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A Computer Code to Calculate the Parameters Used for Radiation Shielding against γ Rays

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A computer code RASH for the parameters used in radiation shielding against γ rays is described. The program is designed to calculate energy absorption coefficients in air, Rhm values, total attenuation coefficients of the shielding materials, and the parameters for the dose buildup factors. The calculations of these parameters are made with the interpolation method proposed by Akima.

KEY WORDS: Radiation shielding/ Rhm values/ Total attenuation coefficients/ Buildup factors/

I. INTRODUCTION

Owing to the recent increase in applications of radioisotopes for a variety of fields, there is a strong need for simple calculation to estimate dose rate at a point and to design the radiation shielding. For this purpose, it is usual to estimate the parameters used for the calculation from numerical tables. However, since these tables are given for a certain set of discrete γ-ray energies, it is necessary to obtain intermediate values by interpolation technique. When one wants to get accurate value, this procedure is very tedious and time consuming.

In order to avoid this tedious calculation, the present author[1] has published tables of parameters used for radiation shielding against 29 γ rays from 16 radioisotopes frequently used, and 6 materials of interest in radiation shielding have been included. These tables are efficient and useful to perform quick, easy, and reasonably accurate calculations for shielding against γ rays from radioisotopes. However, the number of γ-ray energies and also the number of shielding materials in the tables are limited. It is desirable to prepare a computer code to calculate the parameters for arbitrary γ-ray energies and for arbitrary shielding materials.

The computer code RASH has been written to calculate the parameters used for radiation shielding against γ rays. The energy absorption coefficient for air, the Rhm value, the total attenuation coefficient for the shielding material, and the parameters to estimate the dose buildup factor are obtained. The principle of the calculations is the same that used in Ref. 1, except that the Spline interpolation method is replaced by the method proposed by Akima.

II. DOSE RATE

When a point isotropic source with an activity Q (Ci) is placed at a distance d

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(m), the dose rate D (R/h) at the point is given by

$$D = 1.50 \times 10^4 Q/d^2 \sum_i \eta_i E_i \mu_{ei} , \quad (1)$$

where E_i is the γ-ray energy (MeV), η_i is the number of gammas with energy E_i per disintegration, and μ_{ei} is the linear energy absorption coefficient of air for this γ ray (cm^{-1}).

It is convenient to introduce a quantity, D_0, called the Rhm value, which is defined as the dose rate at 1 m from a 1-Ci source ($Q=d=1$). Then Eq. (1) can be expressed as

$$D = D_0 Q/d^2 . \quad (2)$$

When there is a shielding material of thickness x between the source and the point concerned, the dose rate is written by

$$D = 1.50 \times 10^4 Q/d^2 \sum_i \eta_i E_i \mu_{ei} B_i \exp(-\mu_i x) , \quad (3)$$

where B_i and μ_i are the dose buildup factor and the total attenuation coefficient of the shielding material for the γ-ray energy E_i, respectively.

According to Berger,[2] the dose buildup factor can be approximated as

$$B_i = 1 + a_i \mu_i x \exp(b_i \mu_i x) , \quad (4)$$

where a_i and b_i are the parameters which depend on the energy E_i and the shielding material.

III. METHOD OF CALCULATION

The dose rate at a point can be calculated using Eq. (2) or Eq. (3). For this purpose, the Rhm value D_0 for the nuclide, and the energy absorption coefficient for air μ_{ei}, the attenuation coefficient μ_i, and the parameters for the buildup factor a_i and b_i for each γ-ray energy and for each shielding material should be known. The computer code RASH calculates these quantities by interpolation method from the tabulated values.

Hubbell[3] listed values of μ_e for air for 25 γ-ray energies over the energy range between 10 keV and 10 MeV. In the RASH code, this table is stored and the μ_e value for arbitrary energy is obtained by interpolation. Using the μ_{ei} values thus obtained, the Rhm value for the nuclide is calculated from the values of η_i and E_i given in the input data.

The total attenuation coefficients μ are stored for six materials of interest in shielding; water, aluminum, iron, lead, ordinary concrete, and air. These values are taken from the table prepared by Hubbell[3] and the energy region is between 10 keV and 10 MeV. The density of each material is also given in the same table. The composition of the ordinary concrete is the same as that given in the table of McGinnies.[4] For other shielding materials, the table of μ as a function of E should be read in as input data for each element which constitutes the material.

The parameters for the dose buildup factor in Eq. (4) can be calculated only for five common shielding materials; water, aluminum, iron, lead, and concrete. The values of the parameters a and b as a function of energy E for these materials are taken from the tables of Trubey,[5] and stored in the program. These values are based on the data over the range out of 7 mean-free-path lengths. The lower energy limit of the tables is 250 keV for water and 500 keV for other materials. Long-range extrapolation to the lower energy side often causes a deceptive results and should be avoided.

In the RASH code, interpolation with respect to γ-ray energy is made by the method of Akima.[6] His method is based on a piecewise function composed a set of third-degree polynomials and applicable to successive intervals of the data points. The slope of the curve at each data point is determined locally by the coordinates of five points, the center of which is the point in question. A third-degree polynomial between a pair of data points is determined by the coordinates and slopes at these two points. This interpolation method yields a more smooth curve than any other methods and the curve thus obtained is closer to a manually drawn curve.

IV. INPUT DATA SPECIFICATION

In the following we give details of the input data, including FORMAT specifications and explanations of the variables and options.

Card 1. FORMAT (18A4)

Title card

Card 2. FORMAT (I5)

IK=0	Calculate all values.
=1	Calculate Rhm values only.
=2	Calculate attenuation coefficients only.
=3	Calculate buildup factors only.

IK=0 or 1,

Card 3. FORMAT (I5)

IC	Number of times to calculate Rhm values.

Card 4. FORMAT (I5, 2A4)

IR	Number of γ rays emitted from the nuclide.
ELEM	Name of the nuclide.

Card 5. FORMAT (2F10.0)

EE(I)	γ-ray energy (MeV).
WR(I)	γ-ray intensity per disintegration.

IK=0 or 2,

Card 6. FORMAT (I5)

NA	Number of times to calculate attenuation coefficients.

Card 7. FORMAT (3I5)

K=1	Water.
=2	Aluminum.

=3	Iron.
=4	Lead.
=5	Concrete.
=6	Air.
≠1~6	Other materials.
NE	Number of energies to be calculated.
ID=0	Read in energies.
≠0	Use the energy points of the previous calculations.

If K≠1~6,

Card 8.	FORMAT (2A4, 2I5, F10.0)
ELEM	Name of shielding material.
IE	Number of elements in the shielding material.
N	Number of tabulated energies.
DENS	Density of the shielding material (g/cm^3).
Card 9.	FORMAT (7F10.0)
X(I)	Tabulated energies (MeV).
Card 10.	FORMAT (2F10.0)
Z(I)	Aomic number of the element.
WE(I)	Relative abundance of the element.
Card 11.	FORMAT (7F10.0)
Y(I,J)	Attenuation coefficients of i-th element for j-th tabulated energy (cm^2/g).

If K=1~6, omit Cards 8–11.

Card 12.	FORMAT (7F10.0)
EE(I)	Energies to be calculated (When ID=0) (MeV).

IK=0 or 3,

Card 13.	FORMAT (I5)
NB	Number of times to calculate buildup factors.
Card 14.	FORMAT (3I5)
K=1	Water.
=2	Aluminum.
=3	Iron.
=4	Lead.
=5	Concrete.
NE	Number of energies to be calculated.
IF=0	Read in energies to be calculated.
=1	Use the energy points of the previous calculation.
Card 15.	FORMAT (7F10.0)
EE(I)	Energies to be calculated (When IF=0) (MeV).

A card punched STOP in column 1–4 will terminate the run or another input data may follow.

Table I. TEST RUN OUTPUT

```
TEST RUN FOR CO-60 SOURCE AND FOR CONCRETE SHIELDING
CO 60                     1.2018E+00     ROENTGENS/H/M/CI
                      1.1732302E+00 MEV          3.274E-05 1/CM
                      1.3324499E+00 MEV          3.154E-05 1/CM
CONCRETE                 DENSITY=0.2350000E+01
  ENERGY=1.1732 MEV      MASS ABSORPTION COEFFICIENT=0.5897694E-01 CM*2/G
                       LINEAR ABSORPTION COEFFICIENT=0.1385958E+00 CM-1
  ENERGY=1.3324 MEV      MASS ABSORPTION COEFFICIENT=0.5518813E-01 CM*2/G
                       LINEAR ABSORPTION COEFFICIENT=0.1296921E+00 CM-1
CONCRETE
  DOSE BUILDUP FACTOR      B=1+C*U*T*EXP(D*U*T)
          ENERGY               C                  D
        1.1732 MEV           0.9960             0.0872
        1.3342 MEV           0.9543             0.0753
```

V. THE TEST RUN

The test run has been made for ^{60}Co source and for concrete. The program prints out the Rhm value for ^{60}Co, energy absorption coefficient in air, attenuation coefficient, and parameters of the buildup factor for each γ-ray energy from ^{60}Co.

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