Sensitivity of Pressurized Thermal Shock Assessment for Reactor Vessel

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1. Introduction

When the reactor coolant with low temperature is injected into the reactor pressure vessel (RPV) due to the overcooling events or transients, it results in the significant tensile stress at the inner surface of the pressure vessel. This phenomenon, which is called a “PTS (pressurized thermal shock)” event, can adversely affect the structural integrity of the reactor vessel. Therefore, the licensee should show that the calculated value of the reference nil ductility transition temperature at the end of life (RT_{PTS}) satisfies the screening criterion suggested in the US rule 10CFR50.61 [1].

If the value of RT_{PTS} does not satisfy the acceptance criterion, the licensee should perform the plant-specific analysis according to the Regulatory Guide 1.154 including deterministic and probabilistic fracture mechanics analyses [2]. The main purpose of the fracture mechanics analyses is to justify that the calculated through-wall cracking frequency (TWCF) is sufficiently low during operation.

The probabilistic fracture mechanics have many unknowns and uncertainties in calculation. Especially input parameters can critically affect the probability of the vessel failure, Thus, the sensitivity of the input parameters should be discussed. In this study, the sensitivities of the significant input parameters are analyzed considered in the probabilistic fracture mechanics analysis by using the PTS analysis code R-PIE (Reactor-Probabilistic Integrity Evaluation).

2. Analysis

The fracture mechanics analysis is performed in order to assess the structural integrity of RPV of the oldest nuclear power plant (NPP) officially decommissioned in 2017. The basic input parameters such as the geometric information, mechanical and thermal properties are referred to the oldest NPP.

The R-PIE code based on the fracture mechanics is employed to calculate the probability of the vessel failure [3]. Figure 1 depicts the overall calculation process of the probabilistic fracture mechanics analysis in the R-PIE code.

In the PTS analysis, the failure probabilities closely rely on the input transients in the form of temperature and pressure time histories. In this study, the small break loss of coolant accident

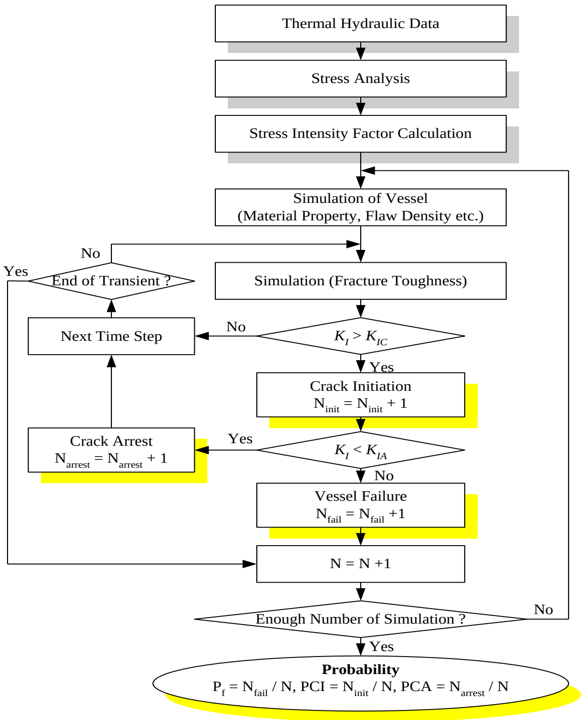

Fig.1 Flow chart of the R-PIE code

(SBLOCA) which is the typical transient event as shown in Figure 2 is considered. It demonstrates that the temperature and pressure decreases dramatically from normal condition to 7 ℃ and 2 MPa, respectively, during the short period approximately 20 minute.

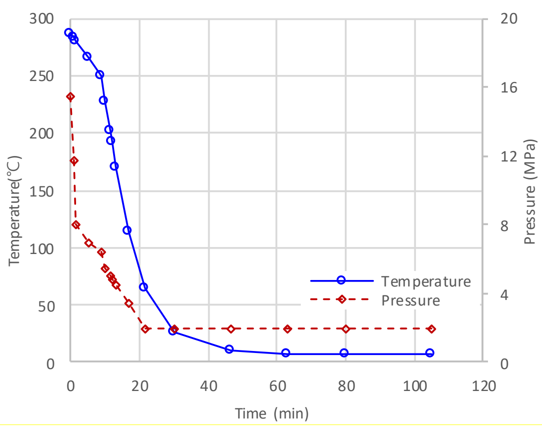

Fig.2 Temperature and pressure time histories of SBLOCA transient

The sensitivity analysis is performed to identify the influence of the significant statistical input parameters, i.e. the crack orientation, crack size, fluence level, and so on. The detailed analysis matrix of the sensitivity analysis is listed in Table 1.

Figure 3 shows the calculated probabilities of the vessel failure in accordance with the crack size:

- As the crack size increases, the probabilities of vessel failure increase.
- The axial oriented cracks show higher failure rates than circumferential oriented cracks when they have same crack sizes and fluence levels.
- In case of the circumferential crack, the crack size significantly affects the probabilities of vessel failure.

According to the 10CFR50.61, the TWCF should remain less than 5×10^{-6} per reactor year for the requested period of continued operation. The TWCF can be estimated by multiplying the sequence frequency and conditional through-wall crack penetration probability. The sequence frequency for SBLOCA is referred to the frequency accordance with the operating experience suggested in the NUREG report [4].

Table 1. Analysis matrix for sensitivity

Input parameters	Values
Flaw orientation	Circumferential, Axial
Flaw size (*l/a*)	Infinite, 24, 12, 6
Flaw distribution model	OCTAVIA, Marshall, Marshall + PSI
Fluence (10^{19} n/cm^2)	0.5 ~ 9 (0.5, 1, 2, 4, 6, 8, 9)
Plastic correction factor	Considering, Not considering
Fracture toughness curve	NRC mean curve, ASME mean curve, Master curve, PROSIR curve

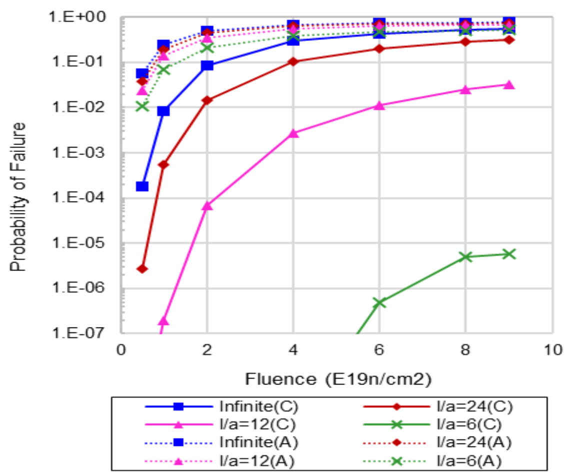

Fig.3 Sensitivity analysis results (crack size)

Table 2. Fluence level exceeding acceptance criteria of TWCF

flaw size (*l/a*)	Crack orientation	
	Circumferential	Axial
Infinite	0.610	<0.5
24	1.100	<0.5
12	3.428	<0.5
6	>9.0	<0.5

The calculated TWCFs for different crack sizes are arranged in Table 2. Other input parameters are conservatively set. As shown in Table 2, the cases circumferential flaw equal to infinite, 24, and 12 do not satisfy the acceptance criteria of TWCF under the fluence level 0.610, 1.100, and 3.428, respectively. In addition, it seems that the axial flaw with every flaw size do not meet acceptance criteria from the early part of operation by affected by neutron irradiation.

3. Results

In this study, the sensitivity analysis is achieved to identify the influence of the input parameters in the PTS assessment. The results can be summarized as below:

- The sensitivity analysis for several important input parameters is performed using the R-PIE code.
- The results of the sensitivity show that the axial oriented cracks can more critically affect the vessel failure.
- The structural integrity of the reactor vessel is guaranteed for the circumferential flaw of size less than *l/a*=6. However, this assessment has large conservatism in the input parameters. Thus, actual failure probability may be much smaller than the results.

Acknowledgment

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