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OGRE-P2, A Monte Carlo Program for Computing Gamma-Ray Leakage From Laminated Slabs with a Distributed Source

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Abstract

A Monte Carlo IBM-7090 program, called OGRE-P2, has been written for the calculation of dose rate on one side of a slab due to a gamma-ray source distributed in energy and space within the slab. The code, except for the source routine, is similar to OGRE-P1 reported earlier.

The Monte Carlo program OGRE-P2 has been written for the IBM-7090 to solve the problem of gamma-ray leakage from a slab of laminated regions of various materials. The dose rate is calculated on one side of the slab. It was written within the framework of the OGRE system,[1] which is a general purpose gamma-ray program. It is essentially the same as the code OGRE-P1,[2] reported previously except for slightly different input, a new source routine (with slave subroutines), a special routine for computing the uncollided dose rate semianalytically, and a special program for preparing data for the source routine.

The source is distributed in energy between a minimum, E_{min}, and a maximum, E_{max}. In addition to a continuous energy spectrum, an array of monoenergetic sources may be included. The source is also distributed in space throughout the slab in an arbitrary fashion. Thus a source distribution, $S(z,E)$, must be supplied, giving the magnitude of the source at the energy E and at the distance z from a given slab face. The dose rate is computed at the opposite slab face. The source is isotropic in direction of emission.

The procedure for picking from the source energy and spatial distribution is as follows: The source data for a continuous energy spectrum and/or a group of delta functions in energy may be supplied to the preparation program on either cards or tape. The problem is simplified in that, over arbitrary spatial intervals, the source will be assumed constant. In these intervals, the energies will be picked from a cumulative energy distribution which is averaged over the interval. To conserve storage space, only one of these distributions is in memory at one time.

To provide these and other data to the main OGRE-P2 code, the preparation code proceeds as follows: It first reads in the source data, $S(z,E)$ (photons-sec^{-1}-cm^{-3}-Mev^{-1}) and $S_j(z)$ (photons-sec^{-1}-cm^{-3}), the monoenergetic sources of energy E_j, and the boundaries of the intervals in which the spatial distribution will be taken to be constant. The final

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1. S. K. Penny, D. K. Trubey, and M. B. Emmett, "OGRE, A General Purpose Monte Carlo Code for Studying the Transport of Gamma Rays," to be published.
2. D. K. Trubey, S. K. Penny, and M. B. Emmett, "OGRE-P1, A Monte Carlo Program for Computing Gamma-Ray Transmission Through Laminated Slabs," ORNL-TM-167, Revised May 23, 1962.

z value read in determines the spatial extent of the source regardless of the z values associated with S(z,E). The values of interval thicknesses and the values of E_j are written on tape followed by the values of

$$SV_i(E) = \int_{z_i}^{z_{i+1}} S(z,E)\ dz,$$

where z_i are values of the interval boundaries for use by the subroutine ATTEN to be described below. The cumulative distribution function for each interval is then produced,

$$C_i(E') = \frac{\int_{E_{min}}^{E'} \int_{z_i}^{z_{i+1}} S(z,E)\ dz\ dE}{\int_{E_{min}}^{E_{max}} \int_{z_i}^{z_{i+1}} S(z,E)\ dz\ dE},$$

and also the total source

$$T = \int_{E_{min}}^{E_{max}} \int_{o}^{z_{max}} S(z,E)\ dz\ dE + \sum_j \int_{o}^{z_{max}} S_j(z)\ dz.$$

The fractions

$$FRAC\emptyset N(i) = \frac{1}{T} \int_{E_{min}}^{E_{max}} \int_{z_i}^{z_{i+1}} S(z,E)\ dz\ dE$$

$$FRADEL(i,j) = \frac{1}{T} \int_{z_i}^{z_{i+1}} S_j(z)\ dz$$

and a table of $C_i(E')$ and E' values are then written on tape for each interval for use by the source routine. The above integrals are performed using Simpson's rule with an arbitrary number of points and either linear or exponential interpolation between values of S(z,E).

The source routine uses the above fractions and table to determine how many histories to start in each interval and to pick the initial energy for

each history. If the energy for a history is to be picked from the continuous distribution, a value of E' is then taken at random from a table of 1000 values uniformly spaced in C(E'). The initial space points are picked uniformly in the interval.

In order to select a direction, a method of importance sampling is used since photons started in a backward direction have a small probability of escaping in the forward direction. This is especially true if the distance to the face of the slab, where the dose rate is computed, is large. Consequently, the direction cosine, γ, was picked from the sum of isotropic and $\cos^n$ distributions. This distribution is

$$f(\gamma) = \frac{A}{2} + (1 - A)(n + 1)\, \gamma^n\, H(\gamma) \ ,$$

where

$H(\gamma) = 1$ for $\gamma > 0$,

$H(\gamma) = 0$ for $\gamma \leq 0$,

A = fraction of histories in isotropic distribution.

To take into account distance from the "detector," the value of A is set equal to $\exp(-\alpha x)$ where x is the distance in mfp and α is an input parameter. The value of A is used to pick randomly from either distribution. The weight of the photon is

$$W = \frac{1/2}{A/2 + (1 - A)(n + 1)\gamma^n\, H(\gamma)} \ .$$

The procedure for picking from the $\cos^n$ distribution is to choose the largest of n + 1 random numbers. The value of n is an input number and may be 0.

The uncollided dose rate is computed in the subroutine ATTEN. The uncollided flux from the continuous spectrum may be written,

$$\phi_c = \int_{E_{min}}^{E_{max}} \int_{0}^{z_{max}} S(z,E) \frac{E_1[x(E)]}{2} \, dz \, dE ,$$

where

$x(E) = \mu(E)(z_{max}-z)$,

z_{max} = thickness of slab,

$\mu(E)$ = total linear absorption coefficient;

or, since the source is assumed constant over an interval, it may be

$$\phi_c = \int_{E_{min}}^{E_{max}} dE \sum_i \frac{SV_i(E)}{2(z_{i+1}-z_i)} \int_{z_i}^{z_{i+1}} E_1(x) \, dz$$

$$= \int_{E_{min}}^{E_{max}} \frac{dE}{\mu(E)} \sum_i \frac{SV_i(E)}{2(z_{i+1}-z_i)} \left[E_2(x) \Big|_{z_{i+1}} - E_2(x) \Big|_{z_i} \right].$$

In like manner, the flux from the monoenergetic sources may be written

$$\phi_d = T \sum_i \sum_j \frac{FRADEL(i,j)}{2\mu(E_j)(z_{i+1}-z_i)} \left[E_2(x) \Big|_{z_{i+1}} - E_2(x) \Big|_{z_i} \right],$$

where x is a function of energy E_j.

Since dose rate, and not flux, is desired, a flux-to-dose conversion factor is included in the integrand and divided by T to yield the uncollided dose rate independent of the number of histories. Thus the Monte Carlo result must be multiplied by T to yield the dose rate (in rads/hr) with the given sources $S(z,E)$ and $S_j(z)$. If the units of source are integrated over time, the result must be divided by 3600 to yield the dose in rads.

SUMMARY OF INPUT

Data Preparation Code

Fortran Card Input Format	
(3I4)	Input option, ITAPE, IREW for ITAPE.
(I4,11F6.2)	NZ, [Z(I), I=1,NZ] , NZ $\leq$ 100.
[I4,(11F6.2)]	NE, [E(J), J=1,NE] , NE $\leq$ 100.
(12F6.2)	([S(I,J), I=1,NZ], J=1,NE), omit if NE = 0.
(I4,11F6.2)	NØDEL, [EDEL(J), J=1,NØDEL] NØDEL $\leq$ 20.
(12F6.2)	([SDEL(I,J), I=1,NZ], J=1, NØDEL) omit if NØDEL = 0.
(6I4)	NØINT, NØCUM, ITERP, MØDEZ, MODEE, IREW for tape 2.
(12F6.2)	Boundaries of intervals (start with the second since the first is assumed to be 0).

If the tape option is used (input option = 2), the tape should be written with a WRITE TAPE Fortran statement corresponding to each of the above cards. Input option = 1 for card input.

ITAPE = logical tape number of input source data.

IREW = rewind option.

= 0, tape not rewound,

= 1, tape rewound at beginning of current problem,

= 2, tape rewound at end of current problem,

= 3, tape rewound at beginning and end of current problem.

NØINT = number of source intervals $\leq$ 50.

NØCUM = number of points for cumulative distribution table $\leq$ 100.

ITERP = number of points in Simpson's rule integration $\leq$ 100.

MØDEZ = type of spatial interpolation assumed for source (1, linear; 2, exponential).

MØDEE = type of energy interpolation assumed for source (1, linear; 2, exponential).

The following tape assignment is required:

32	input
31	output
ITAPE	input source data (if tape option = 2)
2	processed source data.

OGRE-P2 CODE

Fortran Card Input Format	
(3E11.3,Ø13)	No. of histories, energy cutoff (Mev), weight cutoff, initial random number (must end in 1 or 5).
(2I4)	No. of regions, No. of media.
[6(E8.2,I4)]	[Thickness (cm), medium number] region by region.
(I4)	No. of photon flux-to-dose conversion factors.
[10(E7.2)]	[E(Mev), DØSE(E)], E must monotonically increase.
(I2)	Cross section tape option. (2 if cross sections are read from tape 29 and written on tape 30, 1 if cross sections are read from tape 30).

The next section of input is necessary only if the previous integer describing the tape option is equal to 2:[3]

(4I4)	NMED, NINT, ILØW, IHIGH	
⋮		
I4	No. of elements in a given medium.	ith medium
⋮		
I4,E9.3	Element atomic number, density (gm/cc) of element.	

The next input card is always needed:

(I4,F8.2,I4)	n, the source is picked from a $\cos^n$ distribution; α, IREW for tape 1.

The following tape assignment is required:

32	input
31	output
1	processed source data
30	detailed cross section tape
29	master cross section tape (if needed).

3. S. K. Penny, M. B. Emmett, and D. K. Trubey, " A System for Generating Gamma-Ray Cross Section Data for Use with the IBM-7090 Computer," ORNL-TM-234, May 16, 1962.

NMED = number of media.

2^{NINT} = number of intervals in energy groups of cross section table.

$2^{IL\emptyset W}$ = lower energy bound of cross section table (electron rest mass units).

2^{IHIGH} = upper energy bound of cross section table (electron rest mass units).

Note: $NMED[2^{NINT}(IHIGH-IL\emptyset W) + 1] \leq 8888$.

Successive problems may be run by repeating the entire input array and using the proper tape option.

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