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Reflood PCT Prediction Accuracy of SPACE

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1. Introduction

SPACE is the first safety analysis computer code which has been developed by the Korean nuclear society. The code has been developed for the purpose of analyzing various accidents in nuclear power plants, but its main use will be the analysis of a large break loss-of-coolant accident (LBLOCA) and KNF has been developing a best estimate LBLOCA evaluation model using the SPACE code.

One of the key steps for developing a best estimate LBLOCA evaluation model is to evaluate the peak clad temperature (PCT) prediction accuracy, which may be expressed by the statistical difference between the measured PCTs and the predicted ones. Note that the PCT prediction accuracy does not mean the predictive capability for other parameters such as the location or the time of PCTs.

LBLOCA experiments can be divided into three groups according to which phase of the accident is simulated; blowdown, reflood (including the refill phase sometimes) or the entire transient. Certainly, the reflood PCT prediction accuracy should be evaluated using only the experiments simulating the reflood phase.

2. PCT Prediction Accuracy

Reflood experiments conducted in four tests facilities were selected for the evaluation of PCT prediction accuracy. A brief description of those experiments comes first in this section. Models and modeling methods used in code calculations are explained next. The process and result of evaluating PCT prediction accuracy is discussed lastly.

2.1 Reflood Experiments

The reflood experiments selected for the assessment of SPACE were those conducted in FLECHT-SEASET [1], NEPTUN [2], PKL [3], and CCTF [4] facilities.

The FLECHT-SEASET tests have been regarded as representative reflood experiments because the test facility was large and relatively well instrumented. The test facility consisted of a cylindrical test section and auxiliary components such as an external pipe downcomer for the gravity reflood tests. Among the numerous tests performed at the test facility, 17 tests were selected for the code assessment and they had a wide range of initial and boundary conditions such as flooding rate, system pressure, rod power, or rod temperature. Some tests had a time varying flooding rate and all the tests except one were the forced flooding tests.

The NEPTUN test facility was built to study reflooding in bundle geometry. The heater rod bundle consisted of 33 electrically heated rods and four guide tubes. Seven tests having a system pressure of 1 bar or 4 bar, a flooding rate varying from 1.5 cm/s to 15 cm/s, injected water subcooling of 11 K or 78 K, and initial peak clad temperature of 1030 K or 1140 K were used in this code assessment.

The PKL test facility was designed to simulate a Siemens/KWU 4-loop pressurized water reactor (PWR). It consisted of a complete primary circuit including a reactor vessel, a pressurizer, and main coolant loops. Only one test in this facility, PKL-IIB.5 was selected for this code assessment because no information on other tests was available.

The CCTF test facility was designed to model a full height core and four primary loops with components of a four-loop PWR. Though several reflood tests were conducted in the facility, only test C2-4 was used in this code assessment as experimental data of other tests are not available.

2.2 Models and Modeling Methods

In the calculations for this study, SPACE version 2.0 with some modifications by KNF, SPACE-2.0-KNF was used. This version has a special package of models and correlations which is activated only in the core under the reflooding condition. The special package is the same as described in [5] and it consists of the models for interfacial heat transfer coefficients, interfacial friction coefficients, and wall-to-fluid heat transfer coefficients in inverted flow regimes or post-critical heat flux heat transfer modes. As these models depend on the flow regimes, the package includes also a new post-dryout flow regime map and a new logic for the flow regime selection. It should be noted that the spacer grid heat transfer enhancement model explained in [5] was not used in this code assessment since we could not find detailed information on the spacer grids in some test facilities.

As FLECHT-SEASET tests and NEPTUN tests are separate effect tests, only the heated rod section was modeled in a detailed manner for most tests. Only the exception was the FLECHT-SEASET test 33338 which was a gravity-driven reflood test. For this test, the downcomer and its connection to the lower plenum were explicitly modeled to simulate the interaction of hydrostatic heads in the core and in the downcomer.

On the contrary, CCTF C2-4 and PKL-IIB.5 are regarded as integral effect tests. Thus all the primary coolant system components including steam generators were modeled explicitly for these tests.

The heated rod section of all the tests was modeled using axial nodes of 91.44 mm (3.6 inches) length.

2.3 Accuracy Evaluation

Strictly speaking, only one value of PCT is obtainable in one experiment. However, we need sufficiently large number of PCTs in order to make the evaluated PCT prediction accuracy meaningful statistically. So the maximum clad temperatures at not only PCT location but also at its neighboring measurement locations were compared with the predicted values at the corresponding locations. When the prediction location was different from that of measurements, the predicted clad temperature at each time step was obtained by linearly interpolating the predictions of neighboring nodes.

The PCT difference at a location is defined as

$$\Delta PCT_{i,j} = PCT_i^{\text{calculation}} - PCT_{i,j}^{\text{experiment}} \quad (1)$$

where i is the measurement location index and j is the thermocouple index at the location.

The ΔPCT bias is defined as the difference between the average of predicted PCTs and that of measured PCTs.

$$bias = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N_i}\Delta PCT_{i,j}}{\sum_{i=1}^{M} N_i} \quad (2)$$

where M is the number of measurement locations used in the evaluation. N_i is number of intact thermocouples at a measurement location.

The standard deviation of PCT differences is defined as

$$\sigma_{\Delta PCT} = \sqrt{\frac{\sum_{i=1}^{M}\sum_{j=1}^{N_i}\left(\overline{\Delta PCT_{i,j}} - \Delta PCT_{i,j}\right)^2}{\sum_{i=1}^{M} N_i}} \quad (3)$$

One-sided 95% bound of PCT differences is estimated from the following relation.

$$95\% \text{ bound} = 1.645\sigma + bias \quad (4)$$

Fig. 1 presents all the data used to evaluate the PCT prediction accuracy in this study. As shown in the figure, SPACE-2.0-KNF was evaluated to have a conservative bias of ~62 K in the prediction of reflood PCT. The one-sided 95% bound of PCT differences is ~158 K. Note that this prediction error is comparable to but a little larger than that of RELAP5/MOD3.3/K, which has been used in CAREM [6].

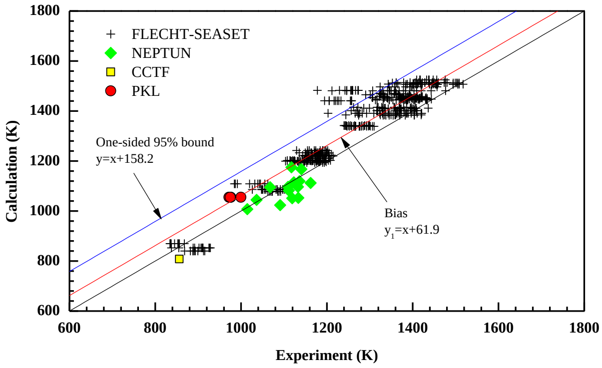

Fig. 1. Accuracy evaluation results

3. Conclusions

Twenty six reflood experiments in four different test facilities were simulated using a special version of SPACE, SPACE-2.0-KNF. Based on the simulation results, the current SPACE code was assessed to have a comparable to but a little larger error than RELAP5/MOD3.3/K in the prediction of reflood PCTs. The efforts to improve SPACE should be continued in the future to have a better reflood PCT prediction accuracy.

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