Comparison of 2D and 3D Fast Neutron Fluence for Reactor Pressure Vessel Nozzle of OPR-1000

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1. Introduction

The Pressure-Temperature (P-T) limit curve has been evaluated mainly for the beltline which is near the reactor core. In 2014, Nuclear Regulatory Commission (NRC) issued Regulatory Issue Summary (RIS) 2014-11 [1] requiring that the extended beltline (ex: nozzle region) be considered when evaluating P-T limit curve. Although the nozzle region has a lower fast (E>1.0MeV) neutron exposure than the beltline, it may result in a more conservative P-T limit curve due to its higher stress geometry.

In order to determine fast neutron fluence (n/cm^2), 2D/1D synthesis method using DORT 3.2 code [2] based on 2D neutron transport calculation has been widely adopted. However, the synthesis method has limitation when applying discontinuous structures such as nozzles. Recently, RAPTOR-M3G 2.0 code [3] was developed performing direct 3D neutron transport calculation.

The purpose of this paper is to compare fast neutron fluence values at the beltline and extended beltline between 2D/1D synthesis method based on DORT 3,2 code and direct 3D calculation based on RAPTOR-M3G 2.0 code. And we discuss the expected Effective Full Power Year (EFPY) that the fast neutron fluence of nozzle region exceeds 1x10^{17} n/cm^2

2. Methods and Results

In this section, the comparison the 2D and 3D neutron transport calculation at the nozzle region of OPR-1000 RPV is discussed in detail. Additionally, the neutron fluence at the nozzle region was calculated at the lowest extent of weld location (z = 260.61 cm) between nozzle and intermediate shell.

2.1 2D neutron transport calculation modeling

The 2D neutron transport calculations were carried out using the DORT 3.2 code and the 2D/1D synthesis method (Eq.1) technique described in Regulatory Guide 1.190 [4].

$$\phi(r,\ \theta,\ z) = \phi(r,\ \theta) \times \frac{\phi(r,\ z)}{\phi(r)} \quad \text{(Eq. 1)}$$

Where, $\phi(r, \theta, z)$ is the synthesized three-dimensional neutron flux distribution, $\phi(r, \theta)$ is the transport solution in R-θ geometry, $\phi(r, z)$ is the transport solution in R-Z geometry, and $\phi(r)$ is the transport solution in R geometry.

Fig. 1 shows the (r, θ) geometry model of OPR-1000 RPV. The nuclear fuel is loaded in a quarter-symmetry, so the modeling was conducted from 0° to 90° in the azimuthal direction.

Fig. 2 shows the (r, z) geometry model of OPR-1000 RPV. The geometric structures of the reactor core, internals components, pressure vessel, biological shielding, cladding, external insulation and outlet nozzle were simulated.

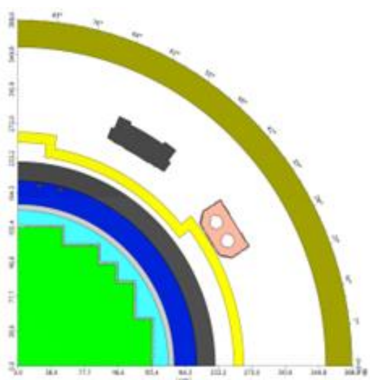


Fig. 1. (r, θ) geometry model for DORT

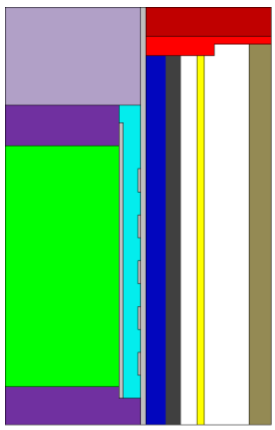


Fig. 2. (r, z) geometry model for DORT

2.2 3D neutron transport calculation modeling

The 3D neutron transport calculations were carried out using the RAPTOR-M3G code. The mesh can be simulated using BOT3P-GGTM [5], and the modeling results for each structure can be checked using TECPLOT [6]. Fig. 3 shows the three-dimensional modeling of OPR-1000 RPV. Modeling was performed from 0° to 90° in the azimuthal direction. The geometric structures of the reactor core, internal components, pressure vessel, biological shielding, surveillance, cladding, external insulation, inlet and outlet nozzles were simulated.

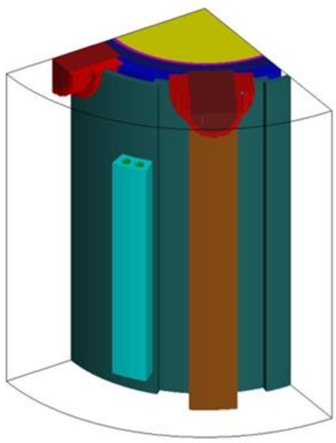


Fig. 3. (r, θ, z) Geometry model for RAPTOR-M3G

2.3 Comparison of the 2D and 3D neutron transport calculation results at the beltline region

Fig. 4 is a graph comparing fast neutron (E > 1.0 MeV) fluence at the beltline region (z = 0 cm) calculated using the 2D and 3D neutron calculation from 1cycle to 13cycle. Comparing the results of 2D and 3D neutron transport calculations, the fast neutron fluence was a difference of approximately 1% or less.

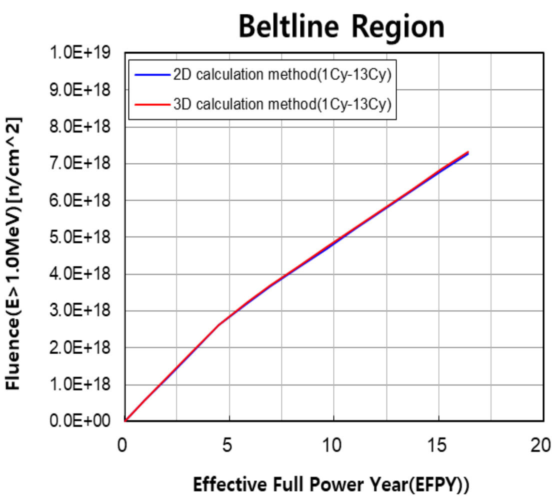


Fig. 4. Comparison of neutron fluence at the beltline region of OPR-1000 RPV between the 2D and 3D calculation

2.4 Comparison of the 2D and 3D neutron transport calculation results at the nozzle region

Fig. 5 is a graph comparing fast neutron (E > 1.0 MeV) fluence at the nozzle region (z = 260.61 cm) calculated using the 2D and 3D neutron calculation from 1cycle to 13cycle. Comparing the results of 2D and 3D neutron transport calculations, the fast neutron fluence in the 2D calculation was approximately 24% higher than in the 3D calculation.

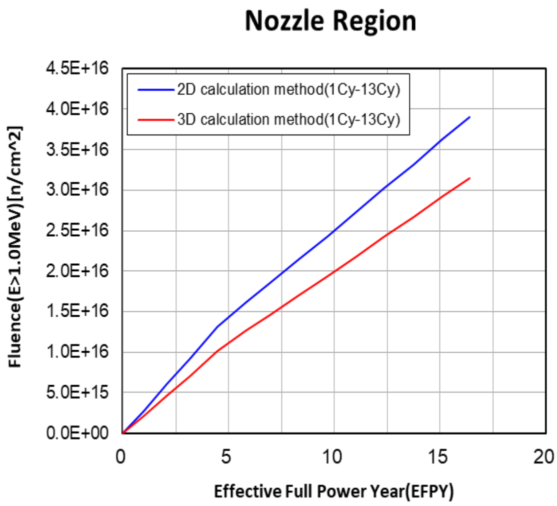


Fig. 5. Comparison of neutron fluence at the nozzle region of OPR-1000 RPV between the 2D and 3D calculation

Fig. 6 shows predicted the neutron fluence at the nozzle region. The dashed line represents the predicted neutron fluence based on the average neutron flux from Cycle 1 to Cycle 13.

The neutron fluence at the nozzle region in the 2D calculation is approximately 7.68×10^{16} n/cm² at the EOL (32EFPY). In the 3D neutron transport calculation, the neutron fluence at the nozzle region is approximately 6.18×10^{16} n/cm² at the EOL (32EFPY).

Additionally, the neutron irradiation effects should be considered when the neutron fluence at the nozzle region is expected to exceed 1×10^{17} n/cm² at the EOL. The neutron fluence at the nozzle region in the 2D calculation is expected to exceed 1×10^{17} n/cm² at the time of 42EFPY. In the 3D neutron transport calculation, the neutron fluence at the nozzle is exceeds 1×10^{17} n/cm² at the time of 52EFPY.

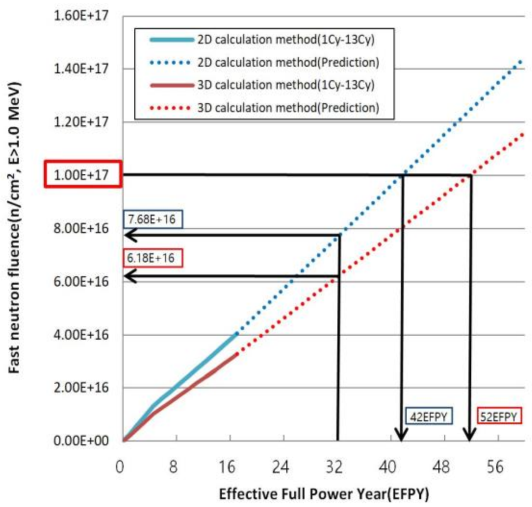
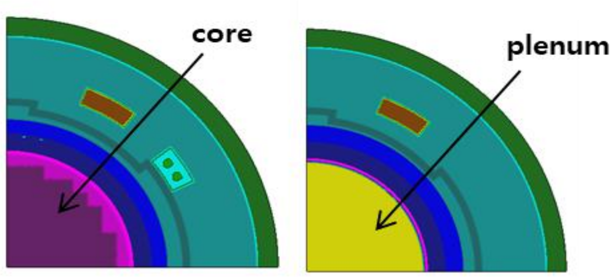


Fig. 6. Predicted neutron fluence at the nozzle region of OPR-1000 RPV

The difference between 2D and 3D neutron transport calculation at the nozzle region (z = 260.61 cm) is (r, θ) model. As shown in Fig 1, the 2D calculation has only one (r, θ) model representing the middle position axially. However, the 3D calculation method has various (r, θ) models along with axial elevation. Fig. 7 shows (r, θ) horizontal cross-section view of RAPTOR-M3G at the beltline and nozzle region.



(a) (b)

Fig 7. (r, θ) horizontal cross-section view of RAPTOR-M3G at (a) the beltline region (z = 0 cm) and (b) the nozzle region (z = 260.61 cm)

The nozzle region is located above the core. However, in 2D calculation, (r, θ) neutron flux is evaluated at the core. Thus, the 2D/1D synthesis method results are excessively conservative, when calculating fast neutron (E > 1.0 MeV) fluence at the nozzle region. It could not accurately reflect the actual neutron fluence at the nozzle region.

3. Conclusions

The neutron fluence at the nozzle region of OPR-1000 RPV in the 2D calculation was approximately 24% higher than in the 3D calculations. This is because the 2D (r, θ) model only considers the axial center position (z = 0cm) of OPR-1000 RPV.

The 3D calculation has various (r, θ) model along with axial location. Therefore, when evaluating complex structures or location above the core such as the nozzle, the model of the 3D calculation is closer to the actual geometric structure.

As a result of the 2D and 3D neutron transport calculations, the neutron fluence at the nozzle region of OPR-1000 RPV is expected not to exceed 1×10^{17} n/cm² at the EOL (32EFPY). However, if the design life of the nuclear power plant is extended, it is necessary to periodically monitor the neutron fluence at the nozzle region of OPR-1000 RPV.

REFERENCES

[1] NRC Regulatory Issue Summary (RIS) 2014-11, “Information on Licensing Applications for Fracture Toughness Requirements for Ferritic Reactor Coolant Pressure Boundary Components,” U.S. Nuclear Regulatory Commission, October 2014.

[2] RSIC Computer Code Collection CCC-650, DOORS 3.2, One-Two and Three-Dimensional Discrete Ordinates Neutron/Photon Transport Code System.

[3] LTR-REA-11-65, Rev. 0 RAPTOR-M3G Version 2.0 User Manual, November 3, 2011.

[4] USNRC Regulatory Guide 1.190, Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence, March 2001.

[5] ENEA Document FPN-P9H6-002, BOT3P Version 5.2: A Pre/Post-Processor System for Transport Analysis, ENEA Center Ricerche Bologna, March 2007

[6] KRIST RAPTOR-M3G Training Program Chapter. 7, Using Tecplot, Westinghouse Proprietary Class 2, 2011.