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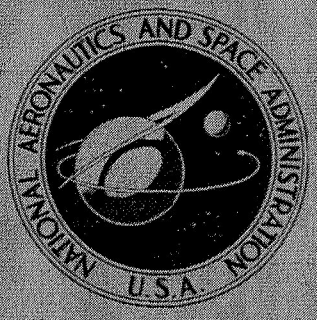

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PROPER 3C: A NUCLEON-PION TRANSPORT CODE

by Jules J. Lambiotte, Jr., John W. Wilson, and Tassos A. Filippas

Langley Research Center
Hampton, Va. 23365

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16. Abstract

A set of computer programs, referred to as the PROPER 3C Transport Code, has been written to calculate and analyze the interaction of nucleons and pions within a prescribed medium. The programs simulate the transport of nucleons and pions (with energies up to 2000 MeV) within a slab. The necessary nuclear interaction cross sections are read from a master data tape which contains cross-section data for various elements. The nuclear interaction data above 400 MeV are incomplete at this time but will be updated as data become available. A particle biography tape is generated and used to compile distributions for particles involved in the transport.

Descriptions of the programs, detailed user's guides, and sample input and output for programs in the code are presented.

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PROPER 3C: A NUCLEON-PION TRANSPORT CODE

By Jules J. Lambiotte, Jr., John W. Wilson,
and Tassos A. Filippas
Langley Research Center

SUMMARY

A set of computer programs, referred to as the PROPER 3C Transport Code, is being used at the Langley Research Center to calculate and analyze the interaction of nucleons and pions within a prescribed medium. The programs simulate the transport of nucleons and pions (with energies up to 2000 MeV) within a slab. The necessary nuclear interaction cross sections are read from a master data tape which contains cross-section data for various elements. The nuclear interaction data above 400 MeV are incomplete at this time but will be updated as data become available. A particle biography tape is generated and used to compile distributions for particles involved in the transport.

Descriptions of the programs, detailed user's guides, and sample input and output for programs in the code are presented.

INTRODUCTION

PROPER 3C is a nucleon-pion transport code which was developed at the Langley Research Center for use in radiation shielding studies. The bulk of this code is the PROPER 3B code given in reference 1. PROPER 3B was developed to simulate the transport of nucleons with energies below 400 MeV. PROPER 3C consists of modified versions of the programs in PROPER 3B, an additional program to extend the transport capability to 2000 MeV (2 GeV), and a replacement for the PROPER 3B statistical program.

The purpose of this paper is to describe the capabilities of the code and to present a detailed user's guide. The theoretical considerations in the model are presented only generally since quite detailed explanations of the transport theory for the nucleons are available in the PROPER 3B description (ref. 1). The pion calculations, which are similar, are described in the section entitled "PROBLEM DESCRIPTION."

The computer programs in the PROPER 3C code use Monte Carlo techniques for the transport of neutrons, protons, and/or pions from energies as high as 2 GeV down to neutron thermal energy. Although the transport medium is restricted to having either a

circular or square cross section, it may consist of a mixture of many elements. There are provisions to allow a source spectrum with any composition of the aforementioned particles, incident at any energy below 2 GeV and at any angle. A continuous slowing down model is used to slow the charged particles. Nuclear interactions also are allowed (presently only for nucleons since pion data are not available). A complete history of each source particle and its derivative particles is developed and recorded on a biography tape. This history includes the particle location within the medium, its direction of travel, energy, parent particle, and chronological generation. The information contained on this tape is used by a distributional analysis program to compute the distribution for each type of particle at any desired depth as a function of particle position or momentum.

The organization of PROPER 3C is shown in figure 1. PROPER 3C contains three transport programs (TWOGEV, PROTOS, and SUPER B), a distributional analysis program (STAT), a master data tape which contains nuclear data for the transport, and two programs (INTPOL1 and INTPOL2) which rearrange the data from the master tape into a form usable by the transport programs.

SYMBOLS

d	distance to nuclear interaction
E_{th}	neutron thermal energy
f(x)	probability density function for variable x
I_j	interval index for the jth variable in frequency distribution function (this function is defined in description for program STAT)
j,K	dummy variables
LOC	total number of computer locations reserved to store frequency distribution function
LOCTOT	number of computer locations needed to store frequency distribution function for all particles at any one depth
$N(I_1,I_2,\ldots,I_j)$	frequency distribution function for j variables
NB	number of bits allotted to each storage bin for computing frequency distribution function

NBIN	number of bins to be packed into each computer word in calculating frequency distribution function
NDEP	total number of depths for which frequency distribution function may be calculated in one pass through biography tape(s)
NLOC	number of computer locations needed to store frequency distribution function for any one type of particle at any one depth
NP	number of different types of particles for which frequency distribution function is to be calculated
n	integer used to define multiplication in "splitting" or "Russian roulette" techniques
n_j	number of intervals into which the range of the variable V_j has been divided
R, θ_R	polar coordinates of projection of particle's position onto X-Y plane (see fig. 2)
V_j	jth variable in frequency distribution function
ΔV_j	interval length of variable V_j
X,Y,Z	Cartesian coordinate system for slab as defined in figure 2
X',Y',Z'	coordinate frame translated from X,Y,Z system such that particle is always positioned at the origin (see fig. 2)
x	generic variable denoting a member of a class of randomly distributed variables
x_i	ith member of a set of equiprobable values of x
θ, ϕ	momentum angles defining direction of travel for a particle (see fig. 2)
π^+, π^o, π^-	pion triplet where +, o, and - refer to charge state

The following units are assumed throughout the paper unless otherwise noted:

length	cm
energy	MeV
angle	radians

PROBLEM DESCRIPTION

The problem to be solved is as follows: Given a source distribution of nucleons and pions (that is, their population, energy, and direction of motion) incident upon the face of a slab of material, determine the distribution of the particles within the slab.

The problem is solved by using the Monte Carlo method. Each incident particle is transported separately through the specified volume.

A continuous slowing down model, like the one described in reference 1, is used to slow the protons. In this model, the proton is slowed in discrete energy steps. The distances the particle travels between these energy levels are obtained from a normal distribution which describes the straggling. The mean and standard deviation of the normal distribution are computed from the theory of energy loss of a charged particle in matter. For charged pions, a continuous slowing down model also is used, but straggling is not computed.

The path to nuclear interaction d is chosen from a set of random numbers[1] distributed according to the exponential distribution function

$$f(d) = \frac{1}{\alpha} e^{-d/\alpha}$$

where α is the collision mean free path. (See ref. 3, ch. 6.) When a nuclear collision occurs, the distribution of secondary particles is obtained from tabular data which have been entered into core storage from a master data tape. These data define the transport characteristics for each type of particle in the given slab material; that is, at various energy levels for an incident particle, the data include the mean free paths, the average number of particles produced from a collision during the cascade process and their energy and direction, and the average number of evaporation particles produced and their energy. The pions are not allowed to have nuclear interactions since data are not yet

---

[1]The random number generator used is the FUNCTION subprogram RANF supplied as software for the CDC series 6000 computer systems by Control Data Corporation. The characteristics of RANF are analyzed in reference 2.

available to define the secondary products. These data will be incorporated as soon as possible. For low-energy neutrons (below 18 MeV), data are entered into core which define the probabilities of absorption, neutron-neutron reactions, neutron—two-neutron reactions, fission, and elastic scattering. The data also define the angular distribution and energy after the reaction. The transport of the source particle is terminated if it leaves the slab, is absorbed, or suffers a collision. All particles resulting from the interaction are treated as secondaries and transported before the process is repeated for the next source particle.

After the transport is completed, a final program, STAT, may be used to calculate desired distribution functions within the slab.

The nuclear interaction data mentioned previously are stored in arrays at equiprobable values of the independent variable (ref. 4). That is, if $f(x)$ is the probability density function for x, the $K + 1$ bounds for the K equiprobable intervals of x are the set x_j $(j = 1,2,\ldots,K+1)$ where each x_i and x_{i+1} satisfy the equation

$$\int_{x_i}^{x_{i+1}} f(x)\, dx = \frac{1}{K}$$

With this approach, a uniform random number is used to generate the interval from which x is obtained.

Quite often when using the Monte Carlo method, one encounters difficulties because either too few particles survive at a certain depth to accurately describe the distribution there or because in certain regions many more particles survive than are needed for an accurate description. These two problems can be approached by using "importance sampling" techniques "splitting" and "Russian roulette," respectively (ref. 3). Splitting means that in certain regions where insufficient populations of particles are present, one arbitrarily creates n particles for each initial particle present and assigns to each particle a weight of $1/n$. The splitting technique should be employed only when the computer resources prohibit the use of more source particles and not even then if the collision frequency distribution is not well defined. Russian roulette is the inverse of splitting and involves the transport of only one particle out of every n particles with a weight of n assigned to it.

These two techniques are programed into the code. The user specifies the splitting and Russian roulette ratios. When a count of all the particles is made by program STAT, the weight assigned to each particle is used to determine whether the particles count as less than, equal to, or greater than a full unit.

PROPER 3C DESCRIPTION

Due to considerations of computer storage and execution time, the transport is conducted in three stages by the following three programs:

(1) TWOGEV (Langley program R2092): TWOGEV transports neutrons, protons, and pions with energies up to 2 GeV, slows the protons to 400 MeV, slows the charged pions to any preselected cut-off, and considers nuclear interactions by the protons and neutrons. The pion nuclear interactions will be included when the data become available. Any nucleons created with energy below 400 MeV are stored on the output biography tape and treated, along with the protons which have been slowed to 400 MeV, by the next link in the code, PROTOS.

(2) PROTOS (Langley program R2091): PROTOS treats protons below 400 MeV and neutrons in the 18 to 400 MeV range. These particles may be introduced as input data through a source spectrum or they may be obtained from a biography tape as a continuation of a TWOGEV run. The protons are slowed to a preselected energy and nuclear interactions are allowed. Any neutron created below 18 MeV is placed on the output biography tape and transported in the third link, SUPER B.

(3) SUPER B (Langley program R2093): SUPER B transports only neutrons whose energy is less than 18 MeV. The neutrons are transported until they exit the slab, are absorbed, or lose energy down to a preselected cut-off.

These three programs require nuclear data which include the kinds and probabilities of nuclear interactions and the number, energy, and directional distributions of derivative particles. This information is available for a limited number of elements (table I) on the master data tape. TWOGEV and PROTOS require auxiliary programs, INTPOL1 and INTPOL2, respectively, to prepare the data in final form.

(4) INTPOL1 (Langley program R2090): INTPOL1 interpolates linearly in atomic weight between elements on the master data tape in the 2 GeV range and mixes the elements to produce the desired shield. The data are output on a "Monte Carlo" tape for input to TWOGEV.

(5) INTPOL2 (Langley program R2089): INTPOL2 performs the same function as INTPOL1 for data in the 400 MeV range. It generates a tape which is used in PROTOS.

The particle distributions are compiled in the final link in the code, STAT.

(6) STAT (Langley program R2094): After the transport is completed, STAT uses the particle-histories output on the biography tape to compute the particle distribution at points within the slab.

These six programs are described herein in the following order: First, the program INTPOL1 and INTPOL2, which supply the Monte Carlo tapes to the transport programs; then, the three transport programs TWOGEV, PROTOS, and SUPER B; and, finally, the program STAT. The flow chart of PROPER 3C is given in figure 1.

PREPARATION OF MONTE CARLO TAPES

Each of the three transport programs requires a nuclear data tape (Monte Carlo tape) as input to the program. The data to be used are on the master data tape which consists of three files containing the nuclear data for the elements specified in table I. The three files contain data in the energy range used by TWOGEV, PROTOS, and SUPER B, respectively. For SUPER B, the data for a particular shield may be copied directly from the master tape if the data are present. (See table I.) However, TWOGEV and PROTOS require the auxiliary programs INTPOL1 and INTPOL2, respectively, to organize the data into usable forms. Abstracts and flow charts for these programs are provided in appendix A and appendix B, respectively. The data for TWOGEV are taken from Bertini's preliminary calculations (ref. 5) which assumed that pion production was through the (3,3)-resonance and that pion decay was 25 percent forward, 25 percent backward, and 50 percent isotropic in the resonance rest frame. With the exception of the pion production, the model is the same as that described in reference 6. Comparison of Bertini's calculations with experimental data are given in reference 7. Reference 6 describes the nuclear interaction model that generates the data used by PROTOS (that is, for energies below 400 MeV), and gives experimental comparisons. The low-energy neutron data for SUPER B has been taken from the United Kingdom Neutron Data File (ref. 1).

Preparation of Data Tape for TWOGEV by INTPOL1 (R2090)

Main program.- The main program is labeled INTPOL1 and defines the following tape (disk) storage units:

TAPE9 – A disk storage unit onto which the user copies the appropriate file from the master data tape. It is later used for intermediate storage.

TAPE7 – A disk storage unit used for intermediate storage.

TAPE10 – A disk storage unit used for intermediate storage.

TAPE8 – A disk storage unit which will contain the final data for all the shields at the completion of the run.

TAPE5 and TAPE6 are the card input and printed output devices, respectively.

INTPOL1 reads the nuclear data from the master data tape. It reads card input to describe the elements for which data are needed (see "Card input"). If data for the element specified are already available from the master data tape, INTPOL1 merely copies the data to a disk file (TAPE10). If the element data are not available, the program interpolates linearly in atomic weight between the next lighter and heavier elements and puts these data on the disk (extrapolation is not permitted). As many elements as are needed to produce the desired shield or shields may be obtained in this fashion. Note from table I that only data for oxygen and aluminum are now available in this energy range so that the interpolation feature is of limited usefulness at this time. More elements will be added to the table as soon as data are available.

Two additional tapes should be described at this point. TAPE9 is a disk file which contains the nuclear data for the elements noted in the TWOGEV portion of table I. TAPE10 (disk) contains the interpolated data as an intermediate tape. The format of the two tapes which is identical is as follows:

Record 1

TAPE9	TAPE10	
Z	ZNEW	The atomic number of the element

Record 2

TAPE9	TAPE10	
ATOM	AA	The atomic weight
ELEMNT	ELMENT	Name of element requested
BTAB	BTABNY	Array containing the equiprobable energies of the evaporation particles in MeV
ATAB	ATABNY	Array containing the equiprobable cosines for the scattering angle
NSPK	NSPKNY	An array containing the mean number of secondary cascade particles per reaction
NSPE	NSPENY	An array containing the mean number of secondary evaporation particles per reaction
DSPK	DSPKENY	An array containing the standard deviation from the mean of secondary cascade particles per reaction
SIGMA	SIGMNY	An array containing the total cross sections in barns

Records 3 through 7

TAPE9	TAPE10	
FACT	FACT	Each record is an array containing equiprobable energies of a particular secondary cascade particle for each equiprobable cosine of the scattering angle. These data have been normalized by the incident energy value at which they were tabulated (see explanation of JE which follows)

The arrays have the following effective dimensions:

```
        4   21   5    2
BTAB  (JE,  I,  IN,  UT)

        4   11   5    5
ATAB  (JE,  L,  IN,  UT)

        4    5    5
NSPK  (JE,  IN,  UT)

        4    5    2
NSPE  (JE,  IN,  UT)

        4    5    5
DSPK  (JE,  IN,  UT)

        4    5
SIGMA (JE,  IN)

        4   11  41   5
FACT  (JE,  L,  I,  IN)
```

where

JE — number of energy points for incident particle (the tables have been prepared at four energy values: 400 MeV, 750 MeV, 1000 MeV, and 2000 MeV)

I — number of values per IN-UT combination and energy group

L — number of cosine values per IN-UT combination and energy group

IN — type of incoming particle

UT — type of secondary particle

The values of IN, UT are

1 for proton
2 for neutron

3 for π^+

4 for π^o

5 for π^-

It should be noted that the five records for FACT are data for UT = 1, 2, 3, 4, 5 in that order. These arrays are described in more detail in the BINOUT1 writeup.

INTPOL1 then calls subroutine REDIG1 which combines the elements into the desired shield. Upon return from REDIG1 one more revision is made to the data. Due to the large storage which would be required by a FACT array effectively dimensioned as FACT (4, 11, 41, 5, 5), the data must be packed. The data are packed six values to a word into a new integer array NFC which has been normalized so that the maximum value of the FACT array is stored in NFC with a value of $2^{10} - 1 = 1023$. The TWOGEV transport program unpacks the data when needed.

The final data tape then has this form:

Record 1

IDENT	See "Card input" (p. 13)

Record 2

DENSIT	As in the description in REDIG1
ELMENT	
BTABNY	
ATABNY	
NSPKNY	
NSPENY	
DSPKENY	
LAMBLA	
PH	

Record 3

C	The multiplicative factor used to normalize the FACT array to 1023 at its maximum
NFC	The FACT array packed six values to a word; NFC is dimensioned as NFC (7517)

These three records are repeated for each shield. The data are stored on disk (TAPE8) as one file and should be copied to the user's tape at the conclusion of the run by COPYBF control card.

Subroutines.- INTPOL1 contains two major programs for combining data into proper combinations and format and for providing printed output.

REDIG1: This subroutine uses the transport data from one or more of the elements on the intermediate disk (TAPE10) to produce data for one or more shields which may have any specified composition (of up to five elements) or density. Data cards defining the composition of the shield(s) are read in. The transport data for each shield are generated by using the data on TAPE10 and are stacked one behind the other on the disk file designated as TAPE9. The data for each shield are in the exact format as the input tape to REDIG1 except that in the second record for each shield, the SIGMNY array has been replaced by two arrays

LAMBLA mean free paths

PH probabilities for hydrogen interaction

These two arrays are dimensioned as

```
          4    5
LAMBLA (JE,  IN)

     4    5
PH (JE,  IN)
```

where JE and IN have the same meanings as before. Data for hydrogen interactions are not yet included so that the user must not request data for compounds which contain hydrogen. A return is made to INTPOL1 where the data are packed and recorded on TAPE8 as previously described.

BINOUT1: This subroutine, when requested, prints the contents of the tapes described previously. Three calls are automatically made by INTPOL1 to list the tapes. The first is to list the tape input to REDIG1, the second is to list the tape output from REDIG1, and the third is to an entry point BIN1 in BINOUT1 which lists only the FACT array after it has been packed into and then unpacked from array NFC. This final printout shows the effect of packing on the original FACT array data. Any of these listings can be suppressed by setting the appropriate sense switch 1, 2, or 3 by using the SWITCH n control card. The output is as follows:

BTAB – This array defines the 20 equiprobable[2] energy intervals for evaporation particles. For every energy level there are two groups each having five columns and 21 rows. The five columns are for the five values of IN and the 21 rows are for the 20 equiprobable intervals.

---

[2]The equiprobable values contained in BTAB, ATAB, and FACT have been computed by using the integral method mentioned in the PROBLEM DESCRIPTION.

ATAB – For each energy level there are 11 groups describing the 10 equiprobable cosine intervals for the cascade particles. Within each group there are five columns for the five types of particles in and five rows for the same five types out.

NSPK – Within each energy level there are five columns for the five types of particles in and five rows for the same five types out.

DSPK – This array has the same format as NSPK.

NSPE – This array has the same format as NSPK except that there are only two rows corresponding to protons and neutrons out.

SIGMA – There are four rows corresponding to the four energy levels and five columns for the five types of particles.

FACT – This array defines for the cascade particles 40 equiprobable energy intervals determined at each of the 10 equiprobable cosine intervals (ATAB). The energy values are normalized to the incident energy levels. In this printed output there are five groups corresponding to the five types of secondary particles. Each group is divided into JE energy levels. Within each energy level there are five columns (corresponding to the five types of incoming particles) and 44 rows (11 values of equiprobable cosine L by four values of equiprobable final energy I). Due to the size of the FACT array, only the first four values of I are printed for each of the 11 values of L. The first four lines are for L = 1, the next four for L = 2, etc.

For the printout of the REDIG1 output tape, LAMBLA (mean free paths), and PH (probabilities for hydrogen reaction) are on the tape instead of SIGMA (cross sections). They are printed under the same format as SIGMA.

Tape input.- The first file from the master data tape should be copied to TAPE9. The master data tape should be unloaded before execution of the program. This can be done with the DROPFIL control card (see Sample Problem Control Cards for INTPOL1).

Card input.- All input variables in this section and in the other input descriptions that follow are typed floating point or integer by the usual I, J, K, L, M, N FORTRAN integer convention unless indicated otherwise.

Card set	Number of cards	FORTRAN name	Columns	Format	Description
A	1	NUMBER	1 to 5	I5	Number of elements for which data are requested
		NSHILD	6 to 10	I5	Number of shields to be produced from the elements in the previous item
B	NUMBER	Z0	1 to 4	A4	Atomic number of the element in table I just lighter than the desired element (right adjusted within field)
		A0	5 to 14	F10.0	Atomic weight of the element in the previous item
		Z1	15 to 18	A4	Atomic number of the element in table I just heavier than the desired element (right adjusted within field)
		A1	19 to 28	F10.0	Atomic weight of the element in the previous item
		ZNEW	29 to 32	A4	Atomic number of the new element $Z0 \leqq ZNEW \leqq Z1$*
		AA	33 to 42	F10.0	Atomic weight of the new element $A0 \leqq AA < A1$*
		ELEMENT	43 to 46	A4	Alphanumeric name of the new element
C	2 * NSHILD	Z0	1 to 4	A4	Atomic number of element 1 in shield
		NA	5 to 14	F10.0	Number of nuclei per unit volume of element 1 multiplied by 10^{24}
		Z1	15 to 18	A4	Corresponding data for element 2 (or blank)
		NB	19 to 28	F10.0	
		Z2	29 to 32	A4	
		NC	33 to 42	F10.0	Corresponding data for element 3 (or blank)
		Z3	43 to 46	A4	
		ND	47 to 56	F10.0	Corresponding data for element 4 (or blank)
		Z4	57 to 60	A4	Corresponding data for element 5 (or blank)
		NE	61 to 70	F10.0	
		Continuation of data for this shield on next card			
		NH	1 to 10	F10.0	Number of hydrogen nuclei per unit volume multiplied by 10^{24} (NH must be set to 0.0 for INTPOL1 usage)
		DENSIT	11 to 20	F10.0	Density of medium, cm^3 (for identification only)
		NR	21 to 25	I5	Number of elements in the compound or mixture excluding hydrogen (e.g., for NaOH, NR = 2)
		IDENT	26 to 29	A4	Identification number of the new material
		ELEMENT	30 to 33	A4	Name or formula of the new material

*If the new element ZNEW is in table I, the data should be merely copied to disk by setting Z0 = Z1 = ZNEW and $AA = A0 \neq A1$.

Tape output.- After execution, the final Monte Carlo data are contained in a file on intermediate disk (TAPE8). A blank tape should be mounted and the contents of TAPE8 should be copied onto it with a COPYBF control card.

Printed output.- As the data for each element are read from TAPE9 in INTPOL1, the atomic number of the element is printed followed by the atomic number of the element requested (ZNEW). When REDIG1 has completed its function, it prints "REDIG OK." For the printed output of the contents of the tape, see subroutine BINOUT1 description.

Preparation of Data Tape for PROTOS by INTPOL2 (R2089)

Due to similarities between INTPOL1 and INTPOL2, only the differences between the two are noted in this section. The details can be found in the section describing INTPOL1.

Main program.- The main program is labeled INTPOL2 and defines the same tape and disk units as INTPOL1. As seen in table I, the data for PROTOS (25 to 400 MeV energy range) is much more extensive so that the interpolation feature has more meaning. The formats of TAPE9 and TAPE10 which differ somewhat from those for INTPOL1 are as follows:

Record 1

TAPE9	TAPE10
Z	ZNEW

Record 2

TAPE9	TAPE10
ATOMV	AA
ELEMNT	ELMENT
BTAB	BTABNY
ATAB	ATABNY
FACT	FACT
NSPK	NSPKNY
NSPE	NSPENY
SIGMA	SIGMNY

The effective dimensions of the arrays are

```
        9  21  2   2
BTAB (JE, I, IN, UT)
        9  11  2   2
ATAB (JE, L, IN, UT)
        9  11 41  2   2
FACT (JE, L, I, IN, UT)
        9   2   2
NSPK (JE, IN, UT)
        9   2   2
NSPE (JE, IN, UT)
         9   2
SIGMA (JE, IN)
```

where JE, I, L, IN, and UT have the same meanings as before. The IN-UT indices are reduced in number because no pion data are used in PROTOS. The nine energy levels are for 25, 50, 100, 150, 200, 250, 300, 350, and 400 MeV.

REDIG2 is called to combine the data for the shields. Upon the return to INTPOL2, FACT is packed as before into an NFC array but only four values to a word. NFC is dimensioned as NFC (4059). The final output tape (on TAPE8, a disk file as before) is the same as the output tape from REDIG1 except that NFC is now a smaller array due to the fewer particle types to be considered. (Pions are not treated in PROTOS.)

Again, three similar calls are made to BINOUT2 to provide printed output.

Subroutines.- INTPOL2 contains two major programs for combining data into proper combinations and format and for providing printed output.

REDIG2: The function of REDIG2 is identical to that of REDIG1. The output tape has the same format as the input tape except that SIGMNY has been replaced by LAMBLA (9, 2) and PH (9, 2) as before.

Cross sections for hydrogen interactions are contained in a data statement so as to include shields containing hydrogen.

BINOUT2: Although similar in function to BINOUT1, the output from BINOUT2 is simplified because there are only four IN-UT combinations and these may be put into four labeled columns.

ATAB – Within each energy level there are 11 rows defining the 10 equiprobable cosine intervals.

BTAB – Within each energy level there are 21 rows defining the 20 equiprobable energy levels.

FACT – Within each energy level there are 44 rows whose meaning is described under BINOUT1.

NSPK – There are nine rows corresponding to the nine energy levels.

NSPE – This array has the same format as NSPK.

SIGMA – There are two columns for neutron and proton cross sections and nine rows for the nine energy levels.

LAMBLA – This array has the same format as SIGMA.

PH – This array has the same format as SIGMA.

Tape input.- The second file from the master data type should be copied to TAPE9.

Card input.- It is the same as the input of INTPOL1 except that NH may be nonzero since interactions with hydrogen are possible.

Tape output.- It is identical to the output of INTPOL1.

Printed output.- It is identical to the output of INTPOL1.

Nuclear Data for SUPER B

The nuclear data for SUPER B need only to be transferred from the third file of the master data tape to TAPE9 by means of control cards. This file contains the low-energy-neutron data for the elements listed in table I. There are two records per element. The COPYBR control card is used to put the two records for the desired element onto the disk TAPE9. The user is restricted to these elements because there is no interpolation capability.

NUCLEON-PION TRANSPORT

The transport is carried out through three programs: TWOGEV, PROTOS, and SUPER B.

TWOGEV (R2092)

Main program.- The main program is labeled TWOGEV and defines the following tape (or disk) storage units:

TAPE4 – The biography tape.

TAPE8 – The source tape (or disk). It is either input to the program or generated within it.

TAPE9 – The Monte Carlo data tape.

TAPE5 and TAPE6 are the card input and printed output devices, respectively.

The purpose of TWOGEV is to call various subroutines and to terminate the output biography tape at the conclusion of the run.

Subroutines.- The main program, TWOGEV, performs mainly the managerial task of calling subroutines which read input, prepare data, perform the calculations, and terminate the output.

PDATA: This subroutine reads from cards the stopping power data used in the program to simulate the slowing down of the protons and computes the tables necessary to define this process. (See ref. 1.) Data from the nuclear data tapes are read into core also.

PIDATA: As an entry point under PDATA, it is similar in function to PDATA except that the input pertains to the pions. Although the charged pion rapidly decays into a muon, no distinction is made between the two in the slowing down process since the stopping power data for the two is very similar (the difference being about 5 percent).

GDATA: This subroutine reads from cards data defining the geometry of the transport medium. No calculations occur in this subroutine.

GEO: The transport is executed in this subroutine. A particle is taken from the source tape that was generated in the source subroutine. The type of particle determines the action to be taken. A proton may either have a nuclear interaction or merely be slowed in energy. A neutron has only nuclear interactions. The charged pions lose energy through continuous slowing down. They are presently not allowed to have nuclear interactions because of the lack of data. Each charged pion decays weakly in 10^{-8} second (half-lifetime) into a muon and neutrino (approximately 99 percent of the time). The neutrino is ignored and the muon is slowed down. The neutral pion π^0 decays electromagnetically in 10^{-16} second into two gamma rays. Because of this short lifetime, the π^0's are only counted and recorded on the biography tape. If the particle is to be slowed, the distance it will travel before losing energy to the next energy level is first taken from the slowing down tables and then the particle is transported that distance and its energy is reduced to the next level. The particle is slowed continually until it either has a nuclear interaction or until it reaches a preselected cut-off energy. For a particle which is to have a nuclear interaction, its free path to interaction is chosen from a set of random numbers distributed according to the exponential collision frequency distribution, and the particle is moved to its interaction site. A call is made to subroutine GENU which uses the nuclear data to determine the kinds and number of secondary particles and places this information in a buffer. GEO then takes another particle either from this buffer or, when it is empty, from the source tape.

For a proton which may either interact or slow down, its free path and slowing down distance are compared, with the lesser distance determining the action taken. This test is made at each energy level in the slowing down tables.

GENU: When a particle suffers a collision, subroutine GENU uses the necessary nuclear data to determine the number and kinds of secondary cascade and evaporation particles, their energies, and their directions.

TEMP: This subroutine is called from GENU to facilitate the conservation of energy in the nuclear collisions (actually only the fourth component of the four-momentum is conserved). A temporary storage is set up to hold data for all the secondary particles resulting from one nuclear interaction. TEMP has an entry point TRY.

TRY: After all secondary particles have been accounted for, the sum of their energies is compared with the energy of the original particle minus the binding energy loss. If the comparison is not sufficiently close, a return is made to GENU and the process is repeated. When a good comparison is found, the pertinent data for the secondary particles are stored in a buffer in the BUFOUT subroutine.

BUFOUT: This subroutine contains a storage buffer where data pertaining to the secondary particles can be stored and retrieved.

The data are stored by a call from TEMP to an entry point BUFIN. The data stored for each secondary particle consists of the particle type, position, direction of movement, energy, energy index within the slowing down tables, relative weight, parent particle, and generation. The buffer is initially set through a call to ENTRY BUFSET. A maximum of 100 particles may be stored at any one time. Any attempt to overstore results in a program exit.

The data are retrieved from the buffer by a call to BUFOUT from GEO. The last particle put in the buffer is retrieved first. Should the buffer be empty, a flag is set to inform GEO to take the next source particle instead.

SOURCE: This subroutine defines the source spectrum incident on the face of the shield. Although any source spectrum made up of the types of particles considered in the transport may be included by the user, certain standard spectra are already programed into the subroutine and may be requested. These include neutron and/or proton source spectra that are normally or isotropically incident, are either spread uniformly over the surface or all incident at the origin, and have energies uniformly distributed over a specified interval.

The source spectrum is written on logical unit 8 (TAPE8) by the following call to subroutine PUT which is a tape input-output routine:

CALL PUT (8, MS, X, Y, Z, SLAT, CTH, STH, CFI, SFI, NP, E, NSOU)

where

MS — index of the energy E in the slowing down table EK; that is, MS is smallest integer such that $EK(MS) \leqq E$ (see description of EK that follows)

X,Y,Z — particle position (see fig. 2)

SLAT — relative weighting of the particle normally set to 1 for primaries

CTH,STH — cosine and sine of the angle θ (see fig. 2)

CFI,SFI — cosine and sine of the angle ϕ (see fig. 2)

NP — particle type (1, 2, 3, 4, 5 for proton, neutron, π^+, π^0, π^-, respectively)

E — energy of the particle

NSOU — source particle identification number

When the user writes his own source program, he has the following variables available, most of which are read into the computer in subroutines PDATA and GDATA:

EK(100,2) — energy values for the slowing down tables; the second index is 1 for proton data and 2 for pion data

M(2) — number of values in the proton and pion tables (a maximum of 100)

NT — number of source particles

RU — radius or half-side of the transport medium

DU — length of medium, $0 < Z < DU$

IG — = 1 for square-cross-section transport medium
= 0 for circular-cross-section transport medium

EO — highest point on energy scale and usually the source energy for a mono-energetic spectrum

These variables are mentioned again under "Card input."

PUT: This input-output subroutine uses the RECIN and RECOUT library subroutines and calls DPACK and UNPACK.

DPACK: This assembly language subroutine packs two computer words into one location.

UNPACK: This assembly language subroutine unpacks one computer word into two locations.

STATI: This subroutine is called to determine whether the particle is still within the limits of the transport medium. It also stores the particle data on the biography tape.

A record is written on the biography tape (logical unit 4, TAPE4) by a call to subroutine PUT:

CALL PUT (4, X, Y, Z, SL1, SL2, EPR, IK1, NSOU, SLAT, IGEN)

where

X,Y,Z — particle coordinates

SL1,SL2 — angles θ and ϕ

EPR — particle energy

IK1 — integer defining the particle type and status, which may have the following values:

1,2,3,4	for protons
-1,-2,-3,-4	for neutrons
11,12,13,14	for π^+
-11,-12,-13,-14	for π^-
0	for π^0
10000	to denote the end of a case – that is, to denote that all particles in the source spectrum have been transported
|IK1| modulo 10	
	= 1 for a moved particle which is still inside the boundary
	= 2 for a moved particle which has passed outside the boundary
	= 3 for a particle moved to a collision site
	= 4 for a new particle

NSOU — parent particle identification number

SLAT — relative weighting of the particle

IGEN — chronological generation of the particle

Three things are done to reduce the number of biography tapes. First, PUT calls a COMPASS subroutine DPACK which packs two values into one word so that there are only five words per record. Second, RECIN and RECOUT are used to block the output. Third, the program is allowed to write to the end of the tape and, thus, there is no wasted space. A DAYFILE message will note the EOT (end of tape) condition and the next tape loaded will also be entered. No data are lost with this procedure. STATI has several entry points.

OUT: As an entry point under STATI, it is called to output particle data on the biography tape.

OUTL: As an entry point under STATI, it is called when the run terminates to write the final record on the biography tape.

CHAN1L: This subroutine computes the elements necessary to transform from a system that moves with the particle to the stationary X,Y,Z system as described in reference 1.

Tape input.- TWOGEV expects the Monte Carlo tape generated from INTPOL1 to be mounted defined as TAPE9. A blank tape should be mounted defined as TAPE4 to be the output biography tape.

Card input.- The main program and several subroutines require card inputs.

The main program TWOGEV controls the flow of the program by means of an input variable I which indicates the subroutine to call. The variable I is read with an I5 FORMAT and may have the following values:

I = 1	calls PDATA, returns; then calls PIDATA and returns.
I = 2	calls GDATA and returns.
I = 3	calls GEO (which calls SOURCE) and returns after transport completed.
I = 6	reads 80 characters from the card immediately following this one. This heading is output from GEO when that subroutine is called.
I = 7, 8, 9, or 10	terminates the run; an end of file is written on the biography tape and a program exit is made.

The subroutine PDATA contains a NAMELIST, PDAT, which includes the following variables:

EO	largest energy to be included in the proton slowing down tables (should be equal to or greater than the energies of the source particles)
ES	cut-off energy for protons
N	number of points in the stopping power tables
EN	N energy values where stopping power tables are generated, $EN_i < EN_{i+1}$
DES	corresponding N values of stopping power, $\frac{MeV}{g/cm^2}$
M	number of energy points desired in proton slowing down tables

KE — indicator for the kind of energy scale in the slowing down tables

KE = 1 gives M - 1 logarithmic steps between EO and ES

KE = 2 gives M - 1 linear steps

KE = 3 indicates that the slowing down table is read instead of computed

EK — table of slowing down values; not input unless KE = 3

RO — density of shield, g/cm^3

ZE — effective atomic number of shield

CF — straggling parameter taken from figure 3

UNIF — a starting value for a uniform distribution of random numbers

RAN — a starting value for a normal distribution of random numbers

AV — atomic or molecular weight

The subroutine PIDATA contains a NAMELIST, PIDAT, which includes the following variables:

EP — largest energy to be included in the pion slowing down tables

EPS — cut-off energy for pions

NP — number of points in the pion stopping power tables

MP — number of energy points desired in the slowing down tables

EN — same as in PDATA but for pion data

DES — same as in PDATA but for pion data

The subroutine SOURCE is called from GEO to prepare the source tape for the transport. A NAMELIST SOURCE contains the following variables:

ISO
= 1 for all source particles incident at (X = 0, Y = 0, Z = 0) (see fig. 2)
= 2 for source particles spread uniformly over the Z = 0 plane
= 4 for source program to be written by the user
This indicator generates a transfer to the end of this subroutine where the user may insert his FORTRAN IV cards.

IS1
= 1 for normal incidence
= 2 for isotropic incidence

FAC — fraction of neutrons in source spectrum

E1 — lowest energy in source spectrum

E2 — highest energy in source spectrum (for monoenergetic source E1 = E2)

The subroutine GDATA contains a NAMELIST, GDAT, which has the following variables:

IG	= 1 for square-cross-section transport medium = 0 for circular-cross-section transport medium
DU	length of transport medium
RU	half-square side or radius
NT	number of source particles

Tape output.- The particle histories are recorded on the biography tape defined as TAPE4.

Printed output.- The main program TWOGEV prints the indicator I.

Subroutine PDATA prints the input data and the slowing down table.

Subroutine PIDATA prints the corresponding pion data.

Subroutine GDATA prints the variables input under GDAT.

Subroutine GEO immediately prints the header card. After the transport for this case is completed, the results are printed in seven columns. The first column indicates the chronological generation of the particles for that row. Columns 3 to 7 contain the number of protons, neutrons, π^+, π^0, and π^-, respectively, in the generation indicated in column 1. The value in column 2 of each row refers to the data in columns 3 to 7 of the next row. It is the number of particles from the generation which suffered nuclear collisions.

Subroutine SOURCE prints the source energy interval and the composition of the source spectrum.

PROTOS (R2091)

PROTOS and TWOGEV are nearly the same in both composition and usage. There are three main differences. First, PROTOS transports only nucleons with energies less than 400 MeV; whereas TWOGEV transports both nucleons and pions with energies up to 2000 MeV. Second, PROTOS may use a biography tape from a TWOGEV run as a source tape; whereas TWOGEV must generate its own source tape. Third, to improve the statistical results, a splitting procedure is incorporated in PROTOS whereby the user may have all source particles split at their first nuclear interaction. That is, for an n to 1 splitting, when each source particle suffers its first nuclear interaction, GENU is called n times instead of once and each of the derivative particles carries a weight of 1/n instead of 1. This weight must then be accounted for in STAT. No such procedure is programed into TWOGEV.

The following description of PROTOS contains only new information since many of the subroutines are identical to their TWOGEV counterparts.

Main program.- The main program is labeled PROTOS. The program card defines the tapes INPUT, OUTPUT, TAPE4, and TAPE9 as in TWOGEV. There is an additional unit, TAPE7, on which may be loaded a biography tape generated in TWOGEV to be used as a source tape.

Subroutines.- As in TWOGEV, the main program PROTOS calls subroutines which read input, prepare data, perform the calculations, and terminate the output.

PDATA: There is no entry PIDATA.

GDATA: See TWOGEV description.

GEO: This subroutine transports only neutrons and protons. For n to 1 splitting, it calls GENU n times. Under directions from the user, it takes source particles from a previously generated biography tape, TAPE7, instead of the usual source tape, TAPE8.

GENU: See TWOGEV description.

TEMP: Total kinetic energy is conserved in this version of the program.

BUFOUT: The maximum number of allowable particles to be stored is 50.

SOURCE: This subroutine is the same as in TWOGEV except that NP = 1 or 2, EK is dimensioned as EK (100), and M is not dimensioned at all.

PUT: See TWOGEV description.

STATI: The variable denoting particle status IK is restricted to neutron and proton values of IK1 only.

CHANIL: See TWOGEV description.

DPACK: See TWOGEV description.

UNPACK: See TWOGEV description.

Tape input.- PROTOS expects the Monte Carlo tape generated from INTPOL2 to be defined as TAPE9. If PROTOS is to be a continuation of a TWOGEV run, the output biography tape from that run should be defined as TAPE7. A blank tape should be mounted as TAPE4 to be the output biography tape.

Card input.- The PROTOS card input is the same as the TWOGEV card input except that

(1) There is no entry point PIDATA and no namelist PIDAT.

(2) ISO may be 3, in which case the source particles are taken from a previously generated biography tape defined as TAPE7.

(3) Namelist GDAT contains an additional variable WHT which is the inverse of the splitting desired. For example, to split 10 to 1, WHT = 0.1. Each particle with all its derivatives is assigned a weight (SLAT) equal to WHT. (See STAT for suggestions in using this option.) Variable WHT is set to 1.0 internally before GDAT is read.

Tape output.- The histories of the particles are recorded on the tape defined as TAPE4.

Printed output.- The PROTOS output is similar to the TWOGEV output except for obvious differences resulting from the fewer types of particles considered.

SUPER B (R2093)

Very few modifications have been made to SUPER B at Langley. For that reason, most of the following description consists of excerpts from reference 1.

The PROTOS program is not useful at lower neutron energies where more detailed data are needed. If PROTOS creates a neutron at a lower energy than 18 MeV, it does not try to continue the transport process but puts it on the biography tape. The SUPER B program reads and copies the biography tape and when it finds a neutron with energy below 18 MeV, it transports the neutron and its derivative neutrons until they are either absorbed, leave the slab, or have a collision. Any neutron with energy below a preselected cut-off value is ignored. For any neutron with energy below thermal energy (a value specified by the user), SUPER B uses a constant mean free path and absorption probability. The program puts the biography of each event onto the new biography tape so that the final result is an expanded tape in the PROTOS format. The transport of the neutron is done by the standard Monte Carlo technique, that is, the mean free path at this energy is found, the actual path length is selected from the exponential distribution, and the particle is moved to the new point. If the neutron is still inside the transport medium, the absorption probability is compared with a random number to test whether absorption occurs. If absorption does not occur, the probabilities for different reactions are found and the element and reaction are selected. The resulting energy and scattering angle are determined and transformed to the laboratory system. The polar angle is transformed to direction cosines and the entire process is repeated for the particle at the new energy or for a new particle.

Main program.- The main program is labeled SUPER B and defines the following tape (or disk) storage units:

TAPE4 – The input biography tape.

TAPE3 – The output biography tape.

TAPE10 – A disk storage unit onto which the user has copied the two appropriate records from the third file of the master data tape.

TAPE5 and TAPE6 are the card input and printed output devices, respectively.

SUPER B reads the nuclear data into core and calls subroutine SUPB.

Subroutines.- The main program SUPER B calls subroutines which read input, prepare data, perform the calculations, and terminate the output.

SUPB: Subroutine SUPB reads the card data input, sets up initial values, and calls subroutine START.

START: Subroutine START reads the PROTOS biography tape until it finds a neutron of energy less than 18 MeV. Since it sometimes happens that in a problem one generates far more neutrons in the 0 to 18 MeV range than are needed for statistical purposes, an option is included which allows the user to employ a Russian roulette procedure to reduce the number of neutrons transported and hence the computation time and the number of output tapes. The Russian roulette procedure is the inverse of the splitting procedure described in PROTOS. In SUPER B, the user specifies the fraction of low-energy neutrons he wishes transported, with each one having its weight divided by this fraction. The neutrons which are not transported are merely deleted from the biography tape. By using the specified fraction and a uniform distribution of random numbers, it is determined whether this particle is to be transported. If so, computation proceeds to ENTRY EXPEN.

EXPEN: This subroutine computes mean free path, computes the new particle position, and tests the absorption probability. If the neutron survives, the control goes to REAKT. If the particle is absorbed, control goes to START. EXPEN uses STATI and OUT to put information on the biography tape.

REAKT: This subroutine uses the probabilities entered as part of the nuclear data to choose first the atomic element of the shield and then the type of reaction. If the reaction is fission, the energy of the new particle and the laboratory scattering angle are computed in REAKT and control goes to REOR. If the reaction is not fission, control is given to the appropriate reaction of ELAST (elastic scattering), INELAS (n,n'), or NTVN (n,2n).

ELAST: This subroutine tests the neutron energy to decide whether isotropic scattering occurs in the center-of-mass (c.m.) system. If not, it selects an angle from a given distribution. It converts the c.m. angle to the laboratory system and calculates the resulting energy in the laboratory system. Control then goes to REOR.

INELAS: This subroutine tests the neutron energy to see if continuous or discrete energy loss is to be applied. If discrete, a level is chosen from the probabilities and the resulting laboratory energy is computed. The scattering is isotropic in the c.m. system. If continuous, the correct parameters for this element are chosen, an energy is drawn from the distribution, and control goes to REOR.

NTVN: This subroutine gets its secondary energy with an even chance from one of two distributions of the same general form as in the continuous part of INELAST.

REOR: This subroutine tests the new energy to find out whether it is below cut-off. If so, control goes to START to search for a new particle. If not, REOR calls CHANIL and when control returns to REOR, it calls EXPEN.

CHANIL
STATI
PUT
DPACK
UNPACK

} See PROTOS description.

Tape input.- The main program SUPER B expects the two records of interest from the third file of the master data tape to be copied to the disk unit designated TAPE10. The biography tape containing the data for the low-energy neutrons from either a TWOGEV or PROTOS run should be mounted as TAPE3. The user must request a blank tape defined as TAPE4 to be the output biography tape.

Card input.- All input variables are defined through a namelist INPU as follows:

EMIN	cut-off energy
DU	length of transport medium
RU	radius or half-side of square
IG	= 1 for square-cross-section transport medium = 0 for circular-cross-section transport medium
NRECPT	the first NRECPT records which go on the biography tape for this case will be printed
IRAN	random number
E1 E2	incident energy interval for this case (for identification purposes only)
ETH	thermal energy
PAAS	probability of absorption at ETH
ALTH	mean free path at ETH
WHT	fraction of low-energy neutrons to be transported, $0 < WHT \leq 1$

Tape output.- The histories of the particles are recorded on the biography tape defined as TAPE4.

Printed output.- The input data are printed and the NRECPT records are printed in columns as X, Y, Z, θ, ϕ, E, IK, NSOU, SLAT, IGEN.

The total number of records on the output tape is printed.

COMPILATION OF PARTICLE DISTRIBUTIONS BY STAT (R2094)

STAT is the final link in the PROPER 3C code. From the histories previously recorded on the biography tape, STAT obtains the information required to compile frequency distribution functions for particles in the transport. Frequency distributions are computed for a particle at any depth within the transport body as a function of the particle's Cartesian or polar coordinates, energy, and/or direction of travel. The output may be in tabular or graphic form and/or on magnetic tape.

Frequency Distribution Function

The frequency distribution function $N(I_1,I_2,\ldots,I_j)$ which is computed in STAT may be best explained by first looking at the one-dimensional case. Consider the flow of a particular type of particle across a plane at a depth Z. Let the range of a variable V_1 be divided into n_1 equal intervals ΔV_1. Then, the frequency distribution function $N(I_1)$ for this type of particle at a depth Z within the body is defined as the number of times the variable V_1, when observed for the particles at this depth, was found to have a value lying in the I_1th interval; that is,

$$(I_1 - 1) \cdot \Delta V_1 < V_1 < I_1 \cdot \Delta V_1$$

The extension to a function of j variables $N(I_1,I_2,\ldots,I_j)$ having $n_1,n_2,\ldots,n_j$ intervals of lengths $\Delta V_1,\Delta V_2,\ldots,\Delta V_j$ is obvious. The values of $N(I_1,I_2,\ldots,I_j)$ will be effectively stored as a j-dimensional array, and for future reference an array element will be called a bin. A maximum of five variables may be included in the distributions. These variables are particle coordinates X and Y (or R and θ_R), energy E, and momentum angles θ and ϕ.

The user must specify the geometry of the volume used for the transport, the depths (values of Z coordinates) at which he desires the counting to be done, and the types of particles he wishes counted. STAT computes $N(I_1,I_2,\ldots,I_j)$ by counting in one of two ways. The first method counts the number of particles crossing a specified plane (Z = Constant). If the path of a requested particle intersects one of the planes, the values of the variables are obtained at that depth by linear interpolation and the appropriate bin is updated. The second method involves counting through a volume. The user specifies another plane at $Z + \Delta Z$ which defines a subslab of the original body or slab. STAT

uses the specifications on X and Y (or R and θ_R) to further partition the subslab into smaller volumes. Now each time the path of a particle intersects one of the boundaries of these volumes, the appropriate bin is updated by 1/2. Figure 4 illustrates a typical situation. The particle intersects bin 4 at A, the face of the subslab, intersects the plane common to bin 4 and bin 2 at B, and goes out the back of bin 2 at C. Bin 4 gets updated by 1/2 for A, both bins 2 and 4 get updated 1/2 for B, and bin 2 gets updated 1/2 for C.

If one or both of the coordinates are not requested as variables, their interval is effectively taken by the program to be $-\infty$ to $+\infty$ (0 to 360° for θ_R). For instance, if Y were not requested, there would be no intersection at B in figure 4.

Calculation of Storage Requirements

A one-dimensional storage area LC is set aside in STAT to hold the frequency distribution function $N(I_1,I_2,\ldots,I_j)$ and update it as the biography records are read from tape. The dimension of this array can and should be modified according to the needs of the particular computer run to make most efficient use of the computer. To be able to specify this dimension, the user should be acquainted with the method of storage and computation used in STAT. First, the storage area is used to compute $N(I_1,I_2,\ldots,I_j)$ as a function of all the variables which appear in any of the desired distributions. Then, to compute the particular distribution $N(I_1,\ldots,I_K)$, where $K \leq j$, which is a function of a subset of the variables in the previous section, a summation is performed over the unneeded variables. For example, suppose N(X,Y) and $N(X,\theta)$ are requested; $N(X,Y,\theta)$ is computed and later summed as follows:

$$N(X,Y) = \sum_{\theta} N(X,Y,\theta)$$

$$N(X,\theta) = \sum_{Y} N(X,Y,\theta)$$

The storage area is constructed as follows. The number of locations NLOC required to store the function for any one type of particle at any one depth is calculated from the user's input specification. For NP types of particles requested, the number of locations needed per depth is

LOCTOT = NP*NLOC

Now if LOC locations are set aside for the storage area by the user, the total number of depths for which $N(I_1,I_2,\ldots,I_j)$ may be calculated in one pass through the

biography tape(s) is determined from NDEP = LOC/LOCTOT by using integer arithmetic. In each pass through the biography tape(s), $N(I_1,I_2,\ldots,I_j)$ is calculated for NDEP more depths until all the depths have been processed. Obviously, the minimum amount of residence time, but also the maximum program length, occurs when enough locations are set aside to accommodate all the depths desired in just one pass through the tapes. The trade-off between the two must be made by the user. The modification to the program can be done easily (1) by changing the dimension of the LC array in the COMMON statement of the main program and (2) by setting LOC equal to this dimension as the first executable statement of the program.

In order to decrease the storage required, the frequency distribution function $N(I_1,I_2,\ldots,I_j)$ is packed NBIN bins to a computer word. The user specifies NBIN and must be careful in the selection to avoid overflow of a bin. The number of bits NB which are allotted to each bin is computed from NB = 59/NBIN by using integer arithmetic, and thus the maximum value a bin could have would be $2^{NB} - 1$. A message is printed which tells the number of times an overflow was attempted. A bin is not allowed to overflow. Its value remains at the maximum. The value of NLOC, needed previously, may be calculated from

$$NLOC = \frac{\left(\prod_{i=1}^{j} n_i\right) - 1}{NBIN} + 1$$

by using integer arithmetic. The LC array is used as follows: Starting at LC(1), the first NLOC locations contain $N(I_1,I_2,\ldots,I_j)$ for particle type 1 at depth 1, the second NLOC locations contain the corresponding information for particle type 2 at depth 1, etc., up to a maximum of the four types of particles that can be requested. The same format for depth 2 is followed starting at LC(LOCTOT + 1). This format continues for as many depths as are being processed in this run.

Thus, from the given values for the indices $I_1,I_2,\ldots,I_j$ and by knowing NLOC and LOCTOT, STAT can compute the LC element LOC1 for the NGth type particle at the NIth depth by (1) computing LOC, the position of this particular element for the first particle type at the first depth, and then by (2) modifying this number as follows:

$$LOC1 = LOC + (NI - 1)*LOCTOT + (NJ - 1)*NLOC$$

Then LC(LOC1) would contain the desired bin.

Weighting

As stated in the PROTOS and SUPER B descriptions, the particles may be weighted differently due to splitting in PROTOS and Russian roulette in SUPER B. This difference in weighting is accounted for in STAT by an integer input NORM. Since the packing scheme used requires an integer count in storage, each bin must be updated by an integral amount. The variable NORM should be the smallest integer value which when multiplied by each of the possible weightings will make all the products integers. Before output of results, each unpacked bin is divided by NORM to yield the correct distribution. Since NORM has the effect of reducing the maximum count a bin can have by a factor of NORM, one can make both good and bad choices for the weightings in the transport.

As one example, the user splits 7 to 1 in PROTOS and keeps 0.3 of low-energy neutrons in SUPER B. The possible weighting factors from PROTOS are 1 and 1/7 and from SUPER B are 1/0.3 and (1/7)/0.3. Therefore, all possible weights are 1, 1/7, 10/3, and 10/21 and NORM must have a value of 21.

As a second example, the user splits 7 to 1 in PROTOS and keeps 0.25 of low-energy neutrons in SUPER B. The possible weighting factors from PROTOS are 1 and 1/7 and from SUPER B are 1/0.25 and (1/7)/0.25. Therefore, all possible weights are 1, 1/7, 4, and 4/7 and NORM must have a value of 7.

Clearly, the choices in the second example are better than those of the first example by a factor of 3 even though the weightings are nearly the same.

Main Program

The main program is labeled STAT and defines the following tape (or disk) storage units:

TAPE4 – The input biography tape.

TAPE10 – An output tape which will contain the frequency distribution functions if tape output is requested.

TAPE5 and TAPE6 are the card input and printed output devices, respectively.

All card input is read in the main program. The logic necessary to identify the variables in the statistics is formulated. The storage requirements for the frequency distribution function are computed and subroutine GEOM is called to calculate the function for the first case and for as many depths as allowed by the storage. Subroutine SUMM is called to compute the desired statistics by summing over the unwanted variables. GEOM is called repeatedly until all the cases have been processed. If there are more depths, the tape is rewound and all cases processed again for these depths.

Subroutines

Program STAT calls the following subroutines in order to read the biography tape and to compute and output the frequency distribution function for the variables specified by the user in the main program.

GEOM: This subroutine, with the aid of subroutines INTSEC, COUNT, ORDER, and LOCAT, obtains the frequency distribution function for one case. It reads the biography tape until it finds a type of particle which has been requested and then traces the movement of the particle through the body by reading successive records from the tape. The location of the depths or subslabs to be processed has been supplied from the main program. If the path of the particle intersects any of these planes or subvolumes (fig. 4), INTSEC is called to obtain the data at the intersection point. Subroutine COUNT is then called to determine, when counting through a volume, whether there are other points of intersection. When IK = 10 000 is encountered on the tape, GEOM returns control to STAT.

INTSEC: Given particle data at two points from the biography tape, subroutine INTSEC computes by linear interpolation the value of the variables at some intermediate point.

COUNT: Once GEOM has determined that the path of the particle intersects any part of the plane or subslab, COUNT is called. If this run is to count across the plane, ORDER is called and given the variables at the intersection point from which it determines the indices $I_1,I_2,\ldots,I_j$ described previously. When counting through a volume, COUNT tracks the particle path by computing the intersections within the subslab (fig. 4) and supplies these values to ORDER.

ORDER: Subroutine ORDER uses the values of each of the variables given from COUNT and the user's input defining the variables to compute the indices $I_1,I_2,\ldots,I_j$. It calls LOCAT to determine the appropriate bin and then UPDAT to update that bin.

LOCAT: Subroutine LOCAT uses the index values supplied by ORDER to compute which LC array element contains the bin and in which part of the word the bin lies. LOCAT has entry points RTREVE, which unpacks and retrieves this part of the word, and UPDAT, which updates the bin by some integral amount.

INIT: Subroutine INIT computes values used by LOCAT in unpacking and updating the LC array.

SUMM: An ordering array is constructed in SUMM to relate the position of each variable in the particular distribution to its position in the larger distribution which is a function of all the variables. The particular distribution is then computed by summing over the unneeded variables in the larger distribution. To retrieve N from the LC

array for a particular set of indices, SUMM calls AD which makes use of the ordering array. The retrieved values are adjusted for the weighting factor and output in a tabular, graphic, or tape format. After this distribution is computed and output, a return is made to STAT.

PREPLT: Subroutine PREPLT substitutes Display Code characters for the values in the two-dimensional number density function to be output as a plot.

PLOTN: Subroutine PLOTN plots $N(I_1)$. The range of N is divided into 50 equal intervals and the user's specification for the variable defines the abscissa. The symbols P, N, +, and - are used to denote $N(I_1)$ for protons, neutrons, π^+, and π^-, respectively.

AD: Subroutine AD uses the ordering array from SUMM to supply LOCAT with the correct ordering of the indices. The value of the bin is retrieved from RTREVE and return to SUMM.

Tape Input

The biography tape should be defined TAPE4. If there is more than one tape, the labeling provided by the operators at the time of the tape generation should handle any continuation problems.

Card Input

The card input for STAT is as follows:

Card set	Number of cards	FORTRAN name	Columns	Format	Description
A	1	NPLNS	1 to 5	I5	Number of depths at which N is to be computed
		NVAR	6 to 10	I5	Total number of different variables which will appear in any of the requested distributions (NVAR ≤ 5)
		NSTAT	11 to 15	I5	Number of different distributions required (NSTAT ≤ 10)
		IOPT	16 to 20	I5	= 1 to count across a plane = 2 to count through a volume
		NCASES	21 to 25	I5	Number of cases on biography tape(s) for which this set of input is applicable (NCASES ≤ 20) (Each case terminates with a record having IK = 10 000.)
		NTAP	26 to 30	I5	Number of reels containing the particle data
		TAP	41 to 50	A10	Tape number of first reel, left justified (not needed for NTAP = 1)
B	1	NPOP(1)	1	I1	= 1 if want distributions for neutrons = 0 if do not want distributions for neutrons
		NPOP(2)	2	I1	Same as in previous item for protons
		NPOP(3)	3	I1	Same as in previous item for PI-
		NPOP(4)	4	I1	Same as in previous item for PI+
		NBIN	5 to 10	I6	Number of bins to be packed into one word
		NORM	11 to 15	I5	Smallest normalization factor which makes all possible relative weights perfect integers
C	1	XM(1)	1 to 10	F10.2	Maximum value of X (or R)
		XM(2)	11 to 20	F10.2	Maximum value of Y (or blank)
		XM(3)	21 to 30	F10.2	Maximum value of Z (see fig. 2)
D	As many as needed	Z(1)	1 to 10	F10.2	First depth at which distribution desired
		DZ(1)	11 to 20	F10.2	Depth of first subslab (set to 0.0 if IOPT = 1)
		Z(2)	21 to 30	F10.2	Second depth
		.	.	.	
		.	.	.	
		.	.	.	
		DZ(4)	71 to 80	F10.2	Depth of fourth subslab
		Z(5)	1 to 10	F10.2	Fifth depth
		.	.	.	
		.	.	.	
		.	.	.	
		DZ(NPLNS)		F10.2	Depth of NPLNS subslab
E	NVAR	VN	1 to 5	A5	Variable name (left justified) (See text that follows for possible entries.)
		NBLK	6 to 10	I5	Number of intervals for this variable (Note restrictions on θ_R and ϕ in text that follows.)
		V	11 to 20	F10.2	Minimum value of first bin*
		DELT	21 to 30	F10.2	Change in value for each bin*
F	NSTAT	NU	1 to 5	I5	Number of variables in this distribution
		VST(1)	6 to 10	A5	Name of first variable in the distribution (left justified) (See text that follows for possible entries.)
		VST(2)	11 to 15	A5	Name of second variable in the distribution (or blank)
		VST(3)	16 to 20	A5	Name of third variable
		VST(4)	21 to 25	A5	Name of fourth variable
		VST(5)	26 to 30	A5	Name of fifth variable
		TAIP	31 to 35	I5	= 0 for no tape output of this distribution = 1 for tape output
		PLOT	36 to 40	I5	= 0 for no plot of this distribution = 1 for a plot No plotting can be done for NU > 2
G	NCASES	E1	1 to 10	F10.4	Lower bound of incident energy spectrum
		E2	11 to 20	F10.4	Upper bound of incident energy spectrum

*When variable is an angle, then input unit is degrees.

The names of the seven variables which might appear in card E or F (in VN or VST) are X,Y,R, THER, THEP, PHIP, or E which are for the coordinates X and Y (or R and θ_R), momentum angles θ and ϕ, and energy E. Due to the rotational symmetries of the variables θ_R and ϕ about the Z-axis and the line Y = X in the X-Y plane, their values are always reduced by STAT to a range of 0 to 45° and the bins should be allocated accordingly.

This entire set of data cards is assumed to be pertinent to the NCASES run. If more distributions are sought, an entire new set of cards is required. The biography tape is always in a rewound position when card A is used.

Tape Output

The frequency distribution function $N(I_1,I_2,\ldots,I_j)$ may be recorded on magnetic tape if requested. The tape should be mounted on logical unit 10. The data will appear on tape in the same order as they appear in the printout. For each case and at each depth, the following information is recorded per distribution:

Record 1

Z,DZ(NPOP(I),I = 1,4),E1,E2

where these variables have been previously defined

Record 2

NUV,(LP(I),VVS(I),DELS(I),LF(I),I = 1,NUV),NR

where

NUV — the number of variables in this distribution

LP(J) — an array element whose value indicates the variable to which the Jth element of the other arrays refer

- LP(J) = 1 for X
- = 2 for Y
- = 4 θ
- = 5 ϕ
- = 6 E
- = 7 R
- = 8 θ_R

VVS(J) — the lower limit of the first bin in the variable indicated by LP(J)

DELS(J) — the change in value from bin to bin for this variable

LF(J) the number of bins allotted to this variable

NR an integer which tells how many records follow to give N for one type of particle

Records 3 through 3 + NR - 1

These NR records contain the frequency distribution function N for the first type of particle requested. Each record contains the following information:

NWS,(INDX(I),I = 1,NW),(SUM(I),I = 1,NWS)

where

NWS the number of elements in the SUM array

NW NUV-1

INDX indices of first NW variables

SUM an array whose Ith element gives N for fixed indices INDX and the Ith interval in the last variable in the statistic

There follows NR more records for each type of particle requested.

The same type format is used on the remaining distributions. Next, the whole procedure is repeated for the next depth and the following depths. Then the procedure is repeated for the next case on the biography tape.

An example of a typical tape output is as follows:

Presume that $N(\theta,E)$ is requested for protons and neutrons at $Z = 10.0$ and $\Delta Z = 0.0$. The incident energy was from 150 to 200 MeV. The momentum angle θ has two bins in range 0 to 90° and the energy E has two bins in range 0 to 200 MeV.
Presume also that the following information was compiled by STAT:

Neutrons

θ	E	
	0 to 100	100 to 200
0 to 45	25	13
45 to 90	16	11

Protons

θ	E	
	0 to 100	100 to 200
0 to 45	18	5
45 to 90	15	8

Then the output tape would contain

Rec 1 10., 0., 1, 1, 0, 0, 150., 200.

Rec 2 2, 4, 0., 45., 2, 6, 0., 100., 2, 2

Rec 3 2, 1, 25, 13

Rec 4 2, 2, 16, 11

Rec 5 2, 1, 18, 5

Rec 6 2, 2, 15, 8

Printed Output

Information which describes the input is printed out. The maximum value which any one bin may have is printed as well as the number of attempts made to overflow the bins. After reading all the data from one case, printed out are IK, the total number of records, and the number of low neutrons. If $IK \neq 10\,000$, there has been a read error.

The distribution function N is recorded in one or more of the following forms (one always gets the tabular form except as noted):

Tabular

The range and interval size for each variable in the particular distribution is printed out. $N(I_1,I_2,\ldots,I_j)$ is printed out by listing the indices of the first $j - 1$ variables and printing N as the jth index varies over its range.

Graphs

Graphs may be obtained for $NU < 3$. For $NU = 1$, a plot of $N(I_1)$ as a function of I is given on the printed output by using the PLOTN subroutine. For $NU = 2$, a rectangular grid based on the variable intervals is established and N is printed out by

N = 0	Blank
N = 1 to 9	1 to 9
N = 10 to 35	A to Z
N > 35	*

The values for the asterisks are printed out below the graph. For this plot the tabular output is suppressed.

Restriction: If a plot for $N(I_1,I_2)$ is requested, there is no tabular printout nor can there be tape output if $I_2 > 120$.

SAMPLE PROBLEM

A sample problem consisting of a source spectrum of 500 particles (40 percent protons and 60 percent neutrons), isotropically incident on the top of the atmosphere with energy uniformly spread over the interval $1500 \leq E \leq 2000$ MeV, was solved by means of

PROPER 3C. The transport medium is an infinitely wide slab of air 1000 cm thick. The air density was assumed to be 1 g/cm^3. Because of the lack of high-energy data for nitrogen, data for pure oxygen have been used for air above 400 MeV. The stopping power data were obtained from reference 8. A splitting of 2 to 1 is performed in PROTOS and 50 percent of the low-energy neutrons are transported in SUPER B. A total of approximately 20 min of central processing time and 60 min of peripheral processing time was required to complete the transport.

Listings of control cards, data input cards, and printer outputs are given for the sample problem.

SAMPLE PROBLEM CONTROL CARDS

SAMPLE PROBLEM CONTROL CARDS FOR INTPOL1

```
JOB,1,300,7100.                                    JOB CARD
RUN(S)                                             COMPILE
REQUEST TAPE11,HY. 206017,RO,JJL,MASTER DATA TAPE  MOUNTS MASTER TAPE
REWIND(TAPE11)
COPYBF(TAPE11,TAPE9)                               PUT HIGH ENERGY DATA
                                                   ON DISK
DROPFIL(TAPE11)                                    UNLOAD MASTER TAPE
REWIND(TAPE9)
SWITCH 3.                                          SUPPRESSES BINOUT1
                                                   PRINTOUT OF PACKED
                                                   FACT ARRAY

LGO.
REQUEST DUMM2,HY. 212054,RIL,JJL,MC 2GEV AIR       MONTE CARLO TAPE
                                                   FOR TWOGEV
REWIND(TAPE8)
COPYBF(TAPE8,DUMM2)                                COPY DATA TO MC TAPE
UNLOAD(DUMM2)
EXIT.
UNLOAD(DUMM2)
7/8/9 CARD
```

SAMPLE PROBLEM CONTROL CARDS FOR INTPOL2

```
JOB,1,300,74000.
RUN(S)
REQUEST TAPE11,HY. 206017,RO,JJL,MASTER DATA TAPE  MOUNTS MASTER TAPE
REWIND(TAPE11)
COPYBF(TAPE11,DIS)                                 SKIP FILE  1
COPYBF(TAPE11,TAPE9)                               COPY FILE  2
DROPFIL(TAPE11)
REWIND(TAPE9)
LGO.
REQUEST DUMM2, HY.1202019,RIL,JJL,MC  DATA AIR     MONTE CARLO TAPE
                                                   FOR PROTOS
REWIND(TAPE8)
COPYBF(TAPE8,DUMM2)                                COPY DATA TO MC TAPE
UNLOAD(DUMM2)
EXIT.
UNLOAD(DUMM2)
7/8/9 CARD
```

SAMPLE PROBLEM CONTROL CARDS FOR TWOGEV

```
JOB,1,400,72000.
RUN(S)
REQUEST DUMM2,HY. 212054,RO,JJL,MC  2GEV AIR
COPYBF(DUMM2,TAPE9,1)

REWIND(TAPE9)
DROPFIL (DUMM2)
REQUEST TAPE4,HY. 509011,RIL,JJL,TWOGEV TEST CASE 2
LGO.
UNLOAD(TAPE4)
EXIT.
UNLOAD(TAPE4)
7/8/9 CARD
```

CARD REFERENCE

MONTE CARLO TAPE
PLACE HIGH ENERGY
AIR DATA ON DISK

OUTPUT BIO TAPE

SAMPLE PROBLEM CONTROL CARDS FOR PROTOS

```
JOB,1,2000,63000.
RUN (S)
REQUEST DUMM2,HY. 1202019,RO,JJL ,MC DATA AIR
COPYBF(DUMM2,TAPE9,1)

REWIND(TAPE9)
DROPFIL (DUMM2)
REQUEST TAPE7,HY. 509011,RO,JJL, TWOGEV TEST CASE
REQUEST TAPE4,HY. SAVTP, RIL,JJL,PROT   TEST CASE2
LGO.
UNLOAD(TAPE7)
UNLOAD(TAPE4)
EXIT.
UNLOAD(TAPE7)
UNLOAD(TAPE4)
7/8/9 CARD
```

CARD REFERENCE

MONTE CARLO TAPE
PUT 400 MEV AIR DATA
ON DISK

SOURCE TAPE
OUTPUT BIO TAPE

SAMPLE PROBLEM CONTROL CARDS FOR SUPER B

```
JOB,1,600,4700.
RUN(S)
REQUEST TAPP11,HY. 206017,RO,JJL,MASTER DATA TAPE
COPYBF(TAPP11,DIS,2)
COPYBR(TAPP11,DIS,24)
COPYBR(TAPP11,TAPE10,2)

DROPFIL(TAPP11)
REQUEST TAPE3, HY. SAVTP, RIL,JJL,SB  TEST CASE2
REQUEST TAPE4, HY. 211050, RO,JJL, PROT TEST CASE2
LGO.
UNLOAD(TAPE3)
UNLOAD(TAPE4)
EXIT.
UNLOAD(TAPE3)
UNLOAD(TAPE4)
7/8/9  CARD
```

CARD REFERENCE

MOUNTS MASTER TAPE
SKIP TWO FILES
SKIP 24 RECORDS
PUT LOW ENERGY
NEUTRON AIR DATA
ON DISK

OUTPUT BIO TAPE
INPUT BIO TAPE

SAMPLE PROBLEM CONTROL CARDS FOR STAT

```
JOB,1,400,65000.
RUN(S)
REQUEST TAPE4,HY. 107021,RO,JJL,SB TEST CASE2
REQUEST TAPE10,HY. SAVTP,RIL,JJL, STAT TEST CASE2

LGO.
UNLOAD(TAPE4)
UNLOAD(TAPE10)
EXIT.
UNLOAD (TAPE4)
UNLOAD (TAPE10)
7/8/9 CARD
```

CARD REFERENCE

INPUT BIO TAPE
REQUESTED ONLY IF
WANT TAPE OUTPUT
FROM STAT

SAMPLE PROBLEM INPUT DATA

```
   SAMPLE PROBLEM CARD INPUT FOR INTPOL1                    CARD REFERENCE

  1    1                                                     CARD SET A
 8   16.0      8    18.      8   16.0    AIR                 CARD SET B
 8   .03764                                                  CARD SET C
0.       1.           1  8. AIR


   SAMPLE PROBLEM CARD INPUT FOR INTPOL2                    CARD REFERENCE

  2    1                                                     CARD SET A
 6   12.0      8    16.      7   14.     N2                  CARD SET B
 8   16.0      8    18.      8   16.     02
 7 .0344       8  .00752                                     CARD SET C
0.       1.           2 7.2 AIR
```

SAMPLE PROBLEM CARD INPUT FOR TWOGEV

```
   6                                                                    I=6 FOR HEADING
  ATMOSPHERIC CALCULATION  500 PARTICLES ISOTROPIC                      HEADING
   1                                                                    I=1 TO CALL PDATA
$PDAT E0=2000.0,R0=1.000,N=74,M=50,ES=400.0,KE=2,ZE=7.2,CF=-5.,         NAMELIST PDAT
UNIF=.3,RAN=.3,AV=14.4,EN(1)=2.0,4.0,6.0,8.0,10.0,14.0,18.0,22.0,26.0,
30.0,34.0,38.0,42.0,46.0,50.0,60.0,70.0,80.0,90.0,100.0,110.0,120.0,
130.0,140.0,150.0,160.0,170.0,180.0,190.0,200.0,220.0,240.0,260.0,
280.0,300.0,320.0,340.0,360.0,380.0,400.0,420.0,440.0,460.0,480.0,
500.0,520.0,540.0,560.0,580.0,600.0,620.0,640.0,660.0,680.0,700.0,
720.0,740.0,760.0,780.0,800.0,820.0,840.0,860.0,880.0,900.0,920.0,
940.0,960.0,980.0,1000.0,1200.0,1400.0,1600.0,2000.0,
DES(1)=141.7,84.16,60.22,
4.727E+01,3.9920E+01,3.049E+01,2.491E+01,2.118E+01,1.851E+01,1.650E01,
1.492E01,1.364E01,1.259E01,1.171E01,1.097E01,9.500,8.428,7.608,6.959,
6.432,5.997,5.629,5.316,5.054,4.839,4.601,4.417,4.252,4.104,3.970,
3.738,3.543,3.378,3.237,3.113,3.006,2.911,2.826,2.751,2.683,2.622,
2.567,2.516,2.471,2.428,2.390,2.354,2.322,2.291,2.263,2.237,2.213,
2.190,2.169,2.149,2.130,2.113,2.097,2.081,2.067,2.053,2.041,2.029,
2.017,2.006,1.996,1.987,1.978,1.969,1.961,1.899,1.861,1.839,1.819$
$PIDAT EP=2000.0,NP=74,MP=50,EPS=2.0,                                   NAMELIST PIDAT
DES(1)=31.50,18.02,13.01,10.35,8.697,6.730,5.597,4.857,4.336,3.949,
3.651,3.414,3.222,3.062,2.928,2.673,2.492,2.358,2.256,2.177,2.114,2.062,
2.021,1.986,1.958,1.934,1.913,1.896,1.882,1.870,1.851,1.838,1.828,1.822,
1.818,1.816,1.816,1.816,1.818,1.820,1.823,1.826,1.830,1.834,1.838,1.842,
1.847,1.852,1.857,1.861,1.866,1.871,1.876,1.881,1.886,1.891,1.896,1.901,
1.906,1.911,1.916,1.920,1.925,1.930,1.934,1.939,1.944,1.948,1.953,1.957,
1.999,2.037,2.071,2.130$
   2                                                                    I=2 TO CALL GDATA
$GDAT DU=1000.,RU=5000.,IG=1,NT=500$                                    NAMELIST GDAT
   3                                                                    I=3 TO CALL GEO
$SORCE ISO=1,IS1=2,FAC=.4,E1=1500.,E2=2000.$                            NAMELIST SORCE
   7                                                                    I=7 TO TERMINATE RUN
```

SAMPLE PROBLEM CARD INPUT FOR PROTOS

```
   6
  ATMOSPHERIC CALCULATION   TEST CASE
   1
$PDAT EO=400.00,RO=1.000,N=80,M=50,ES=1.000,KE=2,ZE=7.2,CF=-5.,
UNIF=.3,RAN=.3,AV=14.4,EN(1)=2.0,4.0,6.0,8.0,10.0,14.0,18.0,22.0,26.0,
30.0,34.0,38.0,42.0,46.0,50.0,50.0,70.0,80.0,90.0,100.0,110.0,120.0,
130.0,140.0,150.0,160.0,170.0,180.0,190.0,200.0,220.0,240.0,260.0,
280.0,300.0,320.0,340.0,360.0,380.0,400.0,420.0,440.0,460.0,480.0,
500.0,520.0,540.0,560.0,580.0,600.0,620.0,640.0,660.0,680.0,700.0,
720.0,740.0,760.0,780.0,800.0,820.0,840.0,860.0,880.0,900.0,920.0,
940.0,960.0,980.0,1000.0,1200.0,1400.0,1600.0,2000.0,2400.0,2800.0,
3200.0,3600.0,4000.0,5000.0,DES(1)=1.417E+02,8.416E+01,6.022E+01,
4.727E+01,3.9920E+01,3.049E+01,2.491E+01,2.118E+01,1.851E+01,1.650E01,
1.492E01,1.364E01,1.259E01,1.171E01,1.097E01,9.500,8.428,7.608,6.959,
6.432,5.997,5.629,5.316,5.054,4.809,4.601,4.417,4.252,4.104,3.970,
3.738,3.543,3.378,3.237,3.113,3.006,2.911,2.826,2.751,2.683,2.622,
2.567,2.516,2.471,2.428,2.390,2.354,2.322,2.291,2.263,2.237,2.213,
2.190,2.169,2.149,2.130,2.113,2.097,2.081,2.067,2.053,2.041,2.029,
2.017,2.006,1.996,1.987,1.978,1.969,1.961,1.899,1.861,1.839,1.819,
1.816,1.822,1.833,1.846,1.860,1.897$
   2
$GDAT DJ=1000.,RU=5000.,IG=1,WHT=.5,NT=0$
   3
$SORCE ISO=3$
   7
```

CARD REFERENCE

I=6 FOR HEADING
HEADING
I=1 TO CALL PDATA
NAMELIST PDAT

I=2 TO CALL GDATA
NAMELIST GDAT
I=3 TO CALL GEO
NAMELIST SORCE
I=7 TO TERMINATE RUN

```
      SAMPLE PROBLEM CARD INPUT FOR SUPER B                                  CARD REFERENCE

 $INPU EMIN=.09,DU=1000.,RU=5000.,IG=1,IRAN=.5,E1=1500.,E2=2000.,WHT=.5,      NAMELIST INPU
 ETH=.0025,PAAS=.07104,ALTH=10.898,NRECPT=50$


      SAMPLE PROBLEM CARD INPUT FOR STAT                                     CARD REFERENCE

    4    2    3    1    1    1     107021                                    CARD SET A
1001     4    2                                                              CARD SET B
  5000.      5000.    1000.                                                  CARD SET C
   .05     0.        20.       0.        50.        0.        100.      0.   CARD SET D
THEP     2  0.       45.                                                     CARD SET E
F      140   0.        5.
    2THEP E                                                                  CARD SET F
    1THEP
    1F
  1500.       2000.                                                          CARD SET G
```

```
07/02/70   LRC CM SCOPE 3.0  65000-131K 06/02/70
15.26.19.DAP0474.          -  0702  1515
15.26.19.                      LRC COMPUTER COMPLEX
15.26.19.JOB,1.100.45000.           R0000,90105,2.
15.26.19.J. LAMBIOTTE              RM 2054
15.26.20.RUN(S)
15.26.27.LGO.
15.26.41.MEMORY  012600 CM
15.26.43.EXIT
15.26.44.SPPRINT(OUTPUT,5)
15.26.48.CPU      0.919780 SEC.
15.26.48.PPU     29.249536 SEC.
15.26.48.DATE      07/02/70
17.06.16. DAP0474.     409 LINES PRINTED. LP21
```

TWOGEV SAMPLE PROBLEM OUTPUT

NEW PHYSICAL DATA

EO= 2000.0 RO= 1.00 NUMBER OF STEPS= 50 Z= 7 CF=-5.00 E CUT OFF=400.0 AKK= 1.100 AVO= 4.18264E+22

Z= 8 A= 1.00 AIR TEXT ON DATATAPE

* * * * *
INFORMATION FOR CALCULATIONS OF STOPPING POWER
Z= 7.2000 A= 14.4000

ENERGY SCALE FOR STOPPING POWER

2.0000E+00	4.0000E+00	6.0000E+00	8.0000E+00	1.0000E+01	1.4000E+01	1.8000E+01
2.2000E+01	2.6000E+01	3.0000E+01	3.4000E+01	3.8000E+01	4.2000E+01	4.6000E+01
5.0000E+01	6.0000E+01	7.0000E+01	8.0000E+01	9.0000E+01	1.0000E+02	1.1000E+02
1.2000E+02	1.3000E+02	1.4000E+02	1.5000E+02	1.6000E+02	1.7000E+02	1.8000E+02
1.9000E+02	2.0000E+02	2.2000E+02	2.4000E+02	2.6000E+02	2.8000E+02	3.0000E+02
3.2000E+02	3.4000E+02	3.6000E+02	3.8000E+02	4.0000E+02	4.2000E+02	4.4000E+02
4.6000E+02	4.8000E+02	5.0000E+02	5.2000E+02	5.4000E+02	5.6000E+02	5.8000E+02
6.0000E+02	6.2000E+02	6.4000E+02	6.6000E+02	6.8000E+02	7.0000E+02	7.2000E+02
7.4000E+02	7.6000E+02	7.8000E+02	8.0000E+02	8.2000E+02	8.4000E+02	8.6000E+02
8.8000E+02	9.0000E+02	9.2000E+02	9.4000E+02	9.6000E+02	9.8000E+02	1.0000E+03
1.2000E+03	1.4000E+03	1.6000E+03	2.0000E+03			

STOPPING POWER

1.4170E+02	8.4160E+01	6.0220E+01	4.7270E+01	3.9920E+01	3.0490E+01	2.4910E+01
2.1180E+01	1.8510E+01	1.6500E+01	1.4920E+01	1.3640E+01	1.2590E+01	1.1710E+01
1.0970E+01	9.5000E+00	8.4280E+00	7.6080E+00	6.9590E+00	6.4320E+00	5.9970E+00
5.6290E+00	5.3160E+00	5.0540E+00	4.8090E+00	4.6010E+00	4.4170E+00	4.2520E+00
4.1040E+00	3.9700E+00	3.7380E+00	3.5430E+00	3.3780E+00	3.2370E+00	3.1130E+00
3.0060E+00	2.9110E+00	2.8260E+00	2.7510E+00	2.6830E+00	2.6220E+00	2.5670E+00
2.5160E+00	2.4710E+00	2.4280E+00	2.3900E+00	2.3540E+00	2.3220E+00	2.2910E+00
2.2630E+00	2.2370E+00	2.2130E+00	2.1900E+00	2.1690E+00	2.1490E+00	2.1300E+00
2.1130E+00	2.0970E+00	2.0810E+00	2.0670E+00	2.0530E+00	2.0410E+00	2.0290E+00
2.0170E+00	2.0060E+00	1.9960E+00	1.9870E+00	1.9780E+00	1.9690E+00	1.9610E+00
1.8990E+00	1.8610E+00	1.8390E+00	1.8190E+00			

EK	DS	PRO
2.0000E+03	0.	0.
1.9673E+03	1.7949E+01	1.5792E+00
1.9347E+03	1.7943E+01	1.5625E+00
1.9020E+03	1.7935E+01	1.5456E+00
1.8694E+03	1.7926E+01	1.5284E+00
1.8367E+03	1.7914E+01	1.5111E+00
1.8041E+03	1.7900E+01	1.4935E+00
1.7714E+03	1.7885E+01	1.4758E+00
1.7388E+03	1.7867E+01	1.4578E+00
1.7061E+03	1.7847E+01	1.4398E+00
1.6735E+03	1.7826E+01	1.4215E+00
1.6408E+03	1.7802E+01	1.4031E+00
1.6082E+03	1.7776E+01	1.3845E+00
1.5755E+03	1.7749E+01	1.3658E+00
1.5429E+03	1.7719E+01	1.3470E+00
1.5102E+03	1.7687E+01	1.3280E+00
1.4776E+03	1.7654E+01	1.3089E+00
1.4449E+03	1.7618E+01	1.2898E+00
1.4122E+03	1.7580E+01	1.2705E+00
1.3796E+03	1.7540E+01	1.2511E+00
1.3469E+03	1.7492E+01	1.2310E+00
1.3143E+03	1.7440E+01	1.2106E+00
1.2816E+03	1.7384E+01	1.1901E+00
1.2490E+03	1.7325E+01	1.1693E+00
1.2163E+03	1.7262E+01	1.1484E+00
1.1837E+03	1.7194E+01	1.1272E+00
1.1510E+03	1.7119E+01	1.1056E+00
1.1184E+03	1.7038E+01	1.0836E+00
1.0857E+03	1.6952E+01	1.0614E+00
1.0531E+03	1.6861E+01	1.0390E+00
1.0204E+03	1.6765E+01	1.0164E+00
9.8776E+02	1.6664E+01	9.9369E-01
9.5510E+02	1.6551E+01	9.7030E-01
9.2245E+02	1.6429E+01	9.4638E-01
8.8980E+02	1.6303E+01	9.2252E-01
8.5714E+02	1.6158E+01	8.9750E-01
8.2449E+02	1.6003E+01	8.7208E-01
7.9184E+02	1.5842E+01	8.4670E-01
7.5918E+02	1.5663E+01	8.2041E-01
7.2653E+02	1.5470E+01	7.9348E-01
6.9388E+02	1.5264E+01	7.6625E-01
6.6122E+02	1.5037E+01	7.3804E-01
6.2857E+02	1.4793E+01	7.0938E-01
5.9592E+02	1.4522E+01	6.8016E-01
5.6327E+02	1.4247E+01	6.5017E-01
5.3061E+02	1.3937E+01	6.1931E-01
4.9796E+02	1.3602E+01	5.8777E-01
4.6531E+02	1.3234E+01	5.5525E-01
4.3265E+02	1.2836E+01	5.2198E-01
4.0000E+02	1.2401E+01	4.8769E-01

THE PION DATA IS AS FOLLOWS

NEW PHYSICAL DATA

EO= 2000.0 RO= 1.00 NUMBER OF STEPS= 50 Z= 0 CF= 0.00 E CUT OFF= 2.0 AKK= 0.000 AVO= 0.

EK	DS	PRO
2.0000E+03	0.	0.
1.9592E+03	1.9168E+01	0.
1.9184E+03	1.9217E+01	0.
1.8777E+03	1.9268E+01	0.
1.8369E+03	1.9321E+01	0.
1.7961E+03	1.9375E+01	0.
1.7553E+03	1.9431E+01	0.
1.7146E+03	1.9488E+01	0.
1.6738E+03	1.9547E+01	0.
1.6330E+03	1.9607E+01	0.
1.5922E+03	1.9669E+01	0.
1.5515E+03	1.9732E+01	0.
1.5107E+03	1.9796E+01	0.
1.4699E+03	1.9863E+01	0.
1.4291E+03	1.9931E+01	0.
1.3884E+03	2.0002E+01	0.
1.3476E+03	2.0075E+01	0.
1.3068E+03	2.0150E+01	0.
1.2660E+03	2.0227E+01	0.
1.2253E+03	2.0306E+01	0.
1.1845E+03	2.0388E+01	0.
1.1437E+03	2.0478E+01	0.
1.1029E+03	2.0568E+01	0.
1.0622E+03	2.0657E+01	0.
1.0214E+03	2.0746E+01	0.
9.8061E+02	2.0833E+01	0.
9.3984E+02	2.0929E+01	0.
8.9906E+02	2.1031E+01	0.
8.5829E+02	2.1133E+01	0.
8.1751E+02	2.1240E+01	0.
7.7673E+02	2.1345E+01	0.
7.3596E+02	2.1460E+01	0.
6.9518E+02	2.1576E+01	0.
6.5441E+02	2.1693E+01	0.
6.1363E+02	2.1811E+01	0.
5.7286E+02	2.1926E+01	0.
5.3208E+02	2.2039E+01	0.
4.9131E+02	2.2156E+01	0.
4.5053E+02	2.2255E+01	0.
4.0976E+02	2.2348E+01	0.
3.6898E+02	2.2417E+01	0.
3.2820E+02	2.2453E+01	0.
2.8743E+02	2.2437E+01	0.
2.4665E+02	2.2329E+01	0.
2.0588E+02	2.2073E+01	0.
1.6510E+02	2.1579E+01	0.
1.2433E+02	2.0642E+01	0.
8.3551E+01	1.8899E+01	0.
4.2776E+01	1.5483E+01	0.
2.0000E+00	8.0401E+00	0.

```
      GDATA
LENGTH=  1000.000
MAX NUMBER OF STARTED PARTICLES=       500
HALF SQUARE SIDE=   5000.00

  ATMOSPHERIC CALCULATION  500 PARTICLES ISOTROPIC

BEGIN M.C. AT  06/25/69  17.36.54.

STARTING RANDOM NUMBERS
GAUSSIAN        .3000
UNIFORM         .3000

  SOURCE ENERGY INTERVAL IS   1500.0  2000.0

  PERCENTAGE OF NEUTRONS IN SOURCE SPECTRUM IS   40.00

  INITIAL NEUTR.  199 PROT.   301
  STARTING WITH  500 PARTICLES ON RANGE .4GEV TO 2GEV

NGEN  COLL     P     N     PI+   PIO   PI-

  1    499    301   199     0     0     0

  2    542   1670  1728   235   240   229

  3    407   1543  1603   114   136   124

  4    243   1052  1102    70    69    75

  5    106    584   651    21    30    42

  6     42    259   259     8    12    14

  7     10    100    99     1     1     3

  8      3     27    29     1     0     1

  9      0      7    11     0     0     1

END M.C. AT 06/25/69  17.42.05.
NO. OF LOW NEUTRONS AND PROTONS IS       9063
 NO. OF PROTONS SLOWED TO  400.0 MEV IS   255

 END OF RUN. NO. OF RECORDS IS    25219
```

```
06/25/69   LRC CM SCOPE 3.0  6600C-131K C4/16/69
17.31.16.DAP5456.          -  0625  1504
17.31.16.                      LRC COMPUTER COMPLEX
17.31.16.JOB,1,400,72000.           R0000,31671,3.
17.31.16.JAY J. LAMBIOTTE,          RM 2054
17.31.16.RUN(S)
17.31.47.ROLLOUT WAITING ON ALL QUIET
17.31.48.ROLLOUT INITIATED.
17.31.50.ROLLOUT COMPLETED.
17.32.48.ROLLIN INITIATED.
17.33.02.ROLLIN COMPLETED.
17.33.02.REQUEST DUMM2,HY. 212054.ROL,JJL,MC 2GEV
17.33.02. AFR
17.33.02. (65 ASSIGNED)
17.33.02.COPYBF(DUMM2,TAPE9,1)
17.33.06.REWIND (TAPE9)
17.33.07.DROPFIL(DUMM2)
17.33.10. RELEASED DUMM2
17.33.14.ROLLOUT WAITING ON ALL QUIET
17.33.14.ROLLOUT INITIATED.
17.33.16.ROLLOUT COMPLETED.
17.34.56.ROLLIN INITIATED.
17.36.11.ROLLIN COMPLETED.
17.36.12.REQUEST TAPE4,HY. 509011,RIL,JJL,TWOGEV
17.36.12.TEST CASE2
17.36.12. (61 ASSIGNED)
17.36.12.LGO.
17.36.46.MEMORY  065100 CM
17.42.05.STOP
17.42.05.SPPRINT(OUTPUT,5)
17.42.07.UNLOAD(TAPE4)
17.42.13.CPU    112.691689 SEC.
17.42.13.PPU    224.813056 SEC.
17.42.13.DATE      06/25/69
18.39.35. DAP5456. PRINT-PP C2032 LINES,LP 25
```

PROTOS SAMPLE PROBLEM OUTPUT

```
     6
     1

        NEW PHYSICAL DATA

EC=400.0    RO= 1.00    NUMBER OF STEPS=   50    Z=    7    CF=-5.00    E CUT OFF=  1.0  AKK= 1.100 AVO=     4.18264E+22

Z= AIR  A=      1.00   AIR   TEXT ON DATATAPE
    4.93207E+01     6.06921E+01     7.78584E+01     8.71307E+01     9.16129E+01     9.45528E+01     9.70800E+01     9.74861E+01
    9.13128E+01     4.89784E+01     6.05218E+01     7.84452E+01     8.82820E+01     9.25465E+01     9.45072E+01     9.58378E+01
    9.59079E+01     9.17556E+01


* * * * *
INFORMATION FOR CALCULATIONS OF STOPPING POWER
 Z=    7.2000  A=   14.4000

ENERGY SCALE FOR STOPPING POWER

 2.0000E+00  4.0000E+00  6.0000E+00  8.0000E+00  1.0000E+01  1.4000E+01  1.8000E+01
 2.2000E+01  2.6000E+01  3.0000E+01  3.4000E+01  3.8000E+01  4.2000E+01  4.6000E+01
 5.0000E+01  6.0000E+01  7.0000E+01  8.0000E+01  9.0000E+01  1.0000E+02  1.1000E+02
 1.2000E+02  1.3000E+02  1.4000E+02  1.5000E+02  1.6000E+02  1.7000E+02  1.8000E+02
 1.9000E+02  2.0000E+02  2.2000E+02  2.4000E+02  2.6000E+02  2.8000E+02  3.0000E+02
 3.2000E+02  3.4000E+02  3.6000E+02  3.8000E+02  4.0000E+02  4.2000E+02  4.4000E+02
 4.6000E+02  4.8000E+02  5.0000E+02  5.2000E+02  5.4000E+02  5.6000E+02  5.8000E+02
 6.0000E+02  6.2000E+02  6.4000E+02  6.6000E+02  6.8000E+02  7.0000E+02  7.2000E+02
 7.4000E+02  7.6000E+02  7.8000E+02  8.0000E+02  8.2000E+02  8.4000E+02  8.6000E+02
 8.8000E+02  9.0000E+02  9.2000E+02  9.4000E+02  9.6000E+02  9.8000E+02  1.0000E+03
 1.2000E+03  1.4000E+03  1.6000E+03  2.0000E+03  2.4000E+03  2.8000E+03  3.2000E+03
 3.6000E+03  4.0000E+03  5.0000E+03

STOPPING POWER

 1.4170E+02  8.4160E+01  6.0220E+01  4.7270E+01  3.9920E+01  3.0490E+01  2.4910E+01
 2.1180E+01  1.8510E+01  1.6500E+01  1.4920E+01  1.3640E+01  1.2590E+01  1.1710E+01
 1.0970E+01  9.5000E+00  8.4280E+00  7.6080E+00  6.9590E+00  6.4320E+00  5.9970E+00
 5.6290E+00  5.3160E+00  5.0540E+00  4.8090E+00  4.6010E+00  4.4170E+00  4.2520E+00
 4.1040E+00  3.9700E+00  3.7380E+00  3.5430E+00  3.3780E+00  3.2370E+00  3.1130E+00
 3.0060E+00  2.9110E+00  2.8260E+00  2.7510E+00  2.6830E+00  2.6220E+00  2.5670E+00
 2.5160E+00  2.4710E+00  2.4280E+00  2.3900E+00  2.3540E+00  2.3220E+00  2.2910E+00
 2.2630E+00  2.2370E+00  2.2130E+00  2.1900E+00  2.1690E+00  2.1490E+00  2.1300E+00
 2.1130E+00  2.0970E+00  2.0810E+00  2.0670E+00  2.0530E+00  2.0410E+00  2.0290E+00
 2.0170E+00  2.0060E+00  1.9960E+00  1.9870E+00  1.9780E+00  1.9690E+00  1.9610E+00
 1.8990E+00  1.8610E+00  1.8390E+00  1.8190E+00  1.8160E+00  1.8220E+00  1.8330E+00
 1.8460E+00  1.8600E+00  1.8970E+00
```

EK	DS	PRO
4.0000E+02	0.	0.
3.9186E+02	3.0200E+00	2.3259E-01
3.8371E+02	2.9897E+00	2.2815E-01
3.7557E+02	2.9586E+00	2.2369E-01
3.6743E+02	2.9270E+00	2.1922E-01
3.5929E+02	2.8948E+00	2.1473E-01
3.5114E+02	2.8617E+00	2.1019E-01
3.4300E+02	2.8276E+00	2.0560E-01
3.3486E+02	2.7926E+00	2.0096E-01
3.2671E+02	2.7570E+00	1.9632E-01
3.1857E+02	2.7208E+00	1.9166E-01
3.1043E+02	2.6837E+00	1.8698E-01
3.0229E+02	2.6458E+00	1.8228E-01
2.9414E+02	2.6070E+00	1.7754E-01
2.8600E+02	2.5669E+00	1.7273E-01
2.7786E+02	2.5255E+00	1.6787E-01
2.6971E+02	2.4834E+00	1.6301E-01
2.6157E+02	2.4406E+00	1.5815E-01
2.5343E+02	2.3969E+00	1.5327E-01
2.4529E+02	2.3517E+00	1.4833E-01
2.3714E+02	2.3053E+00	1.4336E-01
2.2900E+02	2.2576E+00	1.3835E-01
2.2086E+02	2.2086E+00	1.3330E-01
2.1271E+02	2.1584E+00	1.2824E-01
2.0457E+02	2.1070E+00	1.2316E-01
1.9643E+02	2.0543E+00	1.1807E-01
1.8829E+02	2.0001E+00	1.1295E-01
1.8014E+02	1.9444E+00	1.0780E-01
1.7200E+02	1.8872E+00	1.0265E-01
1.6386E+02	1.8284E+00	9.7470E-02
1.5571E+02	1.7681E+00	9.2296E-02
1.4757E+02	1.7059E+00	8.7097E-02
1.3943E+02	1.6404E+00	8.1781E-02
1.3129E+02	1.5740E+00	7.6541E-02
1.2314E+02	1.5084E+00	7.1500E-02
1.1500E+02	1.4385E+00	6.6302E-02
1.0686E+02	1.3661E+00	6.1106E-02
9.8714E+01	1.2918E+00	5.5949E-02
9.0571E+01	1.2150E+00	5.0822E-02
8.2429E+01	1.1355E+00	4.5724E-02
7.4286E+01	1.0534E+00	4.0684E-02
6.6143E+01	9.6829E-01	3.5709E-02
5.8000E+01	8.7998E-01	3.0814E-02
4.9857E+01	7.8794E-01	2.6008E-02
4.1714E+01	6.9247E-01	2.1350E-02
3.3571E+01	5.9221E-01	1.6835E-02
2.5429E+01	4.8664E-01	1.2516E-02
1.7286E+01	3.7497E-01	8.4776E-03
9.1429E+00	2.5435E-01	4.8023E-03
1.0000E+00	1.1661E-01	1.7279E-03

2

```
      GDATA

LENGTH=  1000.000

MAX NUMBER OF STARTED PARTICLES=          0

HALF SQUARE SIDE=   5000.00
   3
   ATMOSPHERIC CALCULATION   TEST CASE
BEGIN M.C. AT  06/26/69  19.38.42.

STARTING RANDOM NUMBERS
GAUSSIAN        .3000
UNIFORM         .3000

 SOURCE PARTICLES FROM BIOGRAPHY TAPE

 SPLIT  2-1 ON FIRST NUCLEAR INTERACTION

 GEN  COLL      P      N

  1       0       0      0

  2    1490    1394   1430

  3    2591    3096   3675

  4    2965    4001   5037

  5    2751    3818   5205

  6    2082    3112   4543

  7    1330    2229   3240

  8     718    1258   2023

  9     366     644   1078

 10     167     313    530

 11      66     145    242

 12      26      47     96

 13      11      21     37

 14       3       6     15

 15       2       1      3

 16       0       1      2

END M.C. AT 06/26/69  19.51.49.

NUMBER OF LOW NEUTRONS IS      15809

 END OF RUN. NO. OF RECORDS IS   182333
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06/26/69   LRC CM SCOPE 3.0  6600B--65K 04/16/69
19.08.09.CAP5577.          -  0626  1455
19.08.09.                      LRC COMPUTER COMPLEX
19.08.09.JCB.1.2000.63000.           R0000.31671.2.
19.08.09.JAY J. LAMBIOTTE.          RM 2054
19.08.09.RUN(S)
19.08.27.LINECNT(10000)
19.08.29.ROLLOUT WAITING ON ALL QUIET
19.08.30.ROLLOUT INITIATED.
19.08.31.ROLLOUT COMPLETED.
19.14.55.ROLLIN INITIATED.
19.14.56.ROLLIN COMPLETED.
19.14.56.REQUEST DUMM2.HY. 1202019.ROL.JJL.MC DAT
19.14.56.A AIR
19.14.56. (67 ASSIGNED)
19.14.57.COPYBF(DUMM2.TAPE9.1)
19.14.59.REWIND (TAPE9)
19.15.00.CROPFIL(DUMM2)
19.15.02. RELEASED DUMM2
19.15.02.SETINDF.
19.15.04.ROLLOUT WAITING ON ALL QUIET
19.15.05.ROLLOUT INITIATED.
19.15.07.ROLLOUT COMPLETED.
19.18.43.ROLLIN INITIATED.
19.18.45.ROLLIN COMPLETED.
19.18.45.REQUEST TAPE7.HY. 509011.ROL.JJL.TWOGEV
19.18.45.TEST CASE
19.18.45. (67 ASSIGNED)
19.18.49.ROLLOUT WAITING ON ALL QUIET
19.18.50.ROLLOUT INITIATED.
19.18.51.ROLLOUT COMPLETED.
19.22.51. ** 211050 **.
19.26.06.ROLLIN INITIATED.
19.26.08.ROLLIN COMPLETED.
19.26.11.
19.38.21.REQUEST TAPE4.HY. SAVTP .RIL.JJL.PROT TE
19.38.22.ST CASE2
19.38.22. (64 ASSIGNED)
19.38.22.LGO.
19.38.39.MEMORY  056000 CM
19.39.03.MT 64 WPE RECOVERED.
19.39.23.MT 64 WPE RECOVERED.
19.39.47.MT 64 WPE RECOVERED.
19.41.10.MT 64 WPE RECOVERED.
19.43.10.MT 64 WPE RECOVERED.
19.43.27.MT 64 WPE RECOVERED.
19.51.49.STOP
19.51.50.SPPRINT(OUTPUT.5)
19.51.51.UNLOAD(TAPE4)
19.52.26.UNLOAD(TAPE7)
19.52.27.CPU    591.370217 SEC.
19.52.27.PPU   1083.629568 SEC.
19.52.27.DATE      06/26/69
20.11.01. CAP5577. PRINT-PP 01932 LINES.LP 21
```

SUPER B SAMPLE PROBLEM OUTPUT

LOW NEUTRONS

EMIN .090 DU 1000.000 RU 5000.000 IG 1

ETH 2.5000E-03 PAAS 7.1040E-02 ALTH 1.0898E+01

INC. ENERGY INTERVAL IS 1500.000 2000.000 WHT IS .50

RANDOM START= .50000

X	Y	Z	THETA	PHI	E	IK	SOURCE	WT	GEN
0.	0.	0.	2.3861E+01	-1.8401E+01	1.6000E+03	4	1	1.000	1
5.5432E+00	-1.8668E+00	1.2960E+01	2.4213E+01	-1.8710E+01	1.5755E+03	1	1	1.000	1
1.2896E+01	-4.4084E+00	3.0341E+01	2.4188E+01	-1.9270E+01	1.5429E+03	1	1	1.000	1
1.6778E+01	-5.7288E+00	3.9400E+01	2.4311E+01	-1.8144E+01	1.5254E+03	1	1	1.000	1
1.6778E+01	-5.7288E+00	3.9400E+01	2.4311E+01	-1.8144E+01	1.5254E+03	3	1	1.000	1
1.6778E+01	-5.7288E+00	3.9400E+01	1.2354E+02	7.6609E+01	6.9877E+01	-14	1	1.000	2
1.8765E+01	2.6152E+00	3.3713E+01	1.2354E+02	7.6609E+01	4.2775E+01	-11	1	1.000	2
2.0317E+01	9.1340E+00	2.9270E+01	1.2354E+02	7.6609E+01	2.0000E+00	-11	1	1.000	2
1.6778E+01	-5.7288E+00	3.9400E+01	3.1877E+01	7.2714E+01	1.5305E+02	0	1	1.000	2
1.6778E+01	-5.7288E+00	3.9400E+01	2.1429E+01	-5.7294E+01	1.3207E+02	14	1	1.000	2
1.7552E+01	-6.9337E+00	4.3048E+01	2.1429E+01	-5.7294E+01	1.2433E+02	11	1	1.000	2
2.1283E+01	-1.2744E+01	6.0641E+01	2.1429E+01	-5.7294E+01	8.3551E+01	11	1	1.000	2
2.4340E+01	-1.7504E+01	7.5054E+01	2.1429E+01	-5.7294E+01	4.2775E+01	11	1	1.000	2
2.5927E+01	-1.9976E+01	8.2538E+01	2.1429E+01	-5.7294E+01	2.0000E+00	11	1	1.000	2
1.6778E+01	-5.7288E+00	3.9400E+01	9.1867E+01	6.8147E+01	2.1785E+01	-4	1	1.000	2
4.6104E+01	6.7396E+01	3.6831E+01	9.1867E+01	6.8147E+01	2.1785E+01	-1	1	1.000	2
4.6104E+01	6.7396E+01	3.6831E+01	9.1867E+01	6.8147E+01	2.1785E+01	-3	1	1.000	2
4.6104E+01	6.7396E+01	3.6831E+01	9.7754E+01	9.9798E+01	1.8427E+01	-4	1	.500	3
1.9520E+01	2.2133E+02	1.5560E+01	9.7754E+01	9.9798E+01	1.8427E+01	-1	1	.500	3
1.9520E+01	2.2133E+02	1.5560E+01	9.7754E+01	9.9798E+01	1.8427E+01	-3	1	.500	3
1.9520E+01	2.2133E+02	1.5560E+01	1.0843E+02	-1.5893E+02	1.176CE+00	4	1	.500	4
1.9518E+01	2.2132E+02	1.5559E+01	1.1354E+02	-1.6371E+02	1.0000E+00	1	1	.500	4
4.6104E+01	6.7396E+01	3.6831E+01	7.6090E+01	6.9852E+01	1.6410E+01	-4	1	1.000	3
4.7716E+01	7.1788E+01	3.7990E+01	7.6090E+01	6.9852E+01	1.6410E+01	-1	1	1.000	3
4.7716E+01	7.1788E+01	3.7990E+01	7.6090E+01	6.9852E+01	1.6410E+01	-3	1	1.000	3
4.7716E+01	7.1788E+01	3.7990E+01	8.1742E+01	6.9793E+01	1.6399E+01	-4	1	1.000	3
5.0855E+01	8.0316E+01	3.9309E+01	8.1742E+01	6.9793E+01	1.6399E+01	-1	1	1.000	3
5.0855E+01	8.0316E+01	3.9309E+01	8.1742E+01	6.9793E+01	1.6399E+01	-3	1	1.000	3
5.0855E+01	8.0316E+01	3.9309E+01	1.0719E+02	6.5582E+01	4.4907E+00	-4	1	1.000	3
5.8663E+01	9.7514E+01	3.3464E+01	1.0719E+02	6.5582E+01	4.4907E+00	-1	1	1.000	3
5.8663E+01	9.7514E+01	3.3464E+01	1.0719E+02	6.5582E+01	4.4907E+00	-3	1	1.000	3
5.8663E+01	9.7514E+01	3.3464E+01	1.4525E+02	2.2456E+01	4.2657E+00	-4	1	1.000	3
6.7675E+01	1.0124E+02	1.9408E+01	1.4525E+02	2.2456E+01	4.2657E+00	-1	1	1.000	3
6.7675E+01	1.0124E+02	1.9408E+01	1.4525E+02	2.2456E+01	4.2657E+00	-3	1	1.000	3
6.7675E+01	1.0124E+02	1.9408E+01	1.6331E+02	-1.4702E+02	4.0708E+00	-4	1	1.000	3
5.9101E+01	9.5676E+01	-1.4679E+01	1.6331E+02	-1.4702E+02	4.0708E+00	-2	1	1.000	3
1.6778E+01	-5.7288E+00	3.9400E+01	3.9889E+01	-3.5162E+01	1.1778E+03	-4	1	1.000	2
4.0528E+01	-2.2459E+01	7.4157E+01	3.9889E+01	-3.5162E+01	1.1778E+03	-1	1	1.000	2
4.0528E+01	-2.2459E+01	7.4157E+01	3.9889E+01	-3.5162E+01	1.1778E+03	-3	1	1.000	2
4.0528E+01	-2.2459E+01	7.4157E+01	8.8604E+01	2.3897E+01	4.7486E+01	14	1	1.000	3
4.2163E+01	-2.1734E+01	7.4201E+01	8.8604E+01	2.3897E+01	4.2775E+01	11	1	1.000	3
4.9512E+01	-1.8478E+01	7.4396E+01	8.8604E+01	2.3897E+01	2.0000E+00	11	1	1.000	3
4.0528E+01	-2.2459E+01	7.4157E+01	4.5658E+01	-4.2576E+01	4.7080E+02	-4	1	1.000	3
5.0397E+01	-3.1526E+01	8.7254E+01	4.5658E+01	-4.2576E+01	4.7080E+02	-1	1	1.000	3
5.0397E+01	-3.1526E+01	8.7254E+01	4.5658E+01	-4.2576E+01	4.7080E+02	-3	1	1.000	3
5.0397E+01	-3.1526E+01	8.7254E+01	6.2621E+01	2.5741E+01	1.6882E+02	-4	1	1.000	4
2.0760E+02	4.4270E+01	1.7763E+02	6.2621E+01	2.5741E+01	1.6882E+02	-1	1	1.000	4
2.0760E+02	4.4270E+01	1.7763E+02	6.2621E+01	2.5741E+01	1.6882E+02	-3	1	1.000	4
2.0760E+02	4.4270E+01	1.7763E+02	1.2997E+02	-1.2551E+02	8.7780E+00	-4	1	1.000	5
2.0541E+02	4.1205E+01	1.7448E+02	1.2997E+02	-1.2551E+02	8.7780E+00	-1	1	1.000	5

END OF RUN, NO. OF RECORDS IS 400701

```
06/27/69   LRC CM SCOPE 3.0  6600D-131K C4/16/69
10.21.03.DAP1603.
10.21.03.                    LRC COMPUTER COMPLEX
10.21.03.JOB,1,600,47000.          R0000,31671,2,
10.21.03.J. LAMBIOTTE            RM 2054
10.21.04.RUN(S)
10.21.18.SETINDF.
10.21.19.LINECNT(10000)
10.22.09.REQUEST TAPP11,HY. 114018,ROL,JJL,NUC DA
10.22.09.TA (400 MEV DOWN)
10.22.09. (55 ASSIGNED)
10.22.10.COPYBF(TAPP11,DIS)
10.22.44.COPYBR(TAPP11,DIS,24)
10.23.23.COPYBR(TAPP11,TAPE10,2)
10.25.01. TAPE 107021.....
10.25.21.REQUEST TAPE3,HY. SAVTP ,RIL,JJL,SB TEST
10.25.21. CASE2
10.25.21. (65 ASSIGNED)
10.26.07.REQUEST TAPE4,HY. 211050,ROL,JJL,PROT TE
10.26.07.ST CASE
10.26.07. (66 ASSIGNED)
10.26.07.LGO.
10.26.21.MEMORY  036500 CM
10.26.27.MT 65 WPE RECOVERED.
10.37.47.MT 65 WPE RECOVERED.
10.37.48.MT 65 WPE RECOVERED.
10.37.50.MT 65 WPE RECOVERED.
10.37.51.MT 65 WPE RECOVERED.
10.37.52.MT 65 WPE RECOVERED.
10.37.53.MT  65  E O T
10.42.04. TAPE 107021 CONT TO 111018.....
10.42.33.
10.44.34.EXIT
10.44.34.EOF ENCOUNTERED BY NAMELIST
10.44.34.SPPRINT(OUTPUT,5)
10.44.35.UNLOAD(TAPE3)
10.44.36.UNLOAD(TAPE4)
10.44.37.CPU    290.765124 SEC.
10.44.37.PPU   1310.113792 SEC.
10.44.37.DATE      06/27/69
11.04.25. DAP1603. PRINT-PP 01300 LINES,LP 26
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STAT SAMPLE PROBLEM OUTPUT

```
  4 PLANES      2 VARIABLES      3 STATISTICS     OPTION 1     WEIGHTING FACTOR  2

STATISTICS REQUESTED FOR NEUTRONS
STATISTICS REQUESTED FOR PI+

  4 BINS/WORD AND 14 BITS/BIN
   THE MAXIMUM VALUE FOR ONE BIN IS       8191.5


       VARIABLES USING
   THEP      E

  NO. LOCATIONS NEEDED PER PLANE IS  140

  4 PLANES USED IN THIS PASS
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                              THE INCIDENT ENERGY INTERVAL FOR THIS CASE IS    1500.00   2000.00

IK=      10000   NO. RECORDS USED=     272993   NO. LOW NEUTRONS=      90613
THE NO. OF TIMES OVERFLOW NOTED IS          0
```

PLANE LOCATED AT Z= 50.00

STATISTIC N(THEP,E ,)
FOR NEUTRONS

VARIABLE	START	DELTA	NO. BINS
THEP	0.00	45.0000	2
E	0.00	5.0000	140

THEP	E													
2	411.0	62.0	30.0	25.5	20.0	12.5	6.5	5.5	6.5	8.0	14.0	10.5	14.5	9.0	6.0
	6.5	8.5	8.5	7.0	4.5	4.0	5.5	3.0	5.0	2.0	6.0	4.5	3.0	6.5	4.0
	1.0	1.0	.5	3.5	4.0	5.0	3.0	2.5	2.0	1.0	4.0	2.5	3.0	4.0	2.5
	7.5	2.0	3.5	3.5	1.0	5.0	2.5	3.0	2.0	2.0	1.5	1.5	1.5	2.5	1.0
	1.0	0.0	1.0	0.0	1.0	1.0	3.5	1.0	0.0	2.0	3.5	1.0	1.0	0.0	1.0
	2.0	1.0	0.0	1.0	1.0	5.0	1.0	0.0	1.0	2.0	0.0	1.0	2.0	1.0	2.0
	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	2.0	0.0	0.0	2.0	0.0	2.0
	4.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	2.0	0.0	0.0	2.0	0.0
	0.0	1.0	0.0	0.0	0.0	1.0	0.0	2.0	0.0	3.0	0.0	0.0	0.0	1.0	1.0
	0.0	0.0	1.0	0.0	0.0										
1	3?6.0	74.0	19.0	14.0	18.5	11.0	9.0	11.5	10.0	5.5	6.5	8.0	2.5	5.5	3.0
	4.0	6.5	7.5	1.0	5.5	3.0	2.0	5.0	6.5	1.0	6.5	2.0	2.0	3.0	4.0
	2.0	2.0	1.0	2.0	1.0	2.5	1.0	0.0	1.5	0.0	1.0	0.0	1.0	0.0	5.5
	2.0	1.5	1.0	0.0	1.0	1.0	1.0	.5	1.0	2.0	1.5	0.0	1.0	0.0	0.0
	1.0	1.0	1.0	1.0	0.0	0.0	1.0	1.0	2.0	1.0	0.0	0.0	0.0	0.0	1.0
	0.0	1.0	0.0	3.0	0.0	1.0	0.0	2.0	0.0	0.0	0.0	2.0	0.0	0.0	1.0
	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	1.0	0.0
	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0

1 LINES DELETED SINCE ALL ZERO

STATISTIC N(THEP,E ,)
FOR PI+

VARIABLE	START	DELTA	NO. BINS
THEP	0.00	45.0000	2
E	0.00	5.0000	140

THEP	E														
2	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	0.0	0.0	2.0	0.0	0.0
	1.0	0.0	2.0	0.0	1.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0	1.0	2.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0
	0.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	2.0	0.0
	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
	1 LINES DELETED SINCE ALL ZERO														
1	0.0	0.0	1.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
	0.0	0.0	1.0	0.0	0.0	0.0	2.0	0.0	0.0	1.0	1.0	0.0	1.0	0.0	0.0
	0.0	0.0	0.0	2.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
	0.0	2.0	0.0	0.0	0.0	0.0	1.0	2.0	1.0	1.0	0.0	1.0	1.0	0.0	0.0
	0.0	1.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
	3 LINES DELETED SINCE ALL ZERO														

PLANE LOCATED AT Z= 50.00

STATISTIC N(THEP,)
FOR NEUTRONS

VARIABLE	START	DELTA	NO. BINS
THEP	0.00	45.0000	2

THEP

717.50 865.50

STATISTIC N(THEP,)
FOR PI+

VARIABLE	START	DELTA	NO. BINS
THEP	0.00	45.0000	2

THEP

31.00 35.00

PLANE LOCATED AT Z= 50.00

STATISTIC N(E ,)
FOR NEUTRONS

VARIABLE	START	DELTA	NO. BINS
E	0.00	5.0000	140

E

807.00	136.00	49.00	39.50	38.50	23.50	15.50	17.00	16.50	13.50	20.50	18.50	17.00	14.50	9.00
10.50	15.00	16.00	8.00	10.00	7.00	7.50	8.00	11.50	3.00	12.50	6.50	5.00	9.50	8.00
3.00	3.00	1.50	5.50	5.00	7.50	4.00	2.50	3.50	1.00	5.00	2.50	4.00	4.00	8.00
9.50	3.50	4.50	3.50	2.00	6.00	3.50	3.50	3.00	4.00	3.00	1.50	2.50	2.50	1.00
2.00	1.00	2.00	1.00	1.00	1.00	4.50	2.00	2.00	3.00	3.50	1.00	1.00	0.00	2.00
2.00	2.00	0.00	4.00	1.00	6.00	1.00	2.00	1.00	2.00	0.00	3.00	2.00	1.00	3.00
1.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	1.00	2.00	0.00	0.00	2.00	0.00	2.00
5.00	0.00	1.00	0.00	2.00	0.00	0.00	0.00	1.00	1.00	2.00	0.00	1.00	3.00	0.00
0.00	2.00	0.00	0.00	0.00	1.00	0.00	3.00	0.00	3.00	0.00	0.00	0.00	2.00	1.00
0.00	0.00	1.00	0.00	0.00										

STATISTIC N(E ,)
FOR PI+

VARIABLE	START	DELTA	NO. BINS
E	0.00	5.0000	140

E

0.00	1.00	2.00	1.00	0.00	0.00	0.00	1.00	1.00	2.00	0.00	0.00	2.00	1.00	0.00
1.00	0.00	3.00	0.00	1.00	0.00	3.00	0.00	0.00	2.00	1.00	0.00	1.00	0.00	0.00
0.00	0.00	0.00	2.00	1.00	1.00	4.00	0.00	0.00	1.00	2.00	0.00	0.00	0.00	1.00
0.00	2.00	0.00	0.00	0.00	0.00	1.00	2.00	1.00	2.00	0.00	1.00	1.00	1.00	0.00
0.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	2.00	0.00
1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
0.00	0.00	0.00	0.00	0.00										

PLANE LOCATED AT Z= 100.00

STATISTIC N(THEP,E ,)
FOR NEUTRONS

VARIABLE	START	DELTA	NO. BINS
THEP	0.00	45.0000	2
E	0.00	5.0000	140

THEP	E													
2	262.0	42.0	25.0	22.0	20.0	15.0	13.0	7.5	3.5	7.5	11.5	10.0	12.5	6.0	7.0
	4.5	6.5	7.5	5.5	6.0	7.0	7.5	5.5	8.5	2.0	5.5	4.5	6.5	6.5	6.0
	.5	3.0	2.0	2.5	4.0	3.5	6.5	.5	4.5	0.0	3.0	4.0	6.0	5.5	2.0
	6.5	2.0	1.5	1.5	1.5	2.0	.5	4.5	1.0	1.5	1.0	1.5	1.0	3.5	1.0
	0.0	1.0	2.5	3.0	0.0	0.0	1.0	3.0	0.0	4.0	1.5	2.0	1.0	0.0	0.0
	1.0	1.0	1.0	0.0	1.0	3.0	1.0	2.0	0.0	1.0	0.0	0.0	2.0	1.0	1.0
	1.0	1.0	2.0	0.0	0.0	1.0	0.0	1.0	2.0	0.0	1.0	0.0	2.0	0.0	3.0
	1.0	0.0	1.0	0.0	1.0	2.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
	0.0	1.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	1.0	0.0	0.0	0.0	1.0	1.0
						1 LINES DELETED SINCE ALL ZERO									
1	334.0	66.0	22.0	16.0	17.0	18.0	10.0	9.0	10.5	6.5	15.0	5.0	7.0	8.0	8.5
	4.0	8.5	8.0	6.5	5.5	8.0	5.5	4.0	3.5	4.0	5.0	3.5	3.5	3.0	4.0
	3.5	6.0	3.5	.5	4.0	3.0	2.0	4.0	2.5	1.5	1.0	1.0	1.0	2.5	3.5
	1.0	2.0	.5	2.5	2.0	1.0	2.5	1.0	0.0	3.0	1.5	1.0	2.0	1.0	0.0
	1.0	1.5	2.0	2.0	1.0	1.0	2.0	1.0	3.0	2.0	0.0	1.0	1.0	0.0	1.0
	1.0	1.0	2.0	3.0	2.0	0.0	0.0	0.0	1.0	1.0	0.0	1.0	0.0	0.0	0.0
	0.0	2.0	0.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0
	1.0	0.0	1.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
	0.0	0.0	0.0	0.0	1.0										

STATISTIC N(THEP,E ,)
FOR PI+

VARIABLE	START	DELTA	NO. BINS
THEP	0.00	45.0000	2
E	0.00	5.0000	140

THEP E

2	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	3.0	0.0	1.0	0.0	0.0
	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0
	1.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
					1 LINES DELETED SINCE ALL ZERO										
1	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	1.0
	0.0	2.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	4.0	2.0	0.0	2.0
	1.0	0.0	0.0	1.0	0.0	0.0	0.0	2.0	1.0	0.0	0.0	0.0	0.0	1.0	2.0
	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	1.0
	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
					2 LINES DELETED SINCE ALL ZERO										
	0.0	0.0	1.0	0.0	0.0										

PLANE LOCATED AT Z= 100.00

STATISTIC N(THEP,)
FOR NEUTRONS

VARIABLE	START	DELTA	NO. BINS
THEP	0.00	45.00C0	2

THEP

737.C0 713.00

STATISTIC N(THEP,)
FOR PI+

VARIABLE	START	DELTA	NO. BINS
THEP	0.00	45.00C0	2

THEP

35.00 29.00

PLANE LOCATED AT Z= 100.00

STATISTIC N(E ,)
FOR NEUTRONS

VARIABLE	START	DELTA	NO. BINS
E	0.00	5.0000	140

E

616.00	108.00	47.00	38.00	37.00	33.00	23.00	16.50	14.00	14.00	26.50	15.00	19.50	14.00	15.50
8.50	15.00	15.50	12.00	11.50	15.00	13.00	9.50	12.00	6.00	10.50	8.00	10.00	9.50	10.00
4.00	9.00	5.50	3.00	8.00	6.50	8.50	4.50	7.00	1.50	4.00	5.00	7.00	8.00	5.50
7.50	4.00	2.00	4.00	3.50	3.00	3.00	5.50	1.00	4.50	2.50	2.50	3.00	4.50	1.00
1.00	2.50	4.50	5.00	1.00	1.00	3.00	4.00	3.00	6.00	1.50	3.00	2.00	0.00	1.00
2.00	2.00	3.00	3.00	3.00	3.00	1.00	2.00	1.00	2.00	0.00	1.00	2.00	1.00	1.00
1.00	3.00	2.00	1.00	0.00	1.00	1.00	2.00	2.00	0.00	1.00	0.00	3.00	1.00	3.00
2.00	0.00	2.00	0.00	3.00	2.00	0.00	1.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00
0.00	2.00	0.00	0.00	0.00	0.00	0.00	3.00	0.00	1.00	0.00	0.00	0.00	2.00	1.00
0.00	0.00	0.00	0.00	1.00										

STATISTIC N(E ,)
FOR PI+

VARIABLE	START	DELTA	NO. BINS
E	0.00	5.0000	140

E

0.00	0.00	0.00	1.00	2.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	2.00
0.00	2.00	1.00	1.00	0.00	0.00	1.00	0.00	1.00	1.00	4.00	4.00	3.00	0.00	2.00
1.00	1.00	0.00	1.00	0.00	1.00	0.00	2.00	1.00	1.00	1.00	0.00	0.00	1.00	2.00
1.00	0.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00
1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	1.00
0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00
1.00	1.00	2.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	1.00	0.00	0.00										

```
06/27/69   LRC CM SCOPE 3.0  66COB--65K 04/16/69
15.55.28.DAP5679.         -  0627  1334
15.55.28.                      LRC COMPUTER COMPLEX
15.55.28.JOB,1,400,65000.           R0000,31671,2,
15.55.28.J. LAMBIOTTE             RM 2054
15.55.29.RUN(S)
15.56.06.ROLLOUT WAITING ON ALL QUIET
15.56.08.ROLLOUT INITIATED.
15.56.09.ROLLOUT COMPLETED.
16.01.04.ROLLIN INITIATED.
16.01.06.ROLLIN COMPLETED.
16.01.06.REQUEST TAPE4,HY.107021,RC,JJL,TEST CASE
16.01.06.
16.01.06. (61 ASSIGNED)
16.01.06.LGC.
16.01.27.MEMORY  C63200 CM
16.06.24.MT  61  E O T
16.09.34.EXIT
16.09.35.SPPRINT(OUTPUT,5)
16.09.36.UNLOAD(TAPE4)
16.09.37.CPU    170.266361 SEC.
16.09.37.PPU    630.407168 SEC.
16.09.37.DATE      06/27/69
20.04.08. DAP5679. PRINT-PP C2437 LINES,LP 25
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RESULTS AND DISCUSSION

The calculations performed by these programs have been compared with other similar calculations and with experimental data. These comparisons differ in two fundamental ways. The calculations with which comparisons are made used the same nuclear interaction data as PROPER 3C, namely, those generated by Bertini; thus the accuracy of the transport calculation itself is checked. The comparison with experimental data is an overall check on both the transport calculation and the nuclear interaction data.

The radiation dose in the atmosphere for a rigidity spectrum with rigidity parameter P_0 of 100 $\frac{MV}{c}$ (where c is speed of light) was calculated by Leimdorfer, Alsmiller, and Boughner (ref. 9) and is compared in figure 5 with the results obtained from PROPER 3C. The absorbed dose (rad) should be used for comparison since the calculation of the biological dose (rem) is model dependent. Further comparisons with results of Armstrong, Alsmiller, and Barish (ref. 10) for the February 1956 solar proton event are shown in figure 6. The upper-limit spectrum for this event was different for the two calculations. Additional details of the results of these comparisons are given in reference 11.

The resultant dose rates in the upper atmosphere at high latitudes due to galactic cosmic rays measured 1 year after solar minimum of cycle 20 are compared with the calculations of PROPER 3C in figure 7. In order to accomplish this calculation, assumptions had to be made for the interaction of the heavy primary particles. Also, the incident spectra are not precisely known (especially for energies less than a few hundred MeV and greater than a few GeV). A detailed discussion of the dose rates and assumptions is given in reference 12.

Although PROPER 3C has been and can be used to obtain useful results, it does have some restrictions which should be restated. Several geometric restrictions of the code may be overcome with modifications. First, the geometry subroutine STATI assumes either a circular or square cross section for the slab. A more complicated geometry subroutine package could be inserted in its place. Second, the code is written for a single homogeneous slab of material as a shield. To include calculations for multilayer composite slabs, it would be necessary to transport all the particles through the first slab and then to use the output biography tape as a source tape on the next slab. This procedure can be accomplished with minor programing changes.

At the time of this publication, the data available for the high-energy portion of the code (program TWOGEV) are not substantial. The data which are available for oxygen and aluminum do not include the pion interaction cross sections. It is planned to update the data library whenever possible. Even though the code does not depend upon the content of the cross-section data, it is highly dependent upon the form in which the data have

been tabulated. This dependence complicates the introduction of data from sources other than those referred to herein.

Finally, several features of the code make it machine dependent (CDC series 6000 computer systems). Nearly all these features are the result of attempts either to reduce core storage requirements or to reduce the number of output biography tapes. To reduce core storage requirements, the FACT array is packed six values to a word for TWOGEV and four values to a word for PROTOS. The packing scheme is highly dependent upon the word length (60 bits) of the CDC computer. STAT also contains word packing with the same dependence. The data to be written on the biography tape are first packed two values to a word by a COMPASS subroutine DPACK and then written on tape by means of a blocking subroutine RECOUT both of which are machine dependent. Subroutines RECIN and UNPACK perform the inverse operations to read the data.

CONCLUDING REMARKS

The PROPER 3C transport code has been successfully used to evaluate the differential spectrum of secondary particles emerging from a large number of materials when these materials are bombarded by energetic nucleons of an arbitrary source configuration The differential spectra after multiplication with appropriate quality factors are integrated to give the radiation dose deposited at any given point in space.

The programs in PROPER 3C are flexible enough to permit many types of radiation transport calculations with little or no modifications by the users. The programs have some limitations, among which are the simplified geometry of the transport medium and the lack of a detailed pion transport. However, both limitations can be removed without much difficulty.

Because of the block structure of the program, one can introduce any degree of geometric complexity by changing subroutine STATI.

The mechanism for pion transport is included in the program but the program does not simulate the transport of pions because the pion-nucleus cross sections are not tabulated.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., January 27, 1971.

APPENDIX A

PROGRAM ABSTRACTS

The following program abstracts give a brief description of the development of each of the respective programs in PROPER 3C. Copies of these abstracts are kept on file. Any communication concerning any of these programs should use the program number (e.g. R2090) as a means of identification.

APPENDIX A

NASA-LANGLEY RESEARCH CENTER

01 3	01 7 PROGRAM NO.	COMPUTER PROGRAM ABSTRACT	01 14 DATE
LAR	R2090		101569

01 20 TITLE OF PROGRAM (61 CHARACTERS MAXIMUM)

Preparation of Monte Carlo Data Tape for R2092

PARENT PROGRAM

02 14 CATEGORY	02 15 SITE	02 18 PROGRAM NO.
K	LAR	R2089

02 26 CATEGORY	02 27 LANGUAGE NO. 1	02 32 LANGUAGE NO. 2	02 37 KEY WORDS (8 MAXIMUM, SEPARATED BY COMMAS)
K	FØR6M		High-Energy Nucleon-Pion Transport, Monte Carlo

WHO TO CONTACT ABOUT THE PROGRAM

05 14 CONTACT	05 28 SITE	05 31 ORGN CODE	05 39 PROJECT NO	05 45 NASA CENTER
J. J. Lambiotte	LAR	11.150	RDP324	

05 48 STATUS

- ☐ A. UNDER DEVELOPMENT
- ☐ B. OPERATIONAL
- ☒ C. COMPLETED

05 49

- ☐ A. THIS PROGRAM IS NOT FOR SHARING

DATES

05 50 INITIATED	05 54 COMPLETED
0668	1069

05 58 REVISION CODE

- ☐ A REVISION
- ☐ B CANCELLATION

TIME AND COST FOR DEVELOPMENT

05 59 MANMONTHS (59 60 61 62 63)	05 64 MACHINE HOURS (64 65 66 67 68)	05 69 COMPUTER TYPE	05 74 TOTAL COST (DOLLARS) (74 75 76 77 78 79 80)
2.	1.	6000	1,0,0,0,.0

ELITE MARGIN | PICA MARGIN

CARD NUMBER	COLUMN 14 ABSTRACT
06	This program is a modification of R2089 and is used to prepare
07	a tape for R2092 which is a transport program requiring
08	nuclear data for pions in addition to neutrons and protons.
09	These data include energies extended to 2000 MeV.
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APPENDIX A

NASA-LANGLEY RESEARCH CENTER

01 4	01 7 PROGRAM NO.	COMPUTER PROGRAM ABSTRACT	01 14 DATE
LAR	R2089		101569

01 20 TITLE OF PROGRAM (61 CHARACTERS MAXIMUM)	PARENT PROGRAM		
Preparation of Monte Carlo Data Tape for R2091	02 14 CATEGORY	02 15 SITE	02 18 PROGRAM NO.
	K	MSC	

02 26 CATEGORY	02 27 LANGUAGE NO. 1	02 32 LANGUAGE NO. 2	02 37 KEY WORDS (8 MAXIMUM, SEPARATED BY COMMAS)
K	FØR6M		Nucleon Transport, Monte Carlo

WHO TO CONTACT ABOUT THE PROGRAM					05 48 STATUS	05 49
05 14 CONTACT	05 28 SITE	05 31 ORGN CODE	05 39 PROJECT NO.	05 45 NASA CENTER		
J. J. Lambiotte	LAR	11.150	RDP324		☐ A. UNDER DEVELOPMENT ☐ B. OPERATIONAL ☒ C. COMPLETED	☐ A. THIS PROGRAM IS NOT FOR SHARING

DATES		05 58 REVISION CODE	TIME AND COST FOR DEVELOPMENT			
05 50 INITIATED	05 54 COMPLETED		05 59 MANMONTHS	05 64 MACHINE HOURS	05 69 COMPUTER TYPE	05 74 TOTAL COST (DOLLARS)
0167	1069	☐ A. REVISION ☐ B. CANCELLATION	.1	.2	6000	200.0

CARD NUMBER	COLUMN 14	ABSTRACT (ELITE MARGIN / PICA MARGIN)
06		This program prepares a Monte Carlo data tape which contains
07		nuclear data for a particular transport medium. The data are
08		for protons and neutrons with energies of 400 MeV (or less).
09		This tape is input to R2091.
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APPENDIX A

NASA-LANGLEY RESEARCH CENTER

01 4	01 7 PROGRAM NO	COMPUTER PROGRAM ABSTRACT	01 14 DATE
LAR	R2092		101569

01 20 TITLE OF PROGRAM (61 CHARACTERS MAXIMUM)	PARENT PROGRAM		
	02 14 CATEGORY	02 15 SITE	02 18 PROGRAM NO.
2000 MeV Monte Carlo Nucleon Transport	K	LRC	R2091

02 26 CATEGORY	02 27 LANGUAGE NO. 1	02 32 LANGUAGE NO. 2	02 37 KEY WORDS (8 MAXIMUM, SEPARATED BY COMMAS)
K	FØR6M	CPS60	Monte Carlo, Nucleon-Pion Transport, High-Energy Transport

WHO TO CONTACT ABOUT THE PROGRAM					05 48 STATUS	05 49
05 14 CONTACT	05 28 SITE	05 31 ORGN CODE	05 39 PROJECT NO.	05 45 NASA CENTER	☐ A. UNDER DEVELOPMENT ☐ B. OPERATIONAL ☒ C. COMPLETED	☐ A. THIS PROGRAM IS NOT FOR SHARING
J. J. Lambiotte	LAR	11.150	RDP324			

DATES		05 58 REVISION CODE	TIME AND COST FOR DEVELOPMENT			
05 50 INITIATED	05 54 COMPLETED		05 59 MANMONTHS	05 64 MACHINE HOURS	05 69 COMPUTER TYPE	05 74 TOTAL COST (DOLLARS)
0668	1069	☐ A REVISION ☐ B CANCELLATION	1.0	1.0	6000	100,000

CARD NUMBER	COLUMN 14	ABSTRACT	ELITE MARGIN / PICA MARGIN
06		Program R2091 has been modified to allow energies up to	
07		2000 MeV and to include the transport of pions. The nucleons	
08		are treated only above 400 MeV. Any particles created or	
09		slowed to below 400 MeV are treated under R2091.	
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APPENDIX A

NASA-LANGLEY RESEARCH CENTER

01 4	01 7 PROGRAM NO.	COMPUTER PROGRAM ABSTRACT	01 14 DATE
LAR	R2091		101569

01 20 TITLE OF PROGRAM (61 CHARACTERS MAXIMUM)	PARENT PROGRAM		
	02 14 CATEGORY	02 15 SITE	02 18 PROGRAM NO.
400 MeV Monte Carlo Nucleon Transport	K	MSC	

02 26 CATEGORY	02 27 LANGUAGE NO. 1	02 32 LANGUAGE NO. 2	02 37 KEY WORDS (8 MAXIMUM, SEPARATED BY COMMAS)
K	FØR6M	CPS60	Monte Carlo, Nucleon Transport, Nuclear Interactions, Electromagnetic Interactions

WHO TO CONTACT ABOUT THE PROGRAM					05 48 STATUS	05 49
05 14 CONTACT	05 28 SITE	05 31 ORGN CODE	05 39 PROJECT NO.	05 45 NASA CENTER	☐ A. UNDER DEVELOPMENT ☐ B. OPERATIONAL ☒ C. COMPLETED	☐ A. THIS PROGRAM IS NOT FOR SHARING
J. J. Lambiotte	LAR	11.150	RDP324			

DATES		05 58 REVISION CODE	TIME AND COST FOR DEVELOPMENT			
05 50 INITIATED	05 54 COMPLETED		05 59 MANMONTHS	05 64 MACHINE HOURS	05 69 COMPUTER TYPE	05 74 TOTAL COST (DOLLARS)
0167	1069	☐ A REVISION ☐ B CANCELLATION	4. (59 60 61 62 63)	2.0 (64 65 66 67 68)	6000	2,000.0 (74 75 76 77 78 79 80)

ELITE MARGIN | PICA MARGIN

CARD NUMBER	COLUMN 14	ABSTRACT
06		This program uses Monte Carlo techniques to simulate the
07		transport of protons in the 0 to 400 MeV range and neutrons
08		in the 18 to 400 MeV range through a slab. The transport
09		characteristics of the nucleons in the slab are input through
10		the tape generated in R2089. Electromagnetic and nuclear
11		interactions are performed. An output history tape of the
12		transport is generated.
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APPENDIX A

NASA-LANGLEY RESEARCH CENTER

01 4	01 7 PROGRAM NO.	COMPUTER PROGRAM ABSTRACT	01 14 DATE
LAR	R2093		101569

01 20 TITLE OF PROGRAM (61 CHARACTERS MAXIMUM)

Monte Carlo Transport of Low Energy Neutrons

PARENT PROGRAM		
02 14 CATEGORY	02 15 SITE	02 18 PROGRAM NO.
K	MSC	

02 26 CATEGORY	02 27 LANGUAGE NO. 1	02 32 LANGUAGE NO. 2	02 37 KEY WORDS (8 MAXIMUM, SEPARATED BY COMMAS)
K	FØR6M	CPS60	Low-Energy Neutron Transport, Monte Carlo

WHO TO CONTACT ABOUT THE PROGRAM

05 14 CONTACT	05 28 SITE	05 31 ORGN CODE	05 39 PROJECT NO.	05 45 NASA CENTER
J. J. Lambiotte	LAR	11.150	RDP324	

05 48 STATUS
- ☐ A. UNDER DEVELOPMENT
- ☐ B. OPERATIONAL
- ☒ C. COMPLETED

05 49
- ☐ A. THIS PROGRAM IS NOT FOR SHARING

DATES		05 58 REVISION CODE	TIME AND COST FOR DEVELOPMENT			
05 50 INITIATED	05 54 COMPLETED		05 59 MANMONTHS	05 64 MACHINE HOURS	05 69 COMPUTER TYPE	05 74 TOTAL COST (DOLLARS)
0167	1069	☐ A REVISION ☐ B CANCELLATION	1.0 (59–63)	.5 (64–68)	6000	5,0,0.0 (74–80)

ELITE MARGIN | PICA MARGIN

CARD NUMBER | COLUMN 14 | ABSTRACT

06 This program uses Monte Carlo techniques to simulate the
07 transport of energy less then 18 MeV. Nuclear data describing
08 (n, 2n), elastic, inelastic, and fission interactions are used
09 by the program. R2093 is the final link in the transport
10 initiated in R2092; it outputs a final history tape which is
11 analyzed by R2094.

12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42

APPENDIX A

NASA-LANGLEY RESEARCH CENTER

01 4	01 7 PROGRAM NO.	COMPUTER PROGRAM ABSTRACT	01 14 DATE
LAR	R2094		101569

01 20 TITLE OF PROGRAM (61 CHARACTERS MAXIMUM)	PARENT PROGRAM		
	02 14 CATEGORY	02 15 SITE	02 18 PROGRAM NO.
Statistical Analysis of a Monte Carlo Transport			

02 26 CATEGORY	02 27 LANGUAGE NO. 1	02 32 LANGUAGE NO. 2	02 37 KEY WORDS (8 MAXIMUM, SEPARATED BY COMMAS)
K	FØR6M	CPS60	Monte Carlo Transport, Particle Flux

WHO TO CONTACT ABOUT THE PROGRAM					05 48 STATUS	05 49
05 14 CONTACT	05 28 SITE	05 31 ORGN CODE	05 39 PROJECT NO.	05 45 NASA CENTER	☐ A. UNDER DEVELOPMENT ☐ B. OPERATIONAL ☒ C. COMPLETED	☐ A. THIS PROGRAM IS NOT FOR SHARING
J. J. Lambiotte	LAR	11.150	RDP324			

DATES		05 58 REVISION CODE	TIME AND COST FOR DEVELOPMENT			
05 50 INITIATED	05 54 COMPLETED		05 59 MANMONTHS	05 64 MACHINE HOURS	05 69 COMPUTER TYPE	05 74 TOTAL COST (DOLLARS)
0967	1069	☐ A. REVISION ☐ B. CANCELLATION	4.0 (59–63)	2.0 (64–68)	6000	2000.0 (74–80)

ELITE MARGIN | PICA MARGIN

CARD NUMBER	COLUMN 14 ABSTRACT
06	This program was written in conjunction with the transport
07	carried out in R2092, R2091, and R2093. It uses the particle
08	histories on the tape generated from the transport to
09	determine the particle density with respect to position,
10	momentum, and/or energy at prescribed depths within the
11	transport medium.
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APPENDIX B

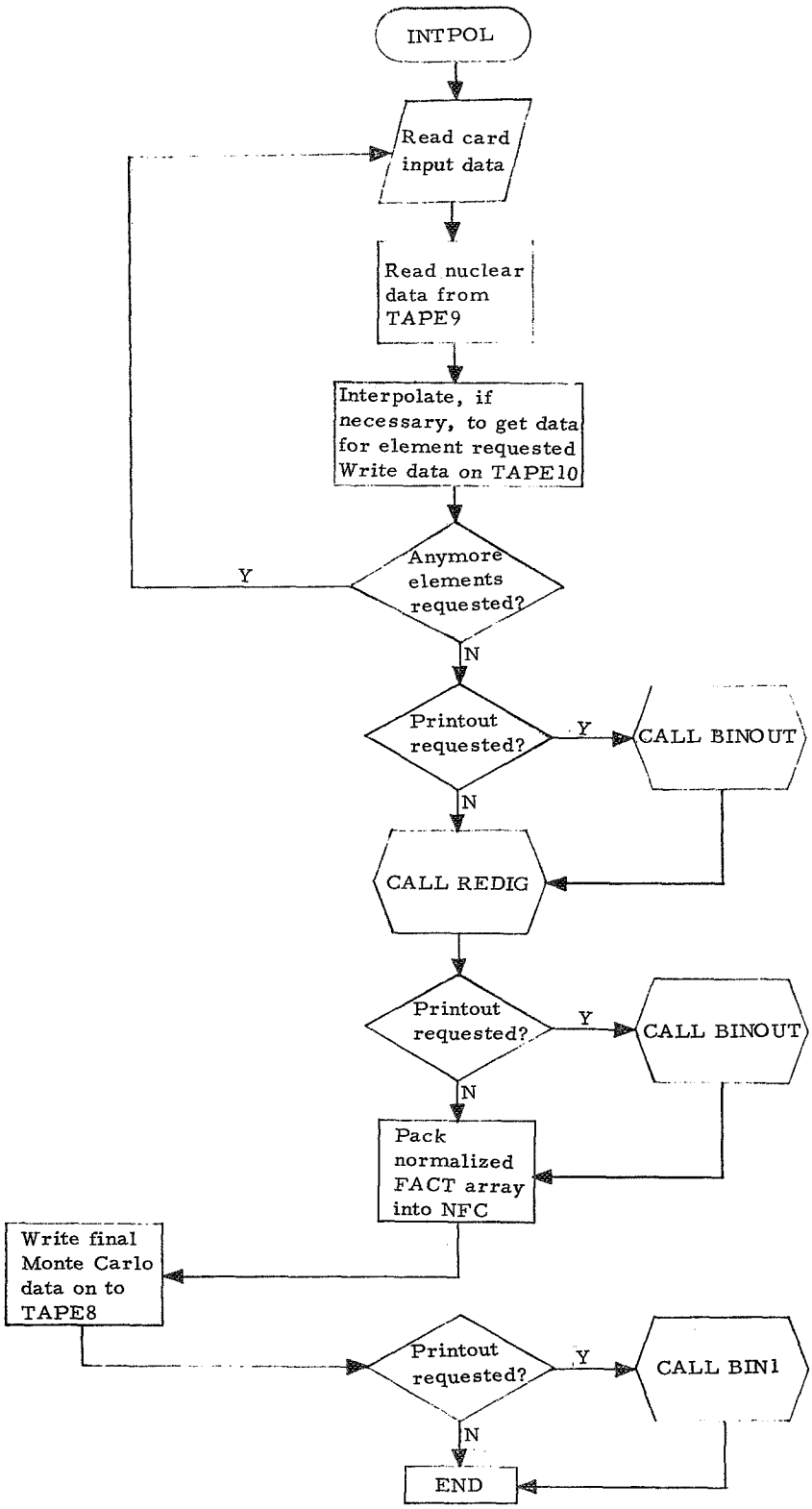
PROGRAM FLOW CHARTS

Separate flow charts are not given for both INTPOL1 and INTPOL2 since they would be identical. Similarly, any subprograms common to both TWOGEV and PROTOS which would have identical flow charts are presented only once as a part of the TWOGEV Flow Charts.

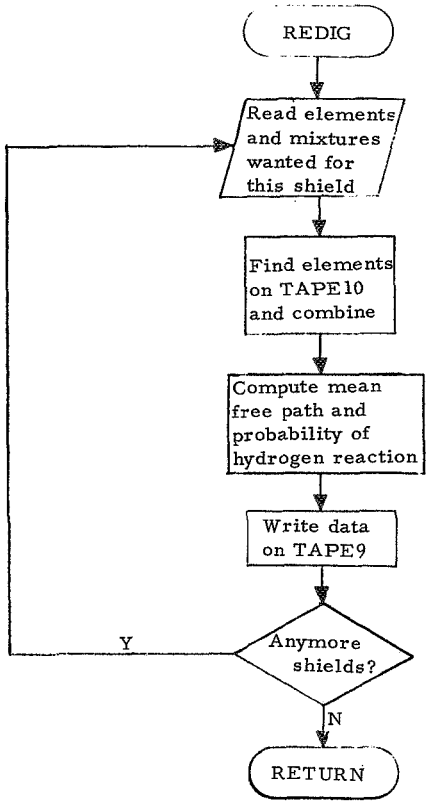
APPENDIX B

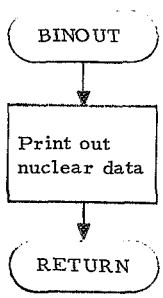
INTPOL1 AND INTPOL2 FLOW CHARTS

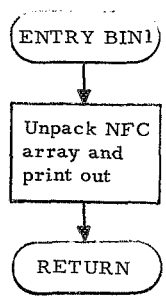
APPENDIX B


INTPOL
Read card input data
Read nuclear data from TAPE9
Interpolate, if necessary, to get data for element requested Write data on TAPE10
Anymore elements requested?
Y
N
Printout requested?
Y
CALL BINOUT
N
CALL REDIG
Printout requested?
Y
CALL BINOUT
N
Pack normalized FACT array into NFC
Write final Monte Carlo data on to TAPE8
Printout requested?
Y
CALL BIN1
N
END

APPENDIX B


REDIG
Read elements and mixtures wanted for this shield
Find elements on TAPE10 and combine
Compute mean free path and probability of hydrogen reaction
Write data on TAPE9
Anymore shields?
Y
N
RETURN

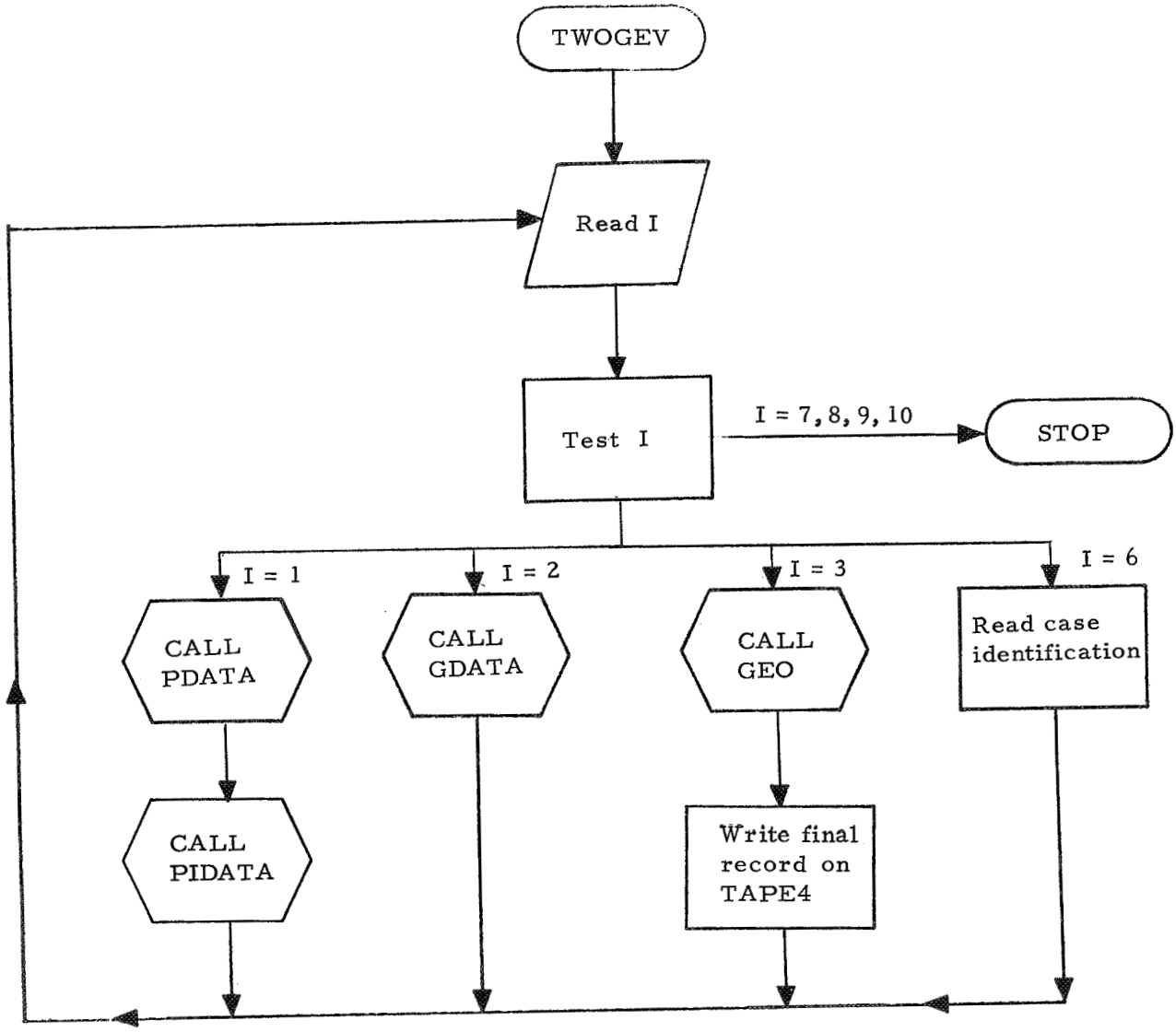

BINOUT
Print out nuclear data
RETURN


ENTRY BIN1
Unpack NFC array and print out
RETURN

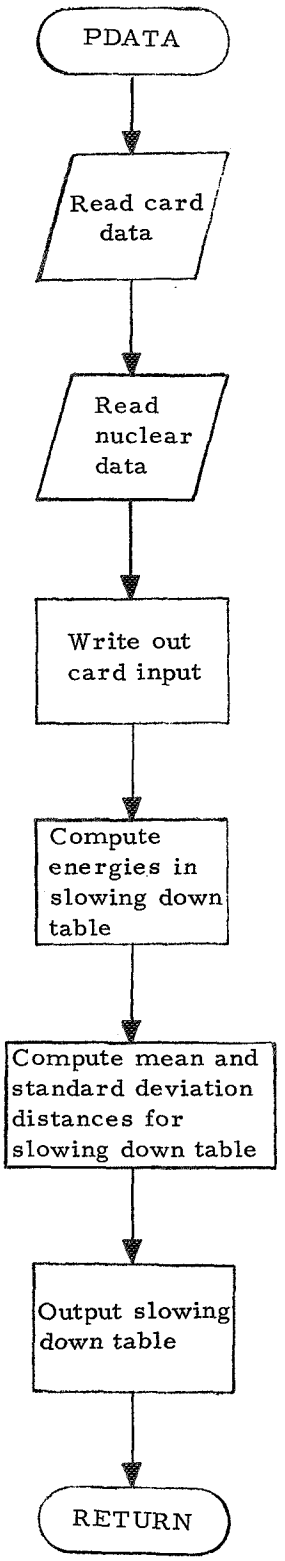
APPENDIX B

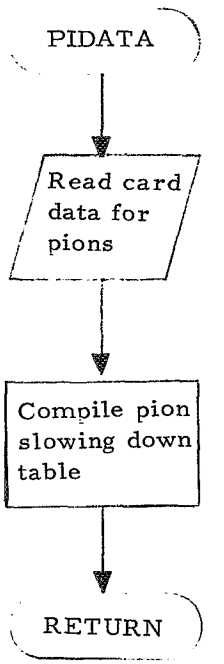
TWOGEV FLOW CHARTS

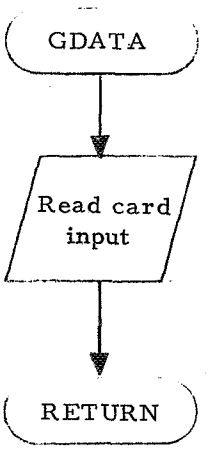
APPENDIX B


TWOGEV
Read I
Test I
I = 7, 8, 9, 10
STOP
I = 1
I = 2
I = 3
I = 6
CALL PDATA
CALL GDATA
CALL GEO
Read case identification
CALL PIDATA
Write final record on TAPE4

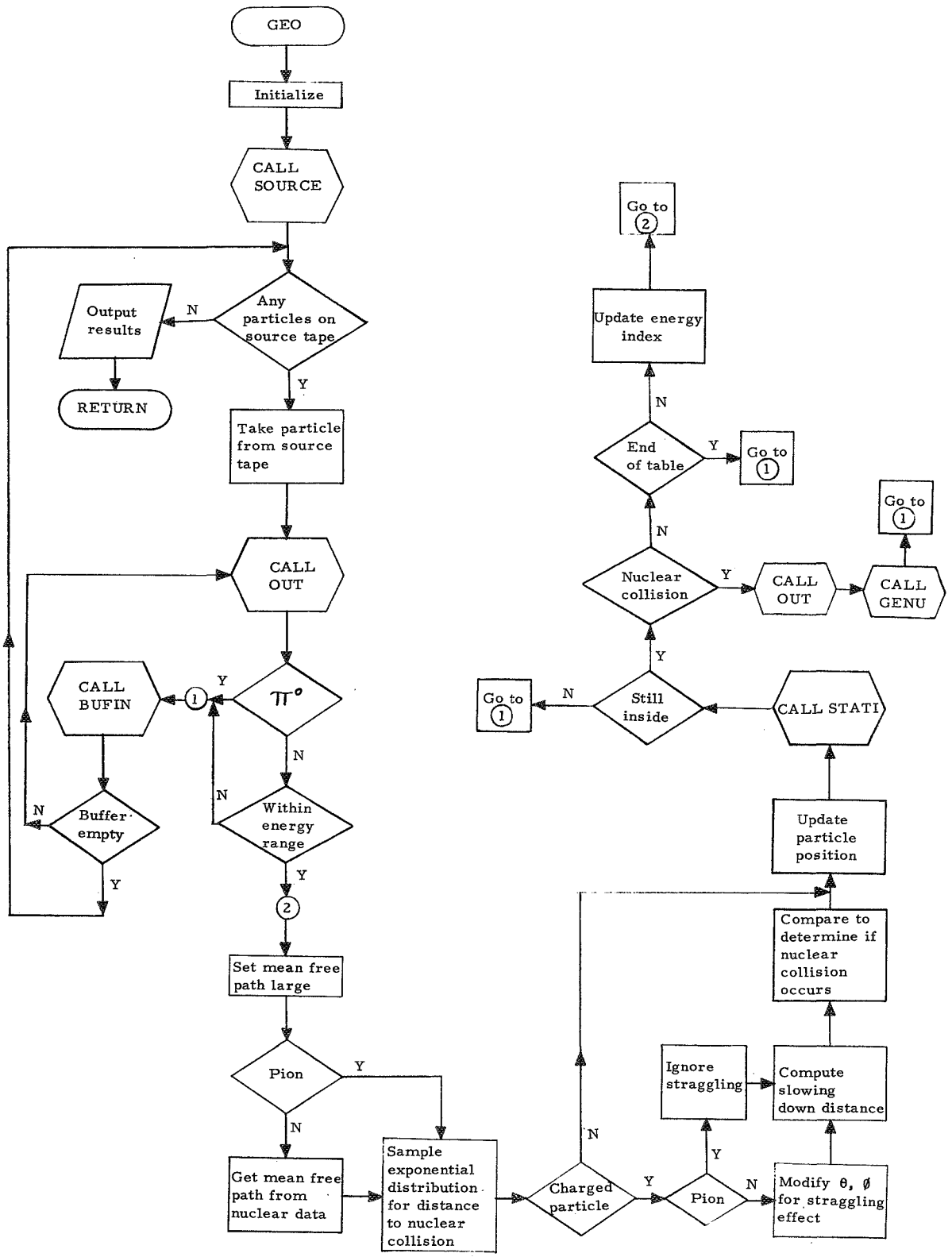
APPENDIX B


PDATA
Read card data
Read nuclear data
Write out card input
Compute energies in slowing down table
Compute mean and standard deviation distances for slowing down table
Output slowing down table
RETURN

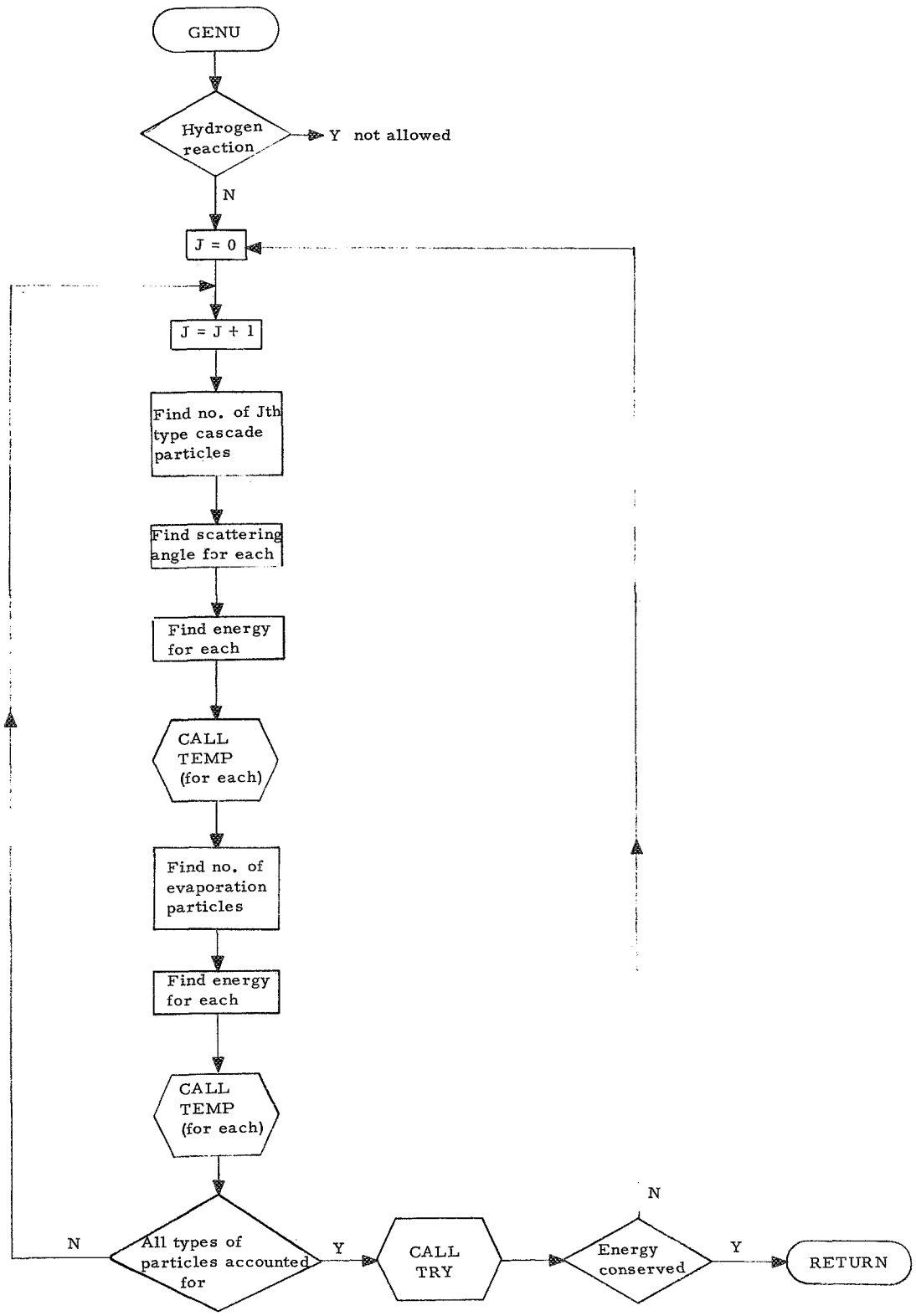

PIDATA
Read card data for pions
Compile pion slowing down table
RETURN


GDATA
Read card input
RETURN

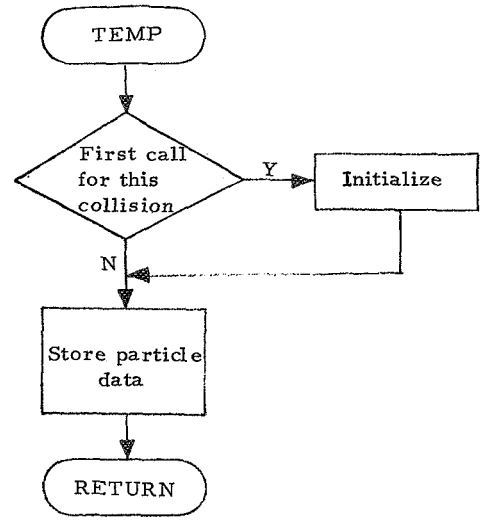
APPENDIX B

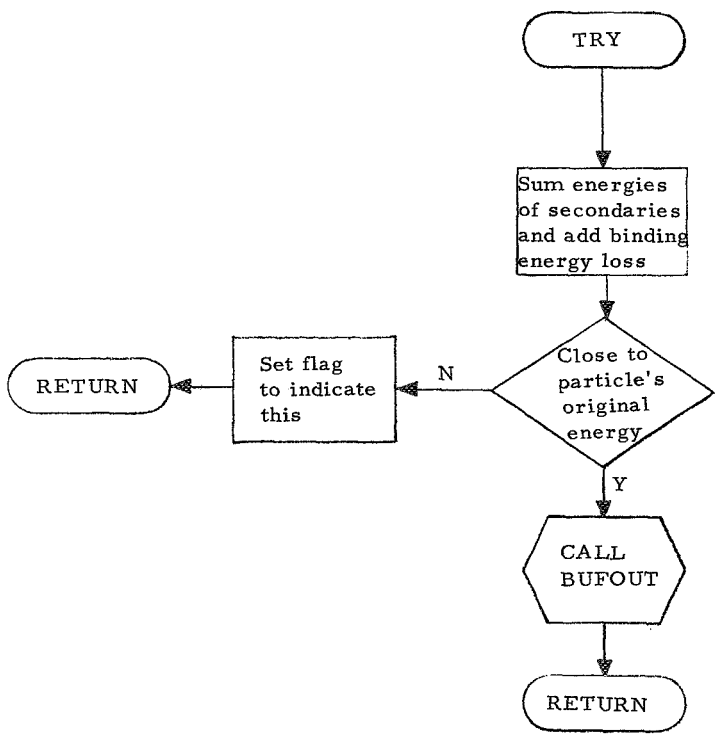

GEO
Initialize
CALL SOURCE
Any particles on source tape
N
Output results
RETURN
Y
Take particle from source tape
CALL OUT
π°
Y
1
CALL BUFIN
N
Buffer empty
N
Y
N
Within energy range
Y
2
Set mean free path large
Pion
Y
N
Get mean free path from nuclear data
Sample exponential distribution for distance to nuclear collision
Charged particle
N
Y
Pion
Y
N
Ignore straggling
Modify θ, ∅ for straggling effect
Compute slowing down distance
Compare to determine if nuclear collision occurs
Update particle position
CALL STATI
Still inside
N
Go to 1
Y
Nuclear collision
Y
CALL OUT
CALL GENU
Go to 1
N
End of table
Y
Go to 1
N
Update energy index
Go to 2

APPENDIX B

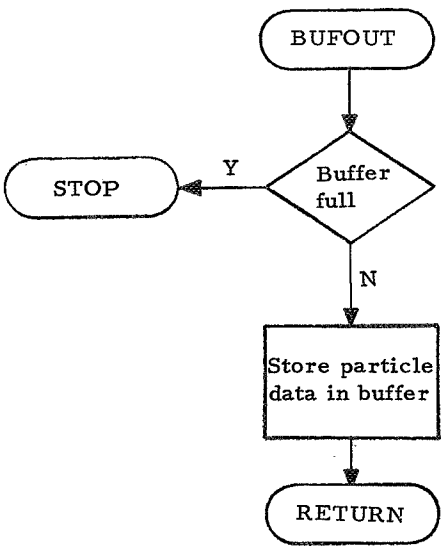

GENU
Hydrogen reaction
Y not allowed
N
J = 0
J = J + 1
Find no. of Jth type cascade particles
Find scattering angle for each
Find energy for each
CALL TEMP (for each)
Find no. of evaporation particles
Find energy for each
CALL TEMP (for each)
All types of particles accounted for
N
Y
CALL TRY
Energy conserved
N
Y
RETURN

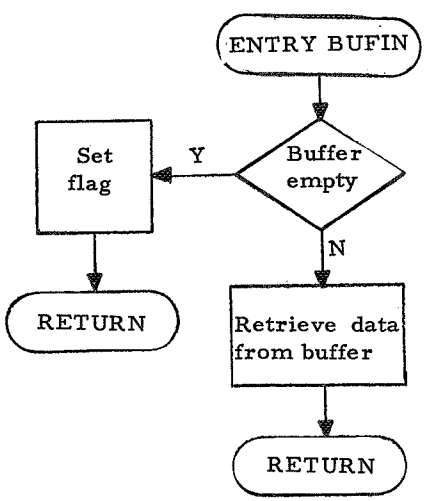
APPENDIX B

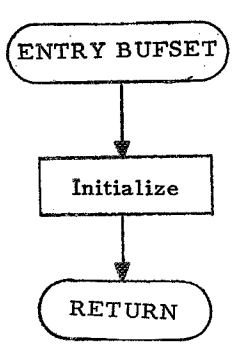

TEMP
First call for this collision
Y
Initialize
N
Store particle data
RETURN

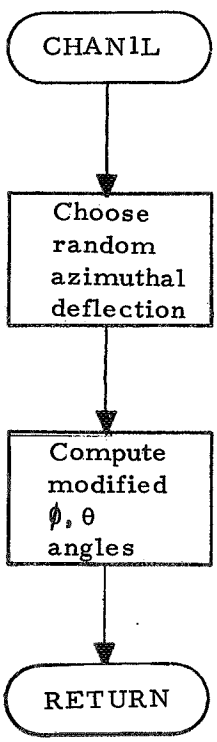

TRY
Sum energies of secondaries and add binding energy loss
Close to particle's original energy
N
Set flag to indicate this
RETURN
Y
CALL BUFOUT
RETURN

APPENDIX B

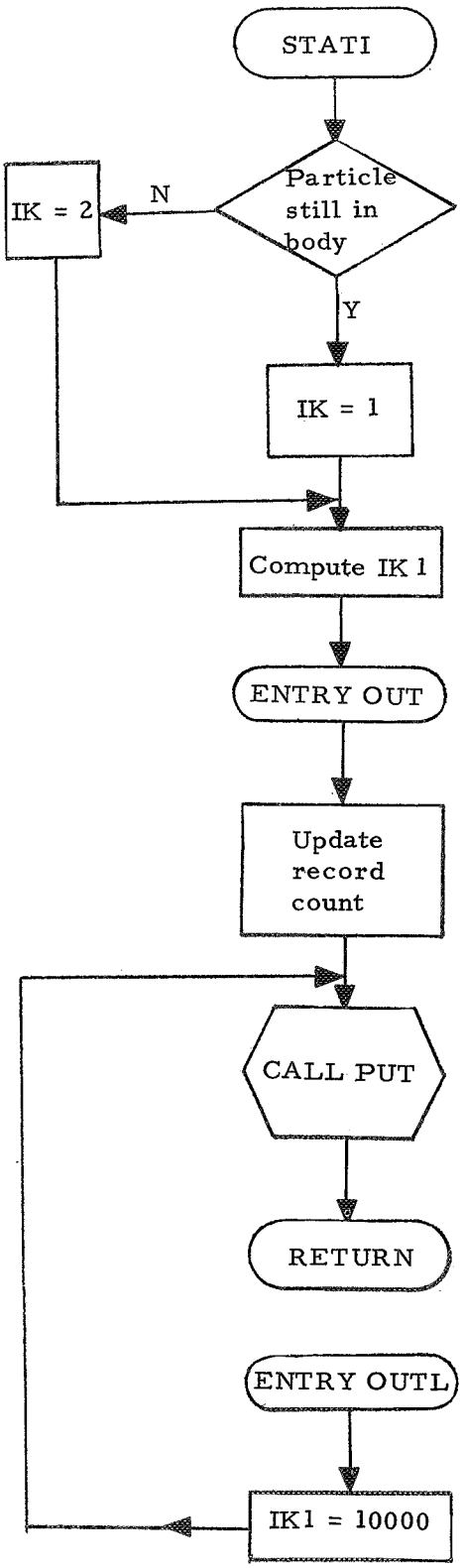

BUFOUT
Buffer full
Y
STOP
N
Store particle data in buffer
RETURN


ENTRY BUFIN
Buffer empty
Y
Set flag
RETURN
N
Retrieve data from buffer
RETURN

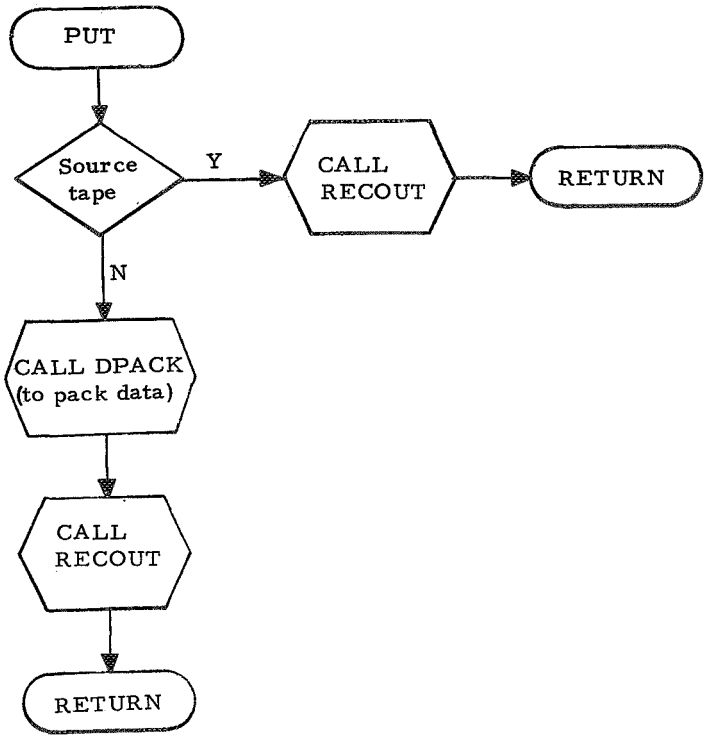

ENTRY BUFSET
Initialize
RETURN

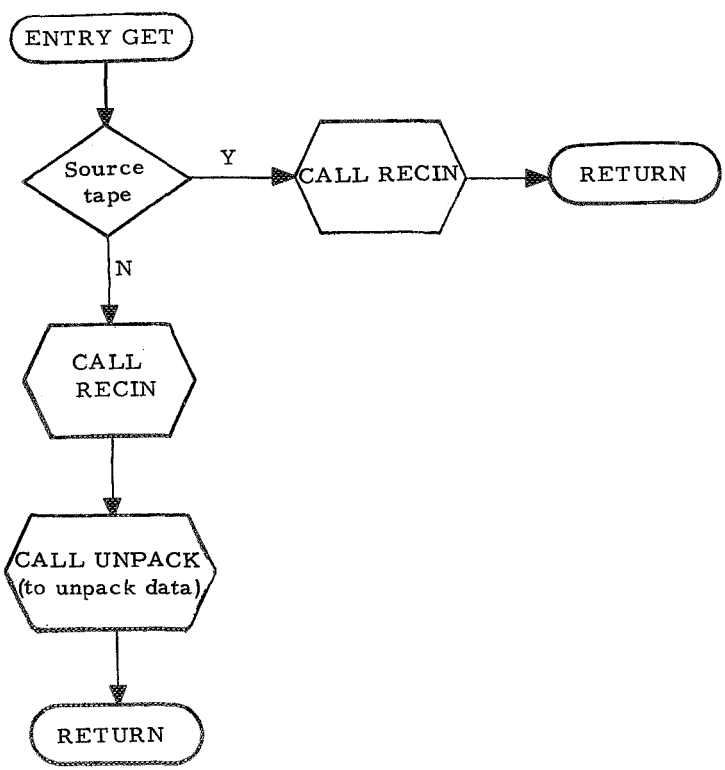

CHAN1L
Choose random azimuthal deflection
Compute modified ϕ, θ angles
RETURN

APPENDIX B


STATI
Particle still in body
N
IK = 2
Y
IK = 1
Compute IK 1
ENTRY OUT
Update record count
CALL PUT
RETURN
ENTRY OUTL
IK1 = 10000

APPENDIX B

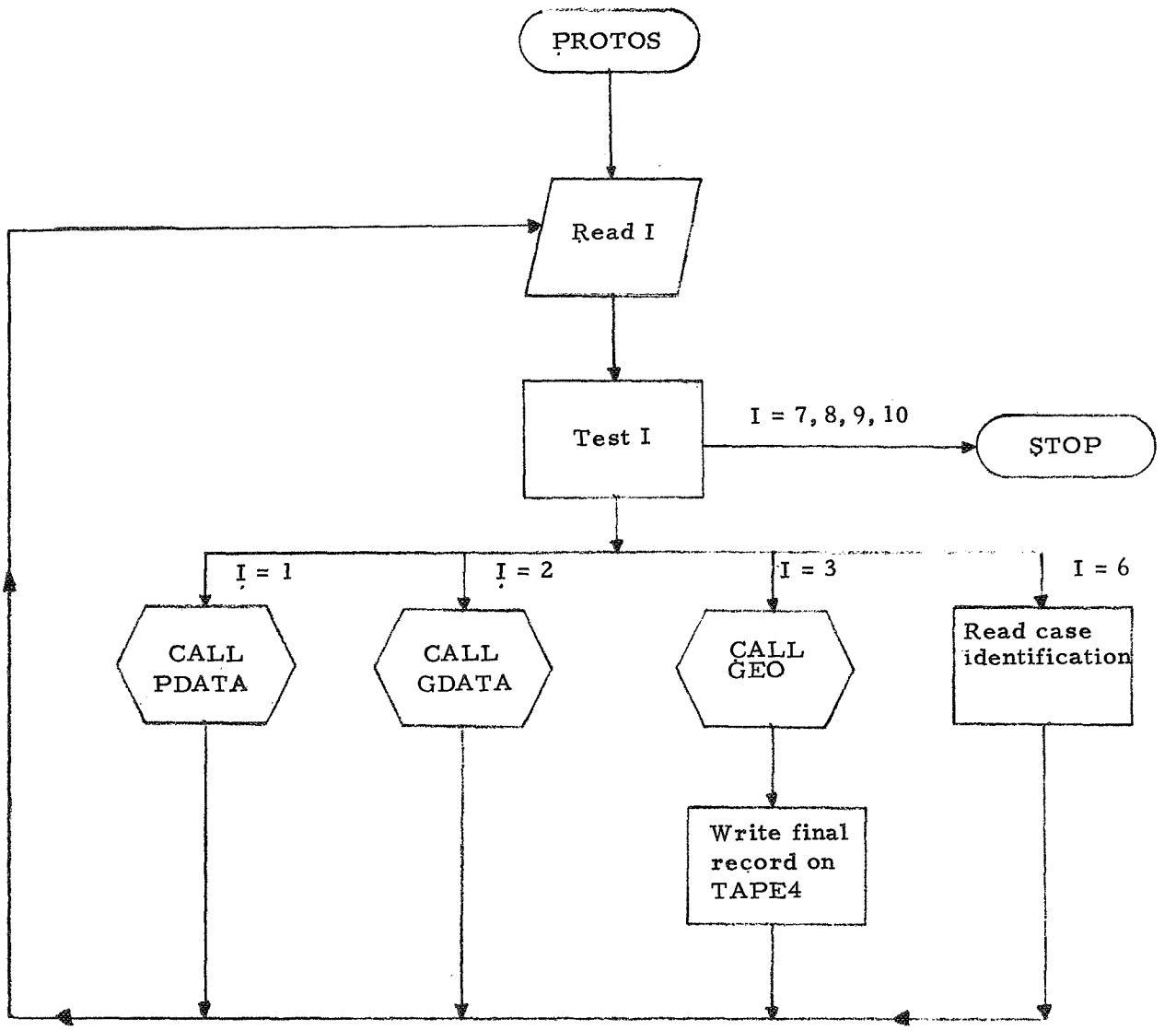

PUT
Source tape
Y
CALL RECOUT
RETURN
N
CALL DPACK (to pack data)
CALL RECOUT
RETURN


ENTRY GET
Source tape
Y
CALL RECIN
RETURN
N
CALL RECIN
CALL UNPACK (to unpack data)
RETURN

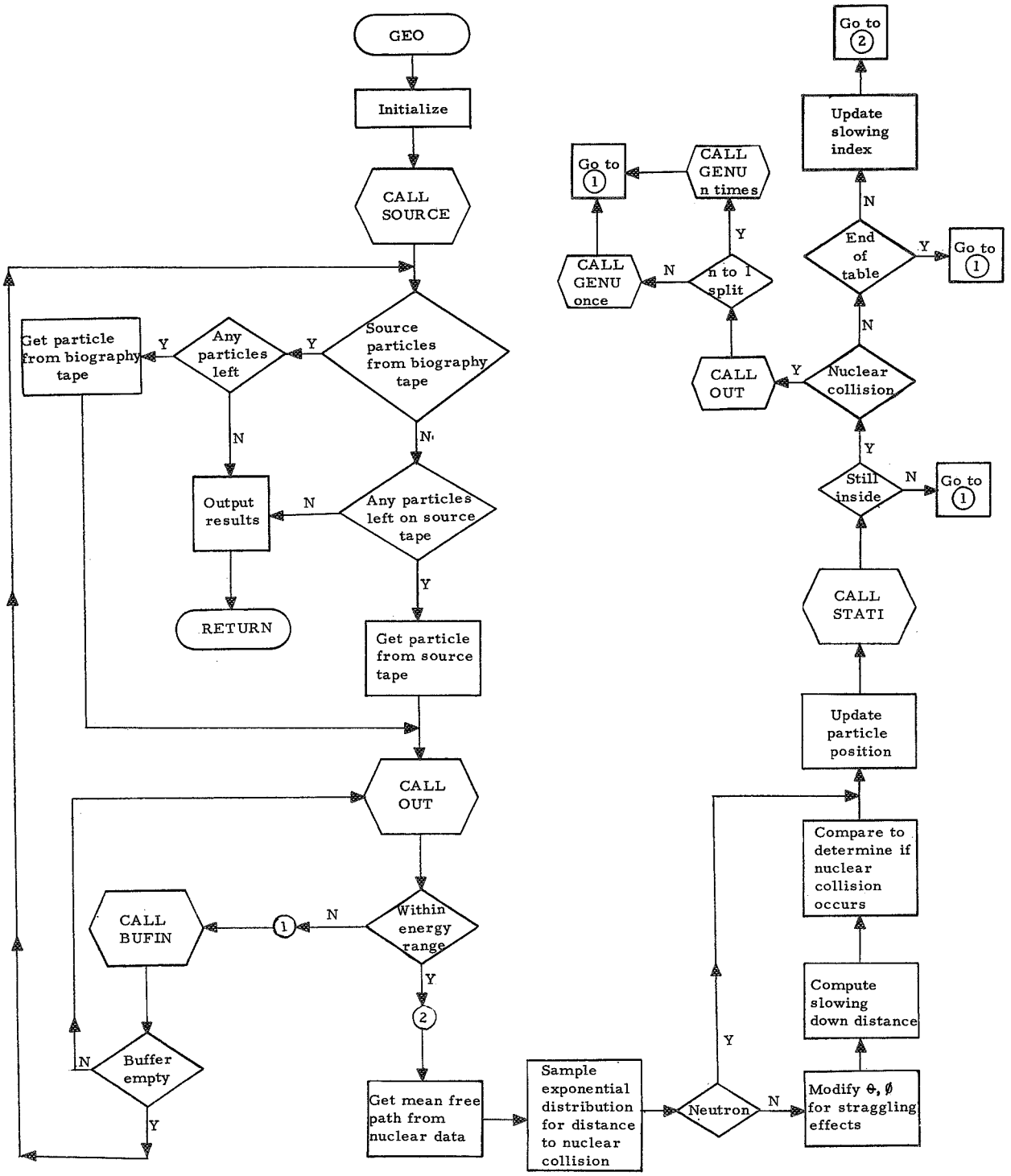
APPENDIX B

PROTOS FLOW CHARTS

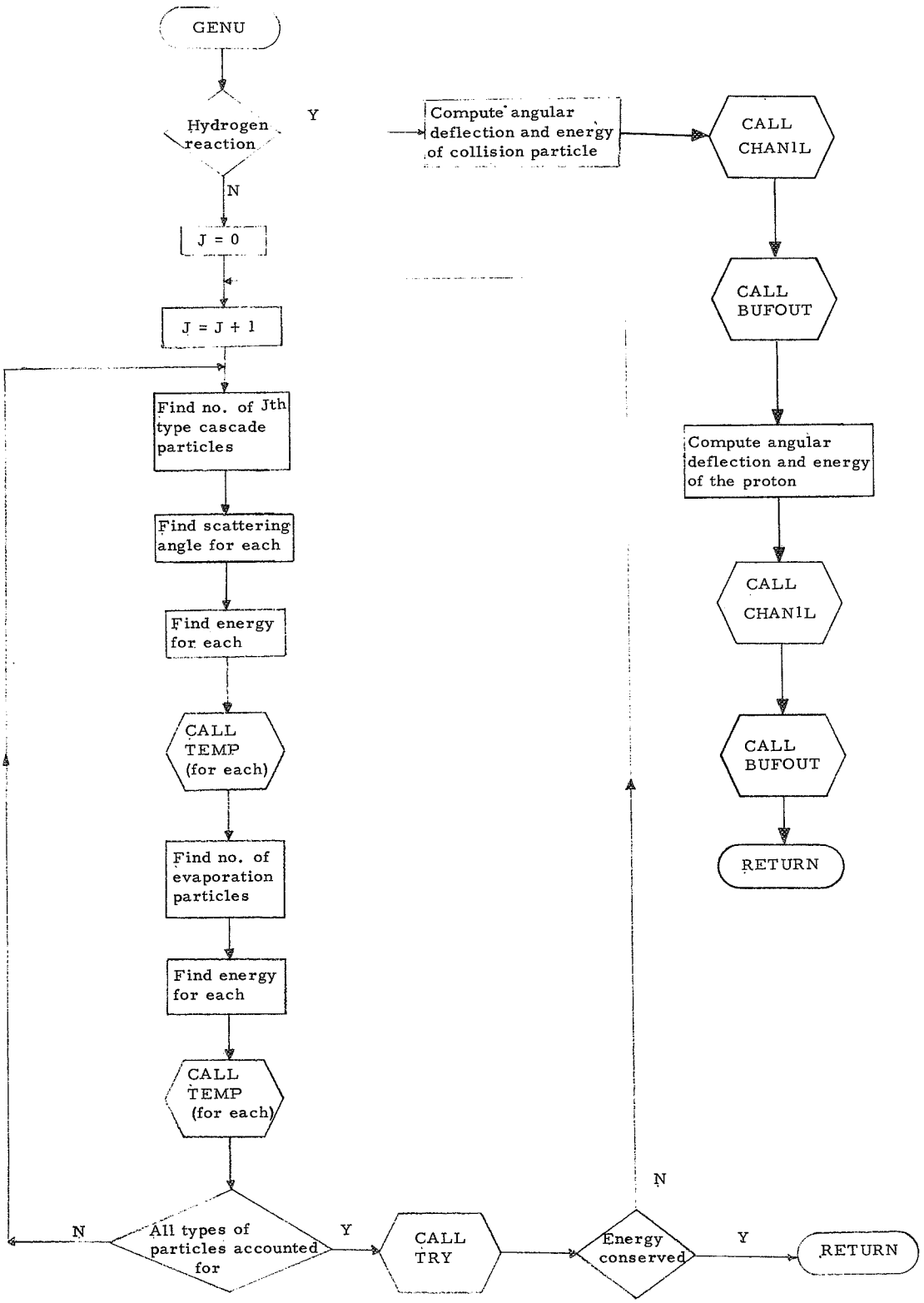
APPENDIX B


PROTOS
Read I
Test I
I = 7, 8, 9, 10
STOP
I = 1
I = 2
I = 3
I = 6
CALL PDATA
CALL GDATA
CALL GEO
Read case identification
Write final record on TAPE4

APPENDIX B


GEO
Initialize
CALL SOURCE
Source particles from biography tape
Y
Any particles left
Y
Get particle from biography tape
N
Output results
N
Any particles left on source tape
N
Y
RETURN
Get particle from source tape
CALL OUT
Within energy range
N
1
CALL BUFIN
Y
2
N
Buffer empty
Y
Get mean free path from nuclear data
Sample exponential distribution for distance to nuclear collision
Neutron
N
Y
Modify θ, ∅ for straggling effects
Compute slowing down distance
Compare to determine if nuclear collision occurs
Update particle position
CALL STATI
Still inside
N
Go to 1
Y
Nuclear collision
Y
CALL OUT
N
n to 1 split
Y
CALL GENU n times
Go to 1
N
CALL GENU once
End of table
Y
Go to 1
N
Update slowing index
Go to 2

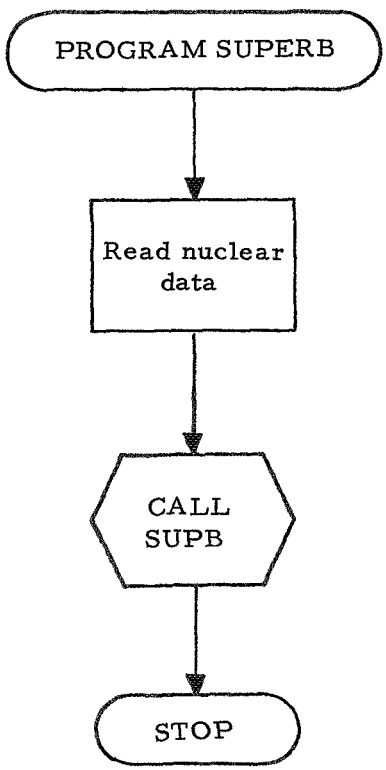
APPENDIX B


GENU
Hydrogen reaction
Y
N
J = 0
J = J + 1
Find no. of Jth type cascade particles
Find scattering angle for each
Find energy for each
CALL TEMP (for each)
Find no. of evaporation particles
Find energy for each
CALL TEMP (for each)
All types of particles accounted for
N
Y
CALL TRY
Energy conserved
N
Y
Compute angular deflection and energy of collision particle
CALL CHANIL
CALL BUFOUT
Compute angular deflection and energy of the proton
CALL CHANIL
CALL BUFOUT
RETURN
RETURN

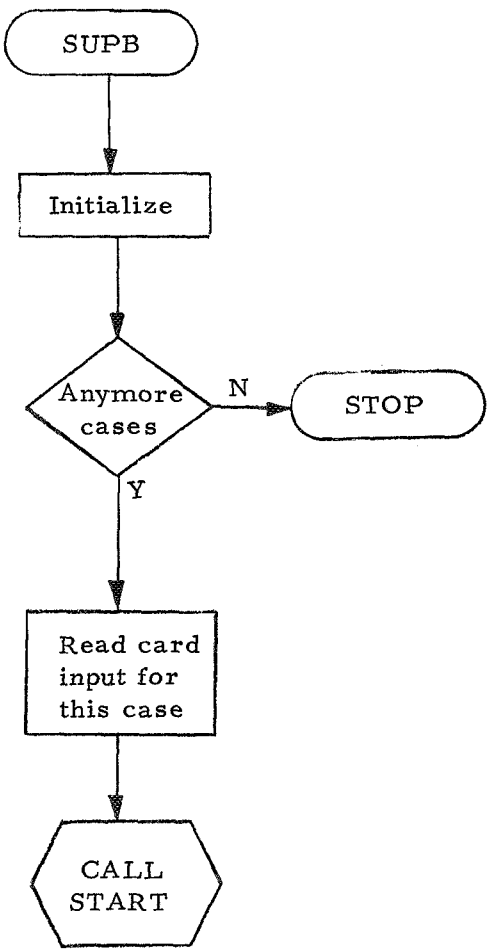
APPENDIX B

SUPER B FLOW CHARTS

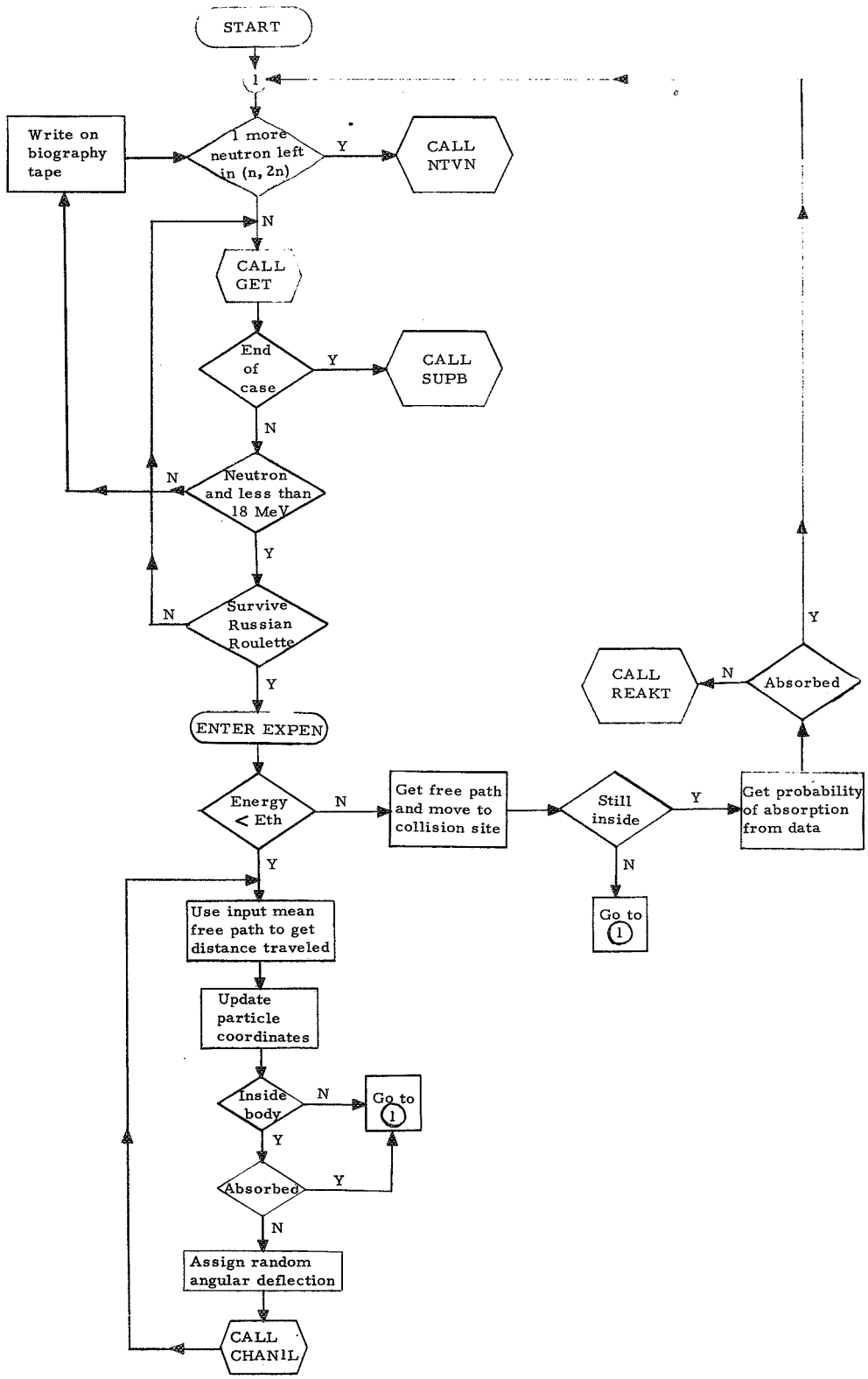
APPENDIX B



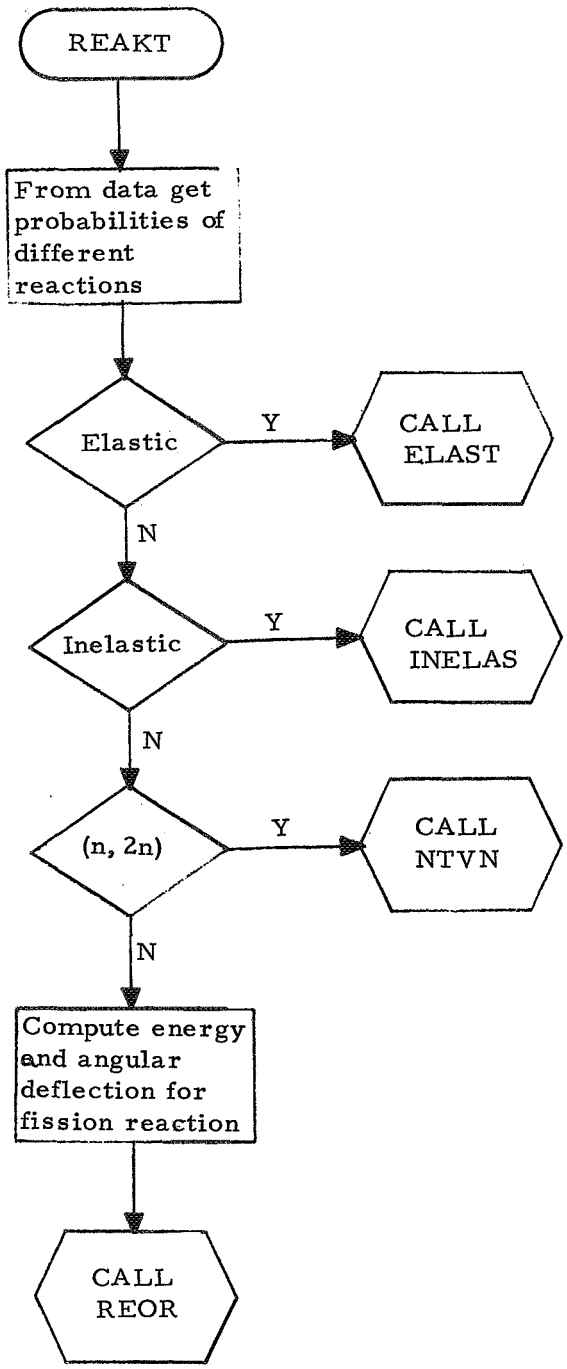
APPENDIX B


SUPB
Initialize
Anymore cases
N
STOP
Y
Read card input for this case
CALL START

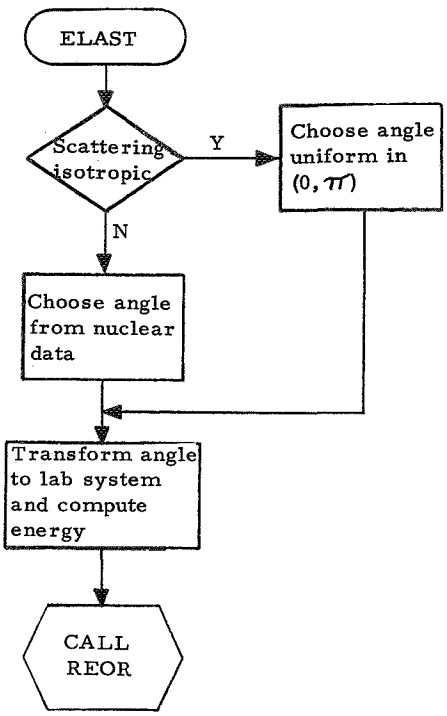
APPENDIX B

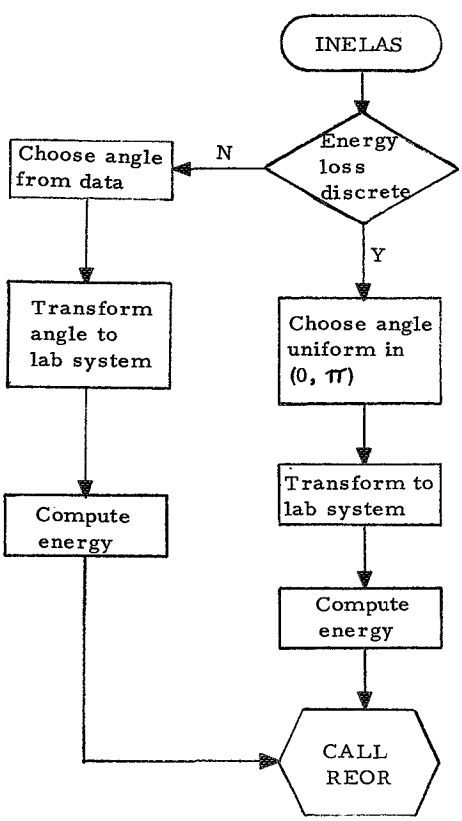

START
1
Write on biography tape
1 more neutron left in (n, 2n)
Y
CALL NTVN
N
CALL GET
End of case
Y
CALL SUPB
N
N
Neutron and less than 18 MeV
Y
N
Survive Russian Roulette
Y
ENTER EXPEN
Energy < Eth
N
Get free path and move to collision site
Still inside
Y
Get probability of absorption from data
N
Go to (1)
Y
Use input mean free path to get distance traveled
Update particle coordinates
Inside body
N
Go to (1)
Y
Absorbed
Y
N
Assign random angular deflection
CALL CHANIL
Y
Absorbed
N
CALL REAKT

APPENDIX B

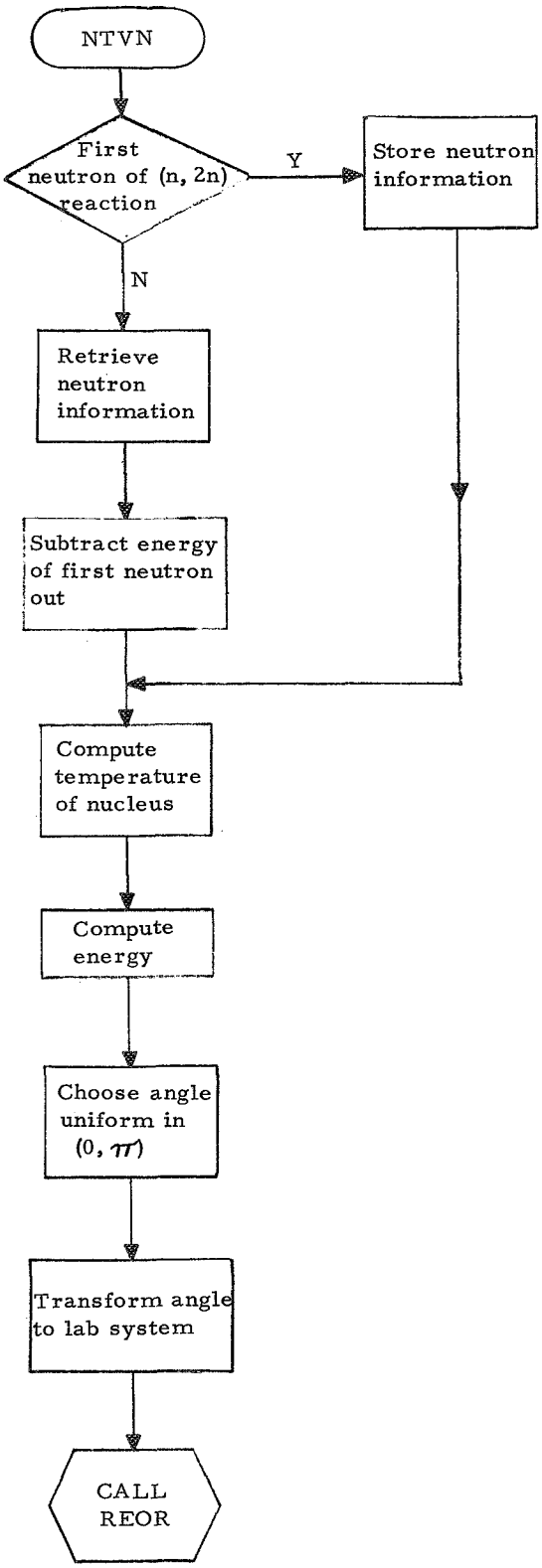

REAKT
From data get probabilities of different reactions
Elastic
Y
CALL ELAST
N
Inelastic
Y
CALL INELAS
N
(n, 2n)
Y
CALL NTVN
N
Compute energy and angular deflection for fission reaction
CALL REOR

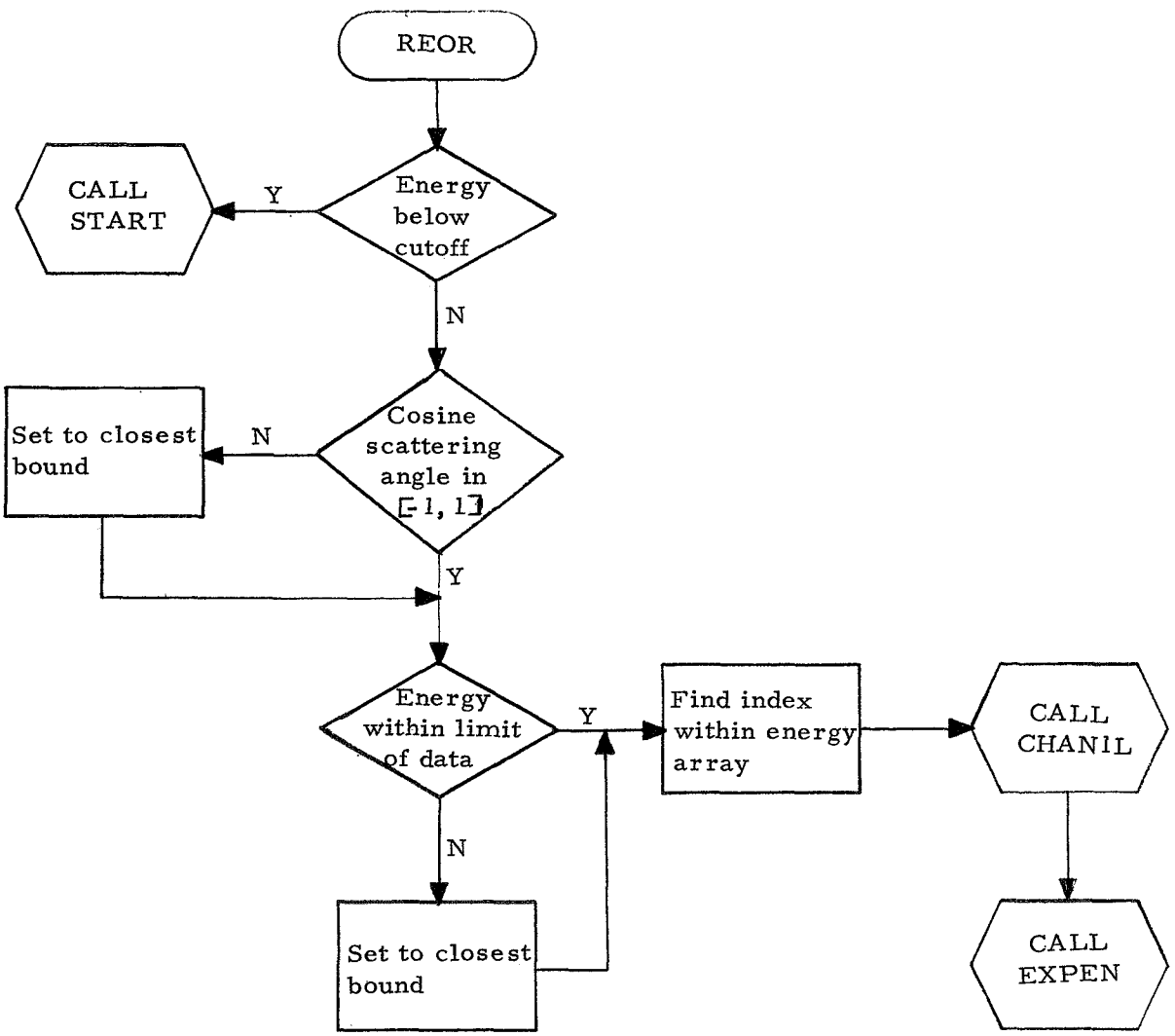
APPENDIX B


ELAST
Scattering isotropic
Y
Choose angle uniform in (0, π)
N
Choose angle from nuclear data
Transform angle to lab system and compute energy
CALL REOR


INELAS
Energy loss discrete
N
Choose angle from data
Y
Transform angle to lab system
Choose angle uniform in (0, π)
Compute energy
Transform to lab system
Compute energy
CALL REOR

APPENDIX B

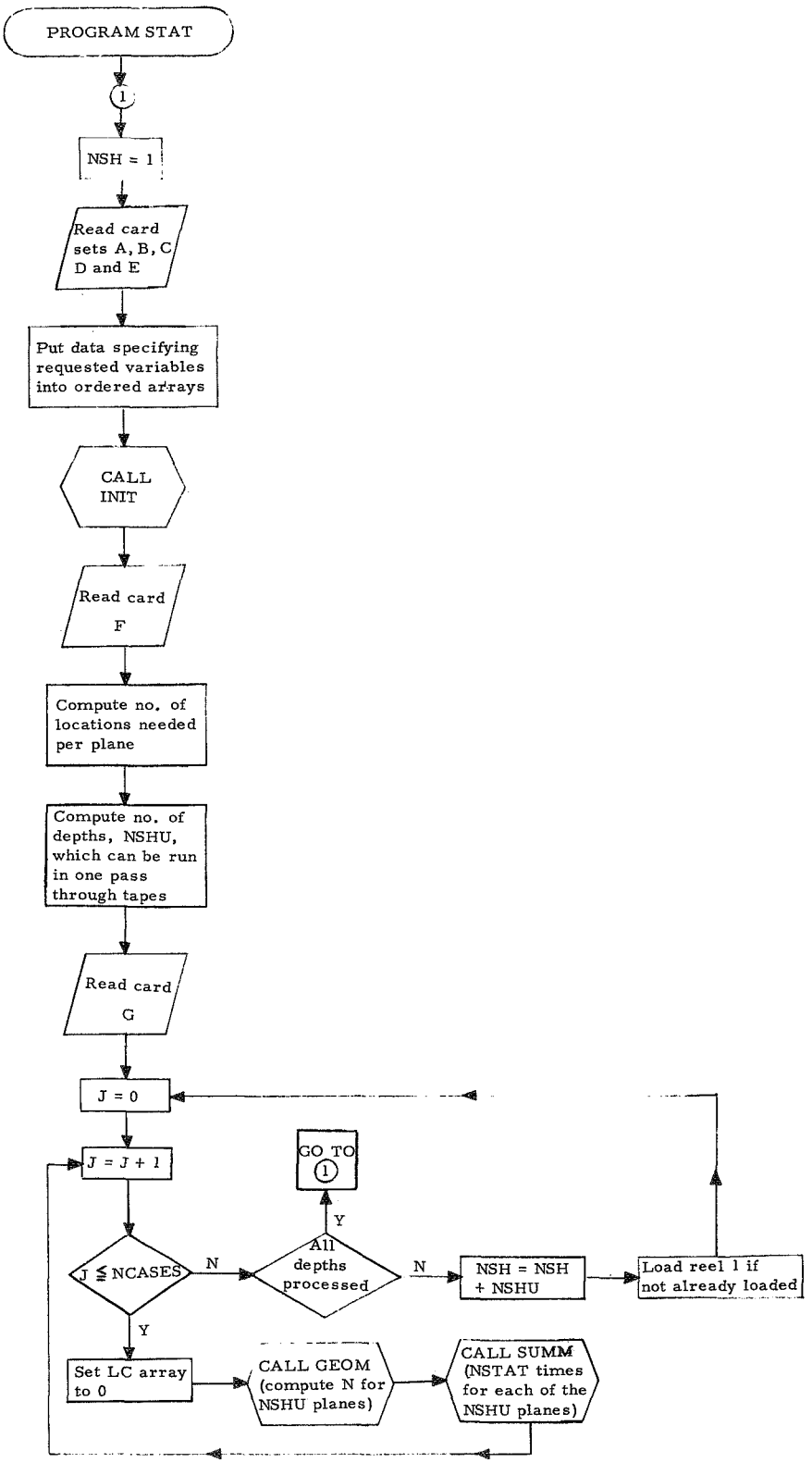

NTVN
First neutron of (n, 2n) reaction
Y
Store neutron information
N
Retrieve neutron information
Subtract energy of first neutron out
Compute temperature of nucleus
Compute energy
Choose angle uniform in (0, π)
Transform angle to lab system
CALL REOR


REOR
Energy below cutoff
Y
CALL START
N
Cosine scattering angle in [-1, 1]
N
Set to closest bound
Y
Energy within limit of data
Y
Find index within energy array
CALL CHANIL
CALL EXPEN
N
Set to closest bound

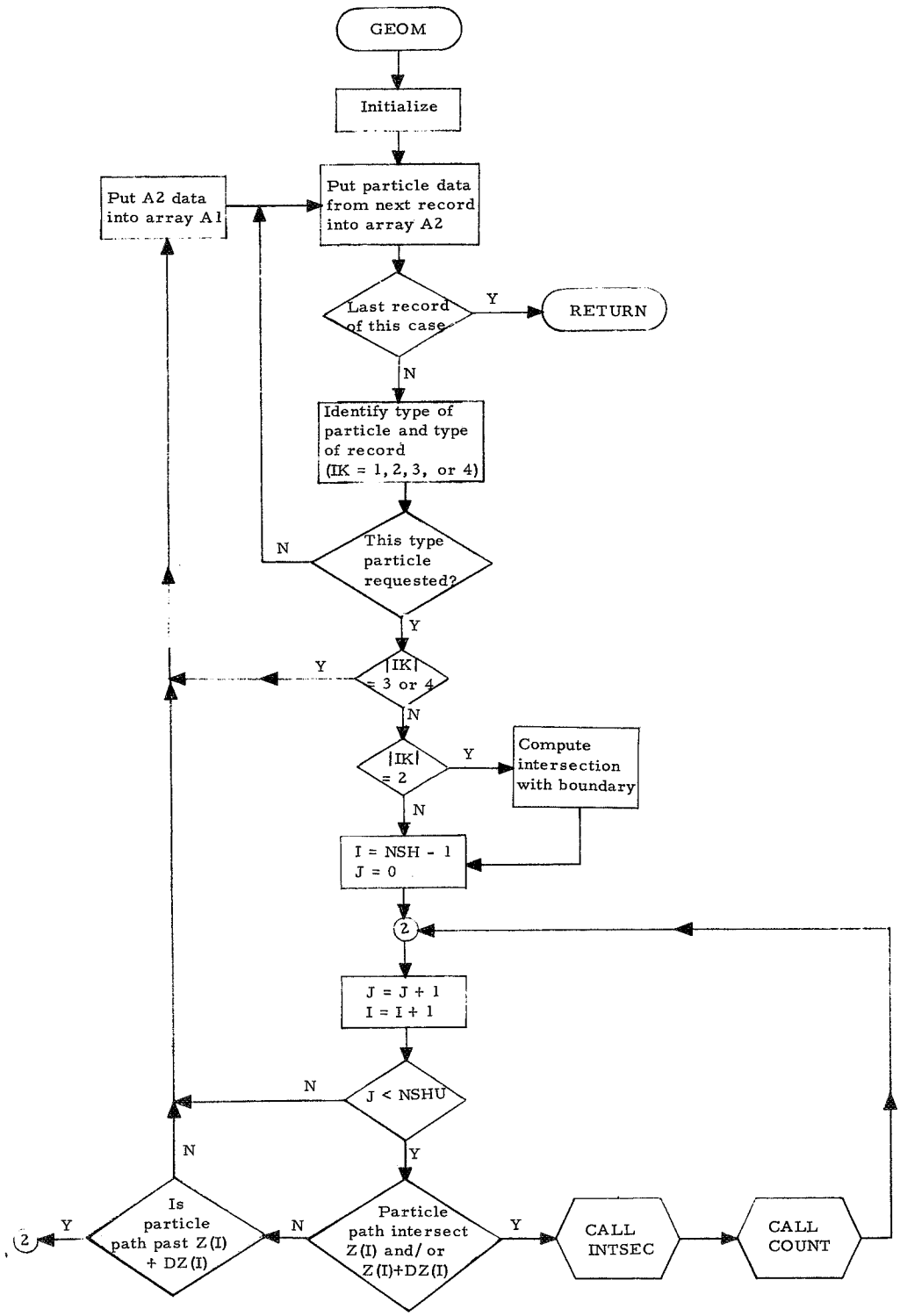
APPENDIX B

STAT FLOW CHARTS

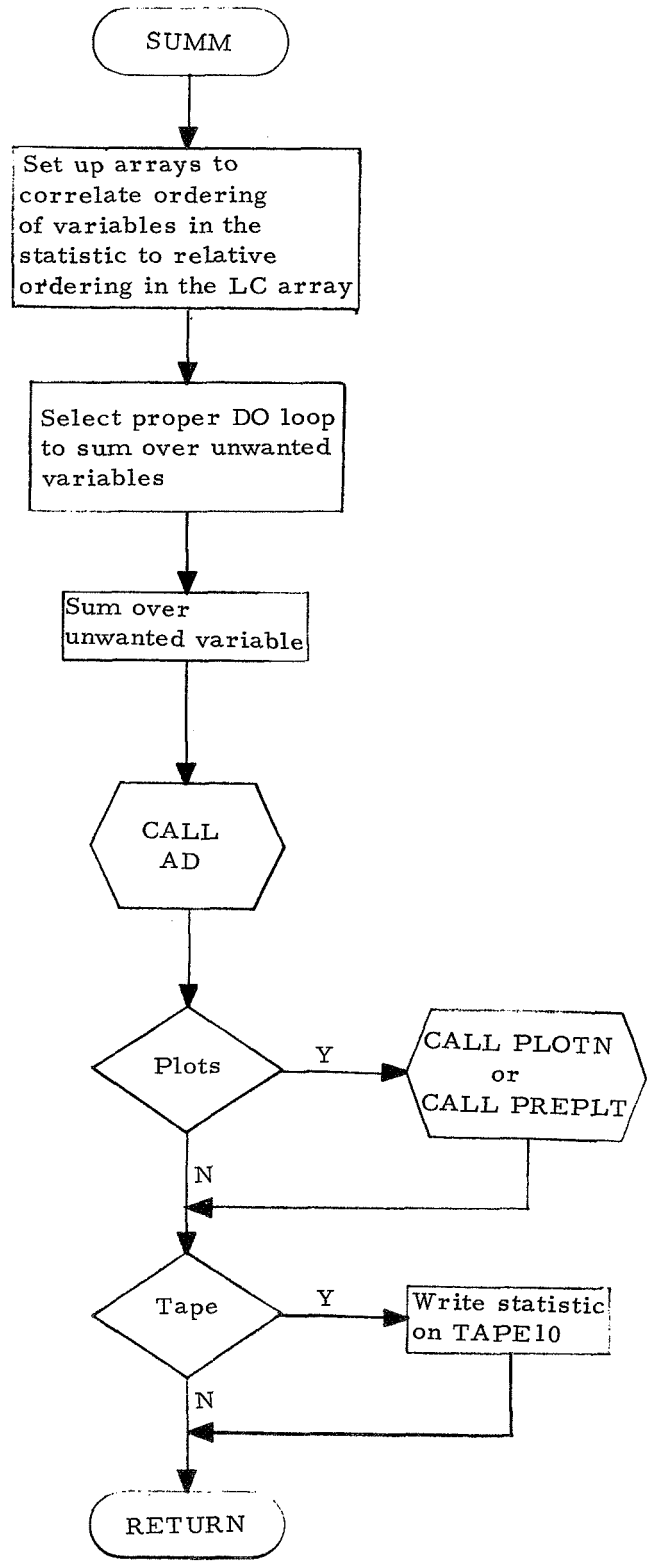
APPENDIX B


PROGRAM STAT
1
NSH = 1
Read card sets A, B, C D and E
Put data specifying requested variables into ordered arrays
CALL INIT
Read card F
Compute no. of locations needed per plane
Compute no. of depths, NSHU, which can be run in one pass through tapes
Read card G
J = 0
J = J + 1
J ≦ NCASES
N
Y
All depths processed
GO TO 1
Y
N
NSH = NSH + NSHU
Load reel 1 if not already loaded
Set LC array to 0
CALL GEOM (compute N for NSHU planes)
CALL SUMM (NSTAT times for each of the NSHU planes)

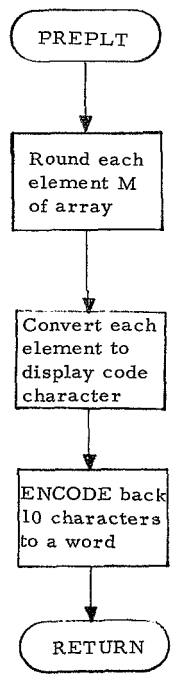
APPENDIX B

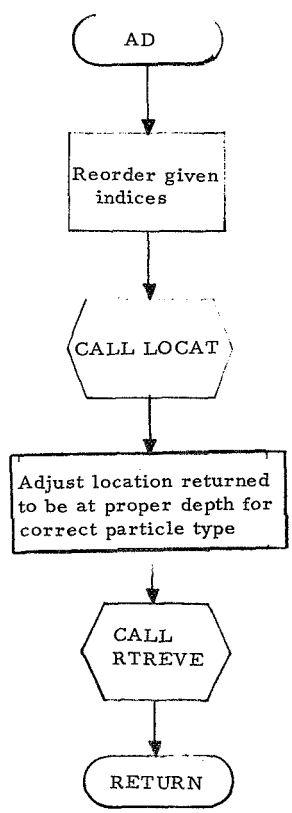

GEOM
Initialize
Put A2 data into array A1
Put particle data from next record into array A2
Last record of this case
Y
RETURN
N
Identify type of particle and type of record (IK = 1, 2, 3, or 4)
This type particle requested?
N
Y
|IK| = 3 or 4
Y
N
|IK| = 2
Y
Compute intersection with boundary
N
I = NSH - 1
J = 0
2
J = J + 1
I = I + 1
J < NSHU
N
Y
N
Is particle path past Z(I) + DZ(I)
Y
2
N
Particle path intersect Z(I) and/or Z(I)+DZ(I)
Y
CALL INTSEC
CALL COUNT

APPENDIX B

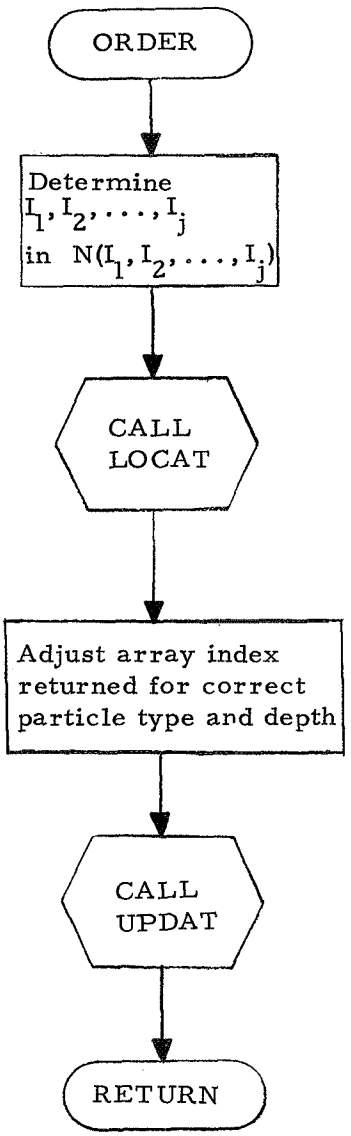

SUMM
Set up arrays to correlate ordering of variables in the statistic to relative ordering in the LC array
Select proper DO loop to sum over unwanted variables
Sum over unwanted variable
CALL AD
Plots
Y
CALL PLOTN or CALL PREPLT
N
Tape
Y
Write statistic on TAPE10
N
RETURN

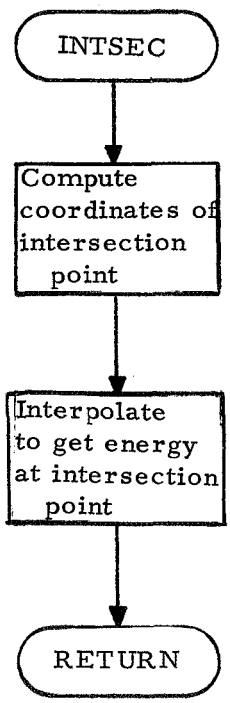
APPENDIX B


PREPLT
Round each element M of array
Convert each element to display code character
ENCODE back 10 characters to a word
RETURN

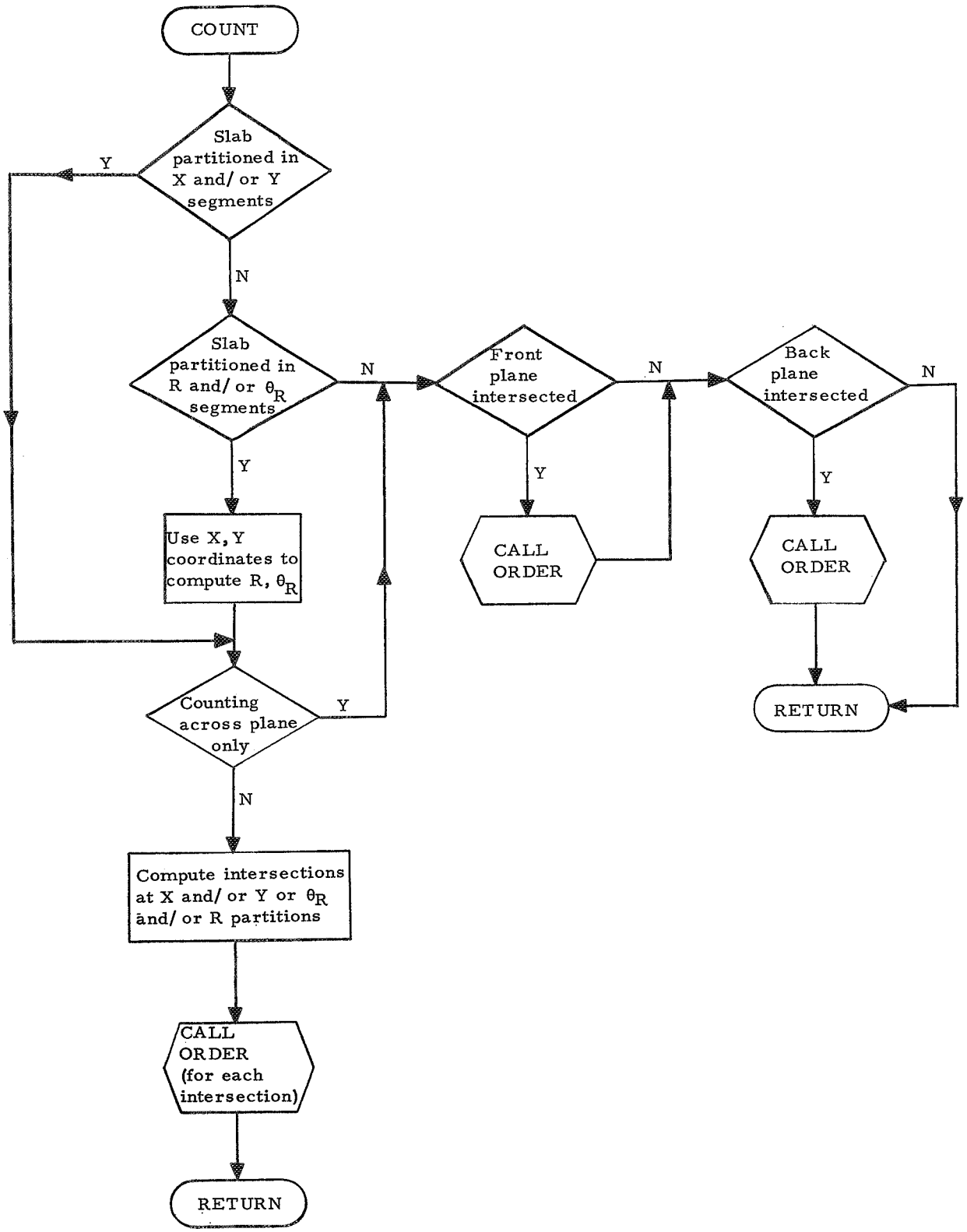

AD
Reorder given indices
CALL LOCAT
Adjust location returned to be at proper depth for correct particle type
CALL RTREVE
RETURN

APPENDIX B

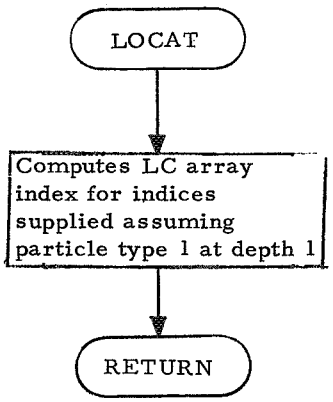

ORDER
Determine
$I_1, I_2, \ldots, I_j$
in $N(I_1, I_2, \ldots, I_j)$
CALL
LOCAT
Adjust array index
returned for correct
particle type and depth
CALL
UPDAT
RETURN

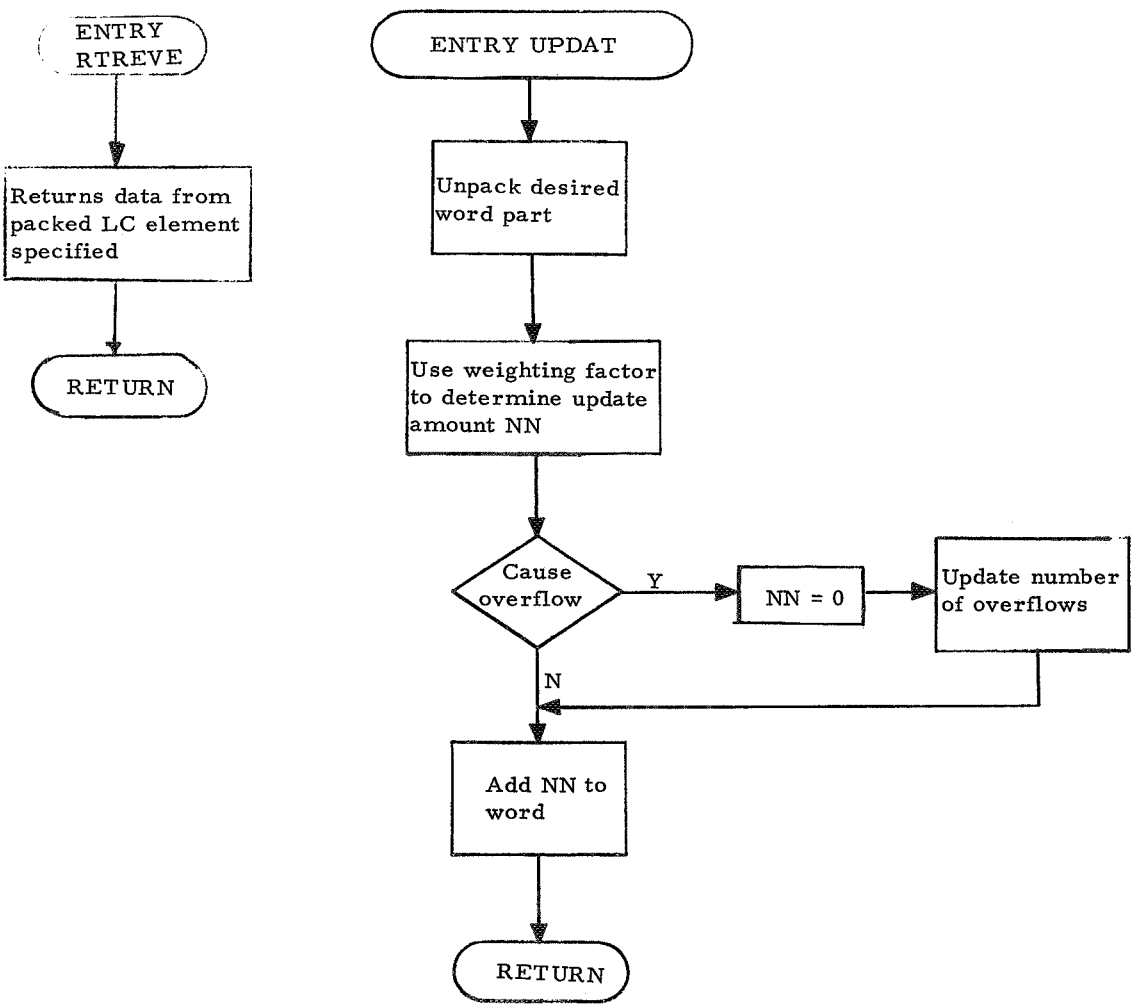

INTSEC
Compute coordinates of intersection point
Interpolate to get energy at intersection point
RETURN

APPENDIX B


COUNT
Slab partitioned in X and/ or Y segments
Y
N
Slab partitioned in R and/ or θ_R segments
N
Front plane intersected
N
Back plane intersected
N
Y
Use X, Y coordinates to compute R, θ_R
Y
CALL ORDER
Y
CALL ORDER
Counting across plane only
Y
N
RETURN
Compute intersections at X and/ or Y or θ_R and/ or R partitions
CALL ORDER (for each intersection)
RETURN

APPENDIX B


LOCAT
Computes LC array index for indices supplied assuming particle type 1 at depth 1
RETURN


ENTRY RTREVE
Returns data from packed LC element specified
RETURN
ENTRY UPDAT
Unpack desired word part
Use weighting factor to determine update amount NN
Cause overflow
Y
NN = 0
Update number of overflows
N
Add NN to word
RETURN

REFERENCES

1. Leimdorfer, Martin; and Crawford, George W.; eds.: Penetration and Interaction of Protons With Matter. Pt. I. Theoretical Studies Using Monte Carlo Techniques. Res. Rep. No. 68-2 (Grant NsG 708), Southern Methodist Univ., Aug. 1968. (Available as NASA CR-108228.)

2. Canavos, George C.: A Comparative Analysis of Two Concepts in the Generation of Uniform Pseudo-Random Numbers. Proceedings of 22nd National Conference, A.C.M. Publ. P-67, Thompson Book Co., 1967, pp. 485-501.

3. Clark, Melville, Jr.; and Hansen, Kent F.: Numerical Methods of Reactor Analysis. Academic Press, Inc., 1964.

4. Leimdorfer, M.; and Barish, J.: A Method of Representing Two-Dimensional Distributions for Use in Monte Carlo Calculations. ORNL-4002 (Contract W-7405-Eng-26), U.S. At. Energy Comm., Jan. 1967. (Available as NASA CR-82502.)

5. Bertini, Hugo W.: Preliminary Data From Intranuclear-Cascade Calculations of 0.75-, 1-, and 2-GeV Protons on Oxygen, Aluminum, and Lead, and 1-GeV Neutrons on the Same Elements. ORNL-TM-1996, U.S. At. Energy Comm., Dec. 1967.

6. Bertini, Hugo W.: Low-Energy Intranuclear Cascade Calculation. Phys. Rev., Second ser., vol. 131, no. 4, Aug. 15, 1963, pp. 1801-1821.

7. Bertini, Hugo W.: Intranuclear-Cascade Calculation of the Secondary Nucleon Spectra From Nucleon-Nucleus Interactions in the Energy Range 340 to 2900 MeV and Comparisons With Experiment. Phys. Rev., Second ser., vol. 188, no. 4, Dec. 20, 1969, pp. 1711-1730.

8. Barkas, Walter H.; and Berger, Martin J.: Tables of Energy Losses and Ranges of Heavy Charged Particles. NASA SP-3013, 1964.

9. Leimdorfer, M.; Alsmiller, R. G., Jr.; and Boughner, R. T.: Calculations of the Radiation Hazard Due to Exposure of Supersonic Aircraft to Solar-Flare Protons. Nucl. Sci. Eng., vol. 27, no. 1, Jan. 1967, pp. 151-157.

10. Armstrong, T. W.; Alsmiller, R. G., Jr.; and Barish, J.: Calculation of the Radiation Hazard at Supersonic Aircraft Altitudes Produced by an Energetic Solar Flare. Nucl. Sci. Eng., vol. 37, no. 3, Sept. 1969, pp. 337-342.

11. Foelsche, T.; Mendell, Rosalind; Adams, Richard R.; and Wilson, John W.: Measured and Calculated Radiation Levels Produced by Galactic and Solar Cosmic Rays in SST Altitudes and Precaution Measures To Minimize Implications at Commercial SST-Operations. NASA paper prepared for French-Anglo United States Supersonic Transport Meeting (Paris, France), Mar. 3, 1969.

12. Wilson, John W.; Lambiotte, Jules J., Jr.; Foelsche, Trutz; and Filippas, Tassos A.: Dose Response Functions in the Atmosphere Due to Incident High-Energy Protons With Application to Solar Proton Events. NASA TN D-6010, 1970.

TABLE I.- ELEMENTS AND MIXTURES ON MASTER DATA TAPE

Program	Element or mixture		Symbol	Atomic weight	Atomic number, Z, for INTPOL	Density	No. atoms per $cm^3 \times 10^{-24}$
TWOGEV	Oxygen		O	16	8		
	Aluminum		AL	27	13		
PROTOS	Carbon		C	12	6		
	Oxygen		O	16	8		
	Aluminum		AL	27	13		
	Chromium		CR	50	24		
	Copper		CU	63	29		
	Ruthenium		RU	96	44		
	Cerium		CE	136	58		
	Tungsten		W	180	74		
	Lead		PB	204	82		
	Uranium		U	238	92		
	Tissue*		$C_{27}H_{21}ON$				
SUPER B	Aluminum		AL	27	13		
	Carbon		C	12	6		
	Silicon		SI	28	14		
	Copper		CU	63	29		
	Lead		PB	204	82		
	Iron		FE	54	26		
	Water	Hydrogen				1.0	0.067
		Oxygen					.0335
	Polyethylene I	Carbon	CH2			0.950	0.04087
		Hydrogen					.08174
	Polyethylene II	Carbon	CH2			0.915	0.03936
		Hydrogen					.07873
	Nylon	C	$C_{12}H_{22}O_2N_2$			1.1399	0.02083
		H					.06683
		O					.006076
		N					.06074
	Tissue*	C	$C_{27}H_{21}ON$			1.0999	0.04769
		H					.03710
		O					.00177
		N					.00176
	Lucite	C	$C_5H_8O_2$			1.1892	0.03581
		H					.05730
		O					.01433
	Air	N				1.0	0.0344
		O					.007527

*Tissue is already in a form acceptable by PROTOS so that INTPOL2 will not be necessary.

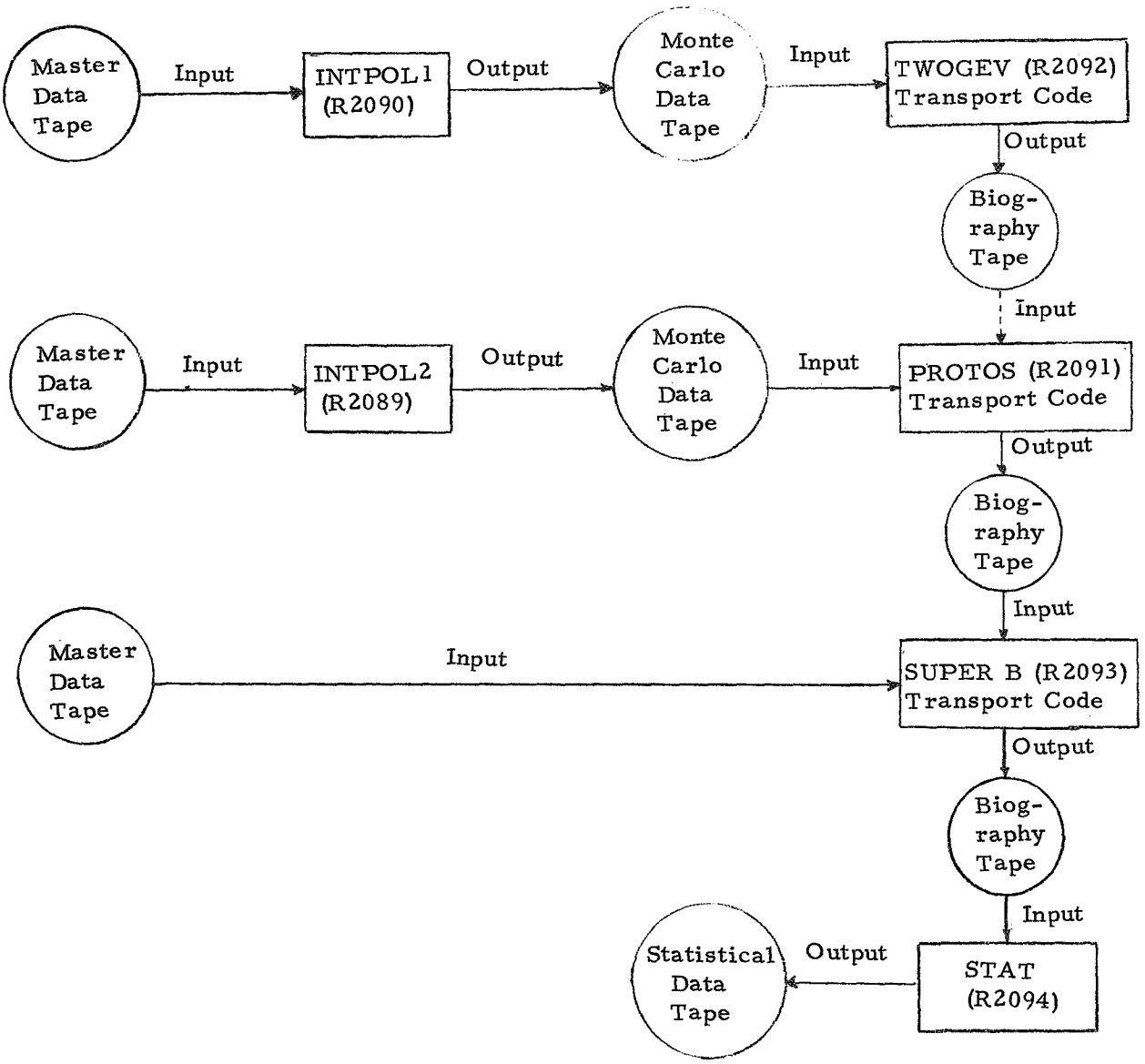


Figure 1.- PROPER 3C flow chart.

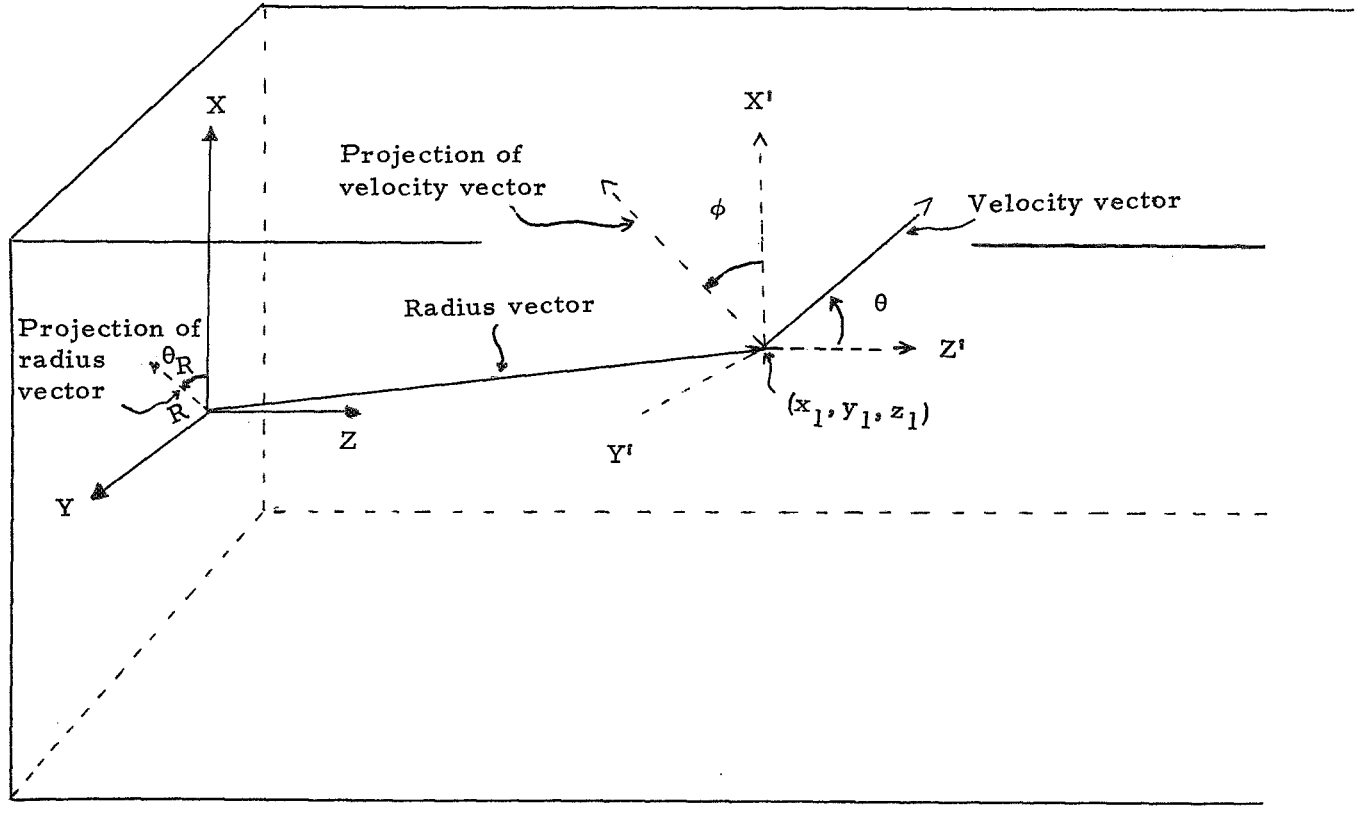


Figure 2.- Geometry of a particle located within the slab at $\left(x_1, y_1, z_1\right)$ with momentum angles θ and ϕ.

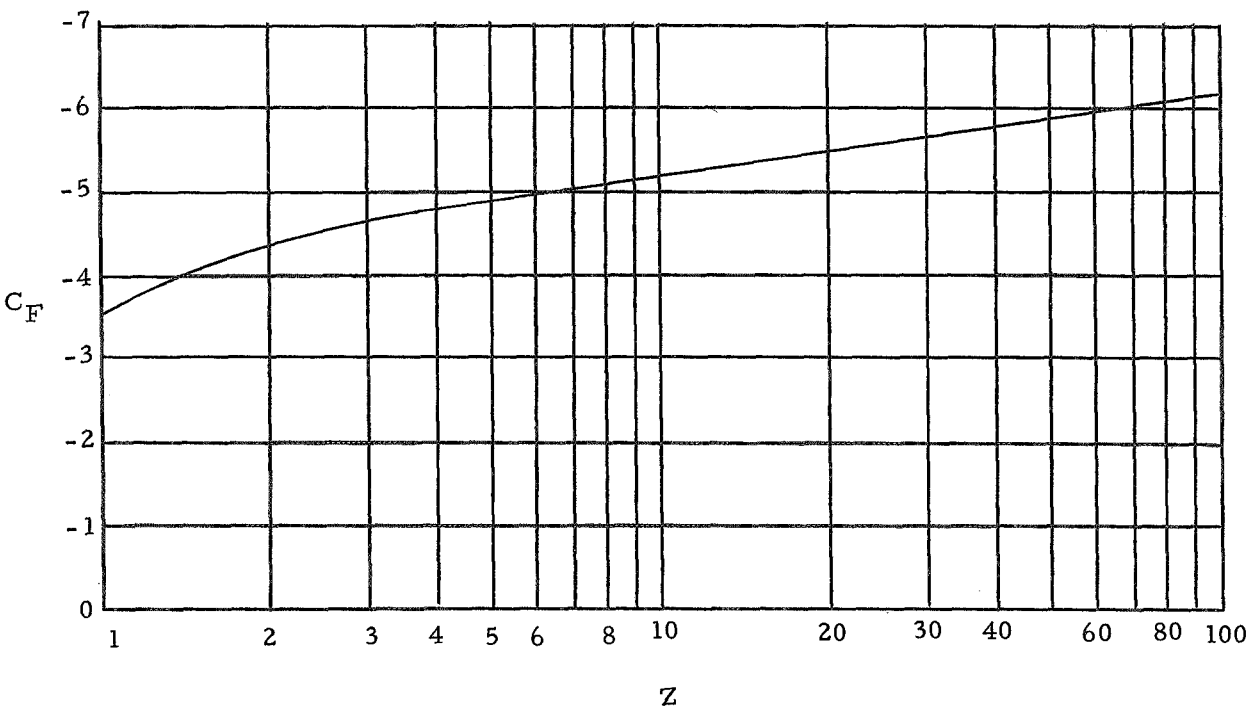


Figure 3.- Variation of parameter C_F with atomic number Z.

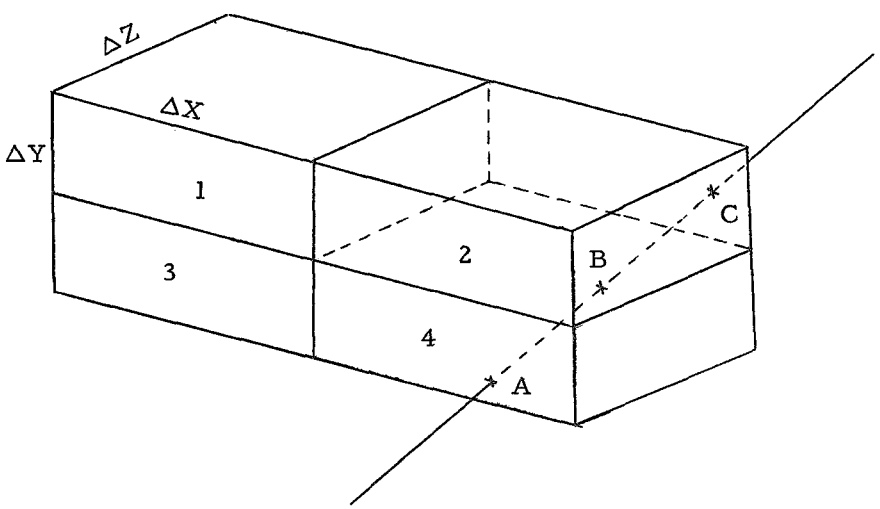


Figure 4.- Typical particle path through a subslab.

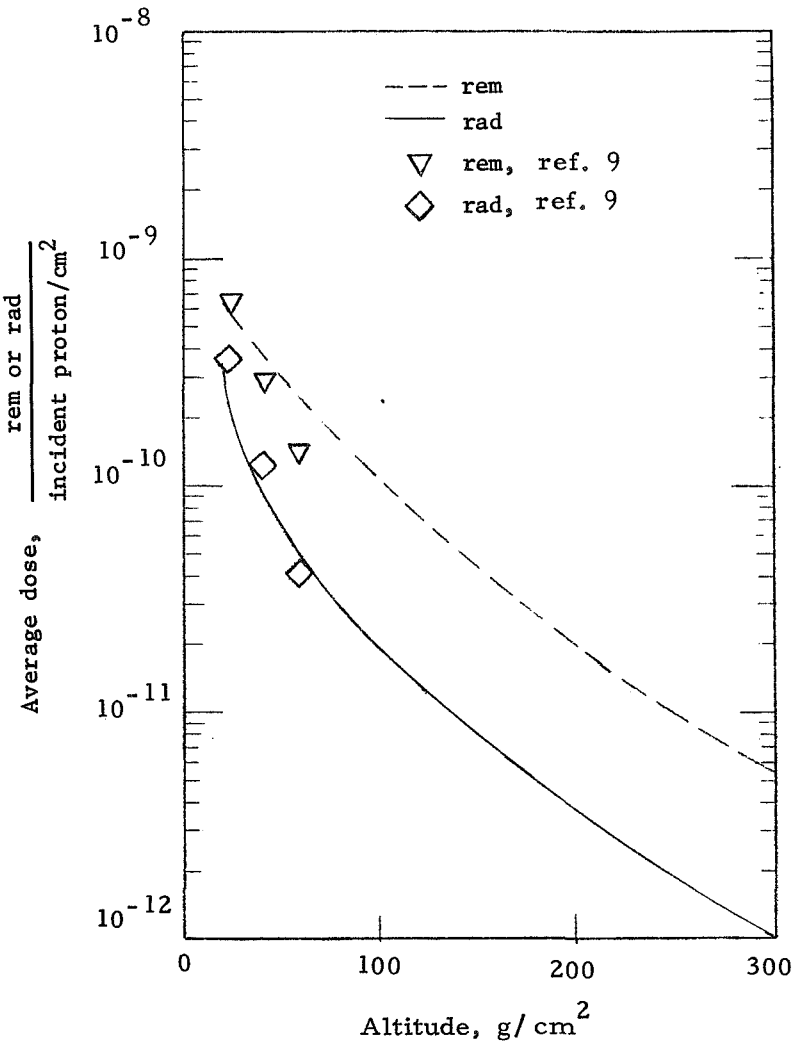


Figure 5.- Radiation dose averaged over the whole body per unit flux as a function of altitude. $P_o = 100 \frac{MV}{c}$.

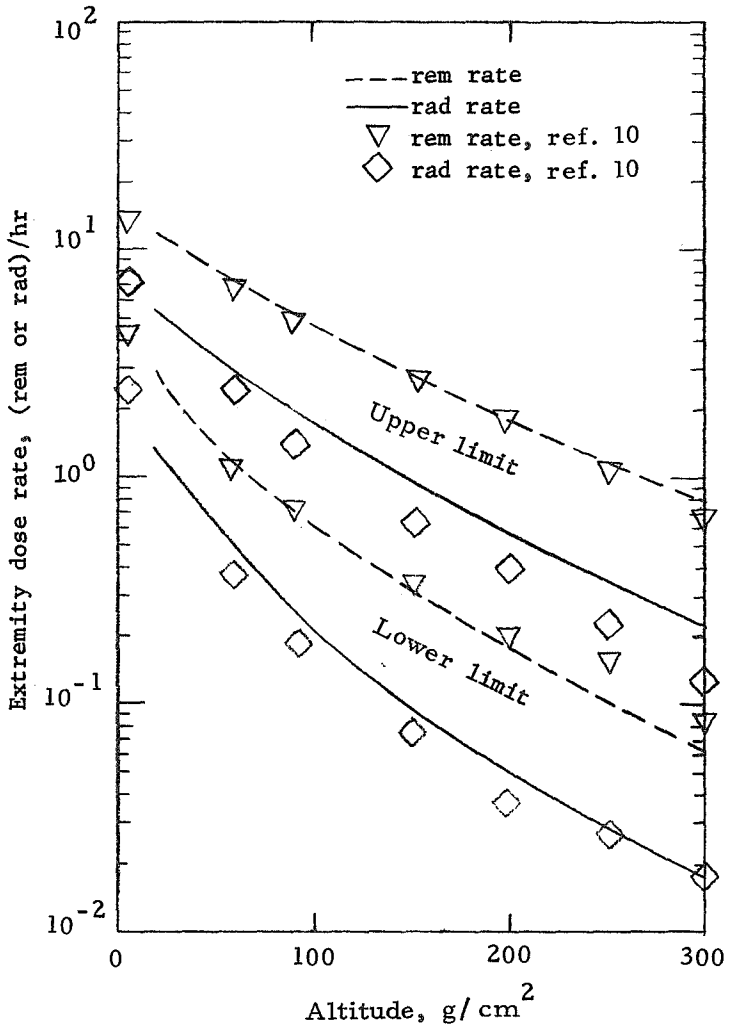


Figure 6.- Upper and lower limits of dose rate in extremities from the prompt spectrum of the February 1956 solar event.

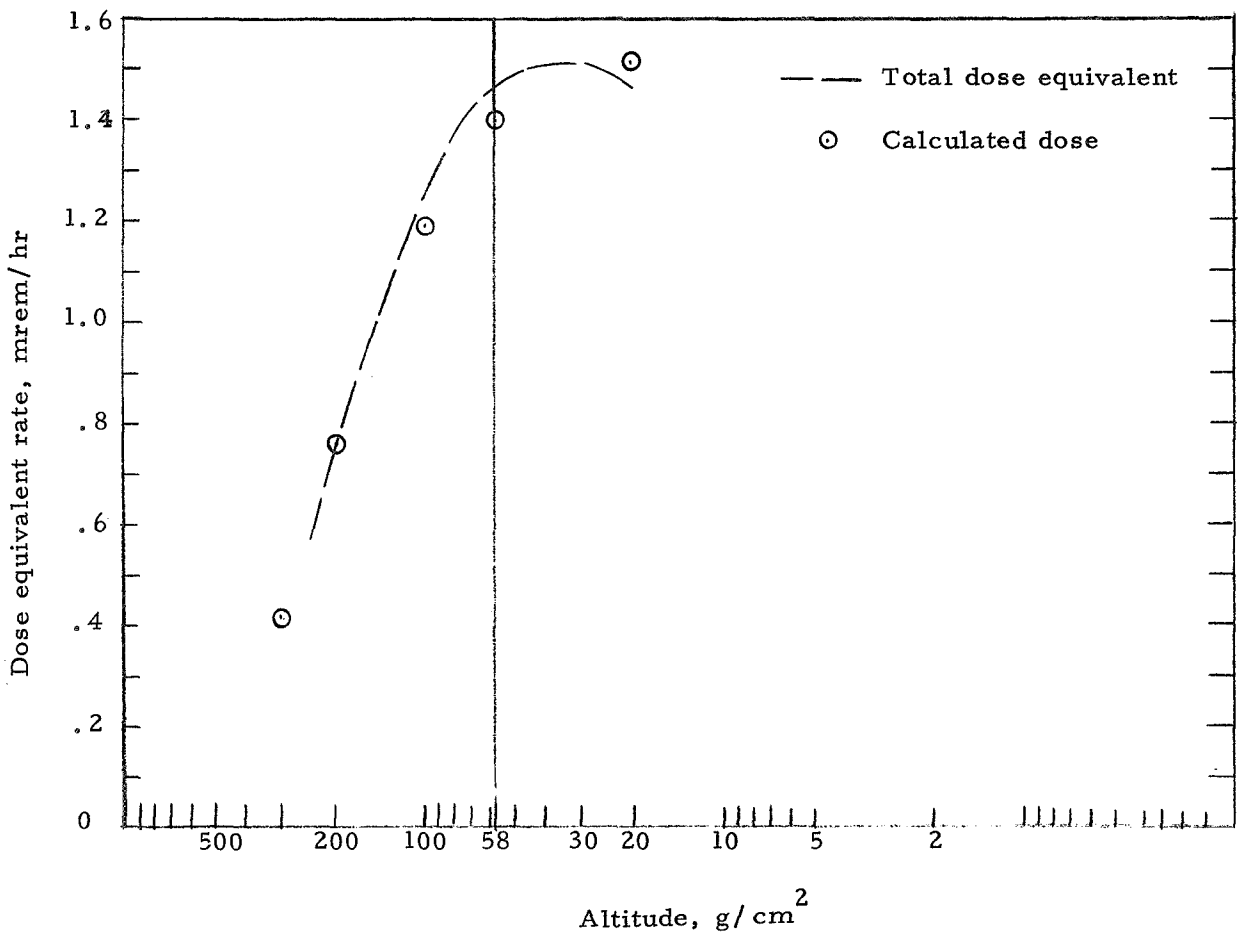


Figure 7.- Calculated and measured dose rates in the upper atmosphere due to galactic cosmic rays.

NASA-Langley, 1971 —— 29 L-7326

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