A SIMPLE CODE FOR USE IN SHIELDING AND RADIATION DOSAGE ANALYSES

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ABSTRACT

A simple code for use in analyses of gamma radiation effects in laminated materials is described in this note. Simple and good geometry is assumed so that all multiple collision and scattering events are excluded from consideration. Buildup factors may be applied to the results of this simplified analysis, when available, to arrive at improved estimates of energy deposition and attenuated intensity for actual materials.

The code proper is capable of handling laminates up to six layers. However, for laminates of more than six layers, the same code may be used to incorporate two additional layers at a time, making use of punch-tape outputs from previous computation on all preceding layers.

Spectrum of attenuated radiation may be obtained as both printed output and punch tape output as desired. This code is written in "Extended Basic" language, compatible with the GE 265 Time Sharing system.

I. Theoretical Fundamentals

Energy deposition resulting from interaction between photons (X-rays, gamma rays) and matter has been discussed in some detail in Reference (1). The basic results, obtained for simple and good geometry in a one-dimensional representation, are

Attenuated spectrum at depth x:

$$I_x(E) = I_o \cdot I(E) \cdot \exp\left[-\int_o^x \sigma(E)\, dm\right] \quad (1)$$

Energy deposited at depth x:

$$q(x) = I_o \int_o^\infty \sigma_a(E) \cdot (I_x/I_o)\, dE \quad (2)$$

where x = depth into the material, in cm.
dm = ρ dx = differential mass depth in gm/sq cm.
ρ = density of material, in gm/cc.
E = energy level, in KeV
I_o = fluence, in cal/sq cm, incident on the surface of the first layer
I(E) = spectrum of the incident radiation, function of E, normalized to unity for E ranging from 0 to infinity
$\sigma(E)$, $\sigma_a(E)$ = mass attenuation and mass absorption coefficients

To circumvent the need for a detailed definition of incident energy spectrum, Planckians expressed in terms of equivalent blackbody temperatures, in KeV units, are used as a convenient means to segregate engineering estimates of shielding and thermomechanical effects completely from specific identification of spectral contents of the primary source, i.e., bomb types, etc. Therefore, the quantity I(E) may be thought of as

$$I(E) = \sum_i I_i \cdot P(E/E_i)$$

where I_i = fluence weighting factor for the i-th equivalent black body, with $\Sigma i \, I_i = 1$, and

$P(\xi)$ = normalized Planckian, as shown in Figure 1.

Since I_o appears in both expressions displayed above, no loss of generality will result if I_o is set equal to unity, corresponding to a fluence of 1 calorie per square centimeter. Thus a normalized dose Q(x) may be defined as

$$Q(x) = q(x)/I_o$$

which is a unique property of the material in question when subjected to an incident spectrum associated with a specific equivalent blackbody temperature, or with a particular combination of spectra associated with a number of black bodies of different equivalent temperatures. The attenuated spectrum is of course given by the ratio $I_x(E)/I_o$, or simply $I_x(E)$, since $I_o = 1$.

When materials of various thicknesses are placed one after another, either as closely spaced laminates or as a series of material layers with air spaces in between, the above computation process can be applied to each layer in succession. The attenuated spectrum from the first layer becomes the incident spectrum for the next layer, and so on. Thus, the entire series of computation may be made by means of a simple loop; the number of layers that may be accommodated becomes strictly a question of the size of machine storage available.

The mass absorption coefficients and the mass attenuation coefficients are both complicated functions of energy level, which have been tabulated by several agencies. For definiteness, the following source data are used -- these data are not always consistent with each other, but they represent the best information available at this time. Logarithmic interpolation is used throughout for establishing pertinent values associated with each energy level of concern.

(1) Photon Cross Sections from 0.001 to 100 MeV for Elements 1 through 100, Los Alamos Scientific Laboratory Report LA-3753, November 15, 1967.

(2) Analytical Approximations for X-ray Cross Sections, Sandia Laboratory, Report SC-RR-66-452, February 1967.

(3) X-ray Attenuation and Absorption Coefficients, The Boeing Company, Report D2-125065-1, September 1966.

A new edition of item (1) is in press, and will be scanned for necessary updating when published. Values to be used can be composites based on all three of the above references, a sample of which is shown on the next page, for the element copper.

For compounds, both coefficients may be approximated by proportional weighting in accordance with their atomic abundancy. Since the mass coefficients have already been referred to unit mass densities, this implies that

$$\sigma = \sum^i A_{X_i} N_i \sigma_{X_i} \Big/ \sum^i A_{X_i} N_i$$

where A_{X_i} is the atomic weight of the element X_i. The molecular formula of the compound in question is of course

$$\prod_i (X_i)_{N_i}$$

For heterogeneous mixtures of several compounds, the attenuation problem involved is far more complex than can be correctly handled by the present simplified approach. However, for an engineering estimate, it will be assumed that they behave like compounds with the same proportion of various elements by weight.

II. Description of the Code "ENEDEP"

The code written in the Extended Basic language for use on the GE-265 Time Sharing system is named ENEDEP (ENErgy DEPosition). It is capable of handling laminations up to six layers of different materials. Various combinations of source temperature (equivalent blackbody temperature) and incident fluence can be processed in series for the same material configuration. The output of this code provides:

(1) Identification of layer material by name, its density and thickness.

(2) Depth, mass depth, energy deposition per unit mass and local radiation intensity in tabular form.

(3) Attenuated spectrum at the back side of the last material layer, in tabular form and/or in punch tape form as desired to be selected by appropriate control indices.

Input data requirement, possible modification to accomodate materials with a large number of edges in their mass absorption coefficients, and a sample problem are discussed in the following sections.

III. Input Data

Input data for executing the ENEDEP code must be presented in the following format:

1200 DATA N, M

N index for printout and punch tape input selection:

0 no attenuated spectrum information at all

1 tabulated attenuated spectrum, punched tape output optional

2 punched tape input and tabulated attenuated spectrum with optional punched tape output

M integer, denoting the number of layers, not greater than 6.

2000* DATA X(I) N(I), :

X(I) Thickness of the I-th layer, in mils

N(I) Number of printout desired in the I-th layer, integer

*2000 is a typical line number, which may be any number greater than 1200, followed by tape input containing

2010* "AAAAAAAAAA", W(I), J(I), :

"AAAAAAAAAA" alpha-numeric string of ten characters, being the name of the material of the I-th layer

W(I) Density of the material in the I-th layer, in gm/cc

J(I) Number of sets of mass attenuation and mass absorption coefficients, integer, not greater than 35

*2010 is a typical line number; for materials with no edges between 0.5 KeV and 200 KeV, there will be 22 sets of coefficients on this prepared tape; for materials with edges, add two sets for each edge.

9900 DATA S_1, P_1, S_2, P_2, ...

S_i Incident fluences, in cal/sq cm (equal to 1 for most cases)

P_i Equivalent blackbody temperature, in KeV units

The usual requirement calls for five sets of S, P combinations, namely, 1, 1, 1, 2, 1, 4, 1, 7, 1, 15. However, any other combinations pertinent to a particular problem can be used.

On the prepared tape, in addition to what is explained above under "2010", there will be other lines of material properties coefficients, specified in triplets, giving:

E(j) Energy coordinate, in KeV

F(j) Mass attenuation coefficient, σ

G(j) Mass absorption coefficient, σ_a

IV. Materials With More than Six Layers

When the material under consideration has more than six layers, the first six layers will be processed as indicated above, using an index N = 1 and obtain a punch tape output. This tape is then read into a new problem, with the following important modifications:

1200 DATA 2, 2

Only two more layers may be treated, due to storage limitation in the GE-265 Time Sharing system.

Line 9900 must be modified to read as follows:

9900 DATA S, P

S, P here must be the same set of parameters pertaining to the punch tape data being read in as tape input.

On occasions, more than 35 entries may be required to provide an adequate representation of the mass attenuation and mass absorption coefficients of one or more materials. In such cases, the dimensional statement in line 20 must be revised accordingly, an example of this may be seen in section V. Due to limitation in the size of data storage capacity, the number of layers of materials may also be adjusted. Thus a typical modification of line 20 may have the following form:

20 E(4, 42), F(4, 42), G(4, 42)

V. Sample Problem

To illustrate the usage of the ENEDEP code, a six layer laminate consisting of the following materials is analyzed:

Quartz	0.013 gm/cm^2	2	mils
Silicon	1.07 gm/cm^2	180	mils
Quartz	0.013 gm/cm^2	2	mils

Platinum	0.0022 gm/cm^2	0.04 mils	
Gold	0.002 gm/cm^2	0.04 mils	
Bi_2Te_3	2.0 gm/cm^2	100	mils

Due to the high Z-number associated with the materials in the last three layers, 42 entries are required for each of these layers. Therefore, the main program is modified to handle only four layers, each with provision for 42 entries. The main program would have to be recycled three times to complete the analysis required for all six layers. Input data for the first four layers used in the first cycle, results for the first four layers, input data for the fifth layer with tape input of attenuated spectrum from the first four layers, output for the fifty layer, input data for the sixth layer with tape input of attenuated spectrum from the first five layers, and output for the sixth layer are displayed in succession at the end of this paper. A summary of results for the entire range of equivalent blackbody temperature from 1 to 16 KeV is displayed in Figures 2 and 3.

VI. Concluding Remarks

A simple code for determining energy deposition dosage and attenuated fluence in material laminates induced by gamma ray radiation is presented. The average running time for one set of fluence and equivalent blackbody temperature is approximately 80 seconds (computer time). This code therefore provides a very convenient and economical tool for parametric studies in shielding problems and energy deposition analyses.

REFERENCE

1) Leipunskii, O. L., Novozhilov, B. V., and Sakhrov, V. N.: The Propagation of Gamma Quanta in Matter, International Series of Monographs on Nuclear Energy, Division X, Reactor Design Physics, Volume 6, Pergamon Press, New York, 1965.

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Z = 29; A = 63.54; ρ = 8.94: j = 28

Note: Values are given in floating point format; powers of ten are shown after the letter E.

j	Phton Energy (KeV)	Attenuation	Absorption
1	0.5000 E 00	0.1120 E 05	0.1120 E 05
2	0.6000 E 00	0.7007 E 04	0.7007 E 04
3	0.8000 E 00	0.3333 E 04	0.3333 E 04
4	0.9320 E 00	0.2237 E 04	0.2237 E 04
5	0.9320 E 00	0.1646 E 05	0.1646 E 05
6	0.1000 E 01	0.1358 E 05	0.1358 E 05
7	0.1100 E 01	0.1046 E 05	0.1046 E 05
8	0.1100 E 01	0.1100 E 05	0.1100 E 05
9	0.1500 E 01	0.5250 E 04	0.5250 E 04
10	0.2000 E 01	0.2400 E 04	0.2400 E 04
11	0.3000 E 01	0.7800 E 03	0.7800 E 03
12	0.4000 E 01	0.3500 E 03	0.3500 E 03
13	0.5000 E 01	0.1900 E 03	0.1900 E 03
14	0.6000 E 01	0.1110 E 03	0.1108 E 03
15	0.8000 E 01	0.5400 E 02	0.5383 E 02
16	0.8980 E 01	0.4100 E 02	0.4083 E 02
17	0.8980 E 01	0.2960 E 03	0.2958 E 03
18	0.1000 E 02	0.2240 E 03	0.2238 E 03
19	0.1500 E 02	0.7600 E 02	0.7580 E 02
20	0.2000 E 02	0.3300 E 02	0.3284 E 02
21	0.3000 E 02	0.1060 E 02	0.1044 E 02
22	0.4000 E 02	0.4570 E 01	0.4422 E 01
23	0.5000 E 02	0.2410 E 01	0.2268 E 01
24	0.6000 E 02	0.1490 E 01	0.1354 E 01
25	0.8000 E 02	0.7080 E 00	0.5826 E 00
26	0.1000 E 03	0.4250 E 00	0.3083 E 00
27	0.1500 E 03	0.2080 E 00	0.1083 E 00
28	0.2000 E 03	0.1480 E 00	0.6055 E-01

TABLE 1. WEIGHTED ATTENUATION AND ABSORPTION COEFFICIENTS

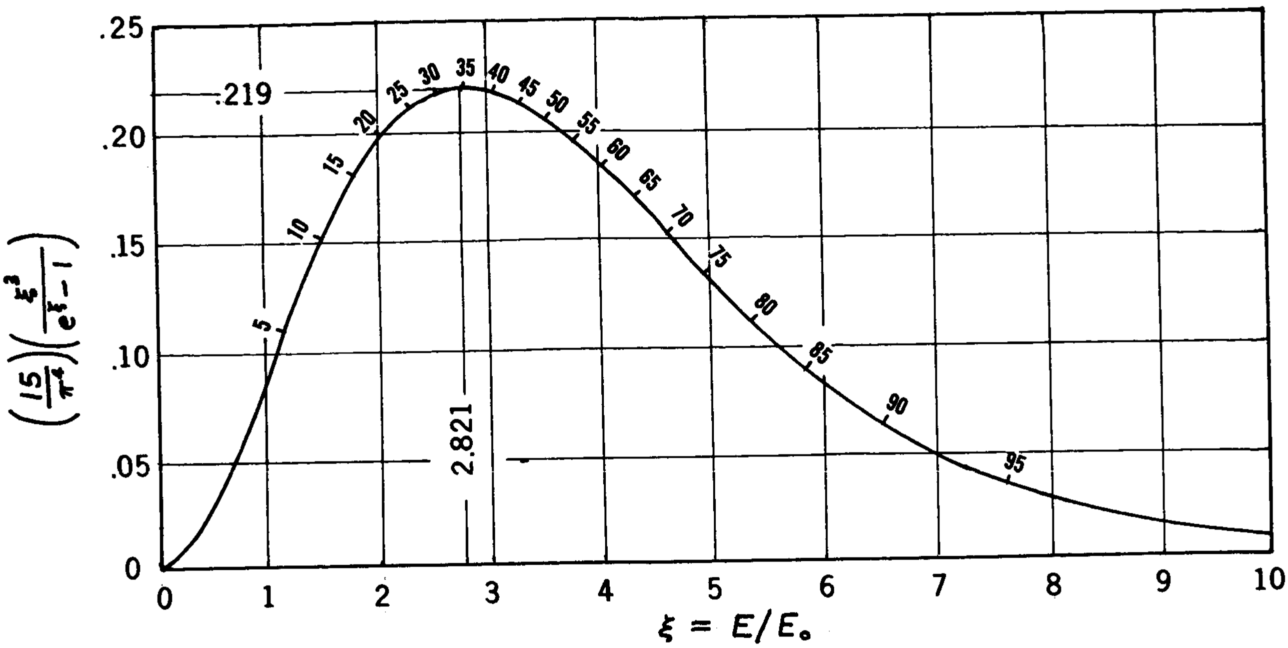

FIGURE 1. NORMALIZED PLANCKIAN

AREA UNDER CURVE = 1