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SENSITIVITIES OF THE FLUX SPECTRUM IN THE CAVITY OF A PWR TO VARIATIONS IN THE CORE SOURCE DISTRIBUTION

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SENSITIVITIES OF THE FLUX SPECTRUM IN THE CAVITY OF A PWR TO VARIATIONS IN THE CORE SOURCE DISTRIBUTION

B. L. Broadhead and R. E. Maerker

As a part of an ongoing, EPRI-sponsored project whose aim is the quantification and reduction of fluence uncertainties in the pressure vessel of operating PWR's, this work describes the calculation of sensitivities necessary for the propagation of PWR core source distribution uncertainties to the flux spectrum at locations of interest (e.g., the cavity or T/4 pressure vessel locations) in the ANO1 reactor. In this case standard perturbation theory[1] requires an adjoint run to be made for each group flux since each group flux is a response. An alternate approach has been developed by Cacuci[2] which should be more efficient than the standard approach although it has not yet been applied to a flux spectrum response.

The standard perturbation theory approach was utilized in this study since, due to the deep penetration of core source neutrons through the reactor internals, water gap and pressure vessel, only the top few source groups contribute appreciably to the detector responses in the pressure vessel and cavity locations. Evidence of this effect is seen in Table 1, where the sensitivity of the flux in the ANO1 cavity position to the ^{235}U fission spectrum is given. The matrix was produced by a series of 1-D adjoint calculations where each of the group fluxes was treated as a response separately.

Note that for the top several groups the relative sensitivities are near 1.0 for the diagonal elements. This indicates that the flux in the cavity for these groups comes primarily from its corresponding source group. This is not the case for the other groups, however. For flux groups 5-24, the sensitivities tend to "saturate" and their values change very little from row 5 down to row 24. A peak in the sensitivity is also seen for flux groups 5-24 to the source groups 3-5. This indicates that the flux in groups 5-24 is due primarily to downscatter from the source neutrons in groups 3-5. Thus, it appears adjoints need to be calculated only for the top 5 flux groups in this application. So far we have only mentioned the energy dependence of the sensitivities under consideration. However, a previous two-dimensional study[3] has shown that the spatial distribution of the adjoint flux is relatively insensitive to the dosimeter response. Therefore, the remaining 2-D adjoints (i.e., those for flux groups 6-24) can be approximated by a renormalization of the group 5 adjoint.

As a final test of this assumption, a 2-D adjoint run was performed for group 7 of the 24 group structure. At selected spatial intervals the group 7 adjoint should compare favorably with corresponding values of the renormalized group 5 adjoint, where from previous work[3] the normalization factor is the ratio of the forward-calculated responses, ϕ_7/ϕ_5. Shown in Table 2 is the comparison of scaled vs. actual adjoint fluxes at selected points in the core. In this case, the adjoint flux in group 4 corresponding to an adjoint source of 1.0 in group 5 was scaled to estimate the adjoint flux in group 4 due to a source of 1.0 in group 7. The scaling of the adjoint fluxes as seen in Table 2 produces accuracies of 6-13%. If in addition, we note that the corresponding 1-D sensitivities also differ and take the ratio of the corresponding elements of the matrix in Table 1 as an additional scaling factor (i.e., element 5, 4 = .37 and element 4, 7 = .34) the resulting differences between the scaled and actual adjoint fluxes now range from 2-5%. Since the sensitivities are simple functions of these adjoint fluxes, the accuracy of the scaled sensitivities should be near 5% or better.

With this procedure the sensitivities of all the detector group fluxes to the source distribution in space can be computed to within 5% with only 5 two-dimensional adjoint runs. The remaining adjoints can be produced by a simple scaling of the group 5 adjoint.

Table 1. Relative Sensitivity Matrix for ANO1 Cavity Flux to ^{235}U Fission Spectrum

Flux Group	E(upper) MeV	Source Group 1	2	3	4	5	6	7	8
1	19.64	1.0							
2	11.05	0.14	0.86						
3	8.19	0.05	0.27	0.68					
4	6.07	0.04	0.17	0.38	0.41				
5	4.07	0.04	0.17	0.34	0.37	0.08			
6	3.01	0.04	0.16	0.31	0.35	0.12	0.02		
7	2.59	0.03	0.14	0.28	0.34	0.13	0.05	0.04	
8	2.12	0.03	0.14	0.28	0.33	0.13	0.05	0.03	
9	1.83	0.03	0.13	0.27	0.33	0.13	0.06	0.04	
10	1.50	0.03	0.12	0.26	0.34	0.14	0.06	0.04	0.01
11	1.22	0.02	0.12	0.26	0.34	0.14	0.06	0.04	0.01
12	0.91	0.02	0.11	0.25	0.34	0.14	0.06	0.05	0.01
13	0.61	0.02	0.11	0.25	0.34	0.14	0.06	0.05	0.01
14	0.37	0.02	0.11	0.25	0.35	0.14	0.06	0.05	0.01
15	0.21	0.02	0.11	0.25	0.35	0.14	0.06	0.05	0.01

Groups 16-24 same as Group 15 above

Table 2. Comparison of Scaled vs. Actual Adjoint Fluxes at Selected Points in the Core of AN01

Interval† (I,J)	ϕ^*7,4††	ϕ^*7,4 (scaled)†††	% difference
30,1	1.553-8‡	1.644-8	5.5 (3.0)#
31,6	2.824-8	3.210-8	12.0 (4.1)
27,23	8.584-9	9.872-9	13.0 (5.2)
33,38	2.759-8	3.081-8	10.5 (2.4)

‡Read 1.553-8 as 1.553×10^{-8}.

†These intervals correspond to the outermost interval of the peripheral assemblies corresponding to azimuthal values of 0°, 11°, 23° and 36°.

††Corresponds to the adjoint flux in group 4 due to a source of 1.0 in group 7.

†††$\phi^*_{5,4}$ scaled by the factor ϕ_7/ϕ_5.

#Numbers in parentheses represent percent differences including a second scale factor taken from Table 1 as described in the text.

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