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SENSITIVITY STUDY OF NEUTRON TRANSPORT THROUGH STANDARD AND REBAR CONCRETE*

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An investigation is under way at ORNL to (1) develop a data base pertinent to the transport of neutrons through thick concrete shields, (2) use the data base in an energy group boundary selection and collapsing scheme, and (3) develop a simple methodology to access the data base to provide rapid solutions to practical shielding problems. This paper describes work carried out to fulfill objective (1), the work consisting of calculations of the transport of fission neutrons through 1- and 2-m-thick slabs of standard concrete[1] and rebar (steel-reinforced) concrete,[2] together with calculations of the sensitivities of the results to total, absorption, and elastic cross sections.

The transport calculations were performed with the one-dimensional discrete ordinates code ANISN[3] in both forward and adjoint modes. The DLC-41C/VITAMIN-C cross-section library[4] (171 neutron, 36 gamma groups) was employed, with a P_3 cross-section expansion and an S_{16} angular quadrature. In all cases the fission source was assumed to be distributed within the first 1-cm thickness of the slab and the detector was assumed to occupy the last 1-cm thickness of the slab. For the rebar concrete the slab constituents were homogenized, with the horizontal and vertical No. 11 reinforcing steel rods comprising 7.6 vol.% of the slab. The quantity calculated was the absorbed dose rate, and care was taken in the mesh interval selection and source description to ensure agreement between the forward and adjoint results to within 0.02%.

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The sensitivity calculations were performed with the SWANLAKE[5] and FORSS[6] codes. The *JULIET* module of *FORSS* based on the *SWANLAKE* algorithm for calculating sensitivity coefficients was used to aid in cross-section handling and plotting.

For all the cases considered, the sensitivity of the total dose rate at the exit face of the slab to the total, absorption and elastic scattering cross sections for the total mix of concrete constituents was determined. For the 1-m standard concrete, the sensitivity to the cross sections for the individual constituents was also determined, as well as the sensitivity to the cross sections corresponding to the water content of the slab. For the remaining cases, only the sensitivity to the cross sections for the total mix was calculated, except for the 1-m rebar slab, in which case the sensitivity to the cross sections for steel was also determined.

Some of the results of the sensitivity calculations are presented in Table 1. An examination of the 1-m standard concrete case shows that 90% of the total cross-section sensitivity of the dose rate is due to neutrons. Elastic scattering is the dominant partial cross section, accounting for 74% of the total dose rate sensitivity. Among the constituents, oxygen, silicon, and hydrogen contribute 38%, 24%, and 22% respectively to the total cross-section sensitivity, which means that these three constituents account for 85% of the total sensitivity of the dose rate. The water in the concrete contributes 26% of the sensitivity. On the other hand, there are some elements that make insignificant contributions. This indicates

Table 1. Cross-Section Sensitivity of Total Dose Rate Transported Through Concrete Slabs (Fission Source)

Cross Section[b]	S, Sensitivity[a]		
	Gamma Groups	Neutron Groups	All Groups
	1-m-thick Standard Concrete		
Σ_t(mix)	-7.18487-01[c]	-7.2481+00	-7.96654+00
Σ_a(mix)	-2.91101-03	-7.3207-01	-7.34982-01
Σ_s(mix)	0.0	-5.8875+00	-5.8875+00
$\Sigma_t(H_2O)$	-3.73450-02	-2.0324+00	-2.06973+00
$\Sigma_a(H_2O)$	-1.73712-02	-1.2218-01	-1.22195-01
$\Sigma_s(H_2O)$	0.0	-1.9224+00	-1.9224+00
	2-m-thick Standard Concrete		
Σ_t(mix)	-5.61354+00	-8.3919+00	-1.40055+01
Σ_a(mix)	-7.63756-03	-1.5209+00	-1.52850+00
Σ_s(mix)	0.0	-6.65681+00	-6.65681+00
	1-m-thick Rebar Concrete		
Σ_t(mix)	-1.01620+00	-8.3633+00	-9.37947+00
Σ_a(mix)	-4.29377-03	-6.6165-01	-6.65948-01
Σ_s(mix)	0.0	-6.5426+00	-6.5426+00
Σ_t(steel)	-2.26255-01	-1.0646+00	-1.29088+00
Σ_a(steel)	-3.06586-03	-2.4869-01	-2.51753-01
Σ_s(steel)	0.0	-4.4376-01	-4.4376-01
	2-m-thick Rebar Concrete		
Σ_t(mix)	-7.15619+00	-9.7171+00	-1.68732+01
Σ_a(mix)	-1.11216-02	-1.27830+00	-1.28946+00
Σ_s(mix)	0.0	-7.52635+00	-7.52635+00

[a] $S_\Sigma(r) = (dR/R)/(d\Sigma/\Sigma)$, where r is a point at phase space, R is the total response (dose rate), and Σ is the macroscopic cross section.

[b] Σ_t, Σ_a, Σ_s are the total, absorption, and elastic scattering macroscopic cross sections.

[c] Read: -7.18487×10^{-1}.

that it would be possible to reduce the number of elements used to represent concrete in a calculation by considering their importance to the total response.

In the case of the 1-m rebar slab, the steel bars increase the magnitude of the sensitivity by 17%. The sensitivity for the 1-m rebar case is 56% of that for the 2-m rebar case. In the 2-m rebar case the gamma sensitivity increases to 42% of the total sensitivity compared to only 10% in the 1-m standard concrete case. The presence of the steel in the 2-m rebar case results in a 20% increase in the magnitude of the sensitivity. Comparing the two 2-m cases shows that elastic scattering contributes 47% and 44% of the total sensitivity for standard and rebar concrete respectively.

Other interesting results can be deduced from the sensitivity profiles, that is, plots of the energy dependence of the sensitivity coefficients for a given medium. Sensitivity profiles have a variety of uses. We are planning to use them to choose a new group structure for a few-group library. It is also possible to develop an automatic group-collapsing scheme on the basis of these coefficients.

All the sensitivities for the total cross section are negative, which means that as the cross section increases the calculated dose rate decreases. It is also observed that the sensitivities are large in the high energy region of the energy spectrum. Fine structure of the sensitivity spectrum caused by the resonances and antiresonances of the constitutent elements are apparent.

From this study a data base for concrete shielding will be developed and will be followed by the development of an efficient methodology for predicting neutron responses.

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