Proof-of-Principle to Unfold an Angle-Energy Dependent Source from Forward and Adjoint Calculations

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Abstract

For many years there has existed a discrepancy between the measured and calculated responses from the Little Boy weapon in Hiroshima. A myriad of solutions have been proposed, but to no avail. If one decides that it does not matter exactly what happened when the weapon exploded since one knows the results (i.e. one has measurements), and if sufficient information exists about those results, one should be able to unfold (Ref. 1) a source. If the source can be unfolded in a controlled environment, then it should be possible to unfold a more complicated source, such as, the Little Boy source.

In operator notation, the Boltzmann transport equation (Ref. 2) is represented as

$$LF = Q, \qquad \text{Eq. 1}$$

where L denotes the linear time-independent Boltzmann transport operator; F is the forward flux and is a function of energy E, direction vector **d**, and position vector **r**; and Q is the source, also a function of E, **d**, and **r**.

If R is a given response function dependent on E, **d**, and **r**; and F is the forward neutron flux as before, then the answer of interest, A, is given by

$$A = \langle R,F \rangle , \qquad \text{Eq. 2}$$

where <> denotes the inner product notation and indicates integration over the common domains of all independent variables E, **d**, and **r**.

The adjoint transport operator L* is defined by

$$\langle F^*,LF \rangle = \langle L^*F^*,F \rangle , \qquad \text{Eq. 3}$$

where the adjoint flux, F*, satisfies the adjoint transport equation

$$L^*F^* = R . \qquad \text{Eq. 4}$$

The mathematically equivalent formulations using the adjoint flux F*, and eqs. 1, 2, 3, and 4 follows from the following:

$$
\begin{aligned}
A &= \langle R,F\rangle = \langle R,F\rangle + \langle F^*,(Q - LF)\rangle \\
&= \langle R,F\rangle + \langle F^*,Q\rangle - \langle F^*,LF\rangle \\
&= \langle R,F\rangle + \langle F^*,Q\rangle - \langle F,L^*F^*\rangle \\
&= \langle (R - L^*F^*),F\rangle + \langle F^*,Q\rangle \\
&= \langle F^*,Q\rangle \qquad \text{Eq. 5}
\end{aligned}
$$

Equations 2 and 5 are seen to be equal, and thus, the answer of interest, A, can be determined in two ways, both of which require the forward source, Q, be known.

However, if Q is unknown, one should be able to calculate the adjoint flux, F*, using Eq. 4 and the adjoint source, R. Then, if one knows a sufficient number of answers of interest (cobalt, europium, sulfur, etc., activations), and has calculated the proper adjoint flux, one should be able to unfold the source, Q.

The two-dimensional discrete-ordinates radiation transport code DORT (Ref. 3) is being used in the forward and adjoint modes in an air/ground scenario. In the forward mode, a polar-angle, energy- dependent source, Q, will be used to calculate activation responses, A, at specific ground ranges. In the adjoint mode, the activation cross sections, R, will used as an adjoint source at the ranges used in the forward mode activations to calculate the polar-angle dependent fluxes, F*. The forward calculated activations, the polar-angle dependent fluxes, and a forward source guess will be input to the STAY’SL code (Ref. 4) to unfold the polar-angle, energy-dependent source, Q’. This output spectrum from STAY’SL, obtained by minimizing chi-square, will be compared with Q to determine if, indeed, the forward source can be unfolded.

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