A Study on the Alternative Fracture Toughness Requirements against PTS Events

Sin-Ae Lee*, Yoon-Suk Chang*
* *Dept. of Nuclear Engineering, Kyung Hee University, 1732 Deokyoungdae-ro, Yongin, Kyunggi, 446-701, Korea*
**Corresponding author: yschang@khu.ac.kr*

1. Introduction

PTS(Pressurized Thermal Shock) is the well-known severe accident scenario which may lead to a failure of RPV(Reactor Pressure Vessel)[1]. In order to show sustainability against PTS events, plant specific structural integrity assessment of RPVs has been performed in accordance with 10CFR50.61 since 1985[2]. However, recently, USNRC released alternative fracture toughness requirements as 10CFR50.61a[3]. In this study, the new PTS requirements as well as general PTS assessment procedures are examined. Subsequently, re-assessment is carried out for a representative RPV and its results are compared to those obtained from the original PTS requirements.

2. Brief review of PTS assessment method

2.1 Analysis model

For the PTS assessment, in general, a simple 2-dimensional analysis model shown in Fig. 1[4] is considered. Since the assessment is focused on the region with maximum neutron fluence exposure, a semi-elliptical surface crack is postulated in the beltline region of the RPV. Also, the circumferentially oriented crack depth is set to 1/4 of the wall thickness.

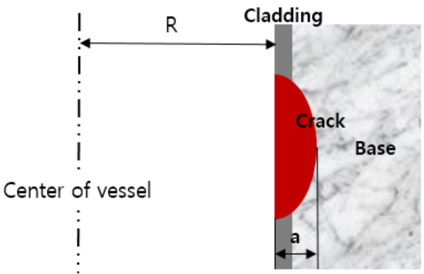

Fig. 1. A semi-elliptical surface crack in the beltline region

2.2 Assessment procedures

A set of PFM(Probabilistic Fracture Mechanics) assessment is carried out based on deterministic fracture mechanics concepts. Stress variations along the RPV wall are used to get the SIFs(Stress Intensity Factors) and temperature distributions along the wall are used to get the fracture toughness. The SIF and fracture toughness are compared to determine the propagation of the crack causing the failure of the RPV, which is used to calculate the probability of the RPV failure. The through-wall cracking frequency is calculated and compared to the acceptance criteria[1]. A variety of statistical parameters related to radiation embrittlement are taken into account for the assessment procedures.

3. PTS re-assessment of a representative RPV

3.1 New PTS requirements

10CFR50.61a was published in 2010 as an alternative of preceding 10CFR50.61. The requirements of 10CFR50.61 define RT_{PTS} values and corresponding PTS screening criteria. Especially, the PTS screening criteria are 270°F for plates, forgings and axial weld materials, and 300°F for circumferential weld materials, respectively[2]. On the other hand, the requirements of 10CFR50.61a define quite different criteria for circumferential welds as well as axial welds, plates and forgings represented in Table I. Here, limit criteria for RPV less than 9.5 in thickness were summarized by considering the specific geometry, except those related to different vessel wall thicknesses.

Table I: Alternative PTS screening criteria[3]

Criterion	Value [°F]
Limit RT_{MAX_AW}	269
Limit RT_{MAX_PL}	356
Limit RT_{MAX_FO}	356
Limit RT_{MAX_CW}	312

The PTS screening criteria have to be compared with corresponding RT_{MAX-X} values such as RT_{MAX-AW}, RT_{MAX-PL}, RT_{MAX-FO} and RT_{MAX-CW}, which are determined in use of the following equations[3].

$$RT_{MAX-AW} = MAX\ \{[\ RT_{NDT(U)-plate} + \Delta T_{30-plate}\ ],\ [\ RT_{NDT(U)-axial\ weld} + \Delta T_{30-axial\ weld}\ ]\} \quad (1)$$

$$RT_{MAX-PL} = RT_{NDT(U)-plate} + \Delta T_{30-plate} \quad (2)$$

$$RT_{MAX-FO} = RT_{NDT(U)-forging} + \Delta T_{30-forging} \quad (3)$$

$$RT_{MAX-CW} = MAX\ \{[\ RT_{NDT(U)-plate} + \Delta T_{30-plate}\ ],\ [\ RT_{NDT(U)-circweld} + \Delta T_{30-circweld}\ ],\ [\ RT_{NDT(U)-forging} + \Delta T_{30-forging}\ ]\} \quad (4)$$

where, the ΔT_{30} value can be determined by Eqs. (5)~(7).

$$\Delta T_{30} = MD + CRP \quad (5)$$

$$MD = A \times (1 - 0.001718 \times T_C) \times (1 + 6.13 \times P \times Mn^{2.471}) \times \varphi t_e^{0.5} \quad (6)$$

$$CRP = B \times (1 + 3.77 \times Ni^{1.191}) \times f(Cu_e,P) \times g(Cu_e,Ni,\varphi t_e) \quad (7)$$

Fig. 2 shows the PTS assessment flow according to 10CFR50.61, in which the yellow box represents the modified part in 10CFR50.61a.

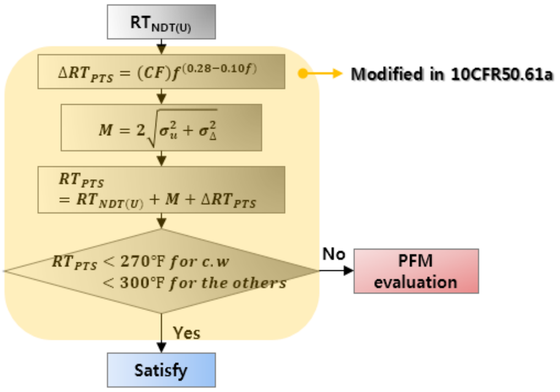

Fig. 2. PTS assessment flow according to 10CFR50.61

Fig. 3 delineates the PTS assessment flow according to the alternative fracture toughness requirements.

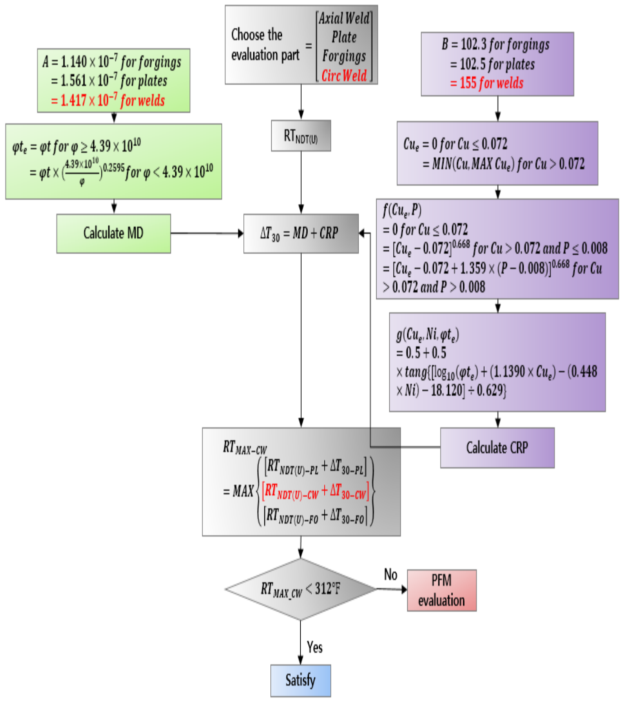

Fig. 3. PTS assessment flow according to 10CFR50.61a

3.2 Re-assessment

Table II shows the key input parameters employed in the re-assessment for operation of 24, 32 and 40EFPY. Since the circumferential welds were the most critical part of the representative RPV, especially, the circumferential welds were taken into account for the re-assessment in this study.

Table II: Input parameters used in PTS re-assessment[5]

Parameter	Value
Thickness including clad	165.1 mm
Average of Cu content	0.29 wt%
Average of Ni content	0.68 wt%
Average of initial RT_{NDT}	-10°F

Fig. 4 represents two PTS screening criteria with corresponding RT_{PTS} and RT_{MAX_CW} values obtained from both requirements. Since the calculated RT_{PTS} exceeded the screening criteria of 300°F for circumferential welds at 27.5EFPY, further detailed PFM analysis was required. Meanwhile, the calculated RT_{MAX_CW} has sufficient margin comparing to the screening criteria of 312°F for the same welds.

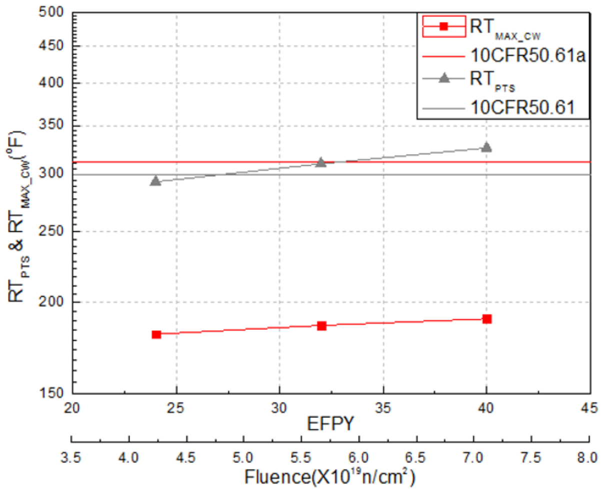

Fig. 4. PTS re-assessment results

4. Concluding remarks

In this study, key features of the new PTS requirements as well as general PTS assessment procedures were examined. Subsequently, PTS re-assessment was carried out for a representative RPV and its results were compared to those obtained from the original requirements. As a result, while the RT_{PTS} value obtained from 10CFR50.61 exceeded the original screening criterion at 27.5EFPY, RT_{MAX_CW} value obtained from 10CRT50.61a was sufficiently lower than the alternative screening criterion.

REFERENCES

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