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Comparison of 2D and 3D Neutron Transport Analyses on Yonggwang Unit 3 Reactor

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1. Introduction

10 CFR Part 50 Appendix H [1] requires periodical surveillance program in the reactor vessel (RV) beltline region of light water nuclear power plant to check vessel integrity resulting from the exposure to neutron irradiation and thermal environment. Exact exposure analysis of the neutron fluence based on right modeling and simulations is the most important in the evaluation. Traditional 2 dimensional (D) and 1D synthesis methodologies have been widely applied to evaluate the fast neutron (E > 1.0 MeV) fluence exposure to RV. However, 2D and 1D methodologies have not provided accurate fast neutron fluence evaluation at elevations far above or below the active core region.

RAPTOR-M3G (RApid Parallel Transport Of Radiation - Multiple 3D Geometries) program for 3D geometries calculation was therefore developed both by Westinghouse Electronic Company, USA and Korea Reactor Integrity Surveillance Technology (KRIST) for the analysis of In-Vessel Surveillance Test and Ex-Vessel Neutron Dosimetry (EVND). Especially EVND which is installed at active core height between biological shielding material and concrete also evaluates axial neutron fluence by placing three dosimetries each at Top, Middle and Bottom part of the angle representing maximum neutron fluence. The EVND programs have been applied to the Korea Nuclear Plants.

The objective of this study is therefore to compare the 3D and the 2D Neutron Transport Calculations and Analyses on the Yonggwang unit 3 Reactor as an example.

2. 2D and 1D Methods

DORT code has been widely applied for 2D and 1D transport calculations and analyses. Traditional 2D and 1D Synthesis code uses 2D or 1D transport solution for a cylindrical reactor model with 3D neutron flux distribution (Eq. 1) described in US Regulatory Guide 1.190 [2]:

$$\phi(r,\theta,z) = \phi(r,\theta) \cdot [\phi(r,z) / \phi(r)] \cdots\cdots (1)$$

Where, $\phi(r,\theta,z)$: Synthesized 3D (r,θ,z) neutron flux distribution

$\phi(r,\theta)$: Transport solution in 2D (r,θ) geometry

$\phi(r,z)$: 2D transport solution for a cylindrical reactor model using the actual axial core power distribution

$\phi(r)$: 1D transport solution for a cylindrical reactor model using the same source per unit height as that used in the 2D (r,θ) calculation

US Regulatory Guide 1.190 requires multi-channel form of Eq. 1 when a strong axial heterogeneity exists due to the presence or absence of the neutron pad in the top or bottom during Neutron Transport Calculations and Analyses, which is a little more difficult and complex.

3. 3D Method

RAPTOR-M3G is a parallel and deterministic radiation transport code [3] for 3D calculations and analyses. The code requires raptor.inp file, sorcery.inp file, and x-section.inp file. The raptor.inp file does not need each model along with present or absence of certain structure. Mesh bodies of i, j and k coordinate in raptor.inp file are produced by BOT3P-GGTM [4] and are easily checked by applying TECPLOT 360 [5]. The model can be produced step by step and also easily revised to provide fine or coarse meshes and removed useless meshes in the interested regions. Fig. [1] shows 3D mesh modeling using TECPLOT 360 as sample.

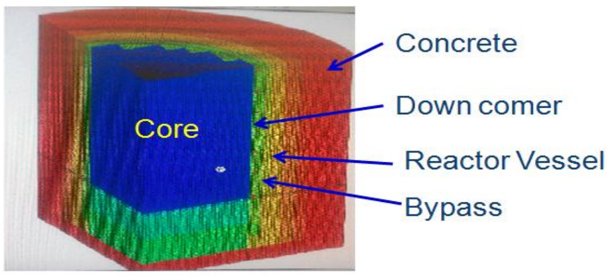

Fig. [1] 3D mesh modeling using TECPLOT 360 as sample. (Baffle, Former plate, Cladding, Air gap, Insulation, etc. are also included)

Modeling with 3D meshes is too big to run with limited computer processors. The beauty of RAPTOR-M3G is to keep the capacity size small enough to be tackled by the parallel computing system, which turns out to be decreased 3D models to be able to run on 64 computer processors with adequate fine mesh structures and save of calculation time by using these parallel processing techniques.

4. 3D & 2D Dosimetry Calculations and Analyses

The ratios between measured and calculated (M/C) results of 2D and 3D analyses for the 1st EVND (7 degree location) of Yonggwang Unit 3 as an example are shown in Table 1 and Table 2 respectively [6].

Table 1. Ratios of M/C results from 2D analysis
[1st EVND (7 degree location) of Yonggwang Unit 3]

Reaction	Top	Middle	Bottom
Cu63(n,α)Co60	0.96	0.97	0.77
Fe54(n,p)Mn54	1.01	1.03	0.87
Ni58(n,p)Co58	1.05	1.00	0.85
Ti46(n,p)Sc46	1.00	0.97	0.85
U238(n,f)Zr95	1.23	1.16	1.00
Avg.	**1.05**	**1.03**	**0.87**

Table 2. Ratios of M/C results from 3D analysis
[1st EVND (7 degree location) of Yonggwang Unit 3]

Reaction	Top	Middle	Bottom
Cu63(n,α)Co60	0.96	0.97	0.78
Fe54(n,p)Mn54	1.00	1.02	0.94
Ni58(n,p)Co58	1.05	0.99	0.93
Ti46(n,p)Sc46	1.00	0.96	0.87
U238(n,f)Zr95	1.18	1.09	1.08
Avg.	**1.04**	**1.01**	**0.92**

US Regulatory Guide 1.190 allows 30% of uncertainty (or deviation) on the M/C ratios in ex-vessel [2]. As shown in Table 1 and 2, the values at top and middle regions were within 5% in both 2D and 3D and value in bottom region was 13% in 2D and 8% in 3D. Thus all data met the Guide. 3D analysis by RAPTOR-M3G code provided better agreement between measured and calculated values than 2D in all regions. 3D results showed close to 1.0, compared to 2D, which implied better accuracy.

The reason to get the M/C ratio of 1.0 in all regions, especially top and bottom, is to simply get the better accuracy and exact analysis at elevations above and below active core. top and bottom regions have not showed good M/C ratio in 2D, even though all data met the Guide. However 3D shows better M/C ratio, so exact and uniform analysis could be acquired by applying RAPTOR-M3G code. This is particularly important because 3D analysis by RAPTOR-M3G code could apply to the irregular structures (nozzle, etc) and strong local neutron effect regions (internal structures like baffle and former plate, etc).

5. Conclusion

1) 3D analysis by RAPTOR-M3G code shows better agreement between calculated and measured results and also provides better accuracy than 2D analysis.
2) It is strongly required to apply 3D analysis by RAPTOR-M3G code for future reactor vessel evaluations in terms of accuracy.
3) Because of the accurate evaluation by RAPTOR-M3G code with 3D, the code can be well applied especially to the irregular and strong local neutron effect regions.

**** RAPTOR-M3G code***

:Up-to-date code developed both by Westinghouse Electronic Company, USA and Korea Reactor Integrity Surveillance Technology (KRIST).
:Only code for 3D analysis of reactor vessel and reactor internal structures.
:Under being reviewed by the US NRC for licensing.
:KRIST is the only organization to hold and operate the code in Korea.

References

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