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Chapter 5 Appendix 12a

ADJOINT ONE-DIMENSIONAL DISCRETE ORDINATES ANALYSIS OF THE EFFECT OF SOURCE ANISOTROPY

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The procedure used to calculate the sulfur activation involves a one-dimensional multigroup adjoint discrete ordinates computation. In the adjoint mode in spherical geometry, the result of such a calculation is an estimate of the angular dependent source importance, $I_K(r,\mu)$, to a given (input) fluence-response function, $R_{K'}$. Here the subscripts K and K' refer to the energy groups in the multigroup approach; $R_{K'}$ is the detector-response function - disintegrations per minute (dpm) of ^{32}P per gram of sulfur per unit incident fluence at the detector in energy group K'; and $I_K(r,\mu)$ is the number of dpm of ^{32}P per gram of sulfur for a unit source in energy group K emitted in the direction with polar cosine μ with respect to the source-detector axis at a distance r from the detector. The derivation of this importance function is available from many sources and will not be repeated here.[1] Note, however, a few things about $I_K(r,\mu)$: 1) it is one-dimensional in that the transport medium only depends on a single spherical geometric variable, r; 2) the forward mode angular dependent fluence, $\phi_K(r,\mu)$, has been replaced in the adjoint mode with a source angular dependent importance; and 3) the azimuthal dependence of the source is irrelevant in one-dimensional geometry for an isotropic detector response, only the total number of neutrons emitted in a polar direction for a given energy group is important.

The result of interest is the total sulfur activation from all neutrons emitted in the Hiroshima explosion. The discrete ordinates calculations provide the importance function at a set of discrete ordinates $\mu_i, i = 1, N$, such that if $S_K\ (\mu_i)$ is the source in energy group K emitted in the polar angle band $\Delta\mu_i$ about μ_i, the activation is given by

$$A(r) = \sum_{K=1}^{N} \sum_{i=1}^{N} W_i \, I_K\,(r, \mu_i)\, S_K\,(\mu_i) \tag{1}$$

Here μ is the polar angle with respect to the source-detector axis, and W_i is the quadrature weight for the i-th interval.

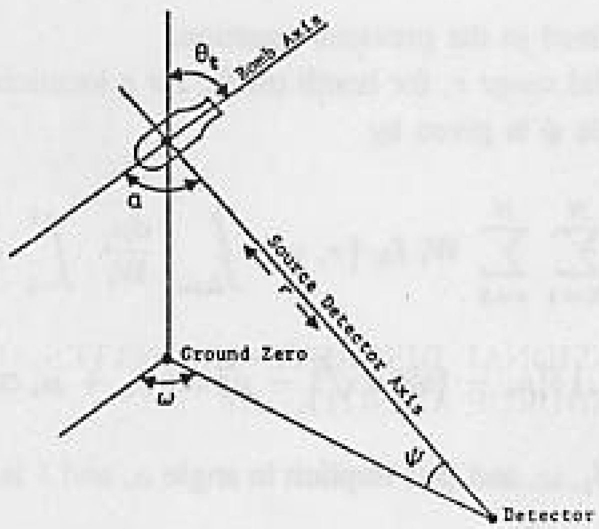

Figure 1. The angles used in the adjoint importance coupling

Now, note that the axis of the source (i.e., the Hiroshima bomb) is not, in general, aligned with the source-detector axis. Thus, we must transform the source description from its natural coordinate system (the bomb axis) into the source-detector system to calculate the total number of neutrons of energy group K emitted into the source-detector polar band $\Delta\mu_i$. This transform is dependent on the tilt angle of the bomb with respect to the vertical, the height-of-burst, and the azimuthal location of the detector with respect to the plane of the vertical and the bomb axis as shown in Figure 1.

Define the angles (Figure 1):

θ_t = tilt angle of the bomb with respect to the vertical,

α = angle between the bomb axis and the source-detector axis,

ω = azimuthal angle of the location of the detector with respect to the plane of the bomb axis and the vertical,

ψ = zenith angle of source-detector axis, that is, $\cos\psi$ = (height-of-burst) $\div$ (slant range, r).

Then we have

$$\cos\alpha = -\sin\theta_t \sin\psi \cos\omega + \cos\psi \cos\beta_t \qquad (2)$$

Now let $\overline{\Omega}_s$ be the source emission solid angle defined by

μ_s = polar cosine with respect to the bomb axis, and

ϕ_s = azimuthal angle defined with respect to the plane of the bomb axis and the source-detector axis.

If we let $\overline{D}$ be the unit vector along the source-detector axis, the polar cosine of $\overline{\Omega}$ with $\overline{D}$ is given by

$$\overline{\Omega}_s \cdot \overline{D} = \mu_i(\alpha, \mu_s, \phi_s) = \sin\alpha \cdot \sqrt{1-\mu_s^2}\cos\phi_s + \mu_s \cos\alpha \qquad (3)$$

where cos α has been defined in the previous equation.

The activation at ground range r, for bomb tilt θ_t, for a location at azimuth ω, and for a height-of-burst zenith angle ψ is given by

$$A(r, \theta_t, \omega, \psi) = \sum_{K=1}^{N} \sum_{i=1}^{N} W_i I_K(r, \mu_i) \int_{\Delta\mu_i} \frac{d\mu_i}{W_i} \int_{-1}^{1} d\mu_s \int_0^{2\pi} d\phi_s \times$$

$$S_K(\mu_s)\,\delta[\mu_i - (\sin\alpha\sqrt{1-\mu_s^2}\cos\phi_s + \mu_s\cos\alpha)] \qquad (4)$$

where the dependence on θ_t, ω, and ψ is implicit in angle α, and δ is the Dirac delta function.

Reference

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