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SUMMARY

A computer program has been developed which will calculate the particle spectra and dose behind multilayer, infinite slabs of shielding from any given energy spectrum of protons impinging normally on the shield. Both spectra and dose are calculated for the incident primary protons that penetrate the shield and for the following types of secondary radiation produced in the shield: cascade protons, cascade neutrons, and evaporation neutrons. This program is written in Fortran IV for the IBM 7094 II computer.

INTRODUCTION

Space vehicles may require shielding to protect astronauts and radiation sensitive components from the hazards of space radiation, the most hazardous of which appears to be the proton radiation. The important sources of proton radiation are the Van Allen belts, solar flares, and galactic cosmic radiation. When space vehicles are irradiated by protons the interaction of protons with atomic nuclei in the vehicle produces secondary nucleons. The most important of these secondary nucleons appears to be the cascade protons, cascade neutrons, and evaporation neutrons. In order to evaluate the shielding requirements it is necessary to evaluate the dose caused by primary and secondary radiation.

Previous computer programs on space radiation shielding have been written by (at least) three groups (see refs. 1 to 3).

References 1 and 2 used the 1958 data of Metropolis et al. for estimating the dose from secondary radiation. The reference 3 program was not designed for general distribution. Recently H. Bertini of ORNL (ref. 4) developed a Monte Carlo program (with an improved nuclear model compared to previous work) for estimating the yields of secondaries and their energies. These reasons combined with the fact that the Lewis computer is now restricted to Fortran IV provided the motivation at the Lewis Research Center to develop a computer program capable of calculating the doses from primary proton and secondary radiation produced in the shield.

The Lewis program (called LPSC) calculates the particle spectra and dose inside a multilayer slab shield due to protons impinging normally on the outer face of the shield. The slabs are infinite in extent and have finite thickness. Spectra and doses may also be calculated at intermediate thicknesses through the shield known as print bounds.

The total dose evaluated includes the doses from primary protons and the secondary radiation consisting of cascade protons, cascade neutrons, and evaporation neutrons. Evaporation protons contribute a negligible amount to the total dose. Other secondary radiation (heavy particles, pions, secondary gammas, etc.) are not evaluated by this program. The flux spectra of the primary protons, cascade protons, and cascade neutrons are calculated in this program.

This program calculates the penetration of normally incident protons, cascade protons, and cascade neutrons using a straight ahead approximation (the primary particle and cascade secondaries are emitted in the same direction as the primary incident particle). This approximation has been shown by reference 5 to be valid for protons with energies $\geq$100 MeV. For energies $<$ 100 MeV this method may over estimate the dose. The evaporation neutrons were assumed to be emitted isotropically.

It may be shown, using the straight-ahead approximation, that the dose received at the center of a sphere due to an isotropic flux outside of the sphere is the same as the dose received behind a slab shield of the same thickness where a flux of the same magnitude is impinging normally to the slab. This will also be true for doses from those secondary particles assumed to be emitted in the direction of the primary particles. Thus the slab doses calculated for the normally incident primary protons and the cascade secondaries will be the same as the doses at the center of the sphere for an isotropic flux outside; however, the evaporation neutron doses are not simply related and pertain only to the slab geometry.

A description of the program and program listing are found on pages 16-32 and 46-73.

SYMBOLS

Some of the symbols used in this report are listed below. Other symbols are defined in the text.

D_{cn} — dose from cascade neutrons, rad or rad/hr and rem or rem/hr

D_{cp} — dose from cascade protons, rad or rad/hr and rem or rem/hr

D_{en} — dose from evaporation neutrons, rad or rad/hr and rem or rem/hr

D_{pp} — dose from primary protons, rad or rad/hr and rem or rem/hr

E — energy in MeV

$G(X_k,\theta_m)$ — attenuation kernel for evaporation neutrons see text for dimensions

$N(>E)$	number of protons with energy greater than E, protons/cm^2 or protons/cm^2 sec
$N(>P)$	number of protons with rigidity greater than P, protons/cm^2 or protons/cm^2 sec
$N(\overline{E}_i, X)$	the primary proton flux at energy $\overline{E}_i$ at depth X, protons/cm^2 or protons/cm^2 sec
$N_{cp}(\overline{E}_j, X_\xi)$	cascade proton flux with energy $\overline{E}_j$ which penetrates the shield, protons/cm^2 or protons/cm^2 sec
$N_{cn}(\overline{E}_j, X_\xi)$	cascade neutron flux with energy $\overline{E}_j$ which penetrates the shield, neutrons/cm^2 or neutrons/cm^2 sec
${}_cN_p(\overline{E}_i, E_j, \delta X_k)$	cascade neutrons with energy E_j produced by incident protons with energy $\overline{E}_i$ in layer δX_k, neutrons/cm^2 or neutrons/cm^2 sec
${}_eN_p(\overline{E}_i, \delta X_k)$	evaporation neutrons produced by protons with energy $\overline{E}_i$ in layer δX_k, neutrons/cm^2 or neutrons/cm^2 sec
${}_cN_n(\overline{E}_i, E_j, \delta X_k)$	cascade neutrons with energy E_j produced by neutrons with energy $\overline{E}_i$ in layer δX_k, neutrons/cm^2 or neutrons/cm^2 sec
${}_eN_n(\overline{E}_i, \delta X_k)$	evaporation neutrons produced by neutrons with energy $\overline{E}_i$ in layer δX_k, neutrons/cm^2 or neutrons/cm^2 sec
${}_cP_p(\overline{E}_i, E_j, \delta X_k)$	cascade protons with energy E_j produced by protons with energy $\overline{E}_i$ in layer δX_k, protons/cm^2 or protons/cm^2 sec
${}_cP_n(\overline{E}_i, E_j, \delta X_k)$	cascade protons with energy E_j produced by neutrons with energy $\overline{E}_i$ in layer δX_k, protons/cm^2 or protons/cm^2 sec
X	depth into the shield, g/cm^2
$y_{cpp}(\overline{E}_i, E_j)$	yield of cascade protons with energy E_j per interacting proton with energy $\overline{E}_i$
$y_{cnp}(\overline{E}_i, E_j)$	yield of cascade neutrons with energy E_j per interacting proton with energy $\overline{E}_i$
$y_{enp}(\overline{E}_i)$	yield of evaporation neutrons per interacting proton with energy $\overline{E}_i$

$y_{cpn}(\overline{E}_i,E_j)$ yield of cascade protons with energy E_j per interacting neutron with energy $\overline{E}_i$

$y_{cnn}(\overline{E}_i,E_j)$ yield of cascade neutrons with energy E_j per interacting neutron with energy $\overline{E}_i$

$y_{enn}(\overline{E}_i)$ yield of evaporation neutrons per interacting neutron with energy $\overline{E}_i$

$n(\overline{E}_i,X)$ neutron flux with energy $\overline{E}_i$ at depth X, neutrons/cm^2 or neutrons/cm^2 sec

P rigidity, MV

METHOD OF CALCULATION

Introduction to Method of Calculation

The initial flow of a calculation progresses as follows; see figure 1. The computer reads in a maximum incident energy E(Max) in MeV at (1). Using the proton range energy data an E(Max) at the exit face (2) is calculated. The desired energy group bounds E_1, E_2, . . . E_n, E(Max) are read in and assumed at the exit face (3). ΔE values are calculated by $\Delta E_1 = (E_1 - 0)$, $\Delta E_2 = (E_2 - E_1)$, . . ., $\Delta E_n = (E(Max) - E_n)$. The number of small δE's contained in each ΔE_i are read. The ΔE_i's and δE's enable the computer to calculate the energy bounds on the exit face. Then the energy bounds are calculated on the incident face (4). The number of protons in each energy group are calculated and the production of secondary particles and the attenuation of all particles for each group is accomplished.

Figure 1 shows three print bounds at B, C, and D where data are printed. Incident proton dose is calculated at the incident face A also.

Proton Energy Groups and Spectra

This program allows the user a choice of reading in the incident energy boundaries or the exit energy boundaries. The use of exit energy boundaries is to be preferred for running a proton energy spectrum. Reading in the incident energy boundaries are preferred for a monoenergetic case.

Some of the details for the case where exit energy boundaries are assumed are as follows:

Tables of range versus energy are supplied as input data for the shield materials being investigated. The Lagrange 2 point interpolation equation is used to interpolate in the tables. The program selects the maximum incident energy E(Max) and calculates the range associated with this energy for the first shield material encountered, R(E(MAX), Material 1) = R(E,1). The thickness T(1) of this first layer is then substracted from R(E,1). The residual range r(E(1),1) of this proton group after passing through T(1) is given by r(E(1),1) = R(E,1) - T(1). The energy E(1) associated with r(E(1),1) is calculated and the range for a proton of this energy in the next material is calculated. The thickness of this layer is then subtracted off and this process is repeated until the maximum energy at the exit face of the shield has been computed.

When the maximum energy at the exit face of the shield is known, the program calculates the energy bounds at the exit face according to the input data. There are two degrees of subdivision for the energy bounds. ΔE represents a large interval and δE represents a small interval. The ΔE boundaries are used as convenient points at which the magnitude $\delta E(J)$ is to change.

The interval bounds of ΔE and the number n of $\delta E(J)$ in each ΔE at the exit face are input data. The $\delta E(J)$ values are calculated by the program. The energy bounds E(I) and energy intervals $\delta E(I)$ on the incident face corresponding to the energy bounds E(J) and energy intervals $\delta E(J)$ on the exit face are then calculated. The average energy of each group I is calculated by,

$$\bar{E}(I) = \frac{E(I + 1) + E(I)}{2} \qquad (I)$$

The average energy $\bar{E}(I)$ is used to calculate the cross sections, yields, and energy of secondary particles. The average energy incident on the next layer is obtained by degrading the energy bounds and calculating a new $\bar{E}(I)$. This is due to the nonlinear change in δE which makes $\bar{E}(I)$ degraded not equal to the new average energy.

The incident energy associated with zero energy at the exit face of the shield is not the minimum incident energy considered because lower energy protons, although they do not penetrate the shield, may produce secondary neutron radiation that can penetrate the shield. The procedure used for finding incident energy intervals below this energy is illustrated by the following example.

Figure 1 shows four print bounds A, B, C, and D. At D, E(0) = 0 MeV is the zero energy point on the exit face of the shield. Similarly there exists a zero energy point at each print bound. At print bound C the energy interval from E(0) = 0 to $E_{0,C}$ is subdivided by the program in one of two ways. (1) This interval may be subdivided the same as this corresponding interval on the exit face D or a new set of subdivisions may be read in. The corresponding intervals on the incident face are found. (2) This interval may be divided into an equal number of increments. The other print bounds will be handled in the same manner.

It was found by running the program that if the same energy bounds were used for neutrons as for protons the neutrons tended to cluster into a few energy groups. Therefore to improve the distribution of dose with energy separate energy bounds were required for neutrons and protons. The neutron energy bounds are read in as a table.

The incident proton spectra may be simulated by one of the following equations. Let either $N(>E)$ or dN/dE be given by $\Gamma(E)$ as indicated in equations (2) and (3).

$$\Gamma(E) = N(>E) \tag{2}$$

or

$$\Gamma(E) = dN/dE \tag{3}$$

then $\Gamma(E)$, the proton spectrum, may be calculated by any one of equations (4), (5), (6), or (7).

$$\Gamma(E) = A\ E^{-B} \tag{4}$$

$$\Gamma(E) = A(E)\exp(-B(E)) \tag{5}$$

$$\mathrm{Log}\ (\Gamma(E)) = \sum_{i=1}^{4} A_i\ E^{i-1} \tag{6}$$

$$\mathrm{Log}\ (\Gamma(E)) = \sum_{i=1}^{4} A_i(\mathrm{Log}\ E)^{i-1} \tag{7}$$

Where the constants A, B or A_i are selected compatible with either equation (2) or (3). See page 26 for a definition of $A(E)$ and $B(E)$. The program will also accept rigidity spectra where

$$\Gamma(P) = N(>P) \tag{8}$$

$$\Gamma(P) = dN/dP \tag{9}$$

then

$$\Gamma(P) = A \exp(-P/P_o) \tag{10}$$

If equations (2) through (10) fail to represent the desired spectrum a table of values may be read in for $N(>E)$ or dN/dE as a function of energy.

When the spectrum is read in as a table the values of dN/dE or $N(>E_i)$, whichever the table contains, will be read and/or interpolated for each value of E_i required by the program.

When the choice of spectrum (equation or table) has been made, the continuous input spectrum is approximated by selecting a finite number of proton energy groups. The number of protons in each group is calculated. For the differential spectrum the number of protons in the i^{th} group is given by

$$N(\overline{E},0) = \left(\frac{dN}{dE}\right)_{\overline{E}_i} \cdot \delta E_i \tag{11}$$

The width of the i^{th} energy interval is δE_i. The midpoint of the i^{th} interval is $\overline{E}_i$. The quantity $(dN/dE)_{\overline{E}_i}$ is calculated from one of the equations or a table.

For the integral spectrum, the number of protons in the i^{th} group is given by

$$N(\overline{E}_i,0) = N(>E_i) - N(>E_{i+1}) \tag{12}$$

When running a monoenergetic case one should select a finite interval width δE such that the midpoint of δE is the required energy E_{mp}. A small δE on the order of 10^{-2} MeV is recommended here. The calculation is not very sensitive to δE where $10^{-3} \leq \delta E \leq 0.1$ MeV. For $\delta E < 10^{-3}$ significant figures are lost during substraction.

Proton Attenuation and Production of Secondaries

When protons penetrate a shield energy is lost due to ionization interactions. The range in a given material and rate of energy loss per unit path length are energy dependent. Protons that are stopped by ionization are removed from the beam. Incident protons which experience inelastic collisions with nuclei in the shield are removed from the beam. The secondary protons and neutrons produced in these inelastic collisions are added to the beam.

Secondary particles are produced by primary protons, cascade protons, and cascade neutrons. Secondaries produced by evaporation neutrons are not calculated by LPSC.

The secondary particles are calculated as follows: The various slabs of materials in the shield are divided into increments δX_k thick and print boundaries X_q (see fig. 2). The print bounds are locations within the shield at which data are printed. The δX_k are used as secondary source regions throughout the shield. Between two consecutive print bounds all δX_k values are the same. When a print bound is crossed the δX_k are again all equal but they may be different (in number and/or size) from those in the previous region.

Indexing presents a problem in a calculation of this nature. In general the index i or I is used to indicate incident particle energies and j or J for exit or secondary particle energies. At an internal boundary the energies incident on the K^{th} layer are the same as those that exit the K-1 boundary. However, even though these energies are the same when viewed as incident particles the subscript i or I will be used and when viewed as exit particles the subscript j or J will be used. One exception will be found in the dose calculation where the exit primary proton energies retain the index i to prevent confusion with secondary particle energies which use the subscript j. These primary particles that exit the shield may be considered incident on a detector to preserve the above rules.

Let $N(\overline{E}_i,X)$ be the number of protons/cm^2 (or protons/cm^2 sec) in each energy group $\overline{E}_i$ at depth X into the shield which are incident on a layer δX_k. Let $N(\overline{E}_j,X + \delta X_k)$ represent the number of protons at energy E_j from $N(\overline{E}_i,X)$ which pass through δK_k without experiencing a nuclear interaction. A drop in energy from $\overline{E}_i$ to $\overline{E}_j$ occurs due to ionization. Let $\Sigma_p(\overline{E}_i)$ be the macroscopic cross section in cm^2/g for proton inelastic collisions. The two quantities $N(\overline{E}_i,X)$ and $N(\overline{E}_j,X + \delta X)$ are related by

$$N(\overline{E}_j,X + \delta X) = N(\overline{E}_i,X) \exp\left(-\Sigma_p(\overline{E}_i) \cdot \delta X_k\right) \tag{13}$$

Since $\exp\left(-\Sigma_p(\overline{E}_i) \cdot \delta X_k\right)$ is the probability that no interactions occur in δX_k then $[1 - \exp(-\Sigma_p(\overline{E}_i) \cdot \delta X_k)]$ is the probability that an interaction does occur in δX_k. Hence the number in $N(\overline{E}_i,X)$ that interact in δX_k is given by $N(\overline{E}_i,X)[1 - \exp(-\Sigma_p(\overline{E})\delta X_k)]$. Let $y_{cpp}(\overline{E}_i,E_j)$ be the average yield of cascade protons at energy E_j produced by an interacting proton at energy $\overline{E}_i$. Let ${}_cP_p(\overline{E}_i,E_j,\delta X_k)$ be the cascade protons at energy E_j produced by protons of energy $\overline{E}_j$ in layer δX_k. The secondary group is related to the incident group by

$${}_cP_p(\overline{E}_i,E_j,\delta X_k) = N(\overline{E}_i,X) \left\{1 - \exp[-\Sigma_p(\overline{E}_i)\delta X_k]\right\} y_{cpp}(\overline{E}_i,E_j) \tag{14}$$

Similarly let ${}_{c}N_{p}(\overline{E}_i,E_j,\delta X_k)$ be the cascade neutrons and $y_{cnp}(\overline{E}_i,E_j)$ the average yield of cascade neutrons. Then the cascade neutrons are related to the incident protons by

$$ {}_{c}N_{p}(\overline{E}_i,E_j,\delta X_k) = N(\overline{E}_i,X)\left\{1 - \exp[-\Sigma_p(\overline{E}_i)\delta X_k]\right\} y_{cnp}(\overline{E}_i,E_j) \tag{15}$$

Let ${}_{e}N_{p}(\overline{E}_i,\delta X_k)$ be the yield of evaporation neutrons produced by the incident proton group $N(\overline{E}_i,X)$. Let $y_{enp}(\overline{E}_i)$ be the average yield of evaporation neutrons per interacting proton at energy $\overline{E}_i$. The evaporation neutrons are assumed to have a fission spectrum. The evaporation neutrons produced are related to the incident protons by

$$ {}_{e}N_{p}(\overline{E}_i,\delta X_k) = N(\overline{E}_i,X)\left\{1 - \exp[-\Sigma_p(\overline{E}_i)\delta X_k]\right\} y_{enp}(\overline{E}_i) \tag{16}$$

When neutrons are incident on a layer δX_k with sufficient energy $\overline{E}_i$ to produce secondaries a similar set of equations can be written

$$ {}_{c}P_{n}(\overline{E}_i,E_j,\delta X_k) = n(\overline{E}_i,X)\left\{1 - \exp[-\Sigma_n(\overline{E}_i)\delta X_k]\right\} y_{cpn}(\overline{E}_i,E_j) \tag{17}$$

$$ {}_{c}N_{n}(\overline{E}_i,E_j,\delta X_k) = n(\overline{E}_i,X)\left\{1 - \exp[-\Sigma_n(\overline{E}_i)\delta x_k]\right\} y_{cnn}(\overline{E}_i,E_j) \tag{18}$$

$$ {}_{e}N_{n}(\overline{E}_i,\delta X_k) = n(\overline{E}_i,X)\left\{1 - \exp[-\Sigma_n(\overline{E}_i)\delta X_k]\right\} y_{enn}(\overline{E}_i) \tag{19}$$

where $n(\overline{E}_i,X)$ represents the incident neutrons/cm^2 (or neutrons/cm^2 sec) at energy $\overline{E}_i$ at depth X and $\Sigma_n(\overline{E}_i)$ represents the neutron inelastic cross sections in cm^2/g. Equations (17), (18) and (19) give the cascade protons, cascade neutrons, and evaporation neutrons, respectively.

The secondary particles produced in a layer δX_k are placed at the center of this layer for calculating attenuation through the remainder of the shield. These secondaries are attenuated across the half layer $\delta X_k/2$ (in which they were born) by removing those that experience inelastic collisions. No higher generation secondary production is calculated in this half layer due to the secondaries that were born here.

Particle penetration through each δX_k is accomplished using the straight ahead approximation except for evaporation neutrons which are assumed to be emitted isotropically.

The data from reference 4[1] gives secondary yields, energies of secondaries, and inelastic cross sections at energies 25 MeV $\leq E \leq$ 400 MeV for C, O, Al, W, Pb, and U for protons and neutrons bombarding. Data for N, Ti, and Fe were obtained by interpolating the data from reference 4 as a function of mass number.

The secondary particle data tables in LPSC contain data up to 1000 MeV. The secondary yields and energy of secondaries were extrapolated from 400 MeV to 1000 MeV by fairing in a curve. For neutron and proton energies > 400 MeV the inelastic cross sections at 400 MeV are used. Low energy (<25 MeV) neutron cross section data were taken from the literature.

The proton cross section tables contain entries in the energy range 10 MeV to 1000 MeV for hydrogenous materials. For nonhydrogenous materials the proton cross section tables contain data in the energy range 25 MeV to 400 MeV. When data beyond the range of the tables are required for yields and energy of secondaries the program will extrapolate the tables using a 2 point Lagrange interpolation equation. If neutron cross sections are called for below the minimum value in the table the cross section is set equal to zero. The proton range energy table contains data up to 10^5 MeV.

The yields for cascade neutrons emitted when cascade neutrons are incident were carried to the low energy threshold for inelastic scattering by assuming the yield below 25 MeV would be given by the ratio $\sigma_{n,n'}/\sigma_{n,x}$. Where $\sigma_{n,n'}$ is the inelastic scattering cross section and $\sigma_{n,x}$ is the total inelastic cross section. This was accomplished for the following materials in this program: carbon, oxygen, nitrogen, aluminum, titanium, iron, uranium, water and polyethylene. For lead and tungsten the n, 2n cross section was included for energies $\leq$ 15 MeV.

Attenuation of Secondaries

The cascade protons are attenuated in the same manner as the primary protons.

The straight ahead approximation is used for both cascade protons and cascade neutrons. Additional generations of secondaries produced by secondaries for both cascade protons and cascade neutrons are calculated or deleted on command.

In this program cascade neutrons are assumed to experience inelastic collisions with nuclei having mass numbers >9. This interaction assumes that the incident neutron was absorbed followed by the emission of secondary cascade

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[1] Reference 4 also gives data for other elements not used in LPSC.

and evaporation particles. This is the same type interaction described for protons only now the bombarding particles are neutrons. Elastic collisions of cascade neutrons with nuclei heavier than the neutron tend to produce small deflections which result in small energy loss, hence a small attenuation.

Elastic collisions of cascade neutrons in hydrogen do have a significant effect on attenuation. This results because the mass of the target is nearly equal to the mass of the incident particle. Some simplifying assumptions were made regarding the elastic collision process in hydrogen. The energy of a neutron scattered off a hydrogen nucleous was averaged (and weighted using differential cross sections) over all angles of scattering. The recoil nucleous was assigned an energy which was the difference between the incident neutron energy and the scattered neutron energy. Both the neutron and proton were assumed to be emitted in the direction of the incident neutron. Tables of scattered neutron energies and recoil nucleous energies were calculated for several incident neutron energies.

The elastic collision of a proton on hydrogen nuclei was assumed to yield two protons both having the same direction as the incident particle and each proton having half the energy of the incident particle.

The above assumptions for neutrons and protons enables data tables to be constructed for hydrogen similar to the secondary particle data tables for the other materials.

The method used to attenuate the dose from evaporation neutrons is similar to the one described in reference 2. The details of this calculation are presented in the section on dose calculations.

The data tape for the LPSC program contains beryllium as the only choice of shield material which does not contain secondary yields. The incident proton spectrum is attenuated by ionization only.

Primary and Cascade Proton Dose

The primary proton flux $N(\overline{E}_i, X_\xi)$ which penetrates the shield is converted to dose in rads by multiplying by the stopping power dE/dX (for water or tissue) and a unit conversion factor U. U is in rad g/MeV or rad g sec/MeV hr depending on the units of $N(\overline{E}_i, X_\xi)$. Let the primary proton rad dose be given by D_{pp} then

$$D_{pp} = U \sum_{i=1}^{I} N(\overline{E}_i, X_\xi) \left(\frac{dE}{dX}\right)_{\overline{E}_i} \tag{20}$$

The rem dose is given by

$$D_{pp} = U \sum_{i=1}^{I} N(\overline{E}_i, X_\xi)\left(\frac{dE}{dX}\right)_{\overline{E}_i} RBE(\overline{E}_i) \tag{21}$$

The RBE factors as a function of proton energy are inserted in the program as a table The RBE data was obtained from reference 6.

Equations (20) and (21) are used to calculate the dose in rad and rem, respectively, for cascade protons where $N(\overline{E}_i, X_\xi)$ is replaced by $N_{cp}(\overline{E}_j, X_\xi)$, summation is accomplished over the index j which represents cascade proton energies, and $(dE/dX)_{\overline{E}_j}$.

Since dE/dX increases with a decrease in E there exists a possibility of a given proton spectrum producing a higher dose at some positive depth than existed at the incident face. In order to observe this effect the increase in dE/dX must outweigh the loss in particle attenuation.

Cascade Neutron Dose

If the cascade neutron flux that penetrates the shield is given by $N_{cn}(\overline{E}_j, X_\xi)$ and the cascade neutron dose is given by D_{cn} then

$$D_{cn} = \sum_{J=1}^{J} N_{cn}(\overline{E}_j, X_\xi)\Lambda(\overline{E}_j) \tag{22}$$

where $\Lambda(\overline{E}_j)$ is the flux to dose conversion factor at neutron energy $\overline{E}_j$.

The values of $\Lambda(\overline{E}_j)$ for the energy interval 0.1 MeV to 10 MeV were obtained from reference 6. The values of $\Lambda(\overline{E}_j)$ for the energy interval 60 MeV to 400 MeV were obtained from reference 7. The data from 10 to 60 MeV were faired in. These conversion factors are based on calculated maximum doses produced in a slab of tissue by normally incident neutrons.

Evaporation Neutron Dose

The evaporation neutron dose is calculated in a manner similar to that of reference 2 with some alterations. The dose, due to evaporation neutrons born in each δX_k, is evaluated as the dose from an infinite plane source at the center of δX_k (see fig. 3). The Albert Welton kernel is integrated over angles and shield layers which are neutron sources.

The rad dose from evaporation neutrons in the entire slab is given by

$$D_{en} = \frac{1}{4\pi} \sum_{m=1}^{M} \sum_{k=1}^{K} \left(\frac{\delta\Omega(\theta_m, \theta_{m+1})}{\cos \theta'_m} \right) \left[\sum_{i=1}^{I} {}_eN_p(\overline{E}_i, \delta X_k) + \sum_{j=1}^{J} {}_eN_n(\overline{E}_j, \delta X_k) \right] G(X_k, \theta'_m) \tag{23}$$

where

$$\delta\Omega(\theta_m, \theta_{m+1}) = 2\pi(\cos \theta_m - \cos \theta_{m+1}) \tag{24}$$

The index m represents the number of angles measured in the interval $0 \leq \theta'_m < 90^\circ$, see figure 3. The angle θ'_m is the midpoint of the angular interval (θ_m, θ_{m+1}). The index k represents the number of increments of shield thickness δX_k. The index i represents the number of energy groups of incident protons which produce evaporation neutrons in δX_k. The index j represents the number of energy groups of incident cascade neutrons which produce evaporation neutrons in δX_k. The units for these sums are particles/cm^2 or particles/cm^2 sec.

The maximum number of angles that can be used is 10. Experience has shown that five angles are adequate in reproducing the dose calculations to two significant figures when compared with the 10 angle calculation. For materials where the evaporation neutron dose is small it may be preferred to run with one angle because the running time is less.

The term $G(X_k, \theta'_m)$ is the attenuation kernel. For hydrogenous material G is the Albert Welton kernel using the coefficients derived by Casper (ref. 8). For nonhydrogenous material G is used as shown by reference 2.

The function $G(X_k, \theta'_m)$ is calculated in LPSC as follows

$$G(X_k, \theta'_m) = C_1 F(\eta) \exp\left(- \sum_{n=k}^{K_{max}} S_n r_n \kappa_n \right) \tag{25}$$

where

$$F(\eta) = \eta^{C_2} \exp(-C_3\eta^{C_4}), \qquad \eta \geq 2.0 \tag{26}$$

Equation (27) represents a straight line extrapolation of $F(\eta)$ versus η for $0 \leq \eta \leq 2.0$.

$$F(\eta) = 0.772 - 0.065\,\eta, \qquad 0 \leq \eta < 2.0 \tag{27}$$

$$\eta = \sum_{n=k}^{K_{max}} H_n \frac{r_n}{P_n} \tag{28}$$

S_n = removal cross section for material n in cm^2/g

r_n = slant path length through material n in g/cm^2

κ_n = a constant

$\kappa_n = 1.0$ for all hydrogenous materials

$\kappa_n = 1.0$ for $2 \leq Z \leq 6$ for nonhydrogenous materials

$\kappa_n = 0.5$ for $Z > 6$ for nonhydrogenous materials

H_n = the ratio of hydrogen density in material n to hydrogen density in water

P_n = the density of material n in g/cm^3

K_{max} = the maximum value to the index on the number of δX_n layers being calculated to the detector point. As the detector point moves the value of K_{max} will change.

The index in equation (25) starts at K and progresses to K_{max}. This indicates that source layers are numbered 1 starting at the incident face and progress to K_{max} at the detector face. Therefore the attenuation applied to the K^{th} layer is from K to K_{max}. As the calculation progresses to a new print bound the value of K_{max} will change. See figure 2.

$$(C_1, C_2, C_3, C_4) = (5.389 \times 10^{-9}, 0.3492, 0.4223, 0.6984) \tag{29}$$

Casper in reference 8 derived the coefficients in equation (29) to fit the data in the range of 10 cm to 130 cm from the source in water.

Equation (29) represents a departure from reference 2.

The value of $C_1 = 5.389 \times 10^{-9}$ is for source terms in particles/cm^2.

Then G is in (rad/flare)/(neutrons/cm^2). If the source terms are in neutrons/cm^2 sec then $C_1 = 3600 \times 5.389 \times 10^{-9}$ and G is in (rad/hr)/(neutrons/cm^2 sec).

If the shield is all nonhydrogenous $G(X_k, \theta_m')$ is calculated using equations (25) and (27) where $\eta = 0$. If the shield is all hydrogenous $G(X_k, \theta_m')$ is calculated using equations (25), (26), and (27) where $\eta \neq 0$.

When some layers following layer n contain hydrogen and some do not, the method of reference 2 is used. Replace S_n with $S_n l_n$. Then if nonhydrogenous material follows layer n, set $l_n = \kappa_n$. If hydrogenous material follows layer n, then l_n is selected as follows:

If

$$\kappa_n = 1.0 \quad \text{then} \quad l_n = 1.0 \tag{30}$$

if

$$\kappa_n = 0.5 \quad \text{then} \quad l_n \text{ is taken as the minimum of}$$

$$l_n = 1.0 \quad \text{or}$$

$$l_n = 0.5 + \frac{1}{15} \sum_{n=k+1}^{K_{max}} \left(H_n \frac{r_n}{P_n} \right) \tag{31}$$

The Albert-Welton kernel (eq. 25) with $F(\eta)$ defined as in equation (26), pertains to neutrons with a fission energy spectrum. Bertini's data indicates that the evaporation neutron energy spectrum is harder than the fission spectrum when incident particle energies are > 25 MeV. This will tend to make the calculated dose from these evaporation neutrons low. Evaporation neutrons do not produce secondary particles in this program.

Equation (23) calculates the rad dose from evaporation neutrons. The rem dose is obtained by multiplying the rad dose by an RBE of 10. The RBE can be readily changed in the program to any value considered more applicable.

Total Doses and Flux and Source Terms

In addition to calculating the individual dose components previously mentioned the program calculates the total proton dose, the total neutron dose, and the total dose from all particles. If dN/dE or N(>E) is input in protons/(cm^2 MeV flare) or protons/(cm^2 flare), the doses calculated are rad/flare and rem/flare. If dN/dE is in protons/(cm^2 MeV sec) then the doses calculated are in rad/hr and rem/hr.

The LPSC will calculate the particle flux at each print bound in particles/cm^2 or particles/cm^2 sec. The evaporation neutron source strengths in units of neutrons/g or neutrons/g sec are also calculated for each δX layer.

PROGRAM DESCRIPTION LPSC

The Lewis Proton Shielding Code (LPSC) consists of the main program PISR and the following subroutines:

FLUXEQ calculates initial proton flux as a function of initial incident energy.

INVALU sets up energy intervals at exit face of slab and at all intermediate print out bounds at which printed output is desired; uses these energy groups to calculate initial incident energy intervals and with FLUXEQ establishes initial proton spectrum.

EVNEDO calculates the evaporation neutron dose based on the source terms from the midpoints of each δX increment.

XS computes the cross sections of protons and neutrons as a function of energy.

LAGRNG interpolation scheme based on Lagrange fundamental formula for interpolation.

YIELDS calculates the yield of secondary particles per collision as a function of the type and energy of the bombarding particle.

RANGE a dual purpose subroutine which calculates the range as a function of energy, and the energy as a function of range.

CASNRG computes the energy of cascade protons and neutrons as a function of the type and energy of the bombarding particle.

DOSEK computes proton and neutron flux to dose conversion factors for doses in rad (or rad/hr) and rem (or rem/hr) as a function of energy.

PROPTY transmits all material properties from magnetic tape to disk storage for faster access and transmits tables of flux to dose conversion factors to core storage.

SORT is a general purpose sorting routine.

The main program PISR is divided into four separate sections. In the first section the input data is entered into the computing machine and large blocks of storage are initialized for later use. The second section contains the calculations for the attenuation of the primary protons, and the collisions producing secondary particles. All secondary particles are assumed to be born at the midpoint of each δX subinterval and are attenuated across the second half of the δX subinterval. The dose calculations are contained in the third section of the main program, and section four controls the output of data.

Subroutine FLUXEQ calculates the flux values of the proton spectrum incident on the shield at various energies. In subroutine INVALU an equation number, entered as input, specifies the particular analytical equation that simulates the spectrum or the table of values of flux versus energy that defines the spectrum. These equations represent either the integral or differential spectral forms. The code converts the rigidity spectral equations to energy and all calculated spectra are presented in terms of energy.

The INVALU subroutine is a two section program which computes all the initial data for a particular problem. The first section contains the computation of the ΔX intervals and δX subintervals and then establishes the energy bounds and average energy for each energy group at the initial incident face. In part two, the number of particles in each energy group is calculated using the spectral values determined in subroutine FLUXEQ. If an integral type spectrum is to be used, the $N(>E)$ is evaluated at the boundary energies of each group and the number of particles in each group is obtained by differencing the successive values at the boundary energies. The differential dN/dE is evaluated at the average energy for each group, and the number of particles in each group is computed by multiplying this value of dN/dE by the difference in boundary energies for that group.

The evaporation neutron dose is computed in subroutine EVNEDO. The first section contains the input statements for the materials which comprise the shield to be analyzed and the computation of the angles to be used for the dose calculations. The second part computes and saves two summations for each angle and δX subinterval. The first is the summation of the product-quotient Hr/P, while the second is the product κSr, with an adjustment multiplier l sometimes being included to account for the variation of materials in the makeup of the slab. Section three computes the evaporation neutron source terms for each δX subinterval and also computes the evaporation neutron dose at each print bound based on the above summations.

Subroutine PROPTY controls the input of data for each material and the flux to dose conversion factor tables from the magnetic tape to the computing machine. The data tape is mounted on logical tape unit 3 and the material data is then transferred to disk storage to decrease access time, if a disk is available, or to logical unit 4 if a disk is not available. This transferring of data reduces the possibility of destroying the master data tape in the process of program execution. The flux to dose conversion factor tables are transferred directly into computer storage. The second section of PROPTY controls the transfer of material data into computer storage and initializes the various subroutines involved for the necessary constants and type of interpolation to be applied to the data. If a call is made for a material which is not available the program will stop and print out an appropriate error message.

The remaining subroutines, XS, LAGRNG, YIELDS, RANGE, CASNRG, DOSEK, and SORT are all straight forward and require no further explanation.

INPUT DATA FOR LPSC

Most of the data used by LPSC is on a data tape. This includes the range energy tables, secondary particle yield functions, energy of secondary particles, cross sections, mass stopping power, flux to dose conversion factors and an RBE table.

The following data is input on cards:

NOCDS - the number of identification or comments cards printed at the beginning of each set of output data. A minimum of one (1) card is required, even if blank, and a maximum of 99 is permissible. Format (I2).

12		73 80
XX		NOID

CARD - The comments or identification card(s) to be printed; a total of NOCDS required. If print position one (1) on output is for carriage control, include appropriate control character in card column one (1) of comments card. Format (12A6).

1	2 72	73 80
	Comments or identification	ID

SPBND - The minimum energy in MeV of incident protons which produce secondary particles.

SNBND - The minimum energy in MeV of incident neutrons which produce secondary particles.

PDSBND - The minimum energy in MeV for computing proton dose due to ionization.

NDSBND - The minimum energy in MeV for computing cascade neutron dose.

BNDLOW - The minimum energy in MeV of the initial incident primary proton spectrum.

KNTRP - A control governing the various generations of protons to be calculated. If KNTRP = 1, primary protons only will be calculated; = 2, primary and first generation secondary protons and evaporation neutrons produced by primary protons will be calculated; = 3, primary and all generations of secondary protons and evaporation neutrons produced by all protons.

KNTRN - The control for the generations of neutrons to be calculated. For KNTRN = 1, first generation cascade neutrons are calculated; = 2, all generations of cascade neutrons and evaporation neutrons from cascade neutrons are calculated.

SOFENO - Material number for dE/dX (of receiver) table to be used in dose calculations.

SOFENO	Material
1	Water
2	Tissue

For SOFENO equal to any other number, the program will stop and print an appropriate error message. Format (5F6.0,3I4).

1 6	7 12	13 18	19 24	25 30	31 34	35 38	39 42		73 80
XX.X	XX.X	XX.X	XX.X	XX.X	X	X	X		Limit 1

KOSW - Branching controls for various calculations throughout the program. Provision has been made for 36 such controls but not all of them are used. The following list describes the effect when the control is set equal to 1 or 2; for any other number some type of error is likely to occur. (The number in parentheses refers to a specific card column.)

KOSW (1) = 1, omit table of neutron source terms;
= 2, print table of neutron source terms;

KOSW (3) = 1, omit table of initial incident energy group bounds, delta energy and average energy for each group, value of dN/dE at the average energy or N(>E) at energy group bounds, and the number of protons in each group;
= 2, print the above table of initial values;

KOSW (5) = 1, calculate the dose at each shield print bound;
= 2, calculate the dose of the initial incident primary proton spectrum only without performing any further shield calculations;

KOSW (7) = 1, energy group bounds for cascade neutron spectrum is the same as that for initial proton energy group bounds;
= 2, energy group bounds for cascade neutron distribution are input data;

KOSW (9) = 1, omit tables of energies of proton particles incident at all δX layers and associated proton cross-sections;
= 2, print tables of energies of protons and associated cross-sections. (This data can be used for checking purposes.);

KOSW (11) = 1, omit tables of primary and secondary proton and cascade neutron spectrum source terms at intermediate print bounds and exit face;
= 2, print tables of all spectrum source terms at intermediate print bounds and exit face;

KOSW (13) = 1, initial incident proton spectra data is not time integrated;
= 2, calculations are based on time integrated initial incident proton spectra data;

KOSW (15) = 1, construct additional energy groups at intermediate print bounds using equal increments;
= 2, construct additional energy groups at intermediate print bounds using variably spaced increments;

KOSW (17) = 1, omit table of total proton and cascade neutron flux terms;
= 2, print table of total proton and cascade neutron flux terms;

KOSW (19) = 1, initial incident energy group boundaries are calculated from the energy group bounds at the exit face and intermediate print bounds;
= 2, initial incident energy group boundaries are input data. (This feature is useful for a monoenergetic case);

KOSW (21) = 1, calculation of proton dose factors due to nuclear interaction is bypassed;
= 2, proton dose factors due to nuclear interaction are calculated.

This version of the program is equipped to handle this type of dose computation; however, at present there is no reliable data for these calculations and KOSW (21) should be set equal to 1. If reliable data is forthcoming it may be used in place of the table of zeros now in the program.

For the following control switches (card columns 25 through 36), the program uses linear interpolation on the raw data when the branching control equals 1; and for the control switch equal to 2 the program replaces the raw data by the logarithms (base 10) of the data and then uses linear interpolation on the logarithms. The interpolation with logarithms option was included to increase the accuracy of the calculations, however the use of this option will also increase the computing time necessary for any problem.

KOSW (25), range-energy;

KOSW (26), proton cross-section;

KOSW (27), neutron cross-section;

KOSW (28), emitted yields for protons bombarding;

KOSW (29), emitted yields for neutrons bombarding;

KOSW (30), energy of cascade particles for protons bombarding;

KOSW (31), energy of cascade particles for neutrons bombarding;

KOSW (32), dE/dX mass stopping power;

KOSW (33), relative biological effectiveness (RBE);

KOSW (34), cascade neutron flux to dose factors for rad or rad/hr units;

KOSW (35), cascade neutron flux to dose factors for rem or rem/hr units;

KOSW (36), proton (nuclear interaction) flux to dose factors. (This table presently contains zeros.) Set KOSW (36) equal to 1.

FORMAT (36I1)

1	2+	36		73 80
X X X X X X X X X X1		XXXXXXXXXXX1		KOSW

NOX - The number of shield thicknesses or print bounds at which data is desired. The maximum number permissable is 20.

NOANG - The number of angles used in computing the evaporation neutron dose. This must be an integer in the range from 1 to 10.

Format (2I4)

1 4	5 8		73 80
XX	XX		Limit 2

The seven pieces of data which follow are needed for each shield thickness at which data is to be printed - a total of NOX cards.

X(J) - The shield thickness in g/cm^2 at the Jth print bound;

NOD2X(J) - The number of δX increments between the Jth and (J-1)th print bounds. If J = 1, the (J-1)th print bound is assumed to be at X = 0. The total number of δX increments for the entire shield must be ≤ 200.

PROPNO(J) - The property number for the material between the Jth and (J-1)th print bounds. This version contains data for the following materials:

Material	PROPNO
Hydrogen	2
Beryllium	104
Carbon	102
Nitrogen	106
Oxygen	107
Aluminum	101
Titanium	108
Iron	103
Tungsten	109
Lead	105
Uranium	110
Water	1
Polyethylene	3

If a PROPNO(J) is set equal to any other number, the program will stop and print an appropriate error message.

P(J) - The density of the Jth material in g/cm^3

H(J) - The ratio of the hydrogen density in the Jth material to that in water;

S(J) - The removal cross-section for the Jth material in cm^2/g

K(J) - The value of κ_k used in the evaporation neutron dose calculations. For $2 \leq Z \leq 6$, $\kappa = 1.0$; and for $Z > 6$, $k = 0.5$. κ must be a non-zero quantity even though no value for κ_k may be required.

Format (F6.0, 2I4, 3F8.0, F6.0)

1 6	7 10	11 14	15 22	23 30	31 38	39 44		73 80
xxx.xx	xx	xxx	x.xxxx	x.xxxx	x.xxxxx	x.x		MATERIAL

If KOSW(19) = 1, the following data is required to establish the energy group bounds at the exit face and intermediate print bounds.

1.) NOINTS(1) - The number of groups of equal energy increments at the exit face, a maximum of 25 groups permissible.

Format (I3)

1 3		73 80
		1 or
xx		NOINT 2

Then NOINTS(1) pairs of numbers defined by:

2.) EOMAX(J,1) - The maximum energy in MeV of the J^{th} group of equal energy increments at the exit face. For example, if the fourth group of intervals has a maximum energy of 100 MeV and the fifth group 200 MeV, then EOMAX(4,1) = 100 and EOMAX(5,1) = 200.

3.) NOINCR(J,1) - The number of energy increments in the J^{th} group at the exit face, i.e., if the fifth group has 5 increments, then NOINCR(5,1) = 5 and the increment size $\delta E = (200-100)/5 = 20$ MeV. The total number of energy increments at the exit face or any intermediate print bound cannot exceed 300. Use as many cards as required with 6 pairs of number per card.

Format (F8.0, I4, F8.0, I4, F8.0, I4, F8.0, I4, F8.0, If, F8.0, I4)

1 8	9 12	13 20	21 24	25 32	33 36	37 44	45 48	49 56	57 59	61 68
xxxx.x	xx	xxxx.x	xx	xxxx.x	xx	xxxx.x	xx	xxxx.x	xx	xxxx.x

69 72	73 80
	1 or
xx	EINT2

For KOSW(15) = 2, a set of data similar to 1) through 3) is needed which applies to the initial face and all intermediate print out boundaries i.e., 4) NOINTS(2), 5) EOMAX(J,2), and 6) NOINCR(J,2). Whereas at the exit face the energy grouping applies to the whole energy grid, at the initial face and print bounds these groups are used to determine the energy grid between $E = E_O$ and $E = 0$ only, where E_O is the energy on the initial face or K^{th} print bound which degrades to $E = 0$ at the $(K + 1)^{th}$ intermediate print bound or exit face. The remainder of the energy grid at the initial face or K^{th} print bound is calculated from the energy grid at the $(K + 1)^{th}$ print bound or exit face. If KOSW(15) = 1, data 4) through 6) are replaced by

4'.) NDE - the number of equal energy increments into which the range E = 0 to $E = E_o$ will be divided at the initial face and intermediate print out bounds, i.e., in the range $(0,E_o)$ there will be NDE increments of size $\delta E = E_o/NDE$. Format (I3).

1 3		73 80
xx		NDE

7.) EIMAX - The maximum energy bound in MeV at the initial incident face.

Format (E12.5)

1 12		73 80
+x.xxxxxE + xx		EIMAX

The monoenergetic case or any case for which the energy grid at the initial incident face is to be input can be computed by setting KOSW(19) = 2, omitting data words 1.) through 7.) above, and inserting the following information:

KEI - The number of energy bounds at the initial incident face;

Format (I3)

1 3		73 80
xx		KEI

EI - The energy bounds for each group, a total of KEI. The maximum number permitted is 300. Format (8F9.0)

1 9	10 18	19 27	28 36	37 45	46 54	55 63	64 72	73 80
xxxx.x	xxxx.x	xxxx.x	xxxx.x	xxxx.x	xxxx.x	xxxx.x	xxxx.x	EI

The spectrum simulation is controlled by two or more cards as follows:

MOVE - A control for the type of spectrum to be used. If $\Gamma(E) = dN/dE$, MOVE = 2, and for $\Gamma(E) = N(>E)$, MOVE = 1.

EQNO - The number of the equation or method describing the proton spectrum at the initial incident face. Seven different forms, numbered 1 through 7, are available and described below.

TITLE - An identification for the title or name of the spectrum. A maximum of 66 characters, including blank spaces, are permitted for this identification. Format (2I3, 11A6)

1 3	4 6	7 72	73 80
x	x	Name of spectrum	CONTRL 1

If EQNO = 1, $\Gamma(E) = AE^{-B}$

The coefficients A and B in the equation are input. Format (2E12.5)

1 12	13 24		73 80
±x.xxxxxE±yy	±x.xxxxxE±yy		CONTRL 2

If EQNO = 2, $\Gamma(P) = N(>P) = A \exp(-P/P_o)$

MOVE = 1 on CONTROL 1 and the coefficients A and P_o replace A and B on CONTROL 2. Format (2E12.S)

IF EQNO = 3, a table of values is to be read as input.

In place of card CONTRL 2, read the following:

NOENTS - The number of entries in the table on card FLUX 3,1. A maximum of 100 entries in the table is permitted. Format (I4)

1 4		73 80
xx		FLUX 3,1

This is followed by the table in Format (F8.0, E10.3, F8.0, E10.3, F8.0, E10.3, F8.0, E10.3). These represent pairs of numbers, the energy EEEE and the corresponding spectra value PROTS at this energy.

1 8	9 18	19 26	27 36	37 44	45 54	55 62
xxx.xx	+x.xxxE±yy	xxx.xx	+x.xxxE±yy	xxx.xx	+x.xxxE±yy	xxx.xx

63 72	73 80
+x.xxxE±yy	FLUX 3,2

Continue with as many cards as required.

$$\text{If EQNO} = 4,\ \Gamma(E) = A(E)\ \exp(-B(E))$$

where $A(E) = \sum_{i=1}^{4} a_i E^{i-1}$ and $B(E) = \sum_{i=1}^{4} b_i E^{i-1}$. The coefficients $\underline{a}$ and $\underline{b}$ are input.

a_i, i = 1, 2, 3, 4. Format (4E12.5)

1 12	13 24	25 36	37 48		73 80
±x.xxxxxE±yy	±x.xxxxxE±yy	±x.xxxxxE±yy	±x.xxxxxE±yy		FLUX 4A

b_i, i = 1, 2, 3, 4. Format (4E12.5)

1 12	13 24	25 36	37 48		73 80
±x.xxxxxE±yy	±x.xxxxxE±yy	±x.xxxxxE±yy	±x.xxxxxE±yy		FLUX 4B

$$\text{If EQNO} = 5,\ \log_{10} \Gamma(E) = \sum_{i=1}^{4} a_i E^{i-1}$$

The $\underline{a_i}$ are input as in card FLUX 4A.

$$\text{If EQNO} = 6,\ \log_{10} \Gamma(E) = \sum_{i=1}^{4} a_i (\log_{10} E)^{i-1}$$

The $\underline{a_i}$ are input as in card FLUX 4A.

$$\text{If EQNO} = 7,\ \Gamma(P) = \frac{dN}{dP} = A\ e^{-P/P_o}$$

MOVE = 2 on CONTRL 1 and the input $\underline{A}$ and $\underline{P_o}$ are in FORMAT (2E12.5) as on CONTRL 2.

For EQNO = 1, 3, 4, 5, 6, MOVE may be either 1 or 2 depending on the data to be used.

The last set of cards construct the cascade neutron energy table. The first card in this set gives the number of entries, NONUBD, in the table. Format (I3).

1 3		73 80
xx		NONUBD

This is followed by the bounds, NUENBD, of the energy groups in descending order . . . 100 MeV, 80 MeV, 60 MeV, . . . 0 MeV. Format (7F10.0).

1 10	11 20	21 30	31 60	73 80
xxx.x	xxx.x	xxx.x	. . .	NUENBD

Use as many cards as required.

TAPFIX Program

Program TAPFIX is a FORTRAN IV computer program which generates from tables of data punched in cards a data tape to be used with the Lewis Proton Shielding Code (LPSC). The tape to be generated is mounted on logical unit 3. The first half of TAPFIX deals with the property data for various materials and the second part controls the tables of flux to dose conversion factors. Following is a list, in sequential order, of the data and formats necessary to generate a tape which is compatible with LPSC.

NOMAT 1 - the number of various materials for which shielding data is available.

NOMAT 2 - the number of receiver materials for which tables of dE/dx (to be used in dose calculations) are available in this program.

FORMAT (2I4)

1 4	5 8		73 80
xx	xx		LIMITS

Following this card should be NOMAT 1 sets of data, one for each material.

MATNO - the number assigned to each material (see list on page 22); hydrogenous materials are in the range 1 through 49, nonhydrogenous materials are assigned numbers greater than 100.

NOFCOM - the number of elements comprising a given material. All the materials in LPSC are single element materials except water and polyethylene which contain two elements. The program is coded to allow compounds with up to four elements. The table entries for secondary yields of compounds are different from the yields for elements in the following way. For a compound, the yields for each element are multiplied by the ratio of the inelastic cross section of the i^{th} element to the total inelastic cross section for the compound, thus the fraction of incident particles that collide with the i^{th} nucleous produce yields from the i^{th} nucleous etc. This requires secondary yields and secondary energies for each element of each compound. If the compound is hydrogenous, the hydrogen data must be placed first in each group of tables. The cross section tables for neutrons and protons bombarding are for the compound or element which ever applies.

GMWT - gram molecular weight of the particular material.

L1 - length of the range-energy table.

L2 - length of the energy of cascade particle table - protons bombarding.

L3 - length of the energy of cascade particle table - neutrons bombarding.

L4 - length of the emitted yield table - protons bombarding.

L5 - length of the emitted yield table - neutrons bombarding.

L6 - length of the proton cross-section table.

L7 - length of the neutron cross-section table.

FORMAT (2I4, E13.6, 7I4)

1 4	5 8	9 21	22 25	26 29	30 33	34 37	38 41	42 45	46 49
xxx	x	±x.xxxxxxE±YY	xx	xx	xx	xx	xx	xx	xx

73
LED

ENERGY - energy grid in MeV for range-energy table.

RANGE - associated range for each entry in ENERGY grid. (L1 pairs of numbers)

FORMAT (8E9.3)

1 9	10 18	19 27	28 36	37 45		64 72	73 80
±x.xxxE±x	±x.xxxE±x	±x.xxxE±x	±x.xxxE±x	±x.xxxE±x	. . .	±x.xxxE±x	±x.xxxE±x

ENRGRP - energy in MeV of bombarding proton for cascade particle energy table.

EPRPR - associated energy in MeV of cascade proton produced.

EPRNU - associated energy in MeV of cascade neutron produced (L2 triads of numbers).

FORMAT (9E8.2)

1 8	9 16	17 24	25 32	33 40	41 48	49 56	57 64	65 72	73 80
±x.xxE±Y	±x.xxE±Y	±x.xxE±Y	±x.xxE±Y	±x.xxE±Y	±x.xxE±Y	±x.xxE±Y	±x.xxE±Y	±x.xxE±Y	

ENRGNU - energy in MeV of bombarding neutron for cascade particle energy table.

ENUPR - associated energy in MeV of cascade proton produced.

ENUNU - associated energy in MeV of cascade neutron produced. (L3 triads of numbers)

FORMAT (Same as for energy of cascade particle table - protons bombarding)

ENERPR - energy in MeV of bombarding proton for emitted yield table;

YPRCP - associated cascade proton yield per inelastic event;

YPRCN - associated cascade neutron yield per inelastic event;

YPREN - associated evaporation neutron yield per inelastic event; (L4 groups of numbers)

FORMAT (8F9.0)

1 9	10 18	19 27	28 36	37 45	46 54	55 63	64 72	73 80
xxx.x	x.xxx	x.xxx	x.xxx	xxx.x	x.xxx	x.xxx	x.xxx	

ENERNU - energy in MeV of bombarding neutron for emitted yield table;

YNUCP - associated cascade proton yield per inelastic event;

YNUCN - associated cascade neutron yield per inelastic event;

YNUEN - associated evaporation neutron yield per inelastic event; (L5 groups of numbers)

FORMAT (Same as for yield tables with protons bombarding)

EBOMP - energy in MeV of proton particle for cross-section table;

XSPR - associated proton cross section in millibarns; (L6 pairs of numbers)

FORMAT (10F7.0)

1 7	8 14	15 21	22 28	29 35	36 42	43 49	50 56	57 63	64 70
xxx.x	xxx.x	xxx.x	xxx.x	xxx.x	xxx.x	xxx.x	xxx.x	xxx.x	xxx.x

73 80

EBOMN - energy in MeV of cascade neutron particle for neutron cross section table.

XSNU - associated cascade neutron cross section in millibarns (L7 pairs of numbers).

FORMAT (Same as for proton cross section table)

This concludes the list of property data for each material. The following data are flux to dose conversion factors for protons and neutrons.

L8 - length of the relative biological effectiveness table (RBE)

L9 - length of neutron flux to dose factors table for rad or rad/hr units

L10 - length of neutron flux to dose factors table for rem or rem/hr units

L11 - length of proton (nuclear interaction) flux to dose factors table

FORMAT (4I4)

1 4	5 8	9 12	13 16		73 80
xx	xx	xx	xx		

RBENRG - energy value in MeV for the RBE table

RBE - associated relative biological effectiveness (L8 pairs of numbers)

FORMAT (F7.0, E9.3, F7.0, E9.3, . . .)

1 7	8 16	17 23	24 32	33 39	40 48	49 55	56 64	
xxx.x	±x.xxxE±Y	xxx.x	±x.xxxE±Y	xxx.x	±x.xxxE±Y	xxx.x	±x.xxxE±Y	

73 80

KlNRG - energy value in MeV for neutron flux to dose conversion table in rad or rad/hr units.

Kl - associated neutron flux to dose conversion factor in (rad/hr)/(neutrons/cm^2 sec) (L9 pairs of numbers).

FORMAT (Same as for RBE table).

K2NRG - energy value in MeV for neutron flux to dose conversion table in rem or rem/hr units.

K2 - associated neutron flux to dose conversion factor in (rem/hr)/(neutron/cm^2 sec) (L10 pairs of numbers).

FORMAT (Same as for RBE table)

KNRG - energy value in MeV for proton (nuclear interaction) flux to dose conversion table.

KK - associated proton flux to dose conversion factor (L11 pairs of numbers).

FORMAT (Same as for RBE table). This last table has zero value entries in this version of the code due to the poor data available.

The last data entered on the tape is NOMAT 2 sets of dE/dx tables; one for each receiver material chosen.

MATNO 2 - the receiver material number

(See table on page 19)

L12 - length of the dE/dx table.

FORMAT (2I4)

1 4	5 8		73 80
xx	xx		

EXENRG - energy value in MeV for dE/dx dose conversion table.

DEDX - associated dE/dx conversion value in MeV cm^2/g (L12 pairs of numbers)

FORMAT (Same as for RBE table)

Sample Problem

A sample problem constructed for instructional purposes follows. The problem was to calculate spectra and doses at three print boundaries for a water shield 30 g/cm^2 thick. The print bounds were chosen at 10 g/cm^2, 20 g/cm^2 and 30 g/cm^2. A time integrated type proton spectrum was used where

$$N(>E) = 7.45\times10^{12}\ E^{-2.12}\ \text{protons/cm}^2$$

when the values at 10 g/cm^2 are calculated the program assumes that the shield consists of 10 g/cm^2 only and similarly for the calculations at 20 and 30 g/cm^2.

The primary protons and all generations of cascade protons, cascade neutrons, and evaporation neutron are calculated. The isotropic emission of evaporation neutrons is simulated using five angles.

Table I contains the input data for the sample problem. The first card indicates the number of comments cards which follow. The card labeled LIMIT 1 contains the cut-off energies for the production of secondary particles by protons, secondary particles by neutrons, proton dose calculations, neutron dose calculations, incident proton energy, and two control numbers used to control the calculation of secondary particles and a receiver material number respectively. The next card labeled KOSW controls the print of data and the manner of interpolation in the various data tables. The next card containing a 3 and 5 indicate the number of print bounds and the number of angles used in the evaporation neutron calculation, respectively. The number of angles used in the evaporation neutron calculation is ≤ 10. Since the running time of the program is angle dependent, five angles are recommended. There are cases where the evaporation neutron dose is less than 1 or 2 percent of the total dose. For these cases one may want to use one angle which will result in the evaporation neutrons running faster. The next 3 cards contain the print bounds, the number of δX contained in ΔX, the material property number, the material density, the hydrogen ratio, the removal cross section (oxygen only) and the value of κ. The next card containing the number 6 indicates the number of ΔE boundaries where δE may change for the exit face. These represent nonzero energies at the exit face. The next card indicates that there exists 6 energies between 0 and 6 MeV, 2 energies between 6 and 10 MeV, 5 energies between 10 and 60 MeV, etc. The next set of data constructs the exit energy bounds at intermediate print boundaries. The next card labeled E Max is the maximum energy of incident protons to be considered. The next two cards labeled FLUX 1 define the proton spec-

E-3080

TABLE I. - INPUT DATA FOR SAMPLE PROBLEM

```
 2
          SAMPLE PROBLEM
          WATER SHIELD
  10.     10.0     2.0     0.0 20.00    3     2     2                                        LIMIT 1
2 2 1 2 1 2 2 2 2 1 1     22222222221                                                      KOSW
   3    5                                                                                  LIMIT 2
 10.     20     1 1.0      1.0       .033      1.0                                         MAT
 20.     10     1 1.0      1.0       .033      1.0
 30.     10     1 1.0      1.0       .033      1.0
  6                                                                                        NOINT 1
  6.         6 10.         2 60.         5 100.        2 600.        5 1000.          2    EINT 1
  7                                                                                        NOINT 2
 6.          6 10.         2 20.         4 40.        10 100.       20 600.           8    EINT 2
 1000.       2                                                                             EINT 2
+1.00000E+03                                                                               EIMAX
  1   IN=A*E**(-B)                                                                         CONTRL 1
+7.45470E+12+2.12000E+0                                                                    CONTRL 2
 17                                                                                        NONUBD
1000.      400.        300.        200.        100.        80.        60.                  NUENBD
50.        40.         30.         20.         10.         8.         6.                   NUENBD
4.         2.          0.                                                                  NUENBD
```

TABLE II. - INPUT DATA PRINTED WITH OUTPUT

SAMPLE PROBLEM
WATER SHIELD

X,MIN (GM/CM**2)	X,MAX (GM/CM**2)	NUMBER OF INCREMENTS	MATERIAL NUMBER	DENSITY (GM/CM**3)	HYDROGEN RATIO	REMOVAL XSECT (CM**2/GM)
0.	10.00	20	1	1.00000	1.000	0.0330
10.00	20.00	10	1	1.00000	1.000	0.0330
20.00	30.00	10	1	1.00000	1.000	0.0330

NUMBER OF ANGLES IN EVAPORATION NEUTRON DOSE CALCULATIONS = 5
ENERGY CUT-OFF LEVEL FOR INITIAL INCIDENT PROTON FLUX = 20.00 MEV.
ENERGY CUT-OFF LEVEL FOR CALCULATING SECONDARY PROTONS = 10.00 MEV.
ENERGY CUT-OFF LEVEL FOR CALCULATING CASCADE NEUTRONS = 10.00 MEV.
ENERGY CUT-OFF LEVEL FOR PROTON DOSE DUE TO IONIZATION = 2.00 MEV.
ENERGY CUT-OFF LEVEL FOR NEUTRON DOSE CALCULATIONS = 0. MEV.

Φ = A*E**(-B) WITH A = 7.45470E 12 AND B = 2.12000E 00

N=A*E**(-B)

TABLE III. - PROTON ENERGY AND SPECTRUM DATA ON INCIDENT FACE OF SHIELD

	ENERGY,E MEV	N(GREATER THAN E) PROTONS/CM**2	DELTA E MEV	E AVG. MEV	(DN/DE)*DELTA E PROTONS/CM**2
1	1.00000E 03	3.25410E 06	1.30969E 02	9.34515E 02	1.12794E 06
2	8.69031E 02	4.38203E 06	1.94066E 02	7.71998E 02	3.10576E 06
3	6.74965E 02	7.48779E 06	9.58219E 01	6.27054E 02	2.87135E 06
4	5.79143E 02	1.03591E 07	9.27806E 01	5.32753E 02	4.64028E 06
5	4.86363E 02	1.49994E 07	8.94875E 01	4.41619E 02	8.08314E 06
6	3.96875E 02	2.30826E 07	8.19988E 01	3.55876E 02	1.46202E 07
7	3.14876E 02	3.77028E 07	6.66912E 01	2.81531E 02	2.47434E 07
8	2.48185E 02	6.24462E 07	1.00618E 01	2.43154E 02	5.72649E 06
9	2.38123E 02	6.81727E 07	8.53009E 00	2.33858E 02	5.48147E 06
10	2.29593E 02	7.36541E 07	3.59819E 00	2.27794E 02	2.50828E 06
11	2.25995E 02	7.61624E 07	3.08554E 00	2.24452E 02	2.25234E 06
12	2.22909E 02	7.84148E 07	2.53497E 00	2.21642E 02	1.92457E 06
13	2.20374E 02	8.03393E 07	1.94586E 00	2.19402E 02	1.52485E 06
14	2.18429E 02	8.18642E 07	1.29111E 00	2.17783E 02	1.03539E 06
15	2.17138E 02	8.28996E 07	1.72220E-01	2.17051E 02	1.39567E 05
16	2.16965E 02	8.30391E 07	1.40966E-01	2.16895E 02	1.14493E 05
17	2.16824E 02	8.31536E 07	5.83687E-02	2.16795E 02	4.74750E 04
18	2.16766E 02	8.32011E 07	4.99058E-02	2.16741E 02	4.06260E 04
19	2.16716E 02	8.32417E 07	4.11892E-02	2.16695E 02	3.35460E 04
20	2.16675E 02	8.32753E 07	3.19099E-02	2.16659E 02	2.60040E 04
21	2.16643E 02	8.33013E 07	2.14863E-02	2.16632E 02	1.75190E 04
22	2.16621E 02	8.33188E 07	9.29642E-03	2.16617E 02	7.57800E 03
23	2.16612E 02	8.33264E 07	9.49160E 00	2.11866E 02	8.30346E 06
24	2.07121E 02	9.16298E 07	1.80027E 00	2.06220E 02	1.71162E 06
25	2.05320E 02	9.33415E 07	1.76819E 00	2.04436E 02	1.72731E 06
26	2.03552E 02	9.50688E 07	1.73527E 00	2.02684E 02	1.74130E 06
27	2.01817E 02	9.68101E 07	1.70516E 00	2.00964E 02	1.75718E 06
28	2.00112E 02	9.85673E 07	1.65983E 00	1.99282E 02	1.75592E 06
29	1.98452E 02	1.00323E 08	1.62329E 00	1.97640E 02	1.76217E 06
30	1.96829E 02	1.02085E 08	1.58801E 00	1.96035E 02	1.76829E 06
31	1.95241E 02	1.03854E 08	1.55294E 00	1.94464E 02	1.77319E 06
32	1.93688E 02	1.05627E 08	1.51384E 00	1.92931E 02	1.77178E 06
33	1.92174E 02	1.07399E 08	1.47367E 00	1.91437E 02	1.76710E 06
34	1.90700E 02	1.09166E 08	1.43734E 00	1.89981E 02	1.76507E 06
35	1.89263E 02	1.10931E 08	1.39445E 00	1.88566E 02	1.75283E 06
36	1.87868E 02	1.12684E 08	1.35040E 00	1.87193E 02	1.73658E 06
37	1.86518E 02	1.14420E 08	1.30667E 00	1.85865E 02	1.71810E 06
38	1.85211E 02	1.16138E 08	1.26072E 00	1.84581E 02	1.69392E 06
39	1.83951E 02	1.17832E 08	1.21275E 00	1.83344E 02	1.66401E 06
40	1.82738E 02	1.19496E 08	1.16377E 00	1.82156E 02	1.62952E 06
41	1.81574E 02	1.21126E 08	1.11372E 00	1.81017E 02	1.59024E 06
42	1.80460E 02	1.22716E 08	1.06005E 00	1.79930E 02	1.54232E 06
43	1.79400E 02	1.24258E 08	1.00449E 00	1.78898E 02	1.48795E 06
44	1.78395E 02	1.25746E 08	6.37638E-01	1.78077E 02	9.58173E 05
45	1.77758E 02	1.26704E 08	6.12797E-01	1.77452E 02	9.31023E 05
46	1.77145E 02	1.27635E 08	5.87585E-01	1.76852E 02	9.02185E 05
47	1.76558E 02	1.28538E 08	5.61888E-01	1.76277E 02	8.71550E 05
48	1.75996E 02	1.29409E 08	5.35503E-01	1.75728E 02	8.38730E 05
49	1.75460E 02	1.30248E 08	5.08736E-01	1.75206E 02	8.04244E 05
50	1.74952E 02	1.31052E 08	4.81253E-01	1.74711E 02	7.67545E 05
51	1.74470E 02	1.31820E 08	4.52829E-01	1.74244E 02	7.28265E 05
52	1.74018E 02	1.32548E 08	4.23895E-01	1.73806E 02	6.87110E 05
53	1.73594E 02	1.33235E 08	3.94743E-01	1.73396E 02	6.44587E 05
54	1.73199E 02	1.33880E 08	4.50764E-01	1.72974E 02	7.41682E 05
55	1.72748E 02	1.34621E 08	4.02334E-01	1.72547E 02	6.67116E 05

TABLE III. - CONTINUED - PROTON ENERGY AND SPECTRUM DATA ON INCIDENT FACE OF SHIELD

	ENERGY,E MEV	N(GREATER THAN E) PROTONS/CM**2	DELTA E MEV	E AVG. MEV	(DN/DE)*DELTA E PROTONS/CM**2
56	1.72346E 02	1.35238E 08	3.51938E-01	1.72170E 02	5.87560E 05
57	1.71994E 02	1.35676E 08	2.99568E-01	1.71844E 02	5.03088E 05
58	1.71694E 02	1.36379E 08	2.00935E-01	1.71594E 02	3.38998E 05
59	1.71493E 02	1.36718E 08	1.64543E-01	1.71411E 02	2.78508E 05
60	1.71329E 02	1.36997E 08	6.81000E-02	1.71295E 02	1.15510E 05
61	1.71261E 02	1.37112E 08	5.82981E-02	1.71232E 02	9.90060E 04
62	1.71202E 02	1.37211E 08	4.80881E-02	1.71178E 02	8.17420E 04
63	1.71154E 02	1.37293E 08	3.72524E-02	1.71136E 02	6.33700E 04
64	1.71117E 02	1.37356E 08	2.50664E-02	1.71105E 02	4.26620E 04
65	1.71092E 02	1.37399E 08	1.08719E-02	1.71087E 02	1.85080E 04
66	1.71081E 02	1.37417E 08	1.11794E 01	1.65491E 02	2.11673E 07
67	1.59902E 02	1.58585E 08	2.13597E 00	1.58834E 02	4.58629E 06
68	1.57766E 02	1.63171E 08	2.10588E 00	1.56713E 02	4.71537E 06
69	1.55660E 02	1.67886E 08	2.07461E 00	1.54623E 02	4.84408E 06
70	1.53585E 02	1.72730E 08	2.04650E 00	1.52562E 02	4.98274E 06
71	1.51539E 02	1.77713E 08	2.01147E 00	1.50533E 02	5.10634E 06
72	1.49527E 02	1.82820E 08	1.96639E 00	1.48544E 02	5.20341E 06
73	1.47561E 02	1.88023E 08	1.93143E 00	1.46595E 02	5.32588E 06
74	1.45630E 02	1.93349E 08	1.89647E 00	1.44681E 02	5.44834E 06
75	1.43733E 02	1.98797E 08	1.85625E 00	1.42805E 02	5.55446E 06
76	1.41877E 02	2.04352E 08	1.81442E 00	1.40970E 02	5.65292E 06
77	1.40062E 02	2.10005E 08	1.77234E 00	1.39176E 02	5.74684E 06
78	1.38290E 02	2.15751E 08	1.72644E 00	1.37427E 02	5.82331E 06
79	1.36564E 02	2.21575E 08	1.67883E 00	1.35724E 02	5.88733E 06
80	1.34885E 02	2.27462E 08	1.63118E 00	1.34069E 02	5.94340E 06
81	1.33254E 02	2.33405E 08	1.58028E 00	1.32463E 02	5.97853E 06
82	1.31673E 02	2.39384E 08	1.52630E 00	1.30910E 02	5.99073E 06
83	1.30147E 02	2.45375E 08	1.46449E 00	1.29415E 02	5.95793E 06
84	1.28683E 02	2.51333E 08	1.40641E 00	1.27979E 02	5.92421E 06
85	1.27276E 02	2.57257E 08	1.34899E 00	1.26602E 02	5.87749E 06
86	1.25927E 02	2.63134E 08	1.28684E 00	1.25284E 02	5.79275E 06
87	1.24640E 02	2.68927E 08	8.19396E-01	1.24231E 02	3.78682E 06
88	1.23821E 02	2.72714E 08	7.89328E-01	1.23426E 02	3.72258E 06
89	1.23032E 02	2.76436E 08	7.58623E-01	1.22652E 02	3.64866E 06
90	1.22273E 02	2.80085E 08	7.27056E-01	1.21909E 02	3.56376E 06
91	1.21546E 02	2.83649E 08	6.94456E-01	1.21199E 02	3.46662E 06
92	1.20851E 02	2.87116E 08	6.61091E-01	1.20521E 02	3.35828E 06
93	1.20190E 02	2.90474E 08	6.25017E-01	1.19878E 02	3.22851E 06
94	1.19565E 02	2.93702E 08	5.88540E-01	1.19271E 02	3.08857E 06
95	1.18977E 02	2.96791E 08	5.51965E-01	1.18701E 02	2.94028E 06
96	1.18425E 02	2.99731E 08	5.14908E-01	1.18167E 02	2.78167E 06
97	1.17910E 02	3.02513E 08	5.89028E-01	1.17615E 02	3.22893E 06
98	1.17321E 02	3.05742E 08	5.26734E-01	1.17057E 02	2.93061E 06
99	1.16794E 02	3.08672E 08	4.61501E-01	1.16563E 02	2.60179E 06
100	1.16333E 02	3.11274E 08	3.93418E-01	1.16136E 02	2.24351E 06
101	1.15939E 02	3.13518E 08	2.64157E-01	1.15807E 02	1.51976E 06
102	1.15675E 02	3.15037E 08	2.16493E-01	1.15567E 02	1.25364E 06
103	1.15459E 02	3.16291E 08	8.96568E-02	1.15414E 02	5.21320E 05
104	1.15369E 02	3.16812E 08	7.67641E-02	1.15331E 02	4.47368E 05
105	1.15292E 02	3.17260E 08	6.33354E-02	1.15260E 02	3.69796E 05
106	1.15229E 02	3.17630E 08	4.90761E-02	1.15204E 02	2.86948E 05
107	1.15180E 02	3.17916E 08	3.30238E-02	1.15163E 02	1.93344E 05
108	1.15147E 02	3.18110E 08	1.43232E-02	1.15140E 02	8.38920E 04
109	1.15132E 02	3.18194E 08	1.51324E 01	1.07566E 02	1.10780E 08
110	1.00000E 02	4.28973E 08	3.00000E 00	9.85000E 01	2.86143E 07

TABLE III. - CONCLUDED - PROTON ENERGY AND SPECTRUM DATA ON INCIDENT FACE OF SHIELD

	ENERGY,E MEV	N(GREATER THAN E) PROTONS/CM**2	DELTA E MEV	E AVG. MEV	(DN/DE)*DELTA E PROTONS/CM**2
111	9.70000E 01	4.57588E 08	3.00000E 00	9.55000E 01	3.15142E 07
112	9.40000E 01	4.89102E 08	3.00000E 00	9.25000E 01	3.48153E 07
113	9.10000E 01	5.23917E 08	3.00000E 00	8.95000E 01	3.85887E 07
114	8.80000E 01	5.62506E 08	3.00000E 00	8.65000E 01	4.29216E 07
115	8.50000E 01	6.05427E 08	3.00000E 00	8.35000E 01	4.79210E 07
116	8.20000E 01	6.53348E 08	3.00000E 00	8.05000E 01	5.37189E 07
117	7.90000E 01	7.07067E 08	3.00000E 00	7.75000E 01	6.04803E 07
118	7.60000E 01	7.67548E 08	3.00000E 00	7.45000E 01	6.84128E 07
119	7.30000E 01	8.35961E 08	3.00000E 00	7.15000E 01	7.77790E 07
120	7.00000E 01	9.13740E 08	3.00000E 00	6.85000E 01	8.89158E 07
121	6.70000E 01	1.00256E 09	3.00000E 00	6.55000E 01	1.02259E 08
122	6.40000E 01	1.10491E 09	3.00000E 00	6.25000E 01	1.18380E 08
123	6.10000E 01	1.22329E 09	3.00000E 00	5.95000E 01	1.38034E 08
124	5.80000E 01	1.36133E 09	3.00000E 00	5.65000E 01	1.62238E 08
125	5.50000E 01	1.52357E 09	3.00000E 00	5.35000E 01	1.92378E 08
126	5.20000E 01	1.71594E 09	3.00000E 00	5.05000E 01	2.30377E 08
127	4.90000E 01	1.94632E 09	3.00000E 00	4.75000E 01	2.78953E 08
128	4.60000E 01	2.22527E 09	3.00000E 00	4.45000E 01	3.42028E 08
129	4.30000E 01	2.56730E 09	3.00000E 00	4.15000E 01	4.25396E 08
130	4.00000E 01	2.99270E 09	2.00000E 00	3.90000E 01	3.43785E 08
131	3.80000E 01	3.33648E 09	2.00000E 00	3.70000E 01	4.05216E 08
132	3.60000E 01	3.74170E 09	2.00000E 00	3.50000E 01	4.82019E 08
133	3.40000E 01	4.22372E 09	2.00000E 00	3.30000E 01	5.79278E 08
134	3.20000E 01	4.80300E 09	2.00000E 00	3.10000E 01	7.04233E 08
135	3.00000E 01	5.50723E 09	2.00000E 00	2.90000E 01	8.67404E 08
136	2.80000E 01	6.37463E 09	2.00000E 00	2.70000E 01	1.08447E 09
137	2.60000E 01	7.45910E 09	2.00000E 00	2.50000E 01	1.37947E 09
138	2.40000E 01	8.83858E 09	2.00000E 00	2.30000E 01	1.79046E 09
139	2.20000E 01	1.06290E 10	2.00000E 00	2.10000E 01	2.38004E 09
140	2.00000E 01	1.30091E 10			

TABLE IV. - PROTON SPECTRUM AT PRINT BOUND

SHIELD THICKNESS, X = 30.00 GM/CM**2

	ENERGY MEV	PRIMARY PROTONS	PROTON FLUX SPECTRA--PROTONS/CM**2 - - - SECONDARY PROTONS AT X - - - FIRST GEN.	HIGHER GEN.	- - - SECONDARY PROTONS IN DX - - - FIRST GEN.	HIGHER GEN.
1	866.904	7.919370E 05	0.	0.	0.	0.
2	700.000	2.180585E 06	0.	0.	0.	0.
3	550.000	2.020211E 06	0.	0.	0.	0.
4	450.000	3.307502E 06	7.458092E 04	0.	3.903917E 03	0.
5	350.000	5.835537E 06	3.384999E 05	0.	2.465283E 04	0.
6	250.000	1.069374E 07	1.428901E 06	1.817471E 03	5.831429E 04	2.528056E 02
7	150.000	1.792542E 07	3.315734E 06	7.411935E 04	2.236859E 05	1.273903E 04
8	90.000	4.071953E 06	1.012522E 06	6.183923E 04	1.471959E 05	1.888723E 04
9	70.000	3.865722E 06	1.159242E 06	1.161289E 05	6.065203E 04	2.905537E 04
10	55.000	1.756365E 06	8.170086E 05	1.019213E 05	2.410356E 05	4.240281E 04
11	45.000	1.569407E 06	5.313601E 05	8.869768E 04	1.637481E 04	3.755304E 04
12	35.000	1.334356E 06	3.301969E 05	6.122606E 04	1.898347E 04	2.116147E 04
13	25.000	1.051935E 06	5.883875E 05	1.359484E 05	6.219119E 04	4.551571E 04
14	15.000	7.111530E 05	2.043174E 05	1.368144E 05	8.939847E 04	9.807572E 04
15	9.000	9.563731E 04	0.	3.385130E 04	0.	3.385130E 04
16	7.000	7.841304E 04	0.	0.	0.	0.
17	5.500	3.250286E 04	0.	5.904960E 04	0.	5.904960E 04
18	4.500	2.780844E 04	0.	0.	0.	0.
19	3.500	2.295842E 04	0.	0.	0.	0.
20	2.499	1.779442E 04	1.833684E 04	6.614626E 03	1.833684E 04	6.614626E 03
21	1.499	1.198700E 04	0.	0.	0.	0.
22	0.499	5.184794E 03	0.	0.	0.	0.
23	0.	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
138	0.	0.	0.	0.	0.	0.
139	0.	0.	0.	0.	0.	0.
TOTALS		5.740811E 07	9.819087E 06	8.780282E 05	9.647251E 05	4.051587E 05
DOSE--RAD		5.989090E 00	1.394484E 00	3.126905E-01	2.113274E-01	2.051372E-01
DOSE--REM		6.258493E 00	1.474654E 00	4.059996E-01	2.914976E-01	2.984463E-01

TABLE V

SHIELD THICKNESS, X = 30.00 GM/CM**2

CASCADE NEUTRON FLUX SPECTRA--NEUTRONS/CM**2

	ENERGY MEV	--- CASCADE NEUTRONS AT X --- FIRST GEN.	HIGHER GEN.	--- CASCADE NEUTRONS IN DX --- FIRST GEN.	HIGHER GEN.
1	700.000	0.	0.	0.	0.
2	350.000	0.	0.	0.	0.
3	250.000	8.200350E 05	0.	2.715983E 04	0.
4	150.000	3.891566E 06	8.453883E 04	9.892934E 04	5.142340E 03
5	90.000	2.702243E 06	2.870130E 05	8.925800E 04	2.225087E 04
6	70.000	3.680100E 06	3.508909E 05	0.	1.159019E 04
7	55.000	3.487177E 06	9.846527E 05	1.531041E 05	7.783744E 04
8	45.000	4.056816E 06	3.765998E 05	0.	1.526421E 04
9	35.000	5.980938E 06	1.222626E 06	3.491327E 04	7.407499E 04
10	25.000	7.668770E 06	3.307985E 06	4.660545E 04	2.147222E 05
11	15.000	7.774245E 06	8.873599E 06	3.804186E 04	6.247649E 05
12	9.000	1.740790E 06	4.082112E 04	0.	0.
13	7.000	5.109648E 05	1.269622E 07	0.	9.493055E 05
14	5.000	2.555096E 04	1.031124E 03	0.	0.
15	3.000	0.	0.	0.	0.
16	1.000	0.	0.	0.	0.
TOTALS		4.233920E 07	2.822598E 07	4.880118E 05	1.994953E 06
DOSE--RAD		3.551066E-01	2.030363E-01	4.632163E-03	1.429791E-02
DOSE--REM		1.870188E 00	1.177189E 00	2.255617E-02	8.307160E-02

TABLE VI

DOSE--RAD

SHIELD THICKNESS GM/CM**2	PRIMARY PROTON (1)	--SECONDARY PROTON--- FIRST GENERATION (2)	HIGHER GENERATION (3)	---CASCADE NEUTRON--- FIRST GENERATION (4)	HIGHER GENERATION (5)	EVAPORATION NEUTRON (6)	TOTAL SECONDARY PROTON (2)+(3)	TOTAL CASCADE NEUTRON (4)+(5)	TOTAL PROTON (1)+(2)+(3)	TOTAL NEUTRON (4)•(5)+(6)	TOTAL DOSE (1)THRU(6)
0.00	3.8802E 03								3.8802E 03		3.8802E 03
10.00	4.4091E 01	3.8469E 00	2.8755E-01	5.9546E-01	1.3658E-01	6.7379E-02	4.1345E 00	7.3203E-01	4.8225E 01	7.9941E-01	4.9025E 01
20.00	1.2974E 01	2.3930E 00	3.3676E-01	4.5684E-01	1.9399E-01	4.8689E-02	2.7298E 00	6.5084E-01	1.5704E 01	6.9953E-01	1.6404E 01
30.00	5.9891E 00	1.3945E 00	3.1269E-01	3.5511E-01	2.0304E-01	3.6985E-02	1.7072E 00	5.5814E-01	7.6963E 00	5.9513E-01	8.2914E 00

TABLE VII

DOSE--REM

SHIELD THICKNESS GM/CM**2	PRIMARY PROTON (1)	--SECONDARY PROTON--- FIRST GENERATION (2)	HIGHER GENERATION (3)	---CASCADE NEUTRON--- FIRST GENERATION (4)	HIGHER GENERATION (5)	EVAPORATION NEUTRON (6)	TOTAL SECONDARY PROTON (2)+(3)	TOTAL CASCADE NEUTRON (4)+(5)	TOTAL PROTON (1)+(2)+(3)	TOTAL NEUTRON (4)+(5)+(6)	TOTAL DOSE (1)THRU(6)
0.00	3.8802E 03								3.8802E 03		3.8802E 03
10.00	4.7885E 01	4.2919E 00	3.6700E-01	3.3416E 00	8.0374E-01	6.7379E-01	4.6589E 00	4.1454E 00	5.2544E 01	4.8192E 00	5.7363E 01
20.00	1.3724E 01	2.7455E 00	4.6356E-01	2.4813E 00	1.1336E 00	4.8689E-01	3.2090E 00	3.6149E 00	1.6933E 01	4.1018E 00	2.1035E 01
30.00	6.2585E 00	1.4747E 00	4.0600E-01	1.8702E 00	1.1772E 00	3.6985E-01	1.8807E 00	3.0474E 00	8.1391E 00	3.4172E 00	1.1556E 01

TABLE VIII

FLUX--PARTICLES/CM**2

SHIELD THICKNESS GM/CM**2	PRIMARY PROTON (1)	- - - SECONDARY PROTON - - - FIRST GENERATION (2)	HIGHER GENERATION (3)	- - - CASCADE NEUTRON - - - FIRST GENERATION (4)	HIGHER GENERATION (5)	TOTAL SECONDARY PROTON (2)+(3)	TOTAL CASCADE NEUTRON (4)+(5)
0.00	1.30058E 10						
10.00	2.78304E 08	1.66912E 07	6.67216E 05	7.81036E 07	1.95063E 07	1.73584E 07	9.76099E 07
20.00	1.06791E 08	1.28100E 07	8.40923E 05	5.70816E 07	2.73415E 07	1.36509E 07	8.44231E 07
30.00	5.74081E 07	9.81909E 06	8.78028E 05	4.23392E 07	2.82260E 07	1.06971E 07	7.05652E 07

TABLE IX

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SHIELD THICKNESS (GM/CM**2)	NEUTRON SOURCE TERM--NEUTRONS/GM EVAPORATION	- - - - - CASCADE - - - - - FIRST GEN.	HIGHER GEN.	SHIELD THICKNESS (GM/CM**2)	NEUTRON SOURCE TERM--NEUTRONS/GM EVAPORATION	- - - - - CASCADE - - - - - FIRST GEN.	HIGHER GEN.
0.250	1.80173E 07	8.46989E 07	0.	10.500	3.90561E 06	2.12698E 06	3.06844E 06
0.750	1.18555E 07	4.06735E 07	1.33371E 06	11.500	3.73588E 06	1.89890E 06	3.01849E 06
1.250	9.25210E 06	2.48771E 07	2.02708E 06	12.500	3.60081E 06	1.70866E 06	2.96559E 06
1.750	7.89753E 06	1.78192E 07	2.44634E 06	13.500	3.47295E 06	1.52813E 06	2.90612E 06
2.250	7.07808E 06	1.36657E 07	2.72929E 06	14.500	3.35673E 06	1.39246E 06	2.84945E 06
2.750	6.48592E 06	1.08234E 07	2.90804E 06	15.500	3.25232E 06	1.28247E 06	2.79318E 06
3.250	6.08188E 06	8.79058E 06	3.02620E 06	16.500	3.22544E 06	1.16781E 06	2.73407E 06
3.750	5.71928E 06	7.28494E 06	3.10209E 06	17.500	3.00239E 06	1.08788E 06	2.68221E 06
4.250	5.50319E 06	6.56909E 06	3.18379E 06	18.500	2.94002E 06	9.86096E 05	2.62220E 06
4.750	5.25585E 06	5.58203E 06	3.20994E 06	19.500	2.87854E 06	9.13255E 05	2.56026E 06
5.250	5.09153E 06	5.09620E 06	3.24961E 06	20.500	2.80066E 06	8.60205E 05	2.50746E 06
5.750	4.92551E 06	4.53949E 06	3.25797E 06	21.500	2.70870E 06	8.04505E 05	2.45558E 06
6.250	4.76907E 06	4.07119E 06	3.25701E 06	22.500	2.63412E 06	7.53956E 05	2.40478E 06
6.750	4.66343E 06	3.67358E 06	3.25871E 06	23.500	2.56506E 06	7.02895E 05	2.35257E 06
7.250	4.62429E 06	3.40851E 06	3.25657E 06	24.500	2.49668E 06	6.61557E 05	2.30237E 06
7.750	4.41090E 06	3.16653E 06	3.24517E 06	25.500	2.43288E 06	6.26129E 05	2.25736E 06
8.250	4.18601E 06	3.07231E 06	3.25287E 06	26.500	2.39965E 06	5.87784E 05	2.20994E 06
8.750	4.13557E 06	2.71042E 06	3.20520E 06	27.500	2.28828E 06	5.59225E 05	2.16715E 06
9.250	4.08094E 06	2.36438E 06	3.15494E 06	28.500	2.24287E 06	5.21866E 05	2.11953E 06
9.750	4.04462E 06	2.32594E 06	3.14348E 06	29.500	2.21967E 06	4.94487E 05	2.07365E 06

trum. The next card with 17 on it indicates the number of energy boundaries used for constructing the cascade neutron energy groups. The following data are the cascade neutron energy boundaries.

Table II is a printout of some of the input data. The first two comments cards describe the purpose and type of shield considered. The three lines of data under the title block show the upper and lower bounds of Δx (labeled x,min and x,max, respectively, in g/cm^2). Also shown are the number of increments in each Δx, the material number (this is a call number for getting data from the tape), the density, the hydrogen ratio, and the removal cross section. This data was kept on cards so it could be readily changed. Below this data is indicated the number of angles used in the evaporation neutron calculation. The next five lines indicate the cut-off energy for the indicated calculations. Below the cut-off energies is the spectrum equation and the coefficients used.

Table III is a print of the incident proton spectrum and the energy boundaries and energy groups used at the incident face. These energies were calculated from input on the exit face. The break between 22 and 23 (left column) shows the maximum energy 2.16621E02 which is >0 at the exit face. Also 2.16612E02 is the first energy group that does not penetrate to the exit face. Similar breaks occur for each print bound. Table III shows six columns of data. The titles should be self explanatory. The column on the left without a title is an index counter showing how many entries there are in the table. Reading from left to right the second column shows the incident proton energy bounds at the incident face of the shield. The next column is N(>E) for the indicated energy bounds in column two. Column four is the difference of successive values in column two. Column five is the midpoint energy of column two. The last column is the difference of successive values of column three and represents protons/cm^2 or protons/cm^2 sec in group i.

If a differential type spectrum were used the column headings for table III would have been: number of entries, proton energy bounds on the incident face in MeV, δE in MeV, average energy in MeV, the differential spectrum in protons/cm^2 MeV or protons/cm^2 MeV sec and the $(dN/dE)\delta E$ in protons/cm^2 or protons/cm^2 sec in each group.

Table IV contains the proton spectrum data for the print bound x = 30. g/cm^2. The data for the print bounds x = 10 and 20. g/cm^2 were deleted from the report. As noted on the incident face data, table III 22 energy groups penetrate the shield. The remainder of the 139 incident energies were stopped by the shield. The zero data between group 24 and group 138 was not included in the report. The column on the left indicates the number of entries in the table. Reading from left to right, the second column indicates the midpoint energy of each proton energy group in MeV at the indicated thickness. The entries in the third column are the number of primary protons in each of the indicated energy groups. These are in protons/cm^2 for time integrated spectra or protons/cm^2 sec for spectra that has not been time integrated as indicated at the top of the table. The following two columns contain the cascade secondary protons at thickness x. The column labeled FIRST GEN contains the first generation cascade protons at x. The next column labeled HIGHER GEN contains the second and higher generation cascade protons at x. The last two columns show the same parameters as the previous two columns, however, these are from the last small δx only before reaching x. At the bottom of this table is indicated the total number of particles in the indicated columns and the rad and rem dose respectively from these components.

Table V is read similarly to table IV only these data are for cascade neutrons at x and from the last small δx only. These data are also for first generation and second and higher generation particles as indicated.

Table VI contains the dose in rad per flare for the various radiation components calculated. The columns are labeled to be self explanatory.

Table VII is read the same as table VI only the units are rem per flare. If the spectrum used was in particles/cm^2 sec the tables VI and VII would be in rad/hr and rem/hr, respectively.

Table VIII contains the total integrated flux for the various particles at the indicated print bounds. The flux of evaporation neutrons was not calculated in this table.

Table IX contains the evaporation and cascade neutron source terms for the various layers. The neutron source terms are in neutrons/g or neutrons/g sec. The location at these source terms is the midpoint of all δx layers.

Sample of Nuclear Interaction Data

The main source of nuclear interaction data used in LPSC which include inelastic cross sections, secondary yields, and energy of secondaries (for nuclei of mass numbers $\geq$12) was supplied by H. Bertini of ORNL (see ref. 4). This data was supplied for 10 elements ranging from carbon (12) to Uranium (238). The program developed by Bertini for estimating the secondary yields and the energies of the secondaries does not give good statistics for nuclei containing few nucleons. Carbon was the lowest mass number believed to give reasonable statistics. Therefore Bertini's data was used for mass numbers $\geq$ carbon in this program. The data when plotted at constant energy as a function of mass number falls on smooth curves; thus interpolation relative to mass number may be accomplished for elements not calculated by Bertini.

The data supplied in reference 4 is voluminous and it was necessary to select from it just the data required for LPSC. A sample of the data required for carbon appears in table X. The top set of data is for protons bombarding. Column one is the energy in MeV of the incident particle. Column two is the average yield of cascade protons per collision. Column three is the average energy in MeV of the emitted protons. Column four is the average number of cascade neutrons emitted per collision. Column five is the average energy in MeV of the emitted cascade neutrons. Column six is the average yield of evaporation neutrons per collision. Column seven is the inelastic cross section in millibarns. The bottom set of data is for incident neutrons bombarding.

The data was all rounded to four significant figures. No claim is made that more than one or two are reliable. The data was plotted as a function of incident particle energy. The values read from smooth curves drawn through the data in table X were used on the data tape.

Nuclear Interaction Data for Hydrogen

When high energy nucleons collide with hydrogen nuclei this program (LPSC) assumes that scattering of the incident particle occurs. It is further assumed that the hydrogen nucleus is added to the beam as an additional proton.

The data in table XI contains the secondary yields, the energies of secondaries, and the cross sections for neutrons and protons bombarding respectively. This table is similar to the previous table X.

Source of Data

Table XII on page 45 was included to show the source of data for proton and neutron cross sections, proton range energy, and proton mass stopping power.

TABLE X. - CARBON

Incident energy in MeV	Average yield of emitted cascade protons per collision	Average energy of emitted protons in MeV	Average yield of emitted cascade neutrons per collision	Average energy of emitted neutron in MeV	Average yield of evaporation neutrons per collision	Inelastic cross section in millibarns
Yield and energy for protons bombarding						
25	0.5806	9.990	0.4153	9.382	0.02697	447.9
50	.8788	18.86	.6338	17.57	.1713	348.9
100	1.177	38.09	.8039	33.02	.2788	271.6
150	1.300	57.97	.8669	52.77	.2820	245.5
200	1.435	77.41	.8507	69.38	.3307	232.3
250	1.499	97.23	.8900	82.57	.3598	222.5
300	1.580	112.9	.8864	103.0	.3249	215.4
350	1.593	132.8	.9325	114.9	.3509	218.0
400	1.642	154.9	.9250	124.4	.3497	233.4
Yield and energy for neutrons bombarding						
25	0.4257	9.095	0.5698	9.865	0.4466	443.8
50	.6290	17.16	.8616	19.31	.5125	353.6
100	.7898	34.62	1.159	38.52	.5848	266.7
150	.8450	51.97	1.339	57.26	.5526	236.8
200	.9075	66.85	1.424	76.58	.5756	224.4
250	.9157	80.08	1.493	97.46	.5800	214.9
300	.8780	102.3	1.563	115.2	.5122	215.9
350	.9038	116.0	1.556	138.2	.4932	215.7
400	.9170	125.1	1.677	151.1	.5301	223.8

TABLE XI. - HYDROGEN DATA

Yield and energy for neutrons bombarding					
E_i, MeV	y_{cpn}	E_j, MeV	y_{cnn}	E_j, MeV	σ, mb
10	1	4.95	1	5.05	930.
25		12.6		12.4	379.
50		25.2		24.8	178.
100		51		49	69.
150		77		73	45.
200		103.5		96.5	37.1
250		130		120	33.8
300		157		143	35.3
350		182		168	36.
400		209		191	35.
Yield and energy for protons bombarding					
E_i, MeV	y_{cpp}	E_j, MeV	y_{cnp}	E_j, MeV	σ, mb
10	2	5	0	0	330
25		12.5			119
50		25			57
100		50			29.5
150		75			25.6
200		100			24
250		125			22.9
300		150			22.4
350		175			22.6
400		200			24

TABLE XII. - REFERENCE TABLE FOR CROSS SECTIONS, RANGE ENERGY, AND MASS STOPPING POWER DATA

Material	Mass stopping power and range energy	Low energy neutron cross sections	High energy proton and neutron cross sections
Hydrogen	Private communication, C.W. Hill Lockheed, Georgia	Reference 9	References 9, 10
Beryllium	↓	No secondaries being generated	Proton attenuation by ionization only
Carbon	↓	Reference 11, 15	Reference 4
Nitrogen	↓	Reference 12	Interpolated data from reference 4
Oxygen	↓	Reference 12, 15	Reference 4
Aluminum	↓	Reference 12	Reference 4
Titanium*	↓	Reference 12	Interpolated data from reference 4
Iron	↓	Reference 13, 15	Interpolated data from reference 4
Tungsten	↓	Reference 14, 16	Reference 4
Lead	↓	Reference 14, 16	Reference 4
Uranium	↓	Reference 15	Reference 4
Water	↓	Reference 9, 12	References 4, 9, 10
Polyethylene	↓	References 9, 10, 11	References 4, 9, 10

*The Lockheed range energy data was interpolated for titanium.

APPENDIX A

LPSC PROGRAM LISTING

E-3080

```
$IBFTC PISR    DECK,LIST
C.....THE LEWIS PROTON SHIELDING CODE (LPSC)
C.....PROTON INDUCED SECONDARY RADIATION.
C.....THIS PROGRAM CALCULATES THE PRIMARY PROTON, CASCADE PROTON,
C.....CASCADE NEUTRON, AND EVAPORATION NEUTRON DOSES IN RAD AND REM
C.....FOR A BEAM OF PROTONS INCIDENT NORMAL TO A SLAB
      COMMON  D2X(20)        , MAX            , EO(300,20)
      COMMON  EI(300)        , DEI(300)       , EIBAR(300)
      COMMON  OP(300)        , OPPRM(300)     , NOD2X(20)
      COMMON  X(20)          , NOX            , ENTOTS(200)
      COMMON  DX(20)         , PROPNO(20)     , C1
      COMMON  PDSBND         , NDSBND         , BNDLOW
      COMMON                   ENRG(100)      , RNG(100)
      COMMON  EBOMBP(25,4)   , EBOMBN(25,4)   , CPSP(25,4)
      COMMON  CPSN(25,4)     , CNSP(25,4)     , CNSN(25,4)
      COMMON  ENSP(25,4)     , ENSN(25,4)     , EBOMP(25,4)
      COMMON  EBOMN(25,4)    , EPROP(25,4)    , EPRON(25,4)
      COMMON  ENEUP(25,4)    , ENEUN(25,4)    , ENRGP(25)
      COMMON  ENRGN(75)      , XSMBP(25)      , XSMBN(75)
      COMMON  SNRG(100)      , RBENRG(20)     , C1NRG(40)
      COMMON  C2NRG(40)      , CNRG(2)        , SOFF(100)
      COMMON  RBE(20)        , CONK1(40)      , CONK2(40)
      COMMON  CONK(2)        , LENGTH(8)      , GMWT
      COMMON  LSOFE          , LRBE           , LK1
      COMMON  LK2            , LK             , NOFCOM
      COMMON  MOVE           , KOSW(36)       , KONSWT
      EQUIVALENCE (KOSW( 1),KOSW1 ),(KOSW( 5),KOSW5 ),(KOSW( 7),KOSW7 ),
     A            (KOSW( 9),KOSW9 ),(KOSW(11),KOSW11),(KOSW(13),KOSW13),
     B            (KOSW(17),KOSW17),(KOSW(21),KOSW21)
      DIMENSION CARD(12),NUENBD(300),NUENRG(300),SIGCNP(300,2),
     APHIJI(300,3),EIBNDS(300),AVGNRG(300),NEUTXS(300),DIST(300),
     BSIGNEL(300),UCNEUT(300,2),
     CUCPRIM(300),UCSEC(300,2),CPP(300,2),CNP(300,2),PROTS(300,5)
     D,NEWTS(300,4),TOTALS(20,9),PDOSE(20,5,3),PDOSRM(20,5,3),NDOSE(20,4
     E),NDOSRM(20,4),EVNUDS(20),EVNDRM(20),ANS(3),CASANS(2)
      DIMENSION TSP(3),TP(3),TD(3),XMID(200),CNTOTS(200,2),SOTEEN(200)
     A,MIDNRG(300)
      REAL NUENBD,NUENRG,NEUTXS,NEWTS,NDOSE,NDOSRM,KOFE
      REAL NDSBND,IPDRAD,IPDREM,IPFLTO
      REAL MIDNRG
      INTEGER SOFFNO
      INTEGER PROPNO
      EQUIVALENCE (PROTS(1),PHIJI(1)),(PROTS(901),CPP(1)),(NEWTS(1),
     ASIGCNP(1)),(NEWTS(601),CNP(1))
      EQUIVALENCE (ANS(1),CPS),(ANS(2),CNS),(ANS(3),ENS)
      EQUIVALENCE (ENRGYP,CASANS(1)),(ENRGYN,CASANS(2))
      EQUIVALENCE (EO(   1),PDOSRM(1)),(EO( 301),EIBNDS(1)),
     1            (EO( 601),AVGNRG(1)),(EO( 901),NEUTXS(1)),
     2            (EO(1201),NUENBD(1)),(EO(1501),DIST(1)),
     3            (EO(1801),SIGNEL(1)),(EO(2101),UCNEUT(1)),
     4            (EO(2701),SOTEEN(1)),(EO(2901),NDOSRM(1)),
     5            (EO(2981),EVNDRM(1)),(EO(3001),UCPRIM(1)),
     6            (EO(3301),UCSEC(1)), (EO(3901),NUENRG(1)),
     7            (EO(4201),PROTS(1)),  (EO(5701),PDOSE(1))
    1 WRITE (6,2)
    2 FORMAT(1H1)
      READ (5,3) NOCDS
    3 FORMAT(I2)
      DO 5 M=1,NOCDS
      READ (5,4) (CARD(J),J=1,12)
    4 FORMAT(12A6)
```

```
    5 WRITE (6,4) (CARD(J),J=1,12)
      MOVE = 1
C.....KNTRP=1 CALCULATE PRIMARY PROTONS ONLY
C.....KNTRP=2 CALCULATE PRIMARY PROTONS PLUS FIRST GENERATION SECONDARY
C     PROTONS AND EVAPORATION NEUTRONS.
C.....KNTRP=3 CALCULATE PRIMARY PROTONS PLUS ALL GENERATIONS OF SECONDARY
C     PROTONS AND EVAPORATION NEUTRONS.
C.....KNTRN=1 CALCULATE FIRST GENERATION CASCADE NEUTRONS
C.....KNTRN=2 CALCULATE ALL GENERATION CASCADE NEUTRONS AND EVAPORATION
C     NEUTRONS.
      READ (5,6) SPBND,SNBND,PDSBND,NDSBND,BNDLOW,KNTRP,KNTRN,SOFENO
    6 FORMAT(5F6.0,3I4)
      READ (5,6664) KOSW
 6664 FORMAT(36I1)
      PROFTD=1.600E-8
      IF (KOSW13 .EQ. 1) PROFTD=PROFTD*3600.
C.....INITIALIZE SUBROUTINES AND READ-IN DATA TABLES.
      CALL PROPTY(1,SOFENO)
C.....EVNEDO-SUBROUTINE- CALCULATES EVAPORATION NEUTRON DOSE
      CALL EVNEDO (1,DUMMY,DUMMY,DUMMY,DUMMY)
      WRITE (6,6665)BNDLOW,SPBND,SNBND,PDSBND,NDSBND
 6665 FORMAT(9X,55HENERGY CUT-OFF LEVEL FOR INITIAL INCIDENT PROTON FLUX
     A =F7.2,5H MEV./9X,80HENERGY CUT-OFF LEVEL FOR CALCULATING SECONDAR
     BY PARTICLES FROM INCIDENT PROTONS =F7.2,5H MEV./9X,81HENERGY CUT-O
     CFF LEVEL FOR CALCULATING SECONDARY PARTICLES FROM INCIDENT NEUTRON
     DS =F7.2,5H MEV./9X,56HENERGY CUT-OFF LEVEL FOR PROTON DOSE DUE TO
     EIONIZATION =F7.2,5H MEV./9X,52HENERGY CUT-OFF LEVEL FOR NEUTRON DO
     FSE CALCULATIONS =F7.2,5H MEV.)
C.....DOSEK-SUBROUTINE- CALCULATES MASS STOPPING POWER,RBE, AND FLUX
C.....TO DOSE CONVERSION FACTOR
C.....YIELDS-SUBROUTINE-CALCULATES YIELDS OF SECONDARY PARTICLES FOR
C.....CASCADE PROTONS, CASCADE NEUTRONS, AND EVAPORATION NEUTRONS
C.....RANGE-SUBROUTINE-CALCULATES RANGE FROM ENERGY OR ENERGY FROM RANGE
C.....XS-SUBROUTINE-CALCULATES PROTON AND NEUTRON CROSS-SECTIONS
C.....CASNRG-SUBROUTINE-CALCULATES ENERGY OF CASCADE PARTICLES
C.....INVALU-SUBROUTINE-CALCULATES INCIDENT ENERGY FROM EXIT ENERGY
C.....INPUT AND ALSO CALCULATES THE INPUT PROTON SPECTRUM
      CALL INVALU
      GO TO (11,7),KOSW7
C.....NONUBD -  NUMBER OF NEUTRON ENERGY BOUNDERIES
C.....NUENBD- NEUTRON ENERGY BOUND
    7 READ (5,8) NONUBD,(NUENBD(K),K=1,NONUBD)
    8 FORMAT(I3/(7F10.0))
    9 DO 10 K=2,NONUBD
C.....SIGCNP(K-1,1)-CASCADE NEUTRONS IN GROUP K-1, FIRST GENERATION
      SIGCNP(K-1,1)=0.0
C.....SIGCNP(K-1,2)-CASCADE NEUTRONS IN GROUP K-1, SECOND AND HIGHER
C.....GENERATIONS
      SIGCNP(K-1,2)=0.0
C.....NUENRG- NEUTRON ENERGY(MID-POINT OF INTERVAL)
   10 NUENRG(K-1)=0.5*(NUENBD(K)+NUENBD(K-1))
      GO TO 13
   11 NONUBD=MAX+1
      DO 12 K=1,NONUBD
   12 NUENBD(K)=FI(K)
      GO TO 9
   13 IPFLTO=0.
      IPDRAD=0.
      IPDREM=0.
      DO 14 J=1,MAX
C.....PHIJI(J,1) -PRIMARY PROTONS IN ENERGY GROUP J
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      PHIJI(J,1)= OPPRM(J)
C.....PHIJI(J,2) -FIRST GENERATION CASCADE PROTONS IN ENERGY GROUP J
      PHIJI(J,2)=0.0
C.....PHIJI(J,3) -SECOND AND HIGHER GENERATION CASCADE PROTONS IN GROUPJ
      PHIJI(J,3)=0.0
C.....EIBND-EXIT ENERGY BOUNDS
      EIBNDS(J)=EI(J)
C.....AVGNRG(J)-AVERAGE ENERGY OF A GROUP
      AVGNRG(J)=EIBAR(J)
      IPFLTO=IPFLTO+PHIJI(J,1)
      CALL DOSEK (AVGNRG(J),DEDX,RABIEF,2)
      DUMMY =PHIJI(J,1)*DEDX
      IPDRAD = IPDRAD+DUMMY
   14 IPDREM = IPDREM+DUMMY*RABIEF
      IPDRAD = IPDRAD*PROFTD
      IPDREM = IPDREM*PROFTD
      GO TO (1414,83),KOSW5
 1414 MAXP1=MAX+1
      EIBNDS(MAXP1)=EI(MAXP1)
      XX=0.0
   15 NOLAY=0
      SUMENT=0.
C.....NOX-   NUMBER OF LARGE DELTA X
      DO 82 M=1,NOX
      EVNUDS(M)=0.0
      EVNDRM(M)=0.0
      IF (M .EQ. 1) GO TO 16
      IF (PROPNO(M) .EQ. PROPNO(M-1))GO TO 1819
   16 CALL PROPTY(3,M)
   17 DO 1717 J=2,NONUBD
 1717 CALL XS   (NUENRG(J-1),NEUTXS(J-1)  ,2)
      DO 18 J=1,MAXP1
      IF (EIBNDS(J) .EQ. 0.0) GO TO 1818
   18 CALL RANGE (EIBNDS(J),DIST(J),2)
      GO TO 1819
 1818 DIST(J)=0.0
C.....LIMIT- NUMBER OF SMALL DELTA X
 1819 LIMIT=NOD2X(M)
C.....HAFD2X- DELTA X/2
C.....D2X(M)-SMALL DELTA X
      HAFD2X=D2X(M)*0.5
   19 DO  50  N=1,LIMIT
C.....XX-DEPTH INTO  THE SHIELD TO WHICH THE CALCULATION HAS PROGRESSED
      XX=XX+D2X(M)
C.....NOLAY- NUMBER OF SMALL DELTA X
      NOLAY=NOLAY +1
      XMID(NOLAY)=XX-HAFD2X
      CNTOTS(NOLAY,1) = 0.0
      CNTOTS(NOLAY,2) = 0.0
      SOTEEN(NOLAY)=0.0
C.....ENTOTS(NOLAY)-SUM OF EVAPORATION NEUTRONS PRODUCED IN D2X(M).
      ENTOTS(NOLAY) = 0.0
      DO 20 J=1,MAX
C.....UCPRIM(J)-UNCOLLIDED PRIMARY PROTONS
      UCPRIM(J)=0.0
      DO 20 JJ=1,2
C.....UCSEC(J,JJ)- UNCOLLIDED SECONDARY PROTONS
      UCSEC(J,JJ)=0.0
C.....CPP- CASCADE PROTONS PRODUCED
   20 CPP(J,JJ)=0.0
      DO 23 JJ=1,2
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      DO 23 J=2,NONUBD
      UCNEUT(J-1,JJ)=0.
C.....CNP(J-1,JJ)- CASCADE NEUTRONS PRODUCED
   23 CNP(J-1,JJ)=0.0
C.....DIST-   PROTON RANGE
   24 DIST(1)=DIST(1)-D2X(M)
      CALL RANGE(DIST(1),EIBNDS(1),3)
      CALL XS(AVGNRG(1),SIGNEL(1),1)
      DO 27 J=2,MAXP1
      DIST(J)=DIST(J)-D2X(M)
      IF (DIST(J) .GT. 0.0) GO TO 25
      EIBNDS(J)=0.0
      IF ((DIST(J-1)+DIST(J)) .GE. 0.0) GO TO 26
      MIDNRG(J-1)=0.0
      GO TO 2626
   25 CALL RANGE(DIST(J),EIBNDS(J),3)
   26 MIDNRG(J-1)=0.5*(EIBNDS(J)+EIBNDS(J-1))
 2626 IF(AVGNRG(J) .LE. 1.E-5) GO TO 28
   27 CALL XS (AVGNRG(J),SIGNEL(J),1)
      MIN=MAX
      GO TO 29
   28 MIN = J-1
   29 GO TO (32,30),KOSW9
   30 WRITE (6,31) (AVGNRG(NN),SIGNEL(NN),NN=1,MIN)
   31 FORMAT(1HL8X,15HCROSS-SECTIONS,/1HJ12X,6HENERGY13X,9HINELASTIC/
     1(2X,1P2E20.5))
   32 DO 3838 J=1,MIN
C.....DUMMY-THIS NAME IS USED FOR SEVERAL DIFFERENT QUANTITIES IN THE
C.....CALCULATION OF SECONDARY PARTICLE PRODUCTION,PARTICLE ATTENUATION,
C.....AND PARTICLE DOSE CALCULATIONS
      CALL RANGE(AVGNRG(J),DUMMY,2)
      IF (DUMMY .LE. D2X(M)) GO TO 34
      DEGMLT=EXP(-SIGNEL(J)*D2X(M))
      UCPRIM(J)=PHIJI(J,1)*DEGMLT
      IF (KNTRP .EQ. 1) GO TO 35
      DO 33 JJ=2,KNTRP
   33 UCSEC(J,JJ-1)=PHIJI(J,JJ)*DEGMLT
      GO TO 35
   34 UCPRIM(J)=0.0
      IF (DUMMY .LT. HAFD2X) GO TO 3838
C.....DEGMLT- PROTON ATTENUATION FACTOR ACROSS DELTA X OR DELTA X/2
      DEGMLT=EXP(-SIGNEL(J)*HAFD2X)
   35 IF((KNTRP .EQ. 1 .AND. KNTRN .EQ. 0) .OR. (AVGNRG(J) .LT. SPBND))
     AGO TO 3838
C.....COLFRA- COLLIDED FRACTION
   36 COLFRA = 1.0 - DEGMLT
      DO 3738 NOM=1,NOFCOM
C.....ANS(K) - YIELDS OF SECONDARY PARTICLES - K=1, CASCADE PROTON --
C     K=2, CASCADE NEUTRON -- K=3, EVAPORATION NEUTRON.
      CALL YIELDS (AVGNRG(J),ANS,NOM,2)
      CALL CASNRG (AVGNRG(J),CASANS,NOM,2)
      IF (KNTRP .LT. 2) GO TO 3737
C.....ENRGYP- ENERGY OF  CASCADE PROTON
C.....DUMRNG- RANGE OF SECONDARY PROTON AT BIRTH
      CALL RANGE (ENRGYP,DUMRNG,2)
      DUMRNG=DUMRNG-HAFD2X
      IF (DUMRNG .LE. 0.0) GO TO 37
      CALL RANGE (DUMRNG,PROE,3)
      CALL XS    (ENRGYP,ATXSEC,1)
      DUMMY=COLFRA*CPS*EXP(-ATXSEC*HAFD2X)
      CALL SORT (PROE  ,EIBNDS,MAX  ,IND)
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      CPP(IND,1)=PHIJI(J,1)*DUMMY +CPP(IND,1)
      SUM=PHIJI(J,1)
      IF (KNTRP .LE. 2) GO TO 37
      CPP(IND,2)=DUMMY*(PHIJI(J,2)+PHIJI(J,3)) +CPP(IND,2)
      SUM=SUM+PHIJI(J,2)+PHIJI(J,3)
   37 IF ((PROPNO(M).LT.50).AND.(NOM.EQ.1)) GO TO 3738
C.....ENTOTS(NOLAY)-EVAPORATION NEUTRONS PRODUCED BY ALL PROTONS
      ENTOTS(NOLAY) = ENTOTS(NOLAY)+COLFRA*ENS*SUM
 3737 IF (KNTRN .EQ. 0) GO TO 3738
C.....ENRGYN- ENERGY OF  CASCADE NEUTRON
      CALL XS    (ENRGYN,ATXSEC,2)
      ATTEN = EXP(-ATXSEC*HAFD2X)
      DUMMY = PHIJI(J,1)*COLFRA*CNS
      CALL SORT (ENRGYN,NUENBD,NONUBD-1,IND)
      CNTOTS(NOLAY,1) = CNTOTS(NOLAY,1)+DUMMY
C.....CNP(IND,1)-CASCADE NEUTRONS PRODUCED BY PRIMARY PROTONS
      CNP(IND,1) = CNP(IND,1)+DUMMY*ATTEN
      IF (KNTRN .EQ. 1) GO TO 3738
C.....CNP(IND,2)-CASCADE NEUTRONS PRODUCED BY SECONDARY PROTONS
      DUMMY = (PHIJI(J,2)+PHIJI(J,3))*COLFRA*CNS
      CNTOTS(NOLAY,2) = CNTOTS(NOLAY,2)+DUMMY
      CNP(IND,2) = CNP(IND,2)+DUMMY*ATTEN
 3738 CONTINUE
 3838 CONTINUE
      IF (KNTRN .EQ. 0 .OR. XX .EQ. D2X(1)) GO TO 43
      DO 42 J=2,NONUBD
      DUMMY=EXP(-NEUTXS(J-1)   *D2X(M))
      DO 39 JJ=1,KNTRN
   39 UCNEUT(J-1,JJ) =SIGCNP(J-1,JJ)*DUMMY
      IF ((KNTRN .LT. 2 .AND. KNTRP .LT. 3) .OR. (NUENRG(J-1) .LT. SNBND
     A)) GO TO 42
      SUM=SIGCNP(J-1,1)+SIGCNP(J-1,2)
      IF(SUM .EQ. 0.0) GO TO 42
      COLFRA=1.-DUMMY
      DO 4141 NOM=1,NOFCOM
      CALL YIELDS (NUENRG(J-1),ANS,NOM,3)
      CALL CASNRG (NUENRG(J-1),CASANS,NOM,3)
      IF (KNTRP .LT. 3) GO TO 40
      CALL RANGE (ENRGYP,DUMRNG,2)
      DUMRNG=DUMRNG-HAFD2X
      IF (DUMRNG .LE. 0.0) GO TO 40
      CALL RANGE (DUMRNG,PROE,3)
      CALL XS     (ENRGYP,ATXSEC,1)
      DUMMY=COLFRA*CPS*EXP(-ATXSEC*HAFD2X)
      CALL SORT (PROE  ,EIBNDS,MAX  ,IND)
      CPP(IND,2)=DUMMY*SUM +CPP(IND,2)
   40 IF (KNTRN .LT. 2) GO TO 4141
      CALL XS    (ENRGYN,ATXSEC,2)
      DUMMY = SUM*COLFRA*CNS
      CALL SORT (ENRGYN,NUENBD,NONUBD-1,IND)
C.....CNP(IND,2)-CASCADE NEUTRONS PRODUCED BY CASCADE NEUTRONS
      CNTOTS(NOLAY,2) = CNTOTS(NOLAY,2)+DUMMY
      CNP(IND,2) = CNP(IND,2)+DUMMY*EXP(-ATXSEC*HAFD2X)
C.....ENTOTS(NOLAY)-EVAPORATION NEUTRONS PRODUCED BY CASCADE NEUTRONS
   41 ENTOTS(NOLAY) = ENTOTS(NOLAY)+COLFRA*ENS*SUM
 4141 CONTINUE
   42 CONTINUE
   43 DO 45 J=1,MAX
      PHIJI(J,1)=UCPRIM(J)
      IF (KNTRP .EQ. 1) GO TO 45
      DO 44 JJ=2,KNTRP
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   44.PHIJI(J,JJ)=UCSEC(J,JJ-1)+CPP(J,JJ-1)
   45 AVGNRG(J)=MIDNRG(J)
      IF (KNTRN .EQ. 0) GO TO 47
      DO 46 JJ=1,KNTRN
      DO 46 J=2,NONUBD
   46 SIGCNP(J-1,JJ)=UCNEUT(J-1,JJ)+CNP(J-1,JJ)
      GO TO 48
   47 IF (KNTRP .EQ. 1) GO TO 50
   48 SUMENT=SUMENT+ENTOTS(NOLAY)
      CNTOTS(NOLAY,1)=CNTOTS(NOLAY,1)/D2X(M)
      CNTOTS(NOLAY,2)=CNTOTS(NOLAY,2)/D2X(M)
      SOTFEN(NOLAY)=ENTOTS(NOLAY)/D2X(M)
      CALL EVNFDO (2,NOLAY,M,N,DUMMY)
   50 CONTINUE
      DO 51 K=1,9
   51 TOTALS(M,K)=0.0
C.....SUMMATION OF PROTON PARTICLES.
   52 DO 53  K=1,KNTRP
      DO 53  MM=1,MIN
      TOTALS (M,K) = TOTALS(M,K)+PHIJI(MM,K)
      IF (K.LT.2) GO TO 53
      TOTALS(M,K+2) = TOTALS(M,K+2)+CPP(MM,K-1)
   53 CONTINUE
   54 IF (KNTRN .EQ. 0) GO TO 56
C.....SUMMATION OF NEUTRON PARTICLES.
      DO 55  K=1,KNTRN
      DO 55  MM=2,NONUBD
      TOTALS (M,K+5) = TOTALS (M,K+5)+SIGCNP(MM-1,K)
   55 TOTALS (M,K+7) = TOTALS (M,K+7)+CNP(MM-1,K)
C.....PROTON DOSE CALCULATIONS.
   56 DO 57 KK=1,3
      DO 57 K=1,5
C.....PDOSE(M,K,KK)- PROTON DOSE IN RAD
      PDOSE (M,K,KK) = 0.0
C.....PDOSRM(M,K,KK)-PROTON DOSE IN REM
   57 PDOSRM(M,K,KK) = 0.0
      DO 59  MM=1,MIN
C.....DEDX-MASS STOPPING POWER OF PROTONS
C.....RABIEF-RELATIVE BIOLOGICAL EFFECTIVENESS (RBE)
      CALL DOSEK (AVGNRG(MM),DEDX,RABIEF,2)
      DO 59  K=1,KNTRP
      DUMMY = PROFTD*PROTS(MM,K)*DEDX
      PDOSE (M,K,1) = PDOSE(M,K,1)+DUMMY
      PDOSRM(M,K,1) = PDOSRM(M,K,1) + DUMMY*RABIEF
      GO TO (58,5757),KOSW21
 5757 IF (AVGNRG(MM) .LT. 10.) GO TO 58
C.....KOFE- NUCLEAR DOSE VARIABLE
      CALL DOSEK (AVGNRG(MM),KOFE,DUMMY,4)
      DUMMY = KOFE*PROTS(MM,K)
      PDOSE (M,K,2) = PDOSE(M,K,2) + DUMMY
      PDOSRM( M, K, 2) = PDOSRM(M,K,2) + DUMMY*RABIEF
   58 IF (K.LT.2) GO TO 59
      DUMMY = PROFTD*PROTS(MM,K+2)*DEDX
      PDOSE (M,K+2,1) = PDOSE(M,K+2,1) + DUMMY
      PDOSRM(M,K+2,1) = PDOSRM(M,K+2,1) + DUMMY*RABIEF
      GO TO (59,5858),KOSW21
 5858 IF(AVGNRG(MM) .LT. 10.) GO TO 59
      DUMMY = KOFE*PROTS(MM,K+2)
      PDOSE (M,K+2,2) = PDOSE(M,K+2,2) + DUMMY
      PDOSRM(M,K+2,2) = PDOSRM(M,K+2,2) + DUMMY*RABIEF
   59 CONTINUE
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      GO TO (5960,5958),KOSW21
 5958 DO 5959 K=1,5
      PDOSE (M,K,3) = PDOSE (M,K,1) + PDOSE(M,K,2)
 5959 PDOSRM(M,K,3) = PDOSRM(M,K,1) + PDOSRM(M,K,2)
C.....NEUTRON DOSE CALCULATIONS.
 5960 DO 60 K=1,4
C.....NDOSE(M,KK)- DOSE AT THICKNESS X FROM CASCADE NEUTRONS IN RAD
      NDOSE (M,K) = 0.0
C.....NDOSRM(M,KK)-DOSE AT THICKNESS X FROM CASCADE NEUTRONS IN REM
   60 NDOSRM(M,K) = 0.0
      IF (KNTRN.EQ.0) GO TO 6161
      DO 61  K=2,NONUBD
      CALL DOSEK(NUENRG(K-1),CNK1,CNK2,3)
      DO 61  KK=1,KNTRN
      NDOSE (M,KK) = NDOSE (M,KK)+NEWTS(K-1,KK)*CNK1
      NDOSE (M,KK+2) = NDOSE(M,KK+2)+NEWTS(K-1,KK+2)*CNK1
      NDOSRM(M,KK) = NDOSRM(M,KK)+NEWTS(K-1,KK)*CNK2
   61 NDOSRM(M,KK+2) = NDOSRM(M,KK+2)+NEWTS(K-1,KK+2)*CNK2
      GO TO 62
 6161 IF (KNTRP .EQ. 1) GO TO  6262
   62 CALL EVNEDO (3,NOLAY,M,LIMIT,EVNUDS(M))
      EVNDRM(M) = 10.0*EVNUDS(M)
 6262 GO TO (82,63),KOSW11
C.....OUTPUT OF ALL DATA.
C
C.....PRIMARY AND SECONDARY PROTON
   63 KNTPG = 0
      ASSIGN 64 TO LIME
   64 LINE1= KNTPG*54+1
      KNTPG = KNTPG +1
      LASTLN = KNTPG*54
      IF (LASTLN - MAX ) 67,66,65
   65 LASTLN = MAX
   66 ASSIGN 69 TO LIME
   67 WRITE (6,68) XX
   68 FORMAT(1H146X,21HSHIELD THICKNESS, X =F8.2,9H GM/CM**2/1H060X,34HP
     1ROTON FLUX SPECTRA--PROTONS/CM**2)
      IF (KOSW(13) .EQ. 1)WRITE(6,6868)
 6868 FORMAT(1H+94X,4H-SEC)
      WRITE (6,6869) (J,AVGNRG(J),(PROTS(J,K),K=1,5),J=LINE1,LASTLN)
 6869 FORMAT(12X,6HENERGY13X,7HPRIMARY13X,34H- - - SECONDARY PROTONS AT
     1X - - -9X,35H- - - SECONDARY PROTONS IN DX - - -/13X,3HMEV15X,7HPR
     2OTONS3X,2(11X,10HFIRST GEN.12X,11HHIGHER GEN.)/(I7,0PF12.3,1P5E22.
     36))
      GO TO LIME, (64,69,74,79)
   69 WRITE (6,70) (TOTALS(M,K),K=1,5),(PDOSE(M,K,1),K=1,5)
   70 FORMAT(1HJ3X,6HTOTALS9X,1P5E22.6/1HJ3X,9HDOSE--RAD6X,5E22.6)
      IF (KOSW(13) .EQ. 1) WRITE (6,71)
   71 FORMAT(1H+12X,3H/HP)
      WRITE (6,72) (PDOSRM(M,K,1),K=1,5)
   72 FORMAT(4X,9HDOSE--REM6X,1P5E22.6)
      IF (KOSW(13) .EQ. 1) WRITE (6,71)
      IF (KNTRN .EQ. 0) GO TO 82
C.....CASCADE NEUTRON OUTPUT.
   73 KNTPG = 0
      ASSIGN 74 TO LIME
   74 LINE1 = KNTPG*54+1
      KNTPG = KNTPG + 1
      LASTLN = KNTPG*54
      IF (LASTLN - NONUBD+1) 77,76,75
   75 LASTLN = NONUBD-1
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   76 ASSIGN 79 TO LIME
   77 WRITE (6,78)XX
   78 FORMAT(1H133X,21HSHIELD THICKNESS, X =F8.2,9H GM/CM**2/1H042X,44HC
     1ASCADE NEUTRON FLUX SPECTRA--NEUTRONS/CM**2)
      IF (KOSW(13) .EQ. 1)WRITE(6,7878)
 7878 FORMAT(1H+86X,4H-SEC)
      WRITE (6,7879) (J,NUENRG(J),(NEWTS(J,K),K=1,4),J=LINF1,LASTLN)
 7879 FORMAT(12X,6HENERGY11X,33H- - - CASCADE NEUTRONS AT X - - -11X,34H
     A- - - CASCADE NEUTRONS IN DX - - -/13X,3HMEV3X,2(11X,10HFIRST GEN.
     B12X,11HHIGHER GEN.)/(I7,0PF12.3,1P4E22.6))
      GO TO LIME, (64,69,74,79)
   79 WRITE (6,80) (TOTALS(M,K),K=6,9),(NDOSE(M,K),K=1,4)
   80 FORMAT(1HJ3X,6HTOTALS9X,1P4E22.6/1HJ3X,9HDOSE--RAD6X,4E22.6)
      IF (KOSW(13) .EQ. 1) WRITE (6,71)
      WRITE (6,72) (NDOSRM(M,K),K=1,4)
      IF (KOSW(13) .EQ. 1) WRITE (6,71)
   82 CONTINUE
C.....DOSE TABLES -- RAD OR RAD/HR
   83 M = 0
      LINKNT=26/KOSW21
      KONGIB = 2*KOSW21-1
   84 WRITE (6,85)
   85 FORMAT(1H159X,9HDOSE--RAD)
      IF(KOSW(13).EQ. 1) WRITE (6,8585)
 8585 FORMAT(1H+68X,3H/HR)
      WRITE (6,86) (LLL,LLL=1,6),IPDRAD,IPDRAD,IPDRAD
   86 FORMAT(77H0SHIELD     PRIMARY     --SECONDARY PROTON--- ---CASCADE N
     1EUTRON---EVAPORATION ,5(5HTOTAL6X)/17H THICKNESS PROTON,2(5X,5HFIR
     2ST6X,6HHIGHER),5X,59HNEUTRON     SECONDARY  CASCADE     PROTON     N
     3EUTRON     DOSE/9H GM/CM**213X,4(11HGENERATION ),11X,6HPROTON5X,7HN
     4EUTRON/12X,6(3H   (I1,1H)6X),53H(2)+(3)     (4)+(5)   (1)+(2)+(3)(4)+
     5(5)+(6) (1)THRU(6)/8H0    0.00,1PE13.4,E88.4,E22.4)
      GO TO (87,90),KOSW5
   87 M = M+1
      TCN = NDOSE(M,1) + NDOSE(M,2)
      TN = TCN+EVNUDS(M)
      DO 88 KK=1,KONGIB
      TSP(KK) = PDOSE(M,2,KK)+PDOSE(M,3,KK)
      TP(KK) = TSP(KK)+PDOSE(M,1,KK)
   88 TD(KK) = TP(KK)+TN
      WRITE (6,89) X(M),(PDOSE(M,K,1),K=1,3),(NDOSE(M,K),K=1,2),EVNUDS
     1(M),TSP(1),TCN,TP(1),TN,TD(1)
   89 FORMAT(1H0F7.2,2X,1P11E11.4)
      GO TO (8991,8989),KOSW21
 8989 WRITE (6,8990) ((PDOSE(M,K,N),K=1,3),TSP(N),TP(N),TD(N),N=2,3)
 8990 FORMAT(9X,1P3E11.4,E44.4,2E22.4)
 8991 IF (M.GE.NDX) GO TO 90
      IF (MOD(M,LINKNT)) 87,84,87
C.....DOSE TABLES -- REM OR REM/HR
   90 M = 0
   91 WRITE (6,92)
   92 FORMAT(1H159X,9HDOSE--REM)
      IF (KOSW13 .EQ. 1) WRITE(6,8585)
      WRITE (6,86) (LLL,LLL=1,6),IPDREM,IPDREM,IPDREM
      GO TO (93,95),KOSW5
   93 M = M+1
      TCN = NDOSRM(M,1)+NDOSRM(M,2)
      TN = TCN+EVNDRM(M)
      DO 94 KK=1,KONGIB
      TSP(KK) = PDOSRM(M,2,KK)+PDOSRM(M,3,KK)
      TP(KK) = TSP(KK)+PDOSRM(M,1,KK)
```

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```
   94 TD(KK) = TP(KK)+TN
      WRITE (6,89) X(M),(PDOSRM(M,K,1),K=1,3),(NDOSRM(M,K),K=1,2),EVNDRM
     1(M),TSP(1),TCN,TP(1),TN,TD(1)
      GO TO (9495,9494),KOSW21
 9494 WRITE (6,8990) ((PDOSRM(M,K,N),K=1,3),TSP(N),TP(N),TD(N),N=2,3)
 9495 IF (M.GE.NOX) GO TO 95
      IF (MOD(M,LINKNT)) 93,91,93
   95 GO TO (100,96),KOSW17
C.....FLUX TABLES
   96 WRITE (6,9696)
 9696 FORMAT(1H148X,21HFLUX--PARTICLES/CM**2)
      IF (KOSW13 .EQ. 1)WRITE (6,9697)
 9697 FORMAT(1H+69X,4H-SEC)
      WRITE (6,9698) (LLL,LLL=1,5),IPFLTO
 9698 FORMAT(7HOSHIELD8X,7HPRIMARY8X,60H- - - SECONDARY PROTON
     1 - - - CASCADE NEUTRON - - -,2(5X,5HTOTAL6X)/10H THICKNESS5X,6HPRO
     2TON10X,2(5HFIRST11X,6HHIGHER10X),9HSECONDARY7X,7HCASCADE/9H GM/CM*
     3*222X,4(10HGENERATION6X ),6HPROTON10X,7HNEUTRON/17X,5(3H  (I1,1H)1
     41X),7H(2)+(3)9X,7H(4)+(5)/1H03X,4H0.001PF18.5)
      GO TO (9797,1),KOSW5
 9797 DO 98  M=1,NOX
      TSP = TOTALS(M,2)+TOTALS(M,3)
      TCN = TOTALS(M,6)+TOTALS(M,7)
   98 WRITE (6,99) X(M),(TOTALS(M,K),K=1,3),(TOTALS(M,K),K=6,7),TSP(1),
     1TCN
   99 FORMAT(1HOF7.2,2X,1P7E16.5)
  100 GO TO (1,101),KOSW1
C.....NEUTRON SOURCE TERMS TABLE
  101 LETA  =NOLAY/2
      IDXSC = (NOLAY+1)/2
      WRITE (6,102)
  102 FORMAT(1H1,2(9X,6HSHIELD10X,32HNEUTRON SOURCE TERM--NEUTRONS/GM7X)
     A)
      IF(KOSW13 .EQ. 1) WRITE(6,10202)
10202 FORMAT(1H+2(57X,4H-SEC,3X))
      WRITE (6,10203)
10203 FORMAT(2X,2(6X,9HTHICKNESS5X,11HEVAPORATION6X,27H        - CASCADE
     A - - - - -)/3X,2(6X,10H(GM/CM**2)21X,10HFIRST GEN.6X,11HHIGHER GEN
     B.))
      DO 103 K=1,LETA
      NDX=IDXSC+K
  103 WRITE (6,104) XMID(K),SOTEEN(K),(CNTOTS(K,J),J=1,2),XMID(NDX),
     ASOTEEN(NDX),(CNTOTS(NDX,J),J=1,2)
  104 FORMAT(F16.3,1P3E17.5,0PF13.3,1P3E17.5)
      IF(MOD(NOLAY,2) .EQ. 1) WRITE(6,104)XMID(LETA+1),SOTEEN(LETA+1),
     A(CNTOTS(LETA+1,J),J=1,2)
      GO TO 1
      END
$IBFTC EVNEDO  LIST,DECK
      SUBROUTINE EVNEDO (INDEX,LAYNO,MM,NN,DOSE)                        0010
C.....EVAPORATION NEUTRON DOSE CALCULATION
      COMMON  D2X(20)          , MAX              , EO(300,20)
      COMMON  EI(300)          , DEI(300)         , EIBAR(300)
      COMMON  OP(300)          , OPPRM(300)       , NOD2X(20)
      COMMON  X(20)            , NOX              , ENTOTS(200)
      COMMON  DX(20)           , PROPNO(20)       , C1
      COMMON  PDSBND           , NDSBND           , BNDLOW
      COMMON                     ENRG(100)        , RNG(100)
      COMMON  EBOMBP(25,4)     , EBOMBN(25,4)     , CPSP(25,4)
      COMMON  CPSN(25,4)       , CNSP(25,4)       , CNSN(25,4)
      COMMON  ENSP(25,4)       , ENSN(25,4)       , EBOMP(25,4)
```

```
      COMMON   EBOMN(25,4)    , EPROP(25,4)    , EPRON(25,4)
      COMMON   ENEUP(25,4)    , ENEUN(25,4)    , ENRGP(25)
      COMMON   ENRGN(75)      , XSMBP(25)      , XSMBN(75)
      COMMON   SNRG(100)      , RBENRG(20)     , C1NRG(40)
      COMMON   C2NRG(40)      , CNRG(2)        , SOFE(100)
      COMMON   RBE(20)        , CONK1(40)      , CONK2(40)
      COMMON   CONK(2)        , LENGTH(8)      , GMWT
      COMMON   LSOFE          , LRBE           , LK1
      COMMON   LK2            , LK             , NOFCOM
      COMMON   MOVE           , KOSW(36)       , KONSWT
      EQUIVALENCE (KOSW(13),KOSW13)
      DIMENSION P(20),H(20),BNDANG(11),RADANG(10),COSCON(10),COSRAD(10),
     AS(20),SUMGPA(10),SUMSR(10,200),SUMHRP(10,200),K(20)
      INTEGER PROPNO,PTEST,PDIF
      REAL KS,KSR
      REAL LI,KI,KLSR,K
      DATA C2,C3,C4/0.3492,0.4223,0.6984/
      GO TO (1,20,27),INDEX
    1 READ (5,3) NOX,NOANG,(X(J),NOD2X(J),PROPNO(J),P(J),H(J),S(J),K(J),
     AJ=1,NOX)
    3 FORMAT(2I4/(F6.0,2I4,3F8.0,F6.0))
      WRITE (6,4)
    4 FORMAT(1H09X,81HX,MIN     X,MAX     NUMBER OF     MATERIAL    DENSITY
     A       HYDROGEN     REMOVAL XSECT/12X,77H(GM/CM**2)        INCREMENTS
     B    NUMBER      (GM/CM**3)      RATIO         (CM**2/GM))
      XMIN=0.0
      DO 2 J=1,NOX
      WRITE (6,5) XMIN,X(J),NOD2X(J),PROPNO(J),P(J),H(J),S(J)
    5 FORMAT(F15.2,F9.2,I10,I12,F14.5,F12.3,F15.4)
    2 XMIN=X(J)
      WRITE (6,6) NOANG
    6 FORMAT(1H08X,59HNUMBER OF ANGLES IN EVAPORATION NEUTRON DOSE CALCU
     1LATIONS =I3)
      ENFTD = 5.389E-9
      IF (KOSW13 .EQ. 1) ENFTD=ENFTD*3600.
      MLAST = 0
      LSTHYD=0
      LSTHLA=0
C.....DELANG- DELTA ANGLE
      DELANG = 1.5707963/FLOAT(NOANG)
C.....BNDANG- BOUNDARY ANGLES OF DELTA ANGLE
      BNDANG(1) = 0.0
C.....RADANG- MID-POINT OF ANGLE INTERVAL
      RADANG(1) = 0.0
      BNDANG(2) = DELANG
      CANGL1 = COS(BNDANG(2))
C.....COSCON- DELTA SOLID ANGLE/(4*PIE*COSRAD)
      COSCON(1) = (1.0-CANGL1)/2.0
C.....COSRAD- COSINE OF MID-POINT ANGLE
      COSRAD(1) = 1.0
      IF(NOANG .LT. 2) GO TO 1
      DO 10  J=2,NOANG
      BNDANG(J+1) = BNDANG(J)+DELANG
      RADANG(J) = (BNDANG(J)+BNDANG(J+1))/2.0
      COSRAD(J) = COS(RADANG(J))
      CANGL2 = COS(BNDANG(J+1))
      COSCON(J) = (CANGL1-CANGL2)/2.0/COSRAD(J)
   10 CANGL1 = CANGL2
      GO TO 100
   20 KOUNT=LAYNO
      M=MM
```

```
      N=NN
      KM1=KOUNT-1
      IF(M .EQ. MLAST) GO TO 6
      MLAST=M
      IF((M .GT. 1) .AND. (PROPNO(M) .EQ. PROPNO(M-1))) GO TO 6
      JUMPO =1
      IF (PROPNO(M) .GT. 100) GO TO 150
C.....H(M)-RATIO OF HYDROGEN IN MATERIAL M TO THAT IN WATER
C.....P(M)- DENSITY OF MATERIAL M IN GRAMS/CM**3
      HOP=H(M)/P(M)
      JUMPO =2
C.....S(M)-REMOVAL CROSS SECTION
  150 KS=K(M)*S(M)
      ASSIGN 120 TO LOKSUN
      IF (M .EQ. 1) GO TO 54
      KK=M-1
   42 IF (PROPNO(M) .NE. PROPNO(KK)) GO TO 45
   50 IF (KK .EQ. 1)GO TO 54
      KK=KK-1
      GO TO 42
   45 PTEST= (PROPNO(M)+PROPNO(KK))/2
      IF((PTEST .GT. 100)  .OR. (PTEST .LT. 50)) GO TO 54
      PDIF =PROPNO(M)-PROPNO(KK)
      IF (PDIF) 48,50,52
   48 LOW=LSTHYD+1
      IGH=M-1
      LAYKNT=0
      IF (LSTHYD .NE. 0) LAYKNT=LSTHLA
      MIN=LAYKNT+1
      DO 160 IN=LOW,IGH
      NUMB=NOD2X(IN)
      D2XKS=D2X(IN)*K(IN)*S(IN)
      DO 160 JJ=1,NUMB
      LKM1=LAYKNT
      LAYKNT=LAYKNT+1
      DO 160 NOA=1,NOANG
      KSR=D2XKS/COSRAD(NOA)
      SUMSR(NOA,LAYKNT)=SUMSR(NOA,LAYKNT)-0.5*KSR
      IF(LAYKNT .EQ. MIN) GO TO 153
      DO 151 LO=MIN,LKM1
  151 SUMSR(NOA,LO)=SUMSR(NOA,LO)-KSR
  153 IF(LSTHYD .EQ. 0) GO TO 152
      DO 154 LO=1,LSTHLA
  154 SUMSR(NOA,LO)=SUMSR(NOA,LO)-KSR
  152                         SUM=H(IN)/P(IN)*(0.5+FLOAT(NOD2X(IN)-JJ))*
     AD2X(IN)/COSRAD(NOA)
      INP1=IN+1
      DO 155 KA=INP1,M
  155 SUM=SUM+H(KA)/P(KA)*DX(KA)/COSRAD(NOA)
  157 LI=0.5+SUM/15.
      IF(LI .GT. 1.0) LI=1.0
      KLSR=KSR*LI/K(IN)
      SUMSR(NOA,LAYKNT)=SUMSR(NOA,LAYKNT)+0.5*KLSR
      IF (LAYKNT .LE. 1) GO TO 160
      DO 159 LO=1,LKM1
  159 SUMSR(NOA,LO)=SUMSR(NOA,LO)+KLSR
  160 CONTINUE
      LSTHLA=KOUNT-1
      IF(K(M) .EQ. 1.)GO TO 54
      ASSIGN 130 TO LOKSUN
      GO TO 60
```

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```
   52 LI=K(M)
      GO TO 60
   54 LI= 1.0
   60 DO 40 J=1,NOANG
C.....RI- SLANT PATH LENGTH ACROSS DELTA X
      RI=D2X(M)/COSRAD(J)
      KSR=KS*RI
      SUMSR(J,KOUNT)=KSR*0.5
      IF (KOUNT .EQ. 1) GO TO 174
      IF(PROPNO(M) .LT. 50) GO TO 129
      LSTP1=LSTHLA+1
      IF(LSTP1 .GT. KM1) GO TO 120
      DO 2525 KO=LSTP1,KM1
 2525 SUMSR(J,KO)=SUMSR(J,KO)+KSR
      IF(LSTHLA .EQ. 0) GO TO 174
  129 GO TO LOKSUN,(120,130)
  130                           SUM=HOP*(0.5+FLOAT(NOD2X(M)-N))*RI
   67 LI=0.5 +SUM/15.
      IF (LI .GT. 1.0) LI=1.0
  120 KLSR=LI*KSR/K(M)
      DO 25 KO=1,LSTHLA
   25 SUMSR (J,KO)=SUMSR (J,KO)+KLSR
  174 GO TO (190,175),JUMPO
  175 HRP=HOP*RI
      SUMHRP(J,KOUNT)=HRP*0.5
      IF(KOUNT .EQ. 1) GO TO 4
      DO 177 KO=1,KM1
  177 SUMHRP(J,KO)=SUMHRP(J,KO)+HRP
      GO TO 40
  190 SUMHRP(J,KOUNT) =0.0
   40 CONTINUE
      IF(PROPNO(M) .LT. 50) LSTHLA=KOUNT
      IF((PROPNO(M) .GT. 100) .OR. (N .NE. NOD2X(M))) GO TO 100
      LSTHYD=M
      GO TO 100
   27 DOSE = 0.
      KOUNT=LAYNO
      M=MM
      LSTP1=LSTHLA+1
      DO 28 J=1,NOANG
      SUMA=0.0
      SUMB=0.0
      IF(LSTHLA .EQ. 0) GO TO 30
      DO 29 KO=1,LSTHLA
      IF (SUMHRP(J,KO) .LT. 2.) GO TO 202
      TERMA = SUMHRP(J,KO)**C2*EXP(-C3*SUMHRP(J,KO)**C4)
      GO TO 200
  202 TERMA = .772 - .065*SUMHRP(J,KO)
  200 TERMB = EXP(-SUMSR(J,KO))
   29 SUMA=SUMA+TERMA*TERMB*ENTOTS(KO)
      SUMA=SUMA*COSCON(J)
      IF (LSTHLA .EQ. KOUNT) GO TO 32
   30 DO 31 KO=LSTP1,KOUNT
      TERMB  = .772*EXP(-SUMSR(J,KO))
   31 SUMB=SUMB+TERMB*ENTOTS(KO)
      SUMB=SUMB*COSCON(J)
   32 CONTINUE
   28 DOSE = DOSE +ENETD*(SUMA+SUMB)
  100 RETURN
      END
$IBFTC XS      LIST,DECK
```

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```
      SUBROUTINE XS(E,XSECT,INDEX)
C.....CROSS-SECTION CALCULATIONS.
C     INPUT CROSS-SECTION DATA IN MILLI-BARNS.
      COMMON  D2X(20)          , MAX              , FO(300,20)
      COMMON  FI(300)          , DEI(300)         , FIBAR(300)
      COMMON  OP(300)          , OPPRM(300)       , NOD2X(20)
      COMMON  X(20)            , NOX              , ENTOTS(200)
      COMMON  DX(20)           , PROPNO(20)       , C1
      COMMON  PDSBND           , NDSBND           , BNDLOW
      COMMON                     ENRG(100)        , RNG(100)
      COMMON  EBOMBP(25,4)     , EBOMBN(25,4)     , CPSP(25,4)
      COMMON  CPSN(25,4)       , CNSP(25,4)       , CNSN(25,4)
      COMMON  ENSP(25,4)       , ENSN(25,4)       , EBOMP(25,4)
      COMMON  EBOMN(25,4)      , EPROP(25,4)      , EPRON(25,4)
      COMMON  ENEUP(25,4)      , ENEUN(25,4)      , ENRGP(25)
      COMMON  ENRGN(75)        , XSMBP(25)        , XSMBN(75)
      COMMON  SNRG(100)        , RBENRG(20)       , C1NRG(40)
      COMMON  C2NRG(40)        , CNRG(2)          , SOFE(100)
      COMMON  RBE(20)          , CONK1(40)        , CONK2(40)
      COMMON  CONK(2)          , LENGTH(8)        , GMWT
      COMMON  LSOFE            , LRBE             , LK1
      COMMON  LK2              , LK               , NOFCOM
      COMMON  MOVE             , KOSW(36)         , KONSWT
      DIMENSION ENERGY(100),DATA(100),CONST(2)
      EQUIVALENCE (ENERGY(1),ENRGP(1)),(DATA(1),XSMBP(1))
      IND=INDEX
      IF (IND   .LT. 3) GO TO 50
      RATIO= 6.0231E-4/GMWT
      DO 100 J=1,2
      MX = 25*(J-1)+LENGTH(J+5)
      CONST(J)=DATA(MX )*RATIO
      KONSWT = KOSW(J+25)
      GO TO (100,108),KONSWT
  108 MN= 25*(J-1)+1
      DO 109 K=MN,MX
      IF (ENERGY(K) .NE. 0.0) GO TO 30
      ENERGY(K)=1.E-10
      GO TO 31
   30 ENERGY(K)=ALOG10(ENERGY(K))
   31 IF(DATA(K) .NE. 0.0) GO TO 33
      DATA(K)= 1.E-10
      GO TO 109
   33 DATA(K)=ALOG10(DATA(K))
  109 CONTINUE
  100 CONTINUE
      GO TO 75
   50 EE=E
      MX = 25*(IND-1)+LENGTH(IND+5)
      KONSWT = KOSW(IND+25)
      GO TO (52,51),KONSWT
   51 EE=ALOG10(EE)
   52 IF( EE .LT. ENERGY(MX )) GO TO 54
      XSECT=CONST(IND)
      GO TO 75
   54 GO TO (56,55),IND
   55 IF(EE-ENRGN(1))   110,120,56
  110 XSECT=0.0
      GO TO 75
   56 MN= 25*(IND-1)+1
      CALL LAGRNG(EE,CROSS,ENERGY(MN),DATA(MN),LENGTH(IND+5),2)
   57 GO TO (59,58),KONSWT
```

```
   58 CROSS=10.**CROSS
   59 XSECT=CROSS*RATIO
   75 RETURN
  120 CROSS=XSMBN(1)
      GO TO 57
      END
$IBFTC DOSEK   LIST,DECK
      SUBROUTINE DOSEK (E,VARB1,VARB2,INDEX)
C.....THIS SUBROUTINE CALCULATES (DE/DX)=SOFF,RBE,NEUTRON FLUX TO DOSE
C.....CONVERSION FACTORS
C.....VARB1-  DUMMY VARIABLE
C.....VARB2-  DUMMY VARIABLE
      COMMON  D2X(20)         , MAX            , FO(300,20)
      COMMON  FI(300)         , DFI(300)       , FIBAR(300)
      COMMON  OP(300)         , OPPRM(300)     , NOD2X(20)
      COMMON  X(20)           , NOX            , ENTOTS(200)
      COMMON  DX(20)          , PROPNO(20)     , C1
      COMMON  PDSBND          , NDSBND         , BNDLOW
      COMMON                    ENRG(100)      , RNG(100)
      COMMON  EBOMBP(25,4)    , EBOMBN(25,4)   , CPSP(25,4)
      COMMON  CPSN(25,4)      , CNSP(25,4)     , CNSN(25,4)
      COMMON  FNSP(25,4)      , FNSN(25,4)     , FBOMP(25,4)
      COMMON  FBOMN(25,4)     , FPROP(25,4)    , FPRON(25,4)
      COMMON  FNEUP(25,4)     , FNEUN(25,4)    , ENRGP(25)
      COMMON  ENRGN(75)       , XSMBP(25)      , XSMBN(75)
      COMMON  SNRG(100)       , RBENRG(20)     , C1NRG(40)
      COMMON  C2NRG(40)       , CNRG(2)        , SOFE(100)
      COMMON  RBE(20)         , CONK1(40)      , CONK2(40)
      COMMON  CONK(2)         , LENGTH(8)      , GMWT
      COMMON  LSOFE           , LRBE           , LK1
      COMMON  LK2             , LK             , NOFCOM
      COMMON  MOVE            , KOSW(36)       , KONSWT
      DIMENSION NOENTS(5),ENERGY(202),TABLE(202),MAXVLU(5),VARB(5),
     AEBND(2),MINS(5)
      DATA (MINS(J),J=1,5)/1,101,121,161,201/
      EQUIVALENCE (SNRG(1),ENERGY(1)),(SOFE(1),TABLE(1)),(NOENTS(1),
     ALSOFE),(EBND(1),PDSBND)
      REAL      MAXVLU,NDSBND
      IF (INDEX.GT.1) GO TO 10
      DO 10  J=1,5
      MX=MINS(J)+NOENTS(J)-1
      MAXVLU(J) = TABLE(MX )
      KONSWT = KOSW(J+31)
      GO TO (10,8),KONSWT
    8 MIN=MINS(J)
      DO 9  K=MIN,MX
      IF (ENERGY(K) .NE. 0.0) GO TO 30
      ENERGY(K)= 1.E-10
      GO TO 31
   30 ENERGY(K)=ALOG10(ENERGY(K))
   31 IF (TABLE(K) .NE. 0.0) GO TO 33
      TABLE(K)=1.E-10
      GO TO 9
   33 TABLE (K)=ALOG10(TABLE(K))
    9 CONTINUE
   10 CONTINUE
      GO TO 300
  100 IF (INDEX.GT.3) GO TO 35
      INDM1 = INDEX-1
  150 IF (E.GT.EBND(INDM1)) GO TO 154
  152 VARB1=0.0
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      VARB2=0.0
      GO TO 300
  154 MX   = 2*INDM1
      MIN = MX -1
  404 DO 400  J=MIN,MX
      EE = E
      LIM=MINS(J)+NOENTS(J)-1
      KONSWT = KOSW(J+31)
      GO TO (402,401),KONSWT
  401 EE = ALOG10(EE)
  402 IF (EE-ENERGY(LIM)) 155,160,160
  160 VARB(J) = MAXVLU(J)
      GO TO 400
  155 LIM=MINS(J)
      CALL LAGRNG (EE,VARB(J),ENERGY(LIM),TABLE(LIM),NOENTS(J),2)
      GO TO (400,403),KONSWT
  403 VARB(J) = 10.**VARB(J)
  400 CONTINUE
      VARB1 = VARB(MIN)
      VARB2 = VARB(MX )
  300 RETURN
  350 MIN = 5
      MX  = 5
      GO TO 404
      END
$IBFTC RANGE   LIST,DECK
      SUBROUTINE RANGE (X,Y,INDEX)
C     RANGE-ENERGY CALCULATIONS
      COMMON  D2X(20)        , MAX           , ED(300,20)
      COMMON  EI(300)        , DEI(300)      , EIBAR(300)
      COMMON  OP(300)        , OPPRM(300)    , NOD2X(20)
      COMMON  X(20)          , NOX           , ENTOTS(200)
      COMMON  DX(20)         , PROPNO(20)    , C1
      COMMON  PDSBND         , NDSBND        , BNDLOW
      COMMON                   ENRG(100)     , RNG(100)
      COMMON  EBOMBP(25,4)   , EBOMBN(25,4)  , CPSP(25,4)
      COMMON  CPSN(25,4)     , CNSP(25,4)    , CNSN(25,4)
      COMMON  ENSP(25,4)     , ENSN(25,4)    , EBOMP(25,4)
      COMMON  EBOMN(25,4)    , EPROP(25,4)   , EPRON(25,4)
      COMMON  ENEUP(25,4)    , ENEUN(25,4)   , ENRGP(25)
      COMMON  ENRGN(75)      , XSMBP(25)     , XSMBN(75)
      COMMON  SNRG(100)      , RBENRG(20)    , C1NRG(40)
      COMMON  C2NRG(40)      , CNRG(2)       , SOFE(100)
      COMMON  RBE(20)        , CONK1(40)     , CONK2(40)
      COMMON  CONK(2)        , LENGTH(8)     , GMWT
      COMMON  LSOFE          , LRBE          , LK1
      COMMON  LK2            , LK            , NOFCOM
      COMMON  MOVE           , KOSW(36)      , KONSWT
      EQUIVALENCE (KOSW(25),KOSW25)
      DIMENSION CON(2)
      IF (INDEX .GT. 1) GO TO 20
      CON(1)=ENRG(1)
      CON(2)=RNG(1)
      L1=LENGTH(1)
      GO TO (50,10),KOSW25
   10 DO 13 I=1,L1
      IF(ENRG(I) .NE. 0.0) GO TO 11
      ENRG(I) = 1.E-10
      GO TO 12
   11 ENRG(I)=ALOG10(ENRG(I))
   12 IF (RNG(I) .NE. 0.0) GO TO 14
```

```
      RNG(I) = 1.E-10
      GO TO 13
   14 RNG(I)= ALOG10(RNG(I))
   13 CONTINUE
      GO TO 50
   20 XX=X
      IM1=INDEX-1
      IF(XX .GE. CON(IM1))     GO TO 25
      Y=0.0
      GO TO 50
   25 GO TO (27,26),KOSW25
   26 XX=ALOG10(XX)
   27 GO TO (28,29),IM1
   28 CALL LAGRNG (XX,Y,ENRG,RNG,L1,2)
      GO TO 30
   29 CALL LAGRNG (XX,Y,RNG,ENRG,L1,2)
   30 GO TO (50,31),KOSW25
   31 Y=10.**Y
   50 RETURN
      END
$IBFTC SORT    LIST,DECK
      SUBROUTINE SORT (E,ERNG,MAXX,I)
      DIMENSION ERNG(300)
      DO 10 J=1,MAXX
      IF(ERNG(J)-E) 14,12,10
   10 CONTINUE
   12 I=J
      GO TO 15
   14 I=J-1
   15 RETURN
      END
$IBFTC YIELDS  LIST,DECK
      SUBROUTINE YIELDS(EE,ANS,NOC,INDEX)
C.....CALCULATION OF YIELDS AS A FUNCTION OF ENERGY OF BOMBARDING
C     PARTICLE.
C
      COMMON  D2X(20)          , MAX              , EO(300,20)
      COMMON  EI(300)          , DEI(300)         , EIBAR(300)
      COMMON  OP(300)          , OPPRM(300)       , NOD2X(20)
      COMMON  X(20)            , NOX              , ENTOTS(200)
      COMMON  DX(20)           , PROPNO(20)       , C1
      COMMON  PDSBND           , NDSBND           , BNDLOW
      COMMON                     ENRG(100)        , RNG(100)
      COMMON  EBOMBP(25,4)     , EBOMBN(25,4)     , CPSP(25,4)
      COMMON  CPSN(25,4)       , CNSP(25,4)       , CNSN(25,4)
      COMMON  ENSP(25,4)       , ENSN(25,4)       , EBOMP(25,4)
      COMMON  EBOMN(25,4)      , EPROP(25,4)      , EPRON(25,4)
      COMMON  ENEUP(25,4)      , ENEUN(25,4)      , ENRGP(25)
      COMMON  ENRGN(75)        , XSMBP(25)        , XSMBN(75)
      COMMON  SNRG(100)        , RBENRG(20)       , C1NRG(40)
      COMMON  C2NRG(40)        , CNRG(2)          , SOFE(100)
      COMMON  RBE(20)          , CONK1(40)        , CONK2(40)
      COMMON  CONK(2)          , LENGTH(8)        , GMWT
      COMMON  LSOFE            , LRBE             , LK1
      COMMON  LK2              , LK               , NOFCOM
      COMMON  MOVE             , KOSW(36)         , KONSWT
      DIMENSION ANS(3),EBOMB(200),CPS(200),CNS(200),ENS(200)
      EQUIVALENCE (EBOMB(1),EBOMBP(1,1)),(CPS(1),CPSP(1,1)),
     A            (CNS(1),CNSP(1,1)),(ENS(1),ENSP(1,1))
C.....CPS(I)-CASCADE PROTONS, CNS(I)-CASCADE NEUTRONS, ENS(I)-EVAPORATION
C.....NEUTRONS
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```
      IF (INDEX .GT. 1) GO TO 100
      DO 321 K=1,2
      KONSWT = KOSW(K+27)
      GO TO (321,40),KONSWT
   40 DO 320 L=1,NOFCOM
      MN=100*(K-1)+25*(L-1)+1
      MX=MN+LENGTH(K+1)-1
      DO 320 I=MN,MX
      IF (EBOMB(I) .NE. 0.0) GO TO 1
      EBOMB(I) = 1.E-10
      GO TO 2
    1 EBOMB(I) = ALOG10(EBOMB(I))
    2 IF (CPS(I) .NE. 0.0) GO TO 3
      CPS(I) = 1.E-10
      GO TO 4
    3 CPS(I)=ALOG10(CPS(I))
    4 IF (CNS(I) .NE. 0.0) GO TO 5
      CNS(I) = 1.E-10
      GO TO 6
    5 CNS(I)= ALOG10(CNS(I))
    6 IF (ENS(I) .NE. 0.0) GO TO 7
      ENS(I) = 1.E-10
      GO TO 320
    7 ENS(I) = ALOG10(ENS(I))
  320 CONTINUE
  321 CONTINUE
      GO TO 200
  100 E=EE
      KONSWT = KOSW(INDEX+26)
      GO TO (104,102),KONSWT
  102 E=ALOG10(E)
  104 MN=100*(INDEX-2)+25*(NOC-1)+1
      CALL LAGRNG(E,ANS(1),EBOMB(MN),CPS(MN),LENGTH(INDEX),2)
      CALL LAGRNG(E,ANS(2),EBOMB(MN),CNS(MN),LENGTH(INDEX),2)
      CALL LAGRNG(E,ANS(3),EBOMB(MN),ENS(MN),LENGTH(INDEX),2)
      GO TO (200,108),KONSWT
  108 DO 110 J=1,3
  110 ANS(J)=10.**ANS(J)
  200 RETURN
      END
$IBFTC CASNRG  LIST,DECK
      SUBROUTINE CASNRG(EE,ANS,NOC,INDEX)
C.....CALCULATES ENERGY OF CASCADE PROTONS AND NEUTRONS AS A FUNCTION
C.....OF THE ENERGY OF THE BOMBARDING PARTICLE.
      COMMON  D2X(20)          , MAX             , EO(300,20)
      COMMON  FI(300)          , DFI(300)        , FIBAR(300)
      COMMON  OP(300)          , OPPRM(300)      , NOD2X(20)
      COMMON  X(20)            , NOX             , ENTOTS(200)
      COMMON  DX(20)           , PROPNO(20)      , C1
      COMMON  PDSBND           , NDSBND          , BNDLOW
      COMMON                     ENRG(100)       , RNG(100)
      COMMON  EBOMBP(25,4)     , EBOMBN(25,4)    , CPSP(25,4)
      COMMON  CPSN(25,4)       , CNSP(25,4)      , CNSN(25,4)
      COMMON  ENSP(25,4)       , ENSN(25,4)      , EBOMP(25,4)
      COMMON  EBOMN(25,4)      , EPROP(25,4)     , EPRON(25,4)
      COMMON  ENEUP(25,4)      , ENEUN(25,4)     , ENRGP(25)
      COMMON  ENRGN(75)        , XSMBP(25)       , XSMBN(75)
      COMMON  SNRG(100)        , RBENRG(20)      , C1NRG(40)
      COMMON  C2NRG(40)        , CNRG(2)         , SOFF(100)
      COMMON  RBE(20)          , CONK1(40)       , CONK2(40)
      COMMON  CONK(2)          , LENGTH(8)       , GMWT
```

```
      COMMON  LSOFE          , LRBE           , LK1
      COMMON  LK2            , LK             , NOFCOM
      COMMON  MOVE           , KOSW(36)       , KONSWT
      DIMENSION ANS(2),EBOMB(200),EPRO(200),ENEU(200)
      EQUIVALENCE (EBOMB(1),EBOMP(1,1)),(EPRO(1),EPROP(1,1)),
     A            (ENEU(1),ENEUP(1,1))
C.....EBOMB- ENERGY OF BOMBARDING PARTICLE
C.....EPRO- SECONDARY PROTON ENERGY
C.....ENEU- SECONDARY NEUTRON ENERGY
      IF (INDEX .GT. 1) GO TO 200
      DO 121 K=1,2
      KONSWT = KOSW(K+29)
      GO TO (121,110),KONSWT
  110 DO 120 L=1,NOFCOM
      MN=100*(K-1)+25*(L-1)+1
      MX=MN+LENGTH(K+3)-1
      DO 120 J=MN,MX
      IF(EBOMB(J) .NE. 0.0) GO TO 1
      EBOMB(J) = 1.E-10
      GO TO 2
    1 EBOMB(J)=ALOG10(EBOMB(J))
    2 IF(EPRO(J) .NE. 0.0) GO TO 3
      EPRO(J) = 1.E-10
      GO TO 4
    3 EPRO(J)=ALOG10(EPRO(J))
    4 IF(ENEU(J) .NE. 0.0) GO TO 5
      ENEU(J) = 1.E-10
      GO TO 120
    5 ENEU(J)=ALOG10(ENEU(J))
  120 CONTINUE
  121 CONTINUE
      GO TO 300
  200 E=EE
      KONSWT = KOSW(INDEX+28)
      GO TO (204,202),KONSWT
  202 E=ALOG10(E)
  204 MN=100*(INDEX-2)+25*(NOC-1)+1
      CALL LAGRNG(E,ANS(1),EBOMB(MN),EPRO(MN),LENGTH(INDEX+2),2)
      CALL LAGRNG(E,ANS(2),EBOMB(MN),ENEU(MN),LENGTH(INDEX+2),2)
      GO TO (300,206),KONSWT
  206 ANS(1)=10.0**ANS(1)
      ANS(2)=10.0**ANS(2)
  300 RETURN
      END
$IBFTC LAGRNG  LIST,DECK
      SUBROUTINE LAGRNG (XX,YY,XTAB,YTAB,LIMIT,RANK)
C.....INTERPOLATION SUBROUTINE BASED ON LAGRANGE-S FUNDAMENTAL FORMULA
C     FOR INTERPOLATION
      DIMENSION XTAB(LIMIT),YTAB(LIMIT),DIFS(15)
      INTEGER ORDER,HALF,ORDM1,RANK
      X=XX
      MAXNO=LIMIT
      ORDER=RANK
      DO 10 INDEX=10,MAXNO,10
      IF (INDEX .GE. MAXNO) GO TO 15
      IF (X - XTAB(INDEX)) 15,55,10
   10 CONTINUE
   15 J=INDEX-9
      DO 25 INDEX=J,MAXNO
      IF (X-XTAB(INDEX)) 28,55,25
   25 CONTINUE
```

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```
   28 HALF=ORDER/2
      ORDM1=ORDER-1
      IF (INDEX .GT. HALF+1) GO TO 33
      MIN=1
      GO TO 39
   33 IF (INDEX .LT. MAXNO-HALF+1) GO TO 37
      MIN=MAXNO-ORDM1
      GO TO 39
   37 MIN=INDEX-HALF
   39 MAX=MIN+ORDM1
      MINM1=MIN-1
      DO 42 J=1,ORDER
      INDEX=MINM1+J
   42 DIFS(J)= X-XTAB(INDEX)
      Y=0.0
      DO 50 J=MIN,MAX
      TERM= YTAB(J)
      DO 45 INDEX = MIN,MAX
      IF (J .EQ. INDEX) GO TO 45
   44 MARK= INDEX-MINM1
      TERM = TERM*DIFS(MARK)/(XTAB(J)-XTAB(INDEX))
   45 CONTINUE
   50 Y=Y+TERM
      YY=Y
   52 RETURN
   55 YY=YTAB(INDEX)
      GO TO 52
      END
$IBFTC PROPTY  LIST,DECK
      SUBROUTINE PROPTY (INDEX,LAYER)
C.....THIS SUBROUTINE TRANSFERS THE MATERIAL PROPERTY DATA FROM TAPE 3
C     TO TAPE 4(OR DISC STORAGE) FOR LATER USE. THE TABLES OF FLUX TO
C     DOSE CONVERSION FACTORS ARE TRANSMITTED FROM TAPE 3 TO CORE
C     STORAGE. AT THE APPROPRIATE TIME THE PROPERTY DATA FOR THE CHOSEN
C     MATERIAL IS TRANSFERRED FROM TAPE 4(OR DISC STORAGE) TO CORE AND
C     ANY SUBROUTINES USING THIS PROPERTY DATA ARE INITIALIZED.
      COMMON  D2X(20)         , MAX              , FO(300,20)
      COMMON  EI(300)         , DEI(300)         , EIBAR(300)
      COMMON  OP(300)         , OPPRM(300)       , NOD2X(20)
      COMMON  X(20)           , NOX              , ENTOTS(200)
      COMMON  DX(20)          , PROPNO(20)       , C1
      COMMON  PDSBND          , NDSBND           , BNDLOW
      COMMON                    ENRG(100)        , RNG(100)
      COMMON  EBOMBP(25,4)    , EBOMBN(25,4)     , CPSP(25,4)
      COMMON  CPSN(25,4)      , CNSP(25,4)       , CNSN(25,4)
      COMMON  ENSP(25,4)      , ENSN(25,4)       , EBOMP(25,4)
      COMMON  EBOMN(25,4)     , EPROP(25,4)      , EPRON(25,4)
      COMMON  FNEUP(25,4)     , FNEUN(25,4)      , ENRGP(25)
      COMMON  ENRGN(75)       , XSMBP(25)        , XSMBN(75)
      COMMON  SNRG(100)       , RBENRG(20)       , C1NRG(40)
      COMMON  C2NRG(40)       , CNRG(2)          , SOFE(100)
      COMMON  RBE(20)         , CONK1(40)        , CONK2(40)
      COMMON  CONK(2)         , LENGTH(8)        , GMWT
      COMMON  LSOFE           , LRBE             , LK1
      COMMON  LK2             , LK               , NOFCOM
      COMMON  MOVE            , KOSW(36)         , KONSWT
      EQUIVALENCE (KOSW(13),KOSW13)
      EQUIVALENCE (LENGTH(1),L1),(LENGTH(2),L2),(LENGTH(3),L3),(LENGTH
     A(4),L4),(LENGTH(5),L5),(LENGTH(6),L6),(LENGTH(7),L7),(LENGTH(8),
     BL8)
      EQUIVALENCE  (LENTH(1),LK1),(FTDCON(1),CONK1(1))
```

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```
      DIMENSION LENTH(3),FTDCON(40,2)
      INTEGER PROPNO
      L=LAYER
      IF (INDEX .GT. 1) GO TO 100
      REWIND 4
      LASTNO=0
      ISAVE=1
      READ (3) NOMAT1
      DO 10 N=1,NOMAT1
      READ (3) NO,NOFCOM,GMWT,L1,L2,L3,L4,L5,L6,L7,(ENRG(J),RNG(J),J=1,
     AL1),((EBOMP(J,K),EPROP(J,K),ENEUP(J,K),J=1,L2),K=1,NOFCOM),((EBOMN
     B(J,K),EPRON(J,K),ENEUN(J,K),J=1,L3),K=1,NOFCOM),((EBOMBP(J,K),CPSP
     C(J,K),CNSP(J,K),ENSP(J,K),J=1,L4),K=1,NOFCOM),((EBOMBN(J,K),CPSN(
     DJ,K),CNSN(J,K),ENSN(J,K),J=1,L5),K=1,NOFCOM),(ENRGP(J),XSMBP(J),J=
     E1,L6),(ENRGN(J),XSMBN(J),J=1,L7)
   10 WRITE(4) NO,NOFCOM,GMWT,L1,L2,L3,L4,L5,L6,L7,(ENRG(J),RNG(J),J=1,
     AL1),((EBOMP(J,K),EPROP(J,K),ENEUP(J,K),J=1,L2),K=1,NOFCOM),((EBOMN
     B(J,K),EPRON(J,K),ENEUN(J,K),J=1,L3),K=1,NOFCOM),((EBOMBP(J,K),CPSP
     C(J,K),CNSP(J,K),ENSP(J,K),J=1,L4),K=1,NOFCOM),((EBOMBN(J,K),CPSN(
     DJ,K),CNSN(J,K),ENSN(J,K),J=1,L5),K=1,NOFCOM),(ENRGP(J),XSMBP(J),J=
     E1,L6),(ENRGN(J),XSMBN(J),J=1,L7)
      REWIND 4
      READ (3) LRBE,LK1,LK2,LK,(RBENRG(J),RBE(J),J=1,LRBE),(C1NRG(J),
     1CONK1(J),J=1,LK1),(C2NRG(J),CONK2(J),J=1,LK2),(CNRG(J),CONK(J),
     2J=1,LK)
      IF (KOSW13 .EQ. 2) GO TO 200
      DO 210 J=1,2
      LIMT=LENTH(J)
      DO 210 K=1,LIMT
  210 FTDCON(K,J)=FTDCON(K,J)*3600.
  200 READ (3) NOMAT2
      DO 12 N=1,NOMAT2
      READ (3) NO,LSOFE,(SNRG(J),SOFE(J),J=1,LSOFE)
      IF (NO .EQ. L ) GO TO    20
   12 CONTINUE
      WRITE (6,14) L
   14 FORMAT(1H08X,58HDATA TAPE DOES NOT CONTAIN DE/DX TABLE FOR MATERIA
     1L NUMBERI4)
   16 REWIND 3
      STOP
   20 REWIND 3
      CALL DOSEK  (DUMMY,DUMMY,DUMMY,1)
      RETURN
  100 IF(PROPNO(L) .GT. LASTNO) GO TO 105
      MAVG=(PROPNO(L)+LASTNO)/2
      IF(MAVG .GT. 100) GO TO 110
      REWIND 4
      ISAVE=1
      GO TO 105
  110 KOUNT=LASTNO-PROPNO(L)
      ISAVE=ISAVE-KOUNT
      KOUNT=KOUNT+1
      DO 103 LL=1,KOUNT
  103 BACKSPACE 4
  105 DO 120 NN=ISAVE,NOMAT1
      READ (4) NO,NOFCOM,GMWT,L1,L2,L3,L4,L5,L6,L7,(ENRG(J),RNG(J),J=1,
     AL1),((EBOMP(J,K),EPROP(J,K),ENEUP(J,K),J=1,L2),K=1,NOFCOM),((EBOMN
     B(J,K),EPRON(J,K),ENEUN(J,K),J=1,L3),K=1,NOFCOM),((EBOMBP(J,K),CPSP
     C(J,K),CNSP(J,K),ENSP(J,K),J=1,L4),K=1,NOFCOM),((EBOMBN(J,K),CPSN(
     DJ,K),CNSN(J,K),ENSN(J,K),J=1,L5),K=1,NOFCOM),(ENRGP(J),XSMBP(J),J=
     E1,L6),(ENRGN(J),XSMBN(J),J=1,L7)
```

```
      IF(PROPNO(L) .EQ. NO) GO TO 150
  120 CONTINUE
      WRITE (6,4) PROPNO(L)
    4 FORMAT(1H08X,51HPROGRAM CANNOT FIND DATA TABLES FOR MATERIAL NUMBE
     1RI4)
      STOP
  150 LASTNO =PROPNO(L)
      ISAVE=NN
      CALL RANGE  (DUMMY,DUMMY,1)
      IF (INDEX .LT. 3) GO TO 151
      IF (KOSW13 .EQ. 1) C1=C1*3600.
      CALL XS (DUMMY,DUMMY,3)
      CALL YIELDS (DUMMY,DUMMY,NOFCOM,1)
      CALL CASNRG (DUMMY,DUMMY,NOFCOM,1)
  151 RETURN
      END
$IBFTC FLUXFQ  LIST,DECK
      SUBROUTINE FLUXEQ (E,FLUX,NO)
C.....CALCULATES INITIAL INCIDENT PROTON SPECTRUM AS A FUNCTION OF
C     INITIAL INCIDENT ENERGIES.
C
C.....IF NO EQUALS-      FLUX EQUALS-
C          1             A*E**(-B),
C          2             A*EXP(-P(E)/P0)   (N(GREATER THAN P)),
C          3             TABLE OF FLUX VS. E AND INTERPOLATION,
C          4             A(E)*EXP(-B(E)),
C          5             10.0**(A1+A2*E+A3*E**2+A4*E**3),
C          6             10.0**(A1+A2*LOG(E)+A3*(LOG(E))**2+A4*(LOG(E))**3),
C          7             -A/P0*EXP(-C1*P(E)/P0)*P1(E)/P(E)
C     WHERE E IS THE GIVEN INCIDENT ENERGY.
C
      COMMON  D2X(20)        , MAX            , E0(300,20)
      COMMON  EI(300)        , DEI(300)       , EIBAR(300)
      COMMON  OP(300)        , OPPRM(300)     , NOD2X(20)
      COMMON  X(20)          , NOX            , ENTOTS(200)
      COMMON  DX(20)         , PROPNO(20)     , C1
      COMMON  PDSBND         , NDSBND         , BNDLOW
      COMMON                   ENRG(100)      , RNG(100)
      COMMON  EBOMBP(25,4)   , EBOMBN(25,4)   , CPSP(25,4)
      COMMON  CPSN(25,4)     , CNSP(25,4)     , CNSN(25,4)
      COMMON  ENSP(25,4)     , ENSN(25,4)     , EBOMP(25,4)
      COMMON  EBOMN(25,4)    , EPROP(25,4)    , EPRON(25,4)
      COMMON  ENEUP(25,4)    , ENEUN(25,4)    , ENRGP(25)
      COMMON  ENRGN(75)      , XSMBP(25)      , XSMBN(75)
      COMMON  SNRG(100)      , RBENRG(20)     , C1NRG(40)
      COMMON  C2NRG(40)      , CNRG(2)        , SOFF(100)
      COMMON  RBE(20)        , CONK1(40)      , CONK2(40)
      COMMON  CONK(2)        , LENGTH(8)      , GMWT
      COMMON  LSOFE          , LRBE           , LK1
      COMMON  LK2            , LK             , NOFCOM
      COMMON  MOVE           , KOSW(36)       , KONSWT
      DIMENSION EEEE(100),PROTS(100),A(4),B(4)
      EE=E
      IF (MOVE.EQ.2) GO TO (10,20,30,40,50,60,70),NO
      MOVE = 2
      GO TO (1,2,3,4,5,6,7),NO
    1 READ (5,100) A(1),B(1)
  100 FORMAT(4E12.5)
      WRITE (6,102) A(1),B(1)
  102 FORMAT(1H08X,22H0 = A*E**(-B) WITH A =1PE13.5,8H AND B =E13.5/1H+
     A8X,1HI)
```

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```
   10 PHI = A(1)*EE**(-B(1))
 1000 FLUX=PHI
 2000 RETURN
    2 READ (5,100) A(1),P0
      WRITE (6,202) A(1),P0
  202 FORMAT(1H08X,44H0(GREATER THAN P) = A*EXP(-P(E)/P0) WITH A =1PE13.
     A5,9H AND P0 =E13.5/1H+8X,1HI)
   20 P = 938.26*SQRT((EE/938.26+1.0)**2-1.0)
      PHI = A(1)*EXP(-P/P0)
      GO TO 100
    3 WRITE (6,302)
  302 FORMAT(1H08X43H0 CALCULATED FROM TABLE OF FLUX VS. ENERGY./1H+8X,
     A1HI)
      READ (5,303) NOENTS,(EEEE(I),PROTS(I),I=1,NOENTS)
  303 FORMAT(I4/(F8.0,E10.3,F8.0,E10.3,F8.0,E10.3,F8.0,E10.3))
      DO 306 I=1,NOENTS
      EEEE(I)=ALOG10(EEEE(I))
  306 PROTS(I)=ALOG10(PROTS(I))
   30 EE=ALOG10(EE)
      CALL LAGRNG(EE,PHI,EEEE,PROTS,NOENTS,2)
      PHI=10.**PHI
      GO TO 100
    4 READ (5,100) A,B
      WRITE (6,402) (I,A(I),I=1,4),(I,B(I),I=1,4)
  402 FORMAT(1H08X,91H0 = A(E)*E**(-B(E)) WITH A(E) AND B(E) OF THE FORM
     1 C(E) = C1 + C2*E + C3*E**2 + C4*E**3 AND/1H+8X,1HI/9X,4(4X,1HAI1,
     2 2H = 1PE13.5,1H,),4H AND/9X,4(4X,1HBI1, 2H = 1PE13.5,1H,))
   40 SUMB = B(4)
      DO 42 I=1,3
      II = 4-I
   42 SUMB = SUMB*EE+B(II)
   50 PHI = A(4)
      DO 46 I=1,3
      II = 4-I
   46 PHI = PHI*EE+A(II)
      IF (NO - 5) 48,5060,5060
   48 PHI=PHI*EXP(-SUMB)
      GO TO 100
 5060 PHI=10.**PHI
      GO TO 100
    5 READ (5,100) A
      WRITE (6,502) (I,A(I),I=1,4)
  502 FORMAT(1H08X,42HLOG 0 = A1 + A2*E + A3*E**2 + A4*E**3 WITH/1H+12X,
     A1HI/13X,4(4X,1HAI1,2H =1PE13.5,1H,))
      GO TO 50
    6 READ (5,100) A
      WRITE (6,602) (I,A(I),I=1,4)
  602 FORMAT(1H08X,61HLOG 0 = A1 + A2*LOG(E) + A3*(LOG(E))**2 + A4*(LOG(
     1E))**3 WITH/1H+12X,1HI/13X,4(4X,1HAI1,2H =1PE13.5,1H,))
   60 EE = ALOG10(EE)
      GO TO 50
    7 READ (5,100) A(1),P0
      WRITE (6,702) A(1),P0
  702 FORMAT(1H08X,53H0(-DN/DE) = A/P0*EXP(-C1*P(E)/P0)*P1(E)/P(E) WITH
     1A =1PE13.5,9H AND P0 =E13.5/1H+8X,1HI)
   70 P1 = EE/938.26 + 1.0
      P = SQRT(P1*P1-1.0)
      PHI =  A(1)/P0*EXP(-938.26*P/P0)*P1/P
      GO TO 100
      END
$IBFTC INVALU  LIST,DECK
```

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```
      SUBROUTINE INVALU
C     INITIAL DATA CALCULATIONS
C     MOVE = 1, INTEGRAL SPECTRUM
C     MOVE = 2, DIFFERENTIAL SPECTRUM
      COMMON  D2X(20)          , MAX              , FO(300,20)
      COMMON  EI(300)          , DEI(300)         , FIBAR(300)
      COMMON  OP(300)          , OPPRM(300)       , NOD2X(20)
      COMMON  X(20)            , NOX              , FNTOTS(200)
      COMMON  DX(20)           , PROPNO(20)       , C1
      COMMON  PDSBND           , NDSBND           , BNDLOW
      COMMON                     ENRG(100)        , RNG(100)
      COMMON  EBOMBP(25,4)     , EBOMBN(25,4)     , CPSP(25,4)
      COMMON  CPSN(25,4)       , CNSP(25,4)       , CNSN(25,4)
      COMMON  ENSP(25,4)       , ENSN(25,4)       , EBOMP(25,4)
      COMMON  EBOMN(25,4)      , EPROP(25,4)      , EPRON(25,4)
      COMMON  ENEUP(25,4)      , ENEUN(25,4)      , ENRGP(25)
      COMMON  ENRGN(75)        , XSMBP(25)        , XSMBN(75)
      COMMON  SNRG(100)        , RBENRG(20)       , C1NRG(40)
      COMMON  C2NRG(40)        , CNRG(2)          , SOFE(100)
      COMMON  RBE(20)          , CONK1(40)        , CONK2(40)
      COMMON  CONK(2)          , LENGTH(8)        , GMWT
      COMMON  LSOFE            , LRBE             , LK1
      COMMON  LK2              , LK               , NOFCOM
      COMMON  MOVIE            , KOSW(36)         , KONSWT
      EQUIVALENCE (KOSW( 3),KOSW3 ),(KOSW(13),KOSW13),(KOSW(15),KOSW15),
     A              (KOSW(19),KOSW19)
      DIMENSION NOINTS(2),EOMAX(25,2),NOINCR(25,2),KNTR(2),ESPEC(200,2),
     ADELTE(25,2),KOUNT(20),TITLE(11),DIST(300)
      EQUIVALENCE (EIBAR(1),DIST(1))
      INTEGER PROPNO,EQNO
      DX(1)=X(1)
      D2X(1)=DX(1)/FLOAT(NOD2X(1))
      IF(NOX-1) 5,9,5
    5 DO 7 J=2,NOX
C.....DX-LARGE DELTA X
C.....X(J)- PRINT BOUNDARY MEASURED NORMAL TO INCIDENT FACE
      DX(J)=X(J)-X(J-1)
C.....D2X(J)-SMALL DELTA X
C.....NOD2X(J)-NUMBER OF SMALL DELTA X IN LARGE DELTA X
    7 D2X(J)=DX(J)/FLOAT(NOD2X(J))
    9 NOXP1=NOX+1
      GO TO (250,260),KOSW19
  260 READ (5,262) KEI,(FI(J),J=1,KEI)
  262 FORMAT(I3/(8F9.0))
      GO TO 45
  250 KLIM=1
   21 READ (5,22) NOINTS(KLIM)
   22 FORMAT (I3)
      INTNO=NOINTS(KLIM)
      READ (5,24) (EOMAX(L,KLIM),NOINCR(L,KLIM),L=1,INTNO)
   24 FORMAT (F8.0,I4,F8.0,I4,F8.0,I4,F8.0,I4,F8.0,I4,F8.0,I4)
      IF (KLIM .EQ. 2) GO TO 228
  220 GO TO (225,222),KOSW15
  222 KLIM=2
      GO TO 21
  225 READ (5,9999) NDE
 9999 FORMAT(I3)
      ENDE=NDE
  228 DO 2011 L=1,KLIM
      ELOWER=0.
      KONTUR =1
```

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```
      ESPEC(1,L)=0.0
      INTNO=NOINTS(L)
      DO 201 J=1,INTNO
C.....DELTE(J,L)-SMALL DELTA E AT EXIT FACE
      DELTE(J,L)=(EOMAX(J,L)-ELOWER)/FLOAT(NOINCR(J,L))
      ELOWER=EOMAX(J,L)
      LIMIT=NOINCR(J,L)
      DO 1202 I=1,LIMIT
      KONTUR=KONTUR+1
 1202 ESPEC(KONTUR,L)=ESPEC(KONTUR-1,L)+DELTE(J,L)
  201 ESPEC(KONTUR,L)=EOMAX(J,L)
 2011 KNTR(L)=KONTUR
      KLIM=1
      DO 10 J=1,NOX
      I=NOXP1-J
      IF (J . NE. 1) GO TO 12
   15 READ (5,16) EIMAX
   16 FORMAT (F12.5)
      EI(1)=EIMAX
      DO 400 II=1,NOX
      IF(II .EQ. 1) GO TO 403
  402 IF (PROPNO(II) .EQ. PROPNO(II-1)) GO TO 404
  403 CALL PROPTY(2,II)
      CALL RANGE (EIMAX,R,2)
  404 R=R-DX(II)
  400 CALL RANGE (R,EIMAX,3)
      EO(1,I)=EIMAX
      GO TO 20
   12 IF (PROPNO(I) .NE. PROPNO(I+1)) CALL PROPTY (2,I)
      EO(1,I)=EI(KEI)
      DO 407 N=2,KEI
      IF(PROPNO(I) .NE. PROPNO(I+1)) CALL RANGE (EI(N),DIST(N),2)
      DIST(N)=DIST(N)+DX(I)
  407 CALL RANGE(DIST(N),EI(N),3)
      GO TO (230,20),KOSW15
C.....DEO-SMALL DELTA E AT INTERNAL PRINT BOUNDS
  230 DEO = EO(1,I)/ENDE
      DO 9997 LL=1,NDE
 9997 EO(LL+1,I)=EO(LL,I)-DEO
      KOUNT(I)= NDE+1
      KM1 = NDE
      GO TO 30
   20 KONTUR=KNTR(KLIM)
      DO 202 L=1,KONTUR
      IF(EO(1,I) .LE. ESPEC(L,KLIM)*1.0001) GO TO 204
  202 CONTINUE
  204 KOUNT(I)=L
      KM1=KOUNT(I)-1
      DO 208 JJ=1,KM1
      IND=KOUNT(I)-JJ
  208 EO(JJ+1,I)=ESPEC(IND,KLIM)
      IF (J . NE. 1) GO TO 30
      KEI=1
      KLIM=2
   30 IF (KM1  .LE. 1 ) GO TO 234
C.....CALCULATE INCIDENT ENERGIES FROM ASSUMED EXIT ENERGIES
      DO 29 N=2,KM1
      KEI=KEI+1
      CALL RANGE (EO(N,I),R,2)
      DIST(KEI)=R+DX(I)
   29 CALL RANGE(DIST(KEI),EI(KEI),3)
```

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```
  234 KEI=KEI+1
      DIST(KEI)=DX(I)
   10 CALL RANGE(DIST(KEI),EI(KEI),3)
      GO TO (35,37),KOSW15
   35 DEO=EI(KEI)/ENDE
      DO 36 LL=1,NDE
      KEI=KEI+1
   36 EI(KEI)=EI(KEI-1)-DEO
      EI(KEI)=0.0
      GO TO 45
   37 KONTUR=KNTR(KLIM)
      DO 38 L=1,KONTUR
      IF(EI(KEI) .LE. ESPEC(L,KLIM)*1.0001) GO TO 39
   38 CONTINUE
   39 LL=L
      KM1=LL-1
      DO 40 L=1,KM1
      KEI=KEI+1
      IND=LL-L
   40 EI(KEI)=ESPEC(IND,KLIM)
   45 DO 500 L=1,KEI
      IF (EI(L) .LE. BNDLOW) GO TO 502
  500 CONTINUE
      GO TO 503
  502 KEI=L
      EI(KEI)=BNDLOW
  503 READ (5,41) MOVE,EQNO,TITLE
   41 FORMAT(2I3,11A6)
      MAX=KEI-1
   55 GO TO (62,64),MOVE
   62 CALL FLUXEQ (EI(1),OP(1),EQNO)
   64 DO 65  J=2,KEI
      DEI(J-1) = EI(J-1)-EI(J)
C.....EIBAR(J)-AVERAGE ENERGY
      EIBAR (J-1) = (EI(J-1)+EI(J))/2.0
      GO TO (142,145),MOVE
  142 CALL FLUXEQ (EI(J),OP(J),EQNO)
C.....OPPRM(J)-INTEGRAL SPECTRUM
      OPPRM(J-1) = OP(J)-OP(J-1)
      GO TO 65
  145 CALL FLUXEQ (EIBAR(J-1),OP(J-1),EQNO)
      OPPRM(J-1)=OP(J-1)*DEI(J-1)
   65 CONTINUE
      GO TO (80,90),KOSW3
   90 WRITE (6,92) TITLE
   92 FORMAT(1HL8X,11A6)
      L = 1
      GO TO (414,430),KOSW19
  414 DO 151 J=1,NOX
      I = NOXP1-J
      LIMIT = KOUNT(I)-1
      DO 425 M=1,LIMIT
      IF (MOD(L,55) .NE. 1) GO TO (420,422),MOVE
  410 GO TO (412,415),MOVE
  412 WRITE (6,413)
  413 FORMAT(1H117X,8HENERGY,E8X,17HN(GREATER THAN E)8X,7HDELTA E14X,6HE
     1 AVG.9X,15H(DN/DE)*DELTA E/21X,3HMEV10X,13HPROTONS/CM**214X,3HMEV1
     27X,3HMEV10X,13HPROTONS/CM**2)
      IF(KOSW13 .EQ. 1)WRITE(6,13413)
13413 FORMAT(1H+,2(46X,4H-SEC10X))
      GO TO 420
```

```
  415 WRITE (6,416)
  416 FORMAT(1H117X,8HENERGY,E13X,7HDELTA E14X,6HE AVG.10X,13HDN/DE(E AV
     1G.)6X,15H(DN/DE)*DELTA E/12X,3(9X,3HMEV8X),17HPROTONS/CM**2-MEV5X,
     213HPROTONS/CM**2)
      IF (KOSW13 .EQ. 1) WRITE(6,16416)
16416 FORMAT(1H+88X,4H-SEC14X,4H-SEC)
  422 WRITE (6,421) L,EI(L),DEI(L),EIBAR(L),OP(L),OPPRM(L)
      GO TO 423
  420 WRITE (6,421) L,EI(L),OP(L),DEI(L),EIBAR(L),OPPRM(L)
  421 FORMAT(I5,3X,1P5E20.5)
  423 IF(L .GE. MAX) GO TO 443
  425 L = L+1
  151 WRITE (6,427)
  427 FORMAT(1H )
  430 DO 435 M=L,MAX
      IF (MOD(M,55) .NE. 1) GO TO (439,441),MOVE
  432 GO TO (433,436),MOVE
  433 WRITE (6,413)
      IF(KOSW13 .EQ. 1) WRITE(6,13413)
      GO TO 439
  436 WRITE (6,416)
      IF (KOSW13 .EQ. 1) WRITE(6,16416)
  441 WRITE (6,155) M,EI(M),DEI(M),EIBAR(M),OP(M),OPPRM(M)
      GO TO 435
  439 WRITE (6,155) M,EI(M),OP(M),DEI(M),EIBAR(M),OPPRM(M)
  155 FORMAT(I5,3X,1P5E20.5)
  435 CONTINUE
  443 GO TO (444,446),MOVE
  444 WRITE (6,155) KEI,EI(KEI),OP(KEI)
      GO TO 80
  446 WRITE (6,155) KEI,EI(KEI)
   80 RETURN
      END
```

APPENDIX B

```
$IBFTC TAPFIX
      DIMENSION ENERGY(100),RANGE(100),ENRGPR(100,5),EPRPR(100,5),
     A          EPRNU(100,5),ENRGNU(100,5),ENUPR(100,5),ENUNU(100,5),
     B          ENERPR(100,5),YPRCP(100,5),YPRCN(100,5),YPREN(100,5),
     C          ENERNU(100,5),YNUCP(100,5) ,YNUCN(100,5),YNUEN(100,5),
     D        EBOMP(100),XSPR(100),EBOMN(100),XSNU(100)
      DIMENSION TABLE(100,6),LENGTH(4),RBENRG(100),RBF(100),K1NRG(100),
     A          K1(100),K2NRG(100),K2(100),KNRG(100),KK(100),EXENRG(100)
     B          ,DEDX(100)
      EQUIVALENCE (TABLE(1,1),K1NRG(1)),(TABLE(1,2),K1(1)),(TABLE(1,3),
     AK2NRG(1)),(TABLE(1,4),K2(1)),(TABLE(1,5),KNRG(1)),(TABLE(1,6),KK(1
     B))
      EQUIVALENCE (LENGTH(1),L8),(LENGTH(2),L9),(LENGTH(3),L10),(LENGTH
     A(4),L11)
      REAL K1NRG,K1,K2NRG,K2,KNRG,KK
      REWIND 3
      READ (5,4) NOMAT1,NOMAT2
    4 FORMAT(2I4)
      WRITE (3) NOMAT1
      DO 2  N=1,NOMAT1
      READ (5,6) MATNO,NOFCOM,GMWT,L1,L2,L3,L4,L5,L6,L7
    6 FORMAT(2I4, F13.6,7I4)
C.....RANGE-ENERGY.
      READ (5,8) (ENERGY(J),RANGE(J),J=1,L1)
    8 FORMAT(8F9.3)
C.....ENERGY OF CASCADE PARTICLES.
C     A.) PROTONS BOMBARDING.
      DO 13 K=1,NOFCOM
   13 READ (5,14) (ENRGPR(J,K),EPRPR(J,K),EPRNU(J,K),J=1,L2)
   14 FORMAT(9F8.2)
C     B.) NEUTRONS BOMBARDING.
      DO 15 K=1,NOFCOM
   15 READ (5,14) (ENRGNU(J,K),ENUPR(J,K),ENUNU(J,K),J=1,L3)
C.....EMITTED YIELDS.
C     A.) PROTONS BOMBARDING.
      DO 9 K=1,NOFCOM
    9 READ (5,10) (ENERPR(J,K),YPRCP(J,K),YPRCN(J,K),YPREN(J,K),J=1,L4)
   10 FORMAT(8F9.0)
C     B.) NEUTRONS BOMBARDING.
      DO 11 K=1,NOFCOM
   11 READ (5,10) (ENERNU(J,K),YNUCP(J,K),YNUCN(J,K),YNUEN(J,K),J=1,L5)
C.....X-SECTIONS.
C     A.) PROTON.
      READ (5,12) (EBOMP(J),XSPR(J),J=1,L6)
   12 FORMAT(10F7.0)
C     B.) NEUTRON.
      READ (5,12) (EBOMN(J),XSNU(J),J=1,L7)
    2 WRITE (3) MATNO,NOFCOM,GMWT,L1,L2,L3,L4,L5,L6,L7,(ENERGY(J),RANGE
     1(J),J=1,L1),((ENRGPR(J,K),EPRPR(J,K),EPRNU(J,K),J=1,L2),K=1,NOFCOM
     2),((ENRGNU(J,K),ENUPR(J,K),ENUNU(J,K),J=1,L3),K=1,NOFCOM),((ENERPR
     3(J,K),YPRCP(J,K),YPRCN(J,K),YPREN(J,K),J=1,L4),K=1,NOFCOM),((ENERN
     4U(J,K),YNUCP(J,K),YNUCN(J,K),YNUEN(J,K),J=1,L5),K=1,NOFCOM),(EBOMP
     5(J),XSPR(J),J=1,L6),(EBOMN(J),XSNU(J),J=1,L7)
      READ (5,18) L8,L9,L10,L11
      READ (5,20) (RBENRG(J),RBF(J),J=1,L8)
      READ (5,20) (K1NRG(J),K1(J),J=1,L9)
      READ (5,20) (K2NRG(J),K2(J),J=1,L10)
      READ (5,20) (KNRG(J),KK(J),J=1,L11)
      DO 22 L=1,3
      MAX= L+L
      LIMIT=LENGTH(L+1)
```

```
      DO 22 J=1,LIMIT
   22 TABLF(J,MAX)= TABLF(J,MAX)/3600.
      WRITE (3) L8,L9,L10,L11,(RBENRG(J),RBF(J),J=1,L8),(K1NRG(J),K1(J),
     AJ=1,L9),(K2NRG(J),K2(J),J=1,L10),(KNRG(J),KK(J),J=1,L11)
      WRITE (3) NOMAT2
      DO 116 N=1,NOMAT2
      READ (5,18) MATNO2,L12
   18 FORMAT(4I4)
C.....DE/DX
      READ (5,20) (EXENRG(J),DEDX(J),J=1,L12)
   20 FORMAT(F7.0,F9.3,F7.0,F9.3,F7.0,F9.3,F7.0,F9.3)
  116 WRITE (3) MATNO2,L12,(EXENRG(J),DEDX(J),J=1,L12)
      END FILE 3
      REWIND 3
      STOP
      END
```

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APPENDIX C

PROGRAM RUNNING TIME

An order of magnitude estimate of the running time of the program may be obtained as follows. Count the number of δx's, δE's, number of angles used in calculating evaporation neutrons, and the number of print bounds, then compute the following,

$$\text{Running time in minutes} = 0.5 + 6.2\times10^{-5} \sum_{p=1}^{P} N_p(\delta E) N_p(\delta x) N_p(LS) + 0.08 \sum_{p=1}^{P} N_p(PB)$$

P = the number of problems stacked in the data deck

$N_p(\delta E)$ = number of proton δE's in problem p (This has to be estimated on the basis of previous runs.)

$N_p(\delta x)$ = number of proton δx's in problem p

$N_p(LS)$ = number of angles in problem p

$N_p(PB)$ = number of print bounds in problem p

This estimate does not reflect the time required to print spectra at each print bound. Also this estimate is based on calculating all generations of secondaries and the use of 69 energy groups for the cascade neutrons. If these conditions are changed new coefficients for 6.2×10^{-5} and 0.08 can be calculated by running a few cases.

Comparison of Running Time for Sample Problem

p = 1

$N_p(\delta E) = 140$

$N_p(\delta x) = 40$

$N_p(LS) = 5$

$N_p(PB) = 3$

Running time in minutes (from formula) = 2.5 min.

Actual time was = 2.3 min.

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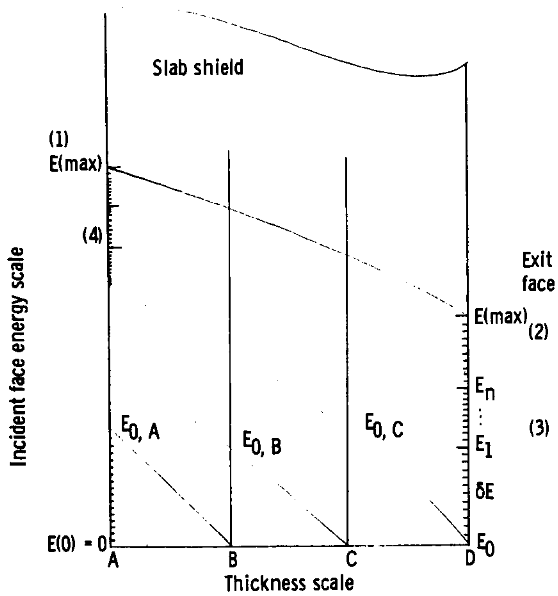

Figure 1. - Energy groups at internal bounds. Vertical lines show print boundaries. Tick marks on vertical lines show energy intervals at the print boundaries.

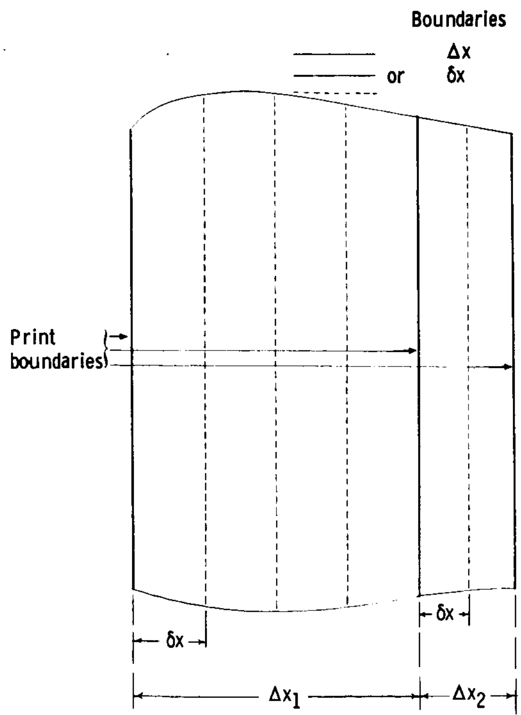

Figure 2. - Construction of print boundaries and secondary source layers.

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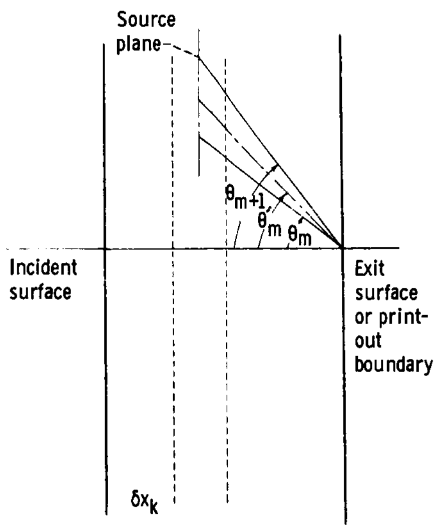

Figure 3. - Source plane location and angle definition (used in evaporation neutron dose calculation).