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OPTIMUM TARGET ORIENTATION IN NUCLEAR REACTION EXPERIMENTS

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SUMMARY

The conditions are examined under which the energy spread in outgoing particles from a nuclear reaction due to finite target thickness is minimized. Physical restrictions on the angle of incidence and emission are explicitly considered, and it is shown that the minimum in energy spread does not always occur at the limits. Targets are considered both in transmission and in reflection. A FORTRAN IV program embodying these results is described. The program determines the optimum target angle for each of a sequence of angles of observation and calculates the energy spread.

INTRODUCTION

In the measurement of high resolution spectra of charged particles from nuclear reactions, it is of interest not only to minimize all energy spreads (raw beam, kinematic effects, and target thickness effects) contributed by the various experimental arrangements but to have a knowledge of how these energy spreads vary over the spectrum. This report is concerned with the effects of finite target thickness. The existence of a target of finite thickness can introduce a spread into the energies of the outgoing particles because the reactions can occur at any depth within the target and both the incident and the outgoing particles lose some energy in traversing the target. In the general case these particles lose energy at different rates. Cohen (ref. 1) has considered this matter and shown that it is possible to reduce this energy spread to zero by choosing the angle with respect to the incident beam at which the target is mounted. Rosenblatt (ref. 2) and Naquib and McDaniels (ref. 3) have pointed out that Cohen ignored the effect on the outgoing particle energy of the change in the energy of the incident particle, and they gave expressions for the proper angle that include this contribution.

As part of an effort to produce a family of computer programs that would be useful in the design and analysis of experiments this matter was considered again. The previous discussions considered the target to be in transmission only; that is, the incident and outgoing particles pass through opposite faces of the target. For completeness, the case when the target is in reflection, that is, the incident and outgoing particles pass through the same face of the target, is also considered.

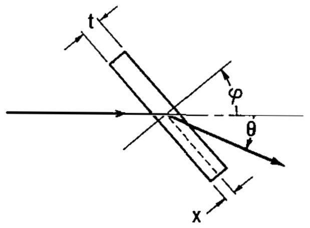


Figure 1. - Physical arrangement for target in transmission.

TARGET IN TRANSMISSION

Throughout this discussion the incident particle will be numbered 1, the target particle 2, the observed particle 3, and the residual particle 4. Let φ be the angle that the normal to the target makes with the beam direction and let θ be the angle at which the outgoing particle is observed. The sign of φ shall be positive when the target normal and the direction of observation are on the same side of the beam line. The target has a thickness t, and x is the normal distance into the target to the point where the reaction occurs as shown in figure 1. Then, as shown in reference 2, the expression for the difference in energy of the outgoing particle from that resulting from the same reaction in an ideally thin target is given by

$$\Delta E_3 = \frac{dE_3}{dx} \frac{t - x}{\cos(\theta - \varphi)} + \left(\frac{\partial E_3}{\partial E_1}\right)_\theta \frac{dE_1}{dx} \frac{x}{\cos \varphi} \tag{1}$$

which can be separated into a constant term and one dependent on x (E's are energies). The constant term does not contribute to the spread in outgoing energies for reactions that occur at different x. The term dependent on x is

$$x\left[\left(\frac{\partial E_3}{\partial E_1}\right)_\theta \frac{dE_1}{dx} \frac{1}{\cos \varphi} - \frac{dE_3}{dx} \frac{1}{\cos(\varphi - \theta)}\right] \tag{2}$$

The maximum difference in outgoing energies (δE_3) occurs between events that take place on the front surface (x = 0) and those that take place on the back surface (x = t) and is given by

$$\delta E_3 = t \frac{dE_1}{dx}\left(\frac{\partial E_3}{\partial E_1}\right)_\theta \left[\frac{1}{\cos \varphi} - \frac{F}{\cos(\theta - \varphi)}\right] \tag{3}$$

where

$$F \equiv \frac{\dfrac{dE_3}{dx}}{\dfrac{dE_1}{dx}\left(\dfrac{\partial E_3}{\partial E_1}\right)_\theta}$$

It is possible to make δE_3 equal to zero by choosing φ such that

$$F \cos \varphi = \cos(\theta - \varphi) \tag{4}$$

However, for large values of F and/or small values of θ, this expression yields nonphysical values of φ.

In any experimental arrangement there are physical limits to the angle that either the incident or observed particles can make with the normal to the target, either because of the design of the target mount or because of errors due to target flatness and nonuniformity. Thus for one reason or another there are maximum values for φ and $\theta - \varphi$, and when the φ given by equation (4) is greater than this value Φ, then the problem becomes a minimization one. The naive conclusion that the minimum occurs at this physical maximum angle Φ is not correct for all values of F.

It is useful to make a change in variables at this point. Let $\varphi = \theta/2 + \delta$ so that

$$\delta E_3 = A\left[\frac{1}{\cos\left(\dfrac{\theta}{2} + \delta\right)} - \frac{F}{\cos\left(\dfrac{\theta}{2} - \delta\right)}\right] \tag{5}$$

where

$$A = t\,\frac{dE_1}{dx}\left(\frac{\partial E_3}{\partial E_1}\right)_\theta$$

Equation (5) is used for $F > 1$; for $F < 1$, it is convenient to write δE_3 as

$$\delta E_3 = B\left[\frac{G}{\cos\left(\dfrac{\theta}{2} + \delta\right)} - \frac{1}{\cos\left(\dfrac{\theta}{2} - \delta\right)}\right] \tag{6}$$

where $G = 1/F$ and $B = t\, dE_3/dx$. The behavior of equation (6) as a one parameter family of curves on G is the same for negative (positive) values of δ as the behavior of

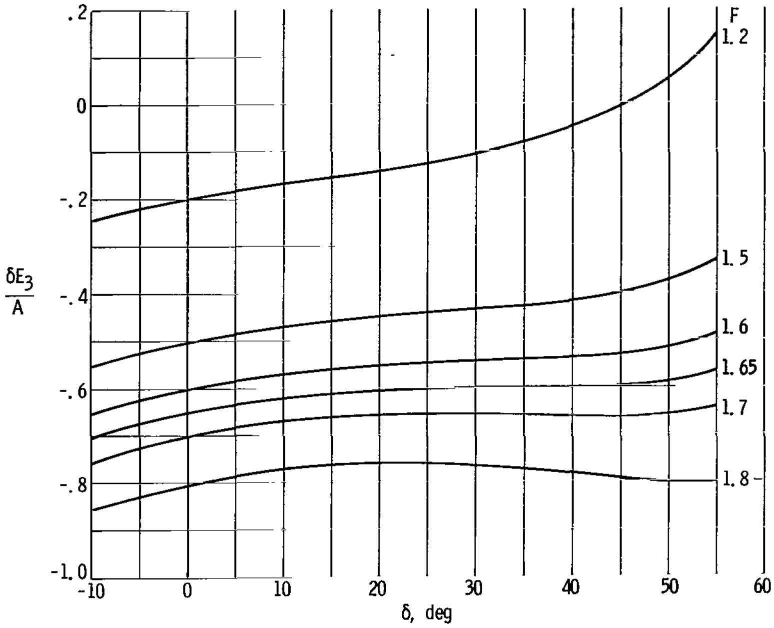


Figure 2. - $\delta E_3/A$ as function of δ for $\theta = 10°$.

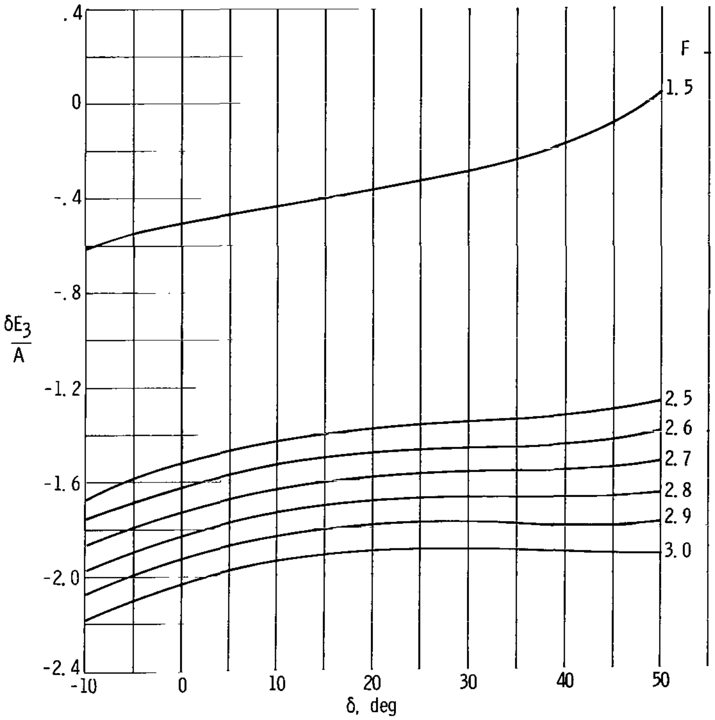


Figure 3. - $\delta E_3/A$ as function of δ for $\theta = 20°$.

equation (5) on F for positive (negative) values of δ. The following discussion is therefore limited to values of $F > 1$.

Figure 2 shows the results of calculations of $\delta E_3/A$ for $\theta = 10^\circ$ and several values of F. It is assumed that the physical design of the target holder sets $\Phi = 60^\circ$ so that δ is limited to 55°. It is seen that as F increases from 1.5 to 1.8 the minimum of $|\delta E_3/A|$ shifts from the physical maximum angle to a smaller angle.

Figure 3 shows a similar plot for $\theta = 20^\circ$. The same type of behavior is seen with the inflection point now occurring for $F \sim 2.8$. As θ increases, the inflection point moves out slowly from a δ value of 35°; thus, for θ in excess of some Θ (44° for the case of $\Phi = 60^\circ$, see eq. (11)), even the inflection point is in the nonphysical region. Thus for $\theta < \Theta$ there are three regions for F: for values of F less than some F', δE_3 can be made zero; for intermediate values, the minimum value of δE_3 is obtained at the physical maximum angle; and at values larger than some F'', the minimum value of δE_3 is found at a smaller angle. For $\theta > \Theta$, there are only the first two of the previous regions. Because of a preference for small angles of incidence or emission the optimum point is chosen at the internal minimum as soon as it develops.

The value of F' is obtained by setting $\theta/2 + \delta$ equal to Φ:

$$F' = \frac{\cos(\theta - \Phi)}{\cos \Phi}$$

To obtain F'', the point of inflection is determined. In expanded form equation (5) is written as

$$\delta E_3 = A\left(\cos \delta \cos \frac{\theta}{2} + \sin \delta \sin \frac{\theta}{2} - F \cos \delta \cos \frac{\theta}{2} + F \sin \delta \sin \frac{\theta}{2}\right)$$

$$\times \left[\left(\cos \delta \cos \frac{\theta}{2} + \sin \delta \sin \frac{\theta}{2}\right)\left(\cos \delta \cos \frac{\theta}{2} - \sin \delta \sin \frac{\theta}{2}\right)\right]^{-1} = A \times \frac{C}{D} \qquad (7)$$

The partial derivative of δE_3 with respect to δ is found to be

$$\frac{\partial(\delta E_3)}{\partial \delta} = \left[(1 + F)\cos \delta \sin \frac{\theta}{2}\left(\cos^2\delta \cos^2 \frac{\theta}{2} - \sin^2\delta \sin^2 \frac{\theta}{2} + 2 \sin^2\delta\right)\right.$$

$$\left. - (1 - F)\sin \delta \cos \frac{\theta}{2}\left(\cos^2\delta \cos^2 \frac{\theta}{2} - \sin^2\delta \sin^2 \frac{\theta}{2} - 2 \cos^2\delta\right)\right] \Big/ D^2 \qquad (8)$$

Setting equation (8) equal to zero yields

$$\tan \delta = \frac{\frac{1 + F}{1 - F} \tan \frac{\theta}{2}}{1 - \frac{2}{\cos^2 \frac{\theta}{2} + \sin^2 \delta}} \tag{9}$$

as a condition for an extremum.

For this extremum to be an inflection point, the value of the second derivative must be zero. The first derivative is of the form X/Y and since we are interested in the value of the second derivature at an extremum, the nonzero part of the second derivative is $(\partial X/\partial \delta)/Y$. The first derivative is given schematically by

$$\frac{\partial \delta E_3}{\partial \delta} = \frac{D \frac{\partial C}{\partial \delta} - C \frac{\partial D}{\partial \delta}}{D^2}$$

so that the nonzero part of the second derivative is

$$\frac{D \frac{\partial^2 C}{\partial \delta^2} - C \frac{\partial^2 D}{\partial \delta^2}}{D^2}$$

Now C contains δ only in first-power trigonometric functions so that $\partial^2 C/\partial \delta^2 = -C$, and in addition, C is nonzero in our range of interest. Thus the value of δ for which the extremum is an inflection point is obtained from

$$D + \frac{\partial^2 D}{\partial \delta^2} = 0$$

This is found to give

$$\tan^2 \delta = \frac{1 + \sin^2 \frac{\theta}{2}}{1 + \cos^2 \frac{\theta}{2}} \tag{10}$$

The F'' is determined from equation (9) when the δ value obtained from equation (10) is used. The Θ is defined by

$$\tan^2\left(\Phi - \frac{\Theta}{2}\right) = \frac{1 + \sin^2\frac{\Theta}{2}}{1 + \cos^2\frac{\Theta}{2}} \qquad (11)$$

Similar expressions are obtained from equation (6) when $F < 1$.

TARGET IN REFLECTION

In some cases it becomes necessary to observe with the target in reflection. The physical arrangement is shown in figure 4. For this definition of angles, δE_3 is again given by equation (3). Let

$$\varphi = -\left[\frac{1}{2}(180^{\circ} - \theta) + \delta\right] = \frac{\theta}{2} - \delta + 90^{\circ}$$

Then

$$\delta E_3 = A\left[\frac{1}{\sin\left(\frac{\theta}{2} - \delta\right)} + \frac{F}{\sin\left(\frac{\theta}{2} + \delta\right)}\right] \qquad (12)$$

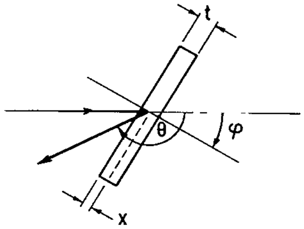


Figure 4. - Physical arrangement for target in reflection.

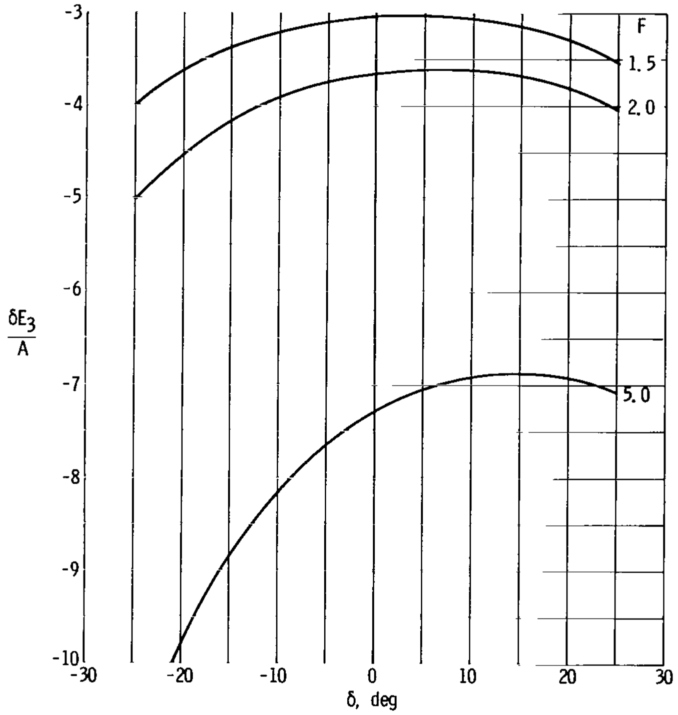


Figure 5. - $\delta E_3/A$ as function of δ for θ = 110°.

Physical arguments indicate that the normal to the target should lie between the incident beam and the detector, being closer to whichever beam consists of the particles with the larger value of dE/dx. Figure 5 shows $\delta E_3/A$ from equation (12) plotted for $\theta = 110^{\circ}$ and several values of F. The improvement in δE_3 made by choosing the minimum point rather than the half-angle position decreases as θ increases from 90° to 180°. For $F = 5$, it amounts to 6.5 percent at 110° and 0.15 percent at 160°. Thus, in general, the choice of $\delta = 0$ is quite acceptable. For completeness, the value of δ at the minimum of $|\delta E_3/A|$ is given by

$$\tan \delta = \left(\frac{1 - F}{1 + F} \cot \frac{\theta}{2}\right)\left(1 - \frac{2}{\cos^2 \frac{\theta}{2} + \cos^2 \delta}\right) \qquad (13)$$

PROGRAM DESCRIPTION

The program consists of a main program ANGOPT plus with several subroutines; one of which, ANGMIN, performs the minimization described previously. At any one detector angle a range of excitation energies in the residual nucleus is viewed, and the target angle can be optimized for only one value within this range. Further, it is often the case that there is more than one region where optimum resolution is needed. Therefore, it was decided to calculate the optimum target angle for two values of excitation energy E^* and, in addition, to calculate the energy spread for these two angles at several other excitation energies.

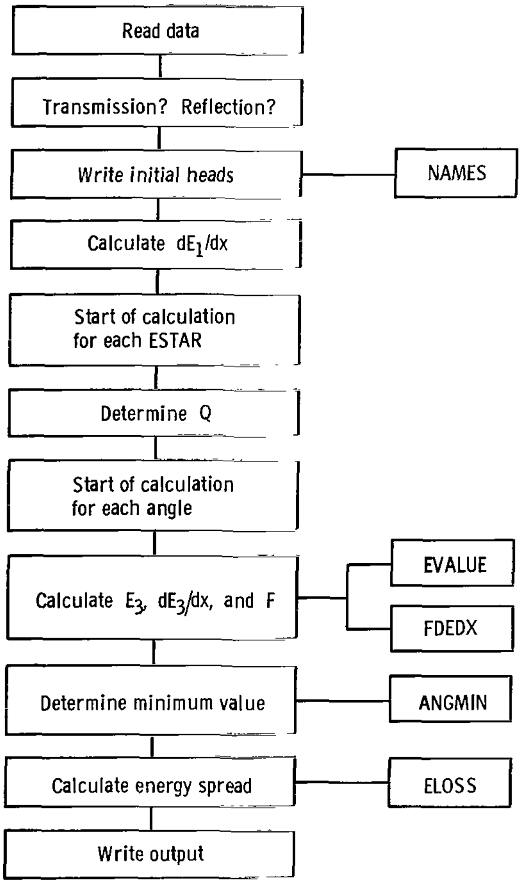


Figure 6. - Operational block diagram of ANGOPT.

An operational block diagram of ANGOPT is shown in figure 6. The major complexity is concerned with the logic used to determine whether the target is in transmission or reflection. The evaluation of $\partial E_3/\partial E_1$ is performed by using equation (5) of reference 2, which is in convenient form for machine calculation. For reflection, the choice of $\delta = 0$ is taken so that in this case ANGMIN is bypassed and φ set to be $-(180 - \theta)/2$. Listings of all the programs are given in appendix A.

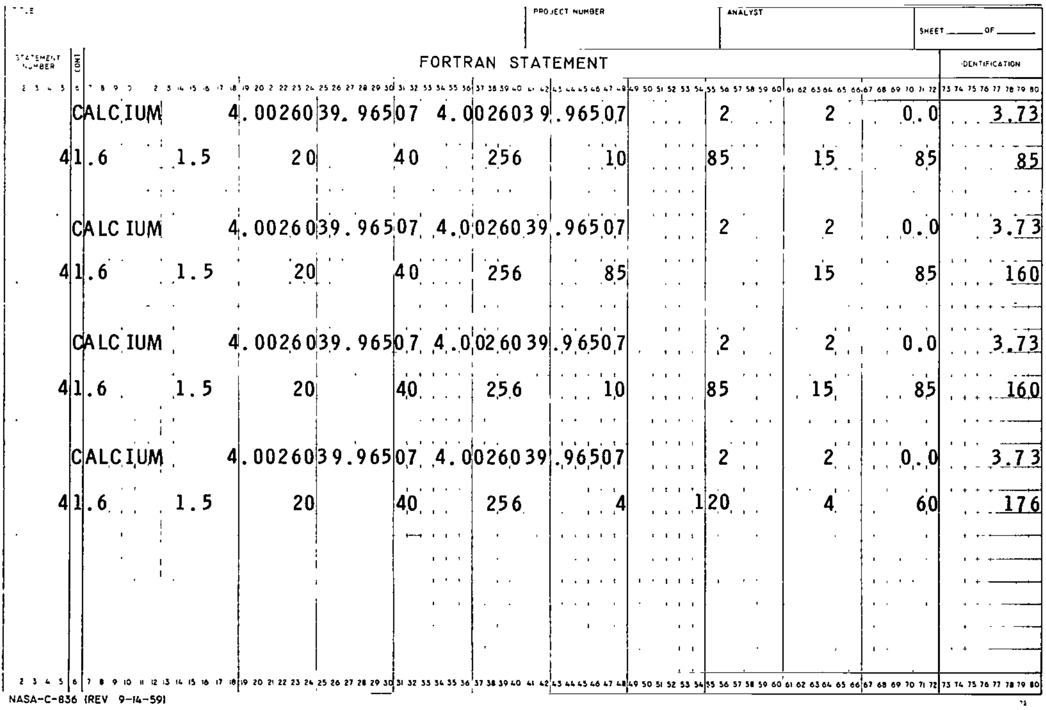
Program Input and Options

The input data cards are described in table I, and the input for four test cases is shown in figure 7. The mean ionization potential ABI can be obtained from reference 4.

The program can be used to calculate either in transmission, reflection, or both by suitable choices of the angles. The values of the angles have the following restrictions:

TABLE I. - DATA INPUT DESCRIPTION

Card	Quality	Format	Input
1	TITLE	2A6	Element name of target
	M1	F8.0	Incident particle mass, amu
	M2	↓	Target particle mass, amu
	M3		Observed particle mass, amu
	M4		Residual particle mass, amu
	Z1		Incident particle charge
	E*(1)		Excitation energy 1, MeV
	E*(2)		Excitation energy 2, MeV
2	EO		Incident energy, MeV
	ABS		Absorber thickness, mg cm^{-2}
	ABZ		Absorber Z
	ABA		Absorber A
	ABI		Mean ionization potential, eV
	THETAO		Initial angle, deg
	THETAT		Maximum angle in transmission, deg
	DTHETA		Angle increment, deg
	THETAR		Lowest angle in reflection, deg
	THETAM		Maximum angle, deg



```
CASE
I    CALCIUM      4.0026039.96507 4.0026039.96507          2        2      0.0     3.73
        41.6    1.5      20      40     256      10       85       15       85       85

II   CALCIUM      4.0026039.96507 4.0026039.96507          2        2      0.0     3.73
        41.6    1.5      20      40     256      85                15       85      160

III  CALCIUM      4.0026039.96507 4.0026039.96507          2        2      0.0     3.73
        41.6    1.5      20      40     256      10       85       15       85      160

IV   CALCIUM      4.0026039.96507 4.0026039.96507          2        2      0.0     3.73
        41.6    1.5      20      40     256       4     1 20        4       60      176
```

Figure 7. - Facsimile of input for test data.

(1) For transmission only:

$\text{THETAO} > 1^{\circ}$

$\text{THETAM} = \text{THETAT}$

(2) For reflection only:

$\text{THETAO} = \text{THETAR} > 1^{\circ}$

(3) For transmission and reflection:

$\text{THETAO} > 1^{\circ}$

$\text{THETAR} \gtreqless \text{THETAT}$

$\text{THETAT} < \text{THETAM}$

Program Output

The output for the input data of figure 7 is shown in appendix B. The heading of the output gives the important description of the physical situation, that is, target in transmission or reflection, target material, incident and observed particles named, and the two values of excitation energies for which φ is optimized. In addition, the input masses, the incident energy, and the absorber thickness are written out.

For each detector angle two target angles are given, one for each of the two input values of E^*. Then for each detector angle the spread in energy for the input E^* and for $E^* = 0$, 5, 10, 15, and 20 million electron volts is given.

Subprograms

ANGMIN function. - This subroutine calculates the value of φ to give the minimum value of energy spread subject to the constraints discussed. It is entered with a value of F and θ and returns $\theta/2 + \delta$ to the calling program. It is written for $\Phi = 60^{\circ}$ and $\Theta = 44^{\circ}$. Equation (9) is solved in an iterative manner with the first choice of δ taken as

$$\delta = \tan^{-1}\left(\frac{F + 1}{F - 1} \tan \frac{\theta}{2}\right)$$

Iteration is stopped when the change in δ is less than 0.001 radian.

ELOSS subroutine. - This subroutine calculates values of δE_3 from equation (3) for the input value of E^* and for E^* values of 0, 5, 10, 15, and 20 million electron volts by using the angle that is optimum for the input E^*. If the sequence of E^* values at a given angle leads to a nonphysical situation, then the energy spread for that and subsequent E* values is set to zero.

FDEDX function. - This subroutine evaluates the Bethe equation for the rate of energy loss without consideration of shell correction:

$$-\frac{dE}{dx} = (3.071\times 10^{-4})\,\frac{z^2 Z}{\beta^2 A}\left[\ln\left(\frac{1.022\times 10^{0}}{1-\beta^2}\right)\frac{\beta^2}{I} - \beta^2\right]$$

where z is the charge of the particle, Z is the atomic number of the stopping material, A is the atomic weight of the stopping material, I is the mean ionization potential of the stopping material in electron volts, and β is the velocity of the particle in units of the velocity of light.

EVALUE function. - The nonrelativistic form of the energy equation is evaluated:

$$E_3 = \left[B\cos\theta \pm \left(A - B^2\sin^2\theta\right)^{1/2}\right]^2$$

where

$$A = \frac{M_4\left[E_1\left(1 - \frac{M_1}{M_3 + M_4}\right) + Q\right]}{M_3 + M_4}$$

$$B = \frac{(M_3 M_1 E_1)^{1/2}}{M_3 + M_4}$$

The M's are the masses, the E's are energies, and Q is the difference between the total kinetic energy before and after the collision. This subroutine is due to J. B. Ball of reference 5.

NAMES subroutine. - This subroutine identifies a light nuclear particle given the mass number and charge. It is a FORTRAN IV version of NAMER due to J. B. Ball of reference 5.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, August 31, 1965.

APPENDIX A

PROGRAM LISTINGS

```
C     ANGOPT
      DIMENSION DEL(2,6,400),TANG(2,400),ANGLAB(400),DELE(6),ESTAR(2),Q(
     12),TITLE(2)
   10 READ  (5,190) TITLE,W1,W2,W3,W4,Z1,Z3,ESTAR(1),ESTAR(2),E0,ABS,ABZ
     1,ABA,ABI,THETAO,THETAT,DTHETA,THETAR,THETAM
      WRITE (6,191)
      IF (THETAO-THETAR) 15,20,20
   15 WRITE (6,192)
      ASSIGN 35 TO MO
      GO TO 25
   20 WRITE (6,193)
      ASSIGN 45 TO MO
   25 MTEST=W1+0.002
      IZ=Z1
      CALL NAMES(MTEST,IZ,IA,IB)
      MTEST=W3+0.002
      IZ=Z3
      CALL NAMES(MTEST,IZ,IC,ID)
      WRITE (6,194) TITLE,IA,IB,IC,ID,ESTAR(1),ESTAR(2)
      WRITE (6,195) W1,W2,W3,W4,E0,ABS
      DEDX0=FDEDX(Z1,W1,E0,ABZ,ABA,ABI)
      KK=0
      DO 80 I=1,2
      ASSIGN 85 TO MA
      ASSIGN 10 TO MB
      J=1
      ANGLAB(J)=THETAO
      Q(I)=(W1+W2-W3-W4)*931.44-ESTAR(I)
   30 E=EVALUE(W1,W3,W4,E0,Q(I),ANGLAB(J))
      DEDX=FDEDX(Z3,W3,E,ABZ,ABA,ABI)
      F=DEDX/(DEDX0*(E/E0)*(((W3+W4)*E+(W4-W1)*E0-W4*Q(I))/((W3+W4)*E+(W
     14-W1)*E0+W4*Q(I))))
      GO TO MO,(35,45)
   35 TANG(I,J)=ANGMIN(ANGLAB(J),F)
      CALL ELOSS(ANGLAB(J),TANG(I,J),E0,Q(I),ABS,ABZ,ABA,ABI,W1,W2,W3,W4
     1,Z3,DEDX0,DEDX,E,DELE)
      DO 40 MN=1,6
   40 DEL(I,MN,J)=DELE(MN)
      J=J+1
      K=J-1
      ANGLAB(J)=ANGLAB(K)+DTHETA
      IF(THETAT-ANGLAB(J)) 55,30,30
   45 TANG(I,J)=-(180.-ANGLAB(J))/2.
      CALL ELOSS(ANGLAB(J),TANG(I,J),E0,Q(I),ABS,ABZ,ABA,ABI,W1,W2,W3,W4
     1,Z3,DEDX0,DEDX,E,DELE)
      DO 50 MN=1,6
   50 DEL(I,MN,J)=DELE(MN)
      J=J+1
      K=J-1
      ANGLAB(J)=ANGLAB(K)+DTHETA
      IF (THETAM-ANGLAB(J)) 65,30,30
   55 IF (THETAT-THETAM) 60,65,65
   60 KK=K
      ASSIGN 120 TO MA
      ASSIGN 125 TO MB
      ANGLAB(J)=THETAR
      ASSIGN 45 TO MO
      GO TO 30
   65 IF(THETAO-THETAR) 70,75,75
   70 ASSIGN 35 TO MO
      GO TO 80
```

```
 75 ASSIGN 45 TO MO
 80 CONTINUE
    KL=K-KK
    M=0
    LSTOP=0
    MM=0
    GO TO MA,(85,120)
 85 ASSIGN 105 TO MC
 90 LSTART=LSTOP+1
    IF(K-13) 95,95,10
 95 LSTOP=K+M+MM
    WRITE  (6,196)(ANGLAB(LINE),(TANG(I,LINE),(DEL(I,JK,LINE),JK=1,6)
   1,I=1,2),LINE=LSTART,LSTOP)
    GO TO MB,(10,125)
100 GO TO MC,(105,110)
105 LSTOP=13+M
    K=K-13
    MM=13
    ASSIGN 110 TO MC
    GO TO 115
110 LSTOP=LSTART+13
    K=K-14
    MM=MM+14
115 WRITE  (6,196)(ANGLAB(LINE),(TANG(I,LINE),(DEL(I,JK,LINE),JK=1,6)
   1,I=1,2),LINE=LSTART,LSTOP)
    WRITE (6,197) TITLE,IA,IB,IC,ID,ESTAR(1),ESTAR(2)
    GO TO 90
120 K=KK
    GO TO 85
125 K=KL
    M=KK
    LSTOP=M
    ASSIGN 10 TO MB
    WRITE (6,191)
    WRITE (6,193)
    WRITE (6,194) TITLE,IA,IB,IC,ID,ESTAR(1),ESTAR(2)
    WRITE (6,195) W1,W2,W3,W4,E0,ABS
    GO TO 85
190 FORMAT(4X2A6,8F8.0/10F8.0)
191 FORMAT(53H1 OPTIMUM ANGLE FOR TARGET TO MINIMIZE ENERGY SPREAD )
192 FORMAT(1H+,54X22HTARGET IN TRANSMISSION)
193 FORMAT(1H+,54X20HTARGET IN REFLECTION)
194 FORMAT(13H0 TARGET IS  ,2A6,25H  INCIDENT PARTICLES ARE  ,A6,A3,25
   1H, OBSERVED PARTICLES ARE ,A6,A3,8H ESTAR1=,F7.3,8H ESTAR2=,F7.3)
195 FORMAT(5H0 M1=F7.5,5X3HM2=F8.4,5X3HM3=F7.5,5X3HM4=F8.4,5X3HE0=F5.2
   1,3HMEV,5X4HABS=F5.2,8HMG/CM**2)
196 FORMAT(2H0 ,5X8HDETECTOR,6X6HTARGET,42X13HENERGY SPREAD/9X5HANGLE,
   18X5HANGLE,15X7HOPTIMUM,7X4HE*=0,8X4HE*=5,8X5HE*=10,7X5HE*=15,7X5HE
   2*=20/(1H0,2F13.2,10X6F12.4//20XF7.2,10X6F12.4))
197 FORMAT(13H1 TARGET IS  ,2A6,25H  INCIDENT PARTICLES ARE  ,A6,A3,25
   1H, OBSERVED PARTICLES ARE ,A6,A3,8H ESTAR1=,F7.3,8H ESTAR2=,F7.3)
    END
```

```
      FUNCTION ANGMIN(ANG,F)
      PHI=ANG/114.59156
      PHE=(ANG-60.)/57.29578
      PHO=ANG/57.29578
      IF(F-1.) 60,10,15
   10 ANGMIN=PHI*57.29578
      RETURN
   15 FF=COS(PHE)/COS(1.047197)
      IF(FF-F) 25,20,20
   20 PHI=ATAN((F-COS(PHO))/SIN(PHO))
      GO TO 10
   25 IF(ANG-40.) 35,30,30
   30 ANGMIN=60.
      RETURN
   35 DEL=ATAN(SQRT((1.+SIN(PHI)**2)/(1.+COS(PHI)**2)))
      A=(1.-(2./(COS(PHI)**2+SIN(DEL)**2)))*(SIN(DEL)*COS(PHI))/(SIN(PHI
     1)*COS(DEL))
      FFF=(A-1.)/(A+1.)
      IF(FFF-F) 40,30,3
   40 DOL=ATAN(((1.+F)/(F-1.))*(SIN(PHI)/COS(PHI)))
   45 DEL=ATAN((((1.+F)/(1.-F))*(SIN(PHI)/COS(PHI)))/(1.-(2./(COS(PHI)**
     12+SIN(DOL)**2))))
      DIL=DEL-DOL
      IF(DIL-0.001) 50,50,55
   50 ANGMIN=(PHI+DEL)*57.29578
      RETURN
   55 DOL=DEL
      GO TO 45
   60 G=1./F
      GG=COS(PHE)/COS(1.047197)
      IF(GG-G) 70,65,65
   65 PHI=ATAN((1.-G*COS(PHO))/(G*SIN(PHO)))
      GO TO 10
   70 IF(ANG-40.) 80,75,75
   75 ANGMIN=ANG-60.
      RETURN
   80 DEL=ATAN(-SQRT((1.+SIN(PHI)**2)/(1.+COS(PHI)**2)))
      A=(1.-(2./(COS(PHI)**2+SIN(DEL)**2)))*(SIN(DEL)*COS(PHI))/(SIN(PHI
     1)*COS(DEL))
      GGG=(A+1.)/(A-1.)
      IF(GGG-G) 85,75,75
   85 DOL=ATAN(((G+1.)/(G-1.))*(SIN(PHI)/COS(PHI)))
   90 DEL=ATAN((((G+1.)/(G-1.))*(SIN(PHI)/COS(PHI)))/(1.-(2./(COS(PHI)**
     12+SIN(DOL)**2))))
      DIL=DOL-DEL
      IF(DIL-0.001) 95,95,100
   95 ANGMIN=(PHI+DEL)*57.29578
      RETURN
  100 DOL=DEL
      GO TO 90
      END
```

```
      SUBROUTINE ELOSS(ANG,TANG,E0,Q,ABS,ABZ,ABA,ABI,W1,W2,W3,W4,Z3,DEDX
     10,DEDX,E,DELE)
      DIMENSION DELE(6)
      BANG=(ANG-TANG)/57.29578
      CANG=TANG/57.29578
      DANG=ANG/57.29578
      JK=1
      A=(E/E0)*(((W3+W4)*E+(W4-W1)*E0-W4*Q)/((W3+W4)*E+(W4-W1)*E0+W4*Q))
      DELE(JK)=ABS*((DEDX0*A/COS(CANG))-(DEDX/COS(BANG)))
      P=(W1+W2-W3-W4)*931.44
   10 JK=JK+1
      EICOM=E0*(W3+W4-W1)/(W3+W4)
      V3SQ=2.0*W4*(EICOM+P)/(W3*(W3+W4))
      VVCM=SQRT(2.0*W1*E0)/(W3+W4)
      TEST=V3SQ-((VVCM*SIN(DANG))**2)
      IF(TEST) 20,15,15
   15 F=EVALUE(W1,W3,W4,E0,P,ANG)
      A=(F/E0)*(((W3+W4)*F+(W4-W1)*E0-W4*P)/((W3+W4)*F+(W4-W1)*E0+W4*P))
      DEDY=FDEDX(Z3,W3,F,ABZ,ABA,ABI)
      DELE(JK)=ABS*((DEDX0*A/COS(CANG))-(DEDY/COS(BANG)))
      P=P-5.
      IF(JK-6) 10,25,25
   20 DELE(JK)=0.
      IF(JK-6) 10,25,25
   25 RETURN
      END
```

```
      SUBROUTINE NAMES(IM,IZ,IW,IX)
      DATA R1,R2,R3,R4,R5,R6,R7,R8,R9,R10,R11/6HPROTON,6HS     ,6HDEUTER
     1,6HONS   ,6HTRITON,6HHELIUM,6H-3    ,6HALPHAS,6H      ,6HNOT NA,6H
     2MED
      IF(IZ.EQ.1.AND.IM.EQ.1) GO TO 110
      IF(IZ.EQ.1.AND.IM.EQ.2) GO TO 111
      IF(IZ.EQ.1.AND.IM.EQ.3) GO TO 112
      IF(IZ.EQ.2.AND.IM.EQ.3) GO TO 113
      IF(IZ.EQ.2.AND.IM.EQ.4) GO TO 114
      IW=-IABS(+R10)
      IX=-IABS(+R11)
      RETURN
  110 IW=-IABS(+R1)
      IX=-IABS(+R2)
      RETURN
  111 IW=IABS(+R3)
      IX=-IABS(+R4)
      RETURN
  112 IW=-IABS(+R5)
      IX=-IABS(+R2)
      RETURN
  113 IW=IABS(+R6)
      IX=-IABS(+R7)
      RETURN
  114 IW=IABS(+R8)
      IX=-IABS(+R9)
      RETURN
      END
```

```
 FUNCTION FDEDX(PZ,PM,EINIT,ABSZ,ABSA,ABSI)
 ARG1=(3.071E-4)*(PZ**2)*ABSZ/ABSA
 ARG2=(1.022E6)/ABSI
 SQBETA=1.0-(931.44/((EINIT/PM)+931.44))**2
 FDEDX=(ARG1/SQBETA)*(ALOG(ARG2*SQBETA/(1.0-SQBETA))-SQBETA)
 RETURN
 END


 FUNCTION EVALUE(W1,W3,W4,E1,Q,ANGLAB)
 THETA=ANGLAB/57.29578
 EICOM=E1*(W3+W4-W1)/(W3+W4)
 V3SQ=2.0*W4*(EICOM+Q)/(W3*(W3+W4))
 VVCM=SQRT(2.0*W1*E1)/(W3+W4)
 EVALUE=0.5*W3*((VVCM*COS(THETA)+SQRT(V3SQ-((VVCM*SIN(THETA))**2)))
2**2)
 RETURN
 END
```

APPENDIX B

OPTIMUM ANGLE FOR TARGET TO MINIMIZE ENERGY SPREAD

Case I

OPTIMUM ANGLE FOR TARGET TO MINIMIZE ENERGY SPREAD 'TARGET IN TRANSMISSION

TARGET IS CALCIUM INCIDENT PARTICLES ARE ALPHAS , OBSERVED PARTICLES ARE ALPHAS ESTAR1= 0. ESTAR2= 3.730

M1=4.00260 M2= 39.9651 M3=4.00260 M4= 39.9651 E0=41.60MEV ABS= 1.50MG/CM**2

DETECTOR ANGLE	TARGET ANGLE	OPTIMUM	ENERGY SPREAD				
			E*=0	E*=5	E*=10	E*=15	E*=20
10.00	6.76	0.	0.	-0.0193	-0.0438	-0.0761	-0.1212
	28.74	-0.0000	0.0148	-0.0056	-0.0314	-0.0654	-0.1128
25.00	16.77	0.	0.	-0.0199	-0.0452	-0.0786	-0.1254
	25.85	-0.0000	0.0143	-0.0054	-0.0304	-0.0634	-0.1097
40.00	26.48	-0.0000	-0.0000	-0.0210	-0.0478	-0.0834	-0.1335
	32.07	-0.0000	0.0149	-0.0057	-0.0320	-0.0668	-0.1160
55.00	35.73	-0.0000	-0.0000	-0.0228	-0.0519	-0.0909	-0.1462
	39.67	-0.0000	0.0161	-0.0062	-0.0347	-0.0728	-0.1268
70.00	44.39	-0.0000	-0.0000	-0.0253	-0.0579	-0.1018	-0.1646
	47.36	-0.0000	0.0179	-0.0068	-0.0387	-0.0815	-0.1428
85.00	52.41	-0.0000	-0.0000	-0.0289	-0.0664	-0.1172	-0.1907
	54.69	-0.0000	0.0204	-0.0078	-0.0444	-0.0940	-0.1656

Case II

OPTIMUM ANGLE FOR TARGET TO MINIMIZE ENERGY SPREAD   TARGET IN REFLECTION

TARGET IS   CALCIUM   INCIDENT PARTICLES ARE ALPHAS   , OBSERVED PARTICLES ARE ALPHAS   ESTAR1= 0.   ESTAR2= 3.730

M1=4.00260   M2= 39.9651   M3=4.00250   M4= 39.9651   E0=41.60MEV   ABS= 1.50MG/CM**2

DETECTOR ANGLE	TARGET ANGLE		ENERGY SPREAD				
		OPTIMUM	E*=0	E*=5	E*=10	E*=15	E*=20
85.00	-47.50	0.5509	0.5509	0.5870	0.6338	0.6974	0.7893
	-47.50	0.5769	0.5509	0.5870	0.6338	0.6974	0.7893
100.00	-40.00	0.4868	0.4868	0.5207	0.5649	0.6250	0.7125
	-40.00	0.5113	0.4868	0.5207	0.5649	0.6250	0.7125
115.00	-32.50	0.4438	0.4438	0.4765	0.5192	0.5776	0.6630
	-32.50	0.4674	0.4438	0.4765	0.5192	0.5776	0.6630
130.00	-25.00	0.4149	0.4149	0.4470	0.4890	0.5466	0.6310
	-25.00	0.4381	0.4149	0.4470	0.4890	0.5466	0.6310
145.00	-17.50	0.3962	0.3962	0.4280	0.4696	0.5269	0.6111
	-17.50	0.4191	0.3962	0.4280	0.4696	0.5269	0.6111
160.00	-10.00	0.3851	0.3851	0.4168	0.4583	0.5155	0.5998
	-10.00	0.4079	0.3851	0.4168	0.4583	0.5155	0.5998

Case III

OPTIMUM ANGLE FOR TARGET TO MINIMIZE ENERGY SPREAD   TARGET IN TRANSMISSION

TARGET IS   CALCIUM   INCIDENT PARTICLES ARE ALPHAS   , OBSERVED PARTICLES ARE ALPHAS   ESTAR1= 0.   ESTAR2= 3.730

M1=4.00260   M2= 39.9651   M3=4.00260   M4= 39.9651   E0=41.60MEV   ABS= 1.50MG/CM**2

DETECTOR ANGLE	TARGET ANGLE	OPTIMUM	ENERGY SPREAD E*=0	E*=5	E*=10	E*=15	E*=20
10.00	6.76	0.	0.	-0.0193	-0.0438	-0.0761	-0.1212
	28.74	-0.0000	0.0148	-0.0056	-0.0314	-0.0654	-0.1128
25.00	16.77	0.	0.	-0.0199	-0.0452	-0.0786	-0.1254
	25.85	-0.0000	0.0143	-0.0054	-0.0304	-0.0634	-0.1097
40.00	26.48	-0.0000	-0.0000	-0.0210	-0.0478	-0.0834	-0.1335
	32.07	-0.0000	0.0149	-0.0057	-0.0320	-0.0668	-0.1160
55.00	35.73	-0.0000	-0.0000	-0.0228	-0.0519	-0.0909	-0.1462
	39.67	-0.0000	0.0161	-0.0062	-0.0347	-0.0728	-0.1268
70.00	44.39	-0.0000	-0.0000	-0.0253	-0.0579	-0.1018	-0.1646
	47.36	-0.0000	0.0179	-0.0068	-0.0387	-0.0815	-0.1428
85.00	52.41	-0.0000	-0.0000	-0.0289	-0.0664	-0.1172	-0.1907
	54.69	-0.0000	0.0204	-0.0078	-0.0444	-0.0940	-0.1656

Case III (Concluded)

OPTIMUM ANGLE FOR TARGET TO MINIMIZE ENERGY SPREAD   TARGET IN REFLECTION

TARGET IS   CALCIUM   INCIDENT PARTICLES ARE ALPHAS   , OBSERVED PARTICLES ARE ALPHAS   ESTAR1= 0.   ESTAR2= 3.730

M1=4.00260   M2= 39.9651   M3=4.00260   M4= 39.9651   E0=41.60MEV   ABS= 1.50MG/CM**2

DETECTOR ANGLE	TARGET ANGLE	OPTIMUM	ENERGY SPREAD E*=0	E*=5	E*=10	E*=15	E*=20
85.00	-47.50	0.5509	0.5509	0.5870	0.6338	0.6974	0.7893
	-47.50	0.5769	0.5509	0.5870	0.6338	0.6974	0.7893
100.00	-40.00	0.4868	0.4868	0.5207	0.5649	0.6250	0.7125
	-40.00	0.5113	0.4868	0.5207	0.5649	0.6250	0.7125
115.00	-32.50	0.4438	0.4438	0.4765	0.5192	0.5776	0.6630
	-32.50	0.4674	0.4438	0.4765	0.5192	0.5776	0.6630
130.00	-25.00	0.4149	0.4149	0.4470	0.4890	0.5466	0.6310
	-25.00	0.4381	0.4149	0.4470	0.4890	0.5466	0.6310
145.00	-17.50	0.3962	0.3962	0.4280	0.4696	0.5269	0.6111
	-17.50	0.4191	0.3962	0.4280	0.4696	0.5269	0.6111
160.00	-10.00	0.3851	0.3851	0.4168	0.4583	0.5155	0.5998
	-10.00	0.4079	0.3851	0.4168	0.4583	0.5155	0.5998

Case IV

OPTIMUM ANGLE FOR TARGET TO MINIMIZE ENERGY SPREAD   TARGET IN TRANSMISSION

TARGET IS   CALCIUM   INCIDENT PARTICLES ARE ALPHAS   , OBSERVED PARTICLES ARE ALPHAS   ESTAR1= 0.   ESTAR2= 3.730

M1=4.00260   M2= 39.9651   M3=4.00260   M4= 39.9651   E0=41.60MEV   ABS= 1.50MG/CM**2

DETECTOR ANGLE	TARGET ANGLE		ENERGY SPREAD				
		OPTIMUM	E*=0	E*=5	E*=10	E*=15	E*=20
4.00	2.71	-0.0000	-0.0000	-0.0192	-0.0436	-0.0757	-0.1205
	48.02	0.0000	0.0194	-0.0074	-0.0412	-0.0857	-0.1480
8.00	5.41	0.	0.	-0.0193	-0.0437	-0.0759	-0.1209
	32.20	-0.0000	0.0153	-0.0058	-0.0325	-0.0678	-0.1169
12.00	8.11	0.0000	0.0000	-0.0194	-0.0439	-0.0763	-0.1215
	26.69	0.	0.0145	-0.0055	-0.0308	-0.0641	-0.1107
16.00	10.79	-0.0000	-0.0000	-0.0195	-0.0442	-0.0768	-0.1224
	24.91	-0.0000	0.0142	-0.0054	-0.0303	-0.0631	-0.1090
20.00	13.46	0.	0.	-0.0197	-0.0446	-0.0775	-0.1236
	24.81	0.	0.0142	-0.0054	-0.0302	-0.0630	-0.1088
24.00	16.11	-0.0000	-0.0000	-0.0198	-0.0450	-0.0783	-0.1250
	25.57	-0.0000	0.0142	-0.0054	-0.0304	-0.0633	-0.1094
28.00	18.74	-0.0000	-0.0000	-0.0201	-0.0456	-0.0793	-0.1267
	26.84	-0.0000	0.0144	-0.0055	-0.0306	-0.0639	-0.1105
32.00	21.35	-0.0000	-0.0000	-0.0204	-0.0462	-0.0805	-0.1286
	28.41	-0.0000	0.0145	-0.0055	-0.0310	-0.0647	-0.1120
36.00	23.93	0.	0.	-0.0207	-0.0470	-0.0818	-0.1309
	30.18	-0.0000	0.0147	-0.0056	-0.0314	-0.0657	-0.1138
40.00	26.48	-0.0000	-0.0000	-0.0210	-0.0478	-0.0834	-0.1335
	32.07	-0.0000	0.0149	-0.0057	-0.0320	-0.0668	-0.1160
44.00	28.99	0.	0.	-0.0214	-0.0487	-0.0851	-0.1364
	34.05	-0.0000	0.0152	-0.0058	-0.0326	-0.0682	-0.1184
48.00	31.48	-0.0000	-0.0000	-0.0219	-0.0498	-0.0870	-0.1396
	36.07	-0.0000	0.0155	-0.0059	-0.0333	-0.0697	-0.1212
52.00	33.92	-0.0000	-0.0000	-0.0224	-0.0510	-0.0891	-0.1432
	38.12	-0.0000	0.0159	-0.0060	-0.0340	-0.0714	-0.1243

Case IV (Continued)

TARGET IS CALCIUM INCIDENT PARTICLES ARE ALPHAS , OBSERVED PARTICLES ARE ALPHAS ESTAR1= 0. ESTAR2= 3.730

DETECTOR ANGLE	TARGET ANGLE	OPTIMUM	ENERGY SPREAD				
			E*=0	E*=5	E*=10	E*=15	E*=20
56.00	36.32	-0.0000	-0.0000	-0.0229	-0.0523	-0.0915	-0.1472
	40.19	-0.0000	0.0162	-0.0062	-0.0349	-0.0733	-0.1277
60.00	38.68	-0.0000	-0.0000	-0.0235	-0.0537	-0.0941	-0.1516
	42.25	-0.0000	0.0166	-0.0064	-0.0359	-0.0753	-0.1315
64.00	41.00	-0.0000	-0.0000	-0.0242	-0.0553	-0.0970	-0.1564
	44.31	-0.0000	0.0171	-0.0065	-0.0369	-0.0776	-0.1357
68.00	43.27	-0.0000	-0.0000	-0.0249	-0.0570	-0.1001	-0.1617
	46.35	-0.0000	0.0176	-0.0067	-0.0381	-0.0802	-0.1404
72.00	45.50	-0.0000	-0.0000	-0.0257	-0.0589	-0.1035	-0.1676
	48.36	-0.0000	0.0182	-0.0070	-0.0393	-0.0829	-0.1454
76.00	47.68	-0.0000	-0.0000	-0.0266	-0.0610	-0.1073	-0.1739
	50.35	-0.0000	0.0188	-0.0072	-0.0407	-0.0860	-0.1510
80.00	49.81	-0.0000	-0.0000	-0.0276	-0.0632	-0.1115	-0.1809
	52.30	-0.0000	0.0195	-0.0075	-0.0423	-0.0893	-0.1571
84.00	51.89	-0.0000	-0.0000	-0.0286	-0.0658	-0.1160	-0.1886
	54.22	-0.0000	0.0202	-0.0078	-0.0440	-0.0930	-0.1639
88.00	53.93	-0.0000	-0.0000	-0.0298	-0.0685	-0.1210	-0.1971
	56.10	-0.0000	0.0210	-0.0081	-0.0458	-0.0971	-0.1712
92.00	55.91	-0.0000	-0.0000	-0.0311	-0.0715	-0.1265	-0.2063
	57.94	-0.0000	0.0219	-0.0084	-0.0479	-0.1015	-0.1794
96.00	57.85	-0.0000	-0.0000	-0.0325	-0.0749	-0.1326	-0.2166
	59.75	-0.0000	0.0229	-0.0088	-0.0501	-0.1064	-0.1883
100.00	59.74	-0.0000	-0.0000	-0.0341	-0.0786	-0.1394	-0.2279
	60.00	-0.0211	0.0034	-0.0306	-0.0749	-0.1354	-0.2236
104.00	60.00	-0.0229	-0.0229	-0.0597	-0.1078	-0.1736	-0.2696
	60.00	-0.0495	-0.0229	-0.0597	-0.1078	-0.1736	-0.2696
108.00	60.00	-0.0540	-0.0540	-0.0942	-0.1468	-0.2190	-0.3244
	60.00	-0.0830	-0.0540	-0.0942	-0.1468	-0.2190	-0.3244

Case IV (Continued)

TARGET IS CALCIUM INCIDENT PARTICLES ARE ALPHAS , OBSERVED PARTICLES ARE ALPHAS ESTAR1= 0. ESTAR2= 3.730

DETECTOR ANGLE	TARGET ANGLE	OPTIMUM	ENERGY SPREAD				
			E*=0	E*=5	E*=10	E*=15	E*=20
112.00	60.00	-0.0912	-0.0912	-0.1357	-0.1939	-0.2737	-0.3907
	60.00	-0.1233	-0.0912	-0.1357	-0.1939	-0.2737	-0.3907
116.00	60.00	-0.1368	-0.1368	-0.1865	-0.2517	-0.3412	-0.4726
	60.00	-0.1727	-0.1368	-0.1865	-0.2517	-0.3412	-0.4726
120.00	60.00	-0.1942	-0.1942	-0.2506	-0.3246	-0.4264	-0.5760
	60.00	-0.2349	-0.1942	-0.2506	-0.3246	-0.4264	-0.5760

Case IV (Continued)

OPTIMUM ANGLE FOR TARGET TO MINIMIZE ENERGY SPREAD   TARGET IN REFLECTION

TARGET IS   CALCIUM   INCIDENT PARTICLES ARE ALPHAS   , OBSERVED PARTICLES ARE ALPHAS   ESTAR1= 0.   ESTAR2= 3.730

M1=4.00260   M2= 39.9651   M3=4.00260   M4= 39.9651   E0=41.60MEV   ABS= 1.50MG/CM**2

DETECTOR ANGLE	TARGET ANGLE	OPTIMUM	ENERGY SPREAD E*=0	E*=5	E*=10	E*=15	E*=20
60.00	-60.00	0.7451	0.7451	0.7891	0.8459	0.9226	1.0325
	-60.00	0.7769	0.7451	0.7891	0.8459	0.9226	1.0325
64.00	-58.00	0.7027	0.7027	0.7448	0.7993	0.8729	0.9786
	-58.00	0.7331	0.7027	0.7448	0.7993	0.8729	0.9786
68.00	-56.00	0.6656	0.6656	0.7062	0.7588	0.8297	0.9318
	-56.00	0.6950	0.6656	0.7062	0.7588	0.8297	0.9318
72.00	-54.00	0.6331	0.6331	0.6724	0.7232	0.7920	0.8909
	-54.00	0.6615	0.6331	0.6724	0.7232	0.7920	0.8909
76.00	-52.00	0.6044	0.6044	0.6425	0.6919	0.7587	0.8551
	-52.00	0.6319	0.6044	0.6425	0.6919	0.7587	0.8551
80.00	-50.00	0.5789	0.5789	0.6160	0.6641	0.7294	0.8236
	-50.00	0.6057	0.5789	0.6160	0.6641	0.7294	0.8236
84.00	-48.00	0.5562	0.5562	0.5924	0.6395	0.7034	0.7958
	-48.00	0.5824	0.5562	0.5924	0.6395	0.7034	0.7958
88.00	-46.00	0.5359	0.5359	0.5714	0.6176	0.6803	0.7711
	-46.00	0.5616	0.5359	0.5714	0.6176	0.6803	0.7711
92.00	-44.00	0.5177	0.5177	0.5527	0.5981	0.6598	0.7493
	-44.00	0.5430	0.5177	0.5527	0.5981	0.6598	0.7493
96.00	-42.00	0.5014	0.5014	0.5358	0.5806	0.6414	0.7298
	-42.00	0.5263	0.5014	0.5358	0.5806	0.6414	0.7298
100.00	-40.00	0.4868	0.4868	0.5207	0.5649	0.6250	0.7125
	-40.00	0.5113	0.4868	0.5207	0.5649	0.6250	0.7125
104.00	-38.00	0.4736	0.4736	0.5072	0.5508	0.6104	0.6971
	-38.00	0.4978	0.4736	0.5072	0.5508	0.6104	0.6971
108.00	-36.00	0.4618	0.4618	0.4950	0.5382	0.5973	0.6834
	-36.00	0.4857	0.4618	0.4950	0.5382	0.5973	0.6834

Case IV (Continued)

```
TARGET IS   CALCIUM      INCIDENT PARTICLES ARE ALPHAS    , OBSERVED PARTICLES ARE ALPHAS    ESTAR1=  0.    ESTAR2=  3.730
  DETECTOR    TARGET                                          ENERGY SPREAD
   ANGLE       ANGLE          OPTIMUM      E*=0      E*=5       E*=10      E*=15      E*=20
  112.00     -34.00           0.4511     0.4511     0.4840     0.5269     0.5856     0.6712
             -34.00           0.4749     0.4511     0.4840     0.5269     0.5856     0.6712
  116.00     -32.00           0.4415     0.4415     0.4742     0.5168     0.5751     0.6604
             -32.00           0.4651     0.4415     0.4742     0.5168     0.5751     0.6604
  120.00     -30.00           0.4328     0.4328     0.4653     0.5077     0.5658     0.6507
             -30.00           0.4563     0.4328     0.4653     0.5077     0.5658     0.6507
  124.00     -28.00           0.4251     0.4251     0.4574     0.4996     0.5574     0.6421
             -28.00           0.4484     0.4251     0.4574     0.4996     0.5574     0.6421
  128.00     -26.00           0.4181     0.4181     0.4503     0.4923     0.5500     0.6345
             -26.00           0.4413     0.4181     0.4503     0.4923     0.5500     0.6345
  132.00     -24.00           0.4119     0.4119     0.4440     0.4859     0.5434     0.6278
             -24.00           0.4350     0.4119     0.4440     0.4859     0.5434     0.6278
  136.00     -22.00           0.4064     0.4064     0.4383     0.4802     0.5375     0.6219
             -22.00           0.4294     0.4064     0.4383     0.4802     0.5375     0.6219
  140.00     -20.00           0.4015     0.4015     0.4334     0.4751     0.5324     0.6167
             -20.00           0.4245     0.4015     0.4334     0.4751     0.5324     0.6167
  144.00     -18.00           0.3972     0.3972     0.4290     0.4706     0.5279     0.6122
             -18.00           0.4201     0.3972     0.4290     0.4706     0.5279     0.6122
  148.00     -16.00           0.3934     0.3934     0.4252     0.4668     0.5240     0.6083
             -16.00           0.4163     0.3934     0.4252     0.4668     0.5240     0.6083
  152.00     -14.00           0.3902     0.3902     0.4219     0.4635     0.5207     0.6049
             -14.00           0.4130     0.3902     0.4219     0.4635     0.5207     0.6049
  156.00     -12.00           0.3874     0.3874     0.4191     0.4606     0.5178     0.6021
             -12.00           0.4103     0.3874     0.4191     0.4606     0.5178     0.6021
  160.00     -10.00           0.3851     0.3851     0.4168     0.4583     0.5155     0.5998
             -10.00           0.4079     0.3851     0.4168     0.4583     0.5155     0.5998
  164.00      -8.00           0.3832     0.3832     0.4149     0.4564     0.5136     0.5979
              -8.00           0.4061     0.3832     0.4149     0.4564     0.5136     0.5979
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Case IV (Concluded)

```
TARGET IS   CALCIUM      INCIDENT PARTICLES ARE ALPHAS    , OBSERVED PARTICLES ARE ALPHAS    ESTAR1=  0.    ESTAR2=  3.730
  DETECTOR    TARGET                                          ENERGY SPREAD
   ANGLE       ANGLE          OPTIMUM      E*=0      E*=5       E*=10      E*=15      E*=20
  168.00      -6.00           0.3818     0.3818     0.4135     0.4550     0.5121     0.5965
              -6.00           0.4046     0.3818     0.4135     0.4550     0.5121     0.5965
  172.00      -4.00           0.3808     0.3808     0.4124     0.4539     0.5111     0.5955
              -4.00           0.4036     0.3808     0.4124     0.4539     0.5111     0.5955
  176.00      -2.00           0.3802     0.3802     0.4118     0.4533     0.5105     0.5949
              -2.00           0.4030     0.3802     0.4118     0.4533     0.5105     0.5949
*01* UNIT05, EOF.                                                                   FIL000      ZE0000
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