RAMA Fluence Methodology - H.B. Robinson Unit 2 Cycle 9 Dosimetry and RPV Flux Comparisons

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INTRODUCTION

Plant life extension has created a growing need to predict best-estimate fluence for the RPV and other reactor internals for 60 years of plant operations and beyond. To address this need, EPRI and the BWRVIP funded TransWare to develop an advanced three-dimensional methodology for modeling reactor systems and predicting neutron fluence. The methodology, referred to as RAMA Fluence Methodology (RAMA), has been approved by the U. S. NRC for fluence applications in accordance with Regulatory Guide 1.190. RAMA has been validated against several industry benchmarks and applied to several commercial boiling water reactors (BWRs). The methodology has been shown to produce accurate results with zero bias across a broad spectrum of experimental and commercial reactor designs, and with no multiplicative adjustments to the data or the results.

The RAMA Fluence Methodology has also been applied to several pressurized water reactor (PWR) designs, with results comparable to the BWRs. To further demonstrate RAMA's capability with PWRs, TransWare is evaluating several measurements taken from the H. B. Robinson Unit 2 (HBR2) reactor. A 3D model of HBR2 was developed with RAMA and calculated fluxes were compared to measurements and calculations reported by others using different methods.

PROBLEM DESCRIPTION

NUREG [1] describes the HBR2 benchmark, including dimensions, material compositions, and neutron source data. HBR2 is a 2300 MWth 3-loop Westinghouse PWR with 157 assemblies and is owned by Progress Energy.

The dimensional and material information was provided for an octant of the HBR2 reactor starting from the center of the core out to and including the biological shield. Axial data was provided at about 213 cm above and below the core mid-plane.

The neutron source was described as a cycle average state-point and as 8 individual state-points. The source data was provided as 2D bundle-by-bundle radial distribution, 12 node axial distribution per bundle, and 2D pin-by-pin distribution per bundle for each state-point.

For irradiation during cycle 9 only, a special surveillance capsule was installed at the 20^{o} azimuth and cavity dosimeters were added at the 270^{o} azimuth. Activity measurements were taken after the cycle 9 irradiation and are reported in [1].

Calculated azimuthal fast fluxes (E > 1MeV) at the inner surface of the RPV are reported at the core mid-plane in [3].

RAMA FLUENCE MODEL

The RAMA fluence model was based on the described benchmark dimensions and materials. The fluence model represents the north-northeast octant of the reactor, which contains the surveillance capsule. Using symmetry, the dosimeter set at 270^{o} is represented in the model at 0^{o}.

The neutron source, which was provided as bundle-average values, was unfolded to provide pin-by-pin data for each of the 12 axial heights. The source data was then expanded to 24 axial heights using a Lagrangian polynomial interpolation method.

The top and bottom surfaces of the model, along with the radial boundary beyond the biological shield, use vacuum boundary conditions. The 0^{o} and 45^{o} boundaries are reflective.

DOSIMETRY RESULTS

Several activation measurements were taken from HBR2 at the end of cycle 9, including surveillance capsule and cavity dosimetry. Table 1 shows the calculated-to-measured (C/M) ratios of 6 different specific activities for the surveillance capsule and cavity dosimeters at the core mid-plane.

TABLE I. DORT and RAMA C/M ratios				
	Sur. Capsule		**Cavity**	
Dosimeter	**DORT**	**RAMA**	**DORT**	**RAMA**
^{237}Np (*n,f*) ^{137}Cs	0.92	0.98	0.61	0.75
^{238}U (*n,f*) ^{137}Cs	0.89	0.93	0.82	0.99
^{58}Ni (n,p) ^{58}Co	0.96	0.88	0.97	1.03
^{54}Fe (n,p) ^{54}Mn	0.93	0.91	0.96	1.07
^{46}Ti (n,p) ^{46}Sc	0.85	0.83	0.90	0.99
^{63}Cu (n,α) ^{60}Co	0.93	0.91	0.96	1.06
Average	**0.91**	**0.91**	**0.87**	**0.98**
Stand. Dev.	**0.04**	**0.05**	**0.14**	**0.12**
Average*	**N/A**	**N/A**	**0.92**	**1.03**
Stand. Dev.*	**N/A**	**N/A**	**0.06**	**0.04**
* Excludes neptunium C/M ratio				

In [1], DORT, BUGLE-96, and the flux synthesis method were used to calculate the specific activities for the HBR2 benchmark. Table I show their C/M ratios along side RAMA's 8 state-point C/M ratios.

Corrections are made to the specific activity of neptunium and uranium for photo-fission, and copper is corrected for cobalt impurities.

FLUX RESULTS

RAMA allows fluxes to be edited from the exact elevational, radial, and azimuthal locations as reported in [3]. Table II and Figure 1 show a comparison of the azimuthal fluxes from RAMA and [3]. Also shown in Table II, the RAMA fluxes are ~20% lower, on average. Figure 1 shows a comparison of the azimuthal shape of the flux profiles from RAMA and [3].

The fluxes reported in [3] are taken from an additional source [4] and no information is given regarding the model used to produce the fluxes.

However, TransWare assumes that the operating history, dimensions, and materials used in the WCAP-14151 model are similar values to those obtained from [1], thereby allowing comparison of the results.

TABLE II. Comparison of RAMA and RNP-F Fast Fluxes for E > 1 MeV (n/cm^2-s)

Azimuth (Deg.)	Fast Flux (E > 1 MeV) RAMA	RNP-F	RAMA/ RNP-F
0	3.24E+10	4.15E+10	0.78
3	3.18E+10	4.01E+10	0.79
5	3.04E+10	3.92E+10	0.78
9	2.61E+10	3.37E+10	0.77
10	2.47E+10	3.23E+10	0.76
12	2.19E+10	2.95E+10	0.74
15	1.90E+10	2.52E+10	0.75
20	1.66E+10	2.31E+10	0.72
25	1.70E+10	2.23E+10	0.76
27	1.63E+10	2.12E+10	0.77
30	1.51E+10	1.96E+10	0.77
35	1.20E+10	1.63E+10	0.74
40	1.07E+10	1.30E+10	0.82
45	1.03E+10	1.22E+10	0.84
		Average Ratio	**0.77**

DISCUSSION OF RESULTS

Both methodologies showed similar trends in the analysis of the surveillance capsule activities.

In [1], the authors cite the neptunium activity in the cavity dosimeter as suspicious. They present their average without that activity. The RAMA average with and without neptunium is presented in Table I.

In general the RAMA comparison to measurements is closer than DORT's for the cavity dosimeters. This could be from a multitude of reasons. The RAMA model has more accurate geometry in the detector well. The steel wall cylinder directly behind the cavity dosimeter set was modeled as a rectangular box in DORT, but was modeled as a cylinder in RAMA. DORT is not a true 3D transport code, and as such, RAMA may more accurately transport the neutrons through the thick reactor pressure vessel.

Comparison of the fluxes calculated by RAMA are shown to be ~20% lower than the predicted fluxes in [3]. Consequently, the predicted fluence in the RPV should be lower. The consistency of the differences between the fluxes and the similar shapes of the curves in Figure 1 indicate that both methods are producing a similar flux profile for the pressure vessel surface at the core mid-plane.

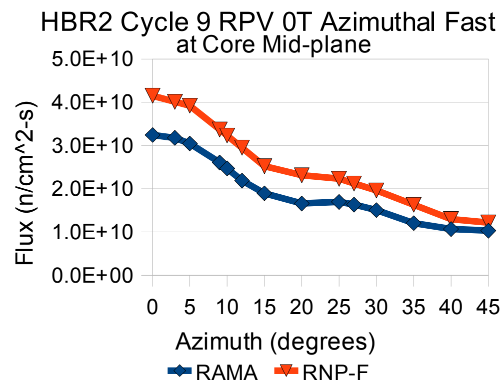

FIGURE 1. Comparison of RAMA and RNP-F Fast Fluxes at RPV Inner Surface at Core Mid-plane

The benchmarking of the RAMA Fluence Methodology against the surveillance capsule and cavity dosimetry combined with the flux comparisons indicates that RAMA may be able to provide significant savings in a pressure vessel fluence analysis versus the methods used to produce the fluxes in [3].

With the support of Progress Energy, additional work is underway to fully characterize the axial dependencies of the HBR2 reactor for the purpose of evaluating additional measurements taken from various axial elevations in the cavity region. These results will be presented in a future paper.

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