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DR. 2178

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Contract No. W-7405-eng-26

Engineering Physics Division

COMPARISON OF ONE- AND TWO-DIMENSIONAL CROSS-SECTION SENSITIVITY
CALCULATIONS FOR A FUSION REACTOR SHIELDING EXPERIMENT*

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Date Published: January, 1979

*Submitted for
Journal publication

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ABSTRACT

Cross-section sensitivities calculated with one- and two-dimensional models of a fusion reactor shielding experiment are compared. The effectiveness of the 2-D calculation in accurately modeling the experiment and detector configurations is demonstrated. At the same time the validity of a 1-D sensitivity study is also demonstrated.

I. INTRODUCTION

A one-dimensional (1-D) cross-section sensitivity study¹ was conducted for the fusion reactor shielding experiments presently underway at the Oak Ridge National Laboratory. Similar cross-section sensitivity analyses² of a scheduled streaming experiment have also been performed using a two-dimensional (2-D) calculational methodology based on the computer program VIP³. The 2-D sensitivity code was developed and tested by R. L. Childs et al., for deep-penetration problems in sodium and for infinite air calculations and compared with 1-D calculations. Agreement was reported to be satisfactory in both cases³.

This note describes another comparison of a 1-D and 2-D sensitivity study for a fusion reactor shielding experiment with an ~ 30 cm thick stainless steel slab as the basic shielding material. The calculated 1-D and 2-D sensitivities of an NE-213 detector response to the cross sections of the component materials of the steel are compared. This comparison is intended to show the important features of the 2-D model and at the same time to test the validity of a 1-D calculational model which was also used to preanalyze the experiment.

Section II describes the 1-D spherical and 2-D cylindrical models used in the calculations. The differences between the calculational models are pointed out and the methods of calculation are briefly described. Section III presents a comparison of the material zone integrated sensitivity values and sensitivity profiles for the 1-D and 2-D calculations. A brief summary of the results together with conclusions is given in Section V.

II. CALCULATIONAL MODELS AND METHODS

II.1. Calculational Models

Figures 1a and 1b show the 1-D spherical model and 2-D cylindrical model, respectively, used in the calculations. In Fig. 1b, the 7.5 cm thick iron region partially surrounding the source is called the source can and the large mass of concrete supporting the source can is called the bulk concrete. The stainless steel slab between the detector and the room wall is called the back shield. Major differences in the 1-D and 2-D calculational models are summarized in Table I.

II.2. Calculational Methods

A coupled macroscopic $45n-16\gamma$ group cross section set obtained from the $171n-36\gamma$ energy group library, DLC-41⁷ was used in both calculations. The neutron response function of the NE-213 detector described in Ref. 2 was used as the adjoint source for both 1-D and 2-D adjoint flux calculations. A review of the different computer codes, approximations and resulting agreement of forward and adjoint integrated responses for the 1-D and 2-D calculations are presented in Table II.

III. COMPARISON OF THE SENSITIVITIES

Table III compares the 1-D and 2-D calculated cross section sensitivities of the NE-213 detector response. The ratios of 1-D and 2-D calculated sensitivities to the total cross sections, Σ_t , and the absorption cross sections, Σ_a , are shown in the last two columns. These ratios take on various values ranging from -1.0 to 4.40, but the absolute magnitude of the sensitivities agree fairly well between the corresponding 1-D and 2-D model. The agreement is particularly good ($\sim 6\%$) for the sensitivity to Σ_t of the stainless steel shield. Since these sensitivities are the

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Fig. 1 (a) One-dimensional spherical model. (b) Two-dimensional cylindrical model.

Table I. Major Differences in the 1-D and 2-D
Computational Models

	1-D	2-D
Geometry	Sphere	R-Z cylinder
Iron source liner	Spherical shell	Half closed annulus
Detector shape	Spherical shell	Thin hoop
Bulk concrete	Not included	Large amount near the detector

Table II. The 1-D and 2-D Computational Methods

	1-D	2-D
Transport calculation	ANISN ⁽⁴⁾	DOT - 3.5 ⁽⁵⁾
P_L-S_N approximation	P_3-S_{12}	P_3-S_8
$\langle\phi\phi^*\rangle$ calculation	JULIET-FLUX ⁽⁶⁾	VIP ⁽³⁾
Sensitivity calculation	FORSS ⁽⁶⁾	FORSS ⁽⁶⁾
Agreement between R and R*	$\sim 0.8\%$	$\sim 0.3\%$

R and R* are the integrated response for the forward and adjoint calculations.

Table III. Comparison of the 1-D and 2-D Sensitivities

Material	1-D Sensitivity to Σ_t , $S_n(\Sigma_t)_1$	1-D Sensitivity to Σ_a , $S_n(\Sigma_a)_1$	2-D Sensitivity to Σ_t , $S_n(\Sigma_t)_2$	2-D Sensitivity to Σ_a , $S_n(\Sigma_a)_2$	$\frac{S_n(\Sigma_t)_1}{S_n(\Sigma_t)_2}$	$\frac{S_n(\Sigma_a)_1}{S_n(\Sigma_a)_2}$
30 cm SS shield	-3.653	-0.274	-3.894	-0.349	0.94	0.79
Iron source liner	-0.809	-0.112	-0.184	-0.041	4.40	2.73
Back shield	+0.053	-0.008	-0.053	-0.011	-1.00	0.73
Room wall	+0.0017	-0.0007	+0.0004	-0.0008	4.25	0.88
Bulk concrete	-	-	-0.330	-0.048	-	-

highest of any material in the experiment, this agreement is most significant. The comparison of the 1-D and 2-D calculated sensitivity profiles in Fig. 2a and 2b for Σ_t of the steel also show remarkably good agreement in the energy dependent importance of this cross section. These results certainly justify the use of 1-D calculations for preanalysis of these experiments in place of more accurate but costly 2-D calculations.

The sensitivity to the absorption cross sections Σ_a of the stainless steel shield is a little less than 1/10 that to Σ_t and therefore less important. The sensitivity to Σ_a of the steel shield for 1-D calculations is $\sim 20\%$ smaller than that for 2-D. This reduction is caused by the attenuation of source neutrons (~ 14 MeV) by the 7.5 cm thick iron source can which was placed between the source and the stainless steel shield in the 1-D calculational model (Fig. 1a). The source can is only partly

Fig. 2 (a) Sensitivity per unit lethargy to the total cross sections of the 30 cm stainless steel calculated by the 1-D model. (b) Sensitivity per unit lethargy to the total cross sections of the 30 cm stainless steel calculated by the 2-D model.

Fig. 3 (a) Sensitivity per unit lethargy to the absorption cross sections of the 30 cm stainless steel calculated by the 1-D model. (b) Sensitivity per unit lethargy to the absorption cross sections of the 30 cm stainless steel calculated by the 2-D model.

present between the source and shield in the case of the 2-D model (Fig. 1b). The net result of these modeling differences is a reduction in the number of neutrons coming into the steel shield in the 1-D model thereby reducing the source energy sensitivity seen in Figs. 3a and 3b. The sensitivity differences due to the iron source can are also clearly seen in the source can sensitivity results shown in Figs. 4a, 4b, 5a, and 5b. Here the source can is clearly $\sim 3-4$ times more important in the 1-D calculation than in the 2-D calculation. This fact suggests that a reduction in the thickness of the iron can to $\sim 1/3$ the present value may result in better simulation of the experiment by a 1-D model.

The sensitivity to the back shield made of stainless steel is less than $1/30$ that to the stainless steel shield (Table III). The positive value of the sensitivity to Σ_t of the back shield in the 1-D calculation is due to the neutrons backscattered into the detector by the back shield (Fig. 6a). In the case of the 2-D calculation, since the detector is finite in size compared to the 1-D model (Fig. 1a, 1b), the importance of backscattered neutrons decreases substantially. The positive sensitivity of backscattered neutrons being detected becomes smaller than the negative sensitivity of the neutrons moderated below the detection threshold energy of 750 keV. Thus, a net negative sensitivity occurs for neutron energies between 750 keV and 6 MeV as shown in Fig. 6b. The sensitivity to the room wall concrete is negligibly small, but in any event, the sensitivity profiles for 1-D and 2-D calculations again have an overall similarity in shape (Figs. 8a, 8b; 9a, 9b).

The sensitivity to the bulk concrete (not included in the 1-D model) is less than $1/10$ of that to the stainless steel shield for the 2-D calculation (Table III). This is so even with the detector placed very near the

Fig. 4 (a) Sensitivity per unit lethargy to the total cross sections of the iron source liner calculated by the 1-D model. (b) Sensitivity per unit lethargy to the total cross sections of the iron source liner calculated by the 2-D model.

Fig. 5 (a) Sensitivity per unit lethargy to the absorption cross sections of the iron source liner calculated by the 1-D model. (b) Sensitivity per unit lethargy to the absorption cross sections of the iron source liner calculated by the 2-D model.

Fig. 6 (a) Sensitivity per unit lethargy to the total cross sections of the back shield calculated by the 1-D model. (b) Sensitivity per unit lethargy to the total cross sections of the back shield calculated by the 2-D model.

Fig. 7 (a) Sensitivity per unit lethargy to the absorption cross sections of the back shield calculated by the 1-D model. (b) Sensitivity per unit lethargy to the absorption cross sections of the back shield calculated by the 2-D model.

Fig. 8 (a) Sensitivity per unit lethargy to the total cross sections of the room wall calculated by the 1-D model. (b) Sensitivity per unit lethargy to the total cross sections of the room wall calculated by the 2-D model.

Fig. 9 (a) Sensitivity per unit lethargy to the absorption cross sections of the room wall calculated by the 1-D model. (b) Sensitivity per unit lethargy to the absorption cross sections of the room wall calculated by the 2-D model.

bulk concrete (Fig. 1b). The sensitivity to the bulk concrete should be smaller for a detector placed farther from the bulk concrete, for instance, on the Z axis. Therefore, neglecting the bulk concrete in the 1-D model does not affect the calculated sensitivity very much.

IV. Summary

Despite large differences in the geometry of the calculational models used in 1-D and 2-D sensitivity analysis of the attenuation experiment, the 1-D calculated sensitivity of the neutron response to the stainless steel shield material (which is most important) agrees with that of 2-D calculated within a range of $6 \sim 20\%$. The modeling of the 7.5 cm thick iron source liner by a spherical shell introduces the largest difference between the two cases. Neglecting the bulk concrete has only a small effect on the response even when the detector is placed near the bulk concrete. The reduction of the thickness of iron source liner to $\sim 1/3$ its present value in future 1-D calculations may improve the simulation of the 2-D geometry and thereby save considerable computational effort in analyzing results from the actual experimental configuration.

Comparison of 1-D and 2-D sensitivity results have shown the effectiveness of the 1-D calculation in accurately modeling the complex shape and exact arrangements of proposed experimental configuration (as shown for the source can, bulk concrete). This lends strong credibility to the validity of the 1-D sensitivity study¹ already conducted for this experiment.

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