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TRAPP, A COMPUTER PROGRAM FOR THE TRANSPORT OF ALPHA PARTICLES AND PROTONS WITH ALL NUCLEAR-REACTION PRODUCTS NEGLECTED

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Abstract

TRAPP is a Fortran IV program primarily intended for carrying out studies of the shielding required to protect astronauts against Van Allen belt protons and against solar-flare protons and alpha particles. The program treats the transport of protons and alpha particles through a homogeneous shield and tissue with the assumptions that all nuclear-reaction products may be neglected and all particles travel in a straight line and undergo a continuous slowing down. The geometry considered is that of a spherical shell shield with a tissue sphere at its center. For an isotropically incident proton or alpha-particle flux per unit energy with maximum energy $\leq$ 3 GeV, the program gives the particle flux per unit energy, the absorbed-dose rate, and the dose-equivalent rate at the center of the tissue sphere as a function of the spherical-shell-shield thickness.

I. INTRODUCTION

Studies of the shielding required to protect astronauts from Van Allen belt and solar-flare protons are usually carried out in the approximation that all nuclear-reaction products may be neglected since it has been shown that the effect of these nuclear-reaction products is not large.[1,2] In this report, a Fortran IV computer program, TRAPP, capable of carrying out such shielding studies is described. The program described hereinafter is available on request from the Radiation Shielding Information Center of the Oak Ridge National Laboratory.

In Section II the geometry considered, the transport equations used, the absorbed-dose and dose-equivalent calculations, and the physical data incorporated into the program are discussed. In Section III the Fortran program is described. In Section IV the program usage is discussed. The input and output for a sample problem are given in Section V.

II. METHOD OF CALCULATION

II.1 GEOMETRY

The geometry considered by the program is that of a homogeneous spherical shell shield with a tissue sphere at its center, as shown in Fig. 1. It is assumed that the incident proton or alpha-particle spectrum is isotropically incident on the shield, and flux and dose results are given only at the geometric center of the shield. Because isotropic incidence is assumed and because it is further assumed (see Section II.2) that all particles travel in straight lines, the radius of the vacuum region, r_V, does not enter into the calculations; i.e., all results provided by the program are independent of r_V.

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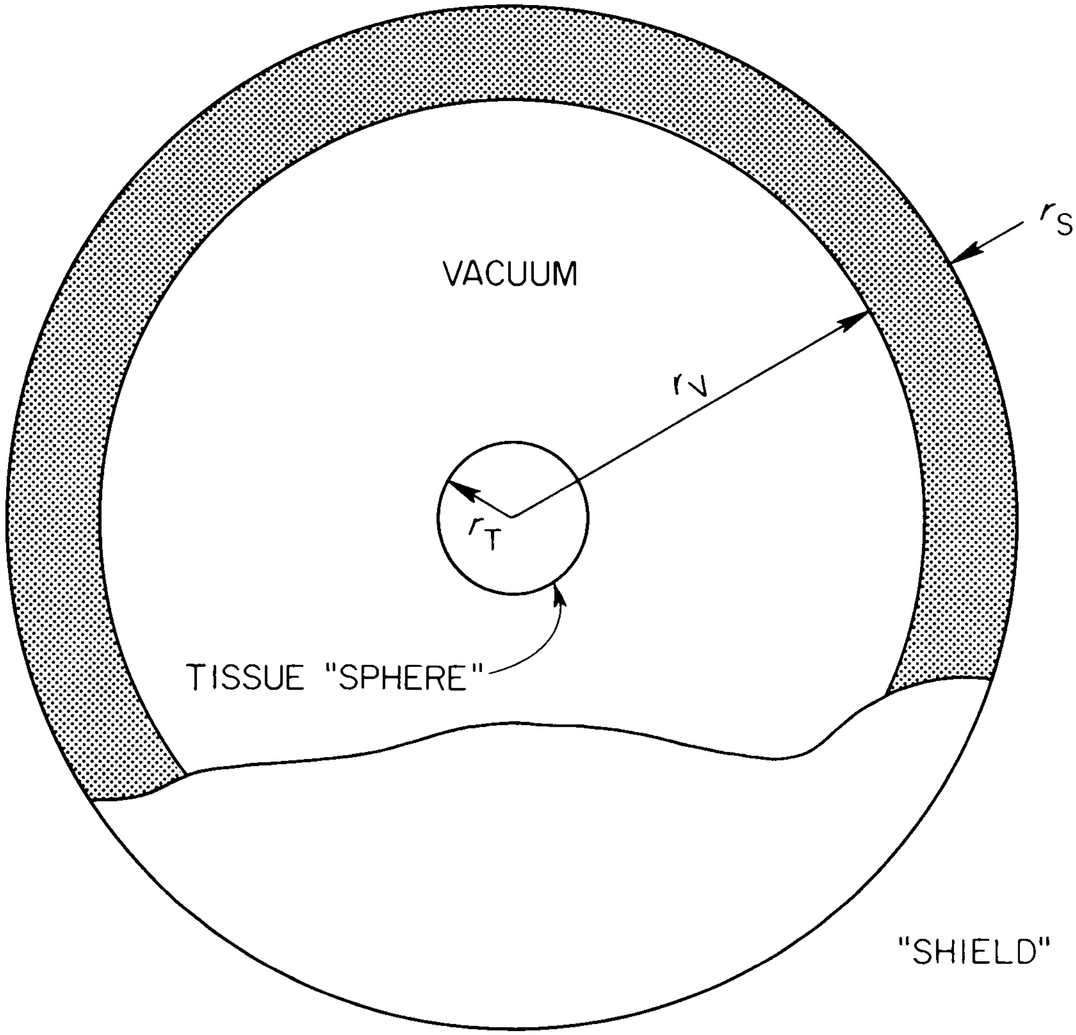

Fig. 1. A schematic diagram of geometry considered in TRAPP.

II.2 PARTICLE TRANSPORT

When a heavy charged particle, e.g., a proton or an alpha particle, passes through matter, it loses energy by the excitation and ionization of atomic electrons and undergoes nuclear collisions. The loss of energy by ionization and excitation occurs by a large number of discrete small steps and is most conveniently treated as a continuous process. In essentially all of the space-shielding calculations that have been done to date, it has been assumed that heavy charged particles undergo a continuous slowing down and travel in a straight line. This is an approximation since it is well known that heavy charged particles in passing through matter undergo both angular deflection and range straggling,[3-5] but these effects are small,[6] and the use of the approximation greatly simplifies space-shielding computations.

When a heavy-particle-nucleus nonelastic collision occurs, the incident particle is absorbed and a variety of particles is emitted. When a heavy-particle-nucleus elastic collision occurs, the incident particle undergoes an energy loss and angular deflection, and the struck nucleus acquires kinetic energy. The energy losses and angular deflections of protons and alpha particles due to elastic collisions with heavy nuclei are sufficiently small that they may be neglected. In hydrogenous media, however, the effects of proton and alpha-particle elastic collisions with hydrogen nuclei are not entirely negligible. In the program described here, all nuclear-reaction products are neglected since it has been shown that in shielding against Van Allen belt and solar-flare proton spectra the effects of nuclear-reaction products are not large.[1,2] The program does, however, provide results with the attenuation of the primary particles due to nuclear collisions both included and neglected. For the purpose of this work, a primary particle will be defined to be an incident particle that has undergone neither elastic nor nonelastic nuclear collision.

With this definition and using the continuous slowing-down and straight-ahead approximations, it follows from conservation of particles that the equation for primary-particle flux in any direction in a homogeneous shield may be written

$$\frac{\partial}{\partial r'} \Phi_j'(E,r') + \sigma_{Sj}'(E)\ \Phi_j'(E,r') = \frac{\partial}{\partial E} [S_{Sj}'(E)\ \Phi_j'(E,r')] \ , \quad j = p,\alpha \qquad \text{(II.1)}$$

$$\sigma_{Sj}' = \sum_a n_{Sa}\ \sigma_{aj} \ , \qquad \text{(II.2)}$$

where

p,α = the subscripts that are used to denote protons and alpha particles, respectively;*

E = the particle kinetic energy;

r' = the position coordinate measured along the direction of motion of the particles being considered;

$\Phi_j'(E,r')$ = the flux of primary particles of type j per unit kinetic energy at position r';

n_{Sa} = the number density of target nuclei of type a in the shield denoted by subscript S (the sum over a in Eq. II.2 is to be carried out over all nuclear species in the shield);

*In all of the equations of this and subsequent sections, the subscript j may be put equal to either p or α, so an explicit indication of this will not be given.

σ_{aj} = the total cross section for the collision of a particle of type j with a nucleus of type a (since elastic collisions with nuclei other than hydrogen will be neglected, σ_{aj} is for elements other than hydrogen taken to be the nonelastic cross section);

$S'_{Sj}(E)$ = the energy loss per unit distance; i.e., the stopping power, of a particle of type j in the shielding material being considered.

In space-shielding calculations it is convenient to use the variable $\rho r'$, where ρ is the density of the shield, rather than r'. Equation II.1 when divided by ρ becomes

$$\frac{\partial}{\partial(\rho r')} \Phi'_j(E,r') + \frac{\sigma'_{Sj}(E)}{\rho} \Phi'_j(E,r') = \frac{\partial}{\partial E} \left[\frac{1}{\rho} S'_{Sj}(E)\, \Phi'_j(E,r')\right] \qquad \text{(II.3)}$$

and with the definitions

$$\begin{aligned} r &= \rho r' \\ \sigma_{Sj}(E) &= \frac{1}{\rho} \sigma'_{Sj}(E) \\ S_{Sj}(E) &= \frac{1}{\rho} S'_{Sj}(E) \\ \Phi_j(E,r) &= \Phi'_j(E,r') \end{aligned} \qquad \text{(II.4)}$$

becomes

$$\frac{\partial \Phi_j(E,r)}{\partial r} + \sigma_{Sj}(E)\, \Phi_j(E,r) = \frac{\partial}{\partial E} \left[S_{Sj}(E)\, \Phi_j(E,r)\right] . \qquad \text{(II.5)}$$

Equation II.5 has the same form as Eq. II.1 but the symbols have slightly different meanings. In particular, if r' is measured in cm, then r is measured in g/cm^2. In the code described here, Eq. II.5 is used; i.e., it is assumed that the transformation to the variable $\rho r'$ has been made.

Equation II.5 may be solved to yield*

$$\Phi_j(E,r) = \Phi_{jo}(E_j) \frac{S_{Sj}(E_j)}{S_{Sj}(E)} \exp\left[- \int_E^{E_j} \frac{\sigma_{Sj}(E')}{S_{Sj}(E')} dE'\right] \tag{II.6}$$

$$\int_E^{E_j} \frac{dE'}{S_{Sj}(E')} = r , \tag{II.7}$$

where

$\Phi_{jo}(E)$ = the angular flux per unit energy of particles of type j which are incident on the shield.

In the case of solar flares, the incident flux will usually have been integrated over time so Φ_{jo} and Φ_j will be fluences rather than fluxes.

The simplicity of Eqs. II.6 and II.7 is a direct consequence of the approximations that have been made. Because of the continuous slowing-down and straightahead approximations, the flux of particles per unit energy in a given direction depends only on the thickness r and the incident spectrum. Equation II.7 expresses the fact that a particle of type j entering the shield with energy E_j will have the energy E at depth r. In Eqs. II.6 and II.7, E must be > zero. If E is set equal to zero in Eq. II.7, then r is the distance that a particle of type j with energy E_j will travel in the shield. The r value so determined is called the range of the particle with energy E_j in the shield. For a specific choice of shield thickness, r,

*See Appendix 1 of Ref. 1.

Eq. II.7, with E set equal to zero, determines the minimum incident particle energy that can reach depth r; i.e., all incident particles of type j with energy < E_{jmin}, defined by

$$\int_{o}^{E_{jmin}} \frac{dE'}{S_{Sj}(E')} = r \ , \tag{II.8}$$

will come to rest before reaching depth r. In Eq. II.6 the exponential factor describes the attenuation of the incident particles due to nuclear reactions. The ratio $\frac{S_{Sj}(E_j)}{S_{Sj}(E)}$ in Eq. II.6 is a Jacobian which transforms from an energy range dE to an energy range dE_j. To understand this, note that from Eq. II.7

$$\left.\frac{\partial E_j}{\partial E}\right|_r = \frac{S_{Sj}(E_j)}{S_{Sj}(E)} \ . \tag{II.9}$$

Equations II.1 to II.7 are written for a single homogeneous medium. The flux of particles that have passed through a succession of different homogeneous media may be obtained by successive utilization of Eqs. II.6 and II.7. To illustrate this, consider the case of a shield followed by tissue and let r_S be the thickness of the shield in the direction of the incident particles being considered. If $r < r_S$, then Eqs. II.6 and II.7 are valid and give the flux at a depth r in the shield. If $r > r_S$, then Eqs. II.6 and II.7 may be used, but the initial flux to be used in the equations is that which exists at the shield-tissue interface. Thus,

$$\Phi_j(E,r) = \Phi_j(E_j',r_S) \frac{S_{Tj}(E_j')}{S_{Tj}(E)} \exp\left[-\int_{E}^{E_j'} \frac{\sigma_{Tj}(E'')}{S_{Tj}(E'')} dE''\right] \ , \quad r > r_S \ , \tag{II.10}$$

$$\int_{E}^{E_j'} \frac{dE''}{S_{Tj}(E'')} = r - r_S \ , \tag{II.11}$$

where

$\Phi_j(E,r)$ = the angular flux per unit energy of particles of type j at the depth $r - r_S$ in the tissue;

$\Phi_j(E_j',r_S)$ = the angular flux per unit energy of particles of type j at the shield-tissue interface;

$S_{Tj}(E)$ = the stopping power of tissue for particles of type j;

$\sigma_{Tj}(E)$ = the total macroscopic nuclear-collision cross section for a particle of type j in the tissue.

Equations II.10 and II.11 are not in a convenient form for numerical computation when several shield thicknesses are to be considered simultaneously. For use in TRAPP, the equations are modified and the flux per unit energy is calculated as a recursive function of the depth increment Δr; i.e., in TRAPP Eqs. II.10 and II.11 are used in the form

$$\Phi_j(E,r + \Delta r) = \Phi_j(E_j',r) \frac{S_{Mj}(E_j')}{S_{Mj}(E)} \exp\left[- \int_E^{E_j'} \frac{\sigma_{Mj}(E'')}{S_{Mj}(E'')} dE''\right] , \qquad (II.12)$$

$$\int_E^{E_j'} \frac{dE''}{S_{Mj}(E'')} = \Delta r , \qquad (II.13)$$

where

$\Phi_j(E,r)$ = the angular flux per unit energy of particles of type j at depth r measured in the direction of the incident particles being considered;

$S_{Mj}(E)$ = the stopping power of medium M, which may be either shield or tissue, for particles of type j;

$\sigma_{Mj}(E)$ = the total nuclear-collision cross section for a particle of type j in medium M.

Equations II.12 and II.13 are still not in the form used in TRAPP because it was found to be numerically more efficient to carry out all internal computations in terms of lethargy, U, rather than in terms of energy. The lethargy U is defined by

$$U = \ell n \frac{E_{max}}{E} , \tag{II.14}$$

where

E_{max} = the maximum incident energy of any particle,

and then Eqs. II.12 and II.13 become

$$\Phi_j(U, r + \Delta r) = \Phi_j(U_j', r) \frac{S_{Mj}(U_j')}{S_{Mj}(U)} \exp\left[- \int_{U_j'}^{U} \frac{\sigma_{Mj}(U'')}{S_{Mj}(U'')} dU''\right] \tag{II.15}$$

$$\int_{U_j'}^{U} \frac{dU''}{S_{Mj}(U'')} = \Delta r \quad , \tag{II.16}$$

where

$$\Phi_j(U,r) = \Phi_j(E,r) E \tag{II.17}$$

$$S_{Mj}(U) = \frac{S_{Mj}(E)}{E} \tag{II.18}$$

$$\sigma_{Mj}(U) = \sigma_{Mj}(E) . \tag{II.19}$$

II.3 ABSORBED-DOSE AND DOSE-EQUIVALENT CALCULATIONS

To assess the effectiveness of a shield in protecting an astronaut, it is necessary to obtain a measure of the biological hazard associated with the radiation absorbed in the astronaut. The quantities that are usually used for this purpose are the absorbed dose and the dose equivalent. The absorbed dose is the energy deposited per gram of tissue at a specific point in the astronaut. The dose equivalent is obtained by weighting the energy deposited per gram of tissue by each particle at a specific point in the astronaut with a quality factor that is dependent on the stopping power of tissue for the particle and adding the weighted contribution of all particles.

Once the particle flux per unit energy has been calculated, the absorbed-dose rate and dose-equivalent rate at the center of the tissue sphere in Fig. 1 may be calculated from the integrals*

$$D_j(r_S,r_T) = 4\pi C \int_{E_C}^{E''_{jmax}} dE\ \Phi_j(E,r_S,r_T)\ S_{Tj}(E) \qquad \text{(II.20)}$$

$$D_{Qj}(r_S,r_T) = 4\pi C_Q \int_{E_C}^{E''_{jmax}} dE\ \Phi_j(E,r_S,r_T)\ S_{Tj}(E)\ Q[S_{Tj}(E)]\ , \qquad \text{(II.21)}$$

where

$D_j(r_S,r_T)$ = the absorbed-dose rate at the center of the tissue sphere due to incident particles of type j;

C = a constant which converts from energy deposition per unit volume to rad [if energy is measured in MeV, then $C = (1.6 \times 10^{-8}$ rad)/(MeV/g)];

*If fluence per unit energy is calculated, then Eqs. II.20 and II.21 give the absorbed dose and dose equivalent, respectively, at the center of the tissue sphere.

$S_{Tj}(E)$ = the energy loss per unit distance, i.e., the stopping power of particles of type j in tissue;

E''_{jmax} = the maximum energy of a particle of type j at the dose point. [This quantity is computed from the equations

$$\int_{E'_{jmax}}^{E_{jmax}} \frac{dE'}{S_{Sj}(E)} = r_S$$

$$\left.\int_{E''_{jmax}}^{E'_{jmax}} \frac{dE'}{S_{Tj}(E)} = r_T \right] ;$$

E_C = the lowest energy particle considered. (In principle, E_C should be zero, but because the range of very low energy particles is very small, a small but finite value of E_C can be used without introducing appreciable error. In TRAPP, an E_C of 0.1 MeV is usually satisfactory.)

$D_{Qj}(r_S, r_T)$ = the dose equivalent at the center of the tissue sphere due to particles of type j;

C_Q = a constant which converts from weighted energy deposition per unit volume to rem [if energy is measured in MeV, then $C_Q = (1.6 \times 10^{-8}\ \text{rem})/(\text{MeV/g})$];

$Q[S_{Tj}(E)]$ = a quality factor which is assumed to be a function of the stopping power of tissue for the type of particle being considered.

It must be emphasized that Eqs. II.20 and II.21 are valid only at the geometric center shown in Fig. 1. At other points in the tissue sphere, the distance a particle travels through the shield and tissue is a function of the angle of incidence, and the expressions for the absorbed dose and dose equivalent are more complicated than those given in Eqs. II.20 and II.21

(see, for example, Ref. 1). Equations II.20 and II.21 remain valid if $r_T = 0$ provided it is assumed that the doses are being calculated in an infinitesimal tissue sphere at the geometric center of the shield. The program TRAPP gives dose results both with $r_T = 0$ and $r_T \neq 0$. It should also be remembered that $\Phi_j(E,r_S,r_T)$ is the angular flux per unit energy. Since isotropic incidence is assumed, $4\pi\Phi_j(E,r_S,r_T)$ is the omnidirectional flux per unit energy, and therefore Eqs. II.20 and II.21 can easily be written in terms of the omnidirectional flux per unit energy.

In TRAPP, the dose calculations are performed in lethargy rather than in energy (see Eqs. II.14), so the integrals used are

$$D_j(r_S,r_T) = 4\pi C \int_{U''_{jmin}}^{U_{max}} dU\ \Phi(U,r_S,r_T)\ S_{Tj}[E_{max}\ \exp(-U)] \qquad \text{(II.22)}$$

$$D_{Qj}(r_S R_T) = 4\pi C_Q \int_{U''_{jmin}}^{U_{max}} dU\ \Phi(U,r_S,r_T)\ S_{Tj}[E_{max}\ \exp(-U)]\ Q\{S_{Tj}[E_{max}\ \exp(-U)]\}, \qquad \text{(II.23)}$$

where

$$U_{max} = \ell n \frac{E_{max}}{E_C} \qquad \text{(II.24)}$$

$$U''_{jmin} = \ell n \frac{E_{max}}{E''_{jmax}} \quad . \qquad \text{(II.25)}$$

II.4 PHYSICAL DATA

In order to carry out the numerical evaluation of the particle fluxes and dose rates, it is necessary to have numerical values for the various physical quantities, i.e., stopping powers, cross sections, etc., that appear in the equations. Some of the required data are included in TRAPP and some of the data must be supplied by the user. A discussion of the data which have been incorporated into the code and the data which must be supplied by the user is given below.

II.4.1 Incident Spectra

The incident Van Allen belt **proton** omnidirectional flux per unit energy must be supplied by the user. The incident solar-flare proton and alpha-particle omnidirectional fluences per unit energy may be supplied by the user or may be obtained from the program. The incident solar-flare proton and alpha-particle omnidirectional fluences per unit energy which are supplied by the program are calculated from the equation (see, for example, Ref. 1)

$$\Phi_{jo} = \frac{J_{oj}}{z_j\, P_o} \frac{E + M_j}{\sqrt{E^2 + 2M_j E}} \exp\left[-\frac{\sqrt{E^2 + 2M_j E}}{z_j\, P_o}\right] , \qquad (II.26)$$

where

M_j = the rest energy of particle of type j;

z_j = the charge number ($z_p = 1$, $z_\alpha = 2$);

P_o = the characteristic rigidity;

J_{oj} = the total omnidirectional fluence of particles of type j with energies between E_{jmin} and 3000 MeV.

The user must supply the quantities P_o, E_{jmin}, and J_{oj}. It should be noted that the program assumes that there are no incident particles of type j with energy less than E_{jmin}.

II.4.2 Stopping Powers

The proton stopping power in the shield material must be specified by the user. The proton stopping power in tissue is included in the program. In the energy range from 0.1 to 1000 MeV, the data in the code were taken from Janni,[7] and in the energy range from 1000 MeV to 3000 MeV, the data were taken from Barkas and Berger.[8]

The stopping powers of alpha particles both in the shield and in tissue are supplied by the code. At alpha-particle energies above 8 MeV, the alpha-particle stopping power is obtained from the proton stopping power by use of the equation (see Ref. 1)

$$S_{A\alpha}(E) = z_\alpha^2 \, S_{Ap}\left(\frac{M_p}{M_\alpha} E\right) , \tag{II.27}$$

where

$S_{A\alpha}(E)$ = the stopping power of alpha particles in any homogeneous material A,

S_{Ap} = the stopping power of protons in any homogeneous material A.

At alpha-particle kinetic energies above approximately 8 MeV, the alpha particles may be assumed to be completely ionized so $z_\alpha = 2$ and Eq. II.27 may be used. At energies below approximately 8 MeV, the average charge of an alpha particle as it slows down is < 2; i.e., an alpha particle at these lower energies continually picks up and loses electrons, and a correction for this continual change in charge must be made. One method of obtaining stopping-power data for alpha particles in this lower energy range is to assume that the shape of the stopping-power curve as a function of energy is independent of material and to scale the measured data for some standard element to agree with the results given by Eq. II.27 at some energy sufficiently high that Eq. II.27 may be assumed to be valid. The measured alpha-particle stopping powers for several materials given in the article by Northcliffe[9] somewhat justifies the assumption that the shape of the stopping-power curve as a function of energy at low energies does not depend strongly on material. In TRAPP, low-energy stopping-power data for alpha particles are obtained for all materials by using the measured alpha-particle stopping power curve in aluminum given by Northcliffe[9] and renormalizing this curve to make it agree with the results of Eq. II.27 at 8 MeV.

II.4.3 Proton-Nucleus Collision Cross Sections

The proton-nucleus cross sections that occur in the equations of Section II.2 were defined to be the proton-nucleus nonelastic cross sections for nuclei and the proton-proton total cross section in the case of hydrogen; that is, elastic collisions with nuclei other than hydrogen were neglected, but elastic proton collisions with hydrogen were assumed to remove primary protons.

The total cross section for proton-proton collisions as a function of energy is well established experimentally. The available experimental data have recently been reviewed by Barashenkov,[10] and the values used in TRAPP are taken from this review.

In the energy range 25 to 3000 MeV, the nonelastic cross sections for protons incident on several elements have been calculated by Bertini.[11,12]*

*All of the data described in Refs. 11 and 12 are available on request from the Radiation Shielding Information Center of the Oak Ridge National Laboratory.

The calculated cross sections are in reasonable agreement with experimental data[13,14] and are therefore suitable for use in shielding calculations. Calculated data are available for many of the elements commonly needed in space-shielding calculations. Furthermore, the cross-section values do not vary rapidly with materials, and values for elements other than those contained in the Bertini calculations can readily be obtained by interpolation. In TRAPP, an interpolation program is included, and the code will supply cross-section data for hydrogen and any element with atomic weight > 12.

In Fig. 2 the macroscopic total nuclear-collision cross sections for copper, aluminum, polyethylene, and tissue are plotted over the energy range from 25 to 3000 MeV. The composition of tissue was taken to be that used in several previous calculations[17-19] and is slightly different from that used by Janni.[7] The tissue composition used is shown in Table 1. The cross sections are not rapidly varying as a function of energy. The increase in the cross section in the vicinity of 300 to 400 MeV is due to the fact that pion production becomes energetically possible in this energy region. In TRAPP all cross sections are set equal to zero for $E < 25$ MeV. The cross sections are not zero below 25 MeV, but for shielding purposes they may be neglected at the lower energies because the proton stopping power is sufficiently large at these lower energies that the protons will with high probability come to rest without undergoing a nuclear collision. A more rigorous way of making this statement is that at energies of < 25 MeV the proton range is very small compared to the mean free path for proton-nucleus collisions, i.e., compared to the reciprocal of the macroscopic cross section.

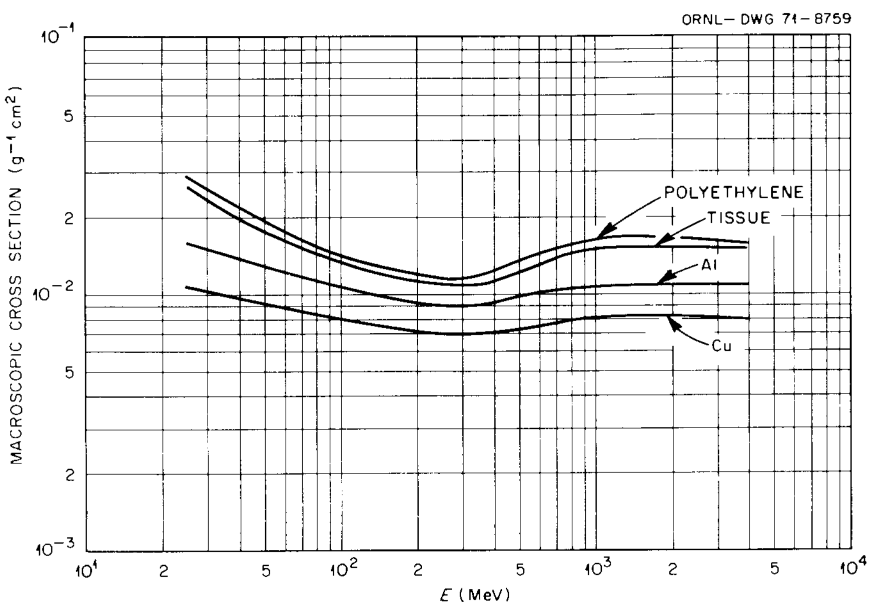

Fig. 2. Primary proton macroscopic nuclear collision cross section vs energy in various materials.

TABLE 1

Composition of Tissue

Element	Number Density of Nuclei (No. cm^{-3})
H	6.265×10^{22}
C	9.398×10^{21}
N	1.342×10^{21}
O	2.551×10^{22}

II.4.4 Alpha-Particle-Nucleus-Collision Cross Sections

The alpha-particle-nucleus-collision cross sections that occur in the equations of Section II.2 were defined in the same manner as the proton-nucleus cross sections; that is, for alpha-particle collisions with nuclei other than hydrogen the collision cross section was defined to be the nonelastic cross section and for alpha-particle collisions with hydrogen the collision cross section was defined to include both the elastic and nonelastic cross sections.

The total alpha-particle-proton-collision cross section has recently been calculated as a function of energy by Barashenkov and Eliseev.[20] These calculated results are in reasonable agreement with the experimental data and are therefore used here.

The alpha-particle-nucleus nonelastic cross sections for elements other than hydrogen are not available either experimentally or theoretically, and therefore only a relatively crude estimate of these cross sections can be made. Here it will be assumed that the nonelastic cross section for an element other than hydrogen can be approximated by the geometric expression[21]

$$\sigma_{A\alpha} = \pi\, r_o^2 (A^{1/3} + A_\alpha^{1/3})^2 \quad , \qquad \text{(II.28)}$$

where

A, A_α = the atomic weight of the nucleus and alpha particle, respectively, and

$r_o = 1.3 \times 10^{-13}$ cm.

The macroscopic collision cross section for alpha particles in several materials is shown in Fig. 3 in the energy range from 25 to 3000 MeV. The composition of tissue is that shown in Table 1. The energy variation

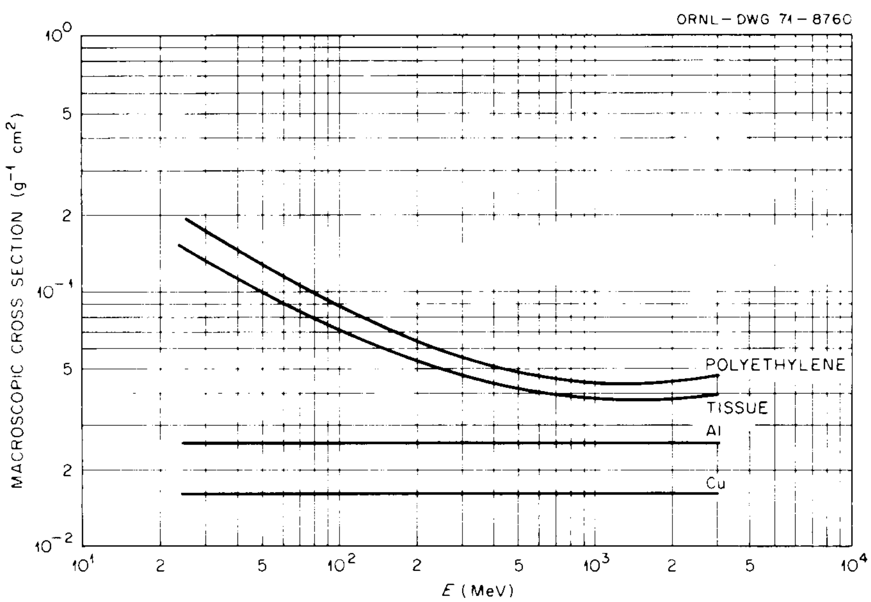

Fig. 3. Primary alpha-particle macroscopic nuclear collision cross section vs energy in various materials.

of the cross section in the case of polyethylene and tissue is due to the presence of hydrogen since, for elements other than hydrogen, the cross section is constant by assumption. The cross sections are not zero below 25 MeV, but, as in the case of protons, they may be neglected below this energy because the range of alpha particles of 25 MeV and less is small compared to the mean free path for alpha-particle-nucleus collisions; i.e., alpha particles with energies of 25 MeV and less will with a very high probability come to rest without undergoing a nuclear collision.

II.4.5 Quality Factor as a Function of Energy Loss Per Unit Distance in Tissue

To calculate the dose equivalent, it is necessary to specify the quality factor as a function of energy loss per unit distance in tissue. For radiation protection purposes, the quality-factor recommendations of the International Commission on Radiological Protection[22] are usually used, and it has been recommended by the Radiological Advisory Panel of the Committee on Space Medicine of the National Academy of Sciences, National Research Council, that these same quality factors be used for space-radiation protection purposes.[23]

The quality factor as a function of stopping power, which corresponds to these recommendations and which is used in TRAPP, is shown in Fig. 4. The quality factor as a function of stopping power is by assumption independent of particle type, so the values in Fig. 4 are used for both protons and alpha particles.

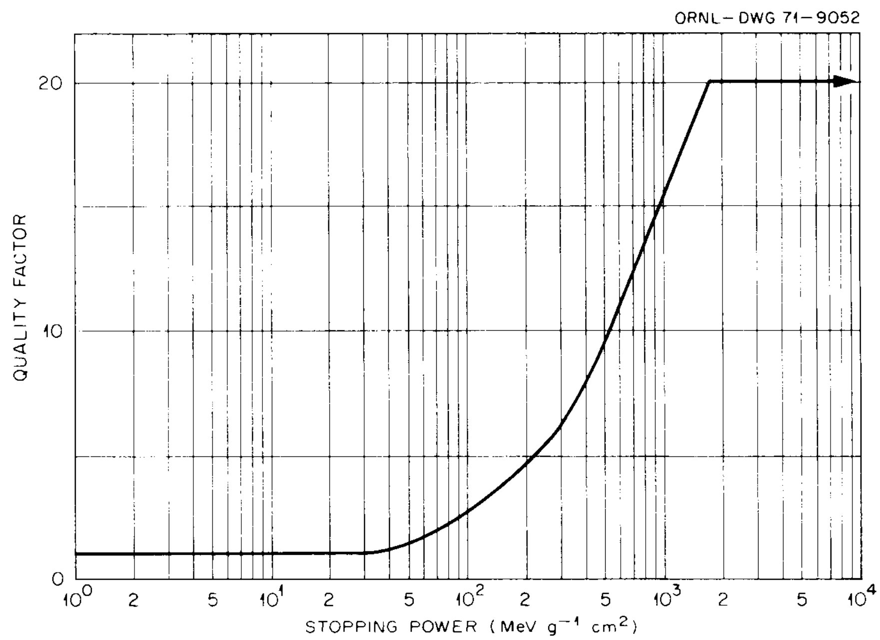

Fig. 4. Quality factor vs stopping power.

III. DESCRIPTION OF THE PROGRAM

TRAPP was designed specifically for processing incident solar-flare protons and alpha particles or incident Van Allen belt proton spectra, but it may also be used for any incident proton or alpha-particle spectrum in the energy range from 0.1 to 3000 MeV isotropically incident on the shield. The program can be divided into two logical sections. The first section, consisting of the MAIN program and subroutine SETBAL along with several auxiliary subroutines, handles all input data and sets up the parameters for both the spherical shell shield and the tissue sphere. The other logical section, consisting of subroutines MAC and BALL along with auxiliary subroutines, calculates the flux or fluence per unit energy vs shield thickness at the center of a tissue sphere of specified thickness, r_T, and at the center of a tissue sphere with $r_T = 0$ for proton or alpha-particle spectra incident on the shield. The flux or fluence per unit energy is used in subsequent calculations giving the absorbed-dose rate or absorbed dose and the dose-equivalent rate or dose equivalent vs shield thickness. In describing the subroutines, for the sake of brevity the word flux is used for both flux and fluence, and dose rate is used for both dose rate and dose.

All input data requirements are met through MAIN. It should be noted that input data are read in on logical 5, all output data are written on logical 6, and the information retained for TRAPPL[24] is written on logical 8 in hexidecimal. Logical 8 can be a magnetic tape or a scratch disc file if TRAPPL is not to be used.

III.1 PROGRAM MAIN

MAIN reads in all data, sets up parameters for the shield and tissue sphere, partially outputs data describing the current case, and outputs absorbed-dose rate and dose-equivalent rate as a function of shield thickness at the center of both a tissue sphere with radius zero and a tissue sphere of specified radius. The operations performed and a description of appropriate parameters are given below.

1. In the following, if IHAVAL = 0 (input parameter), only the proton parameters are computed.
2. Reads in NØKASE, the number of stacked cases to be run. A stacked case is defined to be a grouping (up to 10) of incident spectra (e.g., all solar-flare or all Van Allen belt spectra) with essentially all other parameters constant. (See Section IV for a detailed description of stacked cases.) Such grouping of incident spectra is intended to speed computations.
3. Reads in NØU, NELM, ICUT, (TITLE(I), I = 1, 12), specifying the number of energy points to be used, the number of elements (up to 10) that make up the shield, and an option to change the minimum energy from 0.1 MeV to some larger value read in as ECUT (see below). TITLE consists of 48 alphameric characters used to identify this case.
4. Reads in DELR, DELRB, NØR, NØRB. Specifies the stepsize in the shield and in the tissue sphere, as well as the number of steps in each.
5. Reads in EMAX, ECUT, the maximum and minimum energies to be used in this case. If ICUT is equal to 0, ECUT is assumed to be 0.1 MeV.

6. Reads in pairs of AAA(I), RHØN(I) for NELM elements in the shield. AAA(I) is the atomic weight and RHØN(I) is the weight fraction of the Ith element.

7. Reads in options ISPEC, IXSØP, IHAVAL, IØUTP, IØUTFX.

8. Sets up U and E arrays, the lethargy and energy arrays evenly spaced in lethargy with

   DELU = ALØG(EMAX/ECUT)/(NØU-1)

   E(I) = EMAX*EXP(-(I-1)*DELU)

9. Zeros out QP and QAL arrays. If IXSØP = 1, calls subroutines PRØSIG and ALFSIG to compute QP and QAL at all energy points. QP(I) and QAL(I) are the macroscopic proton and alpha-particle cross sections in the shield.

10. Reads in number of incident spectra and the rigidities of the solar-flare spectra or the altitudes, angles, and time intervals of the Van Allen belt spectra. Then either reads in or computes the incident spectra depending on the value of ISPEC. For ISPEC = 0, the solar-flare spectra are computed in subroutine SPEC. For ISPEC = 1 or 2, see Section IV for a discussion on reading in solar-flare spectra or Van Allen belt spectra. In all three cases, the spectra are converted to lethargy functions by calling subroutine CØNVER and spaced out on the lethargy grid U by calling subroutine SPACER for interpolation.

11. Sets up the stopping-power arrays for protons and alpha particles in the shield and in tissue. Reads in NØSP, the number of proton stopping powers to be read in, and arrays (DP(I), DP1(I), I = 1, NØSP) where DP1(I) is the proton stopping power (MeV g^{-1} cm^2) at DP(I),

the energy in MeV. The proton stopping powers in tissue are stored in MAIN in the array DSTP with the corresponding energies stored in the array PRTP. When required, the alpha-particle stopping powers are obtained by scaling the proton stopping-power data. The stopping powers are converted to functions of lethargy and spaced equally on the lethargy grid U using CØNVER and SPACER, respectively. The lethargy-dependent stopping powers are stored in the following arrays:

SP(I) = stopping powers for protons in the shield at lethargy U(I).

STP(I) = stopping power for protons in tissue at lethargy U(I).

SAL(I) = stopping power for alpha particles in the shield at lethargy U(I).

STAL(I) = stopping power for alpha particles in tissue at lethargy U(I).

12. Calculates ESTP, ESTAL, ESTPB, and ESTAB, which are the stopping powers of proton and alpha particles in tissue as functions of energy. Sets

ESTP(I) = STP(I)*E(I)

ESTAL(I) = STAL(I)*E(I)

ESTPB(I) = ESTP(I)

ESTAB(I) = ESTAL(I)

Arrays ESTP and ESTAL are used in subroutine MAC to evaluate the absorbed-dose integral at the center of the spherical shell shield without a tissue sphere, and arrays ESTPB and ESTAB are used in subroutine BALL to evaluate the absorbed-dose integral at the center of the tissue sphere. These arrays are also used to compute the dose-equivalent integrals in the same subroutines.

13. To calculate the dose equivalent, it is necessary to specify the quality factor as a function of energy loss per unit distance in tissue. A table of the quality factor as a function of energy loss is stored in the data statements DPIN and DALIN. Interpolation in this table is performed by calling subroutine SPACER. The various quality factors are specified by

QESTP(I) = Q(ESTP(I)) = the quality factor for protons in tissue at stopping power ESTP(I) when $r_T = 0$,

QESTAL(I) = Q(ESTAL(I)) = the quality factor for alpha particles in tissue at stopping power ESTAL(I) when $r_T = 0$,

QESTPB(I) = Q(ESTPB(I)) = the quality factor for protons in tissue at stopping power ESTPB(I) when $r_T > 0$, and

QESTAB(I) = Q(ESTAB(I)) = the quality factor for alpha particles in tissue at stopping power ESTAB(I) when $r_T > 0$.

14. Partially outputs data describing this case.

15. Sets QESTP(I) = ESTP(I)*QESTP(I) and QESTAL(I) = ESTAL(I)*QESTAL(I) in order to speed up the computation of the dose-equivalent integrals.

16. Subroutine SIMP2 is called to evaluate the following integrals:

$$\mathrm{SPIN(I)} = \int_{\mathrm{U(I-1)}}^{\mathrm{U(I)}} \frac{\mathrm{dU'}}{\mathrm{SP(U')}} \qquad \text{with SPIN(1) = 0.0}$$

$$\mathrm{SALIN(I)} = \int_{\mathrm{U(I-1)}}^{\mathrm{U(I)}} \frac{\mathrm{dU'}}{\mathrm{SAL(U')}} \qquad \text{with SALIN(1) = 0.0}$$

$$\mathrm{DP1(I)} = \int_{\mathrm{U(I-1)}}^{\mathrm{U(I)}} \frac{\mathrm{QP(U')}}{\mathrm{SP(U')}}\,\mathrm{dU'} \qquad \text{with DP1(1) = 0.0}$$

$$\mathrm{DMAL(I)} = \int_{\mathrm{U(I-1)}}^{\mathrm{U(I)}} \frac{\mathrm{QAL(U')}}{\mathrm{SAL(U')}}\,\mathrm{dU'} \qquad \text{with DMAL(1) = 0.0} \quad .$$

17. Calls subroutine FDELR to compute functions of DELR, the increment in shield thickness. Functions computed are UP(I), UAL(I), JP(I), JAL(I), SPS(I,1), and SALS(I,1).

UP(I) is computed from

$$\int_{UP(I)}^{U(I)} \frac{dU'}{SP(U')} = DELR \quad ,$$

UAL(I) is computed from

$$\int_{UAL(I)}^{U(I)} \frac{dU'}{SAL(U')} = DELR \quad ,$$

JP(I) is the index such that $U(JP(I)-2) < UP(I) \leq U(JP(I))$,

JAL(I) is the index such that $U(JAL(I)-2) < UAL(I) \leq U(JAL(I))$,

$$SPS(I,1) = \frac{SP[UP(I)]}{SP[U(I)]} \quad ,$$

$$SALS(I,1) = \frac{SAL[UAL(I)]}{SAL[U(I)]} \quad .$$

18. Calls subroutine SETBAL to compute parameters for the tissue sphere.

19. If IXSØP (input parameter) = 1, SPS(I,2) and SALS(I,2) are computed from

$$SPS(I,2) = SPS(I,1) * \exp\left[-\int_{UP(I)}^{U(I)} \frac{QP(U')}{SP(U')}\, dU'\right] ,$$

$$SALS(I,2) = SALS(I,1) * \exp\left[-\int_{UAL(I)}^{U(I)} \frac{QAL(U')}{SAL(U')}\, dU'\right] ,$$

and all cross-section data used are printed out.

20. Calls subroutine MAC for computation of fluxes and dose rates.

21. Outputs dose rates as a function of shield thickness on both logical 8 and the standard output logical 6.

22. Repeats with next stacked case.

III.2 FUNCTION ALAG

Function ALAG performs three-point Lagrangian interpolation. If the point being fitted is within the bounds of the function points and the interpolated value of the function is not between the corresponding function values, linear interpolation is used. When the point being fitted is outside the bounds of the function points, linear extrapolation is used.

III.3 SUBROUTINE ALFSIG

Subroutine ALFSIG computes the alpha-particle-nucleus-collision cross sections. Microscopic cross sections are obtained by either interpolation on cross-section vs alpha-particle energy stored in the subroutine in data arrays or by calculating the geometric cross section as defined earlier in the text. These data are converted to macroscopic cross sections, and the values obtained are returned to the calling routines (MAIN for the shield cross sections and SETBAL for the tissue cross sections).

III.4 SUBROUTINE BALL

Subroutine BALL computes the flux at each depth increment in the tissue sphere and calculates the absorbed-dose and dose-equivalent values at the center of the tissue sphere. Subroutine MAC computes the flux as a function of thickness of the shield and has thicknesses specified by the data statement IØPUT at which dose rates are to be computed. When the current thickness of the shield is proper for computing dose rates, subroutine BALL is called. Operations performed are as follows:

1. In the following operations, if IHAVAL (input parameter) = 0, only those values pertaining to protons are computed. If IXSØP (input parameter) = 0, only those values without attenuation are computed. Core-storage restrictions require limiting the fluxes in the core to

those at the current depth and previous depth. Indices KEGB and KEYB are switched at every depth increment to keep track of where currently computed fluxes are to be stored.

2. Fluxes incident on the tissue sphere are the fluxes at the current thickness of the shield.

   PB(I,KEGB,JPZ) = P(I,KEG,JPZ), the proton flux at current shield thickness R(KEG), at lethargy U(I), rigidity PZ(JPZ) or altitude ALT(JPZ) without attenuation due to nuclear collisions;

   PB(I,KEGC,JPZ) = P(I,KGC,JPZ), the proton flux with attenuation;

   ALB(I,KEGB,JPZ) = AL(I,KEG,JPZ), the alpha-particle flux without attenuation;

   ALB(I,KEGC,JPZ) = AL(I,KGC,JPZ), the alpha-particle flux with attenuation.

3. Sets up minimum possible lethargy for protons and alpha particles initially as equal to those values at current thickness of the shield.

   URPB(KEGB) = URP(KEG)

   URALB(KEGB) = URAL(KEG)

4. At each increment of depth in the tissue sphere subroutine BERPB is called to evaluate the fluxes PB and ALB and the minimum possible lethargies of the particles at that depth. URPB(KEGB) is the minimum lethargy for protons and URALB(KEGB) is the minimum for alpha particles.

5. When the center of the tissue sphere is reached, the integrands for the absorbed-dose and dose-equivalent integrals are computed. The value of U(NUU_j) just greater than the minimum possible lethargy of

the j-type particle is known. Subroutine SIMP is called to perform the integration from $U(NUU_j)$ to U(NØU). The dose-rate integrals from URPB(KEGB) to $U(NUU_p)$ and from URALB(KEGB) to $U(NUU_\alpha)$ are calculated by assuming an exponential curve through the known integrands.

6. Dose rates are stored in labeled common /TART/ for subsequent output in the MAIN program. Values stored in TART are defined as:

RRPØUT(IRPØUT) = current thickness of shield stored by subroutine MAC.

DØSPD(IRPØUT,INSECT,JPZ) = absorbed-dose rate for protons.

DØSALD(IRPØUT,INSECT,JPZ) = absorbed-dose rate for alpha particles.

DØSPM(IRPØUT,INSECT,JPZ) = dose-equivalent rate for protons.

DOSALM(IRPØUT,INSECT,JPZ) = dose-equivalent rate for alpha particles.

ERPØUT(IRPØUT,I) = maximum energy at center of sphere; computed in MAC if I = 1 or 3 and in BALL if I = 2 or 4.

IRPØUT = index of current output thickness (shield thickness) incremented in subroutine MAC each time dose rates are computed.

Subscripts INSECT and I in the above are defined as follows:

INSECT = 1 for without attenuation and without tissue sphere; dose rates are computed in MAC.

= 2 for without attenuation and with tissue sphere; dose rates are computed in BALL.

= 3 for with attenuation and without tissue sphere; dose rates are computed in MAC.

= 4 for with attenuation and with tissue sphere; dose rates are computed in BALL.

I = 1 for maximum proton energy without tissue sphere.

= 2 for maximum proton energy with tissue sphere.

= 3 for maximum alpha-particle energy without tissue sphere.

= 4 for maximum alpha-particle energy with tissue sphere.

III.5 SUBROUTINE BERP

BERP is an intermediate interpolation subroutine to compute AL(I,KEY,JPZ) and P(I,KEY,JPZ), the alpha-particle and proton fluxes at the current step in shield thickness. Fluxes are evaluated at lethargy U(I) and with incident spectra at either rigidity, PZ(JPZ), or altitude, ALT(JPZ), angle, ANGLE(JPZ), and time, TIME(JPZ), depending on whether the incident spectrum is solar flare or Van Allen belt. Subscript KEY designates current step in shield thickness and takes values K2 and K2+2 for without and with attenuation (cross sections not used or used). K2 is passed as an argument from the calling routine MAC.

Subroutine URALPH is called to get the pseudo-point source lethargies URP and URAL, the lowest lethargy values possible for protons and alpha particles at the current thickness of the shield. Comparison is then made with UP(U(I)) and UAL(U(I)) from subroutine FDELR. If UP(U(I)) is less than or equal to URP, P(I,KEY,JPZ) is set equal to zero; otherwise, subroutine TERP is called to evaluate P(I,KEY,JPZ). If UAL(U(I)) is less than or equal to URAL, AL(I,KEY,JPZ) is set equal to zero; otherwise, subroutine TERP is called to compute AL(I,KEY,JPZ). If IHAVAL (input parameter designating with or without alpha particles) is zero, only the proton fluxes are computed.

III.6 SUBROUTINE BERPB

Subroutine BERPB is essentially the same as subroutine BERP except ALB(I,KEY,JPZ) and PB(I,KEY,JPZ) are the alpha-particle and proton fluxes computed at the current depth in the tissue sphere. Subroutine URALPB is called to obtain the pseudo-point source lethargies URPB and URALB. Comparison is made with UPB(U(I)) and UALB(U(I)) from subroutine SETBAL to see if the flux is zero at this depth or if subroutine TERP is to be called. If IHAVAL (input parameter designating with or without alpha particles) is zero, only the proton fluxes are computed.

III.7 FUNCTION BINT

BINT is a back interpolation routine. Given a function value ARG and three points (X1,Y1), (X2,Y2), and (X3,Y3) with ARG between Y1 and Y3, BINT finds the value of X between X1 and X3 which has a function value equal to ARG assuming a quadratic passes through the three points.

III.8 SUBROUTINE CONVER

Subroutine CONVER is used to convert functions of energy to functions of lethargy. The argument IØP is used to determine the lethargy calculation function.

If IØP = 1, F(U) = F(E)*E.

If IØP = 2, F(U) = F(E)/E.

III.9 SUBROUTINE FDELR

Subroutine FDELR computes functions of DR. It calls UALFA to find UAL(I), JAL(I), UP(I), and JP(I) as functions of DR (stepsize in the shield) and lethargy U(I), and then computes SALS(I,1) and SPS(I,1). UAL(I) is found from

$$\int_{UAL(I)}^{U(I)} \frac{dU'}{SAL(U')} = DR ,$$

where SAL(U') is the stopping power for alpha particles in the shield at lethargy U'. Then, JAL(I) is the index such that

$$U(JAL(I)-2) < UAL(I) \leq U(JAL(I)) .$$

UP(I) is found from

$$\int_{UP(I)}^{U(I)} \frac{dU'}{SP(U')} = DR$$

with SP(U') the stopping power for proton particles in the shield at lethargy U'. Then JP(I) is the index such that

$$U(JP(I)-2) < UP(I) \leq U(JP(I)) .$$

Then, FDELR calculates $SALS(I,1) = \frac{SAL(UAL(I))}{SAL(U(I))}$ and $SPS(I,1) = \frac{SP(UP(I))}{SP(U(I))}$.

III.10 SUBROUTINE MAC

MAC computes the fluxes at each increment of shield thickness, calculates the absorbed-dose and dose-equivalent rates in the center of the spherical shell shield with a tissue sphere of zero radius and calls subroutine BALL to compute dose rates at the center of the tissue sphere with a specified radius. Operations are performed as follows:

1. In the following operations, if IHAVAL (input parameter) = 0, only those values pertaining to protons are computed. If IXSØP (input parameter) = 0, only those values without attenuation are computed.

Core-storage restrictions require limiting the fluxes in the core to those at the current and previous shield thicknesses. Indices KEG and KEY are switched at every shield-thickness increment to keep track of where currently computed fluxes are to be stored.

2. At every step in shield thickness, subroutine BERP is called to evaluate the minimum possible lethargies, URP(KEY) and URAL(KEY), and the fluxes P and AL where

URP(KEY) = minimum proton lethargy at current shield thickness R(KEY);

URAL(KEY) = minimum alpha-particle lethargy at current shield thickness;

P(I,KEY,JPZ) = the proton flux at current shield thickness R(KEY), at lethargy U(I), rigidity PZ(JPZ), or altitude ALT(JPZ), without attenuation;

P(I,KEY+2,JPZ) = the proton flux with attenuation;

AL(I,KEY,JPZ) = the alpha-particle flux without attenuation;

AL(I,KEY+2,JPZ) = the alpha-particle flux with attenuation.

3. Compares previous shield thickness R(KEG) with the values in data statement IØPUT. If the shield thickness does not match, dose rates are not computed and the next increment in shield thickness is taken. If the current step is the first increment of shield thickness, the incident spectra [fluxes at R(KEG)] are printed out and also written on logical 8. Fluxes are converted to energy functions prior to output.

4. When the shield thickness R(KEG) does match a value in the data statement IØPUT, the absorbed-dose and dose-equivalent values are computed. IRPØUT is incremented and RRPØUT(IRPØUT) is set equal to R(KEG). Minimum lethargies URP(KEG) and URAL(KEG) are converted to maximum energies and saved in ERPØUT(IRPØUT,I). The integrands for the absorbed-dose and dose-equivalent integrals are computed. The value of $U(NUU_j)$ just greater than the minimum possible lethargy of the j-type particle is known from subroutine BERP which passes INØTP and INØTAL in common. INØTP is the index of the first nonzero proton flux value and INØTAL is the index of the first nonzero alpha-particle flux value. Subroutine SIMP is called to perform the integration from $U(NUU_j)$ to U(NØU). The dose-rate integrals from URP(KEG) to $U(NUU_p)$ and from URAL(KEG) to $U(NUU_\alpha)$ are calculated by assuming an exponential curve through the known integrands. Subroutine BALL is called to compute necessary fluxes at each depth increment in the tissue sphere and to calculate the absorbed-dose and dose-equivalent rates at the center of the tissue sphere.
5. Dose rates and associated parameters are saved in labeled common /TART/. Definitions of these variables are given in subroutine BALL.
6. IF IØUTFX (input parameter) = 1, fluxes at R(KEG) in the shield and at the center of the tissue sphere are converted to energy functions, printed out, and also written on logical 8.

III.11 SUBROUTINE MAT3X3

Subroutine MAT3X3 solves matrix equation EX = D for three equations in three unknowns.

III.12 SUBROUTINE PRØSIG

Subroutine PRØSIG computes the proton-nucleus-collision cross sections. Values of the microscopic cross sections are stored in data arrays. Interpolation is performed for both element and energy. The resulting i·-terpolated microscopic cross sections are converted to macroscopic cross sections and returned to the calling routines (MAIN for the shield materials and SETBAL for the tissue cross sections).

III.13 SUBROUTINE SETBAL

Subroutine SETBAL sets up parameters for the tissue sphere as follows:

1. If IHAVAL (input parameter) = 0, only the proton parameters are computed.
2. If IXSØP (input parameter) = 1, subroutines PRØSIG and ALFSIG are called to calculate cross sections, QPB and QALB, for proton and alpha particles in tissue.
3. Computes integrand functions, QESTPB(I) and QESTAB(I), for dose-equivalent calculations in subroutine BALL. Program MAIN evaluates ESTPB(I) and ESTAB(I), the stopping powers of proton and alpha particles in tissue at energy E(I) and evaluates the quality factor Q as a function of these stopping powers. Q(ESTPB(I)) and Q(ESTAB(I)) are passed through common as QESTPB(I) and QESTAB(I). Subroutine SETBAL then sets

   QESTPB(I) = ESTPB(I)*QESTPB(I)

   QESTAB(I) = ESTAB(I)*QESTAB(I) .

4. Sets SPB(I) = STP(I) and SALB(I) = STAL(I) where STP(I) and STAL(I) are the stopping powers for proton and alpha particles in tissue at lethargy U(I) passed through common from the MAIN program.

5. Subroutine SIMP2 is called to compute the integrals

$$\mathrm{SPINB(I)} = \int_{\mathrm{U(I-1)}}^{\mathrm{U(I)}} \frac{dU'}{\mathrm{SPB(U')}} \quad \text{with SPINB(1) = 0.0}$$

$$\mathrm{SALINB(I)} = \int_{\mathrm{U(I-1)}}^{\mathrm{U(I)}} \frac{dU'}{\mathrm{SALB(U')}} \quad \text{with SALINB(1) = 0.0}$$

$$\mathrm{DPB(I)} = \int_{\mathrm{U(I-1)}}^{\mathrm{U(I)}} \frac{\mathrm{QPB(U')}}{\mathrm{SPB(U')}}\, dU' \quad \text{with DPB(1) = 0.0}$$

$$\mathrm{DMALB(I)} = \int_{\mathrm{U(I-1)}}^{\mathrm{U(I)}} \frac{\mathrm{QALB(U')}}{\mathrm{SALB(U')}}\, dU' \quad \text{with DMALB(1) = 0.0} \quad .$$

The variables DPB(I) and DMALB(I) are used as temporary storage since these integrals are needed later in this subroutine for computing functions which are to be used in subroutine BALL.

6. Subroutine UALFA is called to obtain UPB(I), UALB(I), JPB(I), and JALB(I) as functions of U(I) and DR, the stepsize in the tissue sphere. UPB(I) is computed from

$$\int_{\mathrm{UPB(I)}}^{\mathrm{U(I)}} \frac{dU'}{\mathrm{SPB(U')}} = \mathrm{DR} \quad ;$$

UALB(I) is computed from

$$\int_{\mathrm{UALB(I)}}^{\mathrm{U(I)}} \frac{dU'}{\mathrm{SALB(U')}} = \mathrm{DR} \quad .$$

JPB(I) is the index such that

$$\mathrm{U(JPB(I)-2)} < \mathrm{UPB(I)} \le \mathrm{U(JPB(I))}$$

and JALB(I) is the index such that

$$U(JALB(I)-2) < UALB(I) \leq U(JALB(I)) .$$

JPB(I) and JALB(I) are used later in BERPB and TERP to locate values used in interpolation.

7. Subroutine SPACER is called to evaluate

$$SPSB(I,1) = SPB(UPB(I))$$

and

$$SALSB(I,1) = SALB(UALB(I)) .$$

With these values SETBAL computes

$$SPSB(I,1) = SPSB(I,1)/SPB(I)$$

and

$$SALSB(I,1) = SALSB(I,1)/SALB(I) .$$

8. If IXSØP ≠ 0, SETBAL computes SPSB(I,2) and SALSB(I,2) using integrals stored temporarily in DPB(I) and DMALB(I). These values are calculated with

$$SPSB(I,2) = SPSB(I,1)*\exp\left[-\int_{UPB(I)}^{U(I)} \frac{QPB(U')}{SPB(U')}\, dU'\right]$$

and

$$SALSB(I,2) = SALSB(I,1)*\exp\left[-\int_{UALB(I)}^{U(I)} \frac{QALB(U')}{SALB(U')}\, dU'\right] .$$

III.14 SUBROUTINE SIMP

Subroutine SIMP is a modified Simpson's rule integration which returns the integral from XX(1) to XX(I) in AX(I) using the five, eight, and minus one parabolic scheme to obtain the integrals of odd panels.

III.15 SUBROUTINE SIMP2

Subroutine SIMP2 performs parabolic integration with either evenly or unevenly spaced abscissa values. SIMP2 returns the integral from XX(1) to XX(I) in AX(I) or integral from XX(I-1) to XX(I) in AX(I). Panel-wise or accumulative integration is controlled by calling routines.

III.16 SUBROUTINE SPACER

Subroutine SPACER uses three-point Lagrangian interpolation on the logarithms of the function values if all three values are greater than zero. Otherwise, it uses the interpolation scheme directly on the function values. The actual interpolation is performed utilizing subroutine ALAG.

III.17 SUBROUTINE SPEC

Subroutine SPEC computes the differential kinetic energy solar-flare spectra for protons and alpha particles (if IHAVAL = 1). The subroutine is called from MAIN when ISPEC = 0. The spectra are computed as exponential functions of the characteristic rigidity RR and particle normalizations PNØRM and ANØRM. The energy normalization is specified by ENØRM.

The differential proton spectrum is returned to the MAIN program through common in DP1 for protons and DAL1 for alpha particles. These arrays are converted to lethargy functions and spaced out by interpolation to functions in the lethargy grid U.

III.18 SUBROUTINE TERP

TERP is the interpolation routine for computing the flux at the current thickness of the shield or depth in the tissue sphere. It uses either three-point Lagrangian or linear interpolation on the logarithms of the flux at the previous step in the shield or tissue sphere and multiplies that value by appropriate factors to get the flux at the current step. Calling routines BERP and BERPB pass arguments which determine the type of flux (protons or alpha particles), whether without or with attenuation, and whether in the shield or in the tissue sphere.

III.19 SUBROUTINE UALFA

UALFA evaluates UAL and IJ as functions of DR (stepsize in given material) and U(J). UAL is calculated from

$$\int_{UAL}^{U(J)} \frac{dU'}{S(U')} = DR \ .$$

The array TAB1(I) is passed in the argument list by the calling routine with

$$TAB1(1) = 0.0$$

$$TAB1(I) = \int_{U(I-1)}^{U(I)} \frac{dU'}{S(U')} \quad ,$$

where S(U') is the stopping power of either protons or alpha particles in the given material at lethargy U'. TAB1(I) is summed from U(J) down until the sum exceeds DR and then BINT is called to perform the back interpolation to evaluate UAL. IJ is then obtained as the index in U such that

$$U(IJ-2) < UAL \leq U(IJ) \ .$$

IJ is used later in subroutine TERP to locate values used in interpolation.

III.20 SUBROUTINE URALPB

URALPB computes the minimum possible lethargy of either protons or alpha particles at the current depth in the tissue sphere. Calling routine passes either SPINB or SALINB (computed in subroutine SETBAL) as the argument TAB1. Given the arrays U, TAB1, and URSH, the lowest lethargy value possible in the shield at current thickness of the shield, subroutine URALPB returns URN, the lethargy of the pseudo-point source at the current depth RRBALL in the tissue sphere. Conversion of the thickness of the shield to depth in tissue is made by summing TAB1(I) until U(I) is greater than URSH and I $\geq$ 3 and interpolating to find the equivalent depth in tissue. This depth is added to RRBALL to get a total depth of RR.

TAB1(I) is summed again until I $\geq$ 3 and the sum is greater than RR. Then function BINT is called for back interpolation in the partial sums as functions of lethargy U to find URN between U(I-2) and U(I). The argument TAB1(I) is defined as

$$\mathrm{TAB1}(1) = 0.0$$

$$\mathrm{TAB1}(\mathrm{I}) = \int_{\mathrm{U(I-1)}}^{\mathrm{U(I)}} \frac{dU'}{S(U')} \quad ,$$

where S(U') is either the proton or alpha-particle stopping power in tissue evaluated at lethargy U'.

III.21 SUBROUTINE URALPH

Subroutine URALPH computes the lowest possible value of lethargy for protons and alpha particles at the current value of shield thickness. The description of the subroutine is essentially the same as that given in Section III.20.

IV. PROGRAM USAGE

Before running any cases, the user should know what constitutes a stacked case since the number of stacked cases to be run must be input. A stacked case permits the running of up to ten incident spectra on the same shield with a fixed energy grid and fixed increments in shield thickness and tissue depth. For each stacked case, alpha particles are included for all of the incident spectra or none of them. Computations with cross sections are included for all spectra or none of them. Incident spectra for each stacked case must be of the same type, i.e., all Van Allen belt spectra (no alpha particles permitted), all solar-flare spectra computed internally with various rigidities, or all solar-flare spectra to be read in from data cards. If both protons and alpha particles are considered, the pair is counted as one incident spectrum.

As set up, the code permits output of fluxes and dose rates at 18 values of shield thickness from 2 to 100 g cm^{-2}, as well as output of the incident spectra. These values are determined by two data statements in subroutine MAC, and they can readily be changed to suit the user's needs.

In addition to logical 6 for output and logical 5 for input, logical 8 is needed for output if graphs of incident spectra, fluxes, and dose rates are to be obtained from the code TRAPPL.[24] If TRAPPL is not to be used, logical 8 can be a scratch disc file.

IV.1 INPUT-DATA DESCRIPTION

1st Card: Format (14I5)

NØKASE: The number of stacked cases to be run.

Then for each stacked case:

Card A: Format (3I5,12A4)

NØU: The number of energy points to be used for this case. NØU must be less than 151.

NELM: The number of elements comprising the shield (maximum of 10).

ICUT: If ICUT > 0, use cutoff energy ECUT, input on Card C; otherwise use ECUT = 0.1 fixed in the code.

TITLE(I): (I=1,12) Alphameric identification for printed output of dose rates; for example, shield material is aluminum.

Card B: Format (2F10.2,2I5)

DELR: Interval thickness in shield.

DELRB: Interval thickness in tissue sphere.

NØR: Number of radial intervals for the shield. NØR = maximum thickness of shield/DELR.

NØRB: Number of radial intervals for the tissue sphere. NØRB = maximum thickness of tissue sphere/DELRB.

Card C: Format (8F10.2)

EMAX: Maximum energy in MeV for this case. Must be ≤ 3000 MeV.

ECUT: Minimum energy in MeV for this case; not required unless ICUT > 0. If specified, ECUT must be ≥ 0.1 MeV.

Card(s) D_M: Format (8F10.2)

(AAA(I),RHØN(I),I=1,NELM)

AAA(I): The atomic weight of the Ith element comprising the shield. Must be 1 or > 12.

RHØN(I): The weight fraction of the Ith element comprising the shield.

Card E: Format (I4I5)

ISPEC: ISPEC = 0, compute solar-flare spectra internally.

ISPEC = 1, read solar-flare spectra in via cards.

ISPEC = 2, read Van Allen belt spectra in via cards.

IXSØP: IXSØP = 0, run without cross sections.

IXSØP = 1, run with and without cross sections.

IHAVAL: IHAVAL = 0, run without primary alpha particles.

IHAVAL = 1, run with primary alpha particles.

IØUTP: Not used at present.

IØUTFX: IØUTFX = 0, output only the incident spectra.

IØUTFX = 1, output incident spectra and fluxes at values of the shield thickness specified by data statements in subroutine MAC.

Cards F and G are dependent upon the type of spectra given by ISPEC on Card E. For ISPEC = 0, compute solar-flare spectra internally and read in Cards F and G as follows:

Card F: Format (3F15.5,I5)

PNØRM: The omnidirectional fluence of protons (no. cm^{-2}) in the flare with kinetic energy greater than ENØRM.

ANØRM: The omnidirectional fluence of alpha particles (no. cm^{-2}) in the flare with kinetic energy greater than ENØRM.

ENØRM: The normalization energy in MeV.

NØPZ: The number of characteristic rigidities at which solar-flare spectra are to be computed. Must be < 11.

Card(s) G: Format (8F10.2)

(PZ(I),I=1,NØPZ)

PZ(I): Characteristic rigidity (MV) of the solar flare.

For ISPEC = 1 or 2, read in solar-flare spectra or Van Allen belt spectra with Cards F and $G_{i,j}$ as follows:

Card F: Format (14I5)

NØPZ: Number of spectra to be read in; all must be solar-flare spectra (with or without alpha particles) or Van Allen belt spectra (only protons).

Card $G_{o,j}$: Format (I5,5X,3E15.5)

Only NØP(j) is used in calculations. The other quantities, PZ(j), ANGLE(j), and TIME(j), are only for identification.

NØP(j): Number of data points in spectrum being read in.

PZ(j): Rigidity (MV) of solar-flare spectrum or altitude (nautical miles) of Van Allen belt spectrum.

ANGLE(j): Blank if solar-flare spectrum; otherwise the orbital inclination angle (DEGREES) of Van Allen belt spectrum.

TIME(j): Blank if solar-flare spectrum; otherwise the time interval (DAYS) of Van Allen belt spectrum.

Cards $G_{i,j}$: Format (5X,3E15.7)

DP(i,j): Energy point (MeV) in spectra. Energy is increasing for each successive i.

DP1(i,j): Proton spectrum value at energy DP(i,j) for solar-flare spectra (no. cm^{-2} MeV^{-1}) and for Van Allen belt spectra [no. cm^{-2} MeV^{-1} $\{TIME(j)\}^{-1}$].

DAL1(i,j): Alpha-particle spectrum value at energy DP(i,j) for solar-flare spectra (no. cm^{-2} MeV^{-1}); blank if Van Allen belt spectra are incident on the shield or if there are no incident alpha particles.

Repeats Card $G_{i,j}$ for i = 1, NØP(j), then repeats from $G_{o,j}$ for next incident solar-flare spectrum or Van Allen belt spectrum with j = 1, NØPZ.

Card H: Format (14I5)

NØSP: The number of data points in the proton stopping-power table for the shield.

Card(s) J: Format (8F10.2)

(DP(I),DP1(I),I=1,NØSP)

DP(I): Energy point (MeV) in the proton stopping-power table. Energy decreases as I increases. Minimum energy must be less than or equal ECUT.

DP1(I): Differential stopping power for protons ($MeV*cm^2$ g^{-1}) in the shield evaluated at energy DP(I).

After this case is computed, the program repeats from Card A until NØKASE stacked cases have been run.

V. SAMPLE PROBLEM

As a sample problem, TRAPP has been used for solar-flare proton and alpha-particle spectra with characteristic rigidity of 100 MV incident on an aluminum spherical shell shield of maximum thickness of 100 g cm^{-2}. The radius of the tissue sphere, r_T, was taken to be 15 g cm^{-2}, and the incident particle spectra were obtained directly from the code. The sample problem gives the results of calculations with attenuation due to nuclear collisions both included and neglected. Table 2 lists the input data and Tables 3 through 10 display the output for this sample case. The sample problem ran in 57 seconds on the IBM 360/91 computer. Core-storage requirements were 340 K bytes.

TABLE 2

FORTRAN

CODED BY ____________

DATE ____________ REQUEST NO. ____________

PROBLEM: Sample Problem Data

PROGRAM: TRAPP

PAGE 1 OF 4

```
    1
  100    1    OSHIELD MATERIAL ALUMINUM
       0.5       0.5 200    30
    3000.0       0.1
      27.0       1.0
    0    1    1    0    0
        1.0E+09        1.0E+09            30.0    1
     100.0
   95
    5000.0    1.6668    4000.0    1.6432    3600.0    1.6344    3200.0    1.6267
```

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TABLE 2 (cont'd)

CODED BY ______ DATE ______ REQUEST NO. ______

FORTRAN

PROBLEM Sample Problem Data
PROGRAM TRAPP
PAGE 2 OF 4

2800.0	1.6211	2400.0	1.6196	2000.0	1.6258	1600.0	1.6477
1400.0	1.6696	1200.0	1.7046	1000.0	1.7607	960.0	1.7759
940.0	1.7841	920.0	1.7927	900.0	1.8019	880.0	1.8115
860.0	1.8217	840.0	1.8325	820.0	1.8440	800.0	1.8562
780.0	1.8691	760.0	1.8828	740.0	1.8973	720.0	1.9129
700.0	1.9294	680.0	1.9471	660.0	1.9659	640.0	1.9862
620.0	2.0078	600.0	2.0311	580.0	2.0562	560.0	2.0832
540.0	2.1123	520.0	2.1439	500.0	2.1782	480.0	2.2156
460.0	2.2563	440.0	2.3009	420.0	2.3500	400.0	2.4041
380.0	2.4640	360.0	2.5307	340.0	2.6053	320.0	2.6893

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TABLE 2 (cont'd)

CODED BY ____________ DATE ____________ REQUEST NO. ____________

FORTRAN

PROBLEM Sample Problem Data
PROGRAM TRAPP
PAGE 3 OF 4

300.0	2.7845	280.0	2.8931	260.0	3.0181	240.0	3.1636
220.0	3.3347	200.0	3.5388	190.0	3.6564	180.0	3.7865
170.0	3.9313	160.0	4.0932	150.0	4.2757	140.0	4.4827
130.0	4.7198	120.0	4.9940	110.0	5.3147	100.0	5.6952
90.0	6.1540	80.0	6.7186	70.0	7.4311	60.0	8.3601
50.0	9.6250	45.0	10.448	40.0	11.456	36.0	12.443
32.0	13.651	28.0	15.165	24.0	17.123	20.0	19.765
18.0	21.482	16.0	23.563	14.0	26.157	12.0	29.494
10.0	33.965	8.0	40.309	6.0	50.135	4.0	67.606
3.0	83.278	2.0	110.82	1.6	128.96	1.2	155.48

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TABLE 2 (cont'd)

CODED BY ____________

DATE ____________ REQUEST NO. ____________

FORTRAN

PROBLEM Sample Problem Data

PROGRAM TRAPP

PAGE 4 OF 4

```
       1.0    174.02        0.9    185.51       0.8    196.99       0.7   212.01
       0.6    229.99        0.5    251.99       0.4    276.04       0.3   305.58
       0.2    344.46       0.15    371.51       0.1    418.06
```


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TABLE 3

PROGRAM TRAPP

TR(ANSPORT OF) A(LPHA AND) P(ROTON) P(RIMARIES)

CASE NUMBER 1

YOU HAVE SPECIFIED THE FOLLOWING

SOLAR FLARES ARE TO BE COMPUTED INTERNALLY WITH NORMALIZATION ENERGY = 0.3000000E 02 MEV

THE NUMBER/CM**2 OF PROTONS IN THE FLARE WITH KINETIC ENERGY GREATER THAN ENORM ARE 0.1000000E 10

THE NUMBER/CM**2 OF ALPHAS IN THE FLARE WITH KINETIC ENERGY GREATER THAN ENORM ARE 0.1000000E 10

NUMBER OF FLARES COMPUTED AT CHARACTERISTIC RIGIDITIES ARE 1
RIGIDITY(1) = 0.1000000E 03(MV)

PRIMARY PROTONS AND ALPHAS FOR THIS CASE

CASE IS TO BE RUN WITH AND WITHOUT CROSS-SECTIONS

MAXIMUM ENERGY = 0.3000000E 04 MEV MINIMUM ENERGY = 0.9999996E-01 MEV WITH 100 ENERGY POINTS USED FOR CALCULATIONS

THE SHIELD IS COMPOSED OF 1 ELEMENTS
ATOMIC WEIGHT(1) = 27.00 WEIGHT FRACTION(1) = 0.1000000E 01

TABLE 4

E (MEV)	SP(E) (MEV*CM2/G)	STP(E) (MEV*CM2/G)	Q(STP(E))	SAL(E) (MEV*CM2/G)	STAL(E) (MEV*CM2/G)	Q(STAL(E))
3.0000000E 03	1.6234951E 00	2.0330515E 00	1.0000000E 00	7.5449371E 00	9.4289322E 00	1.0000000E 00
2.7033223E 03	1.6202173E 00	2.0323353E 00	1.0000000E 00	7.7867622E 00	9.7394705E 00	1.0000000E 00
2.4359836E 03	1.6194792E 00	2.0346870E 00	1.0000000E 00	8.0622997E 00	1.0093196E 01	1.0000000E 00
2.1950830E 03	1.6213388E 00	2.0401783E 00	1.0000000E 00	8.3752108E 00	1.0494136E 01	1.0000000E 00
1.9780054E 03	1.6264610E 00	2.0496397E 00	1.0000000E 00	8.7280407E 00	1.0946622E 01	1.0000000E 00
1.7823953E 03	1.6348476E 00	2.0630693E 00	1.0000000E 00	9.1243992E 00	1.1454879E 01	1.0000000E 00
1.6061296E 03	1.6471748E 00	2.0814323E 00	1.0000000E 00	9.5682344E 00	1.2023445E 01	1.0000000E 00
1.4472954E 03	1.6634426E 00	2.1047707E 00	1.0000000E 00	1.0062938E 01	1.2657962E 01	1.0000000E 00
1.3041687E 03	1.6843386E 00	2.1375141E 00	1.0000000E 00	1.0613224E 01	1.3364413E 01	1.0000000E 00
1.1751960E 03	1.7100849E 00	2.1609173E 00	1.0000000E 00	1.1224209E 01	1.4148690E 01	1.0000000E 00
1.0589783E 03	1.7410316E 00	2.1755724E 00	1.0000000E 00	1.1900337E 01	1.5017535E 01	1.0000000E 00
9.5425342E 02	1.7782211E 00	2.2181816E 00	1.0000000E 00	1.2648231E 01	1.5980872E 01	1.0000000E 00
8.5988477E 02	1.8217688E 00	2.2743511E 00	1.0000000E 00	1.3473331E 01	1.7042480E 01	1.0000000E 00
7.7484863E 02	1.8725595E 00	2.3396330E 00	1.0000000E 00	1.4382861E 01	1.8214584E 01	1.0000000E 00
6.9822192E 02	1.9309387E 00	2.4146662E 00	1.0000000E 00	1.5384492E 01	1.9506378E 01	1.0000000E 00
6.2917310E 02	1.9976997E 00	2.5003347E 00	1.0000000E 00	1.6485840E 01	2.0928467E 01	1.0000000E 00
5.6695190E 02	2.0735950E 00	2.5975742E 00	1.0000000E 00	1.7695679E 01	2.2493256E 01	1.0000000E 00
5.1088452E 02	2.1591740E 00	2.7074194E 00	1.0000000E 00	1.9023590E 01	2.4213043E 01	1.0000000E 00
4.6036182E 02	2.2555342E 00	2.8309155E 00	1.0000000E 00	2.0479599E 01	2.6101791E 01	1.0000000E 00
4.1483545E 02	2.3634644E 00	2.9691801E 00	1.0000000E 00	2.2074783E 01	2.8174637E 01	1.0000000E 00
3.7381152E 02	2.4838762E 00	3.1235971E 00	1.0000000E 00	2.3821152E 01	3.0448135E 01	1.0000000E 00
3.3684424E 02	2.6178923E 00	3.2956562E 00	1.0000000E 00	2.5731735E 01	3.2940292E 01	1.0000000E 00
3.0353271E 02	2.7667875E 00	3.4867563E 00	1.0000000E 00	2.7820419E 01	3.5670593E 01	1.0141029E 00
2.7351563E 02	2.9316645E 00	3.6985207E 00	1.0000000E 00	3.0102280E 01	3.8659424E 01	1.0806952E 00
2.4646710E 02	3.1140556E 00	3.9334879E 00	1.0000000E 00	3.2594009E 01	4.1930481E 01	1.1611614E 00
2.2209334E 02	3.3154039E 00	4.1924658E 00	1.0000000E 00	3.5313004E 01	4.5510498E 01	1.2594433E 00
2.0012997E 02	3.5373592E 00	4.4784393E 00	1.0000000E 00	3.8277344E 01	4.9421722E 01	1.3807125E 00
1.8033865E 02	3.7818785E 00	4.7937403E 00	1.0000000E 00	4.1509262E 01	5.3697205E 01	1.5626659E 00
1.6250450E 02	4.0508680E 00	5.1409073E 00	1.0000000E 00	4.5028885E 01	5.8370422E 01	1.7450562E 00
1.4643402E 02	4.3464527E 00	5.5230417E 00	1.0000000E 00	4.8858673E 01	6.3469620E 01	1.8597555E 00
1.3195279E 02	4.6708517E 00	5.9430780E 00	1.0000000E 00	5.3026978E 01	6.9036774E 01	1.9768429E 00
1.1890364E 02	5.0267010E 00	6.4044456E 00	1.0000000E 00	5.7558044E 01	7.5109161E 01	2.1632195E 00
1.0714487E 02	5.4165993E 00	6.9109240E 00	1.0000000E 00	6.2478836E 01	8.1731598E 01	2.3345213E 00
9.6549026E 01	5.8435669E 00	7.4664917E 00	1.0000000E 00	6.7819565E 01	8.8949326E 01	2.4789419E 00
8.7001053E 01	6.3107328E 00	8.0755606E 00	1.0000000E 00	7.3604401E 01	9.6812500E 01	2.6351471E 00
7.8397293E 01	6.8215275E 00	8.7428932E 00	1.0000000E 00	7.9905228E 01	1.0537148E 02	2.8243456E 00
7.0644394E 01	7.3796225E 00	9.4736290E 00	1.0000000E 00	8.6754791E 01	1.1468698E 02	3.0394001E 00
6.3658188E 01	7.9893045E 00	1.0273370E 01	1.0000000E 00	9.4143356E 01	1.2481866E 02	3.2697029E 00
5.7362869E 01	8.6545048E 00	1.1148682E 01	1.0000000E 00	1.0213553E 02	1.3583078E 02	3.5116348E 00
5.1690109E 01	9.3799524E 00	1.2105336E 01	1.0000000E 00	1.1078114E 02	1.4779814E 02	3.7417355E 00
4.6578339E 01	1.0170913E 01	1.3150910E 01	1.0000000E 00	1.2012492E 02	1.6078809E 02	3.9733105E 00
4.1972092E 01	1.1032508E 01	1.4293936E 01	1.0000000E 00	1.3021648E 02	1.7488203E 02	4.2152395E 00
3.7821365E 01	1.1970158E 01	1.5541489E 01	1.0000000E 00	1.4110692E 02	1.9016354E 02	4.4330091E 00
3.4081116E 01	1.2990712E 01	1.6903412E 01	1.0000000E 00	1.5285155E 02	2.0671881E 02	4.6595392E 00
3.0710754E 01	1.4100402E 01	1.8389282E 01	1.0000000E 00	1.6552751E 02	2.2461667E 02	4.9188967E 00
2.7673691E 01	1.5305745E 01	2.0009613E 01	1.0000000E 00	1.7919209E 02	2.4422844E 02	5.2393255E 00
2.4936966E 01	1.6614273E 01	2.1776337E 01	1.0000000E 00	1.9385797E 02	2.6525952E 02	5.5983410E 00
2.2470886E 01	1.8031799E 01	2.3700974E 01	1.0000000E 00	2.0953610E 02	2.8800220E 02	5.9914684E 00
2.0248657E 01	1.9573181E 01	2.5796326E 01	1.0000000E 00	2.2633723E 02	3.1255688E 02	6.4101677E 00
1.8246216E 01	2.1253113E 01	2.8076965E 01	1.0000000E 00	2.4438905E 02	3.3904858E 02	6.8584328E 00
1.6441803E 01	2.3065125E 01	3.0558105E 01	1.0000000E 00	2.6377612E 02	3.6764917E 02	7.3468609E 00
1.4815841E 01	2.5024734E 01	3.3254852E 01	1.0000000E 00	2.8455859E 02	3.9850977E 02	7.8745632E 00
1.3350661E 01	2.7144638E 01	3.6186127E 01	1.0251484E 00	3.0688013E 02	4.3168628E 02	8.4262466E 00

TABLE 4 (cont'd)

1.2030377E 01	2.9436111E 01	3.9368332E 01	1.0974312E 00	3.3086987E 02	4.6741895E 02	9.0127125E 00
1.0840666E 01	3.1911835E 01	4.2821838E 01	1.1845837E 00	3.5738599E 02	5.0584302E 02	9.6268215E 00
9.7686052E 00	3.4583588E 01	4.6566620E 01	1.2906771E 00	3.8543652E 02	5.4717944E 02	1.0254482E 01
8.8025627E 00	3.7465668E 01	5.0624680E 01	1.4282427E 00	4.1493945E 02	5.9149463E 02	1.0884238E 01
7.9320555E 00	4.0573425E 01	5.5015488E 01	1.6173067E 00	4.4586499E 02	6.4220288E 02	1.1504931E 01
7.1476345E 00	4.3929901E 01	5.9809952E 01	1.7938614E 00	4.7801025E 02	6.8850317E 02	1.2061561E 01
6.4407864E 00	4.7533035E 01	6.4975357E 01	1.8887348E 00	5.1189453E 02	7.3730884E 02	1.2666871E 01
5.8038406E 00	5.1390472E 01	7.0552139E 01	2.0184593E 00	5.4788062E 02	7.8913940E 02	1.3278148E 01
5.2298841E 00	5.5516510E 01	7.6576324E 01	2.2064962E 00	5.8606543E 02	8.4413892E 02	1.3851878E 01
4.7126875E 00	5.9950134E 01	8.3075989E 01	2.3613672E 00	6.2556323E 02	9.0103198E 02	1.4409692E 01
4.2466383E 00	6.4712280E 01	9.0084122E 01	2.5016394E 00	6.6628735E 02	9.5968628E 02	1.4947927E 01
3.8266735E 00	6.9833099E 01	9.7668396E 01	2.6524591E 00	7.0819653E 02	1.0200532E 03	1.5471703E 01
3.4482441E 00	7.5328461E 01	1.0581046E 02	2.8345098E 00	7.5117725E 02	1.0819580E 03	1.5966481E 01
3.1072388E 00	8.1205429E 01	1.1458307E 02	3.0370121E 00	7.9499268E 02	1.1450713E 03	1.6341507E 01
2.7999563E 00	8.7509308E 01	1.2402106E 02	3.2517881E 00	8.3950830E 02	1.2091873E 03	1.6727325E 01
2.5230618E 00	9.4236679E 01	1.3416582E 02	3.4757977E 00	8.8454126E 02	1.2740554E 03	1.7210953E 01
2.2735491E 00	1.0139259E 02	1.4507814E 02	3.6924763E 00	9.2992798E 02	1.3394194E 03	1.7749680E 01
2.0487118E 00	1.0899652E 02	1.5679881E 02	3.9029236E 00	9.7547388E 02	1.4050229E 03	1.8229614E 01
1.8461094E 00	1.1709154E 02	1.6939284E 02	4.1223946E 00	1.0223862E 03	1.4725945E 03	1.8619247E 01
1.6635437E 00	1.2564417E 02	1.8291270E 02	4.3376503E 00	1.0671653E 03	1.5370898E 03	1.8973053E 01
1.4990311E 00	1.3467543E 02	1.9742181E 02	4.5307961E 00	1.1066604E 03	1.5939800E 03	1.9269470E 01
1.3507881E 00	1.4416235E 02	2.1297606E 02	4.7484550E 00	1.1433174E 03	1.6467791E 03	1.9660110E 01
1.2172060E 00	1.5408864E 02	2.2963324E 02	4.9944191E 00	1.1785200E 03	1.6974849E 03	1.9907349E 01
1.0968332E 00	1.6441223E 02	2.4682021E 02	5.2832642E 00	1.2149832E 03	1.7500046E 03	2.0000000E 01
9.8836464E-01	1.7534317E 02	2.6696948E 02	5.6277609E 00	1.2480791E 03	1.7976711E 03	2.0000000E 01
8.9062256E-01	1.8646872E 02	2.8944116E 02	6.0164509E 00	1.2768198E 03	1.8390679E 03	2.0000000E 01
8.0254692E-01	1.9665900E 02	3.0992017E 02	6.3658962E 00	1.3008665E 03	1.8737034E 03	2.0000000E 01
7.2318023E-01	2.0829567E 02	3.3177783E 02	6.7348671E 00	1.3202622E 03	1.9016421E 03	2.0000000E 01
6.5166306E-01	2.2027754E 02	3.5643359E 02	7.1550016E 00	1.3340847E 03	1.9215510E 03	2.0000000E 01
5.8721846E-01	2.3266797E 02	3.8224365E 02	7.5966406E 00	1.3425686E 03	1.9337688E 03	2.0000000E 01
5.2914697E-01	2.4533441E 02	4.0882642E 02	8.0468473E 00	1.3461108E 03	1.9388694E 03	2.0000000E 01
4.7681826E-01	2.5715503E 02	4.3772046E 02	8.5259790E 00	1.3426760E 03	1.9339182E 03	2.0000000E 01
4.2966449E-01	2.6840308E 02	4.6870850E 02	9.0336399E 00	1.3322996E 03	1.9189788E 03	2.0000000E 01
3.8717389E-01	2.7943091E 02	5.0171265E 02	9.5619211E 00	1.3143325E 03	1.8930972E 03	2.0000000E 01
3.4888530E-01	2.9020459E 02	5.3668750E 02	1.0099652E 01	1.2891902E 03	1.8568875E 03	2.0000000E 01
3.1438315E-01	3.0084814E 02	5.7267139E 02	1.0621921E 01	1.2596191E 03	1.8142915E 03	2.0000000E 01
2.8329295E-01	3.1108643E 02	6.0979199E 02	1.1116845E 01	1.2259458E 03	1.7657891E 03	2.0000000E 01
2.5527740E-01	3.2109741E 02	6.4769360E 02	1.1570830E 01	1.1892915E 03	1.7129971E 03	1.9952652E 01
2.3003238E-01	3.3109302E 02	6.8592603E 02	1.2030543E 01	1.1489919E 03	1.6549553E 03	1.9710571E 01
2.0728391E-01	3.4105029E 02	7.2427588E 02	1.2506100E 01	1.1054014E 03	1.5921655E 03	1.9260269E 01
1.8678510E-01	3.5048706E 02	7.6432349E 02	1.2991395E 01	1.0589883E 03	1.5253118E 03	1.8909821E 01
1.6831344E-01	3.6013843E 02	8.0293115E 02	1.3430439E 01	1.0102578E 03	1.4551248E 03	1.8520340E 01
1.5166849E-01	3.7038330E 02	8.3813232E 02	1.3791284E 01	9.5971826E 02	1.3823333E 03	1.8073807E 01
1.3666946E-01	3.8125830E 02	8.6932129E 02	1.4102509E 01	9.0787427E 02	1.3076548E 03	1.7494400E 01
1.2315387E-01	3.9280200E 02	8.9595386E 02	1.4361250E 01	8.5521631E 02	1.2318137E 03	1.6875809E 01
1.1097491E-01	4.0505444E 02	9.1753833E 02	1.4564054E 01	8.0223267E 02	1.1554971E 03	1.6400818E 01
1.0000032E-01	4.1805908E 02	9.3367749E 02	1.4712855E 01	7.4936548E 02	1.0793503E 03	1.5946759E 01

TABLE 5

TABLE OF MACROSCOPIC CROSS SECTIONS

E (MEV)	PROTON XSECT SHIELD (CM2/G)	PROTON XSECT TISSUE (CM2/G)	ALPHA XSECT SHIELD (CM2/G)	ALPHA XSECT TISSUE (CM2/G)
0.3000000E 04	0.1063617E-01	0.1424420E-01	0.2522901E-01	0.4005936E-01
0.2703322E 04	0.1081671E-01	0.1437340E-01	0.2522901E-01	0.3963287E-01
0.2435984E 04	0.1087526E-01	0.1452985E-01	0.2522901E-01	0.3916479E-01
0.2195083E 04	0.1085160E-01	0.1470443E-01	0.2522901E-01	0.3863463E-01
0.1978005E 04	0.1083531E-01	0.1486422E-01	0.2522901E-01	0.3836617E-01
0.1782395E 04	0.1087843E-01	0.1481405E-01	0.2522901E-01	0.3816153E-01
0.1606130E 04	0.1094590E-01	0.1481181E-01	0.2522901E-01	0.3801264E-01
0.1447295E 04	0.1099836E-01	0.1475747E-01	0.2522901E-01	0.3792680E-01
0.1304169E 04	0.1099453E-01	0.1482768E-01	0.2522901E-01	0.3784474E-01
0.1175196E 04	0.1099109E-01	0.1492649E-01	0.2522901E-01	0.3781198E-01
0.1058978E 04	0.1099745E-01	0.1504497E-01	0.2522901E-01	0.3781198E-01
0.9542534E 03	0.1092386E-01	0.1497092E-01	0.2522901E-01	0.3786490E-01
0.8598848E 03	0.1076386E-01	0.1458357E-01	0.2522901E-01	0.3803786E-01
0.7748486E 03	0.1058544E-01	0.1413960E-01	0.2522901E-01	0.3825780E-01
0.6982219E 03	0.1039825E-01	0.1366997E-01	0.2522901E-01	0.3861608E-01
0.6291731E 03	0.1020935E-01	0.1319650E-01	0.2522901E-01	0.3902939E-01
0.5669519E 03	0.1002364E-01	0.1273411E-01	0.2522901E-01	0.3952374E-01
0.5108845E 03	0.9844579E-02	0.1229229E-01	0.2522901E-01	0.4021797E-01
0.4603618E 03	0.9524211E-02	0.1181244E-01	0.2522901E-01	0.4116496E-01
0.4148354E 03	0.9173740E-02	0.1134587E-01	0.2522901E-01	0.4213648E-01
0.3738115E 03	0.8978333E-02	0.1091597E-01	0.2522901E-01	0.4312908E-01
0.3368442E 03	0.8896552E-02	0.1059617E-01	0.2522901E-01	0.4419255E-01
0.3035327E 03	0.8716092E-02	0.1056257E-01	0.2522901E-01	0.4553079E-01
0.2735156E 03	0.8767974E-02	0.1058073E-01	0.2522901E-01	0.4689436E-01
0.2464671E 03	0.8971125E-02	0.1067120E-01	0.2522901E-01	0.4864646E-01
0.2220933E 03	0.9033702E-02	0.1084545E-01	0.2522901E-01	0.5054258E-01
0.2001300E 03	0.9054318E-02	0.1107121E-01	0.2522901E-01	0.5245744E-01
0.1803387E 03	0.9182811E-02	0.1131292E-01	0.2522901E-01	0.5455825E-01
0.1625045E 03	0.9345584E-02	0.1157047E-01	0.2522901E-01	0.5679931E-01
0.1464340E 03	0.9542558E-02	0.1185463E-01	0.2522901E-01	0.5934170E-01
0.1319528E 03	0.9803087E-02	0.1222372E-01	0.2522901E-01	0.6216377E-01
0.1189036E 03	0.1009072E-01	0.1262219E-01	0.2522901E-01	0.6519854E-01
0.1071449E 03	0.1039826E-01	0.1303940E-01	0.2522901E-01	0.6850672E-01
0.9654903E 02	0.1071880E-01	0.1350843E-01	0.2522901E-01	0.7200313E-01
0.8700105E 02	0.1106246E-01	0.1408910E-01	0.2522901E-01	0.7564700E-01
0.7839729E 02	0.1141044E-01	0.1470056E-01	0.2522901E-01	0.7947242E-01
0.7064439E 02	0.1175752E-01	0.1533087E-01	0.2522901E-01	0.8403152E-01
0.6365819E 02	0.1209953E-01	0.1596990E-01	0.2522901E-01	0.8887458E-01
0.5736287E 02	0.1243305E-01	0.1660895E-01	0.2522901E-01	0.9406054E-01
0.5169011E 02	0.1275550E-01	0.1724082E-01	0.2522901E-01	0.9974694E-01
0.4657834E 02	0.1314736E-01	0.1818802E-01	0.2522901E-01	0.1057224E 00
0.4197209E 02	0.1357571E-01	0.1933779E-01	0.2522901E-01	0.1119145E 00
0.3782137E 02	0.1399935E-01	0.2053196E-01	0.2522901E-01	0.1181692E 00
0.3408112E 02	0.1441397E-01	0.2175366E-01	0.2522901E-01	0.1250460E 00
0.3071075E 02	0.1481606E-01	0.2298764E-01	0.2522901E-01	0.1333494E 00
0.2767369E 02	0.1520292E-01	0.2422005E-01	0.2522901E-01	0.1399904E 00

TABLE 6

INCIDENT SPECTRUM
RIGIDITY OF FLARE = 1.0000000E 02 (MV)

E (MEV)	PROTON NO/MEV CM2	ALPHA NO/MEV CM2
3.0000000E 03	2.7558713E-09	4.4307744E-05
2.7033223E 03	5.9170027E-08	2.7388101E-04
2.4359836E 03	9.5455744E-07	1.4722107E-03
2.1950830E 03	1.1900232E-05	6.9729798E-03
1.9780054E 03	1.1765458E-04	2.9450059E-02
1.7823953E 03	9.4483281E-04	1.1214012E-01
1.6061296E 03	6.2955581E-03	3.8873774E-01
1.4472954E 03	3.5457898E-02	1.2371407E 00
1.3041687E 03	1.7186880E-01	3.6439123E 00
1.1751960E 03	7.2720039E-01	9.9970751E 00
1.0589783E 03	2.7258186E 00	2.5715851E 01
9.5425342E 02	9.1638145E 00	6.2364532E 01
8.5988477E 02	2.7915115E 01	1.4324492E 02
7.7484863E 02	7.7847275E 01	3.1304663E 02
6.9822192E 02	2.0054243E 02	6.5357617E 02
6.2917310E 02	4.8079858E 02	1.3079934E 03
5.6695190E 02	1.0808638E 03	2.5178696E 03
5.1088452E 02	2.2923086E 03	4.6751016E 03
4.6036182E 02	4.6117930E 03	8.3949492E 03
4.1483545E 02	8.8451797E 03	1.4612762E 04
3.7381152E 02	1.6245773E 04	2.4709914E 04
3.3684424E 02	2.8692152E 04	4.0677230E 04
3.0353271E 02	4.8921332E 04	6.5318559E 04
2.7351563E 02	8.0637063E 04	1.0238538E 05
2.4646710E 02	1.2918900E 05	1.5710900E 05
2.2209334E 02	2.0111513E 05	2.3596850E 05
2.0012997E 02	3.0606244E 05	3.4810781E 05
1.8033865E 02	4.5350788E 05	5.0314544E 05
1.6250450E 02	6.5996406E 05	7.1634050E 05
1.4643402E 02	9.4204738E 05	1.0037534E 06
1.3195279E 02	1.3174430E 06	1.3831780E 06
1.1890364E 02	1.8153070E 06	1.8815530E 06
1.0714487E 02	2.4645290E 06	2.5267100E 06
9.6549026E 01	3.2960720E 06	3.3489480E 06
8.7001053E 01	4.3467300E 06	4.3841640E 06
7.8397293E 01	5.6607600E 06	5.6748570E 06
7.0644394E 01	7.2861380E 06	7.2675950E 06
6.3658188E 01	9.2743320E 06	9.2128360E 06
5.7362869E 01	1.1684976E 07	1.1567889E 07
5.1690109E 01	1.4582475E 07	1.4395881E 07
4.6578339E 01	1.8028480E 07	1.7757648E 07
4.1972092E 01	2.2106928E 07	2.1733984E 07
3.7821365E 01	2.6880240E 07	2.6387696E 07
3.4081116E 01	3.2442224E 07	3.1808912E 07
3.0710754E 01	3.8900192E 07	3.8101840E 07
2.7673691E 01	0.0	0.0
2.4936966E 01	0.0	0.0
2.2470886E 01	0.0	0.0
2.0248657E 01	0.0	0.0
1.8246216E 01	0.0	0.0
1.6441803E 01	0.0	0.0
1.4815841E 01	0.0	0.0
1.3350661E 01	0.0	0.0
1.2030377E 01	0.0	0.0

TABLE 6 (cont'd)

1.0840666E 01	0.0	0.0
9.7686052E 00	0.0	0.0
8.8025627E 00	0.0	0.0
7.9320555E 00	0.0	0.0
7.1476345E 00	0.0	0.0
6.4407864E 00	0.0	0.0
5.8038406E 00	0.0	0.0
5.2298841E 00	0.0	0.0
4.7126875E 00	0.0	0.0
4.2466383E 00	0.0	0.0
3.8266735E 00	0.0	0.0
3.4482441E 00	0.0	0.0
3.1072388E 00	0.0	0.0
2.7999563E 00	0.0	0.0
2.5230618E 00	0.0	0.0
2.2735491E 00	0.0	0.0
2.0487118E 00	0.0	0.0
1.8461094E 00	0.0	0.0
1.6635437E 00	0.0	0.0
1.4990311E 00	0.0	0.0
1.3507881E 00	0.0	0.0
1.2172060E 00	0.0	0.0
1.0968332E 00	0.0	0.0
9.8836464E-01	0.0	0.0
8.9062256E-01	0.0	0.0
8.0254692E-01	0.0	0.0
7.2318023E-01	0.0	0.0
6.5166306E-01	0.0	0.0
5.8721846E-01	0.0	0.0
5.2914697E-01	0.0	0.0
4.7681826E-01	0.0	0.0
4.2966449E-01	0.0	0.0
3.8717389E-01	0.0	0.0
3.4888530E-01	0.0	0.0
3.1438315E-01	0.0	0.0
2.8329295E-01	0.0	0.0
2.5527740E-01	0.0	0.0
2.3003238E-01	0.0	0.0
2.0728391E-01	0.0	0.0
1.8678510E-01	0.0	0.0
1.6831344E-01	0.0	0.0
1.5166849E-01	0.0	0.0
1.3666946E-01	0.0	0.0
1.2315387E-01	0.0	0.0
1.1097491E-01	0.0	0.0
1.0000032E-01	0.0	0.0

TABLE 7

PROTONS AS INCIDENT PARTICLES SHIELD MATERIAL ALUMINUM
RIGIDITY OF FLARE = 100. (MV)

SHIELD DEPTH R,S (G/CM2)	ABSORBED DOSE R,T = 0.0 G/CM2 WITHOUT ATTENUATION RAD	ABSORBED DOSE R,T = 15.0 G/CM2 WITHOUT ATTENUATION RAD	ABSORBED DOSE R,T = 0.0 G/CM2 WITH ATTENUATION RAD	ABSORBED DOSE R,T = 15.0 G/CM2 WITH ATTENUATION RAD
2.00	2.1446030E 02	6.6112289E 00	2.0975462E 02	5.3573704E 00
3.00	1.3525841E 02	6.0317316E 00	1.3064166E 02	4.8428593E 00
5.00	7.1081772E 01	5.0564899E 00	6.7105057E 01	3.9883728E 00
7.00	4.4452652E 01	4.2790956E 00	4.1074356E 01	3.3167858E 00
10.00	2.5800735E 01	3.3849392E 00	2.3128326E 01	2.5548525E 00
15.00	1.2984715E 01	2.3641863E 00	1.1097775E 01	1.7082205E 00
20.00	7.5757637E 00	1.7065010E 00	6.1890135E 00	1.1799498E 00
25.00	4.8200083E 00	1.2630272E 00	3.7654133E 00	8.3617419E-01
30.00	3.2488136E 00	9.5446026E-01	2.4279079E 00	6.0468620E-01
35.00	2.2815742E 00	7.3244685E-01	1.6317625E 00	4.4426489E-01
40.00	1.6525850E 00	5.7114434E-01	1.1309614E 00	3.3170503E-01
45.00	1.2269917E 00	4.5100635E-01	8.0398142E-01	2.5056750E-01
50.00	9.2948079E-01	3.5916793E-01	5.8264923E-01	1.9093025E-01
60.00	5.5848438E-01	2.3446155E-01	3.2078892E-01	1.1410320E-01
70.00	3.5205448E-01	1.5740520E-01	1.8505877E-01	6.9901049E-02
80.00	2.3035508E-01	1.0810709E-01	1.1080831E-01	4.3827817E-02
90.00	1.5482777E-01	7.5909615E-02	6.7964733E-02	2.8016329E-02
100.00	1.0652548E-01	5.3997479E-02	4.2676553E-02	1.8120844E-02

TABLE 8

PROTONS AS INCIDENT PARTICLES SHIELD MATERIAL ALUMINUM
RIGIDITY OF FLARE = 100. (MV)

SHIELD DEPTH	DOSE EQUIVALENT R,T = 0.0 G/CM2 WITHOUT ATTENUATION	DOSE EQUIVALENT R,T = 15.0 G/CM2 WITHOUT ATTENUATION	DOSE EQUIVALENT R,T = 0.0 G/CM2 WITH ATTENUATION	DOSE EQUIVALENT R,T = 15.0 G/CM2 WITH ATTENUATION
R,S (G/CM2)	REM	REM	REM	REM
2.00	3.4758838E 02	7.9795351E 00	3.4060547E 02	6.4513826E 00
3.00	2.0672337E 02	7.2601299E 00	1.9996301E 02	5.8153687E 00
5.00	1.0177025E 02	6.0543213E 00	9.6149948E 01	4.7629795E 00
7.00	6.1289398E 01	5.0987158E 00	5.6644516E 01	3.9420271E 00
10.00	3.4317856E 01	4.0091181E 00	3.0753418E 01	3.0181246E 00
15.00	1.6660995E 01	2.7754679E 00	1.4222670E 01	2.0000401E 00
20.00	9.5019932E 00	1.9902678E 00	7.7505684E 00	1.3723421E 00
25.00	5.9502783E 00	1.4642210E 00	4.6395998E 00	9.6668422E-01
30.00	3.9631357E 00	1.1013794E 00	2.9558229E 00	6.9585162E-01
35.00	2.7560968E 00	8.4147316E-01	1.9670801E 00	5.0890946E-01
40.00	1.9814796E 00	6.5357250E-01	1.3529434E 00	3.7856477E-01
45.00	1.4611855E 00	5.1457858E-01	9.5536369E-01	2.8512836E-01
50.00	1.1011276E 00	4.0861458E-01	6.8871081E-01	2.1661657E-01
60.00	6.5532994E-01	2.6533133E-01	3.7563586E-01	1.2884092E-01
70.00	4.1032028E-01	1.7745948E-01	2.1521312E-01	7.8640163E-02
80.00	2.6688647E-01	1.2138242E-01	1.2817836E-01	4.9121447E-02
90.00	1.7858952E-01	8.5007906E-02	7.8277171E-02	3.1330056E-02
100.00	1.2229455E-01	6.0318790E-02	4.8939783E-02	2.0216778E-02

TABLE 9

ALPHAS AS INCIDENT PARTICLES SHIELD MATERIAL ALUMINUM
RIGIDITY OF FLARE = 100. (MV)

SHIELD DEPTH R,S (G/CM2)	ABSORBED DOSE R,T = 0.0 G/CM2 WITHOUT ATTENUATION RAD	ABSORBED DOSE R,T = 15.0 G/CM2 WITHOUT ATTENUATION RAD	ABSORBED DOSE R,T = 0.0 G/CM2 WITH ATTENUATION RAD	ABSORBED DOSE R,T = 15.0 G/CM2 WITH ATTENUATION RAD
2.00	7.4971985E 01	1.3987309E-01	7.1305511E 01	6.9854438E-02
3.00	3.3494766E 01	1.1760461E-01	3.1063736E 01	5.7302967E-02
5.00	1.0690390E 01	8.4513009E-02	9.4280481E 00	3.9239626E-02
7.00	4.5992823E 00	6.1770421E-02	3.8575907E 00	2.7288314E-02
10.00	1.7118998E 00	3.9617911E-02	1.3316221E 00	1.6254984E-02
15.00	4.8433191E-01	2.0108573E-02	3.3229762E-01	7.2925836E-03
20.00	1.7798555E-01	1.0795873E-02	1.0770667E-01	3.4623393E-03
25.00	7.6261640E-02	6.0891956E-03	4.0703818E-02	1.7244907E-03
30.00	3.6180425E-02	3.5567023E-03	1.7031979E-02	8.8886614E-04
35.00	1.8553562E-02	2.1449137E-03	7.7033713E-03	4.7416170E-04
40.00	1.0032091E-02	1.3313137E-03	3.6735984E-03	2.5937124E-04
45.00	5.6953765E-03	8.4211305E-04	1.8393546E-03	1.4478997E-04
50.00	3.3407505E-03	5.4279342E-04	9.5156720E-04	8.2465733E-05
60.00	1.2597817E-03	2.3824864E-04	2.7911575E-04	2.8218710E-05
70.00	5.1653665E-04	1.1010042E-04	8.9014109E-05	1.0141639E-05
80.00	2.2769772E-04	5.3037365E-05	3.0519324E-05	3.8089429E-06
90.00	1.0557067E-04	2.6629001E-05	1.1004725E-05	1.4893703E-06
100.00	5.0979143E-05	1.3757052E-05	4.1324402E-06	5.9793689E-07

TABLE 10

ALPHAS AS INCIDENT PARTICLES SHIELD MATERIAL ALUMINUM
RIGIDITY OF FLARE = 100. (MV)

SHIELD DEPTH R,S (G/CM2)	DOSE EQUIVALENT R,T = 0.0 G/CM2 WITHOUT ATTENUATION REM	DOSE EQUIVALENT R,T = 15.0 G/CM2 WITHOUT ATTENUATION REM	DOSE EQUIVALENT R,T = 0.0 G/CM2 WITH ATTENUATION REM	DOSE EQUIVALENT R,T = 15.0 G/CM2 WITH ATTENUATION REM
2.00	3.5702783E 02	3.8973022E-01	3.3971265E 02	1.8994230E-01
3.00	1.4621577E 02	3.2455546E-01	1.3565733E 02	1.5420532E-01
5.00	4.1782974E 01	2.2925401E-01	3.6862106E 01	1.0387707E-01
7.00	1.6713699E 01	1.6518593E-01	1.4022907E 01	7.1141124E-02
10.00	5.7653608E 00	1.0371077E-01	4.4860287E 00	4.1420218E-02
15.00	1.4975262E 00	5.1140614E-02	1.0277586E 00	1.8060539E-02
20.00	5.1913691E-01	2.6753865E-02	3.1423402E-01	8.3445348E-03
25.00	2.1274799E-01	1.4780432E-02	1.1358279E-01	4.0755756E-03
30.00	9.7377181E-02	8.4790550E-03	4.5852777E-02	2.0587407E-03
35.00	4.8582088E-02	5.0207041E-03	2.0176362E-02	1.0795838E-03
40.00	2.5591228E-02	3.0765336E-03	9.3737841E-03	5.8284169E-04
45.00	1.4246162E-02	1.9206565E-03	4.6021193E-03	3.2094866E-04
50.00	8.2033910E-03	1.2231017E-03	2.3372306E-03	1.8031741E-04
60.00	2.9995015E-03	5.2524940E-04	6.6474825E-04	6.0475519E-05
70.00	1.1991088E-03	2.3868759E-04	2.0670322E-04	2.1355852E-05
80.00	5.1727076E-04	1.1313641E-04	6.9353177E-05	7.8818066E-06
90.00	2.3577640E-04	5.6069519E-05	2.4586014E-05	3.0456813E-06
100.00	1.1197948E-04	2.8639333E-05	9.0806898E-06	1.2085366E-06

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