Suggestion of Use of Containment Integrated Leakage Rate Test for Code Model Validation

Han-Chul Kim [a*], Su-Kyoung Pak [a], Jun-Soo Lee [a]
[a]*Nuclear Korea Institute of Nuclear Safety, 62 Gwahak-ro, Yuseong-gu, Daejeon 34142, Korea*
[*]*Corresponding author: khc@kins.re.kr*

1. Introduction

Validation of a code input model for a nuclear power plant is not possible for many cases due to the unavailability of appropriate test data. Therefore, indirect ways of validation such as code-to-code comparison or benchmark of the relevant experiments are often used. Nevertheless, an integrated leakage rate test (ILRT) for the containment provides some useful data about the thermodynamic state of the containment atmosphere at the calculated maximum pressure for the design-basis accident condition. In this context, it was tried to simulate a successfully completed ILRT performed at a CANDU-6 plant using the MELCOR 1.8.6 [1] input model developed by KINS [2, 3]. The results [4] revealed that such an application has at least some advantages, though with quite a few limitations. Based on the insights obtained from this study, we suggest elaborated test provisions and analysis methods to allow this application in the following sections, even though there have been no problems to meet the regulatory requirements with the current test methods.

2. Current Test Methods

The ILRT is usually conducted during the commissioning of a NPP and then periodically during the preventive maintenance periods in accordance with ANSI/ANS-56.8. It involves various phases such as pressurization, containment atmosphere stabilization, measurement of the overall leakage rate, and verification test followed by depressurization, as shown in Fig. 1. The measurement system usually consists of more than ten drybulb temperature sensors, three relative humidity sensors or dew-point temperature sensors, and absolute pressure and flow sensors, one for each, installed in the containment and connected to the data acquisition system. The mass point analysis technique is used to determine the dry air mass in the containment utilizing the Ideal Gas Law at each time point. Then the leakage rate is calculated by dividing the slope of the air mass by the intercept of the regression line of the air mass points. In addition, upper 95% confidence limit on the leakage rate is determined for comparison with the acceptance criteria [5, 6].

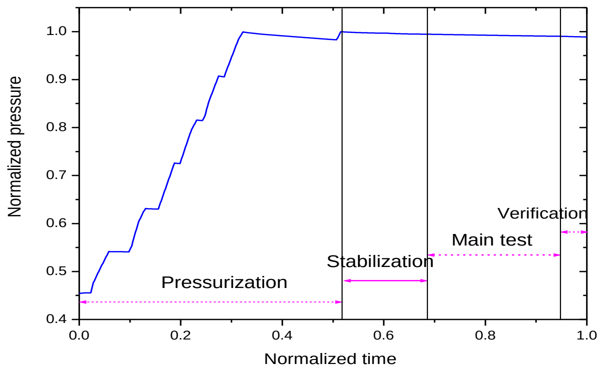


Fig. 1. Pressure history during the whole test period in normalized form.

3. Results from Simulation of an ILRT

2.1 Containment Model

A detailed CANDU-6 model with 51 control volumes, 102 flow paths and 257 heat structures, further developed based on the 40-control volume model [2, 3, 7], was used for the simulation of the ILRT data. Fig. 3 shows the nodalization of this model.

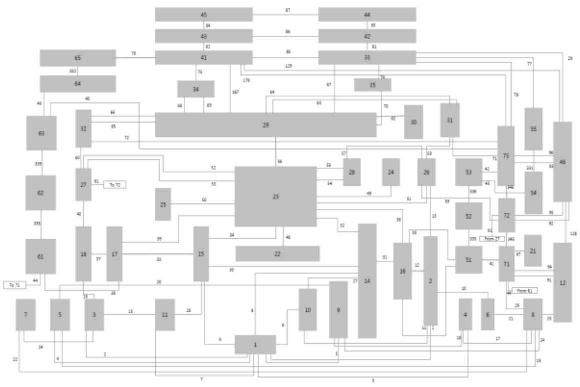


Fig. 2. Containment model.

2.2 Initial conditions

The analysis was carried out for the duration from the beginning of the atmospheric stabilization to the end of the main test just before the verification test. The initial conditions of all the control volumes were established using the measured data of pressure, drybulb temperature, and relative humidity. Since the numbers of sensors are too small compared to that of the control volumes, assumptions were made for some volumes to compose several data of the nearby sensors with weighting values. Leakage was simulated by assuming removal of air from the outside control volumes with the rate determined by the test.

2.3 Analysis Results

The analysis resulted in an underestimation of the containment pressure as shown in Fig. 3, and the pressure difference between the top and the bottom was approximately 1 kPa. It means that instead of using only one pressure sensor as is in the current practice, having sensors more than one would be better to take into account the pressure distribution in the containment.

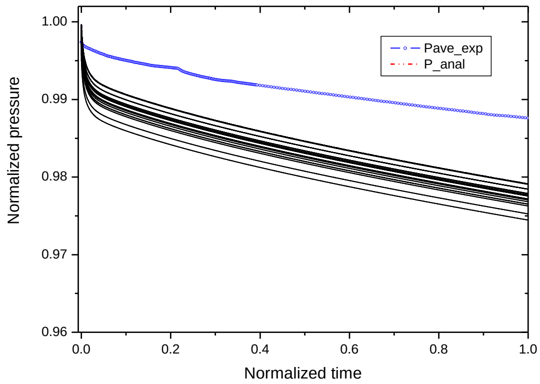


Fig. 3. Comparison of the estimated containment pressure to the test data.

Fig. 4 shows an underestimation of the partial steam pressure as well, and even a different trend between measurement and analysis. The average steam pressure was re-evaluated on our own using the steam table [8] based on the measured data for relative humidity (RH) and temperature close to the RH sensors, replacing the ones based on the dew point temperature calculated from the RH data. The different trend, perhaps a unique phenomenon at a CANDU plant, seems to be resulted from vaporization from the dousing tank or the reactor vault, which was not treated in the analysis model.

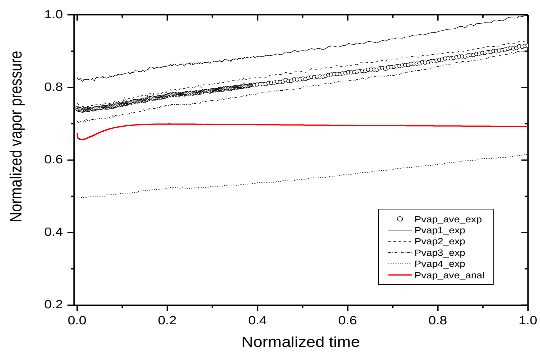
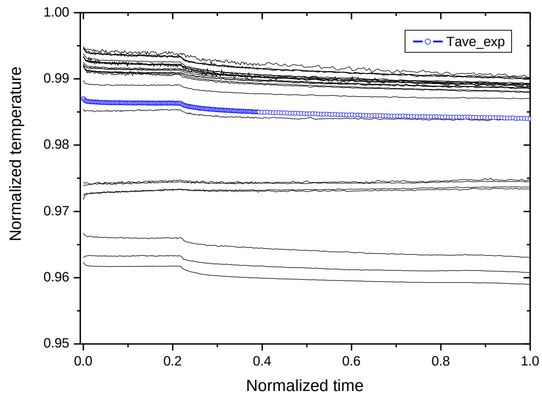
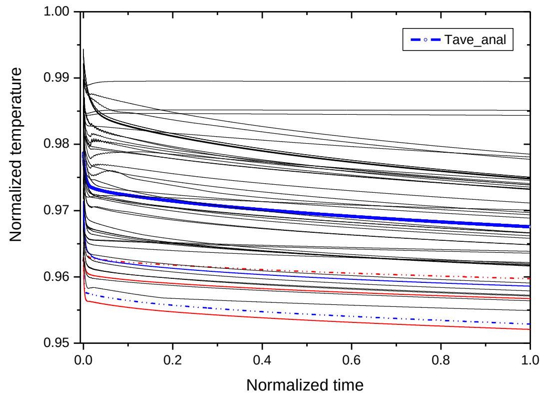


Fig. 4. Comparison of the estimated containment pressure to the test data.

Containment temperature was also underestimated as shown in Fig. 5. There are several possible reasons: absence of steady-state adjustments and inappropriate modelling of the flow characteristics. A rapid decrease of temperature and pressure at the beginning stage seems to be caused by the unsteady-state start of the analysis. In addition, the difference even in the initial average temperature by 2.5 K, calculated by the same method and measurements, may raise a question about the sufficiency of the averaging approach of the ANSI standard. For instance, an arithmetic averaging of local thermal-hydraulic parameters with weighting values to produce a single representing value for a large containment could be a significant simplification of local variation of them.



(a)



(b)

Fig. 5. Temperature distribution in the containment: (a) measurement, (b) analysis result.

Accordingly, total mass of containment air was underestimated by about 0.65% compared to the one calculated by the utility (Fig. 6). The difference between the two sets of data even at the very beginning seems to be also resulted from different levels of lumping the thermal hydraulic parameters.

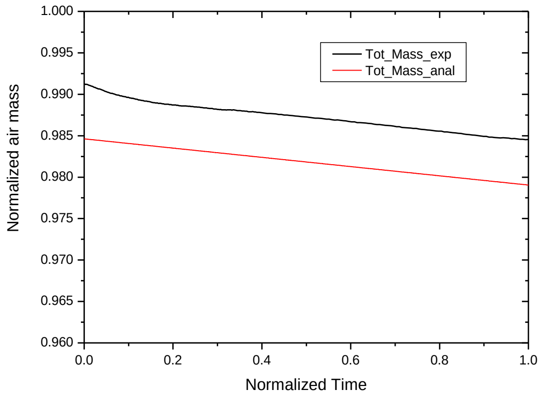


Fig. 6. Temperature distribution in the containment: (a) measurement, (b) analysis result.

4. Suggestion of an Elaborated ILRT

This study revealed some limitations in the application of the ILRT data to the validation of computer models such as those caused by unmatched number of sensors, a simplistic way of lumping the thermal hydraulic parameters by averaging their test data, applicability of the correlations used to determine the partial steam pressure for very dry air. In addition, absence of air flow meters inside the containment and temperature sensors for heat structure surfaces and the environment kept any flow characteristics and heat structure model from being validated.

Based on the insights obtained from this study, we suggest that an ILRT with an elaborated test provisions and analysis methods be made on the utility's own voluntary base to satisfy the specific needs of this kind of applications, i.e., validation of the containment models, during the commissioning stage and just before continued operation, if necessary. Specific provisions that may need to be improved are as follows;

- Use of sensors for pressure, RH, and temperature as much as possible so that the conditions of the control volumes of the model may be traceable
- Installation of air flow meters inside the containment where high gas velocity is expected, and temperature sensors on the important heat structures
- Continuous measurement of the environment temperature
- Use of the raw data for RH and the nearest temperature, and the steam table to calculate the partial pressure of steam
- Division of the containment volume into smaller ones when averaging the thermal hydraulic parameters to calculate the air mass

We expect the above measures may help the utility and the regulatory organization validate their containment models using ILRT data by overcoming the difficulties we met in this study.

5. Conclusions

Simulation of an ILRT performed at a CANDU-6 plant using the MELCOR 1.8.6 input model was tried in order to overcome the difficulties in its validation with real data. The results show underestimation of the main thermal-hydraulic parameters such as pressure, temperature, and the air mass. Such difference might be resulted from the absence of an unsteady-state calculation and the simplistic way of lumping the thermal hydraulic parameters, etc. Based on the insights obtained from this study, we suggest ILRTs with elaborated test provisions and analysis methods to allow this application, which can be made on the utility's own voluntary base during the commissioning stage and before continued operation. They include the use of increased number of sensors, use of air flow meters and temperature sensors for heat structure surfaces and the environment. In addition, improvement of the method to calculate the partial steam pressure, and localization of thermal hydraulic parameters are suggested as well.

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