
Daejeon 34057, Korea
Tel. : +82 42 868 2593, E-mail : sjan177@kaeri.re.kr