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Evaluation of Neutron Fluence at Reactor Pressure Vessel Nozzle using Ex-Vessel Neutron Dosimetry(EVND) and Surveillance capsule

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1. Introduction

The purpose of the Pressure – Temperature(P-T) limit curve is to prevent a failure of reactor pressure vessel during operation of reactor coolant system. In Korea, P-T limit curves have to meet Nuclear Safety and Security Commission Notification 2021-28[1]. The P-T limit curves have been traditionally evaluated based on the beltline region which is most affected by neutron irradiation. However due to the geometric discontinuity, the inside corner regions of the vessel nozzles are the most highly stressed regions of reactor vessel. These higher stresses can potentially result in more restrictive P-T limits, even if the reference nil ductility transition temperatures (RT_{NDT}) for these components are not as high as those of the reactor vessel beltline shell materials that have simpler geometries. In 2014, the NRC issued Regulatory Issue Summary (RIS) 2014-11 [2], which require the consideration of reactor pressure vessel nozzles in P-T limits curve generation.

In order to evaluate the P-T limit curve for nozzle region, an accurate neutron fluence at reactor pressure vessel nozzles is required. Therefore, in the Regulatory Guide 1.190[3], "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence," describes the latest transport calculation method and neutron fluence measurement procedure are provided to obtain reliable fluence at the reactor pressure vessel nozzle.

The evaluation of the neutron fluence at reactor pressure vessel nozzle is based on the irradiation history during the actual operational nuclear fuel cycle. In order to obtain reliable results of the neutron fluence at reactor pressure vessel nozzle, the neutron dosimeter measurement value and neutron transport calculation result should be compared and verified.

In this paper, the neutron fluence at reactor pressure vessel nozzle was evaluated using the measurement results of the upper surveillance capsule neutron monitor and Ex-vessel neutron dosimetry(EVND) close to reactor pressure vessel nozzle. In addition, Westinghouse 3-loop and OPR-1000 were selected and their neutron fluence at reactor pressure vessel nozzle were evaluated.

2. Methods and Results

In this section, the neutron fluence at reactor pressure vessel nozzle evaluation methodology is discussed in detail.

2.1 Best estimated the neutron fluence at reactor vessel nozzle

Best estimated the neutron fluence at reactor vessel nozzle calculated as follows:

$$\phi_{BestEst.} = K \times \phi_{Calc.} \quad (1)$$

Where $\phi_{BestEst.}$ is best estimated the neutron fluence at the location of interest and K is bias factor(Best estimated result/calculation result) calculated from surveillance capsule neutron monitor and Ex-vessel neutron dosimetry(EVND) measurements. $\phi_{Calc.}$ is calculated the neutron fluence at the location of interest.

2.2 Evaluation of the neutron fluence at reactor pressure vessel nozzle using the surveillance capsule monior and Ex-vessel neutron dosimetry(EVND)

Currently, the best estimated the neutron fluence at reactor pressure vessel nozzle is determined using the ratio of best estimated result calculated from surveillance capsule and Ex-vessel neutron dosimetry(EVND) measured value in core region to the transport calculated value. Figure 1 shows Ex-vessel neutron dosimetry system in beltline region.

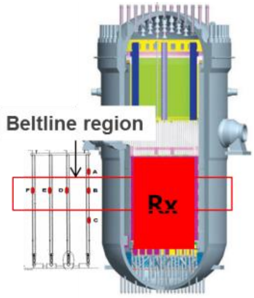

Fig. 1. Ex-vessel neutron dosimetry system in beltline region

If the neutron dosimeter is attached to reactor pressure vessel nozzle, accurate results can be obtained, but it is impossible due to spatial limitation.

Therefore, as shown in Figure 2, accurate result can be obtained from the measured value of upper part of surveillance capsule neutron monitor and Ex-vessel neutron dosimetry(EVND) close to reactor pressure vessel nozzle region.

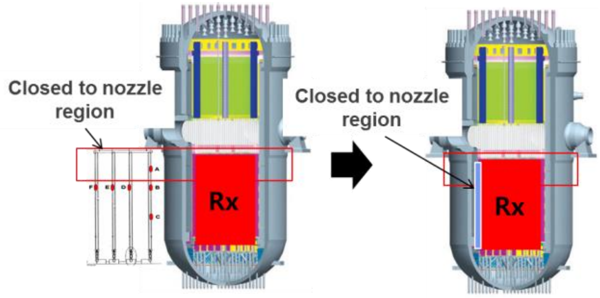

Fig. 2. Ex-vessel neutron dosimetry system(EVND) and Surveillance capsule in nozzle region

2.3 Bias factor at upper part of the surveillance capsule neutron monior and Ex-vessel neutron dosimetry(EVND)

Table I and Table II summarizes the bias factor (BE/C), which is the best estimated value/transport calculation value obtained from the Westinghouse 3-loop and OPR-1000 upper part of the surveillance capsule monitor and upper part of the Ex-vessel neutron dosimetry(EVND) measurement results.

In the case of the Westinghouse 3-loop results, upper part of the Ex-vessel neutron dosimetry(EVND) and upper part of the surveillance capsule monitor bias factors(BE/C) are 1.06 and 0.97. Combined bias factor (BE/C) is 1.01.

In the case of the OPR-1000 results, upper part of the Ex-vessel neutron dosimetry(EVND) and upper part of the surveillance capsule monitor bias factors(BE/C) are 1.11 and 1.02. Combined bias factor (BE/C) is 1.06.

Both Westinghouse 3-loop and OPR-1000 results meet within the range of 20% of the acceptance criteria applied when comparing the measured and calculated values specified in Regulatory Guide 1.190.

As a result, the reliability of the neutron fluence evaluation at reactor pressure vessel nozzle using upper part of surveillance capsule monitor and Ex-vessel neutron dosimetry(EVND) is confirmed.

Table I: Westinghouse 3-loop RPV nozzle BE/C

Parameter	Upper part of EVND	Upper part of SC Monitor	EVND and SC Combined
	Average BE/C	Average BE/C	Average BE/C
Flux(E > 1.0 MeV)	1.06	0.97	1.01
Standard deviation	0.06	0.03	0.01

Table II: OPR-1000 RPV nozzle BE/C

Parameter	Upper part of EVND	Upper part of SC Monitor	EVND and SC Combined
	Average BE/C	Average BE/C	Average BE/C
Flux(E > 1.0 MeV)	1.11	1.02	1.06
Standard deviation	0.11	0.02	0.06

2.4 Comparison of RPV nozzle neuron fluence using beltline bias factor and nozzle region bias factor

Figure 3 is a comparison of the neutron fluence of Westinghouse 3-loop RPV nozzle using nozzle region bias factor and beltline bias factor.

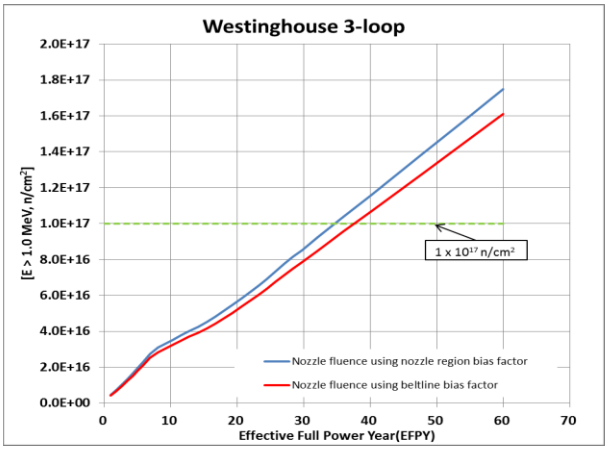

Fig. 3. Comparison of the neutron fluence of Westinghouse 3-loop RPV nozzle

Figure 4 is a comparison of the neutron fluence of OPR-1000 RPV nozzle using nozzle region bias factor and beltline bias factor.

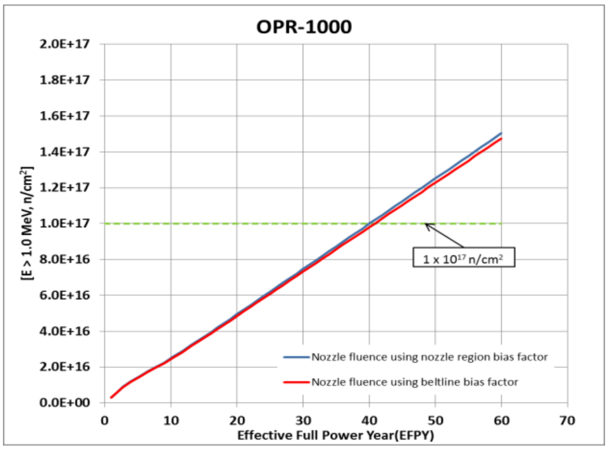

Fig. 4. Comparison of the neutron fluence of OPR-1000 RPV nozzle

Both Westinghouse 3-loop and OPR-1000 result show the higher value of nozzle neutron fluence when nozzle region bias factor are applied. Thus the nozzle neutron fluence when nozzle region bias factor is evaluated conservatively.

2.5 Neutron fluence of reactor pressure vessel nozzle

The nozzle neutron fluence was evaluated at the lowest weld region of the reactor pressure vessel nozzle. Figure 5 shows the neutron fluence at the nozzle with respect to the effective full power years of the Westinghouse 3-loop. The Westinghouse 3-loop nozzle projected neutron fluence will be greater than 1×10^{17} n/cm^2(1 > MeV) at the time of 36EFPY. Figure 6 shows the neutron fluence of the nozzle with respect to the effective full power years of the OPR-1000. The OPR-1000 nozzle projected a neutron fluence will be greater than 1×10^{17}n/cm^2(1 > MeV) at the time of 41EFPY.

Figure 7 is a graph comparing the neutron fluence of the core region and the nozzle of the Westinghouse 3-loop. Figure 8 is a graph comparing the neutron fluence of the core region and the nozzle of the OPR-1000. These figures show that the neutron fluence of core region is higher than the neutron fluence of nozzle. In addition, as the effective full power years(EFPY) increase, the differences between neutron fluence of beltline and neutron fluence of nozzle become large.

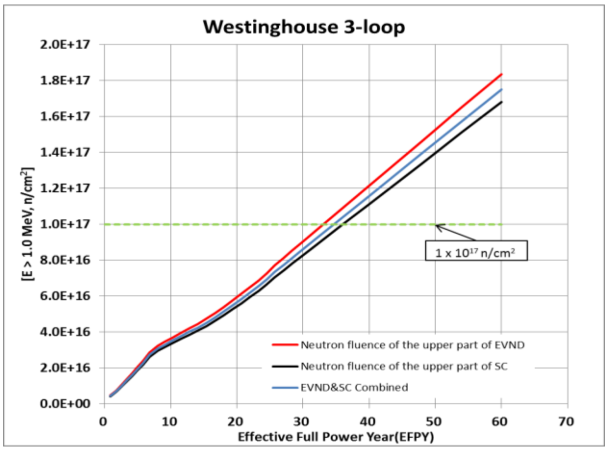

Fig. 5. Westinghouse 3-loop RPV nozzle neutron fluence

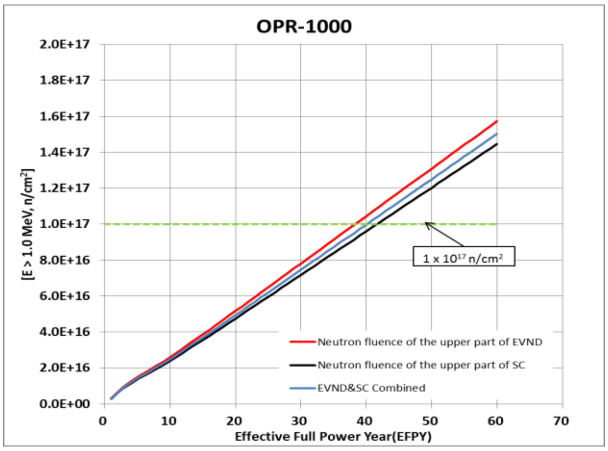

Fig. 6. OPR-1000 RPV nozzle neutron fluence

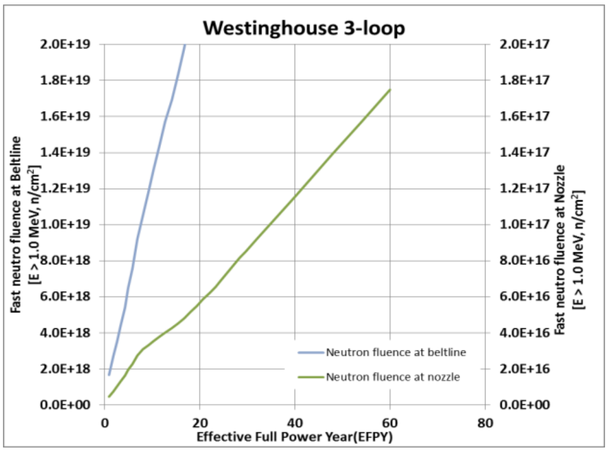

Fig.7. Westinghouse 3-loop RPV nozzle and beltline neutron fluence

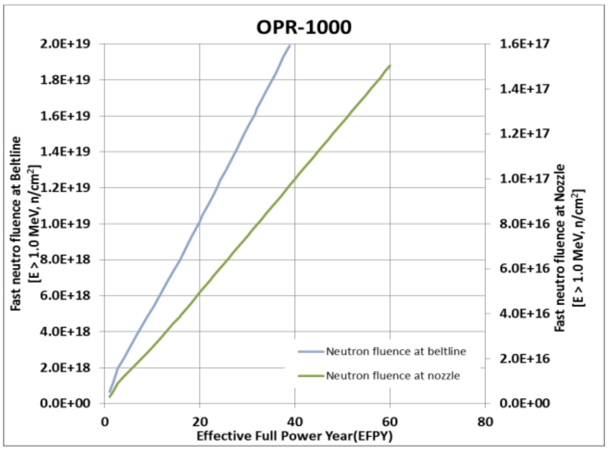

Fig.8. OPR-1000 RPV nozzle and beltline neutron fluence

3. Conclusions

The neutron fluences at reactor pressure vessel nozzle were evaluated using Ex-vessel neutron dosimetry (EVND) and surveillance capsule monitor closed to reactor pressure vessel nozzle. Both the Westinghouse 3-loop and OPR-1000 results meet the range of 20% of the acceptance criteria applied when comparing the measured and calculated values specified in Regulatory

Guide 1.190.

The Westinghouse 3-loop nozzle projected neutron fluence will be greater than 1×10^{17} n/cm^2(1 > MeV) at the time of 36EFPY. The OPR-1000 nozzle projected neutron fluence will be greater than 1×10^{17} n/cm^2(1 > MeV) at the time of 41EFPY.

In conclusion, If plant design life is extended, the neutron fluence at reactor pressure vessel nozzle also increase, it is necessary to continuously evaluated and monitor the neutron fluence at reactor pressure vessel nozzle.

REFERENCES

[1]Nuclear Safety and Security Commission Notification 2021-28, Reactor Pressure Vessel Surveillance Program Criteria, Nuclear Safety and Security Commission, August 2021.

[2]NRC Regulatory Issue Summary (RIS) 2014-11, “Information on Licensing Applications for Fracture Toughness Requirements for Ferritic Reactor Coolant Pressure Boundary Components,” U.S. NuclearRegulatory Commission, October 2014. [Agencywide Documents Access and Management System (ADAMS) Accession Number ML14149A165]

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