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Uncertainty quantification of RELAP5/MOD3.3 for interfacial shear stress during small break LOCA

DUONG Thanh Tung
Vietnam Agency for Radiation and Nuclear Safety, 113, Tran Duy Hung Street, Cau Giay Dist., Hanoi
Email:duongttung@varans.svn

NGUYEN Hoang Anh
Vietnam Agency for Radiation and Nuclear Safety, 113, Tran Duy Hung Street, Cau Giay Dist., Hanoi
Email:nhanh@varans.svn

Richard TREWIN
Group of Safety Analaysis, AREVA GmbH, Paul-Gossen Street 100, 91052 Erlangen, Germany
Email:richard.trewin@areva.com

Hiroshige KIKURA
Res. Lab. for Nuclear Reactors,Tokyo Institute of Technology,
2-12-1-N1-7 Ookayama, Meguro-ku, Tokyo 152-8550, Japan
Email: kikura@nr.titech.ac.jp

ABSRACT: The Best-Estimate Plus Uncertainty (BEPU) is applied as Deterministic Approach for safety analysis of Nuclear Power Plant using the system analysis code. The system analysis code such as Relap5/Mod3.3 is required to be able to simulate the thermal-hydraulic behavior of nuclear reactor in some accident scenarios. Relap5/Mod3.3 is developed based on two-fluid models and 6 conservation equations for each phase which challenge for mathematical modeling such as one-demensional equation, time-dependent equation, multidimensional effects or complicated geometry. Thus, it is necessary to verify the applicability of a system analysis code that is able to predict accurately the two-phase flow such as interfacial shear stress between two phases: liquid and gases. It is also important to know the prediction uncertainty by using computer code due to the constitutive relation in the two-fluid model equation. In PWR's Small-Break LOCA (SB-LOCA) accident, the loop-seal clearing is important phenomena where we would like to know how much water (reflux condensation) will be come into the reactor core from Steam Generator. In this work, the UPTF-TRAM simulated the counter-current flow in Loop-seal Clearing between vapor and liquid in Loop-seal during SB-LOCA is used to verify the applicability of Relap5/Mod3.3 and the experimental data are used to compare with simulation results. Moreover, the uncertainty evaluation or estimation is also investigated by applying the statistical method or BEPU in which the SUSA program developed by GRS is used.

Keywords: *BEPU, Statistical Method, Interfacial Shear Stress, Small Break LOCA.*

I. INTRODUCTION

The computer codes with Best-Estimate method are widely used for multiple purpose: nuclear safety evaluation and analysis, licensing issues, life extention of Nuclear Power Plant by using system analysis code such as ATHLET, RELAP, CATHARE, etc.. The best-estimate codes that solve a two-fluid model of the two-phase mixture of vapor and water, consisting of six conservation equations

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for each node, completed by a large set of constitutive laws describing, for example, the interaction of the phases at the gas-liquid interface, the heat transfer with the walls, and the wall friction, as well as the physical properties of the fluid.

The worldwide established practice is based on thermal–hydraulic modeling, fluid dynamic processes being involved in the given accident scenario. To address uncertainties that analyses necessarily contain, models and boundary conditions are selected in a conservative way, that is, lack of knowledge and accuracy is replaced by unfavorable assumptions in order to avoid results showing unrealistically high safety margins. Some regulators allow the application of a so-called best-estimate approach, where a full system model based on a state-of-art thermal–hydraulic representation of the plant is used together with realistic boundary conditions. This approach can be chosen only on condition that the licensee provides a full uncertainty analysis of the performed modeling, which requires comparatively high effort. Still, the benefit lies in the reduction of unnecessary conservatism, and thus in the possibility of coming to a more economic design of the plant.The system analysis code such as Relap5/Mod3.3 is required to be able to simulate the thermal-hydraulic behavior of nuclear reactor in some accident scenarios. Much of effort in the research works for both numerical and experimental were carried out in order to verify and validate the system analysis code aiming at improvement of the reliability of simulation results.

In this study, the statistical safety analysis method is applied for the SB-LOCA in loop-seal of PWR. This method follow the Code, Scaling, Applicability and Uncertainty Evaluation (CSAU) methodology developed in the 1980s for the U.S. Nuclear Regulatory Commission [2]. The safety analysis code is Relap5/Mod3.3 patch5 that is a best-estimate code in which the multiplier for the uncertainty quantification is developed. Thus, the uncertainty quantification is applied without modification of the source code.

II. EXPERIMENTAL DESCRIPTION

For a typical Pressurized-Water Reactor (PWR) has U-shape of crossover pipes, so-called Loop-seal, which connects the upper plenum with Steam Generator through cold leg (Figure 1). During SB-LOCA, the steam is generated into the reactor core. Steam is vented to the upper plenum and partially gone to the the U-shape tube of Steam Generator through the hot leg. Steam is then condensed by the lower temperature at the Steam Generator, so-called reflux condensation. The reflux-condensation is occured from the both side of U-tube of the Steam Generator; entrance and exit, respectively. In the design of PWR, the reflux condensation plays important role in the reactor safety by refilling the reflux-condesation to the downcomer and cooling the core. However, the water exist in the loop-seal (crossover legs) which stuck the reflux condensation (water) from the SG to the RCP and then going into the downcomer. Thus, an integral effect test was built up to investigate the flow transient during the SB-LOCA which could help improvement the accident management of Nuclear Power Plant (NPP).

The UPTF (Upper Plenum Test Facility) was designed and constructed as a full-size simulation of the 1300 MW 4-loop Grafenrheinfeld PWR of Siemens-KWU. Within the Transient and Accident Management (TRAM) program integral and separate effect tests were carried out to study loop seal clearing and to provide data for the further improvement of computer codes concerning the reactor safety analysis. Several test were performed. The Test A5 is one of series test performing by Siemens which was aimed at studying of flow behavior during SB-LOCA of the NPP including the uncertainty quantification of the interfacial shear stress between liquid and steam at the horizontal pipe of the Loop-seal. In order to measure the interfacial shear stress, the several separate effect tests (SETs) were conducted by changing the initial and boundary conditions. The SET was designed for only one loops including SG, Loop-seal and Pump. The resistance of the pump was modelled by a cap as shown in Figure 2. The main thermal-hydraulic parameters were measured such as liquid, steam flow rate and temperature, the differential pressure, water level in order to calculate the interfacial shear stress. The interfacial shear stress $\tau_{ph,l}$ is then calculated from the experimental data based on the equations (1) and (2) [5]. The additional unknowns require additional relationships between unknowns and dependent variables (constitutive relationships), i.e., for the liquid [5].

$$\frac{\partial\{\rho_l(1-\alpha)A_{x-s}\Delta z\}}{\partial t}+\frac{\partial\{\rho_l(1-\alpha)A_{x-s}u_l\}}{\partial z}\Delta z = \dot{m}_{v-l} \quad (1)$$

$$\frac{\partial\{\rho_l(1-\alpha)A_{x-s}u_l\Delta z\}}{\partial t}+\frac{\partial\{\rho_l(1-\alpha)A_{x-s}u_l^2\}}{\partial z}\Delta z = -\alpha A_{x-s}\frac{\partial\{\rho_l\}}{\partial z}\Delta z - g\rho_l(1-\alpha)\,A_{x-s}sin\{\theta\}\Delta z - \tau_{w,l}A_{w,l} - \tau_{ph,l}A_{ph,l} + \dot{m}_{v-l}u_{ph,l} \quad (2)$$

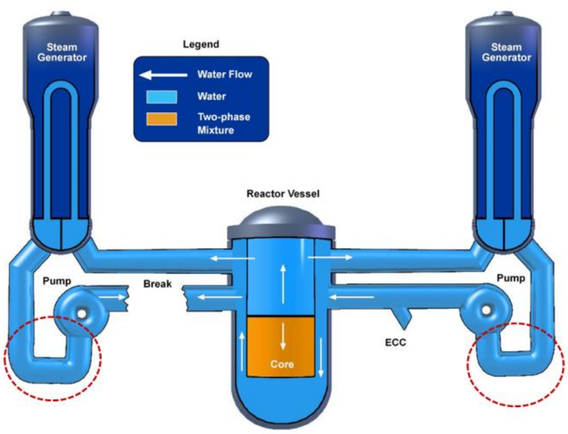

Fig. 1. Crossover pipes (Loop-seal)

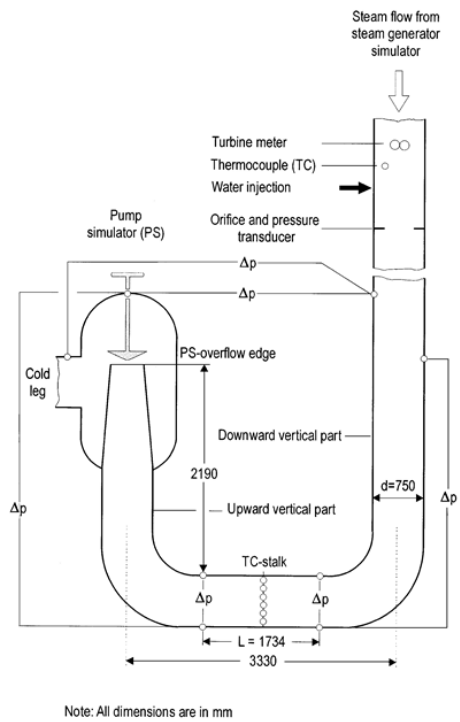

Fig. 2. SET experiment for Loop-seal [4].

III. ANALYSIS METHODS

A. Simulation and comparision the calculated results with experimental data

The Relap5/Mod3.3 is the thermal-hydraulic system analysis code, which has been developped by U.S. NRC. This code is licensed to VARANS in CAMP (Code Analysis and Maintenance Program) framework cooperation.

The nodalization of loop-seal is presented in Figure 3 by modelling the SET as shown in Figure 2. The calculation model used in Relap5 is consisted a double bent pipe from the Steam Generator to the Pump side which is included the Loop-seal, the pump simulator, the cold-leg piping from the pump simulator to the vessel downcomer.

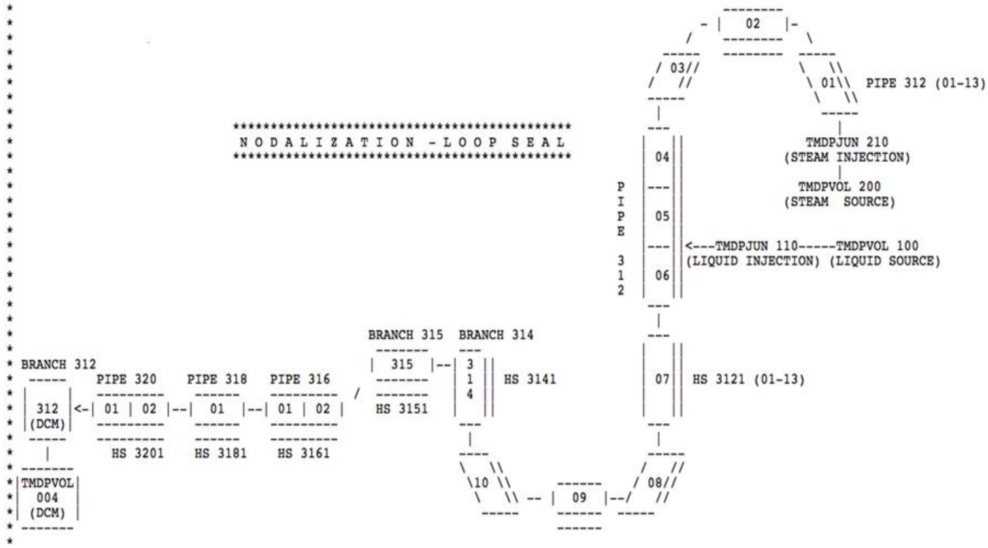

Fig.3. Nodalization of Loop-seal Experiment

Regarding to the Boundary and initial conditions, an time-dependent junction and an time-dependent volume is used to inject the water and steam to the pipe. The boundary conditions are the inlet of steam and water flow rate and temperature, respectively including the pressure oulet in the downcomer (i.e Mass flow rate shown in Figure 4).

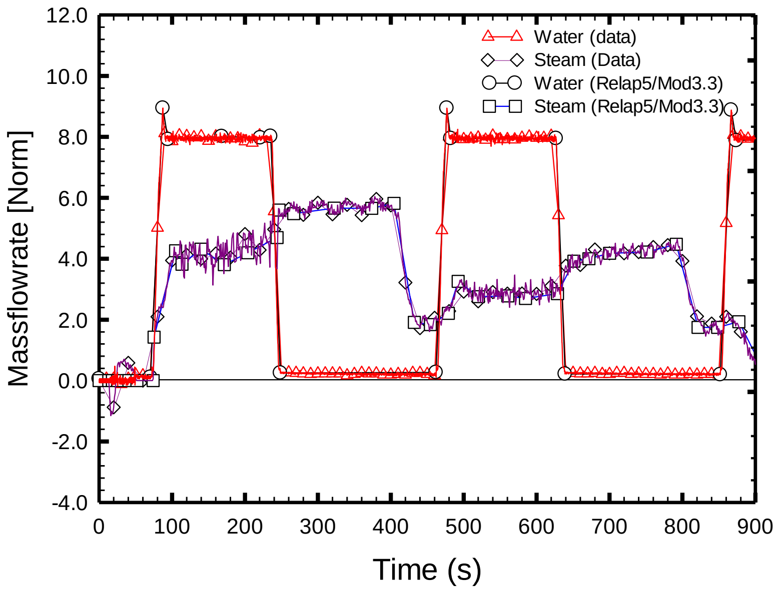

Fig. 4. Boundary condition of steam and water massflowrate.

The comparison of the calculated results by Relap5/Mod3.3 and the experimental data are shown in Figure 5 (a) and Figure 5 (b). The results shown the similar phenomena between calculation and experiment. After clearing in the first period (100-250 s), the amount of liquid left in the pump side is the same as that in the steam generator side of the loop seal. However, there are still some discripancies between the simulation resulsts and experimental data. There are some limitations of computer code as Relap5/Mod3.3 by using

1-D component modeling. And, the interfacial shear stress between steam and liquid is the causes of changing the collapsed water level and pressure drop in the pump and steam generator side. In the PWR SB-LOCA, the pressure drop across a cleared loop will affect the levels in the core and downcomer. As the pressure drop increase, the core level will decreases which can increase the PCT (peak cladding temperature). Therefore, the uncertainty quantification of Interfacial Shear Stress effected to the water level and pressure drop acrossed to the loop-seal is necessary to be investigated.

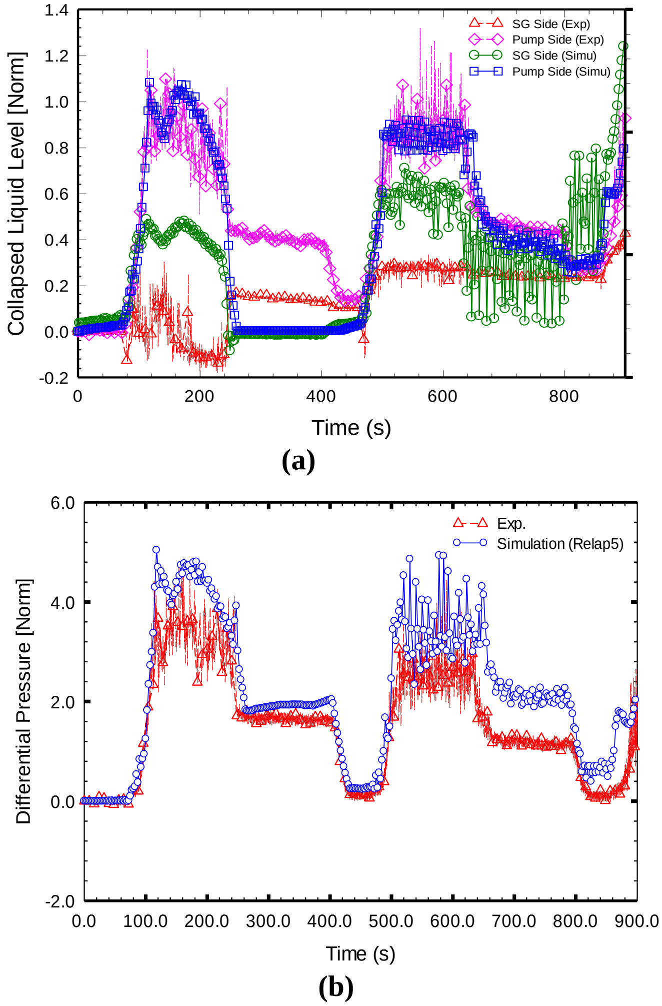

Fig. 5. Comparison of the water level (a) and the differential pressure (b) between simulation results and experimental data.

B. Uncertainty quantification of Interfacial Shear Stress

The uncertainty quantification is based on the statistical analysis of Interfacial Shear Stress (ISS) for both experimental and numerical modelling in the computer code. Briefly description for this method is as following. The term of ISS ($\tau_{ph,l}$) is calculated from the experimental data in time-dependent in the horizontal pipe of loop-seal. Besides, the void fraction is calculated from the interfacial friction model based on the drift-flux model in horizontal slug and stratified flow regime [4]. The Multiplier coefficient is a fraction between ISS calculated from experimental and numerical, respectively. The set of ISS's value is then fitted by a statistical and probability distribution (i.e Gausian Distribution). The input model in Relap5/Mod3.3 is modified by changing the value taken from this distribution. The number of calcualtions (59 runs) is determined by Wilk's formular in order to quantify the uncertainty of ISS. The results of water level for 59 cases (calculated automatically by using post-script) are shown in the Figure 6. The upper and lower tolerance is then defined by the maximum and minimum value for each time point.

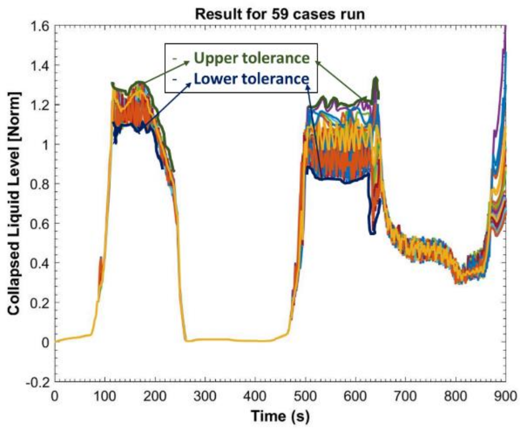

Fig.6. The collapsed liquid level of Pump side for 59 cases of calculation.

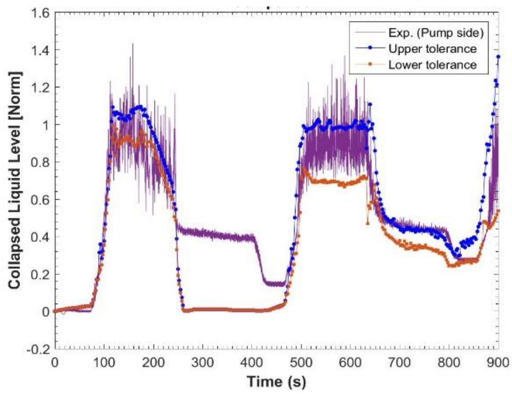

Fig. 7. Uncertainty quantification of Interfacial Shear Stress for water level in pump side.

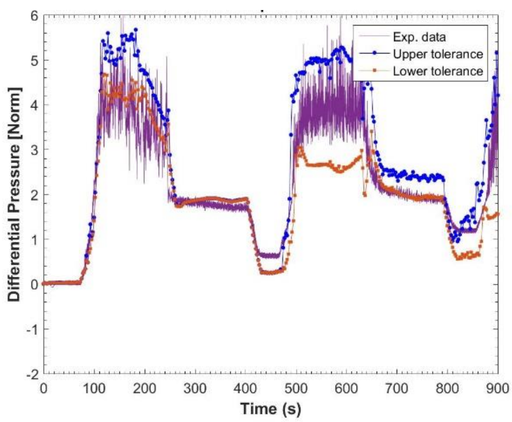

Fig.8. Uncertainty quantification of Interfacial Shear Stress for Differential Pressure in pump side.

The Figure 7 and Figure 8 show that the experimental data for water level and differential pressure in the pump side is in between the upper and lower tolerance of simulation results. The predicted parameters in the loop-seal phenomena during SB-LOCA agree resonably well with measured data.

III. CONCLUDINGS AND REMARKS

The Relap5/Mod3.3 capability for simulation of Loop-seal is verified. The simulation results agree acceptably with experimental data. The uncertainty prediction of Interfacial Shear stress by using Relap5/mod3.3 is investigated for UPTF-TRAM Test A5. The Multiplier coefficient of Interfacial Shear Stress is then determined as the Normal Distribution in the UPTF-TRAM Test A5.

The method of BEPU is applied by using SUSA (developed by GRS). The results of calculation by using system analysis code are modified by adding the multiplier coefficient. The uncertainty prediction by using Relap5/Mod3.3 of the Interfacial shear stress to the important parameters during the Small Break-LOCA is quantified. This is an important step for the application of statistical safety analysis method for the full scale of Nuclear Power Plant where the experimental data of important thermal-hydraulic phenomena is needed.

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