*Transactions of the Korean Nuclear Society Autumn Meeting*
*Gyeongju, Korea, October 25-26, 2012*

# Ex-Vessel Neutron Dosimetry Analysis of Korea Standard Nuclear Plants

MiJoung LIM[a], ByoungChul KIM[a], KyungSik KIM[a], YoungKyou JEON[a], YoungJae MAENG[a], ChoonSung YOO[b]
*a Korea Reactor Integrity Surveillance Technology, 150 Dukjin-dong, Yuseung-gu, Daejeon, 305-353 Korea*
*b Korea Atomic Energy Research Institute, 150 Dukjin-dong, Yuseung-gu, Daejeon, 305-353 Korea*
*nuclear0802@hanmail.net,*

## 1. Introduction

The Code of Federal Regulations (CFRs), Title 10, Part 50, Appendix H [1], 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. Currently, Ex-Vessel Neutron Dosimetry (EVND) sets are installed in 16 operating pressurized water reactors (PWRs) in Korea, and of which YongGwang (YG) Units 3, 4, 5, & 6 and UlChin (UC) Units 3, 4, 5, & 6 are Korea Standard Nuclear Plants (KSNPs). The EVND Program has been designed primarily to meet the code and 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. The EVND sets installed have been analyzed regularly according to the plant specification, which is a part of the comprehensive EVND surveillance programs, in all 16 operating PWRs.

The objective of this study is therefore to present and discuss the first analysis results of the sets of 8 KSNP reactors.

## 2. Role and Installation of EVND System

EVND system is consisted of capsules and bead chains and the location of the system is shown in Fig. 1. The bead chains made of stainless steel also monitors the axial gradient neutron fluence, so it is called bead chain dosimetry. The chain is connected to the axial neutron flux monitoring capsules. Fe, Ni and Co elements in the bead chain dosimetry are used to determine the neutron fluence gradients in the axial direction. The chain can get accurate neutron energy spectrum shape over the beltline region.

There are four resin columns, each with two ex-core detector channels, in the KSNP's. 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.

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 require 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.

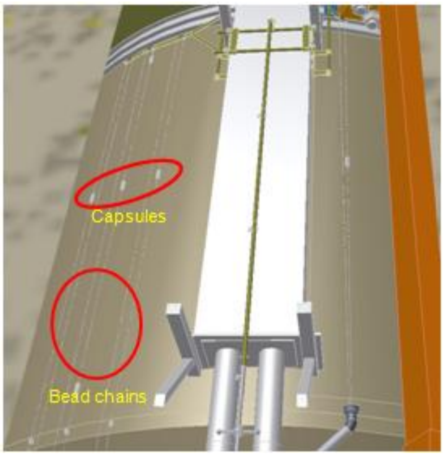


*Fig.1 – EVND system installed at the outer surface of the Korea Standard Nuclear Plant reactors*

## 3. Analysis method

For the dosimetry evaluation, calculations were performed with the RadTrack™ Code System [2]. RadTrack uses the 3D flux synthesis method described in US NRC Regulatory Guide 1.190 [3]. 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 Fig. 2 and 3. 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.

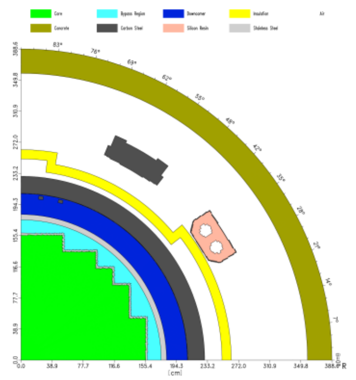

*Fig.2 –[r, θ] model of the Korea Standard Nuclear Plant reactors*

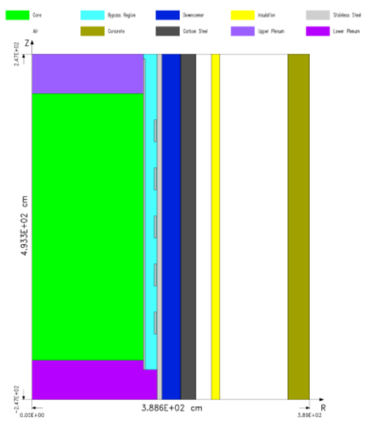

*Fig.3 –[r, z] model of the Korea Standard Nuclear Plant reactors*

A least square adjustment method [6] combining measurement data with the corresponding neutron transport calculations is used to establish the best estimate spectrum and an estimate of the applicable uncertainties at the locations of measurement.

## 4. Results and Discussion

Result of dosimetry evaluations using SNLRML [7] dosimetry cross-section data and a similar comparison for calculated (C) and best estimate (BE) exposure rate expressed in terms of neutron (E > 1.0 MeV) flux is summarized in Table 1.

*TABLE 1–Fast Neutron Exposure Least-Squares Best Estimates-to-Calculated Ratios for Data Base*

| *Exposure Parameter* | *Average BE/C* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *YG3* | *YG4* | *YG5* | *YG6* | *UC3* | *UC4* | *UC5* | *UC6* |
| *In-Vessel Flux(E>1.0MeV)* | *0.97* | *0.90* | *0.93* | *0.95* | *0.92* | *0.92* | *N/A* | *N/A* |
| *Ex-Vessel Flux(E>1.0MeV)* | *1.07* | *1.03* | *1.08* | *1.05* | *1.05* | *1.09* | *1.00* | *1.08* |
| *Combined Bias Flux(E>1.0MeV)* | ***1.02*** | ***0.97*** | ***1.00*** | ***1.00*** | ***0.99*** | ***1.00*** | *N/A* | *N/A* |

BE/C surveillance capsule (in-vessel) values of the KSNPs were lower than 1.0. but EVND (ex-vessel) verification results of the BE/C value were higher than 1.0. As results of the reactor vessel surveillance capsules, neutron fluence evaluation was very likely to be under estimated. Therefore, by utilizing EVND passed through the reactor wall thickness and neutron fluencies measured at the in-vessel, more reliable reactor vessel neutron evaluation was possible. The results showed quantitative comparison between the analytical evaluations and the dosimetry measurements irradiated during the corresponding operating cycle while installed

## 5. Conclusion

Based on the in-vessel surveillance and EVND analysis of 8 KSNP reactors, followings were concluded:

1) EVND supplements the measurement data obtained from the in-vessel surveillance capsules, and thus provides a large comprehensive plant-specific database.
2) 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.
3) Combined bias of two results is the most reliable best estimated neutron fluence. 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.

## References

1. The Code of Federal Regulations (CFRs), Title 10, Part 50, Appendix H, “Reactor Vessel Material Surveillance Program Requirements,” USNRC
2. G. A. Fischer, “RadTrack: An Automated Tool for Tracking the Radiation Environment in LWRs, Version 1.1,” WCAP-16558-NP, Revision 1, Westinghouse Electric Company LLC, 2008.
3. US NRC Regulatory Guide 1.190, “Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence,” 2001.
4. RSICC Data Library Collection DLC-185, “BUGLE-96, Coupled 47 Neutron, 20 Gamma-Ray Group Cross Section Library Derived from ENDF/B-VI for LWR Shielding and Pressure Vessel Dosimetry Applications,” 1996.
5. RSICC Computer Code Collection CCC-650, “DOORS 3.2, One-, Two-, and Three- Dimensional Discrete Ordinate Neutron/Photon Transport Code System,” 1998.
6. S. L. Anderson, “Benchmark Testing of the FERRET Code for Least Squares Evaluation of Light Water Reactor Dosimetry,”WCAP-16558-NP-A, Revision 0, Westinghouse Electric Company LLC, 2006.
7. RSICC Computer Code Collection DLC-178, “SNLRML, Recommended Dosimetry Cross-Section Compendium,” 1994.