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A FORTRAN PROGRAM FOR GAMMA-RADIATION DOSIMETRY
FOR ARBITRARY SOURCE AND TARGET GEOMETRY

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The program DOSEL calculates the first collision dose for gamma-rays in arbitrary finite geometry of source, absorber and target. The basic unit of the program is the subroutine ATINTG which calculates the attenuation term $\exp(- \int_{r_1}^{r_2} \mu(r) dr)$ where the line integral is taken along the straight line path from r_1 to r_2 . The total volume, including both source and target, is subdivided into small rectangular parallelepipeds. The absorption is calculated as exponential, $e^{-\mu x}$, for each elementary volume traversed from the source volume to the target volume. The contributions from all sources are summed to give point-specific absorbed fractions for each elementary volume. The total absorbed fraction is the average of the point functions. The approach used here differs markedly from the current dosimetry procedure of using the Monte-Carlo method.

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I. Introduction

In the formalism of Loevinger and Berman¹ the dose rate to a point at \vec{r}_1 from a photon source of activity A at \vec{r}_2 , both source and target embedded, in a uniform, infinite absorbing medium is:

$$\frac{dD}{dt}(\vec{r}_1 + \vec{r}_2) = \Delta \frac{\mu_{en}(\vec{r}_1)}{\rho(\vec{r}_1)} A(\vec{r}_2) \frac{e^{-\mu|\vec{r}_1-\vec{r}_2|}}{4\pi(\vec{r}_1-\vec{r}_2)^2} B_{en}(\mu|\vec{r}_1-\vec{r}_2|) \quad (1)$$

where Δ is the equilibrium dose constant of the radioactive disintegration, μ_{en} is the linear energy-absorption coefficient, ρ is the mass density, μ is the linear attenuation coefficient, and B_{en} is the point isotropic energy absorption buildup factor. Some values of B_{en} for tissue and water can be found in reference 2.

If only the first collision dose is of interest, $B_{en}(\mu|\vec{r}_1-\vec{r}_2|)$ is unity. If the source to target medium is not uniform, the attenuation term is generalized as:

$$e^{-\mu|\vec{r}_1-\vec{r}_2|} \rightarrow \exp\left[-\int_{r_2}^{r_1} \mu(r) dr\right]. \quad (2)$$

where the line integral is along the straight line joining \vec{r}_2 and \vec{r}_1 .

For distributed sources, the activity is generalized

$$A(\vec{r}_2) \rightarrow a(\vec{r}_2) dV_2; \quad (3)$$

a is the activity density. The total dose rate is then the volume integral:



$$\frac{dD_1}{dt} (\vec{r}_1 \leftarrow v_2) = \Delta \frac{\mu_{en}(\vec{r}_1)}{\rho(\vec{r}_1)} \frac{1}{4\pi} \iiint \frac{a(\vec{r}_2)}{(\vec{r}_1 - \vec{r}_2)^2} \exp\left[- \int_{\vec{r}_2}^{\vec{r}_1} \mu ds\right] dV_2. \quad (4)$$

The subscript 1 on the D indicates the first collision. The form of the integral can be slightly modified by defining the total activity A_T :

$$\frac{dD_1}{dt} (\vec{r}_1 \leftarrow v_2) = \Delta A_T \Phi_1(\vec{r}_1 \leftarrow v_2) \quad (5)$$

where Φ_1 is the first collision point specific absorbed fraction

$$\Phi_1(\vec{r}_1 \leftarrow v_2) = \frac{\mu_{en}(\vec{r}_1)}{4\pi\rho(\vec{r}_1)} \frac{1}{v_2} G(\vec{r}_1 \leftarrow v_2) \quad (6)$$

where G is the "generalized geometric factor,

$$G(\vec{r}_1 \leftarrow v_2) = \iiint_{v_2} \frac{a(\vec{r}_2)}{\bar{a}} \frac{\exp\left[- \int_{\vec{r}_2}^{\vec{r}_1} \mu ds\right]}{(\vec{r}_1 - \vec{r}_2)^2} dV_2, \quad (7)$$

a simple extension of the original definition of the geometric factor by Marinelli, Quimby and Hine³

$$g(\vec{r}_1 \leftarrow v_2) = \iiint \frac{\exp(-\mu|\vec{r}_1 - \vec{r}_2|)}{(\vec{r}_1 - \vec{r}_2)^2} dV_2. \quad (8)$$

The first collision point specific absorbed fraction, or the generalized geometric factor can be used to give the first collision dose for a point.

The average dose is given in terms of the absorbed fraction ϕ where

$$\phi(v_1 \leftarrow v_2) = \iiint \rho(\vec{r}_1) \Phi(\vec{r}_1 \leftarrow v_2) dV_1 \quad (9)$$

and the average dose rate is

$$\frac{d\bar{D}}{dt}(v_1 \leftarrow v_2) = \frac{1}{m_1} A \Delta \phi(v_1 \leftarrow v_2). \quad (10)$$

The capability of this program is to calculate Φ_1 , not Φ ; that is, only first collision terms. Approximations can make this applicable to the general dose case. First, if the volumes involved are small enough, the first collision dose and the total dose are essentially the same; for example, the first collision dose differs from the total dose by only a few percent for tissue spheres of 100 grams or less containing a distributed source.⁴ Second, if the linear absorption coefficient in the formulae for first collision dose is replaced by an effective absorption coefficient $\mu_{eff} \approx \mu_{en}$, the results should be applicable for total doses for objects somewhat larger than those whose dose is adequately described with the first collision dose.⁵ Third, the second and higher collision doses can sometimes be estimated without recourse to numerical integrals to reasonable precision.⁶

2. Method of Calculation

The source and target are included in a single volume. This volume

is divided into up to 3375 equal rectangular parallelepipeds* whose three sides can be chosen independently. The integrals then reduce to sums; in particular the absorption integral becomes

$$\exp \left[- \int_{\vec{r}_1}^{\vec{r}_2} \mu(r) dr \right] \approx \exp \left[- \sum_{n=1}^N \mu_n \Delta s_n \right]$$
$$\approx \prod (1 - \mu_n \Delta s_n) \quad (11)$$

where the index, n , is taken over all cubes traversed by the straight line path from \vec{r}_1 to \vec{r}_2 . The evaluation of the ray lengths in each cube, Δs_n , is done by following the intercepts with the various bounding planes. No absorption is assumed in either the target or the source elementary volumes.

The other integrals involved in evaluating $G(\vec{r}_1 \leftarrow v_2)$ and $\phi_1(v_1 \leftarrow v_2)$ are carried out by simple summation. However, the distance between source and target is reduced slightly. The contribution to a target volume from itself is calculated specially as are the contribution between adjacent volumes. These corrections involve numerical values which were derived by a consistency argument requiring that the results for a specific configuration should be independent of the number of the elementary volumes into which it is subdivided.

*More than 3375 sub-volumes can be specified by increasing the dimensions of the arrays in the program.

3. Program Structure

The program is divided into a main program and a single subroutine.

The subroutine calculates the attenuation:

$$\exp \left[- \int_{\vec{r}_1}^{\vec{r}_2} \mu(r) dr \right]. \quad (12)$$

The main program reads in the configuration and calculates the sums used in the other integrals.

The volume is placed in the first quadrant, and the elementary subvolumes are identified by the indices of their center points. The values for the linear absorption, μ , mass-energy absorption, μ_{en}/ρ , activity density, a , and mass density, ρ , for each point are supplied in the data cards as well as the number and size of the elementary volumes.

The units are assumed to be centimeters and grams, although other units can be used provided the output is converted. The activity density is only used in relative units; any units can be supplied.

The printing can be controlled at five different levels. The levels and the printing included are:

+2 first collision absorbed fraction $\phi_1(v \leftarrow v)$ only

+1 as in +2, the input data and the point function $G(\vec{r}_1 \leftarrow v)$ and $\Phi_1(\vec{r}_1 \leftarrow v)$

0 the output at +1 and the point to point terms including

$$\exp \left[- \int_{\vec{r}_1}^{\vec{r}_2} \mu(r) dr \right] \text{ for each } \vec{r}_1 \text{ and } \vec{r}_2$$

- 1 all the preceding printed output and the intercepts and ray lengths, Δs_n , for each cube.
- 2 includes all the preceding and a few more messages which are useful primarily for debugging.

4. Program Modification

The program as it stands is useful for a completely general case provided the first collision dose is adequate. Because of the generality, the input is voluminous. If a specialized type of problem is being handled, such as point sources, constant attenuation, etc., the program can easily be specialized. The results using one specialized version of this program have been published.⁷

5. Input and Output

All of the input is read in by the main program before calculation starts.

The first input card contains the number controlling printing in I2 format. The allowed values of the number and the control is described in the "Program Structure" section.

The second card contains the three numbers in 3I2 format delimiting the volume size. The first number, LX, indicates the number of elementary volume divisions along the x-axis, the second, LY, the y-axis division, and the third, the z-axis. Presently, the number of divisions along any axis is restricted to 15. This number limitation can be increased by increasing the dimensions of the subscripted variables. The numbers on the second card are used as the upper limit on the numerical integrals; small values will speed execution.

The third card contains the actual lengths, SX, SY, and SZ, of each of the elementary volume sides. These are punched in 3F15.5 format. These lengths are assumed to be in centimeters. The overall volume has dimensions of LX·SX by LY·SY by LZ·SZ.

The fourth and succeeding cards contain the pertinent information about the various elementary volumes. Each card contains the four parameters μ (in cm^{-1}), μ_{en} (in cm^2/g), activity density (relative units) and mass density (g/cm^3), in (9X, 4E14.7). The first of these cards is for the sub-volume centered at $x = y = z = 1$, the second of these is for the sub-volume centered at $x = y = 1 z = 2$, etc. A complete list specifying LX·LY·LZ elementary volumes must be given.

The output is restricted to printing. The amount of printing depends on the value for the printing control parameter specified in the first card. There is considerable literal matter in all of the printed statements which describes the output.

6. FORTRAN Statements

The listing of the FORTRAN statements for DOSE1 is given in Appendix 1. A sample run is described in Appendix 2.

FORTRAN decks and additional copies of this report are available from the author. If any errors or faults in this program or report are found, please report these to the author.

Appendix 1

This appendix contains a complete listing of the program DOSE1.
The subroutine ATINTG precedes the main program. The statements are in
the FORTRAN IV (H) language as implemented on the IBM 360/75 and 91 at
O.R.N.L.

```
SUBROUTINE ATINTG(IX2,IY2,IZ2,IX1,IY1,IZ1,ISET1,AT,DTL)          0004
  REAL MULIN
  COMMON /SCALE/S/SSA,SSX,SSY,SZ
  COMMON /ATENS/MULIN(15,15,15)
101 FORMAT (15H SOURCE CUBE IS,3I5)                                0005
102 FORMAT (8H IN CUBE,I4,2I3,14H RAY LENGTH =,E14.7,5X,3HAT=,E14.7) 0006
104 FORMAT (15H X-INTERCEPT IS,E14.7)                                0007
105 FORMAT (14H X IS CONSTANT)                                 0008
106 FORMAT (17H X AND Y CONSTANT)                                0009
  INUMX=IX2-IX1
  NUMX=IABS(INUMX)
  DX=NUMX
C DX AND NUMX ARE THE NUMBER OF X=CONST. PLANES BETWEEN THE SOURCE AND T 0010
  DLX=DX*DX
  DTLX=DLX*SSX
C DTLX IS THE SQUARE OF THE REAL X-DISTANCE BETWEEN THE SOURCE      0011
C AND THE TARGET.                                                 0012
  IF(INUMX) 1,4,2
  1 CONTINUE
    X1=FLOAT(IX2)+0.5
    GO TO 3
  2 CONTINUE
    X1=FLOAT(IX1)+0.5
  3 CONTINUE
    X2=X1+DX
C X1 AND X2 ARE THE X COORDINATES OF THE SOURCE AND TARGET,        0013
C X1 IS THE LOWER VALUE, X2 THE HIGHER.
  ISX=INUMX/NUMX
  4 CONTINUE
    YST=X2+1.0
    INUMY=IY2-IY1
    NUMY=IABS(INUMY)
    DY=NUMY
C THE VARIABLES NUMY, DY, DYS, DTLY ARE ANALOGOUS TO THE X TERMS. 0014
  DYS=DY*DY
  DTLY=DLX*DYS
C DTLY IS THE SUM OF THE SQUARES OF THE X AND Y COORDINATE CHANGES. 0015
  DTLY=DTLX+DYS*SSY
  IF(INUMY.EQ.0) GO TO 5
  ISY=INUMY/NUMY
  ALPHA=DX/DY
  IALPHA=ISY*ISX
  YST=X1+0.5*ALPHA
  5 CONTINUE
  IF(ISET1.LE.-2) PRINT 101,IX2,IY2,IZ2
  AT=1.0
  INUMZ=IZ2-IZ1
  NUMZ=IABS(INUMZ)
  DZ=NUMZ
  DTZ=DZ*SZ
  DTL=DTLY+DTZ*DTZ
  DIST=SQRT(DTL)
C DIST IS THE LINE LENGTH IN CM.                                     0016
  DL=DLY+DZ*DZ
  IF(DL.LT.3.5) GO TO 28
C DL IS .LT. 3.5 FOR ADJACENT BLOCKS ONLY.
C FOR NON-ADJACENT BLOCKS, THE RAY IS RUN THROUGH THE INTERMEDIATE 0017
C CUBES TO CALCULATE THE ABSORPTION. THE POSSIBLE CONFIGURATIONS 0018
  0019
  0020
  0021
  0022
  0023
  0024
  0025
  0026
  0027
  0028
  0029
  0030
  0031
  0032
  0033
  0034
  0035
  0036
  0037
  0038
  0039
  0040
  0041
  0042
  0043
  0044
  0045
  0046
  0047
  0048
  0049
  0050
  0051
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  0053
  0054
  0055
  0056
  0057
  0058
  0059
  0060
  0061
```

C THAT ARE RECOGNIZED AND HANDLED SEPARATELY ARE X VARIABLE. C062
C X=CONST, AND X AND Y CONSTANT. C063
IF(INUMX) 6,16,7 C064
C HERE X VARIES AND THE PROGRESS ALONG THE RAY IS MEASURED BY THE C065
C X-PROJECTION ONLY. THE RAY IS TRAVERSED IN THE DIRECTION C066
C OF INCREASING X. CC67
6 CONTINUE C068
IX=IX2 C069
IY=IY2 C070
IZ=IZ2 C071
GO TO 8 C072
C IX, IY, IZ ARE THE COORDINATES OF THE CUBE THAT THE RAY IS C073
C PASSING THROUGH C074
7 CONTINUE C075
IX=IX1 C076
IY=IY1 C077
IZ=IZ1 C078
8 CONTINUE C079
Y=YST C080
C X, Y AND Z ARE THE X-INTERCEPTS WITH THE X=L, Y=M AND Z=N PLANES, C081
C WHERE L, M AND N ARE INTEGERS. C082
S=DIST/DX C083
IF(DZ.LT.0.5) GO TO 9 C084
BETA=DX/DZ C085
IBETA=INUMZ/NUMZ*I SX C086
Z=X1+0.5*BETA C087
GO TO 10 C088
9 CONTINUE C089
Z=X2+1.0 C090
10 CONTINUE C091
X=X1+0.5 C092
XX2=-1.0 C093
11 CONTINUE C094
XX1=XX2 C095
C XX1 IS THE VALUE OF THE PREVIOUS INTERCEPT, IF THERE IS NO C096
C PREVIOUS INTERCEPT, THE VALUE IS SET TO -1. THIS LATTER IS AN C097
C IMPOSSIBLE VALUE , SINCE ALL CALCULATIONS ARE IN POSITIVE C098
C VALUES OF GEOMETRY. C099
XX2=AMIN1(X,Y,Z) C100
IF(ISET1.LT.-1) PRINT 104,XX2 C101
XX3=XX2+0.001 C102
IF(XX2.GT.X2) RETURN C103
IF(ISET1.GE.0) GO TO 12 C104
IXP=IX C105
IYP=IY C106
IZP=IZ C107
12 CONTINUE C108
AMU=MULIN(IX,IY,IZ) C109
IF(XX3.LT.X) GO TO 13 C110
X=X+1.0 C111
IX=IX+1 C112
13 CONTINUE C113
IF(XX3.LT.Y) GO TO 14 C114
Y=Y+ALPHA C115
IY=IY+IALPHA C116
14 CONTINUE C117
IF(XX3.LT.Z) GO TO 15 C118
Z=Z+BETA C119

```
    IZ=IZ+IBETA          0120
15  CONTINUE           0121
    IF(XX1.LT.0.0) GO TO 11 0122
    RAY=(XX2-XX1)*S        0123
C RAY IS THE LENGTH OF THE RAY INSIDE THE CUBE.
C AT IS THE ACCUMULATED ATTENUATION, IF RAY*AMU IS NOT MUCH LESS
C THAN 1, THE EXPONENTIAL SHOULD BE USED.          0124
    AT=AT*(1.0-RAY*AMU)    0125
    IF(ISET1.LE.-1) PRINT 102,IXP,IYP,IZP,RAY,AT      0126
    GO TO 11             0127
16  CONTINUE           0128
    IF(INUMY) 17,26,18    0129
C HERE X=CONST. Y1.NE.Y2          0130
17  CONTINUE           0131
    S=DIST/DY            0132
    IY=IY2               0133
    IZ=IZ2               0134
    GO TO 19             0135
18  CONTINUE           0136
    S=DIST/DY            0137
    IY=IY1               0138
    IZ=IZ1               0139
19  CONTINUE           0140
    Y1=FLOAT(IY)+0.5     0141
    Y2=Y1+DY              0142
    IF(DZ.LT.0.5) GO TO 20 0143
    BETA=DY/DZ            0144
    IBETA=INUMZ/NUMZ*IY   0145
    Z=Y1+0.5*BETA        0146
    GO TO 21             0147
20  CONTINUE           0148
    Z=Y2+1.0              0149
21  CCNTINUE          0150
    Y=Y1+0.5              0151
    YY2=-1.0              0152
    IF(ISET1.LE.-1) PRINT 105 0153
22  CONTINUE           0154
    YY1=YY2              0155
    YY2=AMIN1(Y,Z)        0156
    IF(YY2.GT.Y2) RETURN  0157
    YY3=YY2+0.001          0158
    IF(ISET1.GE.0) GO TO 23 0159
    IYP=IY                0160
    IZP=IZ                0161
23  CONTINUE           0162
    AMU=MULIN(IX1,IY,IZ)  0163
    IF(YY3.LT.Y) GO TO 24 0164
    Y=Y+1.0              0165
    IY=IY+1               0166
24  CONTINUE           0167
    IF(YY3.LT.Z) GO TO 25 0168
    Z=Z+BETA              0169
    IZ=IZ+IBETA            0170
25  CONTINUE           0171
    IF(YY1.LT.0.0) GO TO 22 0172
    RAY=(YY2-YY1)*S        0173
    AT=AT*(1.0-RAY*AMU)    0174
    IF(ISET1.LE.-1) PRINT 102,IX1,IYP,IZP,RAY,AT      0175
                                                0176
                                                0177
```

GO TO 22	0178
26 CONTINUE	0179
RAY =1.0	0180
I2=MIN(I21,I22)	0181
IF(ISET1.LE.-1) PRINT 106	0182
I2X=I2+NUMZ	0183
DO 27 I=I2,I2X	0184
AT=AT*(1.0-MULIN(IX1,IY1,I))	0185
IFISET1.GE.0) GO TO 27	0186
PRINT 102,IX1,IY1,I,RAY,AT	0187
27 CONTINUE	0188
RETURN	0189
28 CONTINUE	0190
IF(DL.GE.0.5) GO TO 29	0191
C THIS IS THE SELF DOSE PROBLEM.	0192
AT=4.2248	0193
DTL=SSA	0194
C THIS AT AND DTL GIVE THE CORRECT SELF DOSE TO FIRST ORDER	0195
RETURN	0196
29 CONTINUE	0197
AT=0.588	0198
IF(DL.GE.1.1) RETURN	0199
C THIS IS THE FACE ADJACENT DOSE WHICH IS OVERESTIMATED ON THE USUAL BASIS	0200
AT=0.9008	0201
RETURN	0202
END	0203

C SOURCE DECK FOR *** TOTAL DOSE *****
C THIS IS PROGRAM TOTAL-DOSE FOR NCN-UNIFORM DISTRIBUTIONS. 0204
REAL MULIN,MUEN 0205
COMMON /ATENS/MULIN(15,15,15) 0206
COMMON /SCALES/SSA,SSX,SSY,SZ 0207
DIMENSION MUEN(15,15,15),RDISTP(15,15,15) 0208
DIMENSION ROMASS(15,15,15) 0209
C MULIN IS THE LINEAR ABSORPTION COEFFICIENT FOR A CUBE IN /CM 0210
C MUEN IS THE MASS-ENERGY ABSORPTION COEFFICIENT DIVIDED BY THE DENSITY 0211
C IN CM**2/G. 0212
C RDISTP IS THE RELATIVE ACTIVITY (ISOTOPE) DENSITY. ANY UNITS CAN BE 0213
C USED. 0214
C ROMASS IS THE SPECIFIC GRAVITY OR MASS-DENSITY IN GRAMS/CC. 0215
100 FORMAT (15HOTARGET CUBE IS,3I5) 0216
101 FORMAT ('THE ABSORBED FRACTION (FIRST COLLISION) FOR THE VOLUME', 0217
' & IS',F10.5) 0218
102 FORMAT(14H G-FACTOR TC I,I2,2(IH,,I2),8H) FROM I,I2,2(IH,,I2), 0219
12H)=,1E14.7,18H CM-1, SUB-TOTAL =,E14.7, 15H, ATTENUATION =,E14.7) 0220
103 FORMAT (3I2) 0221
104 FORMAT (3F15.5) 0222
105 FORMAT (9X,4E14.7) 0223
106 FORMAT (5H TO I,I2,1H,,I2,1H,,I2,13H), G-FACTOR =,E14.7, 0224
&29H CM, PT. SPEC. ABS. FRAC. =,E14.7,5H G-1.) 0225
107 FORMAT (* PRINTING CONTROL IS *,I2) 0226
108 FORMAT (*ONUMBER OF PLANES X/Y/Z*,3I3) 0227
1C9 FORMAT (*SCALES, X/Y/Z*,3E20.5) 0228
110 FORMAT (46HC X Y Z LINEAR ABSCRP. MUEN 0229
+29HACTIVITY DENS. MASS DENS. /(1X,3I3,1X,4E16.7)) 0230
READ 103,ISET1 0231
IF(ISET1.LE.1) 0232
+PRINT 107, ISET1 0233
C ISET1 CONTROLS THE LEVEL OF ERROR CHECKING AND PRINTING. 0234
C ISET1 CAN TAKE ON 5 VALUES -2,-1,0,1,2 0235
C THE LOWER VALUES HAVE MORE PRINTING. 0236
READ 103,LX,LY,LZ 0237
IF(ISET1.LE.1) 0238
+PRINT 108,LX,LY,LZ 0239
C LX IS THE NUMBER OF X=CONST PLANES ETC. 0240
C THE PLANES ARE CONSIDERED AS UNIT DISTANCE APART. 0241
C HOWEVER, THE ACTUAL INTERPLANE DISTANCE (IN CM.) IS SX. 0242
READ 104,SX,SY,SZ 0243
IF(ISET1.LE.1) 0244
+PRINT 109, SX,SY,SZ 0245
READ 105,((MULIN(I,J,K),MUEN(I,J,K),RDISTP(I,J,K),ROMASS(I,J,K), 0246
1K=1,LZ),J=1,LY),I=1,LX) 0247
IF(ISET1.LE.1) 0248
+PRINT 110,(((I,J,K,MULIN(I,J,K),MUEN(I,J,K),RDISTP(I,J,K), 0249
+ROMASS(I,J,K),K=1,LZ),J=1,LY),I=1,LX) 0250
VOLUME=SX*SY*SZ 0251
C -VOLUME- IS THE VOLUME OF THE INDIVIDUAL CUBES 0252
VOLTOT=VOLUME*FLOAT(LX*LY*LZ) 0253
C VOLTOT IS THE TOTAL (REAL) VOLUME OF THE SPACE. 0254
SSALOG=ALOG(VOLUME)/1.5 0255
SSA=EXP(SSALOG) 0256
C SSA IS THE SQUARE OF THE (GEOMETRIC) MEAN CUBE DIMENSION 0257
SSX=SX*SX 0258
SSY=SY*SZ 0259

SSY=SY*SY	0260
SSZ=SZ*SZ	0261
ACT=0.0	0262
DO 3 IX=1,LX	0263
DO 2 IY=1,LY	0264
DO 1 IZ=1,LZ	0265
ACT=ACT+ROISTP(IX,IY,IZ)	0266
1 CONTINUE	0267
2 CCNTINUE	0268
3 CONTINUE	0269
AVROIS=ACT*VOLUME/VOLTOT	0270
C AVROIS IS THE AVERAGE ACTIVITY DENSITY	0271
DO 6 IX=1,LX	0272
DO 5 IY=1,LY	0273
DO 4 IZ=1,LZ	0274
RCISTP(IX,IY,IZ)=ROISTP(IX,IY,IZ)/AVRCIS	0275
C RCISTP IS NOW THE ACTIVITY DENSITY DIVIDED BY THE AVERAGE ACTIVITY	0276
C DENSITY.	0277
4 CCNTINUE	0278
5 CONTINUE	0279
6 CCNTINUE	0280
SPABIN=0.0	0281
C THE FOLLOWING REPRESENT THE COORDINATES OF THE TARGET CUBE.	0282
DO 16 IX1=1,LX	0283
DO 15 IY1=1,LY	0284
DO 14 IZ1=1,LZ	0285
GGFCTV=0.0	0286
C *GGFCTV* IS THE GENERALIZED GEOMETRIC FACTOR FOR THE TARGET VOLUME	0287
IF(ISET1.LE.-2) PRINT 100,IX1,IY1,IZ1	0288
DO 13 IX2=1,LX	0289
DO 12 IY2=1,LY	0290
DO 11 IZ2=1,LZ	0291
C THE INDICES ENDING IN -2 ARE THE SCURCE CUBE COORDINATES.	0292
IF(ROISTP(IX2,IY2,IZ2).LT.0.1E-15) GO TO 11	0293
C IF THE ISOTOPE DENSITY IS ZERC, THIS IS NOT AN ACTIVE SOURCE.	0294
CALL ATINTG(IX2,IY2,IZ2,IX1,IY1,IZ1,ISET1,AT,DTL)	0295
GGFCTR= ROISTP(IX2,IY2,IZ2)*AT*VCLUME/(DTL-SSA/4.0)	0296
GGFCTV=GGFCTR+GGFCTR	0297
IF(ISET1.LE.0) PRINT 102,IX1,IY1,IZ1,IX2,IY2,IZ2,GGFCTR,GGFCTV,AT	0298
11 CONTINUE	0299
12 CONTINUE	0300
13 CONTINUE	0301
PSABFR=MUEN(IX1,IY1,IZ1)*GGFCTV/(12.5664*VOLTOT)	0302
C PSABFR IS THE POINT-SPECIFIC-ABSORBED-FRACTION.	0303
IF(ISET1.LE.1)	0304
+PRINT 106,IX1,IY1,IZ1,GGFCTV,PSABFR	0305
SPABIN=SPABIN+ROMASS(IX1,IY1,IZ1)*PSABFR	0306
14 CONTINUE	0307
15 CONTINUE	0308
16 CCNTINUE	0309
AESBFC=SPABIN*VOLUME	0310
PRINT 101,AESBFC	0311
CALL EXIT	0312
STOP	0313
END	0314

Appendix 2

This appendix contains the printout from a run for a single source in the elementary volume (1,1,1). The actual volume is 10 x 10 x .03 cm.; that is, this is a lamina with a point source in one corner.

Notice that the x and y scales are not chosen equally. The absorption coefficients are chosen to match tissue for 0.66 MeV photons.

Thirty cards are needed to specify all of the sub-volume parameters.

The output contains the generalized geometric factor $G(r \leftarrow v)$ and first-collision point-specific absorbed fraction $\Phi_1(r \leftarrow v)$ for each elementary volume. The last line contains the overall first-collision absorbed fraction.

PRINTING CONTROL IS 1

NUMBER OF PLANES X/Y/Z 10 3 1

SCALES, X/Y/Z 0.10000E 01 0.33330E 01 C.30000E-01

X	Y	Z	LINEAR ABSORP.	MUEN	ACTIVITY DENS.	MASS DENS.
1	1	1	0.8999997E-01	0.3000000E-01	0.1000000E 01	0.1000000E 01
1	2	1	0.8999997E-01	0.3000000E-01	0.0	C.1000000E 01
1	3	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
2	1	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
2	2	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
2	3	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
3	1	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
3	2	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
3	3	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
4	1	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
4	2	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
4	3	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
5	1	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
5	2	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
5	3	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
6	1	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
6	2	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
6	3	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
7	1	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
7	2	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
7	3	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
8	1	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
8	2	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
8	3	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
9	1	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
9	2	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
9	3	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
10	1	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
10	2	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
10	3	1	0.8999997E-01	0.3000000E-01	0.0	0.1000000E 01
TO (1, 1, 1), G-FACTOR = 0.7843645E 02 CM,	PT. SPEC. ABS. FRAC. = 0.6242390E-01 G-1.					
TO (1, 2, 1), G-FACTOR = 0.2444251E 00 CM,	PT. SPEC. ABS. FRAC. = 0.1945264E-03 G-1.					
TO (1, 3, 1), G-FACTOR = 0.4731407E-01 CM,	PT. SPEC. ABS. FRAC. = 0.3765505E-04 G-1.					
TO (2, 1, 1), G-FACTOR = 0.2855938E 01 CM,	PT. SPEC. ABS. FRAC. = 0.2272906E-02 G-1.					
TO (2, 2, 1), G-FACTOR = 0.2458476E 00 CM,	PT. SPEC. ABS. FRAC. = 0.1956586E-03 G-1.					
TO (2, 3, 1), G-FACTOR = 0.4757020E-01 CM,	PT. SPEC. ABS. FRAC. = 0.3785874E-04 G-1.					
TO (3, 1, 1), G-FACTOR = 0.6917444E 00 CM,	PT. SPEC. ABS. FRAC. = 0.5505269E-03 G-1.					
TO (3, 2, 1), G-FACTOR = 0.1659211E 00 CM,	PT. SPEC. ABS. FRAC. = 0.1320488E-03 G-1.					
TO (3, 3, 1), G-FACTOR = 0.4258326E-01 CM,	PT. SPEC. ABS. FRAC. = 0.3389001E-04 G-1.					
TO (4, 1, 1), G-FACTOR = 0.2776670E 00 CM,	PT. SPEC. ABS. FRAC. = 0.2209821E-03 G-1.					
TO (4, 2, 1), G-FACTOR = 0.1120366E 00 CM,	PT. SPEC. ABS. FRAC. = 0.8916466E-04 G-1.					
TO (4, 3, 1), G-FACTOR = 0.3504527E-01 CM,	PT. SPEC. ABS. FRAC. = 0.2789088E-04 G-1.					
TO (5, 1, 1), G-FACTOR = 0.1417574E 00 CM,	PT. SPEC. ABS. FRAC. = 0.1128181E-03 G-1.					
TO (5, 2, 1), G-FACTOR = 0.7659072E-01 CM,	PT. SPEC. ABS. FRAC. = 0.6095496E-04 G-1.					
TO (5, 3, 1), G-FACTOR = 0.2842375E-01 CM,	PT. SPEC. ABS. FRAC. = 0.2262116E-04 G-1.					
TO (6, 1, 1), G-FACTOR = 0.8245921E-01 CM,	PT. SPEC. ABS. FRAC. = 0.6562543E-04 G-1.					
TO (6, 2, 1), G-FACTOR = 0.5263241E-01 CM,	PT. SPEC. ABS. FRAC. = 0.4188767E-04 G-1.					
TO (6, 3, 1), G-FACTOR = 0.2279438E-01 CM,	PT. SPEC. ABS. FRAC. = 0.1814097E-04 G-1.					
TO (7, 1, 1), G-FACTOR = 0.5207531E-01 CM,	PT. SPEC. ABS. FRAC. = 0.4144429E-04 G-1.					
TO (7, 2, 1), G-FACTOR = 0.3713865E-01 CM,	PT. SPEC. ABS. FRAC. = 0.2955690E-04 G-1.					
TO (7, 3, 1), G-FACTOR = 0.1812105E-01 CM,	PT. SPEC. ABS. FRAC. = 0.1442169E-04 G-1.					
TO (8, 1, 1), G-FACTOR = 0.3480221E-01 CM,	PT. SPEC. ABS. FRAC. = 0.2769745E-04 G-1.					
TO (8, 2, 1), G-FACTOR = 0.2660148E-01 CM,	PT. SPEC. ABS. FRAC. = 0.2117087E-04 G-1.					
TO (8, 3, 1), G-FACTOR = 0.1458397E-01 CM,	PT. SPEC. ABS. FRAC. = 0.1160669E-04 G-1.					
TO (9, 1, 1), G-FACTOR = 0.2424112E-01 CM,	PT. SPEC. ABS. FRAC. = 0.1929236E-04 G-1.					
TO (9, 2, 1), G-FACTOR = 0.1954227E-01 CM,	PT. SPEC. ABS. FRAC. = 0.1555277E-04 G-1.					
TO (9, 3, 1), G-FACTOR = 0.1166010E-01 CM,	PT. SPEC. ABS. FRAC. = 0.9279726E-05 G-1.					
TO (10, 1, 1), G-FACTOR = 0.1742659E-01 CM,	PT. SPEC. ABS. FRAC. = 0.1386900E-04 G-1.					
TO (10, 2, 1), G-FACTOR = 0.1453717E-01 CM,	PT. SPEC. ABS. FRAC. = 0.1156945E-04 G-1.					
TO (10, 3, 1), G-FACTOR = 0.9299342E-02 CM,	PT. SPEC. ABS. FRAC. = 0.7400905E-05 G-1.					

THE ABSORBED FRACTION (FIRST COLLISION) FOR THE VOLUME IS 0.00668

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