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A SENSITIVITY ANALYSIS OF NEUTRON AND GAMMA TRANSPORT IN AIR

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A method for sensitivity analysis based on the use of the adjoint flux¹ has been used to study coupled neutron-gamma transport in air. The analysis consisted of determining the sensitivity of the total tissue dose at 2000 meters in air to group-averaged sets of nitrogen and oxygen cross sections. While adjoint fluxes have been used in previous sensitivity studies of air,^{2,3} the present approach offers an alternate definition of the sensitivity function designed for ease in physical interpretation, and extends the method to include secondary gamma-ray sensitivity effects. In the sensitivity calculation, the importance of the individual reaction cross sections involved in transport is determined quantitatively as a function of energy. This information may then be used to assess the relevance of integral experiments for design problems, or, in conjunction with estimated cross-section errors, to determine the priorities by reaction type and energy range for future cross-section measurement and/or evaluation.

Equation 1 gives a very straightforward definition of a sensitivity function as the derivative of the calculated response, such as tissue dose, with respect to the l th moment of the cross section for scattering from energy group i to energy group j :

$$\frac{dR}{d\Sigma_{i \rightarrow j}^l} = \int_D \phi_j^{+l} \phi_i^l \quad (1)$$

where D is the domain of $\Sigma_{i \rightarrow j}$. However, experience has shown that a better way to observe the sensitivity is given in Equation 2 as the derivative of the natural log of the response with respect to the natural log of the cross section. This is the function used in this study.

$$\text{Sensitivity}(\Sigma_{i \rightarrow j}^l) = \frac{d(\ln R)}{d(\ln \Sigma_{i \rightarrow j}^l)} = \frac{\int_D \phi_j^{+l} \phi_i^l \Sigma_{i \rightarrow j}^l}{R} \quad (2)$$

The uncertainty in R resulting from a given error in cross section, $\delta \Sigma_{i \rightarrow j}^l$, can be determined according to Equation 3:

$$\delta R_{i \rightarrow j} = \sum_{l=0}^{\max} \int_D \phi_j^{+l} \phi_i^l \delta \Sigma_{i \rightarrow j}^l \quad (3)$$

If the perturbed adjoint is used, the calculation is exact. For cross-section uncertainties which are small enough so that linear perturbation theory is valid, the perturbed adjoint may be approximated by the unperturbed adjoint, and estimates of the resulting uncertainties can be obtained.

The initial set of problems presented here utilized 14-MeV, thermonuclear, and fission neutron sources, and determined the tissue dose in air at 2000 meters with the Snyder-Neufeld⁴ response function for neutrons and the Henderson⁵ response function for gamma rays. The flux calculations extended to 3000 meters to allow for reflection. The plots show sensitivity profiles for the three cases considered, with each bar of the histogram representing the summed sensitivities for all the cross sections for a particular group divided by the lethargy width of that group. Figure 1 presents the sensitivity of the problem to neutron total collision cross sections. The peaks generally correspond to cross-section minima, and the variation of the sensitivity profiles with source is evident, particularly at higher energies.

For the problem with a thermonuclear source, the sensitivity profiles were determined for each of the individual reaction cross sections in the ENDF/B-III listings for N-14, Mat. 1133 (DNA Mat. 4133), and O-16, Mat. 1134 (DNA Mat. 4134). In general, the sensitivity was high for the inelastic cross sections above 10 MeV, while the elastic cross-section sensitivity accounted for almost the total effect at lower energies.

In addition to the sensitivity profiles, Equation 3, with the unperturbed adjoint flux, was employed to predict the effects of a uniform increase of all cross sections. The linear predictions showed good agreement with modified transport calculations for small cross-section uncertainties (for 1% increase in all cross sections, the predicted dose decrease of 7.4 compares with a recalculated decrease of 7.1%), but relatively poorer agreement for larger cross-section uncertainties (for 10% increase in all cross sections, the predicted dose decrease is 74% compared with a recalculated decrease of 48%), indicating non-linear effects.

References

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FIGURE CAPTION

Fig. 1. Total Collision Cross-Section Sensitivity Profile for Three Sources in Air.