Ex-Vessel Neutron Dosimetry Program of Ulchin Unit 4

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1. Introduction

This paper presents the analysis of the first Ex-Vessel Neutron Dosimetry (EVND) set of the Unit 4. The analysis is part of the comprehensive EVND surveillance program in all PWRs in Korea. Currently, EVND sets are installed in 16 PWR operating in Korea and dosimetry sets have been analyzed. On the other hand, unique design features arising from the KSNP's cavity configuration as well as special transport analysis considerations are discussed in this paper. Because of the geometrical similitude of the KSNPs, the design considerations of the Ulchin Unit 4 EVND are also applicable to the KSNP Yonggwang Units 3 through 6 and Ulchin Units 3, 5 & 6. The results show quantitative comparison between the analytical results and the dosimetry measurements irradiated during cycle 9.

The Code of Federal Regulations, Title 10, Part 50, Appendix H, requires that neutron dosimetry be present to monitor the reactor vessel throughout plant life and that material specimens be used to measure damage associated with the end-of-life fast neutron exposure of the reactor vessel. The EVND Program at Korean PWRs has been designed primarily to provide a long term monitoring of fast neutron exposure distributions within the reactor vessel wall that could experience significant radiation induced increases in reference nil ductility transition temperature (RT_{NDT}) over the service lifetime of the plant. When used in conjunction with dosimetry from internal surveillance capsules and with the results of neutron transport calculations, the EVND measurements allow the projection of embrittlement gradients with a minimum uncertainty.

Through plant walk downs it was determined that conventional installation from the nozzle gallery was not possible due to the fact that the reactor vessel insulation support C-channels are welded to the bottom of the Upper Lateral Support, thus, precluding the lowering of EVND support chains. A solution was developed that would required the installation crew to access the cavity space at the elevation of the active core. The resulting high dose level environment placed a premium at rapid installation features.

2. Methods

There are four resin columns, each with two ex-core detector channels, in the Ulchin Unit 4. The EVND support hardware built around the resin column is located well above the axial height of the detectors and thus presents no potential interference. However, in order to ensure that there was no significant neutronic interaction between the EVND support hardware and the ex-core detectors in the silicon-resin-filled canisters, neutron transport calculations were performed. The calculations included two models of 1/8 of the reactor core with the reactor cavity, including a silicon-resin-filled steel canister surrounding the two ex-core detectors: with and without a 1/4″ thick layer of Titanium to the outside of the steel canister. The Titanium support frame only covers a little portion of the area over the effective height of the ex-core detectors. Thus, the postulated maximum effect on any ex-core detector signal would be much less than the normal cycle-by-cycle variation seen by the ex-core detectors as a result of differences due to changes in core loading patterns.

For the dosimetry evaluation, calculations were performed with the RadTrack^{TM} Code System [1]. RadTrack uses the 3D flux synthesis method described in US NRC Regulatory Guide 1.190 [2]. A plant- and cycle-specific library of flux data is constructed within RadTrack using radial and axial power distributions, fuel design specifications, system pressure and temperatures. The geometric model upon which the transport model is based is represented in Figure 1 and 2. The broad group cross section library is based on BUGLE-96 [4]. The flux library obtained synthesizing DORT [5] [r], [r,θ] and [r,z] solutions is interrogated by RadTrack to obtain the accrued fluence and fluence projections at key locations within the reactor geometry, such as the surveillance capsules, EVND chains and the pressure vessel clad/base metal interface.

A least square adjustment method [3] combining measurement data with the corresponding neutron transport calculations is used to establish a best estimate spectrum and an estimate of the applicable uncertainties at the locations of measurement. Result of dosimetry evaluations using SNLRML [6] dosimetry cross-section data. A similar comparison for calculated (C) and best estimate (BE) exposure rate expressed in terms of neutron (E > 1.0 MeV) flux and iron atom displacement rate (dpa/s) are summarized in Table 1.

TABLE 1– Fast Neutron Exposure Least-Squares Best Estimates-to-Calculated Ratios for In-Vessel, Midplane Ex-Vessel and Combine Data Base

Exposure Parameter	*In-Vessel*	*Midplane Ex-Vessel*	*Combined*	
	Average BE/C	*Average BE/C*	*Average BE/C*	*Unc. (1σ)*
Flux (E >1.0MeV)	0.99	1.09	1.04	7.3
dpa/s	0.99	1.15	1.07	10.6

From the gradient measurement activity results compared to the calculated predictions, it becomes apparent that EVND instrument is located axially shifted to lower position compared to the expected design elevation. Nevertheless, the possible shift of gradient chains in axial direction has negligible impact on the analysis results for the ex-vessel neutron dosimetry sensors at the core midplane since the cycle-average neutron flux profile is flat in the center part of the beltline region with little change in the energy spectrum shape.

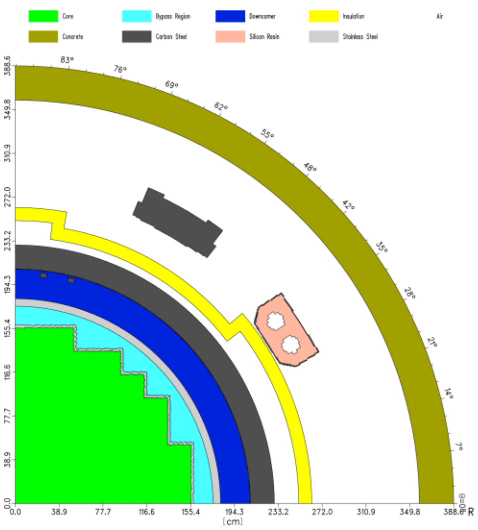

FIG. 1–[r, θ] model of the Ulchin Unit 4 reactor

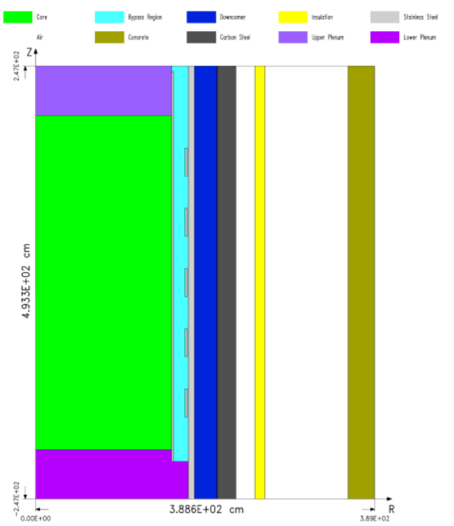

FIG. 2–[r,z]model of the Ulchin Unit 4 reactor

3. Results and Conclusion

The EVND Program is designed to provide verification of fast neutron exposure distributions within the reactor vessel wall and to establish a mechanism to enable long term monitoring of the reactor vessel and vessel support structure that could experience significant radiation induced increases in reference nil ductility transition temperature (RT_{NDT}) over the lifetime of the plant. EVND supplements the measurement data obtained from the in-vessel surveillance capsules, thus providing a large comprehensive plant-specific database. When used with in-vessel dosimetry capsules and results of neutron transport calculations, EVND measurements allow projections of embrittlement gradients through the reactor vessel wall with minimum uncertainty. In turns, minimizing uncertainty in the neutron exposure projections helps to assure that the reactor can be operated in the least restrictive mode possible with respect to regulatory constrains.

On the other hand, for this particular type of plant and EVND design, where crew installation occurs at active core elevation, design constrains place a premium a rapid installation features. Complex geometrical features of the cavity warranted the use of true three-dimensional CAD engine which allow the designer to perform interference control and also to subsequently train crew personnel. Finally, a full mockup was constructed and training was developed to maximize the crew ability to correctly install the instrument in minimum time.

In conclusion, a complete EVND system for KNSP plants has been successfully designed, installed and analyzed for Ulchin Unit 4. Current and future EVND analyses will be supporting the continuous successful operation of PWR units in Korea.

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