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Macroscopic Cross Section Sensitivity Study for the TNS Integral Experiments*

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Integral experiments are being carried out in the Oak Ridge National Laboratory fusion energy program in support of the design of the TNS device (The Next Step). In conjunction with the experiments, the sensitivities of the response of an NE-213 liquid scintillator detector to the macroscopic cross sections of iron, air, stainless steel, borated polyethylene, and concrete have been calculated for the proposed experimental configuration. The objectives of this work were to evaluate the effectiveness of the experimental system in measuring the radiation attenuation in a typical fusion reactor inner toroidal shield configuration and to provide information to guide detailed two- and three-dimensional analyses of the experiment.

The one-dimensional spherical model used to represent the experimental configuration is shown in Fig. 1. Six measurements in which the composition and thickness of the shield are varied have been proposed and are identified as the 0th through 4th measurements. The cross section sensitivities were calculated using the FORSS¹ code system, a P_3 scattering expansion, an S_{16} quadrature, and a coupled 45-neutron, 16-gamma-ray cross section library.² The location of an NE-213 detector was taken to be 124 cm from the D-T neutron source. For this study, the

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detector response function is 1.0 for neutrons and gamma rays with energies > 500 keV and 450 keV, respectively, and 0.0 otherwise. The cross section sensitivities of the neutron and gamma-ray responses were calculated separately using the appropriate adjoint flux for each response.

The cross section sensitivities per unit lethargy of the NE-213 detector neutron and gamma-ray responses to the macroscopic cross sections of the materials comprising the 0th (no shield) and 4th (full shield) measurements are given in Table I. The entries labelled R_n and R_γ are the integrated neutron and gamma-ray detector responses, respectively. For the 0th measurement, $R_\gamma = 0.43 R_n$ and for the 4th measurement, $R_\gamma = 6.6 R_n$. The larger value of R_γ in the latter case arises from the introduction of borated polyethylene into the shield, which is excellent neutron moderator but ineffective in attenuating gamma rays. The remaining entries in the table are sensitivities per unit lethargy $[(\delta R_i/R_i)/(\delta \Sigma/\Sigma), i = n, \gamma]$ of the detector responses integrated over all neutron and gamma-ray energies. These data are the percentage changes in the detector response $(\delta R_i/R)$ due to a 1% increase in the macroscopic cross section $(\delta \Sigma/\Sigma)$. The sensitivity of the responses to the scattering cross section $\Sigma_{i,s}$ was obtained by subtracting the sensitivity to the capture cross section $\Sigma_{i,c}$ from the sensitivity to the total cross section $\Sigma_{i,t}$. Negative values mean that an increase in the cross section results in a decrease in the response.

The neutron response for the 0th measurement is sensitive to the iron and stainless steel cross sections. The positive values of the sensitivity in stainless steel are due to neutrons backscattered into the detector.

The detector gamma-ray response is almost equally sensitive to $\Sigma_{\gamma,t}$ for iron and to both $\Sigma_{n,s}$ and $\Sigma_{\gamma,t}$ for stainless steel. The sensitivities of the gamma-ray response to the gamma-ray production cross sections are included in the sensitivity to $\Sigma_{n,s}$, which results in the positive value (+8.40-2) in the sensitivity of the response to $\Sigma_{n,s}$ of iron.

In the 4th measurement, the neutron response is extremely sensitive to the neutron cross sections for stainless steel, the value being -6.69 for $\Sigma_{n,t}$. The negative values of the sensitivities of the neutron response to the total cross sections of stainless steel, borated polyethylene and iron are nearly proportional to the thickness of each material between the source and the detector. The large values are due to the significant contributions of uncollided source neutrons to the local flux at the end of the shield, a result seen in previous sensitivity studies for the EPR shield design.³ The gamma-ray response for the 4th measurement is most sensitive to $\Sigma_{\gamma,t}$ and $\Sigma_{n,t}$ for stainless steel, and to $\Sigma_{n,t}$ for borated polyethylene. The sensitivities of the detector responses to the cross sections of air and concrete were found to be very small so they have not been included in the table.

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supplied in the near future.

Fig. 1. One-dimensional spherical model of the first attenuation experiment.

Table I

Sensitivity of the Neutron and Gamma-Ray Responses
to Macroscopic Cross Sections

Material	Cross Sections	$[(\delta R_i/R_i)/(\delta \Sigma/\Sigma), i = n, \gamma]$			
		0 th Measurement		4 th Measurement	
		Neutron ($R_n = 9.23$)	Gamma-ray ($R_\gamma = 3.97$)	Neutron ($R_n = 3.72-3$)	Gamma-ray ($R_\gamma = 2.44-2$)
Iron (Fe)	$\Sigma_{n,total}$	-3.06-1 ^a	-1.47-2	-1.07	-3.72-1
	$\Sigma_{n,capt}$	-9.63-2	-9.88-2	-1.24-1	-1.12-1
	$\Sigma_{n,scat}$	-2.10-1	+8.40-2	-9.50-1	-2.60-1
	$\Sigma_{\gamma,t}$	0.0	-5.55-1	0.0	-4.83-4
	$\Sigma_{\gamma,c}$	0.0	-5.87-3	0.0	-3.90-7
	$\Sigma_{n,t} + \Sigma_{\gamma,t}$	-3.06-1	-5.70-1	-1.07	-3.72-1
SS-304 (SS)	$\Sigma_{n,t}$	+1.48-1	+4.27-1	-6.69	-1.91
	$\Sigma_{n,c}$	-2.75-2	-1.48-1	-7.99-1	-7.07-1
	$\Sigma_{n,s}$	+1.76-1	+5.74-1	-5.89	-1.20
	$\Sigma_{\gamma,t}$	0.0	-4.77-1	0.0	-2.61
	$\Sigma_{\gamma,c}$	0.0	-5.33-3	0.0	-1.16-2
	$\Sigma_{n,t} + \Sigma_{\gamma,t}$	+1.48-1	-5.04-2	-6.69	-4.52
Borated polyethy- lene (BP)	$\Sigma_{n,t}$			-1.82	-1.38
	$\Sigma_{n,c}$	No borated polyethylene used in the 0 th measure- ment		-5.30-2	-5.19-1
	$\Sigma_{n,s}$			-1.77	-8.61-1
	$\Sigma_{\gamma,t}$			0.0	-3.88-1
	$\Sigma_{\gamma,c}$			0.0	-1.54-5
	$\Sigma_{n,t} + \Sigma_{\gamma,t}$			-1.82	-1.77

^aRead -3.06 x 10⁻¹

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