Evaluation of Leak and LOCA Probabilities in RCS piping of Domestic NPPs under Fatigue and Stress Corrosion Cracking Conditions

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1. Introduction

10CFR 50.46 'Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors' requires the LB-LOCA evaluation in reactor coolant system (RCS) piping.[1] Based on risk informed regulation (RIR) option 3, re-definition of LB-LOCA is discussed in USA.[2] The technical basis of re-definition of LB-LOCA is the extremely low probability of piping rupture in RCS piping. However, the probability of the piping rupture can not be determined from the field data because no rupture event in RCS piping has been reported. However, expert elicitation and probabilistic approach can be used to estimate the rupture frequency of RCS piping.[3] Probabilistic approach can give us relative information on the rupture probability. Another advantage of the probabilistic approach is to inform the effect of variables by parametric analysis.

In this study, leak and LOCA probabilities in RCS piping of domestic nuclear power plants (NPPs) under fatigue and stress corrosion cracking are evaluated by using the probabilistic piping integrity evaluation program (P-PIE) developed in this study.

2. Development of Probabilistic Piping Integrity Evaluation Program (P-PIE)

First, the probabilistic piping integrity evaluation program (P-PIE) is developed in this study. The algorism of the P-PIE program is as follows;

(1) To assume initial crack distribution and delete the crack found in ISI because the crack has been repaired.
(2) To perform analysis analyze at $t_i(t_{i-1} + \Delta t)$
(3) To include new cracks, which are initiated by fatigue or stress corrosion cracking during Δt, to the crack distribution
(4) To evaluate the stress intensity factor for the cracks under given loading condition and crack growth amount
(5) To check leak or rupture for the piping due to crack growth
(6) To add 1 to the leak number or rupture number if leak or rupture is identified.
(7) To repeat from step 3 to step 6 until $t_i > t_{given}$
(8) To repeat from step 1 to step 7 until given simulation number
(9) To calculate leak or rupture probabilities from the leak or rupture numbers and simulation number.

Fig. 1 shows the algorism of the P-PIE program. P-PIE is programmed by Visual C++. For the validation of P-PIE program, the results are compared with those from PRO-LOCA developed by USNRC.[4] Fig. 2 shows the result of comparison. As shown in the figure, the P-PIE program gives more conservative results.

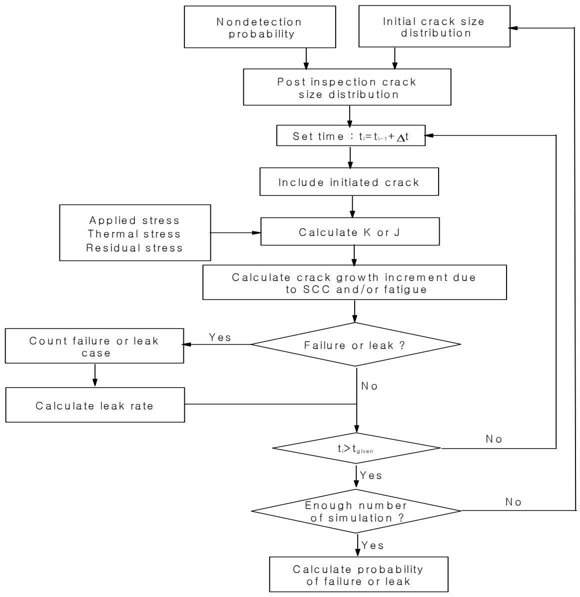

Fig 1. Algorism of P-PIE program

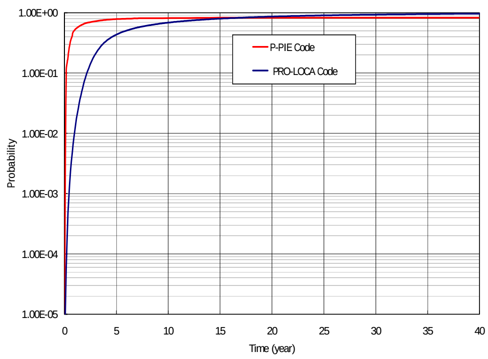

Fig 2. Comparison of P-PIE with PRO-LOCA code

3. Evaluation of Leak and LOCA Probability in Domestic NPPs

The RCS piping failure probability of Kori uni1 is evaluated by using the P-PIE program. The outer diameter and thickness of hot leg, cold leg, and crossover leg of Kori unit 1 are 34.6/2.8, 32.9/2.7, 37.0/3.0 inches, respectively. Probabilities for leak, big leak, and LOCA are calculated .

Fig. 3 shows the probabilities for leak, big leak, and LOCA for hot leg, cold leg, and intermediate leg of Kori unit 1 under fatigue crack growth. At the end of life, probabilities of LOCA ranges from 10^{-11} to 10^{-10}, while those of leak or big leak from $5*10^{-7}$ to $5*10^{-6}$. The result shows the LOCA probability is extremely low. The probability slightly increases as the pipe diameter decreases. The probability also slightly increases as the operating time increases.

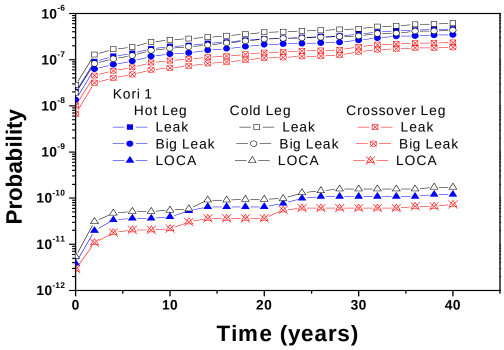

Fig 3. RCS Piping Failure Probabilities in Kori-1

The effect of oxygen on the failure probability is evaluated under stress corrosion cracking condition. Fig. 4 shows the effect in hot leg of Kori unit 1. The probabilities of leak and big leak at the oxygen contents of 0.1, 0.07, and 0.05 ppm under steady state operating condition at the end of life are estimated as about 10^{-2}, 10^{-6}, and 10^{-7}, respectively. This result means that the oxygen content is very sensitive to the failure probability and very low content of oxygen is strongly recommended to the steady state operation against stress corrosion cracking.

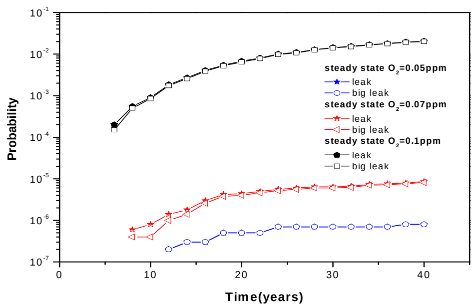

Fig 4. Effect of Oxygen on the failure probability in Hot Leg of Kori-1 under Stress Corrosion Cracking

Fig.5 shows the probabilities for leak, big leak, and LOCA for hot leg, cold leg, and intermediate leg of Ulchin unit 4. The LOCA probability is too small to evaluate. At the end of life, probabilities of leak or big leak range from 10^{-9} to 10^{-8}. The result shows the leak or LOCA probabilities of Ulchin unit 4 is lower than those of Kori unit 1 by the order of 2.

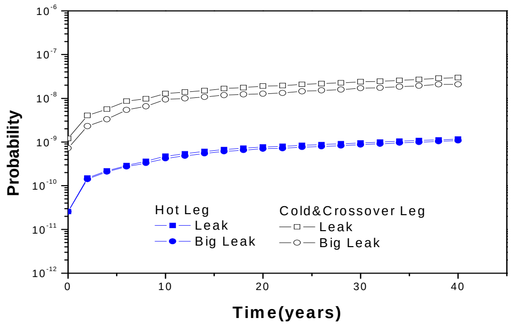

Fig 5 RCS Piping Failure Probabilities in Ulchin-4

4. Conclusion

In this study, leak and LOCA probabilities in RCS piping of domestic nuclear power plants (NPPs) under fatigue and stress corrosion cracking are evaluated by using the probabilistic piping integrity evaluation program (P-PIE) developed in this study

The RCS piping failure probability of Kori uni1 is evaluated by using the P-PIE program. The probabilities for leak, big leak, and LOCA for hot leg, cold leg, and intermediate leg of Kori unit 1 under fatigue crack growth. At the end of life, probabilities of LOCA ranges from 10^{-11} to 10^{-10}, while those of leak or big leak from $5*10^{-7}$ to $5*10^{-6}$. The result shows the LOCA probability is extremely low. The effect of oxygen on the failure probability is also evaluated under stress corrosion cracking condition. The result shows that the oxygen content is very sensitive to the failure probability and very low content of oxygen is strongly recommended to the steady state operation against stress corrosion cracking. The leak or LOCA probabilities of Ulchin unit 4 is lower than those of Kori unit 1 by the order of 2.

REFERENCES

[1] USNRC, 10CFR 50.46 ‘Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors’, 2008

[2] USNRC, 10CFR 50.46a ‘Proposed Rule for 10CFR 50,46’, 2009

[3] USNRC, NUREG-1829, Estimating LOCA Frequencies through the Elicitation Process, 2005

[4] USNRC, PRO-LOCA (Probabilistic Fracture Mechanics Code for LOCA) Code, 2009