N64-29367
(ACCESSION NUMBER)
91
(PAGES)
CR-58296
(NASA CR OR TMX OR AD NUMBER)
(THRU)
1
(CODE)
20
(CATEGORY)
FACILITY FORM 602

# COMPUTER CODES FOR THE EVALUATION OF SPACE RADIATION HAZARDS

## VOL. 5 ELECTRON MONTE CARLO

D2-90418-5

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER

OTS PRICE
XEROX $ 8.60 ph
MICROFILM $

Contract NAS 9-1393

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## GENERAL INFORMATION

The Electron Monte Carlo Program was written for an IBM 7094 computer. The program consists of a main input program and several subroutines written in FORTRAN and FAP programming languages.

### PURPOSE

The calculation of an electron flux penetrating a shield is complicated by scattering and straggling so that Monte Carlo techniques are necessary to achieve an acceptable solution. This Electron Monte Carlo program was developed specifically for the problem of space radiation shielding.

It is desirable to know, given the energy of electrons incident on a particular material or shield, how many of these electrons penetrate the shield and their energy after penetration, and also the energy deposition within the shield. The damage to objects behind the shield can then be determined. The thickness of a particular shield necessary to protect instruments or humans can also be determined.

The shield is considered to consist of infinite parallel slabs. Its geometry (thickness) and the material composition are inputs to the program. The source of electrons incident on the shield face is described by the initial energy of the electrons and their angle of incidence. The electrons penetrate the shield in finite increment thicknesses that are determined by the user. The electrons then suffer discrete energy losses and angular deflections at the end of each increment.

This process is continued until the electrons are transmitted or their energy goes below the energy cut-off.

The results of the penetration calculations are expressed in the energy spectrum and the angular distribution of the transmitted radiation. Also, the spatial distribution of energy loss due to radiation loss in the shield is expressed in the output.

## ASSUMPTIONS

Monte Carlo analysis of the individual collisions suffered by an electron penetrating a shield is prohibitive since many thousands of collisions are made by each electron. Therefore, the electrons were allowed to penetrate a series of small increments of thickness. The electron is assumed to have suffered a discrete energy loss and angular deflection at the end of each increment.

It is also assumed that when an electron passes from one material to another in an increment, the collision point is considered to be at the material interface and the next increment originates from that point.

## LIMITATIONS

A monoenergetic source must be used. The angular distribution of the source can be monodirectional or isotropic.

The shield is limited to twelve successive slabs. A slab can consist of any material for which range and ionization energy loss data is available (see Ref. 1). Each slab can be divided into a maximum of 15 regions for the radiation energy loss

spatial distribution. A shield can have as many as 20 transmission boundaries for forward transmission distribution information. The backscatter transmissions are valid only for the total thickness of the shield. There can be up to 15 energy divisions and 16 angle divisions for the transmission distribution and 15 energy divisions for the radiation loss distribution.

## RECOMMENDATIONS

At present, only a monoenergetic source is available in the program. However, there does exist an option for another source energy spectrum such as a fission electron distribution.

Also, only a spatial distribution for radiation energy losses is recorded. A distribution of all energy losses in the shield can be obtained with only minor changes to the program.

## PROCEDURE

### NOMENCLATURE

A list of symbols and the corresponding names used in the program are presented in Table 1.

### METHOD

In the Monte Carlo method, each particle is followed from its source to its end, i.e., transmission or energy degradation below the cut-off energy. The results of many such particle histories are recorded and these results represent the physical situation.

The calculational scheme was based on the method of Leiss, Penner, and Robinson (Ref. 2), which was also employed by Perkins (Ref. 3). The initial energy, $E_o$, of an electron from a monoenergetic source is specified in the input. The angle of incidence, $\theta_o$, measured with respect to the shield normal, is either monodirectional and is specified in the input, or is determined from an isotropic distribution. In the latter option, $\cos \theta_o = R$, where R is a random number from 0 to 1. This then gives an angle of incidence between 0 and 90°.

The electron is started at the face of the shield where ZT = 0 and its total penetration is measured in the z-direction along the shield normal.

The distance the electron moves in the direction of $\theta$ to its next collision point is chosen in either of two ways: $\Delta T = C$, a constant increment; or $\Delta T = C/E$. The choice is optional to the user. The total penetration of the

TABLE 1. Nomenclature

| MATH SYMBOL | PROGRAM SYMBOL | DEFINITION | UNITS |
|---|---|---|---|
| $E_o$ | EINT | Initial source energy of electron | Mev |
| $\theta_o$ | THINT | Angle of incidence of source electrons | Degrees |
| R | RAND | Random number | |
| E | ENERGY | Energy of electron at a collision point | Mev |
| $\theta$ | THETA | Angle of electron direction measured with respect to shield normal | Radians |
| $\cos\theta$ | COSINE | Cosine of THETA | Radians |
| $\theta$ scat | THTSCT | Scatter angle of electron measured with respect to previous direction | |
| $\Delta T$ | DELT | Path length of electron from one collision point to the next | $gm/cm^2$ |
| t | T | Used in radiation energy loss calculation | |
| | TEST | Path length of electron measured along shield normal | $gm/cm^2$ |
| ZT | TTOT | Total penetration of electron measured along shield normal | $gm/cm^2$ |
| | NOSLAB | Number of slabs in the shield | |
| | NI | Number of boundaries for which transmission distributions are desired | |
| | TMAX(J) | Thickness of each slab J | $gm/cm^2$ |

TABLE 1. Nomenclature (continued)

| MATH SYMBOL | PROGRAM SYMBOL | DEFINITION | UNITS |
|---|---|---|---|
| j | J | Denoted slab the electron is in at the time of calculation | |
| ZB | SUM(J) | The right boundry of slab J | $gm/cm^2$ |
| | ISLB | Denotes the transmission boundary | |
| | ZB(ISLB) | Z coordinate of the transmission boundary | $gm/cm^2$ |
| | REGNO(J) | Number of subregions of each slab for recording radiation energy losses | |
| | IREG | Region in which radiation energy loss has occurred | |
| $1/X_o$ | XZRO | Inverse of radiation length | $cm^2/gm$ |
| $A_j$ | A(J) | Atomic weight of material of slab J | |
| $Z_j$ | Z(J) | Atomic number of material of slab J | |
| | REG(I, J) | Region boundaries for each slab J for recording radiation energy loss | $gm/cm^2$ |
| | KERROR | Error indicator | |
| $E_{ion}$ | EION | Ionization energy loss | Mev |
| $E_{rad}$ | ERAD | Radiation energy loss | Mev |
| dE/dx | DEDX | Rate of ionization energy loss | Mev $cm^2/gm$ |

TABLE 1. Nomenclature (Continued)

| MATH SYMBOL | PROGRAM SYMBOL | DEFINITION | UNIT |
|---|---|---|---|
| $\chi$ | CHI | Angle in base of cone around previous electron direction used to determine new electron direction | |
| | RE | Range of electron of energy, E, No longer used by program | $gm/cm^2$ |
| | ECUT(J) | Energy cut-off for material of slab J | Mev |
| | NOHIST | Number of histories desired | |
| | IHIST | Number of histories being calculated | |
| $\int_0^{\nu} f(0)\nu d\nu$ | FZINT(I) | Table of integral of function for $\nu = 0, 9.3$ | |
| $\nu$ | UPLIM(I) | Upper limit for table of integrals | |
| $\int_0^{\nu} \nu f^{(1)}(\nu)\, d\nu$ | F1INT(I) | Table of integral of function for $\nu = 0, 9.3$ | |
| $\int_0^{\nu} \nu f^{(2)}(\nu)\, d\nu$ | F2INT(I) | Table of integral of function for $\nu = 0, 9.3$ | |
| | ARG(I) | Table of arguments for exponential integral table | |
| $E_1(ARG)$ | EI(I) | Table of exponential integrals | |
| $E_1(\ln E_o/E)$ | EONE | Value of exponential integral for which the argument must be found | |
| | RAND1 | Number used to start random number generator | |

TABLE 1. Nomenclature (continued)

| MATH SYMBOL | PROGRAM SYMBOL | DEFINITION | UNIT |
|---|---|---|---|
| B | BBIG | Parameter used in Moliere | |
| b | SSML or SMLB | Parameter used in Moliere | |
| | SLOPE | Slope of plot of equation, $B - \ln B = b$ | |
| $\beta^2$ | BETSQ | Used in Moliere | |
| | DEN | Normalizing integral | |
| | VALUE | Used in Moliere | |
| | RANGE(I, J) | Table of ranges for slab J and energy I | $gm/cm^2$ |
| | RATE(I, J) | Table of ionization rate for slab J and energy I | $Mev\ cm^2/gm$ |
| | E(I, J) | Table of energies for range and rate tables | Mev |
| | IRDL(I, J, K) | Radiation energy loss array for region I of slab J and energy K | |
| | NANT(I, J, K) | Number transmitted array for energy I, angle bin J and transmission boundary K | |
| | FNEE(I, J, K) | Energy transmission array for energy bin I, angle bin J, and transmission boundary K | |
| C | FACTOR | Input constant to control increment thickness | |

new collision point is then $ZT = \sum (\Delta T_i \cos \theta_i)$. A test is now made to determine whether the electron has been: transmitted through either the front or the back face of the shield, scattered forward to the next slab, scattered backward to a previous slab, or remains in the same slab.

If transmission has occurred, the energy and angle, $\theta$, are recorded. A new history is then begun.

If the electron has been scattered forward or backward to another slab, the slab counter, J, is adjusted by + 1 or - 1, respectively, and the collision point is considered to be at the boundary between the two slabs. The actual $\Delta T$ the electron traveled is determined by $\Delta T = \frac{ZT - Z}{\cos \theta}$.

Energy Losses

IONIZATION ENERGY LOSS. When a collision point has been established, the electron is scattered and some of its energy expended due to radiation energy loss and ionization energy loss. For ionization loss, $\Delta E_{ion} = \frac{dE}{dx} \Delta T$, $\frac{dE}{dx}$ is the average ionization energy loss for an electron of energy, E, for the material of slab, J.

RADIATION ENERGY LOSS. The radiation loss probability was obtained from the relationships derived by Bethe and Heitler (Ref. 4). The inverse of the radiation length, $X_o$, for slab J is calculated as

$$\frac{1}{X_o} = \frac{4\alpha N}{A_i} Z_i^2 r_o^2 \ln (183 Z_i^{-1/3}) \qquad (1)$$

where $\alpha = 1/137$, $N = 6.02 \times 10^{23}$ is Avogadro's number, and $r_o = 2.28 \times 10^{-13}$.

The probability of an electron of energy, $E_o$ degrading to an energy between E and E + dE by radiation loss is

$$P(E_o - E) = \frac{1}{E_o} \frac{\left(\ln \frac{E_o}{E}\right)^{\left[(t/\ln 2)-1\right]}}{\Gamma(t/\ln 2)} \tag{2}$$

where $t = \Delta T/X_o$.

This function can be shown to be normalized, therefore,

$$R = \int_o^E \frac{1}{E_o} \frac{\left(\ln \frac{E_o}{E}\right)^{\left[(t/\ln 2)-1\right]}}{\Gamma(t/\ln 2)} dE \tag{3}$$

If $t/\ln 2 \ll 1$, and with proper substitutions,

$$R \sim \int_{\ln \frac{E_o}{E}}^{\infty} \frac{e^{-x}}{x} t/\ln 2 dx \tag{4}$$

$$R \sim t/\ln 2 \, E_1 (\ln E_o/E)$$

where $E_1$ is the exponential integral of the argument. The new energy, E, after radiation loss, is then determined from the above expression and the radiation energy loss, $E_{rad} = E_o - E$.

Therefore, the new energy of the electron at the end of its path increment is found to be

$$E = E_o - (E_{rad} + E_{ion}).$$

If the spatial distribution of radiation loss is desired, this radiation energy loss is tallied according to the energy division and region in which the loss occurred.

## Scatter Angle

The scatter angle of the electron is determined from the Moliere relationships discussed by Bethe (Ref. 5). The distribution function is expanded in a power series in 1/B which gives,

$$f(\theta_{scat})\,\theta_{scat}\,d\theta_{scat} = \nu d\nu \left[ f^{(0)}(\nu) + B^{-1} f^{(1)}(\nu) + B^{-2} f^{(2)} \nu + \ldots\ldots \right] \quad (5)$$

where: $f^{(0)}(\nu) = 2\nu e^{-\nu}$,

$$f^{(1)}(\nu) = 2e^{-\nu}\left[(\nu^2 - 1)\left\{E_i(\nu)^2 - \ln \nu^2\right\} - 2(1 - 2e^{-\nu^2})\right]$$

$$\frac{1}{4}e^{\nu} f^{(2)}(\nu) = \left[\psi^2(2) + \psi^1(2)\right](\nu^4 - 4\nu^2 + 2) + \int_0^1 t^{-3}\,dt\left[\ln t/(1-t) - \psi(2)\right]$$

$$\left[(1-t)^2 e^{\nu^2 t} - 1 - (\nu^2 - 2)t - (\tfrac{1}{2}\nu^4 - 2\nu^2 + 1)\,t^2\right]$$

The average energy over the path increment used in the Moliere calculation is expressed as

$$E_{mol} = E - (E_{rad} + E_{ion})/2. \quad (6)$$

The variable b is determined as

$$b = \ln\left[\frac{6680\,\Delta T(Z_i + 1)Z_i^{1/3} z^2}{\beta^2 A_i(1 + 3.34a^2)}\right] \quad (7)$$

where $z^2 = 1$, is the square of the charge of the particle; $\beta^2 = 1 - \left(\frac{.51}{E_{mol} + .51}\right)^2$, and $a^2 = (Z_i/137\beta)^2$ is the deviation from the Born approximation.

The equation, $B - \ln B = b$, is solved for the expression B, using an iterative scheme.

The variable $\nu$ is defined by

$$\nu = \theta_{scat}/(X_c B^{1/2}), \tag{8}$$

where $\theta_{scat}$ is the scatter angle measured with respect to the previous electron direction.

The parameter, $X_c$ defined as the total probability of a single scattering through an angle greater than $X_c$ is exactly one, and

$$X_c^2 = \frac{4\pi N \Delta T e^4 Z_i (Z_i + 1) z^2}{A_i \beta^4 (E_{mol} + 0.51)^2} \tag{9}$$

where $e = 4.8028 \times 10^{-10}$ esu.

Substituting,

$$f(\theta_{scat})\, d\theta_{scat} = \frac{d\nu}{X_c B^{1/2}} G(\nu) \tag{10}$$

where $G(\nu) = f^{(0)}(\nu) + B^{-1} f^{(1)}(\nu) + B^{-2} f^{(2)}(\nu)$

Using direct Monte Carlo to determine the scatter angle from the above we have

$$R = \frac{\int_0^{\nu} \left[G(\nu)\right] d\nu}{\int_0^{\pi/X_c B^{1/2}} \left[G(\nu)\right] d\nu} \tag{11}$$

To solve for $\theta_{scat}$ the following process was used. The integrals of each of the functions, $f^0$, $f^1$, and $f^2$, integrated from 0 to $\nu$, were calculated separately and put in tables for $\nu$ in increments up to 9.3. These functions were integrated without their appropriate power of B since it is independent of $\nu$. The upper limit of the denominator of Eq. (11) was determined and a table search

determined the values of the integrals of the three functions. These integrals were then multiplied by the power of B and the result yielded the value of the denominator of Eq. (11). This value was then multiplied by a random number which gave the value of the integral in the numerator of Eq. (11). Another table search, this time on the value of the integral, found the upper limit of the numerator. The scatter angle is then

$$\theta_{scat} = \nu X_c B^{1/2} \tag{12}$$

If the scatter angle is revolved around the previous electron direction, a right cone is formed. The intersection of the new electron direction and the base of the cone can be at any point on the circumference of the base of the cone. Therefore, an angle X is randomly chosen from 0 to $2\pi$ to determine this point of intersection, i.e., $X = 2\pi R$ (see Fig. 1). From the geometry, the new direction, $\theta$, measured with respect to the shield normal is found from the expression:

$$\cos\theta_i = \cos\theta_{i-1} \cos\theta_{scat} + \cos X \sin\theta_{scat} \sin\theta_{i-1}$$

This concludes the calculations necessary for one collision. This process is repeated until the electron history is terminated by transmission or energy degradation below the cut-off energy. Then, when the requested number of histories have been completed, the energy and angular distributions for transmission and/or the spatial distribution of radiation energy losses are edited.

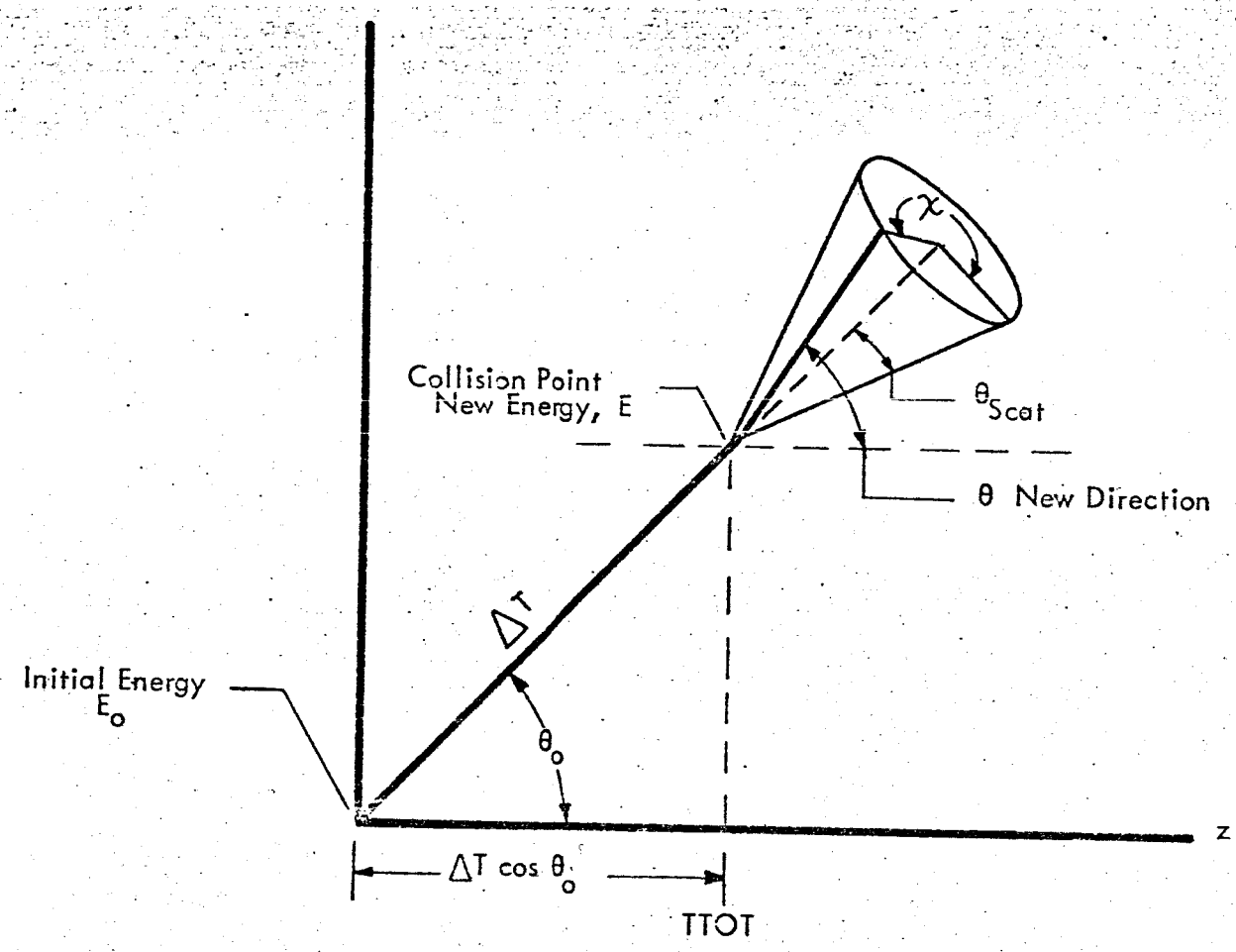



FIGURE 1. Geometry of Collisions

## RESULTS

The results of the Monte Carlo calculations were compared with existing experimental and theoretical data and found to be in good agreement. A comparison with Monte Carlo data of Perkins (Ref. 3) for 2 Mev electrons normally incident on an aluminum shield is shown in Fig. 2.

The extrapolated range of electrons from 1 to 8 Mev normally incident on an aluminum shield was compared with the analytic expression determined by Katz and Penfold (Ref. 6). Table 2 illustrates the comparison.

The backscatter electron results computed by the Monte Carlo program were compared to data obtained experimentally by Wright and Trump (Ref. 7). Figure 3 shows this comparison.

An investigation of the effect of the increment thickness or $\Delta T$ used in the calculation was made. Increments from .025 to .106 gm/cm$^2$ were used for a shield of aluminum. The results were found to lie within the statistical error associated with the number of histories processed and the number of electrons penetrating the slab (see Fig. 4). It was concluded that the Monte Carlo calculations are not limited by the choice of $\Delta T$.

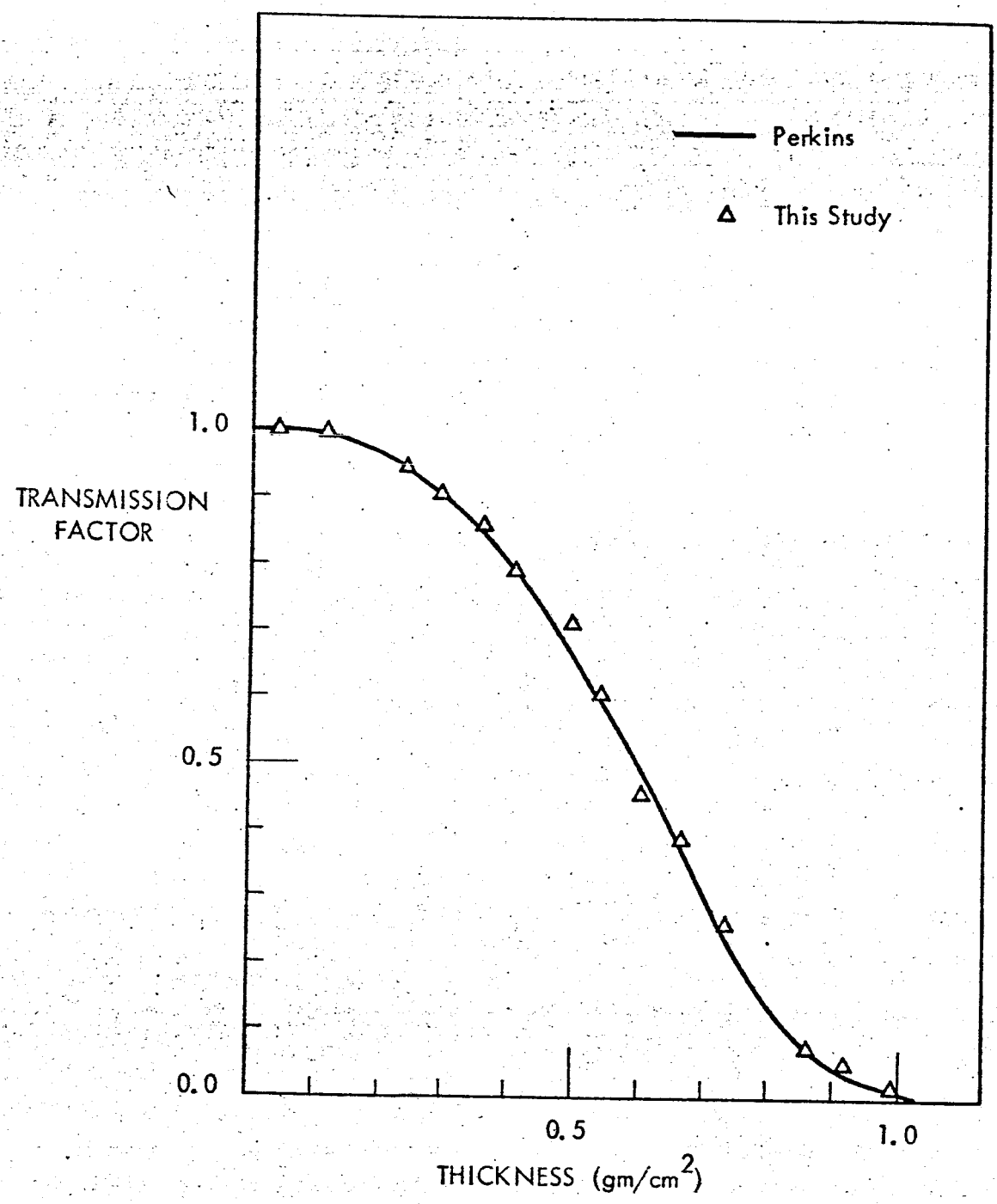



FIGURE 2. Comparison of Results of This Program With the Data of Perkins

TABLE 2. Comparison of the Results of this Program with that of Katz and Penfold

| E (Mev) | R (calc) ( gm/cm$^2$) | R (ref. 6) (gm/cm$^2$) |
|---|---|---|
| 1 | 0.41 | 0.42 |
| 2 | 0.98 | 1.05 |
| 3 | 1.50 | 1.48 |
| 4 | 2.00 | 2.01 |
| 6 | 3.10 | 3.07 |
| 8 | 4.10 | 4.13 |

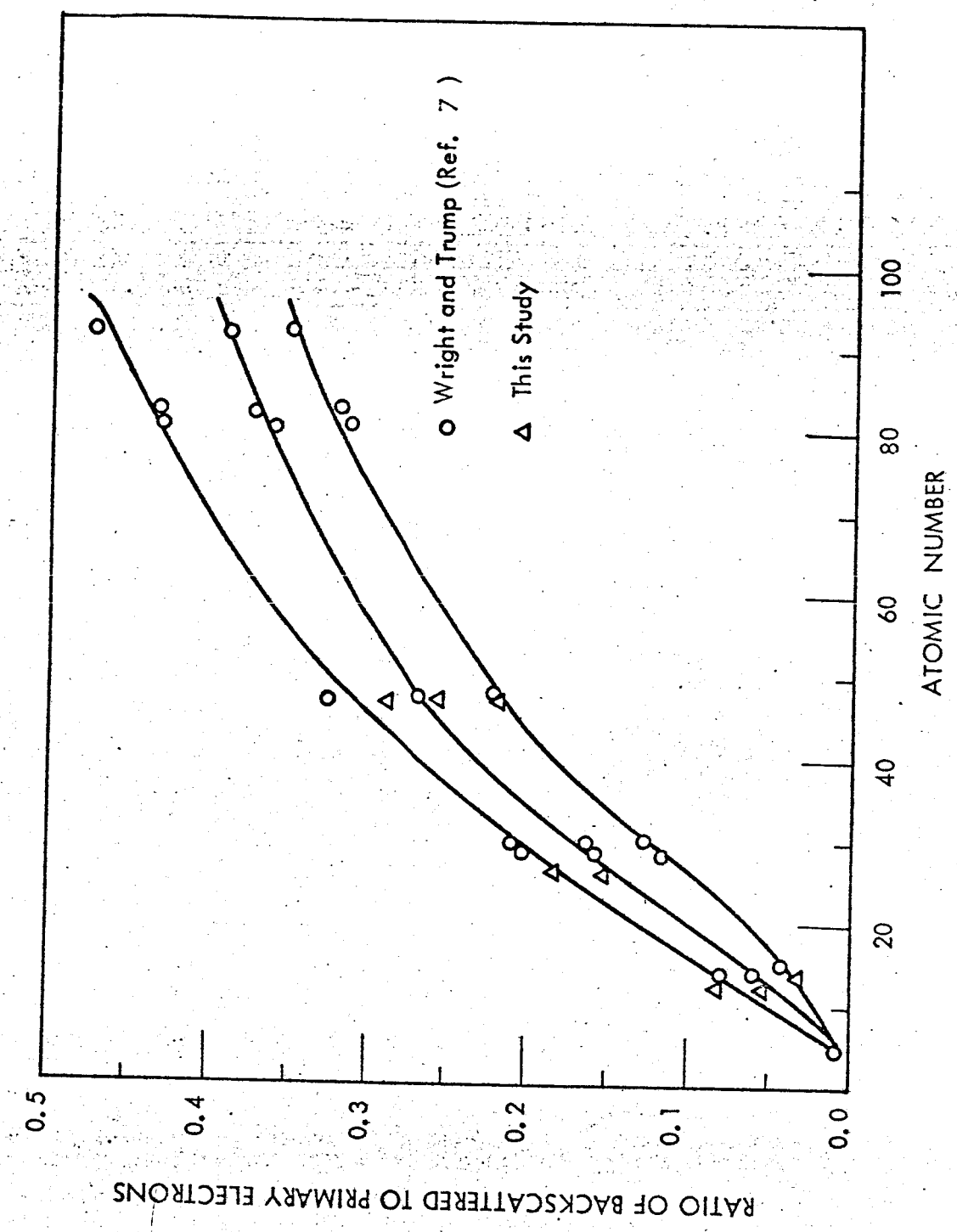



FIGURE 3. Comparison of the Results of This Program With the Data of Wright and Trump.

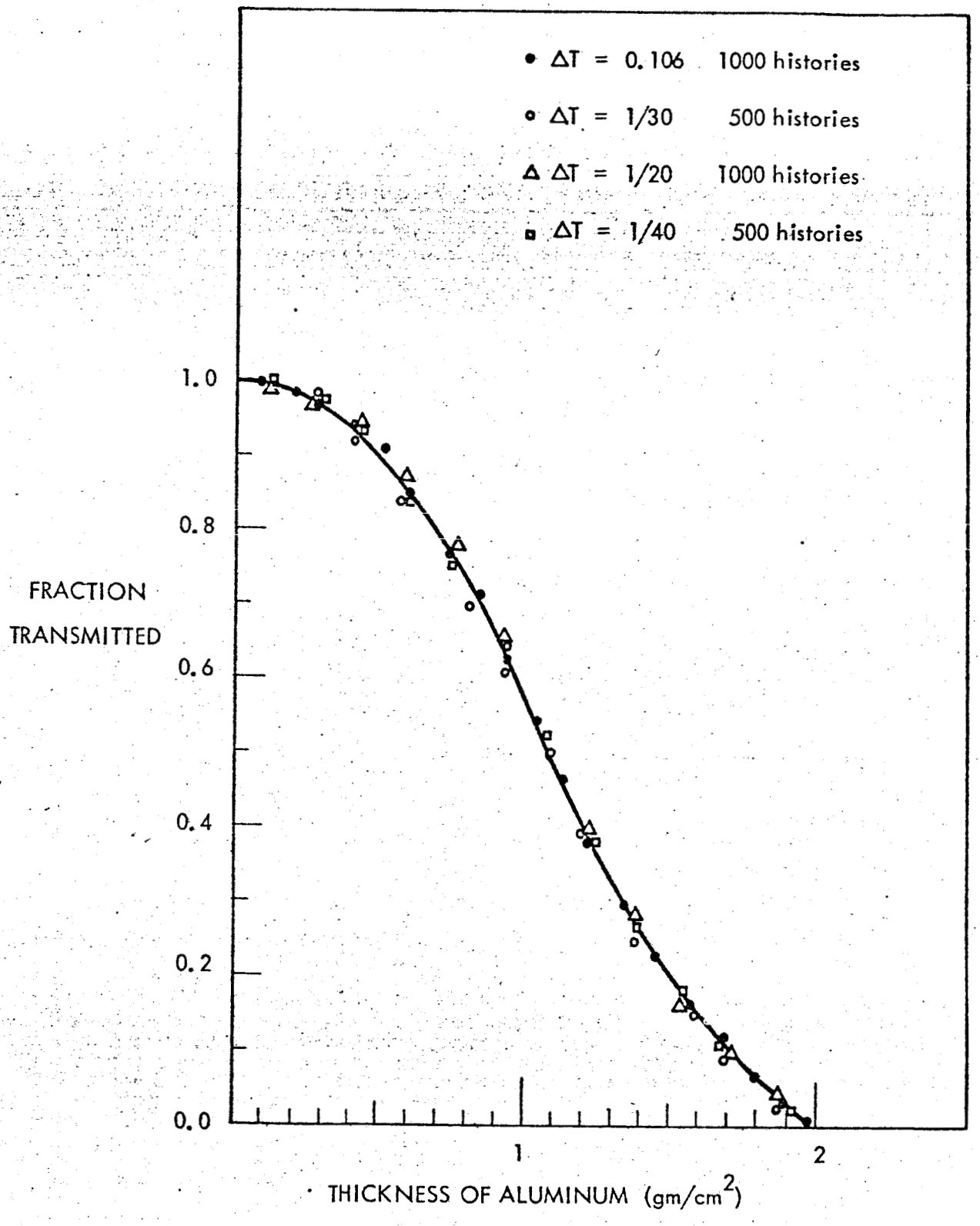



FIGURE 4. Comparison of Increments $\Delta T$

## INPUT PREPARATION AND OUTPUT DESCRIPTION

### INPUT DATA PREPARATION

Following the data card will always be the two sets of permanent tables presented in Tables 3 and 4.

The following cards are necessary for each problem:

Card 1. Problem Description Card (Always Necessary)

| Column | Variable | Format | Definition |
|---|---|---|---|
| 1-72 | DISCPT(I) | 12A6 | Any 72 characters for user to describe the problem. This will be written out at beginning of output. |

Card 2. Option Card (Always Necessary)

| | | | |
|---|---|---|---|
| 1-12 | SLCTE1 | 2A6 | Initial energy option SPECIFY or FISSION on card according to format. |
| 16-27 (left adjusted) | SLCTA1 SLCTA2 | 2A6 | Angle of incidence option SPECIFY or ISOTROPIC on card according to format. |
| 31-48 (left adjusted) | OPT1 | | Output option--TRANSMISSION for transmission distribution. |
| | OPT2 | 3A6 | BREMSSTRAHLUNG for radiation energy loss distribution. |
| | OPT3 | | BREMTRANS for both outputs. |
| 49-50 (right adjusted) | IOP | 12 | Option for selecting increment thickness. IOP = 1 for $\Delta T$ = constant IOP = 2 for $\Delta T$ = constant/energy |
| 51-60 (right adjusted) | NOHIST | 110 | Number of histories for the first output. |
| 61-70 (right adjusted) | NCONT | 110 | Total number of histories for the problem. |

Card 3. Initial Energy (needed only if initial energy is specified, i.e., if SLCTE1, SLCTE2 is SPECIFY)

| Column | Variable | Format | Definition |
|---|---|---|---|
| 1-10 | EINT | E10.0 | Initial energy of electrons (Mev) |

Card 4. Angle of Incidence (needed only if angle of incidence is specified, i.e., if SLCTA1, SLCTA2 is SPECIFY)

| | | | |
|---|---|---|---|
| 1-10 | THINT | E10.0 | Angle of incidence in degrees. |

Card 5. Number of Slabs in Shield (Always Needed)

| | | | |
|---|---|---|---|
| 1-10 (right adjusted) | NOSLAB | I10 | Number of slabs in the shield. (Maximum of 12) |

Card 6.[1] Slab Description (Always Needed)

| | | | |
|---|---|---|---|
| 1-12 (left adjusted) | TPMT1(J) TPMT2(J) | 2A6 | Any 12 characters to denote material of slab J. |
| 13-22 | TMAX(J) | E10.0 | Thickness of slab J ($gm/cm^2$) |
| 23-32 | REGNO(J) | E10.0 | Number of subregions in slab J for tallying radiation losses if OPT1, OPT2, OPT3 is BREMSSTRAHLUNG or BREMTRANS, otherwise leave blank. (Maximum of 15) |
| 33-42 | A(J) | E10.0 | Atomic weight of material of slab J. |
| 43-52 | Z(J) | E10.0 | Atomic number of material of slab J. |
| 53-62 | ECUT(J) (J = 1, NOSLAB) | E10.0 | Cut-off energy for electrons in slab J (Mev). |

1 One card for each slab. These should be placed in order of J = 1, 2, 3, etc.

Card 7. Boundaries for multiple case (necessary only if transmission output is desired, i.e., if OPT1, OPT2, OPT3 is TRANSMISSION)

| Column | Variable | Format | Definition |
|---|---|---|---|
| 1-10 | NI | I10 | Number of boundaries in entire shield for which transmission information is desired. (NI $\geq$ 1, with maximum of 20) |

Card 8. Boundaries for Card 7.

| | | | |
|---|---|---|---|
| 1-10<br>11-20<br>etc.<br>61-70 | ZB(I)<br><br>(I = 1, NI) | 7E10.0 | Z coordinate of boundaries for which transmission information is desired ($gm/cm^2$) in order of increasing magnitude. (If NI = 1, ZB(1) = thickness of shield.) |

Card 9.

| | | | |
|---|---|---|---|
| 1-10 | FACTOR | E10.0 | Constant used to determine increment thickness, $\Delta T$. |
| 11-22<br>(right adjusted) | RAND1 | J12 | Number to start random number generator. Should consist of at least 8 digits with the right most digit being odd. |

Card 10.[2]

| | | | |
|---|---|---|---|
| 1-10 | IMAX(J) | I10 | Number of energies for range-ionization energy loss tables for material of slab J. (Maximum of 50) |

Card 11.[2]

| | | | |
|---|---|---|---|
| 1-10<br>11-20<br>21-30<br>31-40<br>etc. | ENERGY(I, J)<br>RANGE(I, J)<br>RATE(I, J)<br><br>(I = 1, IMAX(J)) | 7E10.0 | Energy in order of increasing magnitude (Mev).<br>Range of electron of above energy ($gm/cm^2$)<br>Rate is dE/dx or ionization energy loss of electron of above energy (Mev $cm^2/gm$) |

2 Set of cards 10 and 11 for each slab J. These should be in order of J = 1, 2, etc.

Card 12. (Always Needed)

| Column | Variable | Format | Definition |
|---|---|---|---|
| 1-10 (right adjusted) | L1 | I10 | Number of energy bins for tallying transmission distribution and radiation energy losses. (Maximum of 20) |

Card 13. (Always Needed)

| | | | |
|---|---|---|---|
| 1-10<br>11-20<br>etc.<br>61-70 | ENGY(I)<br><br>(I = 1, L1) | 7E10.0 | Energy bins for tallying transmission and radiation energy losses (Mev) in order of increasing magnitude. The number will be the maximum energy for bin I. |

Card 14. (Always Needed)

| | | | |
|---|---|---|---|
| 1-10 | L2 | I10 | Number of angle bins. (Maximum of 30) |

Card 15. (Always Needed)

| | | | |
|---|---|---|---|
| 1-10<br>11-20<br>etc.<br>61-70 | ANGLE(I)<br><br>(I = 1, L2) | 7E10.0 | Angle bins for transmission tally (degrees) in order of increasing magnitude. The number will be the maximum angle for bin I. |

Card 16. (Necessary only if NCONT > NOHIST)

| | | | |
|---|---|---|---|
| 1-10 | NOHIST | I10 | Number of histories for next output. |

There can be as many of card 16 as desired. An output edit is performed after completion of number of histories indicated by NOHIST. The only criteria is that the sum of the NOHIST for any problem must equal the number output for NCONT.

More than one problem can be run at a time. With the exception of the permanent data tables, the above input (cards 1 through 16) will be repeated for each problem and will be placed in succession in the data deck.

This data is input on punched IBM data cards.

TABLE 3. Set 1. Values of $\nu$, and Integrals of Functions Integrated from 0 to $\nu$,

| Column | Variable | Format | Definition |
|---|---|---|---|
| 1-6 | UPLIM(I) | E6.0 | $\nu$ |
| 7-16 | FZINT(I) | | $\int_0^{\nu} f^{(0)} \nu' \, d\nu'$ |
| 17-26 | F1INT(I) | 3E10.0 | $\int_0^{\nu} f^{(1)} \nu' \, d\nu'$ |
| 27-36 | F2INT(I) | | $\int_0^{\nu} f^{(2)} \nu' \, d\nu'$ |
| 37-42 | UPLIM(I) | E6.0 | $\nu$ |
| 43-52 | FZINT(I) | | $\int_0^{\nu} f^{(0)} \nu' \, d\nu'$ |
| 53-62 | F1INT(I) | 3E10.0 | $\int_0^{\nu} f^{(1)} \nu' \, d\nu'$ |
| 63-70 | F2INT(I) I = 1, 128 | | $\int_0^{\nu} f^{(2)} \nu' \, d\nu'$ |

TABLE 4. Set 2. Tables of X and Exponential Integral $E_1(X)$

| Column | Variable | Format | Definition |
|---|---|---|---|
| 1-10 | ARG(I) | | X |
| 11-20 | E1(I) | | $E_1(X)$ |
| 21-30 | ARG(I) | 6E10.0 | X |
| 31-40 | E1(I) | | $E_1(X)$ |
| 41-50 | ARG(I) | | X |
| 51-60 | E1(I) | | $E_1(X)$ |

I = 1, 128

## OUTPUT DATA

The output consists of a summary of the input including the number of histories, source energy, angle of incidence, method used to select increment thickness, $\Delta T$, number of slabs in the shield and their respective thicknesses, the number of transmission boundaries and these boundaries. These items are identified in the output. If the input specified that the transmission array is desired, this is then printed. The number of electrons transmitted in each energy and angle bin is under the heading N and the sum of the energy of the electrons transmitted in each energy and angle bin is under the heading E. The angle and energy bins are considered to be $O - E_1$, $E_1 - E_2$, etc., and $O - A_1$, $A_1 - A_2$, etc. The number and energy transmitted for each angle is summed over all energies. Then the total number transmitted is recorded. In the case where there is more than one transmission boundary, the number backscattered (transmitted at angles from 90-180°) is valid only for the case of the thickest slab.

If the radiation energy loss throughout the shield is desired, this array follows the transmission distribution. This array gives the number of times the radiation energy was between energies $O - E_1$, $E_1 - E_2$, etc., for regions of a slab. This array is written for each slab, $J = 1$ to the total number of slabs of the shield. Each of the regions of the slab has a thickness equal to the thickness of the slab divided by the total number of regions in the slab.

## OPERATING INFORMATION

### MACHINE SET-UP AND RUN INFORMATION

#### General Machine Operation

Machine set-up would be as for any program under the FORMON system using no tapes other than A2 (logical 5) for input and A3 (logical 6) for output, and no special switch settings.

Normal exit from the program occurs when the output from the last problem is completed and there is no more input to be read in. Error stops occur when there is either an error in spelling on the input option card or there is an error in calculation. In the case of the former, the appropriate comment is written. For the latter, a value for the error indicator, KERROR, is written. The error indicators and their corresponding errors are as follows:

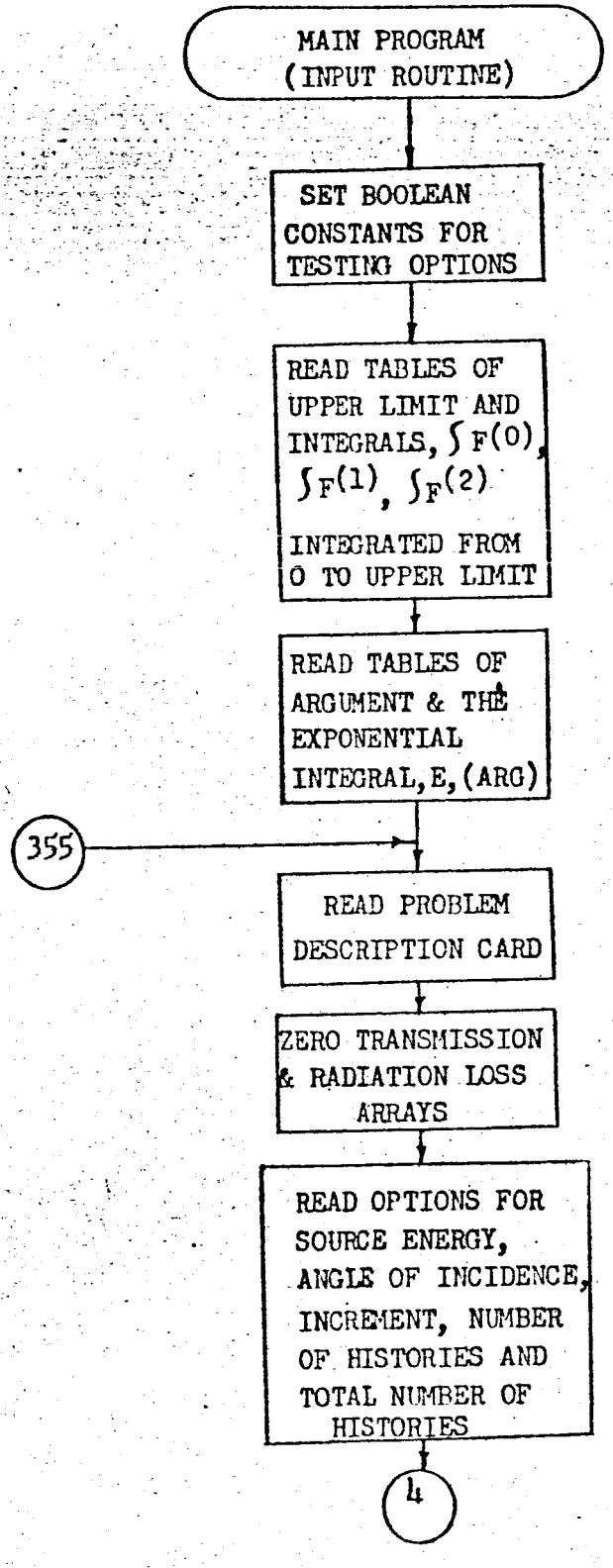
| | |
|---|---|
| KERROR = 2 | Error in subroutine MOLLI. Value of $b < 1$. Check input values of atomic weights and atomic numbers, and the factor for computing the path increment $\Delta T$. |
| = 3 | Error in subroutine RANDE. Check input tables of range, average ionization loss and the corresponding energies. This error occurred because the table was exhausted without finding a value. |
| = 4 | Error in subroutine TLYRD. The radiation energy loss was greater than the values of the energy bins. |

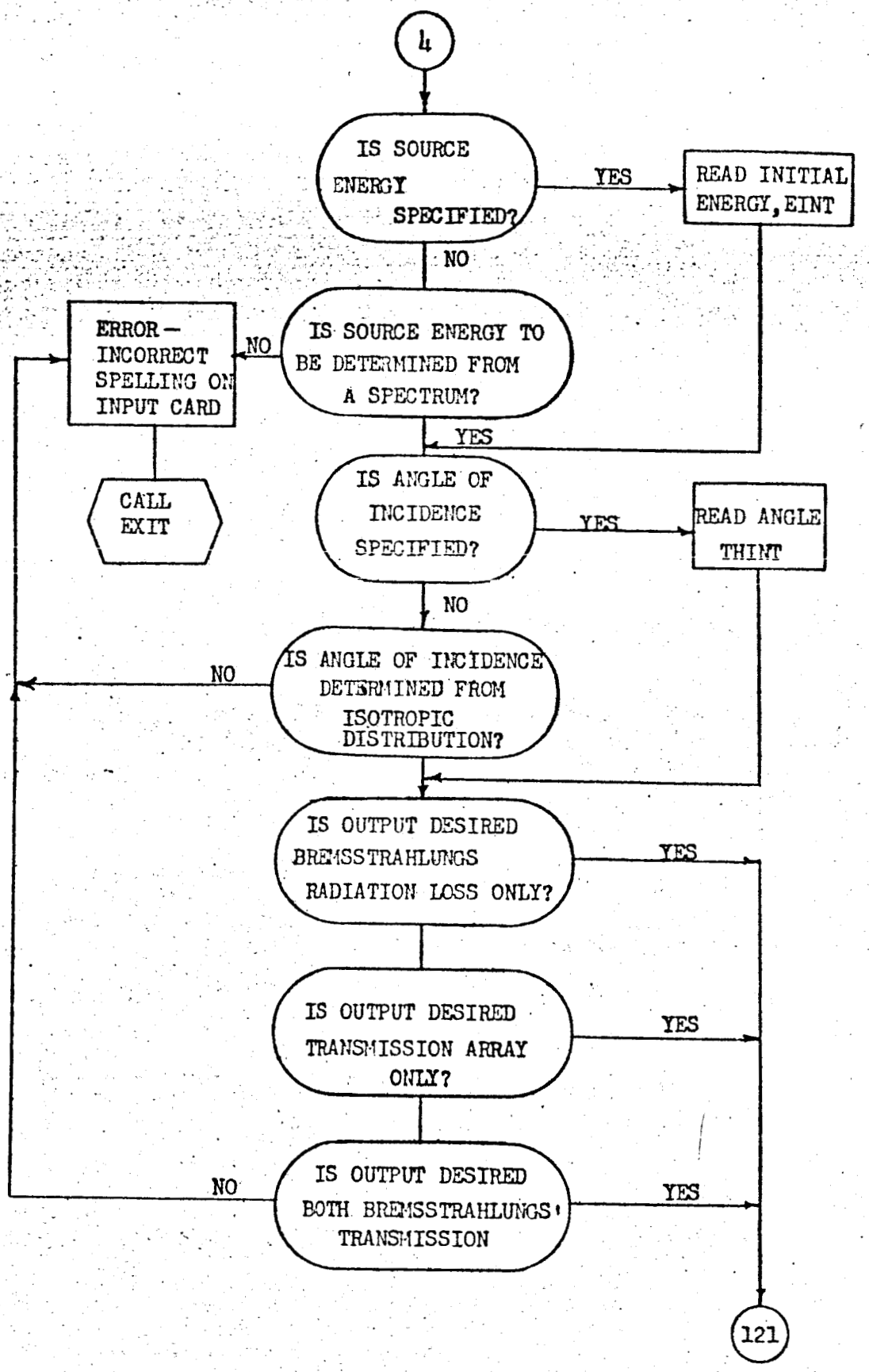
KERROR = 4 (cont'd) Check to see that the last energy bin is as large as or greater than the initial energy of the electron.

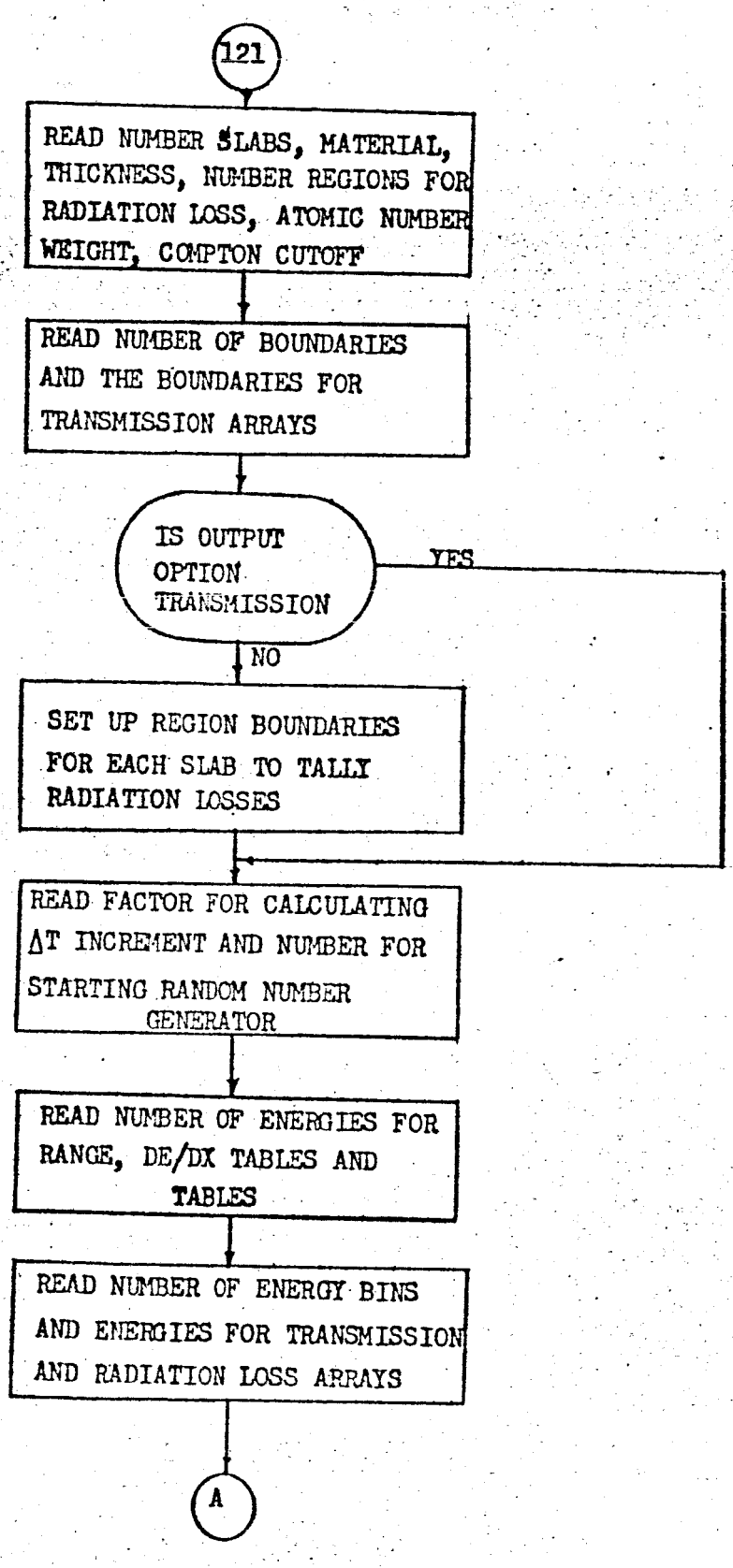
## PROGRAMMING INFORMATION

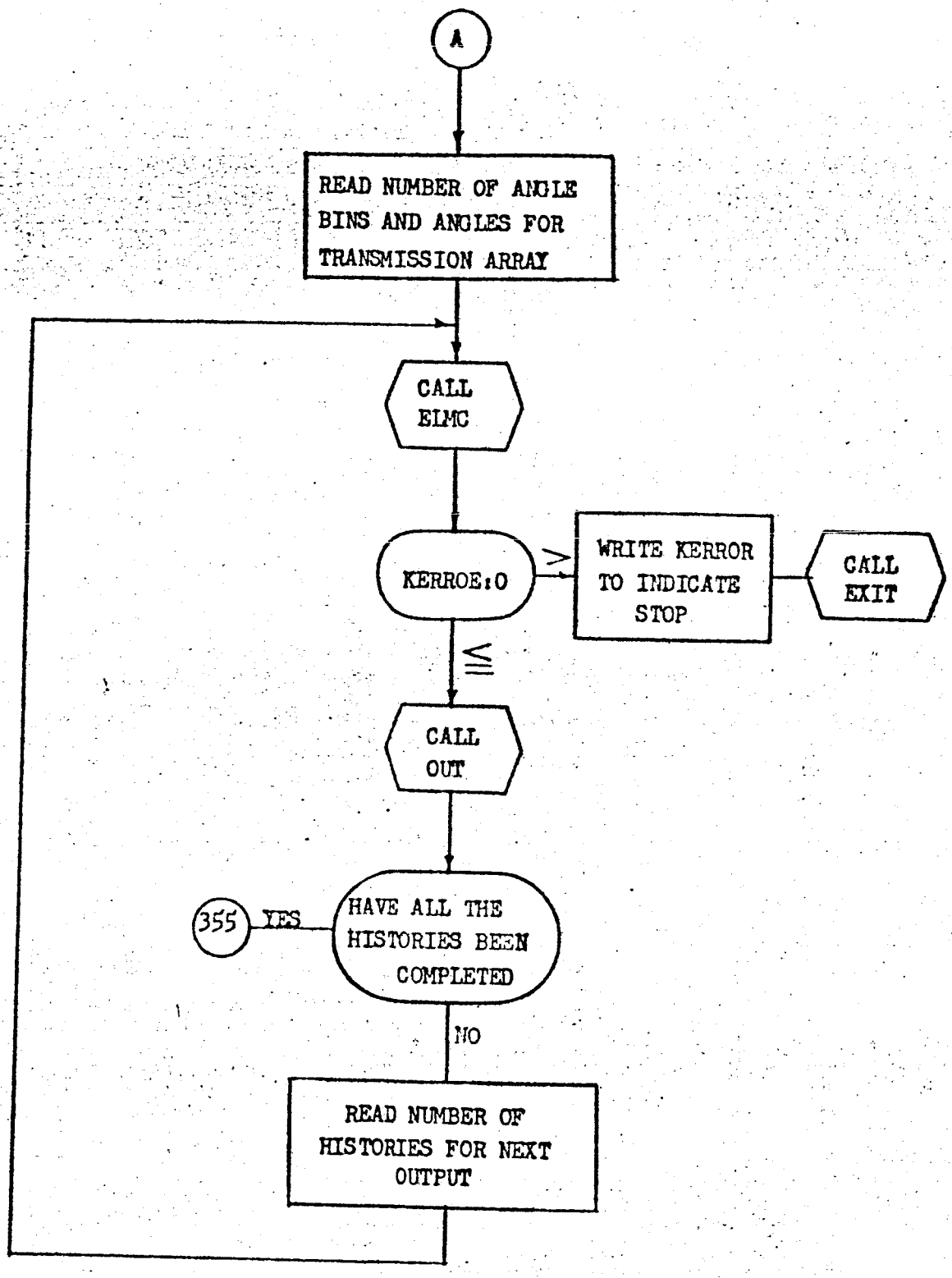
This portion of the report contains the programming information and consists of Flow Charts, Program Listing, Sample Input Data and Sample Problem.

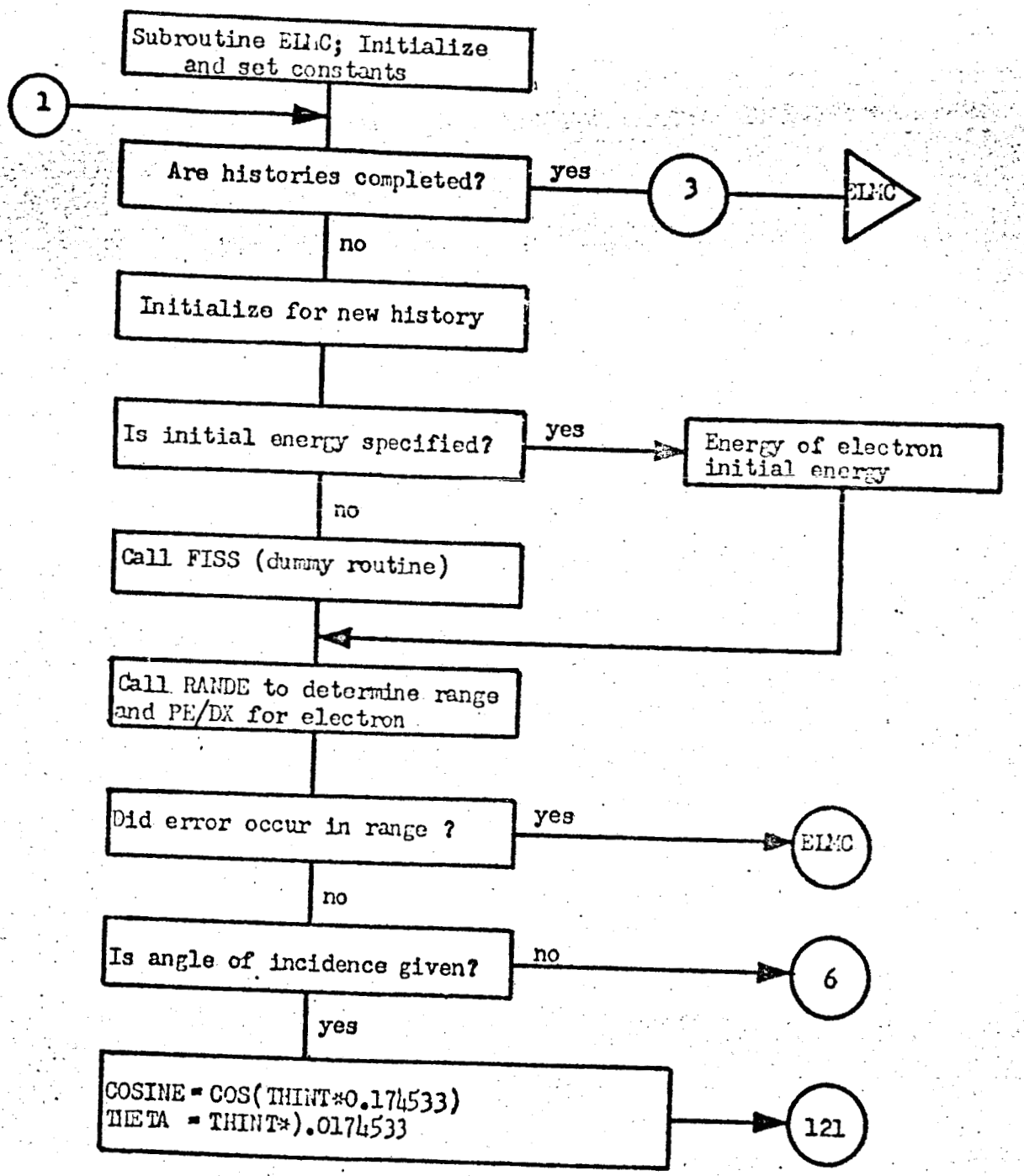
# FLOW CHARTS


MAIN PROGRAM
(INPUT ROUTINE)
SET BOOLEAN CONSTANTS FOR TESTING OPTIONS
READ TABLES OF UPPER LIMIT AND INTEGRALS, ∫F(0), ∫F(1), ∫F(2) INTEGRATED FROM 0 TO UPPER LIMIT
READ TABLES OF ARGUMENT & THE EXPONENTIAL INTEGRAL, E, (ARG)
355
READ PROBLEM DESCRIPTION CARD
ZERO TRANSMISSION & RADIATION LOSS ARRAYS
READ OPTIONS FOR SOURCE ENERGY, ANGLE OF INCIDENCE, INCREMENT, NUMBER OF HISTORIES AND TOTAL NUMBER OF HISTORIES
4

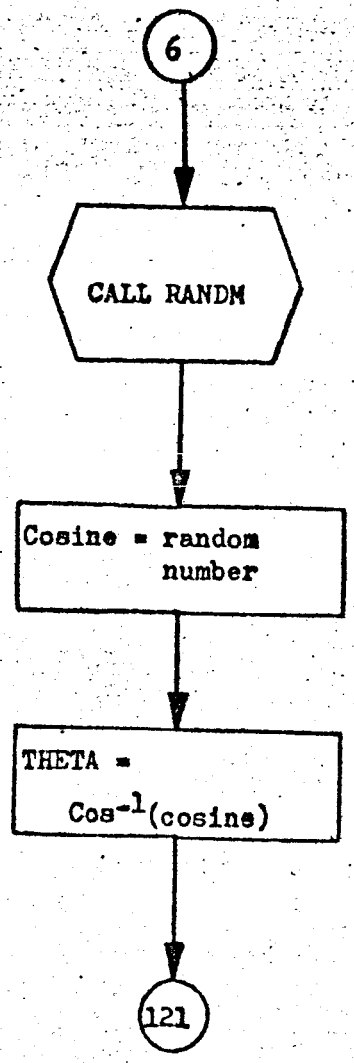

4
IS SOURCE ENERGY SPECIFIED?
YES
READ INITIAL ENERGY, EINT
NO
IS SOURCE ENERGY TO BE DETERMINED FROM A SPECTRUM?
NO
ERROR — INCORRECT SPELLING ON INPUT CARD
CALL EXIT
YES
IS ANGLE OF INCIDENCE SPECIFIED?
YES
READ ANGLE THINT
NO
IS ANGLE OF INCIDENCE DETERMINED FROM ISOTROPIC DISTRIBUTION?
NO
IS OUTPUT DESIRED BREMSSTRAHLUNGS RADIATION LOSS ONLY?
YES
IS OUTPUT DESIRED TRANSMISSION ARRAY ONLY?
YES
IS OUTPUT DESIRED BOTH BREMSSTRAHLUNGS TRANSMISSION
NO
YES
121

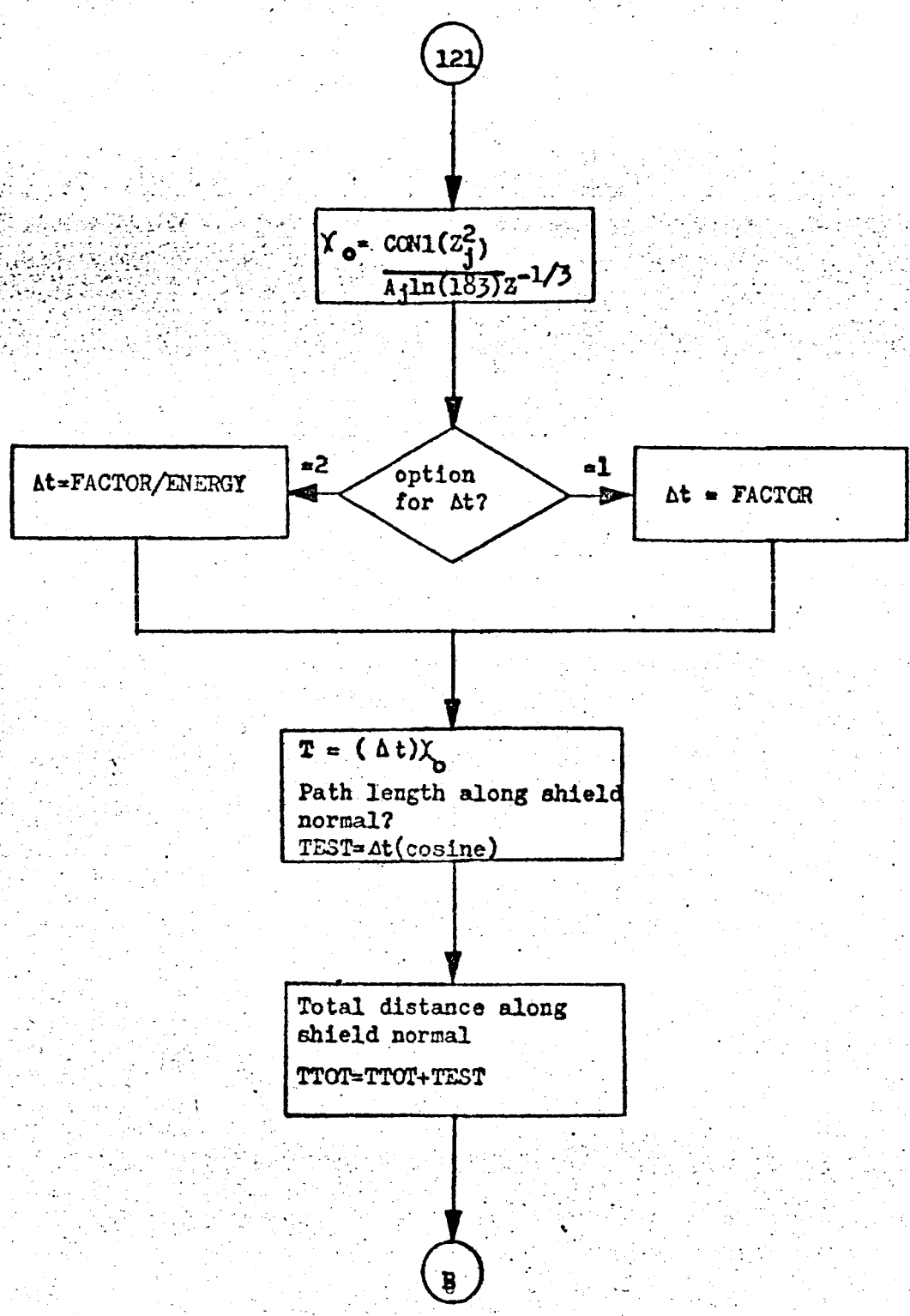

121
READ NUMBER SLABS, MATERIAL, THICKNESS, NUMBER REGIONS FOR RADIATION LOSS, ATOMIC NUMBER WEIGHT, COMPTON CUTOFF
READ NUMBER OF BOUNDARIES AND THE BOUNDARIES FOR TRANSMISSION ARRAYS
IS OUTPUT OPTION TRANSMISSION
YES
NO
SET UP REGION BOUNDARIES FOR EACH SLAB TO TALLY RADIATION LOSSES
READ FACTOR FOR CALCULATING ΔT INCREMENT AND NUMBER FOR STARTING RANDOM NUMBER GENERATOR
READ NUMBER OF ENERGIES FOR RANGE, DE/DX TABLES AND TABLES
READ NUMBER OF ENERGY BINS AND ENERGIES FOR TRANSMISSION AND RADIATION LOSS ARRAYS
A

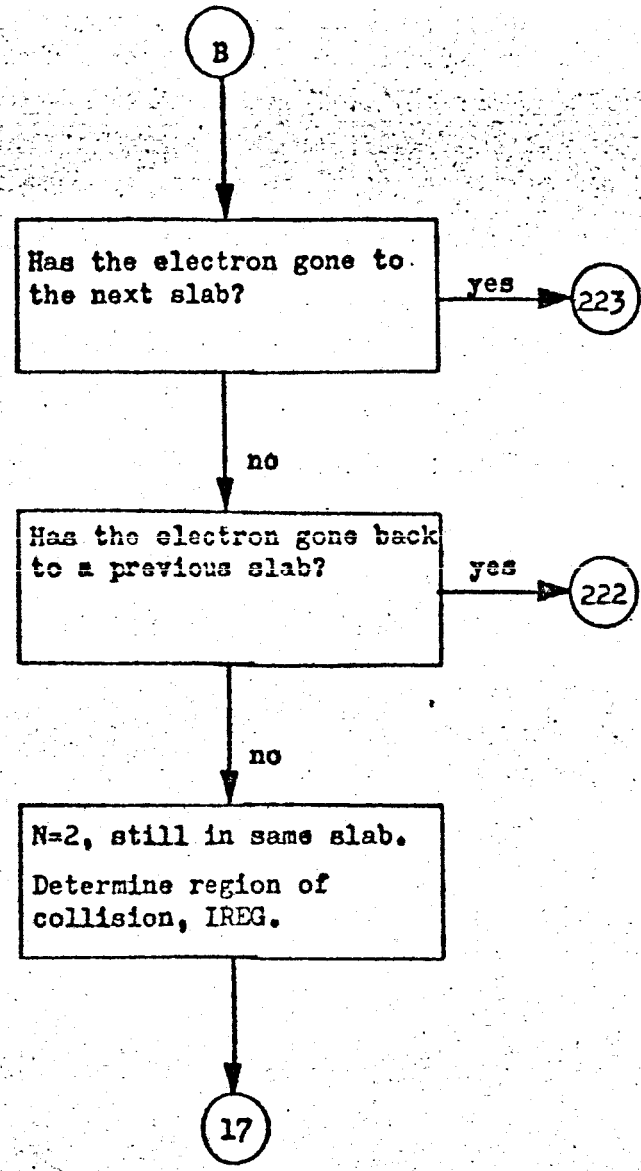

A
READ NUMBER OF ANGLE BINS AND ANGLES FOR TRANSMISSION ARRAY
CALL ELMC
KERROE:0
>
WRITE KERROR TO INDICATE STOP
CALL EXIT
≦
CALL OUT
355
YES
HAVE ALL THE HISTORIES BEEN COMPLETED
NO
READ NUMBER OF HISTORIES FOR NEXT OUTPUT

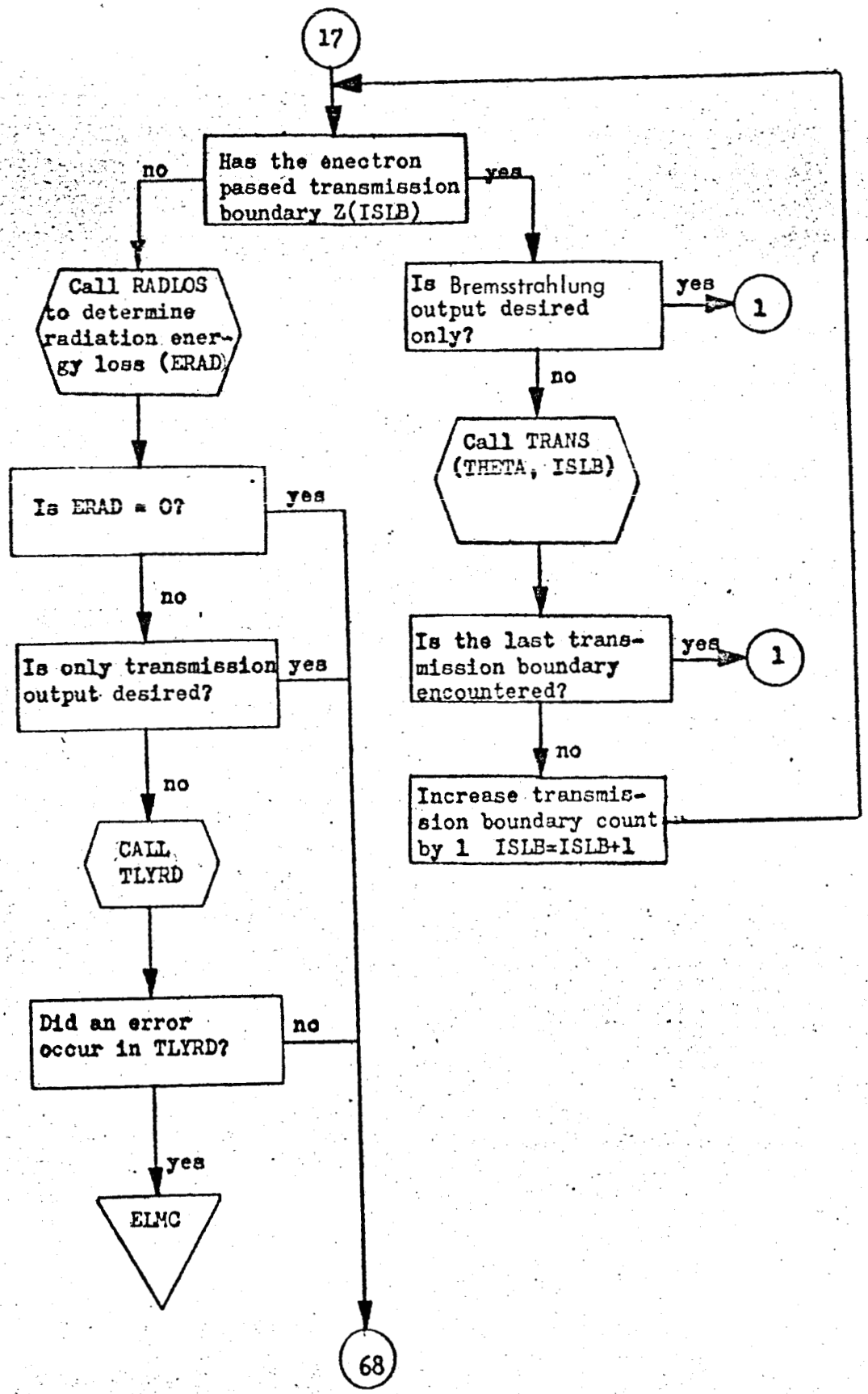


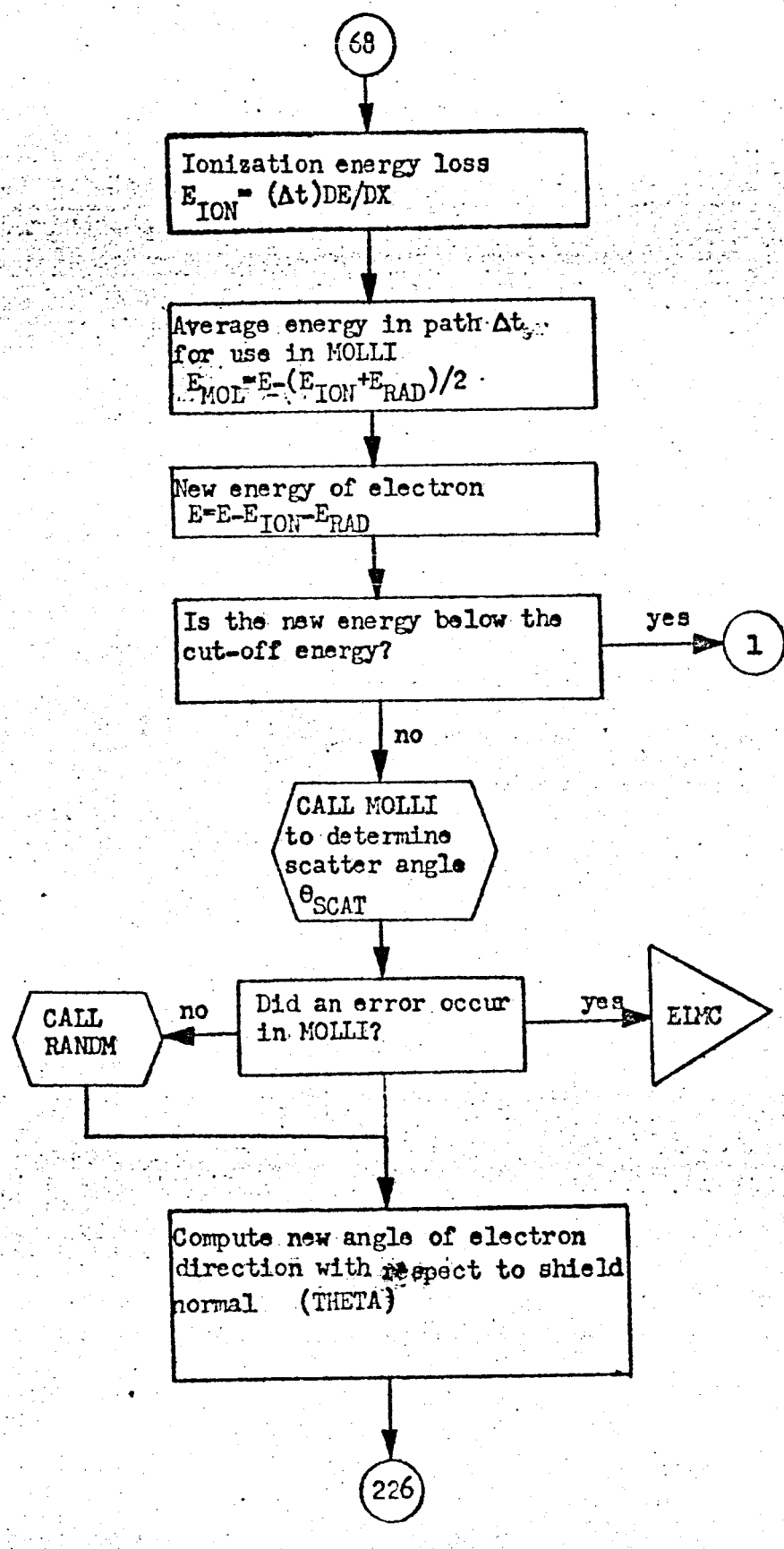

Subroutine ELMC

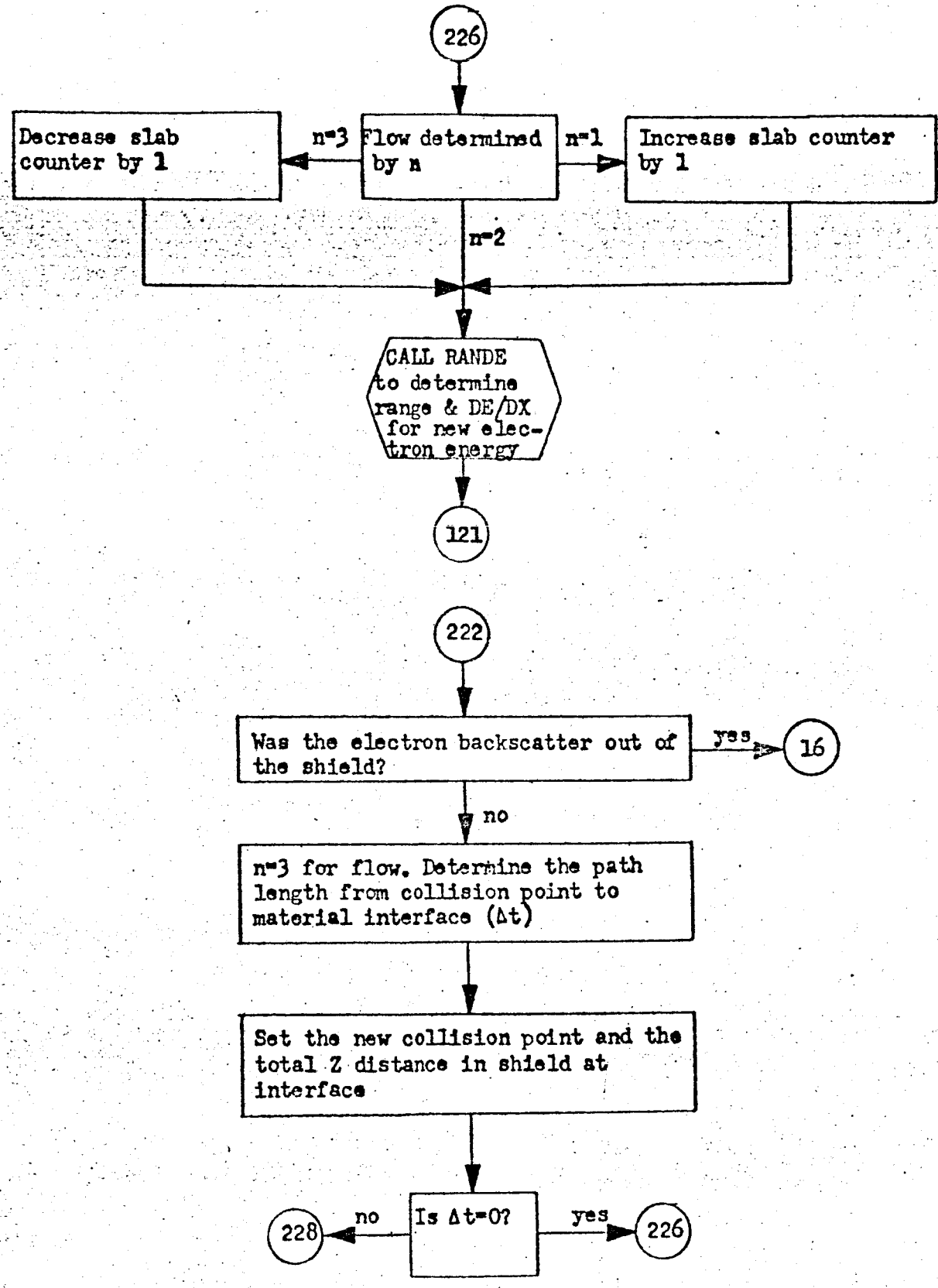

6
CALL RANDM
Cosine = random number
THETA = Cos-1(cosine)
121

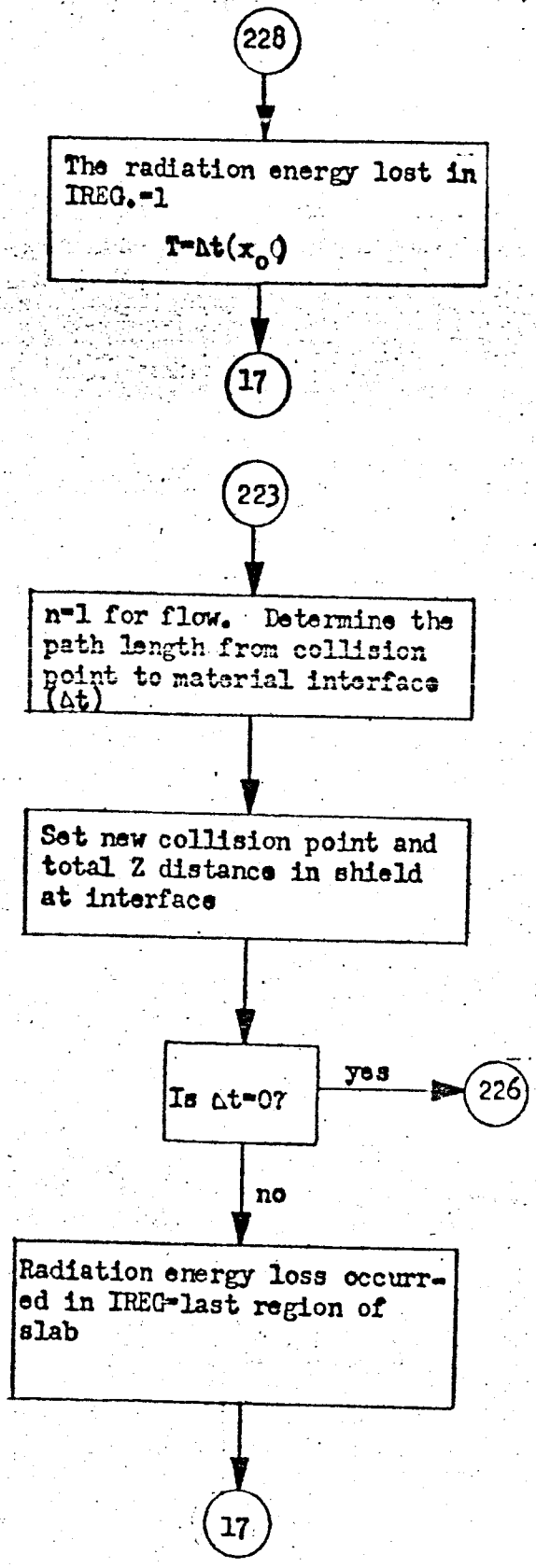

121
$X_o = \frac{CON1(Z_j^2)}{A_j \ln(183) Z^{-1/3}}$
option for Δt?
=2
=1
Δt=FACTOR/ENERGY
Δt = FACTOR
T = (Δt)$X_o$
Path length along shield normal?
TEST=Δt(cosine)
Total distance along shield normal
TTOT=TTOT+TEST
B

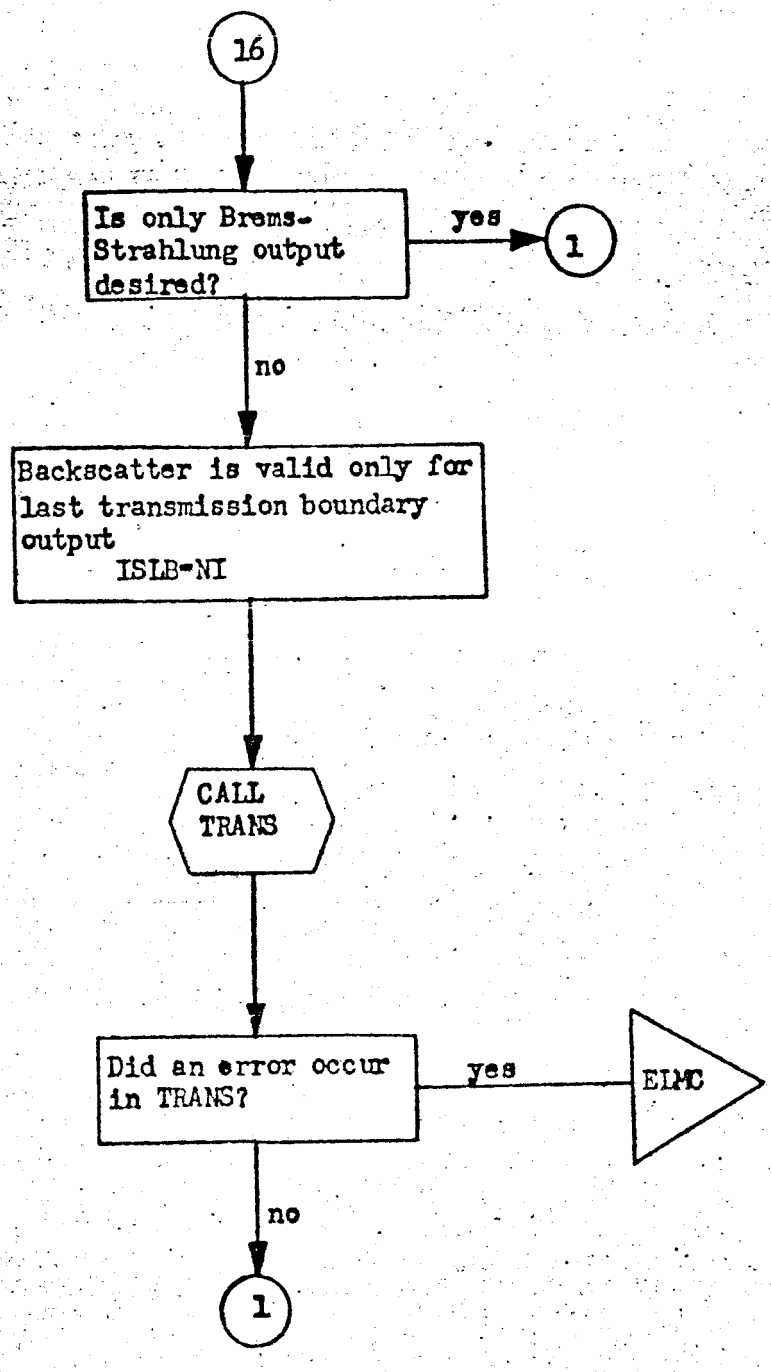

B
Has the electron gone to the next slab?
yes
223
no
Has the electron gone back to a previous slab?
yes
222
no
N=2, still in same slab.
Determine region of collision, IREG.
17


17
Has the enectron passed transmission boundary Z(ISLB)
no
yes
Call RADLOS to determine radiation energy loss (ERAD)
Is Bremsstrahlung output desired only?
yes
1
no
Call TRANS (THETA, ISLB)
Is ERAD = 0?
yes
no
Is only transmission output desired?
yes
Is the last transmission boundary encountered?
yes
1
no
Increase transmission boundary count by 1 ISLB=ISLB+1
no
CALL TLYRD
Did an error occur in TLYRD?
no
yes
ELMC
68

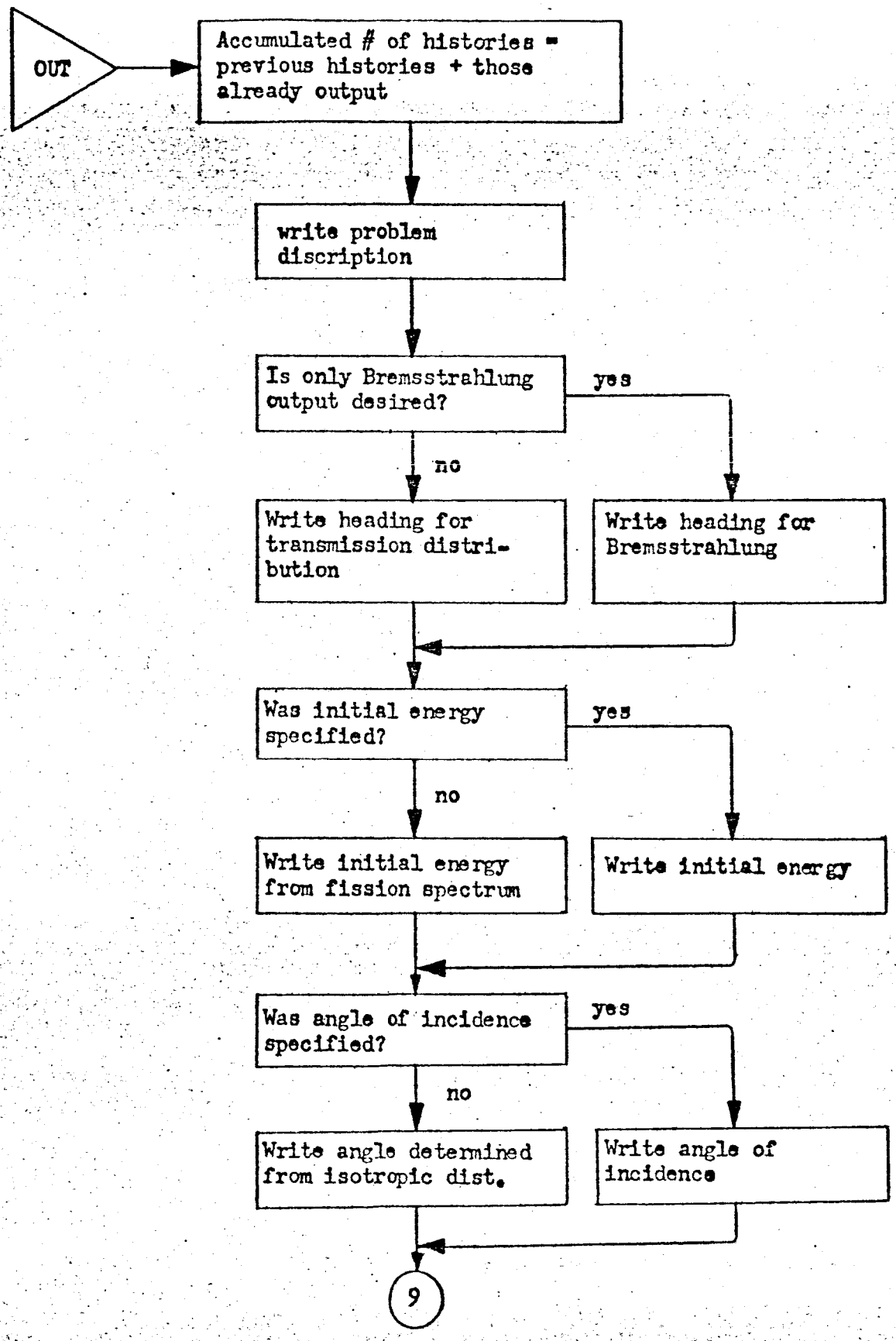

68
Ionization energy loss
$E_{ION} = (\Delta t)DE/DX$
Average energy in path $\Delta t$, for use in MOLLI
$E_{MOL} = E - (E_{ION} + E_{RAD})/2$
New energy of electron
$E = E - E_{ION} - E_{RAD}$
Is the new energy below the cut-off energy?
yes
1
no
CALL MOLLI to determine scatter angle $\theta_{SCAT}$
Did an error occur in MOLLI?
no
CALL RANDM
yes
EIMC
Compute new angle of electron direction with respect to shield normal (THETA)
226

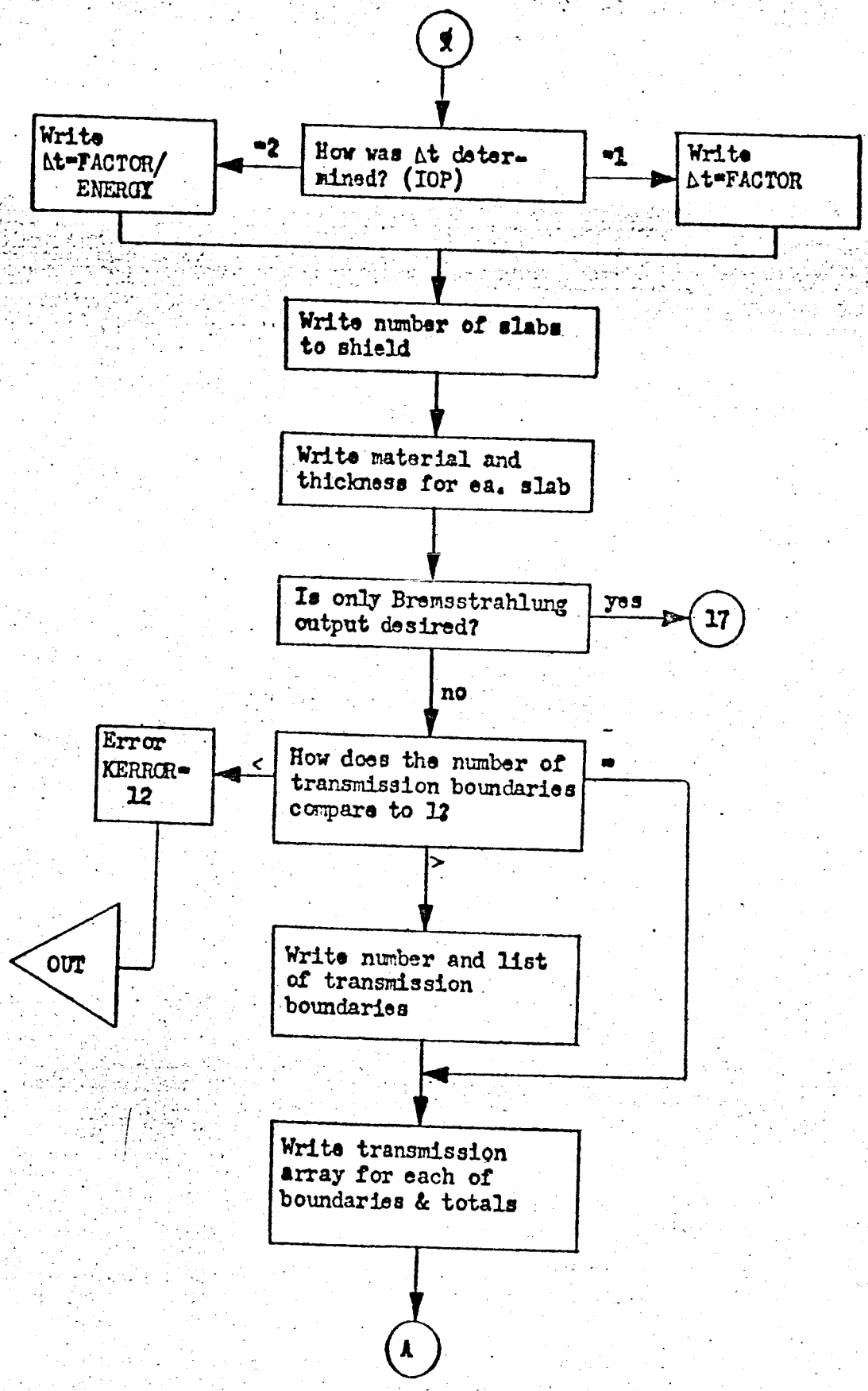

226
Decrease slab counter by 1
n=3
Flow determined by n
n=1
Increase slab counter by 1
n=2
CALL RANDE to determine range & DE/DX for new electron energy
121
222
Was the electron backscatter out of the shield?
yes
16
no
n=3 for flow. Determine the path length from collision point to material interface (Δt)
Set the new collision point and the total Z distance in shield at interface
Is Δt=0?
no
228
yes
226

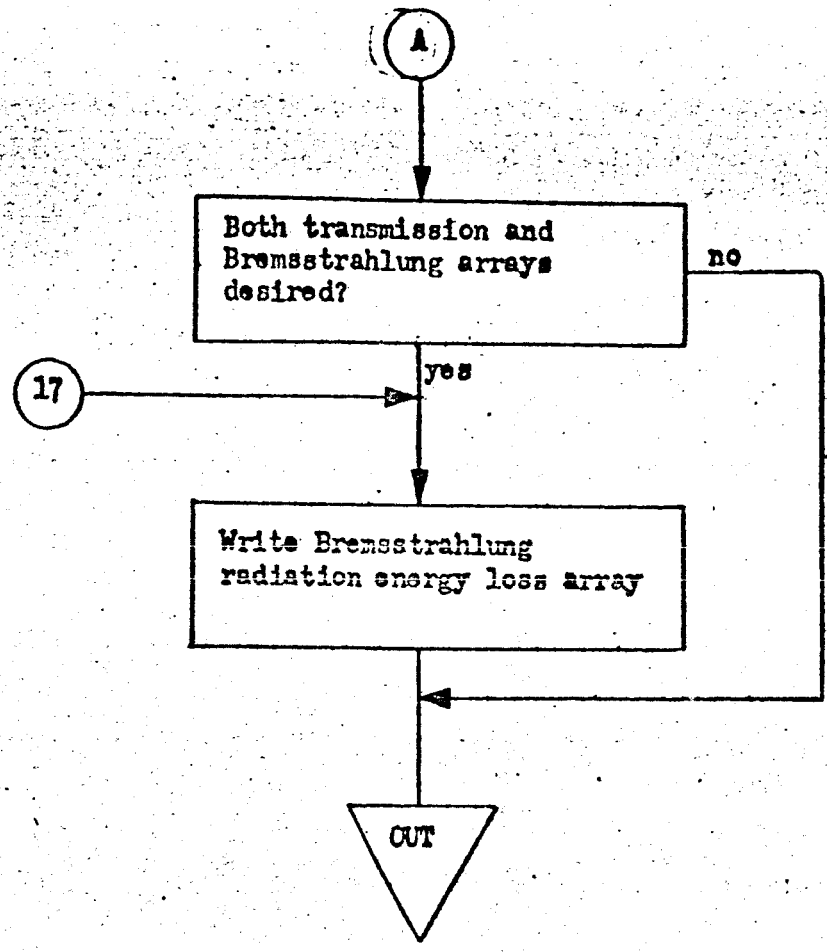

228
The radiation energy lost in IREG.=1
T=Δt(x_o)
17
223
n=1 for flow. Determine the path length from collision point to material interface (Δt)
Set new collision point and total Z distance in shield at interface
Is Δt=0?
yes
226
no
Radiation energy loss occurred in IREG=last region of slab
17

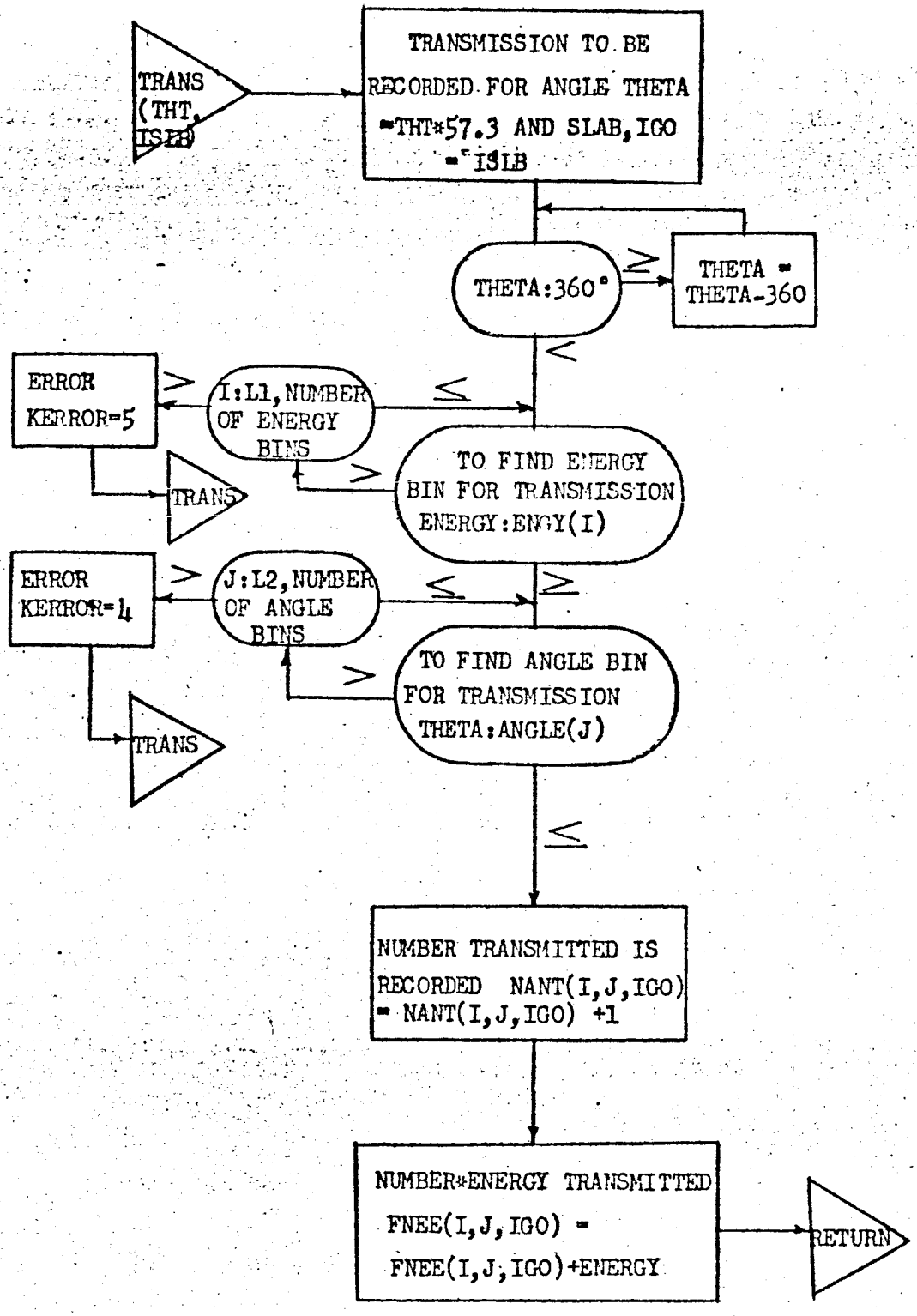

16
Is only Brems-Strahlung output desired?
yes
1
no
Backscatter is valid only for last transmission boundary output
ISLB=NI
CALL TRANS
Did an error occur in TRANS?
yes
ELMC
no
1

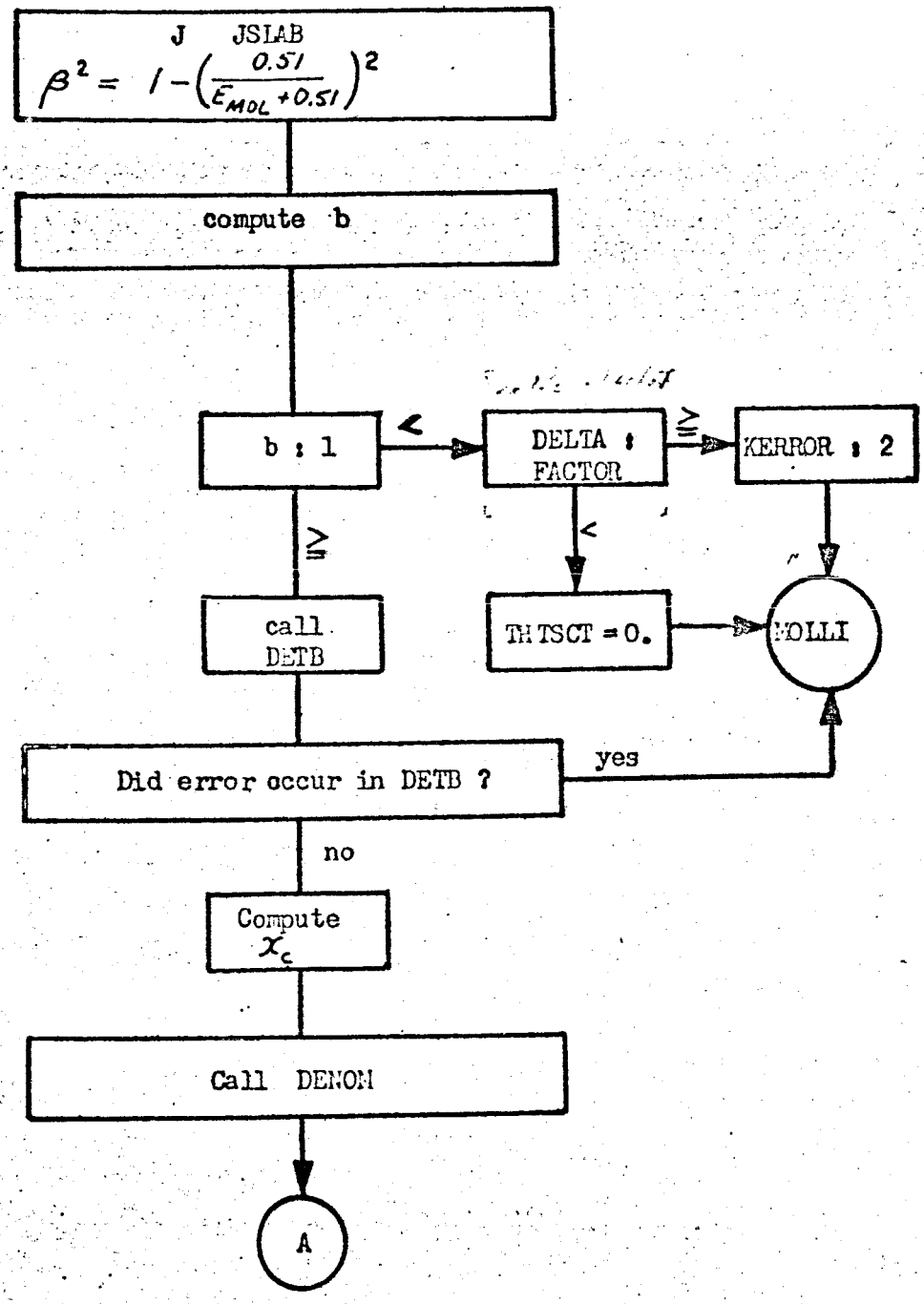
Subroutine OUT




How was Δt determined? (IOP)
=2
Write Δt=FACTOR/ ENERGY
=1
Write Δt=FACTOR
Write number of slabs to shield
Write material and thickness for ea. slab
Is only Bremsstrahlung output desired?
yes
17
no
How does the number of transmission boundaries compare to 12
<
Error KERROR= 12
OUT
>
=
Write number and list of transmission boundaries
Write transmission array for each of boundaries & totals


A
Both transmission and Bremsstrahlung arrays desired?
no
yes
17
Write Bremsstrahlung radiation energy loss array
OUT

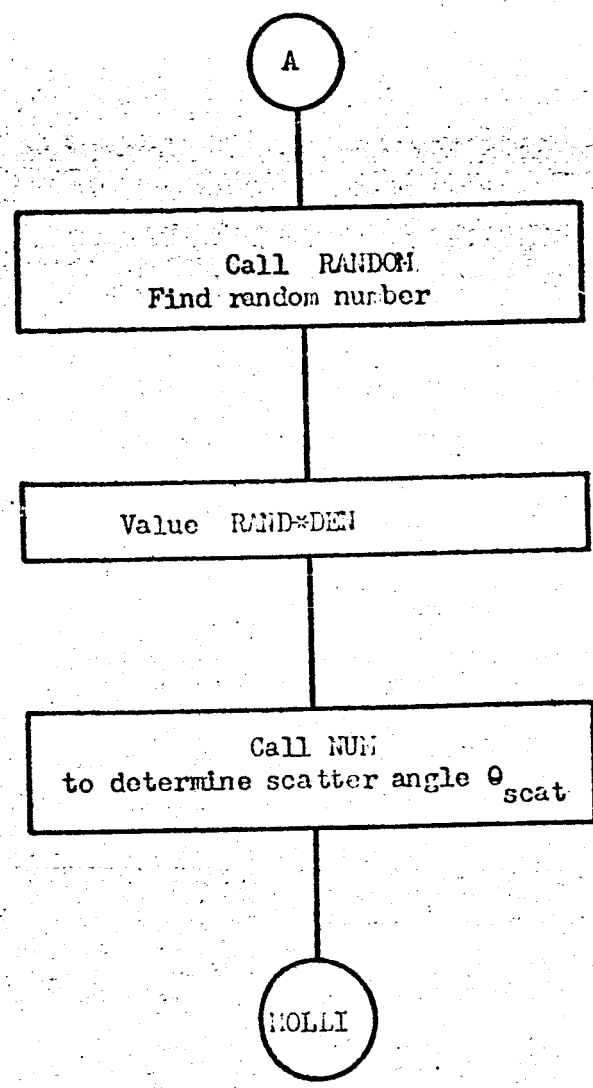

TRANS (THT, ISLB)
TRANSMISSION TO BE RECORDED FOR ANGLE THETA =THT*57.3 AND SLAB, IGO = ISLB
THETA:360°
THETA = THETA-360
ERROR KERROR=5
I:L1, NUMBER OF ENERGY BINS
TRANS
TO FIND ENERGY BIN FOR TRANSMISSION ENERGY:ENGY(I)
ERROR KERROR=4
J:L2, NUMBER OF ANGLE BINS
TRANS
TO FIND ANGLE BIN FOR TRANSMISSION THETA:ANGLE(J)
NUMBER TRANSMITTED IS RECORDED NANT(I,J,IGO) = NANT(I,J,IGO) +1
NUMBER*ENERGY TRANSMITTED FNEE(I,J,IGO) = FNEE(I,J,IGO)+ENERGY
RETURN



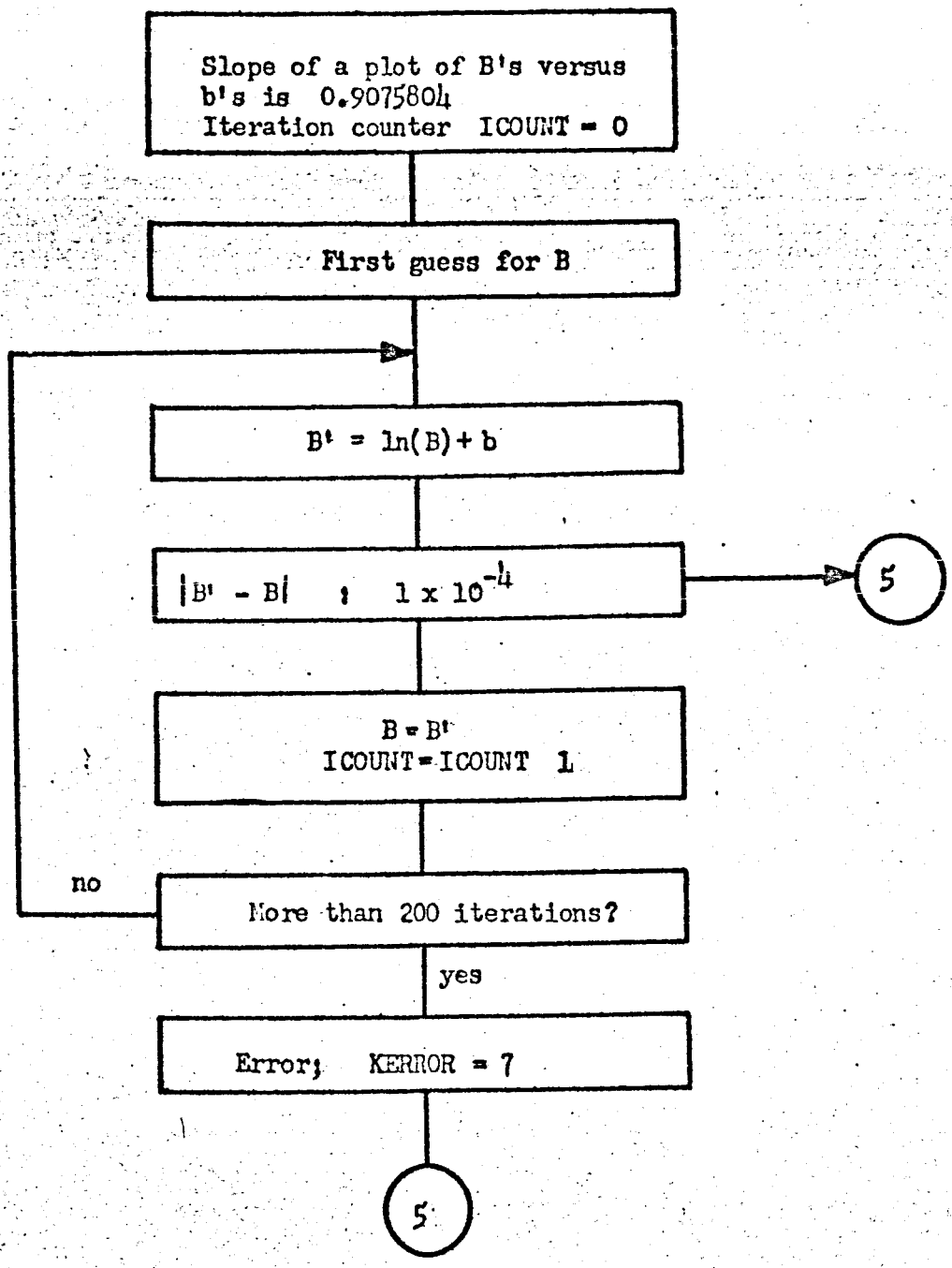

Subroutine MOLLI
(page 1 of 2 )



gl



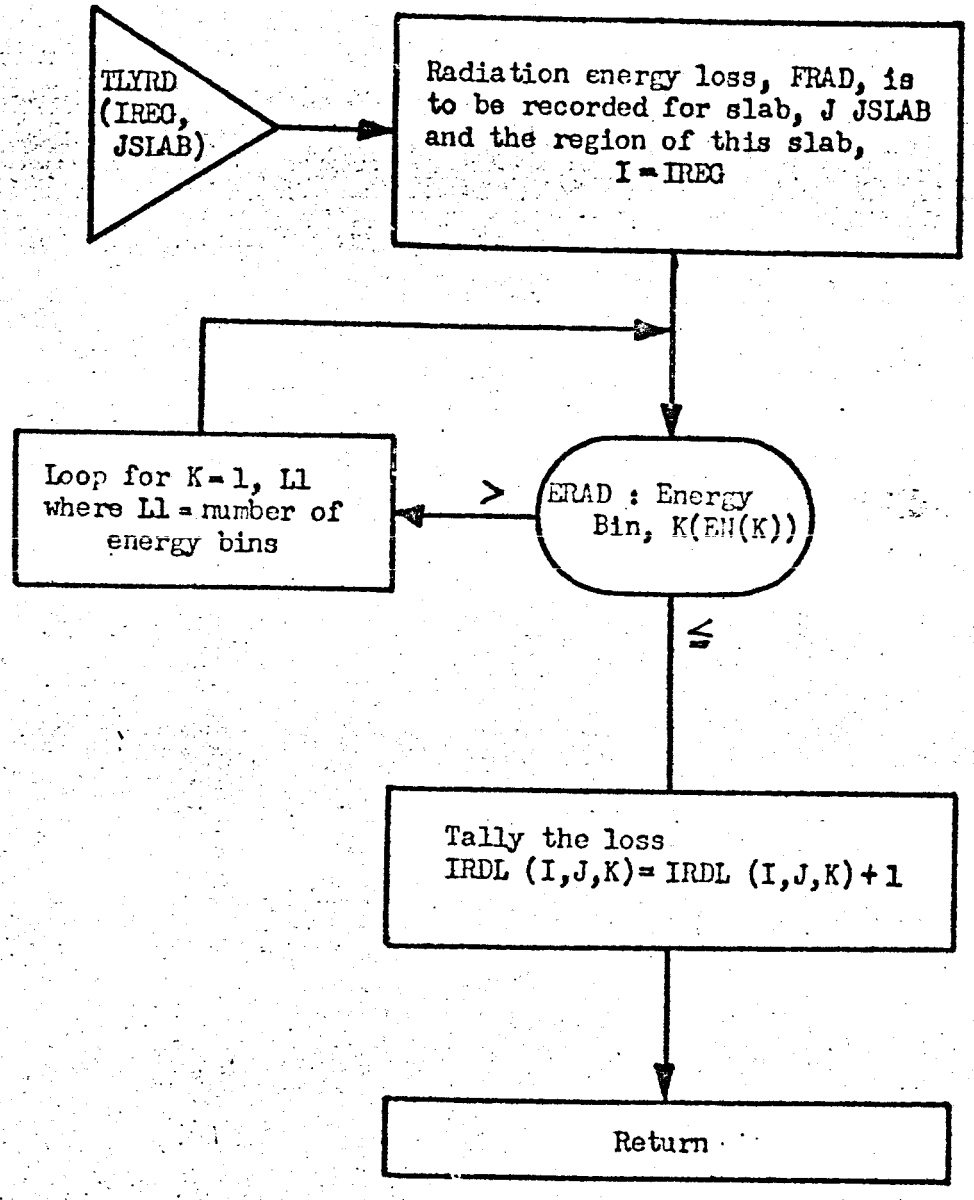

Subroutine MOLLI
(page 2 of 2 )



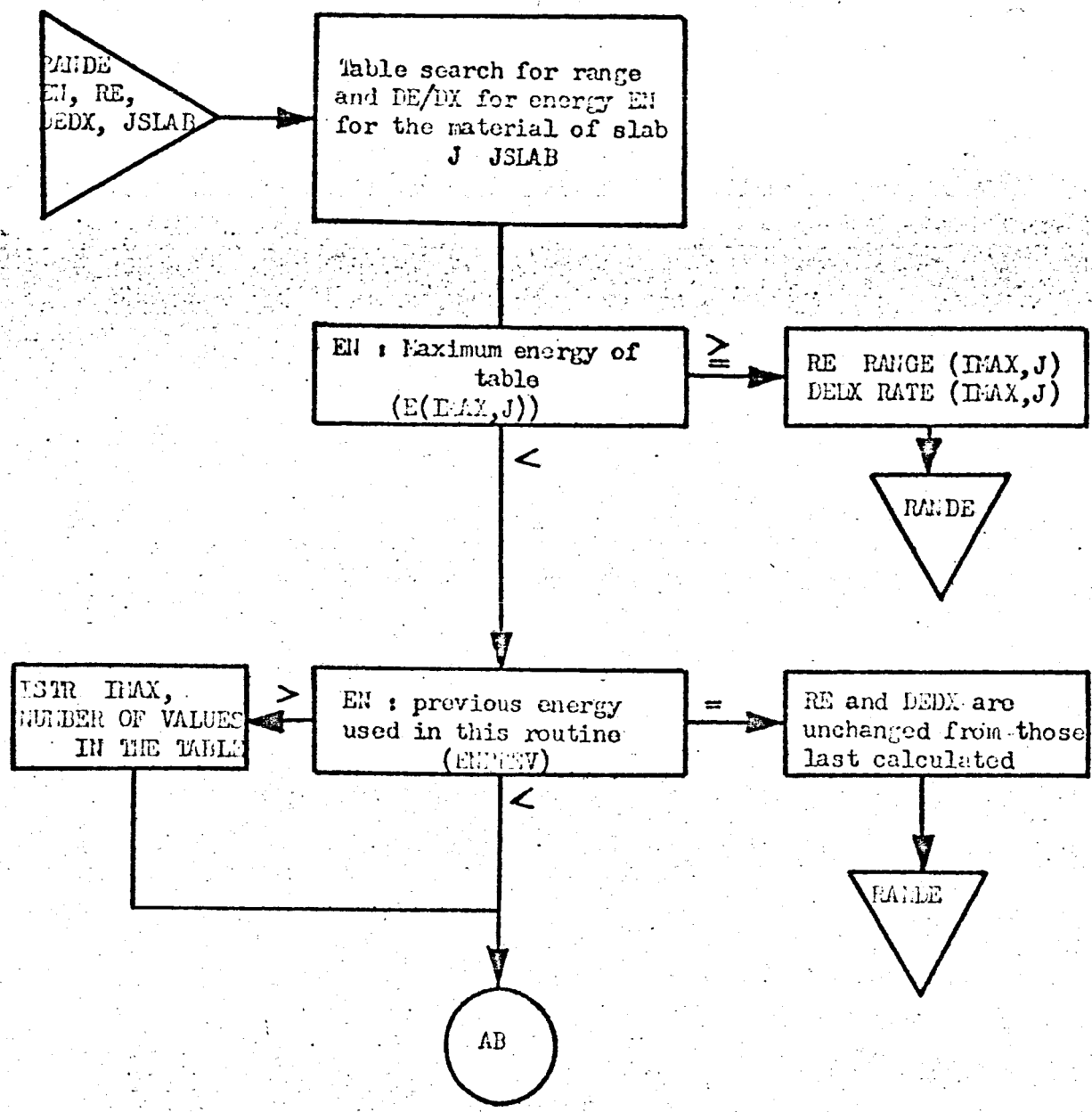

Subroutine DETB



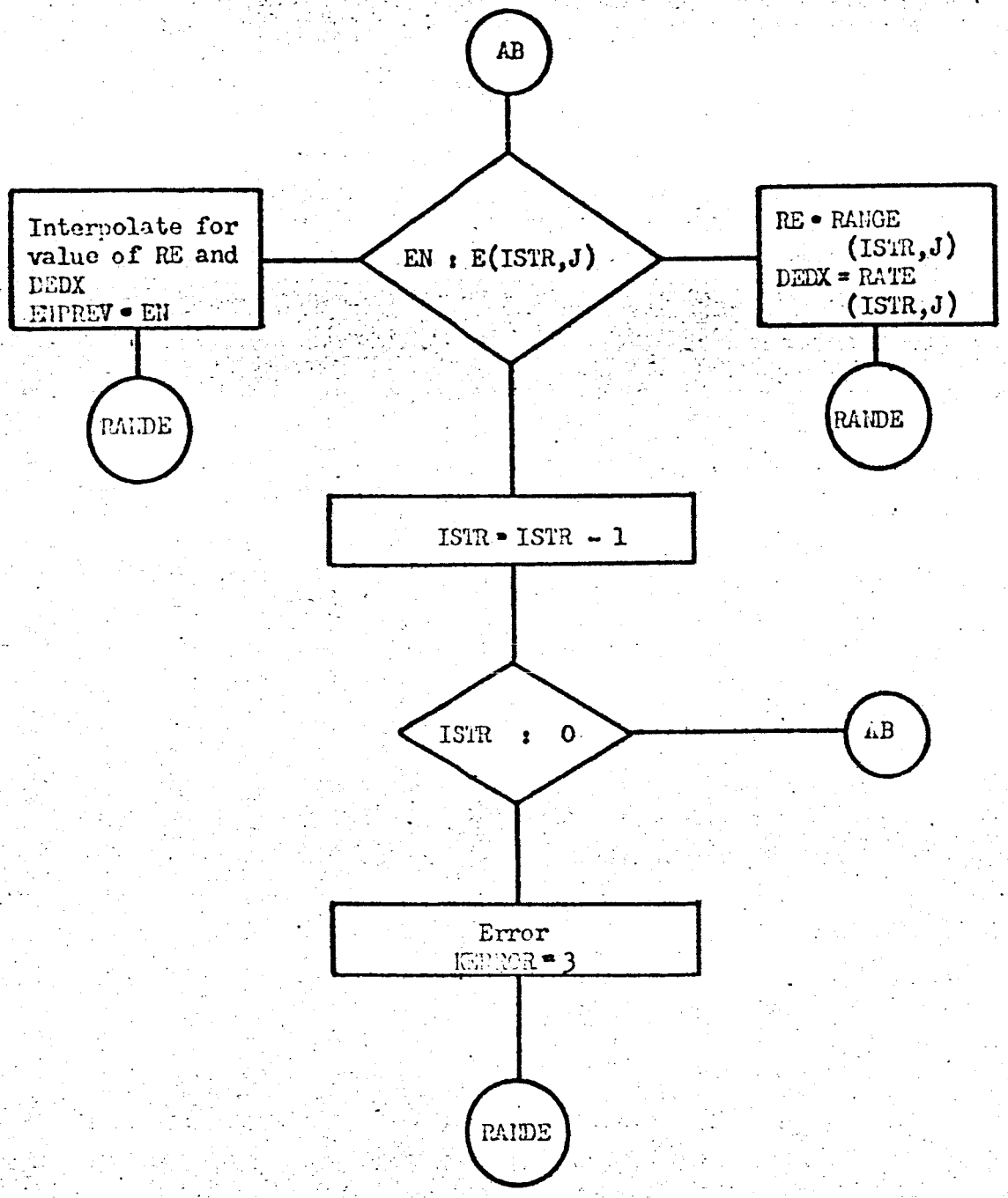
g1




Subroutine TLYRD

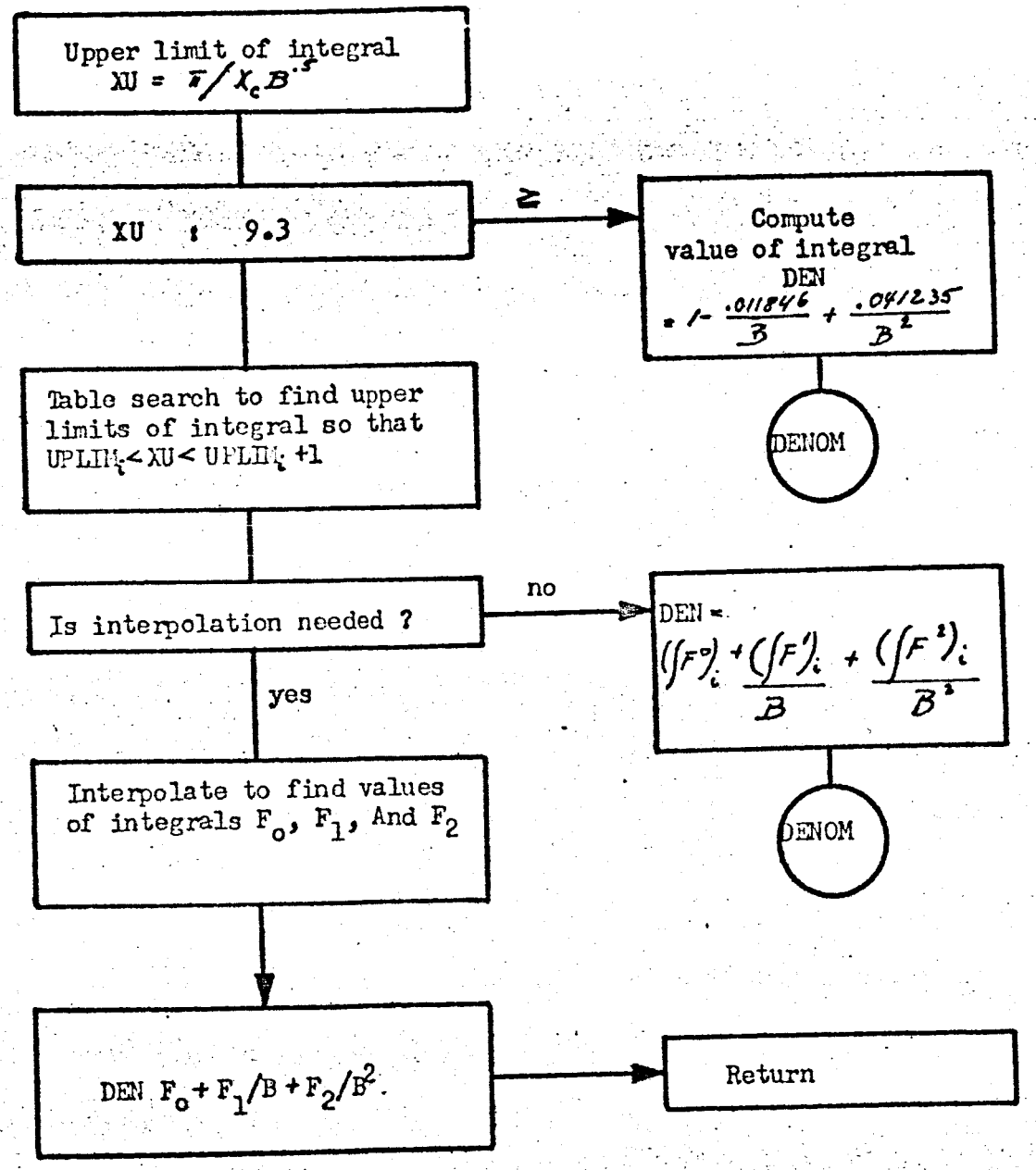



Subroutine Rande
Page 1 of 2




Subroutine RAIDE
Page 2 of 2

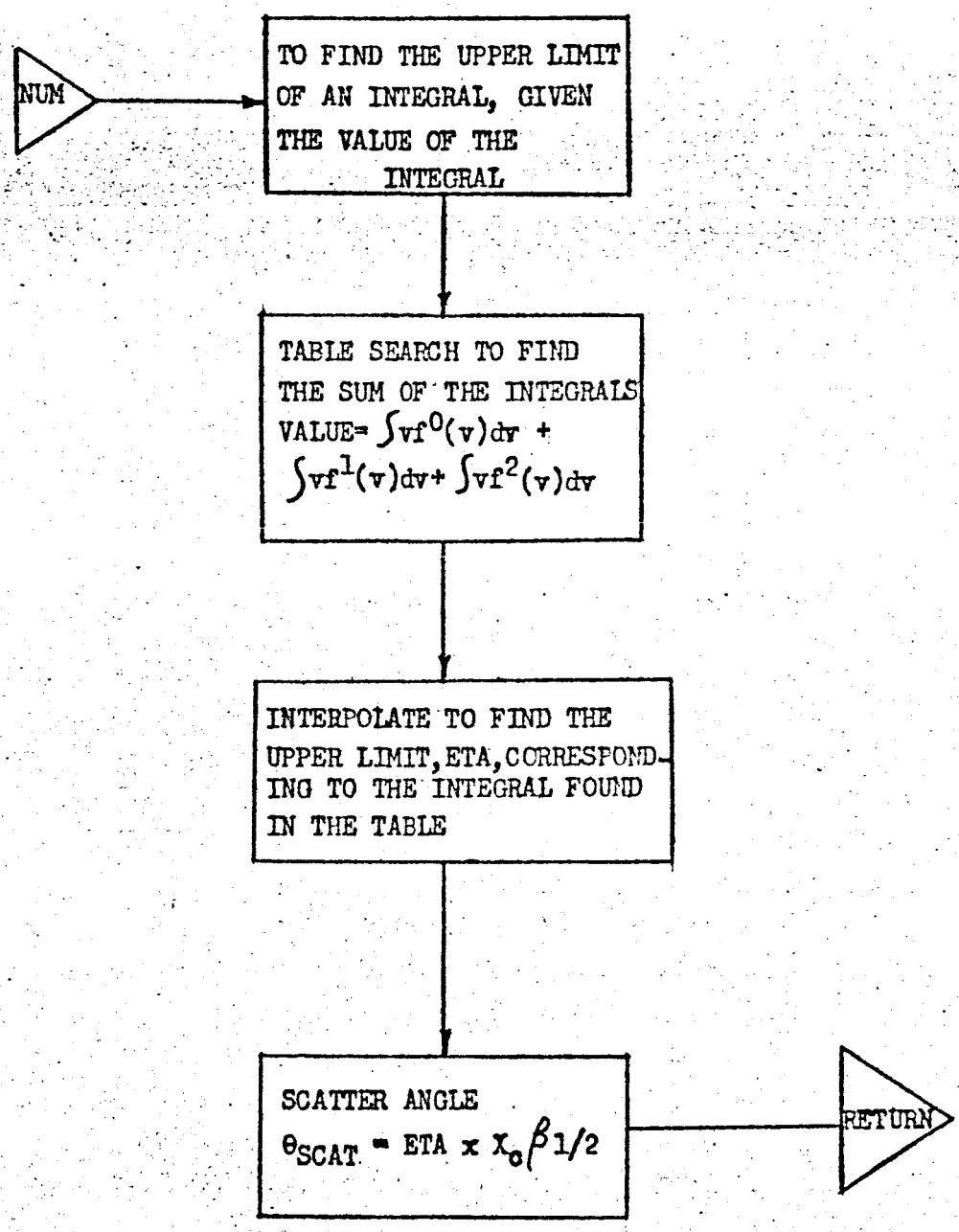
gl

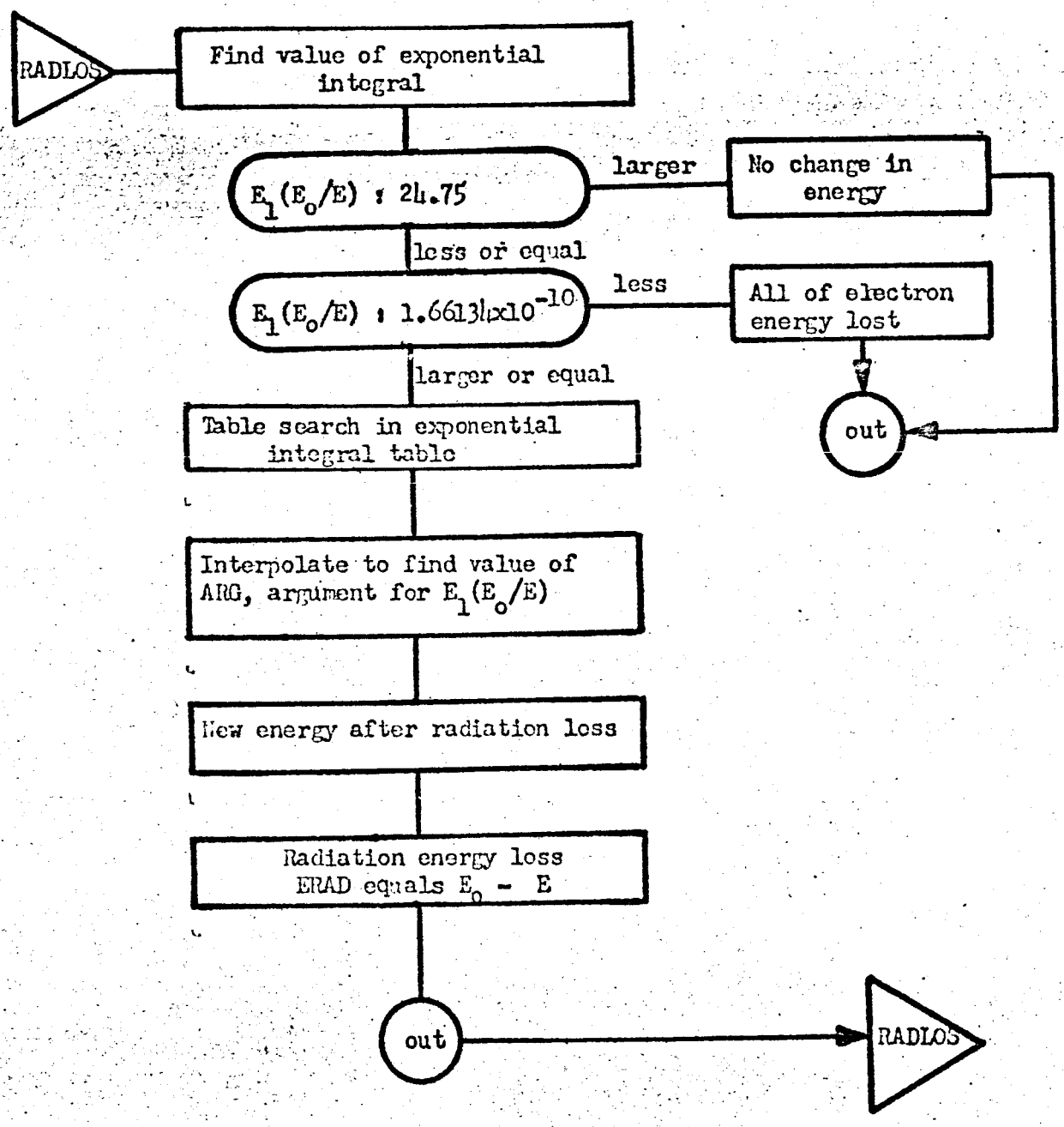



Subroutine DENOM



gl


NUM
TO FIND THE UPPER LIMIT OF AN INTEGRAL, GIVEN THE VALUE OF THE INTEGRAL
TABLE SEARCH TO FIND THE SUM OF THE INTEGRALS VALUE= $\int vf^0(v)dv + \int vf^1(v)dv + \int vf^2(v)dv$
INTERPOLATE TO FIND THE UPPER LIMIT, ETA, CORRESPONDING TO THE INTEGRAL FOUND IN THE TABLE
SCATTER ANGLE $\theta_{SCAT} = ETA \times X_0 \beta 1/2$
RETURN




Subroutine RADLOS

# PROGRAM LISTING

```
      COMMON IMAX,RANGE,RATE,ENERGY,DUM1,E1,DUM2,ARG,DUM3,UPLIM,
     1DUM4,F2INT,DUM5,F1INT,DUM6,F2INT,DISCPT,ECUT,TMAX,Z,A,REG,TPMT1,
     2TPMT2,REGNO,ENGY,ANGLE,NOSLAB,NOHIST,SLCTE1,SPCFY,EINT,SLCTA1,
     3THINT,OPT1,BREM,FACTOR,TRA,BOTH,L1,L2,BLANK,KERROR,NANT,IRDL,SPACE
     4,RAND1,RAND,CON2,ZB,IOP,NI,FNEE,ISCUM
      DIMENSION IMAX(12),RANGE(50,12),RATE(50,12),ENERGY(50,12),E1(128),
     1ARG(128),UPLIM(128),F2INT(128),F1INT(128),F2INT(128),DISCPT(12),
     2TMAX(12),Z(12),A(12),REG(15,12),TPMT1(12),TPMT2(12),REGNO(12),ENGY
     3(15),ANGLE(16),BLANK(7),SPACE(6),ZB(20),FNEE(15,16,20),ECUT(12)
     4,NANT(15,16,20),IRDL(15,12,15)
B     SPCFY=624725233126
B     FISS=263162623146
B     STPC=316246635146
B     BREM=225125446762
B     TRA=635121456244
B     BOTH=225125446351
C     READ ALL TABLES
C     TABLES FOR INTEGRALS
    1 READ INPUT TAPE 5,10,(UPLIM(I),F2INT(I),F1INT(I),F2INT(I),I=1,128)
   10 FORMAT(E6.0,3E10.0,E6.0,3E10.0)
C     TABLES OF E1(X)
    2 READ INPUT TAPE 5,20,(ARG(I),E1(I),I=1,128)
   20 FORMAT(6E10.0)
C     END OF TABLES
  355 READ INPUT TAPE 5,110,(DISCPT(I),I=1,12)
  110 FORMAT(12A6)
      ISCUM=0
      DO 356 I=1,15
      DO 356 J=1,16
      DO 356 K=1,20
      NANT(I,J,K)=0
  356 FNEE(I,J,K)=0.
      DO 357 I=1,15
      DO 357 J=1,12
      DO 357 K=1,15
  357 IRDL(I,J,K)=0
C     READ OPTIONS AND NUMBER OF HISTORIES
    3 READ INPUT TAPE 5,30,SLCTE1,SLCTE2,SLCTA1,SLCTA2,
     1OPT1,OPT2,OPT3,IOP,NOHIST,NCOUT
   30 FORMAT(2A6,3X,2A6,3X,3A6,I2,2I10)
C     CHECK OPTION INPUT
    4 IF(SLCTE1-SPCFY)5,6,5
C     ENERGY IS SPECIFIED IN INPUT
    6 READ INPUT TAPE 5,40,EINT
   40 FORMAT(E10.0)
      GO TO 8
    5 IF(SLCTE1-FISS)7,8,7
C     ERROR RETURN
    7 WRITE OUTPUT TAPE 6,50
   50 FORMAT(40H ERROR STOP -- MISSPELLING ON INPUT CARD)
      CALL EXIT
C     ANGLE
    8 IF(SLCTA1-SPCFY)9,1000,9
```

```
C       READ INPUT ANGLE
 1000   READ INPUT TAPE 5,40,THINT
        GOTO12
      9 IF(SLCTAI- STPC)11,12,11
C       ERROR STOP
     11 WRITE OUTPUT TAPE6,50
        CALLEXIT
     12 IF(OPTI-BREM) 122,121,122
    122 IF(OPTI-TRA) 123,121,123
    123 IF(OPTI-BOTH)124,121,124
    124 WRITE OUTPUT TAPE 6,50
        CALL EXIT
C       READ SLAB DESCRIPTION
    121 READ INPUT TAPE 5,60,NOSLAB,(TPMT1(J),TPMT2(J),TMAX(J),
       1REGNO(J),A(J),Z(J),ECUT(J),J=1,NOSLAB)
     60 FORMAT(I10/(2A6,5E10.0))
    351 READ INPUT TAPE 5,350,NI,(ZB(I),I=1,NI)
    350 FORMAT(I10/(7E10.0))
        IF(OPTI-TRA )352,353,352
    352 SUM=0.
        DO200J=1,NOSLAB
        DIST=TMAX(J)/REGNO(J)
        NOREG=REGNO(J)
        REG(1,J)=SUM+DIST
        DO100I=2,NOREG
    100 REG(I,J)=REG(I-1,J)+DIST
    200 SUM=SUM+TMAX(J)
C       READ RANGE-ENERGY TABLES
    353 READ INPUT TAPE 5,41,FACTOR,RAND1
     41 FORMAT(E10.0,J12)
        DO300J=1,NOSLAB
        READ INPUT TAPE 5,70,IMAX(J)
     70 FORMAT(I10)
        ISTP=IMAX(J)
    300 READ INPUT TAPE 5,61,(ENERGY(I,J),RANGE(I,J),RATE(I,J),I=1,ISTP)
     61 FORMAT (7E10.0)
C       READ ENERGY ANGLE BINS FOR TRANSMISSION
C       AND ABSORPTION TALLY
        READ INPUT TAPE 5,80,L1,(ENGY(I),I=1,L1)
     80 FORMAT(I10/(7E10.0))
        READINPUTTAPE5,80,L2,(ANGLE(I),I=1,L2)
     15 CALLELMC
        IF(KERROR)16,15,17
     17 WRITE OUTPUT TAPE 6,18,KERROR
     18 FORMAT(19H ERROR STOP KERROR=I10)
        CALL EXIT
     16 CALLOUT
        IF(ISUM-NCONT)354,355,354
     50 FORMAT(I10)
    354 READINPUTTAPE5,90,NCHIST
        GOTO19
        END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
      SUBROUTINE ELMC
C     ELECTRON MONTE CARLO
      COMMON SPACE,ECUT, TMAX, Z, A, REG, TPMT1, TPMT2, REGNO, BLANK,
     1NOSLAB,NOHIST,SLECTE,
     1SPCFY,EINT,SLECTA,THINT,OPTION,BREM,FACTOR,TRA,BOTH,L1,L2,
     2ENPREV,ERAD,THTSCT,T,CUBE,EMOL,DELT,KERROR,VOID,ENERGY
     3,RAND1,RAND,CON2,ZB,IOP,NI,EMPTY,ISCUM,AVECOS,COSTHE
      DIMENSION SPACE(2598),TMAX(12),Z(12),A(12),REG(15,12),BLANK(31)
     1,VOID( 7505),REGNO(12),TPMT1(12),TPMT2(12),ZB(20),ECUT(12)
     2,AVECOS(20),SUMCOS(20),SUMI(20),EMPTY(15,16,20)
C     INITIALIZE
      DO 99 ISLB=1,NI
      SUMCOS(ISLB)=0.
      SUMI(ISLB)=0.
   99 CONTINUE
      IOP = IOP
      ENPREV=0.
      IHIST=0
      CUBE=1./3.
      CON1=1.3977649E-03
      CON2=4.80286**4
C     HISTORY COUNTER
    1 IHIST=IHIST+1
      ISLB=1
      TTOT=0.
      J=1
      SUM=TMAX(J)
      IF(IHIST-NOHIST)2,2,3
C     INITIAL ENERGY
    2 IF(SLECTE-SPCFY)4,5,4
    5 ENERGY=EINT
      GO TO 55
C     INITIAL ENERGY FROM FISSION SPECTRUM
C     AT PRESENT NOT AVAILABLE
    4 CALL FISS
C     FIND RANGE AND DE/DX FOR ENERGY
   55 CALL RANDE(ENERGY,RE,DEDX,J)
C     ANGLE OF INCIDENCE
      IF(KERROR)56,56,57
   57 RETURN
   56 IF(SLECTA-SPCFY)6,61,6
   61 COSINE=COSF(THINT*.0174533)
      THETA=THINT*.0174533
      GO TO 121
C     FROM ISOTROPIC DISTRIBUTION
    6 CALL RANDM
      COSINE=RAND
      THETA=ACOSF(COSINE)
  121 XZRO=CON1*Z(J)**2/A(J)*LOGF(183./(Z(J)**CUBE))
      GO TO (1004,1005), IOP
 1004 DELT=FACTOR
      GO TO 1006
 1005 DELT = FACTOR/ENERGY
 1006 T=DELT*XZRO
```

```
      TEST=DELT*COSINE
      TTOT=TTOT+TEST
C     TEST TO DETERMINE WHICH SLAB ELECTRON IS NOW IN
      IF(TTOT-SUM)1013,223,223
C     IS NOT IN SLAB J+1
 1013 IF(TTOT-(SUM-TMAX(J)))222,222,134
C     THE ELECTRON WENT TO SLAB J+1, SO LOCATE IT NOW
C     AT THE BOUNDARY BETWEEN
  223 N=1
      DELT=(SUM-(TTOT-TEST))/COSINE
      T=DELT*XZRO
      TTOT=SUM
      SUM=SUM+TMAX(J+1)
      IF(DELT)227,226,227
  227 IREG=REGNO(J)
      GO TO 17
C     THE ELECTRON BACKSCATTERED TO SLAB J-1
C     IF TOTAL Z IS NEGATIVE THE ELECTRON BACKSCATTERED
C     OUT FRONT OF THE SHIELD
  222 IF(TTOT)16,16,225
C     STILL IN SHIELD
  225 N=3
      SUM=SUM-TMAX(J)
      DELT=((TTOT-TEST)-SUM)/ABSF(COSINE)
      TTOT=SUM
      IF(DELT)228,226,228
  228 IREG=1
      T=DELT*XZRO
      GO TO 17
   16 IF(OPTION-BREM)1002,1,1002
 1002 ISLB=N1
      CALL TRANS(THETA,ISLB)
      IF(KERROR)66,66,67
   67 RETURN
   66 COSTHE=COSTHE
      IF(COSTHE) 1, 666, 666
  666 SUMCOS(ISLB)=SUMCOS(ISLB)+COSTHE
      SUMI(ISLB)=SUMI(ISLB)+1.
      GO TO 1
C      HE ELECTRON IS STILL IN THE SAME SLAB
  134 N=2
      IEND=REGNO(J)
      DO 100 I=1,IEND
      IF(TTOT-REG(I,J))171,171,100
  100 CONTINUE
C     COMPUTE RADIATION LOSS
  171 IREG=I
   17 IF(TTOT-ZB(ISLB))1010,1011,1011
 1011 IF(OPTION-BREM)1014,1    ,1014
 1014 CALL TRANS(THETA,ISLB)
      COSTHE=COSTHE
      IF (COSTHE) 2666, 3666, 3666
 3666 SUMCOS(ISLB)=SUMCOS(ISLB)+COSTHE
      SUMI(ISLB)=SUMI(ISLB)+1.
```

```
 2666 IF(ISLB-NI)1666,1,1
 1666 ISLB=ISLB+1
      GO TO 17
 1010 CALL RADLOS
      IF(ERAD)68,68,172
C     TALLY RADIATION LOSS
 172  IF(OPTION-TRA )1722,68,1722
 1722 CALL TLYRD (IREG,J)
      IF(KERROR)68,68,69
   69 RETURN
C     COMPUTE IONIZATION LOSS
   68 EION=DELT*DEDX
C     ENERGY FOR MOLLIERE CALCULATION
      EMOL=ENERGY-(EION+ERAD)/2.
C     COMPUTE NEW ENERGY
  771 ENERGY=ENERGY-EION-ERAD
      IF (ENERGY-ECUT(J))1,1,77
C     COMPUTE SCATTER ANGLE
   77 CALL MOLLI(J)
      IF(KERROR)70,70,71
   71 RETURN
   70 CALL RANDM
      CHI=2.*3.14159*RAND
      COSINE=COSINE*COSF(THTSCT)+COSF(CHI)*SINF(THTSCT)*SQRTF(1.-COSINE*
     1*2)
  994 THETA=ACOSF(COSINE)
  226 GO TO (18,19,20),N
   20 J = J-1
      GO TO 19
   18 J=J+1
   19 CALL RANDE (ENERGY,RE,DEDX,J)
      GO TO 121
    3 DO 199 ISLB=1,NI
      AVECOS(ISLB)=SUMCOS(ISLB)/SUMI(ISLB)
  199 CONTINUE
      RETURN
      END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
      SUBROUTINE OUT
      COMMON SPACE,DISCPT,ECUT,TMAX,BLANK,REG,TPMT1,TPMT2,REGNO,ENGY,
     1ANGLE,NOSLAB,NOHIST,SLCTE1,SPCFY,EINT,SLCTA1,THINT,
     2OPT1,BREM,FACTOR,TRA,BOTH,L1,L2,VOID,KERROR,NANT,IRDL,ALSO,ZB,IOP,
     3NI,FNEE,ISCUM,AVECOS,COSTHE
      DIMENSION SPACE(2586),DISCPT(12),TMAX(12),BLANK( 24),TPMT1
     1(12),TPMT2(12),REGNO(12),ENGY(15),ANGLE(16),NANT(15,16,20),IRDL(15
     2,12,15),VOID(7),ALSO( 9),ZB(20),KSUM(16),FNEE(15,16,20),REG(15,12)
     3,ECUT(12),HEADN(16),HEADE(16),FSUM(16),AVECOS(20)
      ICP = IOP
      ISCUM=ISCUM+NOHIST
      DO 400 I=1,L2
      HEADN(I)=IHN
  400 HEADE(I)=IHE
C     WRITE PROBLEM DISCRIPTION
      WRITEOUTPUTTAPE6,10,(DISCPT(I),I=1,12),ISCUM
   10 FORMAT(1H1,10X,12A6,3X,I10,9HHISTORIES//)
      IF(OPT1-BREM)2,1,2
    2 WRITEOUTPUTTAPE6,20
   20 FORMAT(1H ,37X,46HELECTRON MONTE CARLO TRANSMISSION DISTRIBUTION//
     1)
      GOTO3
    1 WRITE OUTPUT TAPE6,30
   30 FORMAT(1H ,32X,55HELECTRON MONTE CARLO RADIATION ENERGY LOSS DISTR
     1IBUTION//)
    3 IF(SLCTE1-SPCFY)4,5,4
    5 WRITEOUTPUTTAPE6,40,EINT
   40 FORMAT(32H INITIAL ENERGY SPECIFIED TO BE 1PE15.6,5H MEV.//)
      GOTO6
    4 WRITEOUTPUTTAPE6,50
   50 FORMAT(57H INITIAL ENERGY DETERMINED FROM FISSION ELECTRON SPECTRU
     1M//)
    6 IF(SLCTA1-SPCFY)7,8,7
    8 WRITEOUTPUTTAPE6,60,THINT
   60 FORMAT(44H INITIAL ANGLE OF INCIDENCE SPECIFIED TO BE 1PE15.6,8H D
     1EGREES//)
      GOTO9
    7 WRITE OUTPUT TAPE 6,70
   70 FORMAT(66H INITIAL ANGLE OF INCIDENCE DETERMINED FROM ISOTROPIC DI
     1STRIBUTION//)
    9 GO TO (111,112), IOP
  111 WRITE OUTPUT TAPE 6, 113, FACTOR
  113 FORMAT(9H DELTA T=F7.4//)
      GO TO 116
  112 WRITE OUTPUT TAPE 6, 114, FACTOR
  114 FORMAT(9H DELTA T=F7.4,7H/ENERGY//)
  116 WRITE OUTPUTTAPE6,80,NOSLAB
   80 FORMAT(19H SHIELD CONSISTS OF110,6H SLABS//)
      DO100J=1,NOSLAB
  100 WRITEOUTPUTTAPE6,110,J,TPMT1(J),TPMT2(J),TMAX(J)
  110 FORMAT(5H SLAB13,4H IS 2A6,13H OF THICKNESS1PE15.6,10H GM./CM**2)
C     TEST FOR OUTPUT ARRAY WANTED
  115 IF (OPT1-BREM) 117, 17 , 117
```

```
  117 IF (NI-1) 118, 13 , 119
  118 KERROR = 12
      RETURN
  119 WRITE OUTPUT TAPE 6, 121, NI
  121 FORMAT(32H TRANSMISSION DISTRIBUTIONS FOR I3,6H CASES//)
      DO 122 I=1, NI
  122 WRITE OUTPUT TAPE 6, 123, I, ZB(I)
  123 FORMAT(5H CASEI3,23H IS A SLAB OF THICKNESS1PE15.6,10H GM./CM**2//
     1)
C     WRITE TRANSMISSION ARRAY
   13 DO 1004 ISLB=1,NI
      LM1=1
      LM2=5
      KTRANS=1
      WRITE OUTPUT TAPE 6,1334,ISLB,ZB(ISLB)
 1334 FORMAT(35HOTRANSMISSION DISTRIBUTION FOR CASEI4,24H WITH SLAB OF T
     1HICKNESS 1PE15.6,10H GM./CM**2//)
 1444 IF(L2-LM2)14,14,16
   14 LM2=L2
      KTRANS=2
   16 WRITE OUTPUTTAPE6,120,(ANGLE(I),I=LM1,LM2)
  120 FORMAT(1H0,50X,18HTRANSMISSION ANGLE//1H ,15X,5(F6.2,12X)//)
      WRITE OUTPUT TAPE 6,160,(HEADN(I),HEADE(I),I=LM1,LM2)
  160 FORMAT(7H ENERGY,7X,10(A6,3X)//)
      DO200I=1,L1
  200 WRITEOUTPUTTAPE6,130,ENGY(I),(NANT(I,J,ISLB),FNEE(I,J,ISLB),J=LM1,
     1LM2)
  130 FORMAT(1H ,F6.3,4X,5(I6,2X,F 8.2,2X))
      DO 211 J=LM1, LM2
      FSUM(J)=0.
      KSUM(J) = 0
      DO 212 I=1, L1
      FSUM(J)=FSUM(J)+FNEE(I,J,ISLB)
  212 KSUM(J) = KSUM(J)+NANT(I,J,ISLB)
  211 CONTINUE
      WRITE OUTPUT TAPE 6, 216, (KSUM(J),FSUM(J),J=LM1,LM2)
  216 FORMAT(7HOTOTALS,4X,5(I6,2X,F8.2,2X))
      GO TO (15, 213),KTRANS
   15 LM1=LM1+5
      LM2=LM2+5
      GO TO 1444
  213 ISUM = 0
      DO 214 J=1, L2
  214 ISUM = ISUM+KSUM(J)
       WRITE OUTPUT TAPE 6, 215, ISUM
  215 FORMAT(21HOTOTAL TRANSMITTED = I10)
 1004 CONTINUE
      WRITE OUTPUT TAPE 6,99
   99 FORMAT(1H0,45X,31H AVERAGE  TRANSMISSION  COSINES//2(15X,10HTHICKN
     1ESS ,15X,10H   COSINE ,10X))
      WRITE OUTPUT TAPE 6,999,(ZB(I),AVECOS(I),I=1,NI)
  999 FORMAT(/2(10X,F15.6,10X,E15.6,10X))
      IF(OPT1-BCTH)11,25,11
   25 WRITE OUTPUT TAPE 6,30
```

```
C     WRITE RADIATION ENERGY LOSS ARRAY
   17 DO21J=1,NCSLAB
      LM2=6
      LM1=1
      KTRANS=1
   26 IF(L1-LM2)18,18,22
   18 LM2=L1
      KTRANS=2
      GOTO22
   22 WRITEOUTPUTTAPE6,140,(ENGY(I),I=LM1,LM2)
  140 FORMAT(53X,13HENERGY (MEV.)//7H REGION,4X,6(F6.3,7X)//)
      NOREG=REGNO(J)
      DO300I=1,NOREG
  300 WRITEOUTPUTTAPE6,150,I,(IRDL(I,J,K),K=LM1,LM2)
  150 FORMAT(1H ,I6,4X,6(I6   ,7X))
      GO TO (27,21),KTRANS
   27 LM1=LM1+6
      LM2=LM2+6
      GO TO 26
   21 CONTINUE
   11 RETURN
      END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
      SUBROUTINE TRANS(THT,ISLB)
      COMMON BLANK,ENGY,ANGLE,SPACE,L1,L2,VOID,KERROR,NANT,ALSO,ENERGY
     1,TOO,FNEE,ISCUM,AVFCOS,COSTHE
      DIMENSION BLANK(2862),ENGY(15),ANGLE(16),SPACE(12),VOID(7),
     1NANT(15,16,20),ALSO(2705),TOO(25),FNEE(15,16,20),AVECOS(20)
      IGO=ISLB
      THE=THT
      COSTHE=COSF(THE)
      THETA=THT   *57.296
    5 IF (THETA-360.) 3, 4, 4
    4 THETA = THETA-360.
      GO TO 5
    3 DO 100 I=1,L1
      IF(ENERGY-ENGY(I)) 1,1,100
  100 CONTINUE
      KERROR=5
      RETURN
    1 DO 200 J=1,L2
      IF(THETA-ANGLE(J)) 2,2,200
  200 CONTINUE
      KERROR=4
      RETURN
    2 NANT(I,J,IGO)=NANT(I,J,IGO)+1
      FNEE(I,J,IGO)=FNEE(I,J,IGO)+ENERGY
      RETURN
      END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
      SUBROUTINE MOLLI(JSLAB)
      COMMON BLANK,Z,A,SPACE,FACTOR,EMPTY,THTSCT,T,CUBE,EMOL,DELT,
     1KERROR,VOID,DEN,SMLB,BBIG,CHIC,VALUE,EN,RAND1,RAND,CON2
      DIMENSION BLANK(2622),Z(12),A(12),SPACE(256),VOID( 7500),EMPTY(6)
      J=JSLAB
      BETSQ=1.-(.51/(EMOL+.51))**2
      SMLB=LOGF(6680.*DELT*(Z(J)+1.)*Z(J)**CUBE/(BETSQ*A(J)(1.+4.5BE-05
     1*Z(J)**2*(1.+4.*EMOL*(EMOL+1.))/EMOL*(EMOL+1.))))
      IF(SMLB-1.)3,4,4
    3 IF(DELT-FACTOR)10,20,20
   10 THTSCT=0.
      RETURN
   20 KERROR=2
      RETURN
C     FIND BBIG SUCH THAT BBIG-LN(BBIG)=SMLB
    4 CALL DETB
      IF(KERROR) 1,1,2
    2 RETURN
    1 CHIC=SQRTF(CON2*29.47689E-05*DELT*Z(J)*(Z(J)+1.)/(A(J)*(EMOL+.51)*
     1(1.-BETSQ**2))
C     FIND INTEGRAL FROM 0 TO 2*PI/(CHI*BBIG**1/2)
      CALL DENOM
C     FIND RANDOM NUMBER
      CALL RANDM
      VALUE=RAND*DEN
C     FIND UPPER LIMIT OF INTEGRA EQUAL TO VALUE
      CALL NUM
      RETURN
      END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
      SUBROUTINE DETB
      COMMON BLANK,KERROR,SPACE,BSML,BBIG
      DIMENSION BLANK(2914),SPACE( 7501)
      SLOPE=9.075804E-01
      ICOUNT=0
      BBIG=(20.*(SLOPE-1.)+BSML+LOGF(20.1))/SLOPE
    6 BPM=LOGF(BBIG)+BSML
      IF(ABSF(BPM-BBIG)-1.E-04) 5,5,4
    4 BBIG=BPM
      ICOUNT=ICOUNT+1
      IF(ICOUNT-200) 6,6,7
    7 KERROR=7
    5 RETURN
      END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
      SUBROUTINE TLYRD (IREG,JSLAB)
C     SUBROUTINE TO TALLY RADIATION LOSS IN REGION I OF MATERIAL J
      COMMON BLANK,EN,SPACE,L1,DUM1,DUM2,ERAD,VOID,KERROR,NANT,IRDL
      DIMENSION BLANK(2862),EN(15),SPACE(28),VOID(5),NANT(15,16,20),IRDL
     1(15,12,15)
      J=JSLAB
      I=IREG
      DO 100 K=1,L1
      IF(ERAD-EN(K)) 1,1,100
  100 CONTINUE
      KERROR=4
C     ERROR-RADIATION LOSS GREATER THAN MAXIMUM ENERGY INCREMENT
      RETURN
    1 IRDL(I,J,K)=IRDL(I,J,K)+1
      RETURN
      END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
      SUBROUTINE RANDE (EN,RE,DEDX,JSLAB)
      COMMON MAX,RANGE,RATE,E,SPACE,ENPREV,BLANK,KERROR
      DIMENSION MAX(12),RANGE(50,12),RATE(50,12),E(50,12),SPACE(1095),
     1BLANK(6)
C     TEST FOR ENERGY GREATER THAN TABLE
      J=JSLAB
      IMAX=MAX(J)
      IF(EN-E(IMAX,J))2,1,1
C     RANGE AND DE/DX EQUAL LAST OF TABLE
    1 RE=RANGE(IMAX,J)
      DEDX=RATE(IMAX,J)
      RETURN
C     COMPARE ENERGY TO PREVIOUS ENERGY
    2 IF(EN-ENPREV) 7,4,5
C     SAME ENERGY SO RETURN
    4 RETURN
C     ENERGY GREATER THAN PREVIOUS ENERGY
    5 ISTR=IMAX
      GO TO 7
C     ENERGY LESS THAN PREVIOUS ENERGY
    3 ISTR=ISTR-1
      IF(ISTR) 6,6,7
C     ERROR RETURN - TABLE EXHAUSTED
    6 KERROR=3
      RETURN
C     CONTINUE LOOKING
    7 IF(EN-E(ISTR,J)) 3,9,10
C     ENERGY EQUAL
    9 RE=RANGE(ISTR,J)
      DEDX=RATE(ISTR,J)
      RETURN
C     ENERGY GREATER SO INTERPOLATE
   10 RE=((EN-E(ISTR,J))*(RANGE(ISTR,J)-RANGE(ISTR+1,J)))
     1/(E(ISTR,J)-E(ISTR+1,J))+RANGE(ISTR,J)
      DEDX=((EN-E(ISTR,J))*(RATE(ISTR,J)-RATE(ISTR+1,J)))
     1/(E(ISTR,J)-E(ISTR+1,J))+RATE(ISTR,J)
      ENPREV=EN
      RETURN
      END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
      SUBROUTINE DENOM
      COMMON BLANK,DUM1,UPLIM,DUM2,FZINT,DUM3,F1INT,DUM4,
     1F2INT,SPACE,DEN,SMLB,BBIG,CHIC
      DIMENSION BLANK(2070),UPLIM(128),FZINT(128),F1INT(128),
     1F2INT(128),SPACE( 7829)
      XU=3.14159/(CHIC*SQRTF(BBIG))
      IF(XU-9.3)3,4,4
    4 DEN=1.-.0118416/BBIG+.041235/(BBIG**2)
      RETURN
    3 DO 100 I=1,93
      IF(XU-UPLIM(I)) 1,2,100
  100 CONTINUE
      RETURN
    2 DEN=FZINT(I)+F1INT(I)/BBIG+F2INT(I)/(BBIG**2)
      RETURN
    1 CONST=(UPLIM(I-1)-XU)/(UPLIM(I-1)-UPLIM(I))
      FZRO=CONST*(FZINT(I-1)-FZINT(I))+FZINT(I-1)
      FONE=CONST*(F1INT(I-1)-F1INT(I))+F1INT(I-1)
      FTWO=CONST*(F2INT(I-1)-F2INT(I))+F2INT(I-1)
      DEN=FZRO+FONE/BBIG+FTWO/(BBIG**2)
      RETURN
      END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
                    00003          ENTRY  NUM

  TRANSFER VECTOR
00000  625051636060      SORT

  LINKAGE DIRECTOR
00001  000000000000
00002  456444606060

00003 -0634 00 4 00001  NUM     SXD     NUM-2,4
00004  0634 00 1 00001          SXA     NUM-2,1
00005  0774 00 1 00000          AXT     0,1
00006  0560 00 0 53200          LDQ     B
00007  0260 00 0 53200          FMP     B
00010  0601 00 0 00252          STQ     BSQ
00011  0500 00 1 72531          CLA     F2INT+1-64,1
00012  0601 00 0 00250          STQ     TEMP
00013  0241 00 0 00252          FDP     BSQ
00014 -0600 00 0 00250          STQ     TEMP
00015  0500 00 1 72732          CLA     F1INT+1-64,1
00016  0241 00 0 53200          FDP     B
00017  0131 00 0 00000          XCA
00020  0300 00 0 00250          FAD     TEMP
00021  0300 00 1 73133          FAD     F2INT+1-64,1
00022  0601 00 0 00250          STQ     TEMP
00023  0500 00 0 53176          CLA     VALUE
00024  0340 00 0 00250          CAS     TEMP
00025  1 00100 1 00027          TXI     *+2,1,64
00026  0020 00 0 00027          TRA     *+1
00027  0500 00 1 72571          CLA     F2INT+1-64+32,1
00030  0601 00 0 00250          STQ     TEMP
00031  0241 00 0 00252          FDP     BSQ
00032 -0600 00 0 00250          STQ     TEMP
00033  0500 00 1 72772          CLA     F1INT+1-64+32,1
00034  0241 00 0 53200          FDP     B
00035  0131 00 0 00000          XCA
00036  0300 00 0 00250          FAD     TEMP
00037  0300 00 1 73173          FAD     F2INT+1-64+32,1
00040  0601 00 0 00250          STQ     TEMP
00041  0500 00 0 53176          CLA     VALUE
00042  0340 00 0 00250          CAS     TEMP
00043  1 00040 1 00045          TXI     *+2,1,32
00044  0020 00 0 00045          TRA     *+1
00045  0500 00 1 72611          CLA     F2INT+1-64+32+16,1
00046  0601 00 0 00250          STQ     TEMP
00047  0241 00 0 00252          FDP     BSQ
00050 -0600 00 0 00250          STQ     TEMP
00051  0500 00 1 73012          CLA     F1INT+1-64+32+16,1
00052  0241 00 0 53200          FDP     B
00053  0131 00 0 00000          XCA
00054  0300 00 0 00250          FAD     TEMP
00055  0300 00 1 73213          FAD     F2INT+1-64+32+16,1
00056  0601 00 0 00250          STQ     TEMP
00057  0500 00 0 53176          CLA     VALUE
```

```
00060  0340 00 0 00250     CAS   TEMP
00061  1 00020 1 00063     TXI   *+2,1,16
00062  0020 00 0 00063     TRA   *+1
00063  0500 00 1 72621     CLA   F2INT+1-64+32+16+8,1
00064  0601 00 0 00250     STO   TEMP
00065  0241 00 0 00252     FDP   BSQ
00066 -0600 00 0 00250     STQ   TEMP
00067  0500 00 1 73022     CLA   F1INT+1-64+32+16+8,1
00070  0241 00 0 53200     FDP   B
00071  0131 00 0 00000     XCA
00072  0300 00 0 00250     FAD   TEMP
00073  0300 00 1 73223     FAD   F2INT+1-64+32+16+8,1
00074  0601 00 0 00250     STO   TEMP
00075  0500 00 0 53176     CLA   VALUE
00076  0340 00 0 00250     CAS   TEMP
00077  1 00010 1 00101     TXI   *+2,1,8
00100  0020 00 0 00101     TRA   *+1
00101  0500 00 1 72625     CLA   F2INT+1-64+32+16+8+4,1
00102  0601 00 0 00250     STO   TEMP
00103  0241 00 0 00252     FDP   BSQ
00104 -0600 00 0 00250     STQ   TEMP
00105  0500 00 1 73026     CLA   F1INT+1-64+32+16+8+4,1
00106  0241 00 0 53200     FDP   B
00107  0131 00 0 00000     XCA
00110  0300 00 0 00250     FAD   TEMP
00111  0300 00 1 73227     FAD   F2INT+1-64+32+16+8+4,1
00112  0601 00 0 00250     STO   TEMP
00113  0500 00 0 53176     CLA   VALUE
00114  0340 00 0 00250     CAS   TEMP
00115  1 00004 1 00117     TXI   *+2,1,4
00116  0020 00 0 00117     TRA   *+1
00117  0500 00 1 72627     CLA   F2INT+1-64+32+16+8+4+2,1
00120  0601 00 0 00250     STO   TEMP
00121  0241 00 0 00252     FDP   BSQ
00122 -0600 00 0 00250     STQ   TEMP
00123  0500 00 1 73030     CLA   F1INT+1-64+32+16+8+4+2,1
00124  0241 00 0 53200     FDP   B
00125  0131 00 0 00000     XCA
00126  0300 00 0 00250     FAD   TEMP
00127  0300 00 1 73231     FAD   F2INT+1-64+32+16+8+4+2,1
00130  0601 00 0 00250     STO   TEMP
00131  0500 00 0 53176     CLA   VALUE
00132  0340 00 0 00250     CAS   TEMP
00133  1 00002 1 00135     TXI   *+2,1,2
00134  0020 00 0 00135     TRA   *+1
00135  0500 00 1 72630     CLA   F2INT+1-64+32+16+8+4+2+1,1
00136  0601 00 0 00250     STO   TEMP
00137  0241 00 0 00252     FDP   BSQ
00140 -0600 00 0 00250     STQ   TEMP
00141  0500 00 1 73031     CLA   F1INT+1-64+32+16+8+4+2+1,1
00142  0241 00 0 53200     FDP   B
00143  0131 00 0 00000     XCA
00144  0300 00 0 00250     FAD   TEMP
00145  0300 00 1 73232     FAD   F2INT+1-64+32+16+8+4+2+1,1
```

```
00146  0601 00 0 00250          STO    TEMP
00147  0500 00 0 53176          CLA    VALUE
00150  0340 00 0 00250          CAS    TEMP
00151  0020 00 0 00154          TRA    LESS
00152  0020 00 0 00233          TRA    OUT
00153  0020 00 0 00204          TRA    GREAT
00154  0500 00 1 72627   LESS   CLA    F2INT-1,1
00155  0601 00 0 00251          STO    TEMP1
00156  0241 00 0 00252          FDP    BSQ
00157 -0600 00 0 00251          STO    TEMP1
00160  0500 00 1 73030          CLA    F1INT-1,1
00161  0241 00 0 53200          FDP    B
00162  0131 00 0 00000          XCA
00163  0300 00 0 00251          FAD    TEMP1
00164  0300 00 1 73231          FAD    F2INT-1,1
00165  0601 00 0 00251          STO    TEMP1
00166 -0760 00 0 00003          SSM
00167  0300 00 0 00250          FAD    TEMP
00170  0601 00 0 00253          STO    TEST1
00171  0500 00 0 00250          CLA    TEMP
00172  0302 00 0 53176          FSB    VALUE
00173  0601 00 0 00250          STO    TEMP
00174  0500 00 1 73433          CLA    UPLIM,1
00175  0302 00 1 73432          FSB    UPLIM-1,1
00176  0241 00 0 00253          FDP    TEST1
00177  0260 00 0 00250          FMP    TEMP
00200  0760 00 0 00003          SSP
00201  0300 00 1 73433          FAD    UPLIM,1
00202  0601 00 0 00247          STO    ETA
00203  0020 00 0 00235          TRA    OUT1
00204  0500 00 1 72631   GREAT  CLA    F2INT+1,1      VALUE GREATER TEMP
00205  0601 00 0 00251          STO    TEMP1
00206  0241 00 0 00252          FDP    BSQ
00207 -0600 00 0 00251          STO    TEMP1
00210  0500 00 1 73032          CLA    F1INT+1,1
00211  0241 00 0 53200          FDP    B
00212  0131 00 0 00000          XCA
00213  0300 00 0 00251          FAD    TEMP1
00214  0300 00 1 73233          FAD    F2INT+1,1
00215  0601 00 0 00251          STO    TEMP1          F AT I-1
00216  0302 00 0 00250          FSB    TEMP
00217  0601 00 0 00253          STO    TEST1
00220  0500 00 0 00251          CLA    TEMP1
00221  0302 00 0 53176          FSB    VALUE
00222  0601 00 0 00250          STO    TEMP
00223  0500 00 1 73434          CLA    UPLIM+1,1
00224  0302 00 1 73433          FSB    UPLIM,1
00225  0241 00 0 00253          FDP    TEST1
00226  0260 00 0 00250          FMP    TEMP
00227  0760 00 0 00003          SSP
00230  0300 00 1 73434          FAD    UPLIM+1,1
00231  0601 00 0 00247          STO    ETA
00232  0020 00 0 00235          TRA    OUT1
00233  0500 00 1 73433   OUT    CLA    UPLIM,1
```

```
00234  0601 00 0 00247          STO     ETA
00235  0500 00 0 53200   OUT1   CLA     B
00236  0074 00 4 00000          TSX     $SQRT,4
00237  0131 00 0 00000          XCA
00240  0260 00 0 53177          FMP     CHIC
00241  0131 00 0 00000          XCA
00242  0260 00 0 00247          FMP     ETA
00243  0601 00 0 71724          STO     THTSCT
00244 -0534 00 4 00001          LXD     NUM-2,4
00245  0534 00 1 00001          LXA     NUM-2,1
00246  0020 00 4 00001          TRA     1,4
00247  0 00000 0 00000    ETA   PZE
00250  0 00000 0 00000   TEMP   PZE
00251  0 00000 0 00000   TEMP1  PZE
00252  0 00000 0 00000   BSQ    PZE
00253  0 00000 0 00000   TEST1  PZE
                 73433          COMMON  2070
                 73433   UPLIM  COMMON  129
                 73232   F2INT  COMMON  129
                 73031   F1INT  COMMON  129
                 72630   F2INT  COMMON  129
                 71724          COMMON  323
                 71724  THTSCT  COMMON  1
                 53200          COMMON  7507
                 53200       B  COMMON  1
                 53177    CHIC  COMMON  1
                 53176   VALUE  COMMON  1
                                END
```

```
                00004          ENTRY   RADLOS

  TRANSFER VECTOR
00000  512145244460      RANDM
00001  256747606060      EXP

  LINKAGE DIRECTOR
00002  000000000000
00003  512124434662

00004 -0634 00 4 00002  RADLOS SXD     RADLOS-2,4
00005  0634 00 1 00002         SXA     RADLOS-2,1
00006  0774 00 1 00000         AXT     0,1
00007  0074 00 4 00000         TSX     $RANDM,4
00010  0241 00 0 71723         FDP     T
00011  0260 00 0 00114         FMP     =.69315
00012  0601 00 0 00110         STD     EONE
00013  0302 00 0 00115         FSB     =24.75
00014  0120 00 0 00106         TPL     OUT1          NO CHANGE IN ENERGY
00015  0500 00 0 00110         CLA     EONE
00016  0302 00 0 00113         FSB     =1.66134E-10
00017 -0120 00 0 00103         TMI     OUT2          NEW ENERGY=0.
00020  0500 00 0 00110         CLA     EONE
00021  0340 00 1 73736         CAS     E1+1-64,1
00022  1 00100 1 00024         TXI     *+2,1,64
00023  0020 00 0 00024         TRA     *+1
00024  0340 00 1 73776         CAS     E1+1-64+32,1
00025  1 00040 1 00027         TXI     *+2,1,32
00026  0020 00 0 00027         TRA     *+1
00027  0340 00 1 74016         CAS     E1+1-64+32+16,1
00030  1 00020 1 00032         TXI     *+2,1,16
00031  0020 00 0 00032         TRA     *+1
00032  0340 00 1 74026         CAS     E1+1-64+32+16+8,1
00033  1 00010 1 00035         TXI     *+2,1,8
00034  0020 00 0 00035         TRA     *+1
00035  0340 00 1 74032         CAS     E1+1-64+32+16+8+4,1
00036  1 00004 1 00040         TXI     *+2,1,4
00037  0020 00 0 00040         TRA     *+1
00040  0340 00 1 74034         CAS     E1+1-64+32+16+8+4+2,1
00041  1 00002 1 00043         TXI     *+2,1,2
00042  0020 00 0 00043         TRA     *+1
00043  0340 00 1 74035         CAS     E1+1-64+32+16+8+4+2+1,1
00044  1 00001 1 00046         TXI     *+2,1,1
00045  0020 00 0 00046         TRA     *+1
00046  0302 00 1 74035         FSB     E1,1
00047 -0120 00 0 00051         TMI     *+2
00050  1 00001 1 00051         TXI     *+1,1,1
00051  0500 00 1 74036         CLA     E1+1,1
00052  0302 00 1 74035         FSB     E1,1
00053  0601 00 0 00112         STD     TEMP1
00054  0500 00 1 74036         CLA     E1+1,1
00055  0302 00 0 00110         FSB     EONE
00056  0241 00 0 00112         FDP     TEMP1
00057 -0600 00 0 00112         STQ     TEMP1
```

```
00060  0500 00 1 73635          CLA     ARG+1,1
00061  0302 00 1 73634          FSB     ARG,1
00062  0131 00 0 00000          XCA
00063  0260 00 0 00112          FMP     TEMP1
00064 -0760 00 0 00003          SSM
00065  0300 00 1 73635          FAD     ARG+1,1
00066 -0760 00 0 00003          SSM
00067  0074 00 4 00001          CALL    EXP
00070  1 00000 0 00072
00071  0 00103 0 00002
00072  0131 00 0 00000          XCA
00073  0260 00 0 53175          FMP     ENERGY
00074  0601 00 0 00111          STO     X
00075  0500 00 0 53175          CLA     ENERGY
00076  0302 00 0 00111          FSB     X
00077  0601 00 0 71725          STO     ERAD
00100 -0534 00 4 00002  OUT     LXD     RADLOS-2,4
00101  0534 00 1 00002          LXA     RADLOS-2,1
00102  0020 00 4 00001          TRA     1,4
00103  0500 00 0 53175  OUT2    CLA     ENERGY
00104  0601 00 0 71725          STO     ERAD
00105  0020 00 0 00100          TRA     OUT
00106  0600 00 0 71725  OUT1    STZ     ERAD
00107  0020 00 0 00100          TRA     OUT
00110  0 00000 0 00000   EONE   PZE
00111  0 00000 0 00000   X      PZE
00112  0 00000 0 00000   TEMP1  PZE
                 74035          COMMON  1812
                 74035      E1  COMMON  129
                 73634     ARG  COMMON  129
                 71725          COMMON  838
                 71725    ERAD  COMMON  1
                 71723          COMMON  1
                 71723       T  COMMON  1
                 53175          COMMON  7509
                 53175  ENERGY  COMMON  1
                                END

 LITERALS
00113  140555252202
00114  200542711072
00115  205614000000
```

SAMPLE INPUT DATA

```
*       DATA
.1      9.950166-34.136190-3.011404     .2      3.921056-21.547448-2.043951
.3      8.606881-23.101783-2.088491     .4      1.478562-14.643744-2.133684
.5      2.211992-15.692073-2.168174     .6      3.023236-15.809404-2.181999
.7      3.873735-14.683330-2.165999     .8      4.727075-12.181006-2.126374
.9      5.551419-1-1.63142-2.071999     1.      6.321205-1-6.50541-2.009599
1.1     7.018028-1-1.20562-1-.049426    1.2     7.630723-1-1.78269-1-.045551
1.3     8.154807-1-2.33574-1-.073176    1.4     8.591419-1-2.82450-1-.078199
1.5     8.946011-1-3.21884-1-.059612    1.6     9.226957-1-3.50098-1-.026362
1.7     9.444243-1-3.66567-1.013638     1.8     9.608367-1-3.71856-1.056123
1.9     9.729488-1-3.67356-1.095485     2.0     9.816851-1-3.54961-1.12669
2.1     9.878456-1-3.36769-1.14802      2.2     9.920937-1-3.14825-1.160848
2.3     9.949590-1-2.90939-1.160236     2.4     9.968497-1-2.66587-1.151884
2.5     9.980704-1-2.42869-1.138582     2.6     9.988416-1-2.20531-1.122614
2.7     9.993185-1-2.00008-1.105696     2.8     9.996071-1-1.81494-1.089574
2.9     9.997782-1-1.65006-1.075352     3.0     9.998774-1-1.50443-1.063376
3.1     9.999337-1-1.37641-1.053875     3.2     9.999651-1-1.26403-1.046662
3.3     9.999821-1-1.16530-1.041625     3.4     9.999912-1-1.07834-1.038154
3.5     9.999960-1-1.00144-1.036059     3.6     9.999984-1-9.33119-2.034946
3.7     9.999996-1-8.72128-2.034238     3.8     1.          -8.17408-2.034005
3.9     1.          -7.68080-2.034129   4.0     1.000001    -7.23411-2.034466
4.1     1.000001    -6.82793-2.034909   4.2     1.000001    -6.45717-2.035386
4.3     1.000001    -6.11756-2.035891   4.4     1.000001    -5.80548-2.036422
4.5     1.000001    -5.51788-2.036971   4.6     1.000001    -5.25212-2.037516
4.7     1.000001    -5.00593-2.038039   4.8     1.000001    -4.77735-2.038532
4.9     1.000001    -4.56466-2.03899    5.      1.000001    -4.36637-2.039417
5.1     1.000001    -4.18116-2.039814   5.2     1.000001    -4.00787-2.04018325
5.3     1.000001    -3.84545-2.040462   5.4     1.000001    -3.69299-2.040777
5.5     1.000001    -3.54968-2.041075   5.6     1.000001    -3.41476-2.041352
5.7     1.000001    -3.28758-2.041612   5.8     1.000001    -3.16755-2.041855
5.9     1.000001    -3.05412-2.042081   6.0     1.000001    -2.94682-2.04229
6.1     1.000001    -2.84519-2.04248975 6.2     1.000001    -2.74883-2.042675
6.3     1.000001    -2.65739-2.0428466  6.4     1.000001    -2.57052-2.0430066
6.5     1.000001    -2.48792-2.043159   6.6     1.000001    -2.40930-2.0433029
6.7     1.000001    -2.33442-2.0434366  6.8     1.000001    -2.26303-2.0435629
6.9     1.000001    -2.19492-2.0436804  7.0     1.000001    -2.12989-2.043789
7.1     1.000001    -2.06774-2.0438916  7.2     1.000001    -2.00832-2.0439854
7.3     1.000001    -1.95145-2.044074   7.4     1.000001    -1.89700-2.0441579
7.5     1.000001    -1.84483-2.0442366  7.6     1.000001    -1.79481-2.0443104
7.7     1.000001    -1.74683-2.0443816  7.8     1.000001    -1.70076-2.0444479
```

| | | | | | |
|---|---|---|---|---|---|
| 7.9 | 1.000001 | -1.65651-2.044513 | 8.0 | 1.000001 | -1.61399-2.044574 |
| 8.1 | 1.000001 | -1.57311-2.044633 | 8.2 | 1.000001 | -1.53377-2.0446904 |
| 8.3 | 1.000001 | -1.49591-2.044745 | 8.4 | 1.000001 | -1.45945-2.0447966 |
| 8.5 | 1.000001 | -1.42431-2.0448435 | 8.6 | 1.000001 | -1.39045-2.044887 |
| 8.7 | 1.000001 | -1.35779-2.044926 | 8.8 | 1.000001 | -1.32628-2.044961 |
| 8.9 | 1.000001 | -1.29586-2.0449935 | 9.0 | 1.000001 | -1.26648-2.045026 |
| 9.1 | 1.000001 | -1.23810-2.0450585 | 9.2 | 1.000001 | -1.21068-2.045091 |
| 9.3 | 1.000001 | -1.18416-2.0451235 | 9.3 | 1.000001 | -1.18416-2.0451235 |
| 9.3 | 1.000001 | -1.18416-2.0451235 | 9.3 | 1.000001 | -1.18416-2.0451235 |
| 9.3 | 1.000001 | -1.18416-2.0451235 | 9.3 | 1.000001 | -1.18416-2.0451235 |
| 9.3 | 1.000001 | -1.18416-2.0451235 | 9.3 | 1.000001 | -1.18416-2.0451235 |
| 9.3 | 1.000001 | -1.18416-2.0451235 | 9.3 | 1.000001 | -1.18416-2.0451235 |
| 9.3 | 1.000001 | -1.18416-2.0451235 | 9.3 | 1.000001 | -1.18416-2.0451235 |
| 9.3 | 1.000001 | -1.18416-2.0451235 | 9.3 | 1.000001 | -1.18416-2.0451235 |
| 9.3 | 1.000001 | -1.18416-2.0451235 | 9.3 | 1.000001 | -1.18416-2.0451235 |
| 9.3 | 1.000001 | -1.18416-2.0451235 | 9.3 | 1.000001 | -1.18416-2.0451235 |
| 9.3 | 1.000001 | -1.18416-2.0451235 | 9.3 | 1.000001 | -1.18416-2.0451235 |
| 9.3 | 1.000001 | -1.18416-2.0451235 | 9.3 | 1.000001 | -1.18416-2.0451235 |
| 9.3 | 1.000001 | -1.18416-2.0451235 | 9.3 | 1.000001 | -1.18416-2.0451235 |
| 9.3 | 1.000001 | -1.18416-2.0451235 | 9.3 | 1.000001 | -1.18416-2.0451235 |
| 9.3 | 1.000001 | -1.18416-2.0451235 | 9.3 | 1.000001 | -1.18416-2.0451235 |
| 9.3 | 1.000001 | -1.18416-2.0451235 | 9.3 | 1.000001 | -1.18416-2.0451235 |
| 9.3 | 1.000001 | -1.18416-2.0451235 | 9.3 | 1.000001 | -1.18416-2.0451235 |
| 19.7 | 1.34700-1019.5 | 1.66134-1019.3 | 2.04924-10 | | |
| 19.1 | 2.52797-1018.9 | 3.11883-1018.7 | 3.84820-10 | | |
| 18.5 | 4.74863-1018.3 | 5.86037-1018.1 | 7.23319-10 | | |
| 17.9 | 8.92858-1017.7 | 1.102261-917.5 | 1.360933-9 | | |
| 17.3 | 1.680508-917.1 | 2.075377-916.9 | 2.563347-9 | | |
| 16.7 | 3.166451-916.5 | 3.911961-916.3 | 4.833636-9 | | |
| 16.1 | 5.973274-915.9 | 7.382633-915.7 | 9.125824-9 | | |
| 15.5 | 1.128226-815.3 | 1.395036-815.1 | 1.725207-8 | | |
| 14.9 | 2.133857-814.7 | 2.639730-814.5 | 3.266070-8 | | |
| 14.3 | 4.041712-814.1 | 5.002429-813.9 | 6.192620-8 | | |
| 13.7 | 7.667396-813.5 | 9.495188-813.3 | 1.176099-7 | | |
| 13.1 | 1.457038-712.9 | 1.805459-712.7 | 2.237673-7 | | |
| 12.5 | 2.773962-712.3 | 3.439555-712.1 | 4.265844-7 | | |
| 11.9 | 5.291900-711.7 | 6.566376-711.5 | 8.149873-7 | | |
| 11.3 | 1.011790-611.1 | 1.256460-610.9 | 1.560735-6 | | |

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10.7      1.939263-610.5      2.410323-610.3      2.996747-6
10.1      3.727057-69.9       4.636905-69.7       5.770885-6
9.5       7.184799-69.3       8.948516-69.1       1.114958-5
8.9       1.389772-58.7       1.733064-58.5       2.162117-5
8.3       2.698647-58.1       3.369957-57.9       4.210407-5
7.7       5.263270-57.5       6.583100-57.3       8.238736-5
7.1       1.031714-46.9       1.292828-46.7       1.621140-4
6.5       2.034301-46.3       2.554717-46.1       3.210873-4
5.9       4.039038-45.7       5.085468-45.5       6.409264-4
5.3       8.086087-45.1       1.021300-34.9       1.291484-3
4.7       1.635249-34.5       2.073400-34.3       2.632911-3
4.1       3.348879-33.9       4.267142-33.7       5.447820-3
3.5       6.970133-33.3       8.939031-33.1       1.149440-2
2.9       1.482399-22.7       1.918183-22.5       2.491484-2
2.3       3.250214-22.1       4.261413-21.9       5.620402-2
1.7       7.465402-21.5       1.000185-11.3       1.354488-1
1.1       1.859867-1.9        2.601839-1.7        3.737688-1
 .5       5.597736-1.3        9.056767-1       1.-11.822924
      7.-22.150838        4.-22.681264        1.-24.037930
      7.-34.391617        4.-34.948241        1.-36.331539
      7.-46.687914        4.-47.247230        1.-48.633225
      7.-58.989869        4.-59.549455        1.-51.093572+1
      7.-61.129239+1      4.-61.185200+1      1.-61.323830+1
      7.-71.359497+1      4.-71.415459+1      1.-71.554088+1
      7.-81.589755+1      4.-81.645717+1      1.-81.784346+1
      7.-91.820014+1      4.-91.875976+1      1.-92.014605+1
     7.-102.050272+1     4.-102.106234+1     1.-102.244863+1
     7.-112.280531+1     4.-112.336493+1     1.-112.475122+1
ELECTRON MONTE CARLO FOR 3 MEV OF LEAD AND INITIAL ANGLE OF 0 DEG
SPECIFY        SPECIFY        BREMTRANS          1.      1000      1000
3.
0.
         1
LEAD        1.6        15.        207.21     82.        .01
         2
.8        1.6
.095       81536047153
        25
0.        0.        0.        .01        .000893    7.29       .02
.00251    4.87      .03       .00497     3.78       .04        .00778
```

| | | | | | | |
|---|---|---|---|---|---|---|
| 3.16 | .05 | .0113 | 2.74 | .06 | .0151 | 2.45 |
| .07 | .0194 | 2.24 | .08 | .0240 | 2.07 | .09 |
| .0291 | 1.93 | .10 | .0343 | 1.82 | .15 | .0652 |
| 1.48 | .20 | .101 | 1.30 | .25 | .142 | 1.19 |
| .30 | .185 | 1.13 | .35 | .230 | 1.08 | .40 |
| .277 | 1.04 | .45 | .326 | 1.02 | .50 | .375 |
| 1.00 | .55 | .426 | .989 | .60 | .476 | .979 |
| .65 | .528 | .972 | .70 | .579 | .966 | .75 |
| .631 | .963 | .80 | .683 | .960 | | |

10

| | | | | | | |
|---|---|---|---|---|---|---|
| .3 | .6 | .9 | 1.2 | 1.5 | 1.8 | 2.1 |
| 2.4 | 2.7 | 3. | | | | |

7

| | | | | | | |
|---|---|---|---|---|---|---|
| 15. | 30. | 45. | 60. | 75. | 90. | 180. |

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SAMPLE PROBLEM

ELECTRON MONTE CARLO FOR 3 MEV OF LEAD AND INITIAL ANGLE OF 0 DEG 1000HISTORIES

ELECTRON MONTE CARLO TRANSMISSION DISTRIBUTION

INITIAL ENERGY SPECIFIED TO BE 3.000000E 00 MEV.

INITIAL ANGLE OF INCIDENCE SPECIFIED TO BE 0. DEGREES

DELTA T= 0.0950

SHIELD CONSISTS OF 1 SLABS

SLAB 1 IS LEAD OF THICKNESS 1.600000E 00 GM./CM**2
TRANSMISSION DISTRIBUTIONS FOR 2 CASES

CASE 1 IS A SLAB OF THICKNESS 8.000000E-01 GM./CM**2

CASE 2 IS A SLAB OF THICKNESS 1.600000E 00 GM./CM**2

TRANSMISSION DISTRIBUTION FOR CASE 1 WITH SLAB OF THICKNESS 8.000000E-01 GM./CM**2

TRANSMISSION ANGLE

| | 15.00 | | 30.00 | | 45.00 | | 60.00 | | 75.00 | |
|---|---|---|---|---|---|---|---|---|---|---|
| ENERGY | N | E | N | E | N | E | N | E | N | E |
| 0.300 | 4 | 0.73 | 5 | 0.83 | 7 | 1.25 | 3 | 0.50 | 1 | 0.21 |
| 0.600 | 1 | 0.44 | 3 | 1.59 | 5 | 2.85 | 5 | 2.18 | 1 | 0.33 |
| 0.900 | 4 | 3.16 | 7 | 5.02 | 4 | 2.93 | 8 | 6.15 | 6 | 4.83 |
| 1.200 | 5 | 5.50 | 3 | 3.05 | 6 | 6.43 | 8 | 8.19 | 8 | 8.41 |
| 1.500 | 6 | 8.34 | 14 | 18.15 | 10 | 13.35 | 13 | 18.28 | 5 | 6.93 |
| 1.800 | 3 | 5.00 | 9 | 15.02 | 11 | 17.70 | 20 | 33.45 | 8 | 13.44 |
| 2.100 | 9 | 17.80 | 19 | 36.79 | 31 | 61.08 | 20 | 39.47 | 6 | 12.08 |
| 2.400 | 6 | 13.17 | 17 | 36.84 | 7 | 14.99 | 6 | 12.98 | 5 | 10.80 |
| 2.700 | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. |
| 3.000 | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. |
| TOTALS | 38 | 54.13 | 77 | 117.30 | 81 | 120.59 | 83 | 121.20 | 40 | 57.03 |

TRANSMISSION ANGLE

| | 90.00 | | 180.00 | |
|---|---|---|---|---|
| ENERGY | N | E | N | E |
| 0.300 | 1 | 0.05 | 0 | 0. |
| 0.600 | 1 | 0.57 | 0 | 0. |
| 0.900 | 1 | 0.66 | 0 | 0. |
| 1.200 | 1 | 1.06 | 0 | 0. |
| 1.500 | 1 | 1.46 | 0 | 0. |
| 1.800 | 3 | 5.13 | 0 | 0. |
| 2.100 | 6 | 11.77 | 0 | 0. |
| 2.400 | 0 | 0. | 0 | 0. |
| 2.700 | 0 | 0. | 0 | 0. |
| 3.000 | 0 | 0. | 0 | 0. |
| TOTALS | 14 | 20.71 | 0 | 0. |

TOTAL TRANSMITTED = 333

TRANSMISSION DISTRIBUTION FOR CASE 2 WITH SLAB OF THICKNESS 1.600000E 00 GM./CM**2

TRANSMISSION ANGLE

| | 15.00 | | 30.00 | | 45.00 | | 60.00 | | 75.00 | |
|---|---|---|---|---|---|---|---|---|---|---|
| ENERGY | N | E | N | E | N | E | N | E | N | E |
| 0.300 | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. | 1 | 0.14 |
| 0.600 | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. |
| 0.900 | 0 | 0. | 0 | 0. | 0 | 0. | 1 | 0.81 | 0 | 0. |
| 1.200 | 1 | 0.96 | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. |
| 1.500 | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. |
| 1.800 | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. |
| 2.100 | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. |
| 2.400 | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. |
| 2.700 | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. |
| 3.000 | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. | 0 | 0. |
| TOTALS | 1 | 0.96 | 0 | 0. | 0 | 0. | 1 | 0.81 | 1 | 0.14 |

TRANSMISSION ANGLE

| | 90.00 | | 180.00 | |
|---|---|---|---|---|
| ENERGY | N | E | N | E |
| 0.300 | 0 | 0. | 11 | 1.39 |
| 0.600 | 0 | 0. | 11 | 5.31 |
| 0.900 | 0 | 0. | 25 | 18.51 |
| 1.200 | 0 | 0. | 31 | 33.05 |
| 1.500 | 0 | 0. | 35 | 47.27 |
| 1.800 | 0 | 0. | 42 | 69.76 |
| 2.100 | 0 | 0. | 30 | 58.78 |
| 2.400 | 0 | 0. | 26 | 58.07 |
| 2.700 | 0 | 0. | 20 | 50.18 |
| 3.000 | 0 | 0. | 9 | 25.22 |
| TOTALS | 0 | 0. | 240 | 367.54 |

TOTAL TRANSMITTED = 243

AVERAGE TRANSMISSION COSINES

| THICKNESS | COSINE | THICKNESS | COSINE |
|---|---|---|---|
| 0.800000E 00 | 0.723862E 00 | 0.160000E 01 | 0.661921E 00 |

ELECTRON MONTE CARLO RADIATION ENERGY LOSS DISTRIBUTION

ENERGY (MEV.)

| REGION | 0.300 | 0.600 | 0.900 | 1.200 | 1.500 | 1.800 |
|---|---|---|---|---|---|---|
| 1 | 723 | 33 | 15 | 5 | 3 | 4 |
| 2 | 947 | 37 | 24 | 9 | 8 | 2 |
| 3 | 1086 | 38 | 20 | 13 | 12 | 4 |
| 4 | 1217 | 47 | 14 | 12 | 4 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | 1166 | 33 | 14 | 13 | 7 | 4 |
| 6 | 930 | 29 | 14 | 6 | 3 | 2 |
| 7 | 753 | 25 | 9 | 4 | 5 | 1 |
| 8 | 594 | 11 | 7 | 4 | 2 | 0 |
| 9 | 427 | 10 | 3 | 2 | 1 | 0 |
| 10 | 310 | 5 | 2 | 0 | 0 | 0 |
| 11 | 161 | 2 | 3 | 0 | 0 | 0 |
| 12 | 105 | 2 | 0 | 1 | 0 | 0 |
| 13 | 64 | 0 | 0 | 1 | 0 | 0 |
| 14 | 26 | 2 | 0 | 0 | 0 | 0 |
| 15 | 13 | 0 | 0 | 0 | 0 | 0 |

ENERGY (MEV.)

| REGION | 2.100 | 2.400 | 2.700 | 3.000 |
|---|---|---|---|---|
| 1 | 2 | 3 | 0 | 1 |
| 2 | 2 | 3 | 3 | 0 |
| 3 | 9 | 1 | 0 | 0 |
| 4 | 3 | 1 | 1 | 0 |
| 5 | 3 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 |
| 7 | 1 | 0 | 0 | 0 |
| 8 | 1 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0 |

## REFERENCES


1. Nelms, A. T., "Energy Loss and Range of Electrons and Positrons", NBS Circular 577, U. S. Government Printing Office, Washington, D.C., 1956.

2. Leiss, J. F., Penner, S., and Robinson, L. S., "Range-Straggling of High-Energy Electrons in Carbon", Phys. Rev. 107, 1544 (1962).

3. Perkins, J. F., "Monte Carlo Calculation of Transport of Fast Electrons", Phys. Rev. 126, 1781 (1962).

4. Bethe, H. A., and Heitler, W., Proc. Roy. Soc., A146, 83 (1934).

5. Bethe, H. A., Phys. Rev. 89, 1256 (1953).

6. Katz, L., and Penfold, A. S., "Range-Energy Relations for Electrons and the Determination of Beta-Ray End-Point Energies by Absorption", Rev. of Mod. Phys. 24, 28 (1952).

7. Wright, K. A., and Trump, J. G., "Backscattering of Megavolt Electrons from Thick Targets", J. of Appl. Phys. 33, 687 (1962).