LA-7961-MS

Informal Report

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A Simplified Computer Program for General Fission Product Formation and Decay Calculations

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This report was not edited by the Technical Information staff.

Work supported by the US Department of Energy, Office of Military Application.

UNITED STATES
DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

LA-7961-MS
Informal Report

UC-32 and UC-80
Issued: August 1979

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A Simplified Computer Program for General Fission Product Formation and Decay Calculations

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FISPRO: A SIMPLIFIED COMPUTER PROGRAM FOR GENERAL FISSION PRODUCT FORMATION AND DECAY CALCULATIONS

by

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Patrick G. Bailey

ABSTRACT

This report describes a computer program that solves a general form of the fission product formation and decay equations over given time steps for arbitrary decay chains composed of up to three nuclides. All fission product data and operational history data are input through user-defined input files. The program is very useful in the calculation of fission product activities of specific nuclides for various reactor operational histories and accident consequence calculations.

I. INTRODUCTION

Much attention has been focused recently on the possible and probable environmental and health hazards of nuclear reactor power applications. The determination of the health hazard effects of a nuclear accident requires a detailed knowledge of the inventory of the fission products released. Although the simulation and severity of hypothetical nuclear reactor accidents are not well understood, the physics of the fission process has been adequately modeled, and the fission product yields from fission have been measured and tabulated.

Elaborate fission product simulation programs, such as ORIGEN and CINDER, have been developed to describe the concentrations of essentially all fission product nuclides in a reactor, both short- and long-lived, for a given fission operational history. Such large programs take into account all formation and decay schemes of each individual nuclide, including all nuclear reaction mechanisms; require complex input data; and generally require long computer running times.

The FISPRO program has been developed to model fission product concentrations with simplified nuclide formation and decay chains. In contrast with more elaborate programs, FISPRO considers only three nuclides per decay chain, ignores neutron absorption loss reactions, requires only two simple input files, and calculates the concentrations of up to 50 desired nuclides over a given fission operational history having a maximum of 1000 time steps. Depending upon the selection of input options, results can also be produced in dose units.

II. FISSION PRODUCT EQUATIONS

A. Physical Description

Fission products are formed during a fission process and decay through either radioactive decay or other nuclear processes such as neutron absorption. The amount of fission product formation, or yield, for a specific fission product is dependent on the fissioning material and the energy of the fission neutrons. Typical fission yields for U^{233}, P^{239}, Th^{232}, U^{238}, and U^{235} as a function of the mass number of the fission product are readily available in tabular or graphic form in the literature.[1]

Although nuclides having mass numbers in the range of 70 to 160 are formed directly from fission, the fission product decay equations are generally written in the form of a decay chain sequence.[2] A general fission product formation and decay chain sequence are shown in Fig. 1. Formation and decay chain sequences of the form shown in Fig. 1 are used in the FISPRO program. These decay chain sequences do not include nuclear reaction removal mechanisms, such as neutron absorption reactions. Each decay chain sequence represents nuclide formation and decay for constant nuclear mass number. Each chain begins with a parent nuclide, N_1, that is formed from a fission yield, y_1, and is removed by radioactive decay at the rate given by λ_1. Subsequent nuclides in the sequences are identified by their position relative to the parent. The daughter nuclide, N_2, is formed with its direct fission yield, y_2, and from decay from the parent nuclide with formation branching ratio, β_2. The granddaughter nuclide, N_3, is formed in a similar manner from the daughter nuclide.

B. Decay Chain and Nuclide Selection

Complete decay chain sequences for particular mass numbers have been identified in previous studies[1-4] and are used implicitly in large fission product calculation codes.[5,6] However, for specific applications, only the behavior of certain nuclides may be of interest. For such applications, the complex decay chains containing those nuclides may be simplified with certain assumptions to the form shown in Fig. 1. One such application is a calculation that considers only those fission products that are major contributors to short-term health hazard effects.

C. Mathematical Description

The rate of change of the parent, daughter, and granddaughter nuclides of any general decay chain of the form given in Fig. 1 can be expressed as

$$\frac{dN_1(t)}{dt} = y_1 \; FR(t) - \lambda_1 \; N_1(t), \tag{1}$$

$$\frac{dN_2(t)}{dt} = y_2 \; FR(t) + \beta_2 \; \lambda_1 \; N_1(t) - \lambda_2 \; N_2(t), \text{ and} \tag{2}$$

$$\frac{dN_3(t)}{dt} = y_3 \; FR(t) + \beta_3 \; \lambda_2 \; N_2(t) - \lambda_3 \; N_3(t); \tag{3}$$

where FR(t) is the fission rate for fission product formation.

III. SOLUTION METHOD

The general solution to the fission product Eqs. (1) through (3) can be obtained by using Laplace transform techniques.[7] The transformed equations can be written as

$$N_1(s) = \frac{N_1(o)}{(s+\lambda_1)} + \frac{y_1 \; FR(s)}{s(s+\lambda_1)}, \tag{4}$$

$$N_2(s) = \frac{N_2(o)}{(s+\lambda_2)} + \frac{y_2\ FR(s)}{s(s+\lambda_2)} + \frac{\beta_2\ \lambda_1}{(s+\lambda_2)}\ N_1(s), \text{ and} \tag{5}$$

$$N_3(s) = \frac{N_3(o)}{(s+\lambda_3)} + \frac{y_3\ FR(s)}{s(s+\lambda_3)} + \frac{\beta_3\ \lambda_2}{(s+\lambda_3)}\ N_2(s); \tag{6}$$

where FR(s) is the fission rate transformed to the s variable domain.

The complete solutions for the daughter and granddaughter nuclides then become

$$N_2(s) = \frac{N_2(o)}{(s+\lambda_2)} + \frac{y_2\ FR(s)}{s(s+\lambda_2)} + \beta_2\ \lambda_1 \left[\frac{N_1(o)}{(s+\lambda_1)(s+\lambda_2)} + \frac{y_1\ FR(s)}{s(s+\lambda_1)(s+\lambda_2)} \right], \text{ and} \tag{7}$$

$$N_3(s) = \frac{N_3(o)}{(s+\lambda_3)} + \frac{y_3\ FR(s)}{s(s+\lambda_3)} + \beta_3\ \lambda_2 \left\{ \frac{N_2(o)}{(s+\lambda_2)(s+\lambda_3)} + \frac{y_2\ FR(s)}{s(s+\lambda_2)(s+\lambda_3)} \right.$$

$$\left. + \beta_2\ \lambda_1 \left[\frac{N_1(o)}{(s+\lambda_1)(s+\lambda_2)(s+\lambda_3)} + \frac{y_1\ FR(s)}{s(s+\lambda_1)(s+\lambda_2)(s+\lambda_3)} \right] \right\} . \tag{8}$$

It is convenient to express the solutions given by Eqs. (4), (7), and (8) in these forms for explicit inverse Laplace transform evaluation within the program.

The solution method includes the use of vectors for storing various nuclide information, whose lengths are equal to the total number of nuclides considered. The vectors store the nuclide identification, such as name, concentration, chain sequence identifier, decay constant, and other nuclide-dependent parameters. Although separate decay chain sequences may be stored in order, nuclides within each chain sequence are stored parent first, daughter second, and then granddaughter, if any.

The time-dependent concentration equations described by Eqs. (4), (7), and (8) are then solved over discrete time steps where the fission rate, FR(t), is assumed constant. Given the problem operational history in terms of a sequence of such time steps, the solution algorithm cycles through all nuclides in their vector order for each time step. In this manner, all concentrations are calculated and stored at the end of each time step and used as the initial concentrations in the calculations for the next time step.

IV. THE FISPRO PROGRAM

The FISPRO program is written in standard FORTRAN-IV for compilation and execution on the Los Alamos Scientific Laboratory Livermore Time-Sharing System (LTSS). All program input is specified on two user-generated input files. The program produces tabular, restart, and graphic output data on three separate output files. The program input files specify the fission product nuclides to be considered, nuclide-dependent data, and the fission rate operational history of the desired calculation. The program calculates the resulting fission product history in terms of curies versus time for each nuclide specified. Depending on the amount of input nuclide data, the fission product history may also be expressed in terms of rems available per given volume. The structure and input information required for these files is given in Sec. V. The program consists of the main program and 20 subroutines. All routines are listed in Table I with a brief description of their purpose. The program is not overlaid and requires a total of 244 255 octal locations to execute using CHAT on LTSS.[8] Only minor programming changes are required to execute the program with the FTN compiler on LTSS. The Appendix contains a complete listing of the program for compilation with the CHAT compiler on the LTSS system.

V. PROGRAM INPUT FILE

The FISPRO program requires the two separate user-supplied input data files, TAPE1 and TAPE2. The TAPE1 data file identifies those fission product nuclides to be considered, and provides all the nuclide information required. The TAPE2 data file specifies the operational history of the desired calculation in terms of fission rate versus time. Both files may be easily constructed using the LTSS TRIX AC utility.[9]

A. TAPE1: Fission Product Nuclide Input Data File

The TAPE1 data file identifies the number of nuclides to be considered, the relationship of consecutive nuclides in terms of the decay chain sequence, and all necessary nuclide property information. Nuclides in a decay chain sequence are identified as a parent, daughter, or granddaughter (in that order). The information required for each nuclide includes its position in its decay chain, its decay half-life, its yield from fission, and its formation branching ratio. Additional information may be given for selected dose calculations, but it is not required. Note that because of the simplified form of the input decay chain sequence, the fission product yield of the parent nuclides should represent the accumulative yield of that nuclide. The formation and decay in the total chain that result in this nuclide are thereby included, but they are not considered explicitly. The fission yields used for the daughter and granddaughter nuclides are the direct nuclide yield from fission. The TAPE1 card image form is given in Table II, and the input variables are defined in Table III. A maximum of 50 separate fission product nuclides is allowed.

B. TAPE2: Fission Rate Operational History Input Data File

The operational history of the calculation is described in terms of a constant fission rate (given in watts) over specified time step sizes, for an arbitrary number of time steps. It is important to note that the program calculates tabular and graphical results only at the end of each time step. A core reload option is also available that simulates a core reload at the beginning of each time step. The TAPE2 card image form is given in Table IV, and the input variables are described in Table V. A maximum of 1000 time steps is allowed.

VI. PROGRAM OUTPUT FILES

During execution, the program first destroys and then creates the two output data files, TAPE3 and TAPE4. These files contain the tabulated results and the restart information, respectively. A third output file, TAPE5, containing all plotted data may also be produced, depending on the input value of KPLT on the TAPE2 data. In addition, a microfiche film file containing all plotted results is automatically produced.

A. TAPE3: Tabular Results Output File

This file lists the activity of each nuclide in curies in tabular form at the end of each time step. If dose conversion factors are included in the TAPE1 nuclide input data file, then tabular listings for dose in rems for both thyroid-organ dose and whole-body dose per given volume are also provided. A summary printout is also provided at the end of each tabular listing that orders the relative contributions from each nuclide at the end of the final time step. The TAPE3 output file is normally printed using the LTSS ALLOUT utility.[10]

B. TAPE4: Restart Data File

The restart data file consists of a comment line followed by the nuclide concentrations in atoms per given volume at the end of the final time step. The restart option allows the consecutive calculation of many TAPE2 time step files to provide detailed graphical or tabular information for specific time-step intervals.

C. Microfiche Film File

This film file is automatically generated and given a name of the form FX10577---, where the last three characters vary for each run. The file is not automatically given to the system. The file contents may be examined using the LTSS SCAN utility, and can be given to the system for microfiche production using the LTSS GIVE utility.[11,12] The title and box number of the microfiche card are defined in subroutine PLOTCI, and should be modified by the user.

D. TAPE5: Plotted Data File

The file TAPE5 is written only when the parameter KPLT on the TAPE2 input file is set equal to one. This file contains all the data plotted in the microfiche film file. The file is written as follows:

```
IN, NPTS, KU, TREST
(XX(I), YY(I), I=1,NPTS)
```

where

IN = Nuclide index.
NPTS = Number of (x,y) data points.
KU = Time unit index.
TREST = Problem restart time (s).
XX(I),YY(I) = Each (x,y) data point plotted.

This file is useful for transmitting the plotted data to other facilities.

VII. EXAMPLE CALCULATIONS

Three example calculations illustrating sample input files are considered. The first two examples compare a reactor operational history, including a core reloading over one year. The third example uses the restart option to examine the decay of fission products at zero power, following the first example. As in many applications of the program, the same TAPE1 nuclide data file is used in all examples.

A. Example TAPE1 Nuclide Data File

A nuclide data file for use with the FISPRO program has been constructed for use in a nonpower reactor safety study. The data file contains those nuclides that exhibit the most hazardous short-term health effects for thyroid-organ and whole-body doses. Twenty-five nuclides that exhibit these short-term health effects were chosen from previous reactor safety studies.[13-15] The fission product decay chains for each of these nuclides were each simplified to the form of Fig. 1 by eliminating nuclides with half lives much shorter than those under consideration, deleting all nuclides in each chain after those under consideration, and deleting all extraneous branching paths. The resulting decay chains contain a total of only 28 nuclides.

The example TAPE1 nuclide data file is listed in Table VI. The decay schemes, half lives, and branching ratios were obtained from Refs. 1 and 4. The fission product yields are based on accumulative and direct fission product yields for U^{235} thermal ENDF/B-IV data.[16,17] The dose conversion factors for both thyroid-organ and whole-body doses are taken from Ref. 14.

B. Example 1: Simple One-Year Operational History

This is an example of the fission product activities resulting in a U^{235} reactor that operates at an average daily continuous power of 255 kW for 26 weeks, shuts down for one week during which one-quarter of the core is reloaded, then again operates continuously at power for another 25 weeks. The year of operation is divided into 68 time steps of varying duration for plotting purposes. The core reload is assumed to occur at the beginning of the fourth day during the reload interval. The operational history input data file (TAPE2) for this example is shown in Table VII. The summary printout ordering the concentration results at the end of the last time step is given in Table VIII. The concentration-activity histories of the two nuclides of highest activity at the time, Xe^{133} and I^{133}, are illustrated in Figs. 2 and 3.

C. Example 2: Complex One-Year Operational History

This is an example of the effects of daily operation of the Example 1 problem. The reactor is now assumed to operate only 12 h per day, 5 days per week. For comparison purposes, the total yearly operational power level in

MW-days is assumed to be the same in both examples. Therefore, an operational power of 714 kW is used in this example. The operational history input data file (TAPE2) now includes time steps as short as 12 h. A total of 624 time steps are used. Portions of this input data file are given in Table IX. The summary printout of the nuclide concentrations (activities) at the end of the last weekend is given in Table X. The concentration-activity histories of Xe^{133} and Zr^{95} are shown in Figs. 4 and 5. Comparison of Figs. 2-5 illustrates the effect of the operational history differences.

D. Example 3: Shutdown Decay Using Restart

This example demonstrates the use of the restart option to examine the behavior of the results obtained in Example 1 during an assumed two-day shutdown period. The initial nuclide concentrations are the final concentrations of Example 1 recovered by the restart option from the restart data file (TAPE4).

The operational history input data file (TAPE2) consists of 24 two-hour time steps and is given in Table XI. The summary printout for the nuclide concentration activities at the end of these two days is given in Table XII. The concentration-activity histories of Xe^{133} and Zr^{95} are shown in Figs. 6 and 7.

VIII. SUMMARY

The utility of the program is illustrated by the above examples. Considering the present status of most calculative techniques for radiation dose involving reactor releases, the accuracy of the fission product inventory calculated with FISPRO is more than adequate. The inclusion of variable operational history and the overall simplicity of the input data files are essential elements in calculative schemes where timely, reasonable results are required. The assumptions inherent in the FISPRO program must be considered when applying the program to a specific problem. Whether additional calculative efforts are required depends on the complexity of the problem and the specific requirements of the researcher.

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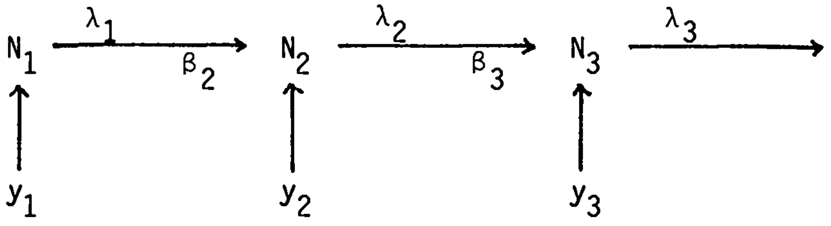

Fig. 1. General fission product formation and decay chain sequence.

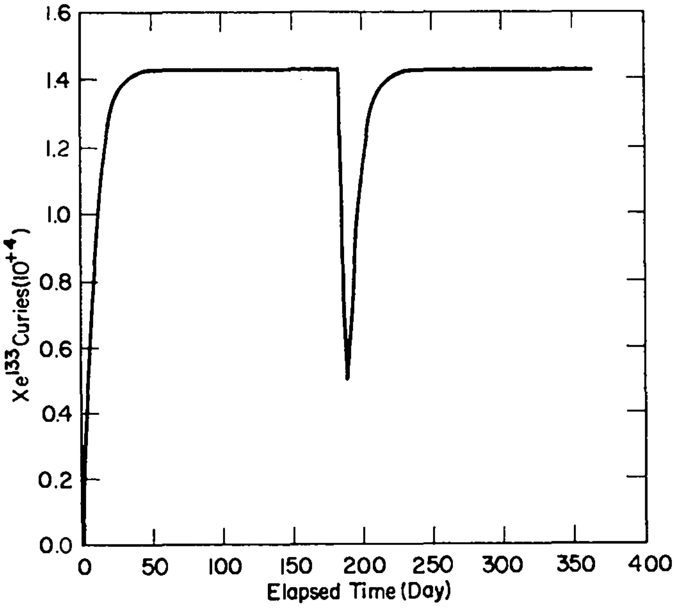

Fig. 2. Concentration history of Xe^{133} - Example 1.

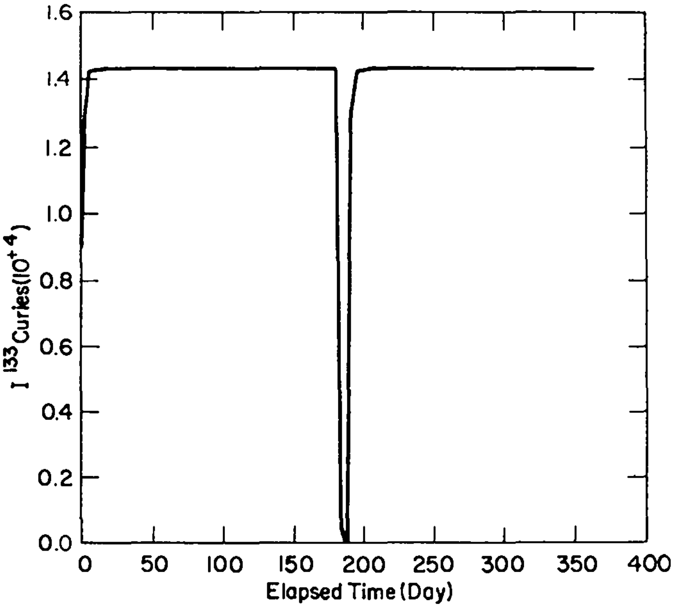

Fig. 3. Concentration history of I^{133} - Example 1.

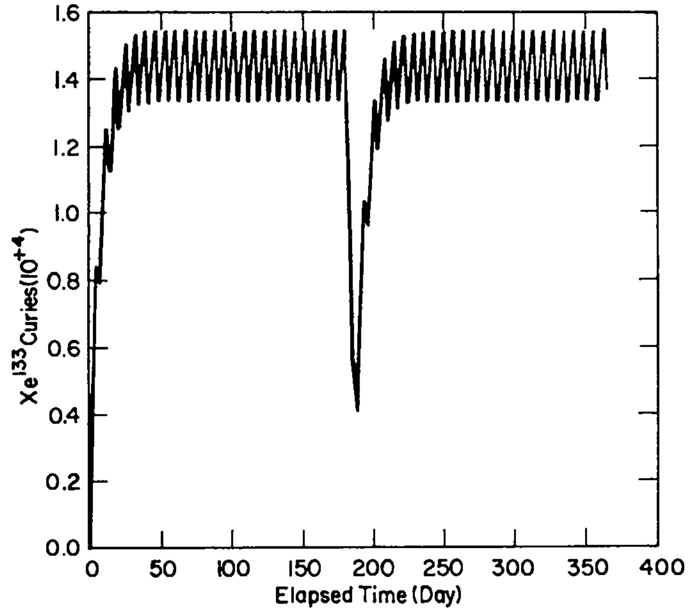

Fig. 4. Concentration history Xe^{133} - Example 2.

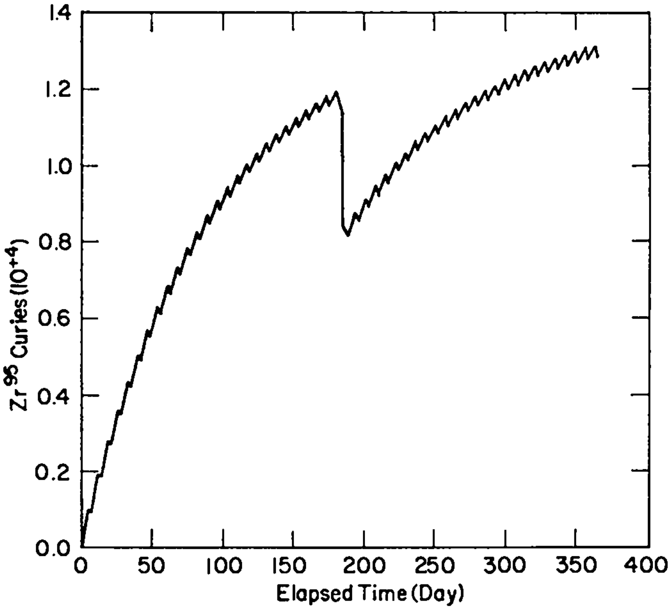

Fig. 5. Concentration history Zr^{95} - Example 2.

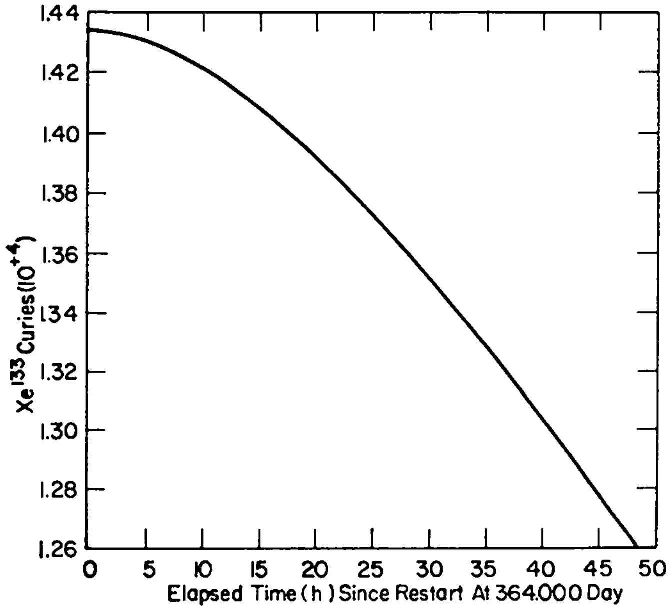

Fig. 6. Concentration history Xe^{133} - Example 3.

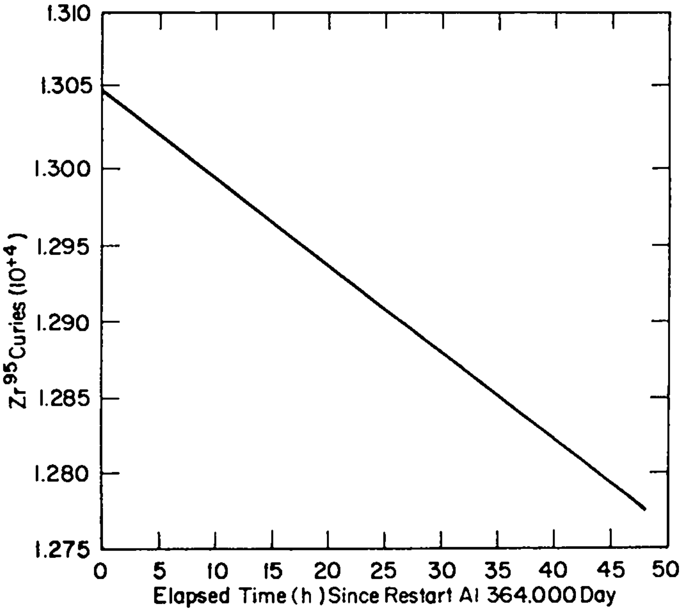

Fig. 7. Concentration history Zr^{95} - Example 3.

TABLE I

DESCRIPTION OF FISPRO SUBROUTINES

Routine	Description
MAIN	Controls input/output and program flow.
TTOSEC	Converts time and units to time in seconds.
SECTOT	Converts time in seconds to time and units.
PARENT	Solves the equations for parent nuclides.
DAUGHT	Solves the equations for daughter nuclides.
GRANDA	Solves the equations for granddaughter nuclides.
ZLAP1 through ZLAP4	Numerically calculates the inverse Laplace transform of factored polynomials from first to fourth order, respectively.
PRTCI PRTTR PRTBR	Writes the tabular results in curies, rem to thyroid organ, and rem to whole body per given volume, onto the TAPE3 output file.
DESORT	Sorts array information in decreasing order.
PLOTCI PLOTTR PLOTBR	Plots the various results in graphic form on the microfiche plot output file.
ZEROCK NEXP EXPLBL NDIGIT	Routines used by the plotting routines to simplify the information plotted.

TABLE II

CARD IMAGE FORMAT: NUCLIDE INPUT DATA FILE (TAPE1)

TAPE1 File Line Number	Input Variables	Format
1	NN	(I5)
2 through NN+1	ID, IT, X, T, IU, D, BR, DCT, DCB	(A6, I4, 2F10.5, A1, E12.6, F10.5, 2E8.2)

TABLE III

NUCLIDE INPUT DATA FILE (TAPE1) VARIABLES

Variable	Description
NN	Number of nuclides to be considered.
For Each Nuclide	
ID	Nuclide name.
IT	Decay chain position identifier of this nuclide: 0: Parent nuclide. 1: Daughter nuclide. 2: Granddaughter nuclide.
X	Initial nuclide concentration. (Default is zero.)
T	Decay half-life of this nuclide.
IU	Time units of T: S: Seconds. M: Minutes. H: Hours. D: Days. Y: Years. C: Centuries.
D	Fission product yield in per cent for this nuclide.
BR	Daughter or granddaughter formation branching ratio for this nuclide. (Default is 1.0.)
DCT	Dose conversion factor for thyroid organ dose in rem/Ci inhaled for this nuclide.
DCB	Dose conversion factor for whole-body dose in rem/Ci/m^3 for this nuclide.

TABLE IV

CARD IMAGE FORMAT: OPERATIONAL HISTORY INPUT DATA FILE (TAPE2)

TAPE2 File Line Number	Input Variables	Format
1	NZ, IREST, KPRT, KPLT	(4I5)
2 through NZ+1	DT, IU, P, COREF	(F10.5, A1, 2F10.5)

TABLE V

OPERATIONAL HISTORY INPUT DATA FILE (TAPE2) VARIABLES

Variable	Description
NZ	Number of time zones to be considered.
IREST	Restart parameter. 0: Initial nuclide concentrations are to be read from the TAPE1 input data. 1: Initial nuclide concentrations are to be read from the TAPE4 restart data file.
KPRT	Detailed nuclide result history skip option. 0: Write nuclide results after each time step on TAPE3 output file. 1: Skip these results.
KPLT	TAPE5 output plotted data file option. 0: TAPE5 not created. 1: TAPE5 created.
For Each Time Step	
DT	Time step size.
IU	Time units of DT. Refer to Table III. (Default is seconds.)
P	Fission rate power in watts.
COREF	Core fraction left after a reload before this time step. (Default is 1.0.)

TABLE VI

EXAMPLE OF NUCLIDE DATA FILE (TAPE1)

```
    28
  BR83   0    0.        2.4    H 0.531268E 0
 KR83M   1    0.      114.     M 4.192270E-6
 KR85M   0    0.        4.44   H 1.313640E 0               2.00E-1 3.64E-2
  KR85   1    0.       10.6    Y 2.333270E-3    0.225      1.80E-1 4.75E-4
  BR87   0    0.       54.5    S 2.194590E 0
  KR87   1    0.       78.     M 0.349267E 0    0.970      9.70E-1 1.81E-1
  KR88   0    0.        2.8    H 3.594440E 0               2.00E 0 4.07E-1
  SR89   0    0.       50.5    D 4.845960E 0               5.00E 2
  SR90   0    0.       28.     Y 5.913380E 0               7.00E 2
  ZR95   0    0.       65.     D 6.464270E 0               2.20E 2 1.62E-1
  NB95   1    0.       35.     D 1.810980E-5               2.10E 2 1.66E-1
 RU103   0    0.       39.7    D 3.137420E 0               1.40E 2 1.11E-1
 RU106   0    0.        1.01   Y 0.391237E 0               1.70E 2 4.31E-2
  I129   0    0.   170000.     C 0.658903E 0
TE131M   0    0.       30.     H 2.831800E 0               3.40E 4 3.14E-1
  I131   1    0.        8.05   D 3.975160E-3               4.80E 5 8.72E-2
 TE132   0    0.       77.     H 4.230910E 0               8.80E 4 4.75E-2
  I132   1    0.        2.3    H 1.695820E-2               6.60E 3 5.11E-1
  I133   0    0.       20.8    H 6.658020E 0               1.80E 5 1.54E-1
 XE133   1    0.        5.27   D 6.513530E-4               4.00E-1 9.06E-3
  I135   0    0.        6.74   H 6.349250E 0               4.40E 4 4.19E-1
 XE135   1    0.        9.2    H 9.310950E-2               9.10E-1 5.07E-2
 CS136   0    0.       13.     D 6.277150E 0               2.10E 3 4.78E-1
 CS137   0    0.       30.     Y 6.268080E 0               1.30E 3 1.22E-1
 BA140   0    0.       12.8    D 6.320240E 0               5.90E 2 4.44E-2
 LA141   0    0.        3.8    H 5.889500E 0
 CE141   1    0.       33.     D 2.311250E-5               1.60E 1 1.83E-2
 CE144   0    0.      280.     D 5.456640E 0               1.30E 1 4.31E-3
C
C         EXAMPLE TAPE1 U-235 NUCLIDE DATA FILE.
C
C         NUCLIDE CARD FORMAT  (A6,I4,2F10.5,A1,E12.6,F10.5,2E8.2)
C         NUCLIDE CARD DATA
C              ID NAME
C              PARENT, DAUGHTER, OR GRANDDAUGHTER (0,1,2) (REF. 1)
C              INITIAL CONCENTRATION (ATOMS/VOLUME)
C              HALF-LIFE NUMBER (REF. 1)
C              HALF-LIFE UNITS (S,M,H,D,Y,C = SEC,MIN,ETC.)
C              U-235 THERMAL FISSION PRODUCT YIELD (REF. 2)
C                   ACCUMULATIVE YIELDS FOR PARENTS
C                   DIRECT YIELDS FOR DAUGHTERS
C              FORMATION BRANCHING RATIO (REF. 1)
C              REM/CI INHALED FOR THYROID ORGAN DOSE1 (REF. 3)
C              REM/CI-SEC/M/M/M PHOTON WHOLE-BODY DOSE (REF. 3)
C
C         REFERENCES
C              1.  BOOK BY ZYSIN (539Z99VT, C.1).
C              2.  T-2 ENDF/8-4 0.025 U-235 FISSION DATA LISTING.
C              3.  WASH-1400, APPENDIX 6, PAGES D-12 AND C-5.
```

TABLE VII

OPERATIONAL HISTORY INPUT DATA FILE (TAPE2) FOR EXAMPLE 1

```
  62       0    0    0
 1.0         D 255000.
 2.0         D 255000.
 4.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
 7.0         D 255000.
  1.0        D      0.
  1.0        D      0.
  1.0        D      0.
  1.0        D      0.   0.75
  1.0        D      0.
  1.0        D      0.
  1.0        D      0.
 1.0         D 255000.
```

```
(CONTINUED)

2.0         D 255000.
4.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
7.0         D 255000.
EXAMPLE 1 TAPE2 INPUT FILE.
26 WEEKS AT 255 kW.
 1 WEEK AT    0 kW WITH RELOAD ON 4TH DAY.
25 WEEKS AT 255 kW.
```

TABLE VIII

PRINTOUT OF FINAL NUCLIDE CONCENTRATIONS FOR EXAMPLE 1

```
PROGRAM FISPRO RESULTS.

                 NUCLIDE CONCENTRATIONS (CURIES PER GIVEN VOLUME)
                 RELATIVE COMPARISONS.

                 AT ELAPSED TIME OF 3.144960E+07 SECONDS
                 SINCE RESTART TIME OF 0. SEC.


                 NUCLIDE CURIES PER VOLUME

                  XE133           1.4341E+04
                   I133           1.4339E+04
                  XE135           1.3875E+04
                   I135           1.3674E+04
                  BA140           1.3611E+04
                  CS136           1.3519E+04
                   ZR95           1.3052E+04
                  LA141           1.2684E+04
                  CE141           1.2566E+04
                   NB95           1.2222E+04
                   SR89           1.0083E+04
                   I132           9.1487E+03
                  TE132           9.1122E+03
                   KR88           7.7414E+03
                  RU103           6.6413E+03
                  CE144           6.1692E+03
                   I131           6.1075E+03
                 TE131M           6.0989E+03
                   KR87           5.3370E+03
                   BR87           4.7265E+03
                  KR85M           2.8292E+03
                  KR83M           1.1442E+03
                   BR83           1.1442E+03
                  RU106           3.6632E+02
                   SR90           2.6601E+02
                  CS137           2.6337E+02
                   KR85           3.4716E+01
                   I129           4.9380E-05

                 TOTAL            2.1110E+05
```

TABLE IX

PORTIONS OF THE OPERATIONAL HISTORY INPUT DATA FILE (TAPE2) FOR EXAMPLE 2

```
624     0    1    0
 12.0    H 714000.
 12.0    H      0.
 12.0    H 714000.
 12.0    H      0.
 12.0    H 714000.
 12.0    H      0.
 12.0    H 714000.
 12.0    H      0.
 12.0    H 714000.
 12.0    H      0.
 24.0    H      0.
 24.0    H      0.
          .
          .
          .
    24 ADDITIONAL WEEKS
    AT 12 LINES PER WEEK.
          .
          .
          .
 12.0    H 714000.
 12.0    H      0.
 12.0    H 714000.
 12.0    H      0.
 12.0    H 714000.
 12.0    H      0.
 12.0    H 714000.
 12.0    H      0.
 12.0    H 714000.
 12.0    H      0.
 24.0    H      0.
 24.0    H      0.
 12.0    H      0.
 12.0    H      0.
 12.0    H      0.
 12.0    H      0.
 12.0    H      0.
 12.0    H      0.
 12.0    H      0.     0.75
 12.0    H      0.
 12.0    H      0.
 12.0    H      0.
 24.0    H      0.
 24.0    H      0.
```

(CONTINUED)

```
 12.0    H 714000.
 12.0    H      0.
 12.0    H 714000.
 12.0    H      0.
 12.0    H 714000.
 12.0    H      0.
 12.0    H 714000.
 12.0    H      0.
 12.0    H 714000.
 12.0    H      0.
 24.0    H      0.
 24.0    H      0.
          .
          .
          .
    23 ADDITIONAL WEEKS
    AT 12 LINES PER WEEK.
          .
          .
          .
 12.0    H 714000.
 12.0    H      0.
 12.0    H 714000.
 12.0    H      0.
 12.0    H 714000.
 12.0    H      0.
 12.0    H 714000.
 12.0    H      0.
 12.0    H 714000.
 12.0    H      0.
 24.0    H      0.
 24.0    H      0.
```

EXAMPLE 2 TAPE2 DATA FILE,
TOTAL OF 52 WEEKS,
EACH WEEK DIVIDED INTO 7 DAYS,
FIRST 5 DAYS OF EACH WEEK ARE
    DIVIDED INTO TWO 12-HR PERIODS,
26 WEEKS AT 714 kW DURING
    FIRST HALF OF EACH WEEKDAY,
1 WEEK AT 0 kW WITH RELOAD ON
    4TH DAY,
25 WEEKS AT 714 kW DURING
    FIRST HALF OF EACH WEEKDAY.

TABLE X

PRINTOUT OF FINAL NUCLIDE CONCENTRATIONS - EXAMPLE 2

```
PROGRAM FISPRO RESULTS.

         NUCLIDE CONCENTRATIONS (CURIES PER GIVEN VOLUME)
         RELATIVE COMPARISONS.

         AT ELAPSED TIME OF 3.144960E+07 SECONDS
         SINCE RESTART TIME OF  0.       .

         NUCLIDE  CURIES PER VOLUME

           XE133          1.3675E+04
            ZR95          1.2878E+04
           BA140          1.2682E+04
           CS136          1.2610E+04
           CE141          1.2294E+04
            NB95          1.2244E+04
            SR89          9.9093E+03
            I132          6.8417E+03
           TE132          6.6373E+03
           RU103          6.4959E+03
           CE144          6.1501E+03
            I131          6.0144E+03
            I133          3.2069E+03
          TE131M          2.3248E+03
           XE135          9.4365E+02
           RU106          3.6546E+02
            SR90          2.6599E+02
           CS137          2.6335E+02
            I135          6.1989E+01
            KR85          3.4739E+01
           KR85M          5.8721E-01
           LA141          5.6390E-01
            KR88          7.3050E-03
           KR83M          4.4067E-04
            BR83          9.2586E-05
            I129          4.9379E-05
            KR87          1.9249E-10
            BR87          0.

         TOTAL            1.2590E+05
```

TABLE XI

OPERATIONAL HISTORY INPUT DATA FILE (TAPE2) - EXAMPLE 3

```
   24       1         0    0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
  2.0        H        0.0
EXAMPLE 3 TAPE2 INPUT FILE,
A RESTART FILE,
TWO DAYS AT ZERO POWER.
```

TABLE XII

PRINTOUT OF FINAL NUCLIDE CONCENTRATIONS - EXAMPLE 3

```
PROGRAM FISPRO RESULTS.

          NUCLIDE CONCENTRATIONS (CURIES PER GIVEN VOLUME)
          RELATIVE COMPARISONS.

          AT ELAPSED TIME OF 1.728000E+05 SECONDS
          SINCE RESTART TIME OF 364.000 DAY.

          NUCLIDE  CURIES PER VOLUME

             ZR95          1.2777E+04
            XE133          1.2623E+04
             NB95          1.2249E+04
            BA140          1.2214E+04
            CS136          1.2151E+04
            CE141          1.2108E+04
             SR89          9.8097E+03
            RU103          6.4134E+03
            CE144          6.1387E+03
             I132          6.0973E+03
            TE132          5.9152E+03
             I131          5.7152E+03
             I133          2.8963E+03
           TE131M          2.0119E+03
            XE135          1.1109E+03
            RU106          3.6495E+02
             SR90          2.6597E+02
            CS137          2.6333E+02
             I135          9.8192E+01
             KR85          3.4734E+01
            LA141          1.9989E+00
            KR85M          1.5750E+00
             KR88          5.3494E-02
            KR83M          5.1298E-03
             BR83          1.0912E-03
             I129          4.9380E-05
             KR87          4.1373E-08
             BR87          0.

          TOTAL            1.2126E+05
```

APPENDIX

COMPLETE LISTING OF FISPRO PROGRAM

```
      PROGRAM FISPRO(TAPE1,TAPE2,TAPE3,TAPE4,TAPE5,TAPE63=100B)
C        CALCULATES THE TIME-DEPENDENT HISTORY OF FISSION PRODUCTS.
C        WRITTEN BY:  PATRICK BAILEY, Q-6.

C        GIVEN:
C           NUMBER OF TIME ZONES, NZ
C           RESTART PARAMETER, IREST (0/1 = NO/YES)
C           DETAILED TIME STEP PRINT OUTS, KPRT (0/1 = YES/NO)
C           CREATE TAPE5 PLOTTED DATA FILE (0/1 = YES/NO)
C           NUMBER OF NUCLIDES, NN
C           FOR EACH TIME ZONE:  I=1,NZ
C              ZONE DURATION, DT
C              DURATION UNIT, IU (S, M, H, D, Y, OR C)
C              POWER, P (WATTS)
C              CORE FRACTION (LEFT AFTER A RELOAD)
C                  AT THE BEGINNING OF THE TIME ZONE

C           FOR EACH NUCLIDE:    J=1,NN
C              IDENTIFICATION, ID
C              PARENT OR DAUGHTER FLAG, IT (0/1 = PARENT/DAUGHTER)
C              INITIAL QUANTITY, X
C              HALF-LIFE, T
C              HALF-LIFE UNIT, IU (S, M, H, D, Y, OR C)
C              FISSION PERCENTAGE PRODUCTION (DIRECT), D
C              DAUGHTER FROM PARENT BRANCHING RATIO, BR (BLANK = 1.)
C              THYROID DOSE CONVERSION FACTORS (REM/CI-INHALED)
C              WHOLE BODY DOSE CONVERSION FACTORS (REM/CI/M/M/M)

C        CALCULATES
C           LAMDA'S, L (1/SEC)
C           FISSION RATE, FR (FISSIONS/SEC)
C           NUCLIDE QUANTITIES BEFORE, X, AND AFTER, Y, EACH TIME ZONE

C        ASSUMES:
C           1. FISSION RATE (POWER) IS CONSTANT OVER EACH TIME ZONE.
C           2. ONLY PARENT, PARENT-DAUGHTER, AND
C              PARENT-DAUGHTER-GRANDAUGHTER
C              NUCLIDE DECAY CHAINS ARE ALLOWED.
C           3. MAXIMUM OF MAXNZ TIME ZONES AND MAXNN NUCLIDES ALLOWED.
C              NOTE: /B1/ ARRAYS ARE ALL OF LENGTH (MAXNZ),
C                    /B2/ ARRAYS ARE ALL OF LENGTH (MAXNN), AND
C                    /B3/ ARRAYS XX AND YY ARE OF LENGTH (MAXNZ+1), WHILE
C                    /B5/ ARRAY XS IS OF LENGTH (MAXNZ+1,MAXNN).

      COMMON /B1/ NZ,DT(1000),P(1000),FR(1000),ET(1000),COREF(1000)
      COMMON /B2/ NN,ID(50),IT(50),X(50),Y(50),T(50),IU(50),
     1            D(50),BR(50),L(50),DCT(50),DCB(50)
      COMMON /B3/ IZ,IN,XX(1001),YY(1001),XB(2),YB(2)
      COMMON /B4/ IREST,TREST,KPRT,KPLT
      LCM B5
      COMMON /B5/ XS(1001,50)
      LCM CBLK
      COMMON/CBLK/ BUFF(5000)
      REAL ID,IU,L

      DATA MAXNZ /1000/, MAXNN /50/


C        TAPE1 IS THE NUCLIDE DATA INPUT FILE
C        TAPE2 IS THE TIME ZONE DATA INPUT FILE
C        TAPE3 IS THE PROGRAM'S OUTPUT FILE.
C        TAPE4 IS THE RESTART NUCLIDE CONCENTRATION FILE.
C        TAPE5 IS THE PLOTTED DATA OUTPUT FILE
C             (WRITTEN ONLY IF NZ IS GIVEN WITH A MINUS SIGN)
```

```
      CALL CHANGE (7H+FISPRO)

      WRITE (59,800)
  800 FORMAT ("EXECUTING FISPRO",/,
     1   "   TAPE1 = NUCLIDE INPUT DATA.",/,
     2   "   TAPE2 = TIME ZONE INPUT DATA.",/,
     3   "   TAPE3 = OUTPUT DATA.",/,
     5   "   TAPE4 = RESTART AND POSTFIS DATA.",/,
     6   "   TAPE5 = OPTIONAL PLOTTED DATA.")


C        DESTROY ANY EXISTING VERSIONS OF GENERATED TAPE FILES.
      CALL DEVICE(7HDESTROY,5HTAPE3)
      CALL DEVICE(7HDESTROY,5HTAPE5)
      REWIND 1
      REWIND 2
      REWIND 3
      REWIND 4
      REWIND 5

C        READ IN THE TIME ZONE PARAMETERS AND THE RESTART DATA

      READ (2,10) NZ,IREST,KPRT,KPLT
   10 FORMAT (4I5)
      IF (NZ.LE.MAXNZ)  GO TO 15
      WRITE (59,810) NZ,MAXNZ
  810 FORMAT(/," NZ = ",I3,/,
     1   " AND IS GREATER THAN THE ",I3," ALLOWED.",/,
     2   " FATAL ERROR.")
      CALL EXIT

   15 READ (2,20) (DT(I),IU(I),P(I),COREF(I),I=1,NZ)
   20 FORMAT (F10.5,A1,F10.5,F10.5)
C        CONVERT TIME DURATIONS TO SECONDS
      CALL TTOSEC(NZ,DT,IU)
C        CONVERT BLANK CORE FRACTIONS TO ONE
      DO 22  I=1,NZ
      IF (COREF(I).LE.0.)  COREF(I)=1.
   22 CONTINUE

C        CREATE TAPE5 PLOTTED DATA FILE VIA KPRT
      IF (KPRT.EQ.1)  CALL DEVICE(6HCREATE,5HTAPE5,200000,0)

C        READ IN THE NUCLIDE PARAMETERS

      READ (1,10) NN
      IF (NN.LE.MAXNN) GO TO 25
      WRITE (59,820) NN,MAXNN
  820 FORMAT (/," NN = ",I3,/,
     1   " AND IS GREATER THAN THE ",I3," ALLOWED.",/,
     2   " FATAL ERROR.")
      CALL EXIT

   25 READ (1,30) (ID(J),IT(J),X(J),T(J),IU(J),D(J),BR(J),
     1             DCT(J),DCB(J),J=1,NN)
   30 FORMAT (A6,I4,2F10.5,A1,E12.6,F10.5,2E8.2)
C        INCLUDE RESTART DATA IF REQUESTED
      IF (IREST.EQ.1) GO TO 44
C        FOR NO RESTART
      TREST=0.
      GO TO 45
C        FOR A RESTART
   44 TB4=TREST
```

```
      READ (4,16) CC
   16 FORMAT (1A1)
      READ (4,17) TREST,(X(J),J=1,NN)
   17 FORMAT (1PE14.7,/,(1P5E14.7))
      TREST=TREST+TB4

C         CONVERT HALF-LIVES TO SECONDS
   45 CALL TTOSEC(NN,T,IU)
C         FISSION RATES AND ELAPSED TIME SINCE TREST
      ET(1)=DT(1)
      DO 40  I=1,NZ
      IF (I.GT.1)  ET(I)=ET(I-1)+DT(I)
   40 FR(I)=P(I)/(1.6E-13*200.)
C         CONVERT D FROM PERCENT
C         AND ALL BLANK (ZERO) BRANCHING RATIOS TO ONE
      DO 50  J=1,NN
      D(J)=D(J)/100.
      IF (BR(J).EQ.0.)  BR(J)=1.
   50 CONTINUE
C         LAMDBA'S
      DO 60  J=1,NN
   60 L(J)= 0.69314718/T(J)
C         CHECK FOR ALL ZERO DOSE CONVERSION FACTORS AND FLAG
      DO 62  I=1,NN
      IF (DCT(I).GT.0.)  GO TO 63
   62 CONTINUE
      KDCT=0
      GO TO 64
   63 KDCT=1
   64 DO 66  I=1,NN
      IF (DCB(I).GT.0.)  GO TO 67
   66 CONTINUE
      KDCB=0
      GO TO 68
   67 KDCB=1
   68 CONTINUE

C         OUTPUT INPUT
      WRITE (3,70) NZ,IREST,KPRT,KPLT,TREST
   70 FORMAT ("1PROGRAM FISPRO RESULTS.",//,
     1   " TIME ZONE INFORMATION",//,
     2   " NZ    = ",I3,/,
     2   " IREST = ",I3,/," KPRT  = ",I3,/," KPLT  = ",I3,/,
     3   " TREST = ",1PE15.7,///)
      DO 72  I=1,NZ
      XX(I)=DT(I)
   72 CALL SECTOT(XX(I),YY(I),KU,Q)
      WRITE (3,75) (I,XX(I),YY(I),DT(I),ET(I),P(I),COREF(I),FR(I),I=1,NZ)
   75 FORMAT (3X,"IZ   TIME STEP SIZE",
     1   "          DT(SEC)        TIME(SEC)     POWER(WATTS)",
     1   "  CORE FRACTION     FISSION RATE(1/SEC)",//,
     2   (1X,I4,0PF13.3,1X,A3,1PE15.5,1PE15.5,1PE15.5,1PE15.5,1PE22.5))
      WRITE (3,80) NN
   80 FORMAT ("1NUCLIDE DECAY CHAIN INFORMATION.",//,
     1   " NN = ",I3,////)
      IF (IREST.NE.0) WRITE (3,81)
   81 FORMAT (" RESTART DATA USED FROM TAPE4.",///)
      WRITE (3,82)
   82 FORMAT (2X,"IN",7X,"ID   IT   INITIAL AMOUNT",
     1   "   HALF-LIFE(SEC)   LAMBDA(1/SEC)    DIRECT YIELD",
     2   "     BRANCH RATIO",//)
      DO 88  J=1,NN
      IF (IT(J).EQ.0) WRITE(3,84) J,ID(J),IT(J),X(J),T(J),L(J),D(J)
   84 FORMAT (I4,3X,A6,I5,1PE17.5,1PE17.5,1PE16.5,1PE16.5)
```

```
      IF (IT(J).EQ.1) WRITE(3,86) J,ID(J),IT(J),X(J),T(J),L(J),D(J),BR(J)
   86 FORMAT (I4,3X,A6,I5,1PE17.5,1PE17.5,1PE16.5,1PE16.5,0PF16.5)
   88 CONTINUE

      WRITE (3,380) NN
  380 FORMAT ("1NUCLIDE DOSE CONVERSION INFORMATION.",//,
     1   " NN = ",I3,////)
      IF (IREST.NE.0) WRITE (3,381)
  381 FORMAT (" RESTART DATA USED FROM TAPE4.",///)
      WRITE (3,382)
  382 FORMAT (2X,"IN",7X,"ID",5X,"THYROID ORGAN DOSE",
     1   8X,"WHOLE BODY DOSE",/,
     2   22X,"REM/CI-INHALED",5X,"REM/CI/CUBIC METER",//)
      DO 388  J=1,NN
  388 WRITE (3,384) J,ID(J),DCT(J),DCB(J)
  384 FORMAT (I4,3X,A6,1P2E23.2)

C        CALCULATE AND PRINT EQUILIBRUM CONCENTRATIONS
C        ASSUMING FIRST TIME ZONE POWER LEVEL.
      DO 300  I=1,NN
      Y(I)=D(I)*FR(1)
      IF (IT(I).NE.0)  Y(I)=Y(I)+BR(I)*Y(I-1)*3.7E+10
  300 Y(I)=Y(I)/(3.7E10)
      WRITE (3,310) (I,ID(I),IT(I),Y(I),I=1,NN)
  310 FORMAT ("1NUCLIDE EQUILIBRUM CONCENTRATIONS IN CURIES",/,
     1   " ASSUMING FIRST TIME STEP POWER LEVELS.",///,
     2   2X,"IN",7X,"ID   IT",3X,
     3   "EQUILIBRUM AMT",//,(I4,3X,A6,I5,1PE17.5))

C        STORE THE INITIAL VALUES IN XS IN DUMMY TIME STEP ONE.
      DO 90  J=1,NN
   90 XS(1,J)=X(J)

C        DO FOR ALL TIME ZONES
      DO 150  IZ=1,NZ

C        ALTER DENSITIES BY THE CORE FRACTION LEFT AFTER A CORE RELOAD
C        AT THE BEGINNING OF THE TIME STEP.
      DO 110  IN=1,NN
  110 X(IN)=X(IN)*COREF(IZ)

C        DO FOR ALL NUCLIDES
      DO 100  IN=1,NN

      IF (IT(IN).LT.0.OR.IT(IN).GT.2) WRITE (59,95) IT(IN),IN
   95 FORMAT (/," IT = ",I3," AND IS OUT OF RANGE FOR NUCLIDE",I3)
C        PERFORM THE DECAY TRANSMUTATIONS
      IF (IT(IN).EQ.0)  CALL PARENT
      IF (IT(IN).EQ.1)  CALL DAUGHT
      IF (IT(IN).EQ.2)  CALL GRANDA
C        CORRECT FOR POSSIBLE UNDERFLOW
      IF (Y(IN).LT.1.E-100)  Y(IN)=0.
C        STORE THE CALCULATED RESULTS
      XS(IZ+1,IN)=Y(IN)

  100 CONTINUE

C        UPDATE THE INITIAL VALUE FOR THE NEXT TIME STEP
      DO 115  IN=1,NN
  115 X(IN)=Y(IN)

  150 CONTINUE

C        STORE NUCLIDE RESULTS (IN ATOMS/VOLUME) AT END OF TIME ZONE NZ
```

```
C        ON UNIT 4 FOR RESTART AND POSTFIS (GIVE TWICE DEFAULT FILE SIZE).
      CALL DEVICE(7HDESTROY,5HTAPE4)
      REWIND 4
C        WRITE THE TAPE4 RESTART FILE (ALSO USED FOR POSTFIS PLOTTING)
      CC=1HC
      WRITE (4,16) CC
      TREST4=ET(NZ)+TREST
      WRITE (4,17) TREST4,(XS(NZ+1,IN),IN=1,NN)

C        CONVERT THE STORED RESULTS FROM ATOMS TO CURIES
C        FOR THE OUTPUT PORTION ONLY.
      NZ1=NZ+1
      DO 200  IZ=1,NZ1
      DO 200  IN=1,NN
  200 XS(IZ,IN)=XS(IZ,IN)*L(IN)/3.7E10

C        OUTPUT THE RESULTS

C        PLOT THE RESULTS IN CURIES
      CALL PLOTCI
C        PRINT THE RESULTS IN CURIES
      CALL PRTCI

        IF (KDCT.EQ.0)  GO TO 220

C        PLOT THE RESULTS IN REM DOSE TO THYROID
      CALL PLOTTR
C        PRINT THE RESULTS IN REM DOSE TO THYROID
      CALL PRTTR

  220 IF (KDCB.EQ.0)  GO TO 240

C        PLOT THE RESULTS IN REM DOSE TO WHOLE BODY
      CALL PLOTBR
C        PRINT THE RESULTS IN REM DOSE TO WHOLE BODY
      CALL PRTBR

  240 CONTINUE

      WRITE (59,850)
  850 FORMAT ("FISPRO FINISHED.")

      CALL EXIT
      END
      SUBROUTINE TTOSEC(N,T,IU)
C        CONVERTS THE TIME INPUT UNITS IN ARRAY T OF LENGTH N
C        FROM THE UNIT DENOTED BY ARRAY IU OF LENGTH N
C        INTO SECONDS.
C        ALLOWABLE IU VALUES ARE: S, M, H, D, Y, AND C.
C        A BLANK DEFAULTS TO S (SECONDS).
      DIMENSION T(1),IU(1)
      REAL IU

      DO 10  J=1,N
      IF (IU(J).EQ.1H )  GO TO 10
      IF (IU(J).EQ.1HS)  GO TO 10
      T(J)=T(J)*60.
      IF (IU(J).EQ.1HM)  GO TO 10
      T(J)=T(J)*60.
      IF (IU(J).EQ.1HH)  GO TO 10
      T(J)=T(J)*24.
      IF (IU(J).EQ.1HD)  GO TO 10
      T(J)=T(J)*365.
      IF (IU(J).EQ.1HY)  GO TO 10
```

```
      T(J)=T(J)*100.
      IF (IU(J).EQ.1HC)  GO TO 10

      WRITE (59,800) J,IU(J)
  800 FORMAT (/,"ERROR IN TAPE1 INPUT IN TIME INPUT UNITS",
     1   " FOR ARRAY INDEX NUMBER",I2,/,
     2   " IU(J,/, =",A2,", WHICH IS NOT ALLOWED.",/,
     3   " FATAL ERROR.")
      CALL EXIT

   10 CONTINUE

      RETURN
      END
      SUBROUTINE SECTOT(T,IU,KU,Q)
C        CONVERTS THE TIME INPUT VALUE T
C        FROM SECONDS
C        INTO UNITS DENOTED BY IU.
C        ALLOWABLE IU VALUES ARE: S, M, H, D, Y, AND C.

C        M IS THE MAXIMUM NUMBER OF UNITS ALLOWED
C        BEFORE CHAINGING TO THE NEXT LARGER UNIT.
C        KU IS THE CHOSEN UNIT INDEX
C        AND Q IS THE ULTIMATE CONVERSION FACTOR (DIVISOR)

      DIMENSION JU(6),TU(6)
      REAL IU,JU
      DATA JU /3HSEC,3HMIN,3H HR,3HDAY,3H YR,3HCEN/
      DATA TU /60.,60.,24.,365.,100.,0./
      DATA M /5/

      Z=1.
      Q=1.
      DO 10  KU=1,5
      Z=Q*M*TU(KU)
      IF (T.LT.Z)  GO TO 20
      Q=Q*TU(KU)
   10 CONTINUE
      KU=6

   20 IU=JU(KU)
      T=T/Q

      RETURN
      END
      SUBROUTINE PARENT
C        GIVEN:    DX(IN)/DT = D(IN)*FR(IZ) - L(IN)*X(IN),
C          AND:    X(IN).
C        FINDS:    Y(IN),
C        WHERE:    X(IN) IS GIVEN AS THE INITIAL AMOUNT AT TIME TREST,
C          AND:    Y(IN) IS THE AMOUNT AFTER TIME DT(IZ).

      COMMON /B1/ NZ,DT(1000),P(1000),FR(1000),ET(1000),COREF(1000)
      COMMON /B2/ NN,ID(50),IT(50),X(50),Y(50),T(50),IU(50),
     1            D(50),BR(50),L(50),DCT(50),DCB(50)
      COMMON /B3/ IZ,IN,XX(1001),YY(1001),XB(2),YB(2)
      REAL ID,IU,L

      IF (L(IN).EQ.0.)  GO TO 100

      RA=D(IN)*FR(IZ)
      Y(IN) = X(IN)*ZLAP1(DT(IZ),L(IN))
     1        + RA *ZLAP2(DT(IZ),0.,L(IN))
      RETURN
```

```
  100 WRITE (59,110) IN
  110 FORMAT(/," PARENT CALLED WITH LAMBDA = 0. FOR NUCLIDE",I3,//,
     1   " FATAL ERROR")
      CALL EXIT

      RETURN
      END
      SUBROUTINE DAUGHT
C        GIVEN:    DX(IN-1)/DT = D(IN-1)*FR(IZ) - L(IN-1)*X(IN-1),
C          AND:    DX(IN)/DT   = D(IN)*FR(IZ) - L(IN)*X(IN)
C                                + BR(IN)*L(IN-1)*X(IN-1),
C          AND:    X(IN).
C        FINDS:    Y(IN),
C        WHERE:    X(IN) IS GIVEN AS THE INITIAL AMOUNT AT TIME TREST,
C          AND:    Y(IN) IS THE AMOUNT AFTER TIME DT(IZ).

      COMMON /B1/ NZ,DT(1000),P(1000),FR(1000),ET(1000),COREF(1000)
      COMMON /B2/ NN,ID(50),IT(50),X(50),Y(50),T(50),IU(50),
     1            D(50),BR(50),L(50),DCT(50),DCB(50)
      COMMON /B3/ IZ,IN,XX(1001),YY(1001),XB(2),YB(2)
      REAL ID,IU,L

      IF (IN.EQ.1)  GO TO 100
      IF (L(IN).EQ.0.)  GO TO 120
      IF (L(IN).EQ.L(IN-1))  GO TO 140
      IF (BR(IN).EQ.0.)  GO TO 160

      RB=D(IN)  *FR(IZ)
      RA=D(IN-1)*FR(IZ)
      Y(IN) = X(IN)*ZLAP1(DT(IZ),L(IN))
     1        + RB *ZLAP2(DT(IZ),0.,L(IN))
     2        + (BR(IN)*L(IN-1)) *
     3          (X(IN-1)*ZLAP2(DT(IZ),L(IN-1),L(IN))
     4           +RA*ZLAP3(DT(IZ),0.,L(IN-1),L(IN)))
      RETURN

  100 WRITE (59,110)
  110 FORMAT (/," DAUGHT CALLED WITH IN = 1.")
      GO TO 200
  120 WRITE (59,130) IN
  130 FORMAT(/," DAUGHT CALLED WITH LAMBDA = 0. FOR NUCLIDE",I3)
      GO TO 200
  140 WRITE (59,150) IN
  150 FORMAT (/," DAUGHT CALLED WITH L(IN) = L(IN-1) FOR NUCLIDE",I3)
      GO TO 200
  160 WRITE (59,170) IN
  170 FORMAT (/,"DAUGHTER CALLED WITH BR = 0. FOR NUCLIDE",I3)

  200 WRITE (59,210)
  210 FORMAT (/," FATAL ERROR")
      CALL EXIT

      RETURN
      END
      SUBROUTINE GRANDA
C        GIVEN:    DX(IN-2)/DT = D(IN-2)*FR(IZ) - L(IN-2)*X(IN-2),
C          AND:    DX(IN-1)/DT = D(IN-1)*FR(IZ) - L(IN-1)*X(IN-1)
C                                + BR(IN-1)*L(IN-2)*X(IN-2),
C          AND:    DX(IN)/DT   = D(IN)*FR(IZ) -L(IN)*X(IN)
C                                + BR(IN)*L(IN-1)*X(IN-1),
C          AND:    X(IN).
C        FINDS:    Y(IN),
C        WHERE:    X(IN) IS GIVEN AS THE INITIAL AMOUNT AT TIME TREST,
```

```
C          AND:    Y(IN) IS THE AMOUNT AFTER TIME DT(IZ).
      COMMON /B1/ NZ,DT(1000),P(1000),FR(1000),ET(1000),COREF(1000)
      COMMON /B2/ NN,ID(50),IT(50),X(50),Y(50),T(50),IU(50),
     1            D(50),BR(50),L(50),DCT(50),DCB(50)
      COMMON /B3/ IZ,IN,XX(1001),YY(1001),XB(2),YB(2)
      REAL ID,IU,L

      IF (IN.LE.2)  GO TO 100
      IF (L(IN).EQ.0.)  GO TO 120
      IF (L(IN-1).EQ.0.)  GO TO 140
      IF (L(IN-2).EQ.0.)  GO TO 160
      IF (L(IN).EQ.L(IN-1))  GO TO 180
      IF (L(IN).EQ.L(IN-2))  GO TO 200
      IF (L(IN-1).EQ.L(IN-2))  GO TO 220
      IF (BR(IN).EQ.0.)  GO TO 240
      IF (BR(IN-1).EQ.0.)  GO TO 260

      RC=D(IN)*FR(IZ)
      RB=D(IN-1)*FR(IZ)
      RA=D(IN-2)*FR(IZ)
      Y(IN) = X(IN)*ZLAP1(DT(IZ),L(IN))
     1        +RC *ZLAP2(DT(IZ),0.,L(IN))
     2        +BR(IN)*L(IN-1) *
     3       (X(IN-1)*ZLAP2(DT(IZ),L(IN),L(IN-1))
     4        +RB*ZLAP3(DT(IZ),0.,L(IN),L(IN-1))
     5        +(BR(IN-1)*L(IN-2)) *
     6         (X(IN-2)*ZLAP3(DT(IZ),L(IN),L(IN-1),L(IN-2))
     7         +RA*ZLAP4(DT(IZ),0.,L(IN),L(IN-1),L(IN-2))))
      RETURN

  100 WRITE (59,110) IN
  110 FORMAT (/," GRANDA CALLED WITH IN = ",I1)
      GO TO 300
  120 WRITE (59,130) IN
  130 FORMAT (/," GRANDA CALLED WITH LAMBDA = 0. FOR NUCLIDE",I3)
      GO TO 300
  140 WRITE (59,150) IN-1
  150 FORMAT (/," GRANDA CALLED WITH LAMBDA = 0. FOR NUCLIDE",I3)
      GO TO 300
  160 WRITE (59,170) IN-2
  170 FORMAT (/," GRANDA CALLED WITH LAMBDA = 0. FOR NUCLIDE",I3)
      GO TO 300
  180 WRITE (59,190) IN,IN-1
  190 FORMAT (/," GRANDA CALLED WITH",/,
     1   " LAMBDA'S EQUAL FOR NUCLIDES",I3," AND",I3)
      GO TO 300
  200 WRITE (59,190) IN,IN-2
      GO TO 300
  220 WRITE (59,190) IN-1,IN-2
      GO TO 300
  240 WRITE (59,250) IN
  250 FORMAT (/," GRANDA CALLED WITH BR = 0. FOR NUCLIDE",I3)
      GO TO 300
  260 WRITE (59,250) IN-1

  300 WRITE (59,310)
  310 FORMAT (/," FATAL ERROR.")
      CALL EXIT

      RETURN
      END
      FUNCTION   ZLAP1(T,A)
C        VALUE IS THE INVERSE LAPLACE TRANSFORM OF:
```

```
C             1/( S+A )

C          EVALUATED AT TIME T.

      ZLAP1=EXP(-A*T)

      RETURN
      END
      FUNCTION   ZLAP2(T,A,B)
C        VALUE IS THE INVERSE LAPLACE TRANSFORM OF:

C             1/( (S+A)*(S+B) )

C          EVALUATED AT TIME T.

      IF (A.EQ.B)  GO TO 10
      ZLAP2=(EXP(-A*T) - EXP(-B*T))/(B-A)
      RETURN
C        FOR A = B
   10 ZLAP2=EXP(-A*T)*T
      RETURN

      END
      FUNCTION   ZLAP3(T,A,B,C)
C        VALUE IS THE INVERSE LAPLACE TRANSFORM OF:

C             1/( (S+A)*(S+B)*(S+C) )

C          EVALUATED AT TIME T.

      AA=A
      BB=B
      CC=C
      IF (A.EQ.B)  GO TO 30
      IF (A.EQ.C)  GO TO 40
      IF (B.EQ.C)  GO TO 50
C        ALL DIFFERENT
      ZLAP3=((EXP(-A*T)-EXP(-C*T))/(C-A)
     1      -(EXP(-B*T)-EXP(-C*T))/(C-B)) / (B-A)
      RETURN

C        AA = BB, CC IS DIFFERENT.
   10 ZLAP3=(((CC-AA)*T-1.)*EXP(-AA*T) + EXP(-CC*T))/(CC-AA)**2
      RETURN

C        A = B = C.
   20 ZLAP3=EXP(-A*T)*T*T/2.
      RETURN

C        A = B.
   30 IF (A.EQ.C)  GO TO 20
      GO TO 10
C        A = C.
   40 IF (A.EQ.B)  GO TO 20
      BB=C
      CC=B
      GO TO 10
C        B = C.
   50 IF (B.EQ.A)  GO TO 20
      AA=C
      CC=A
      GO TO 10
```

```
      END
      FUNCTION   ZLAP4(T,A,B,C,D)
C        VALUE IS THE INVERSE LAPLACE TRANSFORM OF:

C              1/( (S+A)*(S+B)*(S+C)*(S+D) )

C        EVALUATED AT TIME T.

      AA=A
      BB=B
      CC=C
      DD=D
      IF (A.EQ.B)  GO TO 40
      IF (A.EQ.C)  GO TO 50
      IF (A.EQ.D)  GO TO 60
      IF (B.EQ.C)  GO TO 70
      IF (B.EQ.D)  GO TO 80
      IF (C.EQ.D)  GO TO 90
C        ALL DIFFERENT
      ZLAP4=((EXP(-A*T)-EXP(-C*T))/(C-A)
     1     - (EXP(-B*T)-EXP(-C*T))/(C-B)
     2     + (EXP(-B*T)-EXP(-D*T))/(D-B)
     3     - (EXP(-A*T)-EXP(-D*T)) / (D-A))/((B-A)*(D-C))
      RETURN

C        A = B = C = D.
   10 ZLAP4=EXP(-A*T)*T*T*T/6.
      RETURN

C        AA = BB,  CC AND DD ARE DIFFERENT.
   20 ZLAP4=( (EXP(-AA*T)*((CC-AA)*T-1.)+EXP(-CC*T))/((CC-AA)**2)
     1       -(EXP(-AA*T)*((DD-AA)*T-1.)+EXP(-DD*T))/((DD-AA)**2))
     2      / (DD-CC)
      RETURN

C        AA = BB = CC,  DD IS DIFFERENT
   30 ZLAP4=(  EXP(-AA*T)*T*T/(2.*(DD-AA))
     1       -(EXP(-AA*T)*((DD-AA)*T-1.)+EXP(-DD*T)))/((DD-AA)**3)
      RETURN

C        AA = BB, CC = DD.
   35 ZLAP4=(EXP(-AA*T)*((CC-AA)*T-1.)+EXP(-CC*T))*(1./((CC-AA)**2))
     1     *(T-2./(CC-AA))
     2      - EXP(-AA*T)*T*T/(CC-AA)
      RETURN

C        AA = BB.
   40 IF (CC.EQ.DD)  GO TO 100
      IF (AA.EQ.CC)  GO TO 110
      IF (AA.EQ.DD)  GO TO 120
      GO TO 20
C        A = C.
   50 BB=C
      CC=B
      GO TO 40
C        A = D.
   60 BB=D
      DD=B
      GO TO 40
C        B = C.
   70 AA=C
      CC=A
      GO TO 40
C        B = D
```

```
   80 AA=D
      DD=A
      GO TO 40
C        C = D.
   90 AA=C
      BB=D
      CC=A
      DD=B
      GO TO 40
C        AA = BB, AND CC = DD.
  100 IF (AA.EQ.CC)  GO TO 10
      GO TO 35
C        AA = BB = CC, CC .NE. DD.
  110 GO TO 30
C        AA = BB = DD, CC .NE. AA.
  120 CC=D
      DD=C
      GO TO 30

      END
      SUBROUTINE PRTCI
C        PRINTS THE RESULTS IN CURIES ON TAPE3.

      COMMON /B1/ NZ,DT(1000),P(1000),FR(1000),ET(1000),COREF(1000)
      COMMON /B2/ NN,ID(50),IT(50),X(50),Y(50),T(50),IU(50),
     1            D(50),BR(50),L(50),DCT(50),DCB(50)
      COMMON /B3/ IZ,IN,XX(1001),YY(1001),XB(2),YB(2)
      COMMON /B4/ IREST,TREST,KPRT,KPLT
      LCM B5
      COMMON /B5/ XS(1001,50)
      REAL ID,IU,L

C        CHECK FOR DETAILED TIME STEP PRINTOUT
      IF (KPRT.EQ.1)  GO TO 400

C        NZPP = NUMBER OF TIME ZONE OUTPUT LINES PER PAGE
C        NNPP = NUMBER OF NUCLIDE COLUMNS PER PAGE
      NZPP=50
      NNPP=5
      JZ=0
      Z=0.
      MZ=NZ/NZPP + 1
      MN=NN/NNPP + 1
      ITE=0
      DO 200  IMZ=1,MZ
      ITS=ITE+1
      ITE=ITS+NZPP-1
      IF (ITE.GT.NZ)  ITE=NZ
      INE=0
      DO 100  IMN=1,MN
      INS=INE+1
      INE=INS+NNPP-1
      IF (INE.GT.NN)  INE=NN

    5 DX=TREST
      CALL SECTOT(DX,TU,KU,Q)
      WRITE (3,10) DX,TU
   10 FORMAT ("1PROGRAM FISPRO RESULTS.",//,
     1   42X,"NUCLIDE CONCENTRATIONS (CURIES PER GIVEN VOLUME)",//,
     1   42X,"ET = ELAPSED TIME SINCE RESTART TIME OF",
     2   F8.3,1X,A3,".",///)
   15 WRITE (3,20) (J,J=INS,INE)
   20 FORMAT (42X,"IN:",I9,4I15)
   25 WRITE (3,30) (ID(J),J=INS,INE)
```

```
   30 FORMAT (/,"  IZ",8X,"DT(SEC)",8X,"ET(SEC)",5X,5(9X,A6),/,/)
C        USE XX AS A TEMPORARY STORAGE ARRAY.
      DO 300  J=INS,INE
  300 XX(J)=XS(1,J)
      IF (IMZ.EQ.1)  WRITE (3,50) JZ,Z,Z,(XX(J),J=INS,INE)
   35 DO 40  K=ITS,ITE
      DO 310  J=INS,INE
  310 XX(J)=XS(K+1,J)
   40 WRITE (3,50) K,DT(K),ET(K),(XX(J),J=INS,INE)
   50 FORMAT (I4,1P2E15.6,5X,1P5E15.6)

  100 CONTINUE

  200 CONTINUE

C        COMPARE RELATIVE CURIES AT END OF LAST TIME STEP
  400 DO 405  I=1,NN
      YY(I)=XS(NZ+1,I)
  405 XX(I)=ID(I)
      CALL DESORT(NN,YY,XX)
      WRITE (3,410) ET(NZ),DX,TU
  410 FORMAT ("1PROGRAM FISPRO RESULTS.",//,
     1   10X,"NUCLIDE CONCENTRATIONS (CURIES PER GIVEN VOLUME)",/,
     1   10X,"RELATIVE COMPARISONS.",//,
     1   10X,"AT ELAPSED TIME OF",1PE14.6," SECONDS",/,
     2   10X,"SINCE RESTART TIME OF",0PF8.3,1X,A3,".",///)
      WRITE (3,420) (XX(I),YY(I),I=1,NN)
  420 FORMAT (10X,"NUCLIDE",2X,"CURIES PER VOLUME",//,
     1   (11X,A6,1PE19.4))
C        GET TOTAL CURIES
      TREM=0.
      DO 430  I=1,NN
  430 TREM=TREM+YY(I)
      WRITE (3,440) TREM
  440 FORMAT (/,12X,"TOTAL",1PE19.4)

      RETURN
      END
      SUBROUTINE PRTTR
C        PRINTS THE RESULTS IN THYROID DOSE REM.

      COMMON /B1/ NZ,DT(1000),P(1000),FR(1000),ET(1000),COREF(1000)
      COMMON /B2/ NN,ID(50),IT(50),X(50),Y(50),T(50),IU(50),
     1            D(50),BR(50),L(50),DCT(50),DCB(50)
      COMMON /B3/ IZ,IN,XX(1001),YY(1001),XB(2),YB(2)
      COMMON /B4/ IREST,TREST,KPRT,KPLT
      LCM B5
      COMMON /B5/ XS(1001,50)
      REAL ID,IU,L

C        CHECK FOR DETAILED TIME STEP PRINTOUT
      IF (KPRT.EQ.1)  GO TO 400

C        NZPP = NUMBER OF TIME ZONE OUTPUT LINES PER PAGE
C        NNPP = NUMBER OF NUCLIDE COLUMNS PER PAGE
      NZPP=50
      NNPP=5
      JZ=0
      Z=0.
      MZ=NZ/NZPP + 1
      MN=NN/NNPP + 1
      ITE=0
      DO 200  IMZ=1,MZ
      ITS=ITE+1
```

```
      ITE=ITS+NZPP-1
      IF (ITE.GT.NZ)  ITE=NZ
      INE=0
      DO 100  IMN=1,MN
      INS=INE+1
      INE=INS+NNPP-1
      IF (INE.GT.NN)  INE=NN

    5 DX=TREST
      CALL SECTOT(DX,TU,KU,Q)
      WRITE (3,10) DX,TU
   10 FORMAT ("1PROGRAM FISPRO RESULTS.",//,
     1   42X,"NUCLIDE DOSE TO THYROID ORGAN (REM PER GIVEN VOLUME)",//,
     4   42X,"(DIRECT CURIES TO REM CONVERSION INSIDE REACTOR CORE)",//,
     1   42X,"ASSUMING CLOUD CONCENTRATION = 1 CI/CUBIC METER",/,
     2   42X,"     AND EXPOSURE DURATION   = 1 SEC",/,
     3   42X,"     AND BREATHING RATE = 2.66E-4 CUBIC-METERS/SEC.",//,
     1   42X,"ET = ELAPSED TIME SINCE RESTART TIME OF",
     2   F8.3,1X,A3,".",///)
   15 WRITE (3,20) (J,J=INS,INE)
   20 FORMAT (42X,"IN:",I9,4I15)
   25 WRITE (3,30) (ID(J),J=INS,INE)
   30 FORMAT (/,"  IZ",8X,"DT(SEC)",8X,"ET(SEC)",5X,5(9X,A6),/,/)
C        CONVERT CURIES TO THYROID REM
C             ASSUMING CLOUD CONCENTRATION = 1 CI/M/M/M
C                  AND EXPOSURE DURATION = 1 SEC.
C        BREATHING RATE = 2.66E-4 M-M-M/SEC.
      DO 300  J=INS,INE
  300 XX(J)=XS(1,J)*DCT(J)*2.66E-4
      IF (IMZ.EQ.1)  WRITE (3,50) JZ,Z,Z,(XX(J),J=INS,INE)
   35 DO 40  K=ITS,ITE
      DO 310  J=INS,INE
  310 XX(J)=XS(K+1,J)*DCT(J)*2.66E-4
   40 WRITE (3,50) K,DT(K),ET(K),(XX(J),J=INS,INE)
   50 FORMAT (I4,1P2E15.6,5X,1P5E15.6)

  100 CONTINUE

  200 CONTINUE

C        COMPARE RELATIVE DOSE AT END OF LAST TIME STEP
  400 DO 405  I=1,NN
      YY(I)=XS(NZ+1,I)*DCT(I)*2.66E-4
  405 XX(I)=ID(I)
      CALL DESORT(NN,YY,XX)
      WRITE (3,410) ET(NZ),DX,TU
  410 FORMAT ("1PROGRAM FISPRO RESULTS.",//,
     1   10X,"NUCLIDE DOSE TO THYROID ORGAN (REM PER GIVEN VOLUME)",/,
     1   10X,"RELATIVE COMPARISONS.",//,
     4   10X,"(DIRECT CURIES TO REM CONVERSION INSIDE REACTOR CORE)",//,
     1   10X,"ASSUMING CLOUD CONCENTRATION = 1 CI/CUBIC METER",/,
     2   10X,"     AND EXPOSURE DURATION   = 1 SEC",/,
     3   10X,"     AND BREATHING RATE = 2.66E-4 CUBIC-METERS/SEC.",//,
     1   10X,"AT ELAPSED TIME OF",1PE14.6," SECONDS",/,
     2   10X,"SINCE RESTART TIME OF",0PF8.3,1X,A3,".",///)
      WRITE (3,420) (XX(I),YY(I),I=1,NN)
  420 FORMAT (10X,"NUCLIDE",5X,"REM PER VOLUME",//,
     1   (11X,A6,1PE19.4))
C        GET TOTAL REM
      TREM=0.
      DO 430  I=1,NN
  430 TREM=TREM+YY(I)
      WRITE (3,440) TREM
  440 FORMAT (/,12X,"TOTAL",1PE19.4)
```

```
      RETURN
      END
      SUBROUTINE PRTBR
C        PRINTS THE RESULTS IN WHOLE BODY PHOTON DOSE REM.

      COMMON /B1/ NZ,DT(1000),P(1000),FR(1000),ET(1000),COREF(1000)
      COMMON /B2/ NN,ID(50),IT(50),X(50),Y(50),T(50),IU(50),
     1            D(50),BR(50),L(50),DCT(50),DCB(50)
      COMMON /B3/ IZ,IN,XX(1001),YY(1001),XB(2),YB(2)
      COMMON /B4/ IREST,TREST,KPRT,KPLT
      LCM B5
      COMMON /B5/ XS(1001,50)
      REAL ID,IU,L

C        CHECK FOR DETAILED TIME STEP PRINTOUT
      IF (KPRT.EQ.1)  GO TO 400

C        NZPP = NUMBER OF TIME ZONE OUTPUT LINES PER PAGE
C        NNPP = NUMBER OF NUCLIDE COLUMNS PER PAGE
      NZPP=50
      NNPP=5
      JZ=0
      Z=0.
      MZ=NZ/NZPP + 1
      MN=NN/NNPP + 1
      ITE=0
      DO 200  IMZ=1,MZ
      ITS=ITE+1
      ITE=ITS+NZPP-1
      IF (ITE.GT.NZ)  ITE=NZ
      INE=0
      DO 100  IMN=1,MN
      INS=INE+1
      INE=INS+NNPP-1
      IF (INE.GT.NN)  INE=NN

    5 DX=TREST
      CALL SECTOT(DX,TU,KU,Q)
      WRITE (3,10) DX,TU
   10 FORMAT ("1PROGRAM FISPRO RESULTS.",//,
     1   42X,"NUCLIDE DOSE TO WHOLE BODY (REM PER GIVEN VOLUME)",//,
     4   42X,"(DIRECT CURIES TO REM CONVERSION INSIDE REACTOR CORE)",//,
     1   42X,"ASSUMING CLOUD CONCENTRATION = 1 CI/CUBIC METER",/,
     2   42X,"     AND EXPOSURE DURATION   = 1 SEC.",//,
     1   42X,"ET = ELAPSED TIME SINCE RESTART TIME OF",
     2   F8.3,1X,A3,".",///)
   15 WRITE (3,20) (J,J=INS,INE)
   20 FORMAT (42X,"IN:",I9,4I15)
   25 WRITE (3,30) (ID(J),J=INS,INE)
   30 FORMAT (/,"  IZ",8X,"DT(SEC)",8X,"ET(SEC)",5X,5(9X,A6),/,/)
C        CONVERT CURIES TO THYROID REM
C             ASSUMING CLOUD CONCENTRATION = 1 CI/M/M/M
C                  AND EXPOSURE DURATION = 1 SEC.
      DO 300  J=INS,INE
  300 XX(J)=XS(1,J)*DCB(J)
      IF (IMZ.EQ.1)  WRITE (3,50) JZ,Z,Z,(XX(J),J=INS,INE)
   35 DO 40  K=ITS,ITE
      DO 310  J=INS,INE
  310 XX(J)=XS(K+1,J)*DCB(J)
   40 WRITE (3,50) K,DT(K),ET(K),(XX(J),J=INS,INE)
   50 FORMAT (I4,1P2E15.6,5X,1P5E15.6)

  100 CONTINUE
```

```
  200 CONTINUE
C        COMPARE RELATIVE DOSE AT END OF LAST TIME STEP
  400 DO 405  I=1,NN
      YY(I)=XS(NZ+1,I)*DCB(I)
  405 XX(I)=ID(I)
      CALL DESORT(NN,YY,XX)
      WRITE (3,410) ET(NZ),DX,TU
  410 FORMAT ("1PROGRAM FISPRO RESULTS.",//,
     1   10X,"NUCLIDE DOSE TO WHOLE BODY (REM PER GIVEN VOLUME)",/,
     1   10X,"RELATIVE COMPARISONS.",//,
     4   10X,"(DIRECT CURIES TO REM CONVERSION INSIDE REACTOR CORE)",//,
     1   10X,"ASSUMING CLOUD CONCENTRATION = 1 CI/CUBIC METER",/,
     2   10X,"     AND EXPOSURE DURATION   = 1 SEC.",/,
     1   10X,"AT ELAPSED TIME OF",1PE14.6," SECONDS",/,
     2   10X,"SINCE RESTART TIME OF",OPF8.3,1X,A3,".",///)
      WRITE (3,420) (XX(I),YY(I),I=1,NN)
  420 FORMAT (10X,"NUCLIDE",5X,"REM PER VOLUME",//,
     1   (11X,A6,1PE19.4))
C        GET TOTAL REM
      TREM=0.
      DO 430  I=1,NN
  430 TREM=TREM+YY(I)
      WRITE (3,440) TREM
  440 FORMAT (/,12X,"TOTAL",1PE19.4)

      RETURN
      END
      SUBROUTINE DESORT(N,Y,X)
C        SORTS ARRAY Y(N) INTO DECREASING ORDER
C        ARRAY X(N) GOES ALONG FOR THE RIDE.
      DIMENSION X(1),Y(1)

      L=0
   10 L=L+1
      IF (L.EQ.N)  GO TO 50
      YMAX=Y(L)
      J=L
      DO 20  I=L,N
      IF (Y(I).LE.YMAX) GO TO 20
      YMAX=Y(I)
      J=I
   20 CONTINUE
      IF (J.EQ.L)  GO TO 10
      YMAX=Y(J)
      XT=X(J)
      M=J-L
      DO 30  I=1,M
      K=J+1-I
      Y(K)=Y(K-1)
   30 X(K)=X(K-1)
      Y(L)=YMAX
      X(L)=XT
      GO TO 10

   50 RETURN
      END
      SUBROUTINE PLOTCI
C        PLOTS THE RESULTS IN CURIES ON MICROFICHE.

      COMMON /B1/ NZ,DT(1000),P(1000),FR(1000),ET(1000),COREF(1000)
      COMMON /B2/ NN,ID(50),IT(50),X(50),Y(50),T(50),IU(50),
     1            D(50),BR(50),L(50),DCT(50),DCB(50)
```

```
      COMMON /B3/ IZ,IN,XX(1001),YY(1001),XB(2),YB(2)
      COMMON /B4/ IREST,TREST,KPRT,KPLT
      LCM B5
      COMMON /B5/ XS(1001,50)
      LCM CBLK
      COMMON/CBLK/ BUFF(5000)
      DIMENSION LZ(8),LXS(2),LXE(2),LX(8)
      DATA NLZ,LZ /33, 33HFISSION PRODUCT RESULTS IN CURIES/,
     1     NLY /6/,
     2     NLXS,LXS /14, 14HELAPSED TIME (/,
     3     NLXE,LXE /19, 19H) SINCE RESTART AT /
      DATA BLK /10H          /

C        PLOTTING ROUTINES.
      CALL FILM80
      CALL IDENT80(77,BUFF,5000,0,105,0)
      CALL HEAD80(77,25,25HFISPRO PLOTS.      BAILEY,
     1   10HBOX Q6/PGB)
      CALL KEEPFLM(77)

C        PLOTTING EACH NUCLIDE HISTORY INDIVIDUALLY
      LFLAG=0
      DO 100  IN=1,NN

      XX(1)=0.0
      YY(1)=XS(1,IN)
      NPTS=NZ+1

      DO 10  IZ=1,NZ
      XX(IZ+1)=ET(IZ)
   10 YY(IZ+1)=XS(IZ+1,IN)

C        CHECK FOR ALL ZERO Y VALUES
      CALL ZEROCK(NPTS,YY,IFLAG)
C        DO NOT PLOT ALL ZERO Y VALUES
      IF (IFLAG.NE.0)  GO TO 100

C        ALTER TIME UNITS FOR PLOTTING
      DX=XX(NPTS)-XX(1)
      CALL SECTOT(DX,TU,KU,Q)
      DO 15  I=1,NPTS
   15 XX(I)=XX(I)/Q

      IF (KPLT.NE.1)  GO TO 30
      WRITE (5,20) IN,NPTS,KU,TREST
      WRITE (5,25) (XX(I),YY(I),I=1,NPTS)
   20 FORMAT (3I5,E20.7)
   25 FORMAT (1P6E12.5)
   30 CONTINUE

C        FORM THE Y AND X AXIS LABELS
      LY=ID(IN)
      IF (LFLAG.NE.0)  GO TO 880
      LFLAG=1
      IF (TREST.NE.0.)  GO TO 840
C        FOR TREST = 0.
      NLX=14+3+1
      REWIND 63
      WRITE (63,810) LXS,TU,LXE(1)
  810 FORMAT (A10,A4,A3,A1)
      READ (63,820) (LX(I),I=1,2)
  820 FORMAT (A10,A8)
      GO TO 880
C        FOR TREST NOT 0.
```

```
  840 DX=TREST
      CALL SECTOT(DX,TTU,LU,Q)
      NLX=14+3+19+11+4
      REWIND 63
      WRITE (63,850) LXS,TU,LXE,DX,TTU,(BLK,I=1,3)
  850 FORMAT (A10,A4,A3,A10,A9,F11.3,1X,A3,3A10)
      READ (63,860) (LX(I),I=1,8)
  860 FORMAT (8A10)
  880 CONTINUE

C         ADJUST THE Z LABEL FOR DATA EXPONENTS
      NLZT=NLZ
      K=NEXP(NPTS,YY)
      IF (K.NE.0)  CALL EXPLBL(NPTS,YY,K,NLZT,LZ)

      LIN=1
      IF (NPTS.GT.50)  LIN=0
      NSYM=197
      CALL PLOTM(XX,YY,NPTS,1,LIN,NSYM,-1.,10.,10.,
     1   LZ,NLZT,LX,NLX,LY,NLY)

  100 CONTINUE

      RETURN
      END
      SUBROUTINE PLOTTR
C         PLOTS THE RESULTS IN THYROID DOSE REM ON MICROFICHE.

      COMMON /B1/ NZ,DT(1000),P(1000),FR(1000),ET(1000),COREF(1000)
      COMMON /B2/ NN,ID(50),IT(50),X(50),Y(50),T(50),IU(50),
     1            D(50),BR(50),L(50),DCT(50),DCB(50)
      COMMON /B3/ IZ,IN,XX(1001),YY(1001),XB(2),YB(2)
      COMMON /B4/ IREST,TREST,KPRT,KPLT
      LCM B5
      COMMON /B5/ XS(1001,50)
      LCM CBLK
      COMMON/CBLK/ BUFF(5000)
      DIMENSION LZ(8),LXS(2),LXE(2),LX(8)
      DATA NLZ, LZ /49,
     1     49HFISSION PRODUCT INHALATION DOSE TO THYROID IN REM/,
     1     NLY /6/,
     2     NLXS,LXS /14, 14HELAPSED TIME (/,
     3     NLXE,LXE /19, 19H) SINCE RESTART AT /
      DATA BLK /10H          /

C         PLOTTING EACH NUCLIDE HISTORY INDIVIDUALLY
      LFLAG=0

C         CONVERT CI TO REM
C          CONCENTRATION OF 1 CI/M/M/M AND
C          DURATION OF 1 SEC.
C         BREATHING RATE = 2.66E-4 CUBIC METER / SEC.

      DO 100  IN=1,NN

      XX(1)=0.0
      YY(1)=XS(1,IN)*DCT(IN)*2.66E-4
      NPTS=NZ+1

      DO 10  IZ=1,NZ
      XX(IZ+1)=ET(IZ)
   10 YY(IZ+1)=XS(IZ+1,IN)*DCT(IN)*2.66E-4

C         CHECK FOR ALL ZERO Y VALUES
```

```
      CALL ZEROCK(NPTS,YY,IFLAG)
C        DO NOT PLOT ALL ZERO Y VALUES
      IF (IFLAG.NE.0)  GO TO 100

C        ALTER TIME UNITS FOR PLOTTING
      DX=XX(NPTS)-XX(1)
      CALL SECTOT(DX,TU,KU,Q)
      DO 15  I=1,NPTS
   15 XX(I)=XX(I)/Q

      IF (KPLT.NE.1)  GO TO 30
      WRITE (5,20) IN,NPTS,KU,TREST
      WRITE (5,25) (XX(I),YY(I),I=1,NPTS)
   20 FORMAT (3I5,E20.7)
   25 FORMAT (1P6E12.5)
   30 CONTINUE

C        FORM THE Y AND X AXIS LABELS
      LY=ID(IN)
      IF (LFLAG.NE.0)  GO TO 880
      LFLAG=1
      IF (TREST.NE.0.)  GO TO 840
C        FOR TREST = 0.
      NLX=14+3+1
      REWIND 63
      WRITE (63,810) LXS,TU,LXE(1)
  810 FORMAT (A10,A4,A3,A1)
      READ (63,820) (LX(I),I=1,2)
  820 FORMAT (A10,A8)
      GO TO 880
C        FOR TREST NOT 0.
  840 DX=TREST
      CALL SECTOT(DX,TTU,LU,Q)
      NLX=14+3+19+11+4
      REWIND 63
      WRITE (63,850) LXS,TU,LXE,DX,TTU,(BLK,I=1,3)
  850 FORMAT (A10,A4,A3,A10,A9,F11.3,1X,A3,3A10)
      READ (63,860) (LX(I),I=1,8)
  860 FORMAT (8A10)
  880 CONTINUE

C        ADJUST THE Z LABEL FOR DATA EXPONENTS
      NLZT=NLZ
      K=NEXP(NPTS,YY)
      IF (K.NE.0)  CALL EXPLBL(NPTS,YY,K,NLZT,LZ)

      LIN=1
      IF (NPTS.GT.50)  LIN=0
      NSYM=197
      CALL PLOTM(XX,YY,NPTS,1,LIN,NSYM,-1.,10.,10.,
     1   LZ,NLZT,LX,NLX,LY,NLY)

  100 CONTINUE

      RETURN
      END
      SUBROUTINE PLOTBR
C        PLOTS THE RESULTS IN WHOLE BODY DOSE IN REM ON MICROFICHE.


      COMMON /B1/ NZ,DT(1000),P(1000),FR(1000),ET(1000),COREF(1000)
      COMMON /B2/ NN,ID(50),IT(50),X(50),Y(50),T(50),IU(50),
     1            D(50),BR(50),L(50),DCT(50),DCB(50)
      COMMON /B3/ IZ,IN,XX(1001),YY(1001),XB(2),YB(2)
```

```
      COMMON /B4/ IREST,TREST,KPRT,KPLT
      LCM B5
      COMMON /B5/ XS(1001,50)
      LCM CBLK
      COMMON/CBLK/ BUFF(5000)
      DIMENSION LZ(8),LXS(2),LXE(2),LX(8)
      DATA NLZ,LZ /38, 38HFISSION PRODUCT WHOLE BODY DOSE IN REM/,
     1     NLY /6/,
     2     NLXS,LXS /14, 14HELAPSED TIME (/,
     3     NLXE,LXE /19, 19H) SINCE RESTART AT /
      DATA BLK /10H          /

C        PLOTTING EACH NUCLIDE HISTORY INDIVIDUALLY
      LFLAG=0

C        CONVERT CI TO REM

      DO 100  IN=1,NN

      XX(1)=0.0
      YY(1)=XS(1,IN)*DCB(IN)
      NPTS=NZ+1

      DO 10  IZ=1,NZ
      XX(IZ+1)=ET(IZ)
   10 YY(IZ+1)=XS(IZ+1,IN)*DCB(IN)

C        CHECK FOR ALL ZERO Y VALUES
      CALL ZEROCK(NPTS,YY,IFLAG)
C        DO NOT PLOT ALL ZERO Y VALUES
      IF (IFLAG.NE.0)  GO TO 100

C        ALTER TIME UNITS FOR PLOTTING
      DX=XX(NPTS)-XX(1)
      CALL SECTOT(DX,TU,KU,Q)
      DO 15  I=1,NPTS
   15 XX(I)=XX(I)/Q

      IF (KPLT.NE.1)  GO TO 30
      WRITE (5,20) IN,NPTS,KU,TREST
      WRITE (5,25) (XX(I),YY(I),I=1,NPTS)
   20 FORMAT (3I5,E20.7)
   25 FORMAT (1P6E12.5)
   30 CONTINUE

C        FORM THE Y AND X AXIS LABELS
      LY=ID(IN)
      IF (LFLAG.NE.0)  GO TO 880
      LFLAG=1
      IF (TREST.NE.0.)  GO TO 840
C        FOR TREST = 0.
      NLX=14+3+1
      REWIND 63
      WRITE (63,810) LXS,TU,LXE(1)
  810 FORMAT (A10,A4,A3,A1)
      READ (63,820) (LX(I),I=1,2)
  820 FORMAT (A10,A8)
      GO TO 880
C        FOR TREST NOT 0.
  840 DX=TREST
      CALL SECTOT(DX,TTU,LU,Q)
      NLX=14+3+19+11+4
      REWIND 63
      WRITE (63,850) LXS,TU,LXE,DX,TTU,(BLK,I=1,3)
```

```
  850 FORMAT (A10,A4,A3,A10,A9,F11.3,1X,A3,3A10)
      READ (63,860) (LX(I),I=1,8)
  860 FORMAT (8A10)
  880 CONTINUE

C        ADJUST THE Z LABEL FOR DATA EXPONENTS
      NLZT=NLZ
      K=NEXP(NPTS,YY)
      IF (K.NE.0)  CALL EXPLBL(NPTS,YY,K,NLZT,LZ)

      LIN=1
      IF (NPTS.GT.50)  LIN=0
      NSYM=197
      CALL PLOTM(XX,YY,NPTS,1,LIN,NSYM,-1.,10.,10.,
     1   LZ,NLZT,LX,NLX,LY,NLY)

  100 CONTINUE

      RETURN
      END
      SUBROUTINE ZEROCK(N,Y,IFLAG)
C        GIVEN THE ARRAY Y(N)
C        IFLAG IS SET = 0
C        IF ALL Y VALUES ARE ZERO, IFLAG IS SET = 1.
      DIMENSION Y(1)

      IFLAG=0
      DO 10  I=1,N
      IF (Y(I).NE.0.)  GO TO 20
   10 CONTINUE
      IFLAG=1

   20 RETURN
      END
      FUNCTION   NEXP(N,A)
C        CALCULATES THE VALUE OF THE EXPONENT OF 10 (NEXP)
C        REQUIRED SO THAT THE MAXIMUM VALUE OF
C        THE ARRAY A(N) * 10.**NEXP
C        IS BETWEEN 1 AND 10.
C        USEFUL FOR GRAPHICAL SCALING.
      DIMENSION A(1)

      NEXP=0
      AMAX=A(1)
      IF (N.EQ.1)  GO TO 20
      DO 10  I=2,N
      IF (A(I).GT.AMAX)  AMAX=A(I)
   10 CONTINUE
   20 B=AMAX
      IF (NEXP.NE.0) B=AMAX*(10.**NEXP)
      IF (B.GT.10.)  GO TO 30
      IF (B.GE.1.0)  GO TO 40
C        B IS .LT. 1
      NEXP=NEXP+1
      GO TO 20
C        B IS .GT. 10
   30 NEXP=NEXP-1
      GO TO 20

   40 RETURN
      END
      SUBROUTINE EXPLBL(N,Y,K,NLZ,LZ)
C        ALTERS THE DATA ARRAY Y(N)
C        ACCORDING TO THE POWER OF TEN EXPONENT K
```

```
C        AND REFORMS THE LZ LABEL
C        WHICH IS NLZ CHARACTERS LONG
C        TO INCLUDE THE POWER OF TEN EXPONENT.
      DIMENSION Y(1),LZ(1),FMT(4)
      DATA XLP/1H(/, XA10/3HA10/, XA/2H,A/, XM/8H,A8,A1,I/,
     1     XA1/3H,A1/, XRP/1H)/
      DATA TLS /8H (IN 1.E/, TLE /1H)/

      DO 10  I=1,N
      IF (K.NE.0) Y(I)=Y(I)*(10.**K)
   10 CONTINUE
      TS=1H-
      IF (K.LT.0)  TS=1H+
      K=IABS(K)
      ND=NDIGIT(K)

C        CONSTRUCT LABEL FORMAT FOR WRITING THE LZ LABEL
      NLZ1=NLZ/10
      NLZ2=NLZ-10*NLZ1
      IF (NLZ1*NLZ2.EQ.0)  GO TO 20
      REWIND 63
      WRITE (63,110) XLP,NLZ1,XA10,XA,NLZ2,XM,ND,XA1,XRP
  110 FORMAT (A1,I5,A3,A2,I5,A8,I5,A3,A1)
      GO TO 40
   20 IF (NLZ1.EQ.0)  GO TO 30
      REWIND 63
      WRITE (63,120) XLP, NLZ1,XA10,XM,ND,XA1,XRP
  120 FORMAT (A1,I5,A3,A8,I5,A3,A1,7X)
      GO TO 40
   30 REWIND 63
      WRITE (63,130) XLP,XA,NLZ2,XM,ND,XA1,XRP
  130 FORMAT (A1,A2,I5,A8,I5,A3,A1,8X)
   40 READ (63,140) FMT
  140 FORMAT (3A10,A3)

C        REFORM THE LZ LABEL
      NLZ1=NLZ1+1
   50 REWIND 63
      WRITE (63,FMT) (LZ(I),I=1,NLZ1),TLS,TS,K,TLE
      NLZ=NLZ+8+1+ND+1
      NLZ1=NLZ/10
      NLZ2=NLZ-10*NLZ1
      IF (NLZ2.NE.0)  NLZ1=NLZ1+1
   60 READ (63,200) (LZ(I),I=1,NLZ1)
  200 FORMAT (8A10)

      RETURN
      END
      FUNCTION   NDIGIT(N)
C        CALCULATES THE NUMBER OF DIGITS (NDIGIT)
C        IN THE ABSOLUTE VALUE OF THE NUMBER N.
C        USEFUL FOR ENCODE/DECODE.

      NDIGIT=1
      IF (N.EQ.0)  RETURN
      M=IABS(N)
   10 L=M/(10**NDIGIT)
      IF (L.EQ.0)  GO TO 20
      NDIGIT=NDIGIT+1
      GO TO 10

   20 RETURN
      END
```

☆U.S. Government Printing Office: 1979 — 677-013/158

Printed in the United States of America. Available from
National Technical Information Service
US Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Microfiche $3.00

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