**PORTIONS
OF THIS
DOCUMENT
ARE
ILLEGIBLE**

EBT Time-Dependent Point Model Code: Description and User's Guide

Jane F. Roberts Nermin A. Uckan

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It
has been reproduced from the best available
copy to permit the broadest possible avail-
ability.

MASTER

OAK RIDGE NATIONAL LABORATORY

OPERATED BY UNION CARBIDE CORPORATION FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
Price: Printed Copy \$5.50; Microfiche \$3.00

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Energy Research and Development Administration, United States Nuclear Regulatory Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

ORNL/CSD/TM-27

Contract No. W-7405-eng-26

COMPUTER SCIENCES DIVISION

EBT TIME-DEPENDENT POINT MODEL CODE: DESCRIPTION AND USER'S GUIDE

Jane F. Roberts
Computer Sciences Division

and

Nermin A. Uckan
Fusion Energy Division

Date Published: July 1977

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, no, any of their contractors, subcontractors, or their employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

NOTICE

This document contains information of a preliminary nature. It is subject to revision or correction and therefore does not represent a final report.

UNION CARBIDE CORPORATION, NUCLEAR DIVISION
operating the
Oak Ridge Gaseous Diffusion Plant • Oak Ridge National Laboratory
Oak Ridge Y-12 Plant • Paducah Gaseous Diffusion Plant
for the
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

TABLE OF CONTENTS

ACKNOWLEDGMENTS	v
ABSTRACT	1
1. INTRODUCTION	1
2. PHYSICS MODEL	2
3. PROGRAM LOGIC AND ORGANIZATION	4
3.1. Description of Routines	4
3.2. Integration	10
3.3. Input	11
3.4. Execution	13
3.5. Output: Printed	14
3.6. Output: Plotting	15
REFERENCES	17
APPENDIX A	23
APPENDIX B	25
APPENDIX C	37
APPENDIX D	81

ACKNOWLEDGMENTS

This work was supported by the Fusion Energy Division at Oak Ridge National Laboratory.

We would like to specifically acknowledge and thank C. L. Hedrick of the Fusion Energy Division and S. E. Attenberger of the Computer Sciences Division for their help in distinguishing, interpreting, and resolving physical and numerical difficulties encountered during code development.

EBT TIME-DEPENDENT POINT MODEL CODE: DESCRIPTION AND USER'S GUIDE

Jane F. Roberts
Computer Sciences Division

and

Nermin A. Uckan
Fusion Energy Division

ABSTRACT

A D-T time-dependent point model has been developed to assess the energy balance in an EBT reactor plasma. Flexibility is retained in the model to permit more recent data to be incorporated as they become available from the theoretical and experimental studies. This report includes the physics models involved, the program logic, and a description of the variables and routines used. All the files necessary for execution are listed, and the code, including a post-execution plotting routine, is discussed.

1. INTRODUCTION

As a first step in assessing the energy balance in an EBT reactor plasma,¹ a simulation model (point model) has been developed in which the bulk plasma is characterized by simple energy and particle containment times, with appropriate density and temperature scaling. In view of uncertainties in the theoretical coefficients and the present lack of experimental evidence in this area, flexibility is retained in the simulation model to permit more recent data to be incorporated as they become available.

The full time-dependent point model for D-T fusion in EBT consists of nine coupled nonlinear ordinary differential equations (discussed in Sect. 2). The program logic and organization is outlined in Sect. 3. A description of the variables, a listing of the files, and the execution routine are given in appendixes.

BLANK PAGE

2. PHYSICS MODEL

The particle and energy balance equations used in the code are

$$\begin{aligned} \frac{dn_D}{dt} = & S_{DCOLD} + S_{DBEAM}(1 - f_D) - n_D n_T^{<sv>} DT \\ & + n_e n_{OD}^{<sv>} ioniz - \frac{n_D}{\tau_{p,D}}, \end{aligned} \quad (1)$$

$$\frac{dn_T}{dt} = S_{TCOLD} - S_{DBEAM} f_D - n_D n_T^{<sv>} DT + n_e n_{OT}^{<sv>} ioniz - \frac{n_T}{\tau_{p,D}}, \quad (2)$$

$$\frac{dn_\alpha}{dt} = S_{DBEAM} f_D + n_D n_T^{<sv>} DT - \frac{n_\alpha}{\tau_{p,\alpha}}, \quad (3)$$

$$\begin{aligned} \frac{dn_I}{dt} = & (n_D n_T^{<sv>} DT + S_{DBEAM} f_D) I_N + \frac{n_D}{\tau_{p,D}} I_D + \frac{n_T}{\tau_{p,T}} I_T + \frac{n_\alpha}{\tau_{p,\alpha}} I_\alpha \\ & + \frac{n_I}{\tau_{p,I}} (I_I - 1), \end{aligned} \quad (4)$$

$$\begin{aligned} \frac{dn_{HI}}{dt} = & (n_D n_T^{<sv>} DT + S_{DBEAM} f_D) I_N + \frac{n_D}{\tau_{p,D}} I_D + \frac{n_T}{\tau_{p,T}} I_T + \frac{n_\alpha}{\tau_{p,\alpha}} I_\alpha \\ & + \frac{n_{HI}}{\tau_{p,HI}} (I_{HI} - 1), \end{aligned} \quad (5)$$

$$\frac{dn_{OD}}{dt} = \frac{n_D}{\tau_{p,D}} f_{RD} - n_e n_{OD}^{<sv>} ioniz, \quad (6)$$

$$\frac{dn_{OT}}{dt} = \frac{n_T}{\tau_{p,T}} f_{RT} - n_e n_{OT}^{<sv>} ioniz, \quad (7)$$

$$\begin{aligned} \frac{d}{dt}(p_e) = F_{\mu} + S_{DBEAM}(f_{DB,e} + f_D^U f_{\alpha e}) + n_D n_T \langle \sigma v \rangle_{DT} (U_{\alpha} f_{\alpha e} - 3T_e) \\ - \frac{p_e}{\tau_{E,e}} - p_{ei} - p_{RAD}, \end{aligned} \quad (8)$$

$$\begin{aligned} \frac{d}{dt}(p_i) = n_D n_T \langle \sigma v \rangle_{DT} (U_{\alpha} f_{\alpha i} - 3T_i) + S_{DBEAM}(U_{BEAM} f_{DB,i} + f_D^U f_{\alpha i}) \\ + p_{ei} - \frac{p_i}{\tau_{E,i}}, \end{aligned} \quad (9)$$

where

$$\begin{aligned} n_e &= n_D + n_T + 2n_{\alpha} + Z_I n_I + Z_{HI} n_{HI}, \\ n_i &= n_D + n_T, \\ p_e &= \frac{3}{2} n_e T_e, \\ p_i &= \frac{3}{2} n_i T_i. \end{aligned}$$

As a first step, a simple model has been analyzed. The equations implemented in the current version of the EBT point model code (see Appendix A) are a subset of Eqs. 1-9. The parameters used in Eqs. 1-9 are listed in Appendix B.

The code was developed using the full set of equations. The modifications were accomplished by changing expressions in various subroutines (maintaining the full expressions in comment statements) and by specific choices of input parameters. This will be discussed in detail later in this report.

The units of both the model and the code are mks ("temperatures," representing energy, are in keV). The only numerical problem this has caused so far is in expressions like $n_D n_T \langle \sigma v \rangle_{DT}$. Since densities are $\sim 10^{20}$ and cross-sections $\sim 10^{-20}$, it is necessary in coding to force the

order of multiplication with parentheses to avoid overflows on the PDP-10:
DEND(DENT-SIGYDT).

3. PROGRAM LOGIC AND ORGANIZATION

Figure 1 shows how control flows from one routine to another. Specifically, MAIN controls the run. INIT and PRINT1 are called at the very beginning for initialization of variables and parameters and initial printout; the rest of the subroutines are called repeatedly as integration progresses in time.

A simplified flow chart appears in Fig. 2. There are only two main loops: the larger loop represents integration of the equations in time until some final, specified time (controlled in MAIN), and the smaller loop represents repeated integration over a specific time-step until the convergence criterion is met for all equations (controlled by EXTINT).

Except for EXTINT, ERROR, F, PRINT2, and GETVAR, the subroutines have no arguments — all variables, parameters, and combinational terms are passed to routines through common blocks. Table 1 shows which common blocks are currently used in which routines. All commons appear to their full extent in MAIN (for initial allocation of core) and nearly all commons appear in PRINT2, to facilitate output (for debugging, for example).

3.1. Description of Routines

A listing of the EBT time-dependent point model code is in Appendix C. A descriptive listing of all the variables used in the code appears in Appendix B. The routines operate as follows:

MAIN

MAIN controls the integration of the equations, calculates global variables for output, controls the frequency of output (in integration time) and checks feedbacks on cold fueling rates. The cold fueling rates are decreased or increased in order to keep n_D and n_T near the operating value n_{DTf} , after the neutrals reach steady state. The feedback of S_{DCOLD} , S_{TCOLD} , if $X > TISTAR$ (the time for n_{0i} to reach steady state), is as follows for $i = D, T$:

$$\text{if } n_i > n_{DTf} \text{ and } \frac{dn_i}{dt} > 0, S_{iCOLD} = \alpha S_{iCOLD}, \quad \alpha < 1;$$

$$\text{if } n_i < n_{DTf} \text{ and } \frac{dn_i}{dt} < 0, S_{iCOLD} = \beta |iLOSS|, \quad \beta > 1.$$

MAIN also controls the turning off of microwave power after ignition.

INIT

INIT does all the initialization necessary for the run: makes initial assignments, reads input data from EBT7EQ.IN, sets up a Y-array of dependent variables for EXTINT, and opens the output files specified by PRTFIL and PLTFIL.

PRINT1

PRINT1 does the initial printout into the files PRTFIL and PLTFIL.

PRINT2(X, H0)

PRINT2 does the printout at time X during integration of the equations.

GETVAR(Y)

GETVAR takes the dependent variables out of the array Y (used by EXTINT) and gives them mnemonic names in the common block VARBL.

F(X, Y, DY)

F calculates the right-hand sides of the differential equations for EXTINT (see the list of equations in Appendix A and the descriptive list of variables in Appendix B).

FCOUNT counts how many times F has been called by EXTINT; it normally takes on values like 7, 13, 21, 53, etc. FCOUNT > 200 indicates problems with the equations converging smoothly.

SIGDT

SIGDT reads $\langle \sigma v \rangle_{DT}$ as a function of T_i from SIGVDT.DAT (the first time it is called). Then $\langle \sigma v \rangle_{DT}$ is calculated through linear interpolation of the values corresponding to the temperatures that bracket T_i (found by a binary search of the array TEMP).

SIGION

SIGION calculates $\langle \sigma v \rangle_{ioniz}$ as a function of T_e , and $\langle \sigma v \rangle_{cx}$ as a function of T_i .

$$\langle \sigma v \rangle_{ioniz} = 10^{-6} \exp \left\{ \sum_{i=0}^6 a_i [\ln(10^3 T_e)]^i \right\} ,$$

$$\langle \sigma v \rangle_{cx} = 10^{-6} \exp \left\{ \sum_{i=0}^8 b_i [\ln(10^3 T_i)]^i \right\} .$$

COLMB

COLMB calculates $P_{e,i}$, the power transferred to the electrons from the ions during Coulomb collisions:

$$P_{e,i} = 1.5 \times 10^{-19} \frac{n_e}{T_e^{3/2}} \sum_{j=D,T} \frac{Z_j^2 n_j}{A_j} (T_e - T_i) (\ln \Lambda) .$$

where

$$\ln \Lambda = 39.4 - \ln \left(\frac{\sqrt{n_e}}{T_e} \right) , \text{ in the full model;}$$

$$\ln \Lambda = 17.0 , \text{ currently.}$$

TAUS

Taus calculates all the particle and energy confinement times, using Kovrizhnykh's results.²

$$\tau_{p,j} = C_j \frac{1}{v_j} \left(1 + \frac{v_j^2}{\Omega_j^2} \right) , \quad j = D, T, \alpha, I, HI ,$$

$$v_j = 2.218 \times 10^{-10} \ln \Lambda \frac{n_j Z_j^2}{\sqrt{A_j} T_i^{3/2}} ,$$

$$C_j = \frac{3}{4} \left[\frac{R_T}{R_c} \left(1 + 10^{-3} \frac{Z_j E_r R_c}{T_i} \right) \right]^2 ,$$

$$\Omega_j = 10^3 \frac{T_i}{Z_j B R_c a} \left(1 + 10^{-3} \frac{Z_j E_r R_c}{T_i} \right) ,$$

$$\frac{1}{\tau_{p,i}} = \frac{n_D}{n_i} \frac{1}{\tau_{p,D}} + \frac{n_T}{n_i} \frac{1}{\tau_{p,T}} ,$$

$$\frac{1}{\tau_{cx}} = \langle \sigma v \rangle_{cx} \frac{n_D n_{OD} + n_T n_{OT}}{n_i}$$

$$\tau_{E,COND} = \frac{3}{7} \tau_{p,i} \quad (\text{currently, } \tau_{E,COND} = 0) ,$$

$$\tau_S = 0.24 \times 10^{13} \frac{T_e^{3/2}}{n_e} \quad (\text{currently, } \tau_S = 0) ,$$

$$\frac{1}{\tau_{E,i}} = \frac{1}{\tau_{p,i}} + \frac{1}{\tau_{cx}} + \frac{1}{\tau_{E,COND}} \quad \left(\text{currently, } \frac{1}{\tau_{E,i}} = \frac{1}{\tau_{p,i}} + \frac{1}{\tau_{cx}} \right) ,$$

$$\tau_{E,e} = \tau_{p,i} .$$

FRACT

FRACT calculates the fractions of energy transferred by various mechanisms. (See ref. 1.)

$$f_{\alpha i} = \frac{T_e}{50} - 0.37 \left(\frac{T_e}{50} \right)^{7/4} ,$$

$$f_{\alpha e} = 1 - f_{\alpha i} ,$$

$$f_{DB,i} = 0.5 \exp \left[-0.0916 \frac{U_{DBEAM}}{U_{CR}} \left(1 + 0.5 \frac{\tau_S}{\tau_{cx}} \right) \right] \\ + 0.5 \exp \left[-0.635 \frac{U_{DBEAM}}{U_{CR}} \left(1 + 0.5 \frac{\tau_S}{\tau_{cx}} \right) \right] ,$$

$$f_{DB,e} = 1 - f_{DB,i} \quad (\text{currently, } f_{DB,i} = f_{DB,e} = 0 ;$$

$$f_{RD} = f_{RT} = 0 ; f_H = 0 .)$$

POWRAD

POWRAD calculates the power losses due to various types of radiation: Bremsstrahlung, line radiation, and synchrotron radiation.

$$P_{\text{BREM}} = 3 \times 10^{-21} Z_{\text{eff}} n_e^2 T_e^{1/2} ,$$

$$Z_{\text{eff}} = \frac{\sum_j Z_j^2 n_j}{\sum_j Z_j n_j} = \frac{\sum_j Z_j^2 n_j}{n_e} , \text{ for } j = \text{D, T, } \alpha, \text{ I, HI} ,$$

$$P_{\text{LINE}} = 2 \times 10^{-17} n_{\text{HI}} n_e \text{ (currently, } P_{\text{LINE}} = 0) ,$$

$$P_{\text{SYNC}} = 1.5 \times 10^5 \sqrt{\frac{n_e B^5}{a}} T_e^{11/4} (1 - R_e) \left(1 + \frac{T_e}{204}\right)$$

$$\text{(currently, } P_{\text{HSYNCH}}, F_{\text{HSYNC}} = 0) ,$$

$$P_{\text{RAD}} = P_{\text{BREM}} + P_{\text{SYNC}} - F_{\text{HSYNC}}^0 + P_{\text{LINE}} .$$

SPUTR

SPUTR will calculate the sputtering rates of impurities off the walls. Currently, this routine is not even called (no impurities are implemented in the code).

FUFRAC

FUFRAC will calculate f_D , the fraction of the deuterium beam which undergoes suprathermal fusion.

$$f_D = \frac{U_{\text{DBEAM}} n_T F(U_{\text{DBEAM}}, T_e)}{1.76 \times 10^4 n_e} .$$

Currently FUFRAC is not even called, as there is no deuterium beam.

As the physics is understood better and as more things are implemented in the code, the form of the subroutines will change, particularly TAUS, FRACT, POWRAD, SPUTR, FUFRAC, and of course F. And as the expressions become more complicated, the calling sequence of some of the subroutines by F may need to be changed to keep everything consistent in time.

3.2 Integration

Integration of the differential equations is done by EXTINT, a deferred-limit integrator written by J. P. Boris and N. K. Windsor, using the extrapolation method developed by R. Bulerisch and J. Stoer.³

The arguments are described in the initial comments in the listing of EXTINT in Appendix C.

EXTINT calls a subroutine, ERROR (also contained in the file EXTINT.F4), which determines whether or not all the equations have met the convergence criterion (EPS) for integration over the time-step (H0). If not, after HMAX extrapolation attempts, H0 is halved. The original ERROR did a relative error check,

$$\left| \frac{dY_i/dX}{Y_{imax}} \right| < EPS ,$$

for convergence of the i^{th} equation, $S(I) = Y_{imax}$ = the maximum value yet reached by Y_i . But this has been changed to give a strict relative error check,

$$\left| \frac{dY_i/dX}{Y_i} \right| < EPS ,$$

for convergence of the i^{th} equation.

3.3. Input

The input file, EBT7EQ.IN, is listed in Appendix C. The input formats in INIT (except for the first record) are such that the first eight spaces are skipped. Thus the variable name is typed in those first eight spaces, next to each input value, simplifying modification of the input file for the user.

The input variables are as follows:

LABEL (1st record)	An 80-character descriptive title of the run, to appear on both printer output and DISSPLA plots.
PRTFIL	A 10-character file name for the printer output.
PLTFIL	A 10-character file name for the (intermediate) plot file.
EPS	The convergence criteria for EXTINT and ERROR ($EPS < 10^{-6}$ would require double precision).
MMAX	The maximum number of extrapolation attempts EXTINT makes before decreasing the time-step.
XSTART	The starting time in seconds (usually 0.0).
H0	The initial time-step for EXTINT in seconds.
XFINAL	The final time in seconds.
PRTFRQ	The frequency in seconds with which printer and plotting output is required, for example, every 0.5 sec.
EPS0	"Error condition" for neutral equations. Neutrals reach steady state when dn_{OD}/dt and dn_{OT}/dt are less than EPS0.
CIGNIT	Ignition criterion. When $CPALP = CPLOSS + CIGNIT$, ignition has occurred.
ZI	Nuclear charge of the low-Z impurity ions.
AI	Mass number of the low-Z impurity ions.

ZHI	Nuclear charge of the high-Z impurity ions.
AHI	Mass number of the high-Z impurity ions.
PMICRO	Microwave power, input as MW/m ³ (converted to keV/m ³ /sec for computation).
UDBEAM	Deuterium beam energy.
UALPHA	The energy of the alpha particles = 3.5 MeV for D-T fusion (in keV).
PBEAM	Total beam power (0.0 for no beams).
RCURVA	$\frac{VB}{B}$ = the radius of curvature of the B-field.
RMAJOR	Major radius of the EBT, in meters.
RMINOR	Minor radius of the EBT, in meters.
ERATIO	$\frac{10^{-3} E_r R_c}{T_i}$, the ratio of the radial electric field to the ion temperature.
BFIELD	Magnitude of the $\vec{B}$ -field at the center of the midplane, in tesla.
DENDTF	Final deuterium density desired = final tritium density desired, in m ⁻³ .
DENØDF	Final neutral deuteron density desired, in m ⁻³ .
DENØTF	Final neutral triton density desired, in m ⁻³ .
TEF	The final electron temperature desired, in keV.
TIF	The final ion temperature desired, in keV.
DEND	The initial deuteron density, in m ⁻³ .
DENT	The initial triton density, in m ⁻³ .
DENA	The initial alpha particle density, in m ⁻³ .
DENIM	The initial low-Z impurity density, in m ⁻³ .
DENHIM	The initial high-Z density, in m ⁻³ .

DEN $\emptyset$ D	The initial neutral deuterium density, in m^{-3} .
DEN $\emptyset$ T	The initial neutral tritium density, in m^{-3} .
TE	The initial electron temperature, in keV.
TI	The initial ion temperature, in keV.

3.4. Execution

The point model code has been developed for the DECsystem-10 (PDP-10). Execution can be either in time-sharing mode or batch mode.

Figure 3 shows the execution flow. The files necessary are as follows (listings are in Appendix C).

EBT7EQ.IN	Input data
EBT7EQ.F4	Source file for point model code, containing routines MAIN, INIT, PRINT1, GETVAR, PRINT2, F, SIGDT, SIGION, COLMB, TAUS, FUFRAC, SPUTR, FRACT, and POWRAD.
EXTINT.F4	Source file containing EXTINT and ERROR.
SIGVDT.DAT	Resident disk file containing $\langle\sigma v\rangle_{DT}$ as a function of T_i (used by SIGDT).
DIS7EQ.F4	Source file of DISSPLA plotting program.
DISVEC.CMD DISTEK.CMD	Command files of all DISSPLA modules to be linked in to execute DISSPLA program.

The output consists of two files:

PRINT.7EQ	Printer output of variables and parameters in time (see example in Appendix D).
PLOT.7EQ	Intermediate plot file - contains data which is input to plotting program, DIS7EQ.F4 (example in Appendix D).

The names of these two output files are character input values of the variables PRTFIL and PLTFIL read in from EBT7EQ.IN, so that successive

runs can be done without overwriting the output files, merely by changing the output file names.

To run under Batch, one needs an additional file, a Batch command file such as 7EQ.CMD, listed in Appendix C. With error-checking at every other step, this file should enable the user to trace aborted runs through the messages printed in the user's Batch log.

The monitor command

```
._SUBMIT 7EQ.CMD/TIME:10:00/CORE:50K/AFTER:18:00↓
```

will submit the Batch job to run after 6 p.m. with 50K core (necessary for the plots), for a maximum time of 10 minutes. It will create a BATCH log file named 7EQ.LOG in the user's disk space. A /RESTART switch will force the Batch job to completely restart after a system crash (normally the Batch jobs continue from the point of interruption, unless the crash is severe).

3.5. Output: Printed

The printed output will be in the user's disk area in a file with the name the user chose to be the value of the input variable PRTFIL, which, in our example, is PRINT.7EQ.

To have this output printed, the user needs to give the monitor print command:

```
._PRINT PRINT.7EQ↓
```

The /DISPOSE:RENAME switch, if used, will remove the file from the user's disk area for temporary storage in a system area until it is printed, after which the file disappears.

3.6. Output: Plotting

The DISSPLA plotting routine, DIS7EQ.F4, makes five semi-log plots (listing in Appendix C):

1. electron, ion, and alpha densities vs time,
2. electron and ion temperatures vs time,
3. total alpha power and total power losses vs time,
4. deuterium and tritium cold fueling rates vs time,
5. time-step (H0) vs time.

Simple execution of this program may require two changes by the user:

1. The input to the plotting routine is the outfile designated by the input variable PLTFIL, in our example PLOT7EQ. If a different file name is used, the OPEN and CLOSE statements in the plotting program must be changed to the new value of PLTFIL.
2. A device-initialization routine must be the first DISSPLA subroutine called. So depending on whether a Tektronix CRT terminal is being used or Versatek printer plots are desired, either the CALL TKTRN (ICPS, IMODE) or the CALL VRSTEC instruction must be implemented, and the other one commented out (see listing in Appendix C). Also, the value of ICPS should be 30 or 120 depending on the line-speed of the Tektronix terminal.

Depending on which plotting device is being used, the user must link in the routines listed either in DISVEC.CMD or DISTEK.CMD (listed in Appendix C), for example,

```
.EX DIS7EQ.F4,@DISVEC.CMD↓.
```

If the Tektronix terminal is being used (handy for time-sharing), DISSPLA rings the bell upon completion of a plot and waits for a carriage return from the user before generating the next plot.

If the Versatek printer is being used to produce plots, the user needs to run the post-processor utility program VECVER:

```
.R VECVER↓  
FILE:↓  
FILE: (esc)
```

and the plots will automatically be queued to the Versatek printer (with the /DISPOSE:RENAME switch). An example of the Versatek plots is in Appendix D.

References

1. D. G. McAlees et al., *The EIMO Bumpy Torus Reactor (EBTR) Reference Design*, ORNL/TM-5669 (1976).
2. L. M. Kovrizhnykh, "Transport Phenomena in Toroidal Magnetic Systems," *Zh. Eksp. Teor. Fiz.* 56:877 (1969) [*Sov. Phys. JETP*, 29:475 (1969)].
3. Roland Bulirsch and Joseph Stoer, "Numerical Treatment of Ordinary Differential Equations by Extrapolation Methods," *Numerische Mathematik*, 8:1-13 (1966).

Fig. 1. Subroutine hierarchy.

Fig. 2. Simplified flow chart.

Fig. 3. Execution of seven-equation point model.

Table 1. Location of common blocks in routines^a

Routines Common blocks	MAIN	INIT	PRINT1	GETVAR	PRINT2	EXTINT	ERROR	T	SIGDT	SIGION	COLMB	TAUS	FUFRA	SPUTR	FRACT	POWRAD
VARBLE	x✓	x✓	x✓	x✓	x✓			x✓	x✓	x✓	x✓	x✓	x✓	x✓	x✓	x✓
INPUT	x✓	x✓	x✓	x✓	x			x✓		x	x	x✓	x	x	x	x✓
SIGMAS	x	x✓			x✓			x✓	x✓	x✓		x✓				
TIMEP	x				x✓			x✓				x✓				
TIMEE	x				x✓			x✓				x✓				
TINEX	x				x✓			x				x✓				
FRAC	x				x			x✓			x✓				x✓	x✓
POWER	x✓				x✓			x✓			x✓					x✓
INRATE	x✓	x✓			x✓			x✓								x✓
RATE	x✓				x✓			x✓								
DIFLOS	x				x			x✓								
SPUT	x				x			x						x✓		
SKATES	x				x			x								
RECYCL	x				x			x								
POMTRN	x✓				x✓			x✓								
ALF	x✓				x✓			x✓								
GLOBAL	x✓	x✓			x✓			x✓								
IGNITE	x✓	x✓			x											
CLOG	x	x✓			x			x								
PARAM	x✓	x✓	x		x✓			x			x✓	x✓				
DBYDT	x✓				x✓			x✓								
CONTRL	x✓	x✓	x✓													
ERRCOM	x✓	x✓	x✓				x									
PRTLAB	x✓	x✓	x✓		x											

^a x = common appears.
 ✓ = variables are used.

Appendix A

EQUATIONS IMPLEMENTED IN THE CODE

$$\frac{dn_D}{dt} = S_{DCOLD} - n_D n_T \langle \sigma v \rangle_{DT} + n_e n_{OD} \langle \sigma v \rangle_{ioniz} - \frac{n_D}{\tau_{p,D}} . \quad (1)$$

$$\frac{dn_T}{dt} = S_{TCOLD} - n_D n_T \langle \sigma v \rangle_{DT} + n_e n_{OT} \langle \sigma v \rangle_{ioniz} - \frac{n_T}{\tau_{p,T}} . \quad (2)$$

$$\frac{dn_\alpha}{dt} = n_D n_T \langle \sigma v \rangle_{DT} - \frac{n_\alpha}{\tau_{p,\alpha}} . \quad (3)$$

$$\frac{dn_I}{dt} = 0 . \quad (4)$$

$$\frac{dn_{HI}}{dt} = 0 . \quad (5)$$

$$\frac{dn_{OD}}{dt} = \begin{cases} S_{DCOLD} - n_e n_{OD} \langle \sigma v \rangle_{ioniz} & \text{if } \left| \frac{dn_{OD}}{dt} \right| < \epsilon_0 , \\ 0 & \text{otherwise .} \end{cases} \quad (6)$$

$$\frac{dn_{OT}}{dt} = \begin{cases} S_{TCOLD} - n_e n_{OT} \langle \sigma v \rangle_{ioniz} & \text{if } \left| \frac{dn_{OT}}{dt} \right| < \epsilon_0 , \\ 0 & \text{otherwise .} \end{cases} \quad (7)$$

$$\frac{dp_e}{dt} = p_\mu + n_D n_T \langle \sigma v \rangle_{DT} (U_\alpha f_{\alpha e} - e T_e) - \frac{p_e}{\tau_{E,e}} - p_{ei} - p_{RAD} . \quad (8)$$

$$\frac{dp_i}{dt} = n_D n_T \langle \sigma v \rangle_{DT} (U_\alpha f_{\alpha e} - 3 T_i) + p_{ei} - \frac{p_i}{\tau_{E,i}} , \quad (9)$$

BLANK PAGE

where

$$n_e = n_D + n_T + 2n_\alpha ,$$

$$n_i = n_D + n_T ,$$

$$p_e = \frac{3}{2} n_e T_e ,$$

$$p_i = \frac{3}{2} n_i T_i .$$

Appendix B
VARIABLES IN CODE

Code variable	Analytical expression (if any)	Description
AHI	A_{HI}	Atomic number of high-Z impurity ions
AI	A_I	Atomic number of low-Z impurity ion
ALFAE	$n_D n_T \langle \sigma v \rangle_{DT} U_{\alpha} f_{\alpha e}$	Power delivered from α particles to electrons
ALFAI	$n_D n_T \langle \sigma v \rangle_{DT} U_{\alpha} f_{\alpha i}$	Power delivered from α particles to ions
ALPHA	$10^{-3} Z_j \frac{E_r R_C}{T_i}$	The product of the charge of the particle $\times$ ERATIO
AREA	S	Surface area of bumpy torus
BDFUSN	$S_{DBEAM} f_D$	Rate of fusion of deuterium beam with plasma tritons
BFIELD	B	Magnetic field strength at center of midplane
BFUSNE	$S_{DBEAM} f_D U_{\alpha} f_{\alpha i}$	Specific power delivered to electrons by 3.5 MeV alphas from suprathermal fusion
BFUSNI	$S_{DBEAM} f_D U_{\alpha} f_{\alpha i}$	Specific power delivered to ions by 3.5 MeV alphas from suprathermal fusion
C		Power conversion factor from keV/sec/m ³ to MW (in MAIN)
C	C_j	Coefficient for $\tau_{p,j}$ (in TAUS)

Appendix B (continued)

Code variable	Analytical expression (if any)	Description
CIGNIT		Ignition criterion (ignition: CPALP - CPLOSS > CIGNIT), MW
COLFRJ	ν_j	Collision frequency for the j th particle (j = D, T, α , I, HI)
COLOM	$\frac{\nu_j}{\Omega_j}$	The ratio of the collision frequency to the precession for particle j
COULOG	$\ln \Lambda$	Coulomb logarithm
CPALP		Total alpha power produced (in whole device), MW
CPLOSS		Total power losses (in whole device), MW
DBEAME	$S_{DBEAM}^U D_{BEAM}^f f_{DB,e}$	Specific power directly delivered to electrons from deuterium beam (keV/sec/m ³)
DBEAMI	$S_{DBEAM}^U D_{BEAM}^f f_{DB,i}$	Specific power directly delivered to ions from deuterium beam (keV/sec/m ³)
DELTAX	Δt	Change in time between successive printouts
DENØ	n_0	Total neutral density (m ⁻³) = $n_{0D} + n_{0T}$
DENØD	n_{0D}	Neutral deuterium density (m ⁻³)
DENØDF	n_{0Df}	Final neutral deuterium density desired (m ⁻³)
DENØT	n_{0T}	Neutral tritium density (m ⁻³)

Appendix B (continued)

Code variable	Analytical expression (if any)	Description
DENØTF	n_{OTf}	Final neutral tritium density (m^{-3})
DENA	n_{α}	Alpha particle density (m^{-3})
DEND	n_D	Deuterion density (m^{-3})
DENDTF	n_{DTf}	Final deuterion density = final triton density desired
DENE	n_e	Total electron density (m^{-3})
DENHIM	n_{HI}	High-Z impurity density (m^{-3})
DENI	n_i	Total ion density (m^{-3})
DENIM	n_I	Low-Z impurity density (m^{-3})
DENT	n_T	Triton density (m^{-3})
DERIV	$\frac{d}{dt}$	Array of right-hand sides of equations (for printout)
DIFA	$\frac{n_{\alpha}}{\tau_{p,\alpha}}$	Alpha particle diffusion loss rate
DIFD	$\frac{n_D}{\tau_{p,D}}$	Deuterium particle diffusion loss rate
DIFHIM	$\frac{n_{HI}}{\tau_{p,HI}}$	High-Z impurity particle diffusion loss rate

Appendix B (continued)

Code variable	Analytical expression (if any)	Description
DIFIM	$\frac{n_I}{\tau_{p,I}}$	Low-Z impurity particle diffusion loss rate
DIFT	$\frac{n_T}{\tau_{p,T}}$	Tritium particle diffusion loss rate
DLOSS		Total losses in n_D equation
DY	$\frac{d}{dt}$	Array of right-hand sides
ENTAU		Global $n\tau$ product
EPS	ϵ	Convergence criterion
EPS0	ϵ_0	"ERROR condition" for neutral equations (steady state)
ERATIO	$\frac{10^{-3} E_r R_c}{T_i}$	The ratio of the radial electric field $\times$ the radius of curvature to the ion temperature
FAE	$f_{\alpha,e}$	Fraction of 3.52 MeV alpha energy given to electrons
FAI	$f_{\alpha,i}$	Fraction of 3.52 MeV alpha energy given to ions
FCOUNT		Number of times EXTINT calls F during integration over one time-step
FD	f_D	Fraction of deuterium beam which undergoes suprathermal fusion
FDBE	$f_{DB,e}$	Fraction of injected deuterium beam energy given directly to electrons

Appendix B (continued)

Code variable	Analytical expression (if any)	Description
FDBI	$f_{DB,i}$	Fraction of injected deuterion beam energy given directly to ions
FH	f_H	Fraction of hot-electron annuli synchrotron radiation energy transferred to background plasma
FHSYNC	$f_H P_{H\text{SYNC}}$	Power delivered to background electrons due to synchrotron radiation from hot-electron annuli
FRD	f_{RD}	Fraction of deuterions which are recycled
FRT	f_{RT}	Fraction of tritons which are recycled
HØ		The integration time-step (modified by EXTINT)
LABEL		An 80-character label for plots and printer output
MMA		The minimum number of extrapolations before having HØ.
NMA		Number of equations = 9
OMEGAJ	Ω_j	Precession frequency for the j^{th} type particle $j = D, T, \alpha, I, HI$
PALPHA		ALFAE + ALFAI = total power delivered to electrons + ions by α particles
PBEAM	P_{BEAM}	(Deuterium) beam power

Appendix B (continued)

Code variable	Analytical expression (if any)	Description
PBREM	P_{BREM}	Power loss due to Bremsstrahlung
PCOLMB	$P_{e,i}$	Power transfer from electrons to ions by Coulomb collisions
PE	P_e	Electron "pressure" = $\frac{3}{2} n_e T_e$
PHSYNC	P_{Hsync}	Power loss due to synchrotron radiation (from hot-electron annuli)
PI	P_i	Ion "pressure" = $\frac{3}{2} n_i T_i$
PLINE	P_{LINE}	Power loss due to line radiation
PLOSS		Total power losses (keV)
PLTFIL		The plot file name
PMICRO	P_{μ}	Specific power delivered to background electrons from microwaves (keV/sec/m ³)
PRAD	P_{RAD}	Total power losses due to various radiation processes
PRTFIL		The print file name
PRTFRQ		Printer and plotting output frequency in seconds (integration time)
PSYNC	P_{SYNC}	Power loss due to synchrotron radiation (from background electrons)

Appendix B (continued)

Code variable	Analytical expression (if any)	Description
PT	$p_e + p_i$	Total "pressure" for electrons and ions
RATEØD	$n_e n_{OD}^{<\sigma v>}_{\text{ioniz}}$	Deuterium - neutral ionization rate
RATEØT	$n_e n_{OT}^{<\sigma v>}_{\text{ioniz}}$	Tritium - neutral ionization rate
RATEDT	$n_D n_T^{<\sigma v>}_{DT}$	Deuterium - tritium fusion rate
RCURVA	R_C	Radius of curvature of field = $\langle \frac{vB}{B} \rangle$
RE	R_e	Reflection coefficient (used in calculating P_{SYNC})
RECYLD	$\left(\frac{n_D}{\tau_{p,D}} \right) f_{RD}$	Deuteron recycling rate
RECYLT	$\left(\frac{n_T}{\tau_{p,T}} \right) f_{RT}$	Triton recycling rate
RMAJOR	R_T	Major radius (m)
RMINOR	a	Minor radius (m)
S		Array (in ERROR) of magnitudes of dependent variables for relative error check
SØBEAM	$S_{\text{ØBEAM}}$	Deuterium injection rate for fast atoms (beam) ($\text{m}^{-3}\text{sec}^{-1}$)
SDCOLD	S_{DCOLD}	Deuterium injection rate for fast cold fuel ($\text{m}^{-3}\text{sec}^{-1}$)

Appendix B (continued)

Code variable	Analytical expression (if any)	Description
SIGVCX	$\langle \sigma v \rangle_{CX}$	Maxwellian-averaged charge-exchange cross-section
SIGVDT	$\langle \sigma v \rangle_{DT}$	Maxwellian-averaged D-T fusion cross-section
SIGVIO	$\langle \sigma v \rangle_{ioniz}$	Maxwellian-averaged ionization cross-section
SIGVXD	$\langle \sigma v \rangle_{CX-D}$	Maxwellian-averaged charge-exchange cross-section for D
SIGVXT	$\langle \sigma v \rangle_{CX-T}$	Maxwellian-averaged charge-exchange cross-section for T
SPUTA	I_{α}	Sputtering coefficient for alpha particles
SPUTD	I_D	Sputtering coefficient for deuterons
SPUTHI	I_{HI}	Sputtering coefficient for low-Z impurities (self-sputtering)
SPUTI	I_I	Sputtering coefficient for high-Z impurities (self-sputtering)
SPUTN	I_N	Sputtering coefficient for neutrons
SPUTT	I_T	Sputtering coefficient for tritons
SRATEA	$\left(\frac{n_{\alpha}}{r_{p,\alpha}} \right) I_{\alpha}$	Sputtering rate for alpha particles
SRATED	$\left(\frac{n_D}{r_{p,D}} \right) I_D$	Sputtering rate for deuterons

Appendix B (continued)

Code variable	Analytical expression (if any)	Description
SRATEN	$(n_D n_T \langle \sigma v \rangle_{DT} + S_{DBEAM} f_D) I_n$	Sputtering rate for neutrons
SRATET	$\left(\frac{n_T}{\tau_{p,T}} \right) I_T$	Sputtering rate for tritons
SSRHIM	$\left(\frac{n_{HI}}{\tau_{p,HI}} \right) I_{HI}$	Self-sputtering rate for high-Z impurities
SSRIM	$\left(\frac{n_I}{\tau_{p,I}} \right) I_I$	Self-sputtering rate for low-Z impurities
STCOLD	S_{TCOLD}	Tritium injection rate for cold fuel ($m^{-3}sec^{-1}$)
TACOND	$\tau_{E,COND}$	Energy confinement time for conduction
TACX	τ_{CX}	Charge-exchange time = $\frac{1}{n_0 \langle \sigma v \rangle_{CX}}$
TAEe	$\tau_{E,e}$	Energy confinement time for electron
TAEI	$\tau_{E,i}$	Energy confinement time for ion
TAGLOB	$\frac{p_e + p_i}{PLOSS}$	"Global" confinement time
TALFAE	$n_D n_T \langle \sigma v \rangle_{DT} (U_\alpha f_{\alpha e} - 3T_e)$	Net power delivered from α -particles to electrons
TALFAI	$n_D n_T \langle \sigma v \rangle_{DT} (U_\alpha f_{\alpha i} - 3T_i)$	Net power delivered from α -particles to ions

Appendix B (continued)

Code variable	Analytical expression (if any)	Description
TAPA	$\tau_{p,\alpha}$	Particle confinement time for alpha particles
TAPD	$\tau_{p,D}$	Particle confinement time for deuterons
TAPHIM	$\tau_{p,HI}$	Particle confinement time for high-Z impurities
TAPIM	$\tau_{p,I}$	Particle confinement time for low-Z impurities
TAPION	$\tau_{p,i}$	Particle confinement time for ions (weighted average for D and T)
TAPT	$\tau_{p,i}$	Particle confinement time for tritons
TAS	τ_s	Spitzer ion-electron momentum exchange time
TBEAME	$S_{DBEAM}(U_{DBEAM}f_{DB,e} + f_D U_{\alpha} f_{\alpha e})$	Total power delivered to electrons from D-beam (including α 's)
TBEAMI	$S_{DBEAM}(U_{DBEAM}f_{DB,i} + f_D U_{\alpha} f_{\alpha i})$	Total power delivered to ions from D-beam (including α 's)
TDSTAR	t_D^*	Time (seconds) that n_{0D} takes to reach steady state
TE	T_e	Electron temperature (keV)
TEF	T_{ef}	Final electron temperature desired (keV)
TI	T_i	Ion temperature (keV)
TIF	T_{if}	Final ion temperature desired (keV)

Appendix B (continued)

Code variable	Analytical expression (if any)	Description
TLOSS		Total losses in n_T equation
TRANE	$\frac{3}{2} \frac{n_e T_e}{\tau_{E,e}} = \frac{p_e}{\tau_{E,e}}$	Specific power loss from electrons due to transport processes
TRANI	$\frac{3}{2} \frac{n_i T_i}{\tau_{E,i}} = \frac{p_i}{\tau_{E,i}}$	Specific power loss from ions due to transport processes
TTSTAR	τ_t^*	Time (seconds) that n_{0T} takes to reach steady state
UALPHA	U_α	Energy of alpha particles = 3.52×10^3 keV from D-T fusion
UCR	U_{CR}	Critical energy during the slowing down process, at which energy is being transferred equally to plasma ions and electrons
UDBEAM	$U_{D\text{BEAM}}$	Energy of injected deuterons (keV)
VOLUME	V	Volume of "torus" = $2\pi^2 R_T a^2$
X	t	Integration time (seconds)
XFINAL	t_{final}	Final integration time (seconds)
XOLD		Previous printout time; do printout if $X - XOLD \geq \text{PRTFRQ}$
XSTART	t_{start}	Initial integration time (seconds)
Y		Array of dependent variables for EXTINT

Appendix B (continued)

Code Variable	Analytical expression (if any)	Description
ZEFF	Z_{eff}	Effective charge = $\Sigma Z_j^2 n_j / \Sigma Z_j n_j$ $j = D, T, \alpha, I, HI$
ZHI	Z_{HI}	Charge number of high-Z impurity
ZI	Z_I	Charge number of low-Z impurity

Appendix C

LISTINGS OF FILES

EBT7EQ.IN

EBT7EQ.F4

EXTINT.F4

SIGVDT.DAT

DIS7EQ.F4

DISVEC.CMD

DISTEK.CMD

7EQ.CMD

ETB7EQ.IN - Sample Input File

```

*35 REACTOR(48 COILS) - PMICRO SHUTOFF - 12/10/76
PRTFIL PRINT.7EQ
PLTFIL PLOT.7EQ
EPS 1.000000E-06
NMAX 4
XSTART 0.000000E+00
H0 1.000000E-06
XFINAL 1.000000E+02
PRTRD 0.500000E+00
EPS0 1.000000E-05
CIGNIT 0.000000E+00
CI 0.000000E+00
AI 0.000000E+00
ZHI 0.000000E+00
AHI 0.000000E+00
PMICRO 0.200000E+00
UDBEAM 1.000000E+02
UALPHA 3.500000E+03
PBEAM 0.000000E+00
RCURVA 2.700000E+00
RMAJOR 6.000000E+01
RMINOR 1.000000E+00
ERATIO 0.100000E+00
BFIELD 2.500000E+00
DENDTF 0.750000E+20
DENODF 1.000000E+12
DENATF 1.000000E+12
TEF 1.500000E+01
TIF 1.000000E+01
DEND 0.500000E+20
DENT 0.500000E+20
DENA 1.000000E+15
DENIM 1.000000E+00
DENHIM 1.000000E+00
DENOD 1.000000E+14
DENOT 1.000000E+14
TE 1.000000E+00
TI 1.000000E+00

```

EBT7EQ.F4 - Point Model Code Source Listing

```

C*****
C
C      REACTOR TIME-DEPENDENT POINT MODEL FOR EBT
C
C      7 EQUATIONS -- PLOTTING
C
C      PHYSICIST:  N.A. MCKAN, FUSION ENERGY DIVISION
C      PROGRAMMER: J.F. ROBERTS, COMPUTER SCIENCES DIVISION
C                  OAK RIDGE NATIONAL LABORATORY
C                  OAK RIDGE, TENNESSEE 37830
C*****
C
C      MKS UNITS ARE USED:
C          TIME IS IN SECONDS
C          DENSITIES ARE IN  $\text{g}/\text{cm}^3$ 
C          POWERS ARE IN MEGAWATTS/ $\text{cm}^3$ 
C          TEMPERATURES ARE IN KEV
C          ENERGIES ARE IN KEV
C          PRESSURES ARE IN  $\text{keV}/\text{cm}^3$ 
C
C      INTEGRATION IS DONE BY A "DEFERRED-LIMIT INTEGRATOR", CALLED
C          EXTINT, WRITTEN BY J.P.BORIS AND N.K.WINSOR
C
C      EXTINT CALLS A SUBROUTINE CALLED ERROR, WHICH DEFINES
C          CONVERGENCE CRITERIA. OUR ERROR ROUTINE IS FROM FRED JAEGER.
C
C      EXTINT ALSO CALLS A SOURCE SUBROUTINE, F, WHICH SETS UP THE
C          RIGHT-HAND SIDES OF THE DIFFERENTIAL EQUATIONS.
C
C      THE DEPENDENT VARIABLES FOR THE D.E.'S ARE AS FOLLOWS:
C          Y(1) = DEND = DEUTERON DENSITY
C          Y(2) = DENT = TRITON DENSITY
C          Y(3) = DENA = ALPHA PARTICLE DENSITY
C          Y(4) = DENIM = LOW-Z IMPURITY DENSITY
C          Y(5) = DENHIM = HIGH-A IMPURITY DENSITY
C          Y(6) = DENØD = DEUTERON NEUTRAL DENSITY
C          Y(7) = DENØT = TRITON NEUTRAL DENSITY
C          Y(8) = PE = ELECTRON PRESSURE
C          Y(9) = PI = ION PRESSURE
C
C      OTHER DEPENDENT VARIABLES ARE ALGEBRAIC COMBINATIONS OF
C          THE DEPENDENT VARIABLES DEFINED BY THE DIFFERENTIAL EQUATIONS
C          DENE = DEND+DENT+2*DENA+2I*DENIM+2HI*DENHIM
C              = ELECTRON DENSITY
C          DENI = DEND + DENT = ION DENSITY
C          DENØ = DENØD + DENØT = TOTAL NEUTRAL DENSITY
C          TE = (2/3)*(PE/DENE) = ELECTRON PRESSURE
C          TI = (2/3)*(PI/DENI) = ION PRESSURE
C
C      IMPLICIT REAL (A-H,O-Z), INTEGER(I-N)
C      REAL*8 PRTEIL,PLTFIL
C      EXTERNAL F,ERROR,EXTINT
C      INTEGER FCOUIT
C
C      -----COMMON BLOCKS FOR VARIABLES, INPUT VALUES, & DERIVED EXPRESSIONS
C

```

```

C
COMMON/VARBLE/DEND,DENT,DENA,DENIM,DENHIM,DENOD,DENOT,
      PE,PI,DENE,DENI,DENØ,TE,TI
COMMON/INPUT/ZI,AI,ZHI,AHI,PMICRO,UDBEAM,UALPHA,PBEAM,
      VOLUME,AREA,RCURVA,RMAJOR,RMINOR,ERATIO,BFIELD
COMMON/SIGMAS/SIGVDT,SIGVIO,SIGVCX,SIGVXD,SIGVXT
COMMON/TIMEP/TAPD,TAPT,TAPA,TAPIM,TAPHIM,TAPION
COMMON/TIMEE/TAEI,TACND
COMMON/TIMEX/TAS,TACX
COMMON/FRAC/FDBE,FDBI,FAE,FAI,FRD,FRT,FH,FD
COMMON/POWER/PSYNC,PHSYNC,FHSYNC,PLINE,PBREM,PRAD,PCOLMB
COMMON/INRATE/SDBEAM,SDCOLD,STCOLD,DENDTF,DENØTF,DENØTF,TEF,
      TDSTAR,TTSTAR,DLOSS,TLOSS
COMMON/RATE/RATEDT,RATEØD,RATEØT,BDFUSN
COMMON/DIFLOS/DIFD,DIFT,DIFA,DIFIM,DIFHIM
COMMON/SPUT/SPUTN,SPUTD,SPUTT,SPUTA,SPUTI,SPUTHI
COMMON/SRATES/SRATEN,SRATED,SRATET,SRATEA,SSRHIM
COMMON/RECYCL/RECYLD,RECYLT
COMMON/POUTRN/DBEAME,DBEAMI,BFUSNE,BFUSNI,TBEAME,TBEAMI,TRANE,
      TRANI
COMMON/ALF/ALFAE,ALFAI,TALFAE,TALFAI
COMMON/GLOBAL/PALPHA,PLOSS,CPALP,CPLOSS,TAGLOB,ENTAU,C
COMMON/IGNITE/CIGNIT,TIF
COMMON/CLOG/COULOG
COMMON/PARAM/FCOUNT,EPSØ
COMMON/DBYDT/DERIV(9)
COMMON/CONTRL/XSTART,HØ,XFINAL,PRTFRQ
COMMON/ERRCOM/EPS,S(100),Y(100),NMAX,MMAX
COMMON/PRTLAB/LABEL(20),PRTFIL,PLTFIL

C
C
C
C
C-----CONVERT PMICRO TO KEV/SEC/M2*3 FOR CALCULATIONS
C
C      PMICRO=6.242197E+21*PMICRO
C
C
C***** MAIN INTEGRATION LOOP *****
C
C      X=XSTART
C      XOLD=XSTART
150  FCOUNT=Ø
C
C
C      CALL EXTINT(NMAX,X,Y,F,HØ,MMAX,ERROR)
C
C
C      CALL GETVAR(Y)
C
C
C***** IF (TE.LT.1.Ø) HØ=1.ØE-5
C***** IF (TI.LT.1.Ø) HØ=1.ØE-5
C

```

```

C-----PT IS TOTAL "PRESSURE"
C      TAGLOB IS A GLOBAL CONFINEMENT TIME
C      ENTAU IS A GLOBAL (ICN) DENSITY*(CONFINEMENT TIME)
C
C      PT=PE+PI
C      PALPHA=ALFAE+ALFAI
C      PLOSS=TRANE+TRANI+3.0*RATEDT*(TE+TI)+PRAD
C      TAGLOB=PT/PLOSS
C      ENTAU=DENI*TAGLOB
C
C
C-----CPALP IS TOTAL ALPHA POWER (MEGAWATTS)
C      CPLOSS IS TOTAL POWER LOST (MEGAWATTS)
C
C      CPALP=C*PALPHA
C      CPLOSS=C*PLOSS
C
C-----REGULATE FREQUENCY OF OUTPUT WITH DELTAX
C
C      30  DELTAX=X-XOLD
C          IF (DELTAX.LT.PRIFRO) GO TO 1000
C
C          CALL PRINT2(X,H0)
C
C          XOLD=X
C
C-----FEEDBACK ON SDCOLD AND STCOLD FOR NEXT TIME-STEP
C
C      1000 IF(X.LE.TDSTAR) GO TO 1020
C
C          IF(DEND.GT.DENDTF.AND.DERIV(1).GT.0.0) SDCOLD=0.9*SDCOLD
C          C**** IF(DEND.GT.DENDTF.AND.DERIV(1).GT.0.0) H0=1.0E-02
C          IF(DEND.LT.DENDTF.AND.DERIV(1).LT.0.0) SDCOLD=1.1*ABS(DLOSS)
C          C**** IF(DEND.LT.DENDTF.AND.DERIV(1).LT.0.0) H0=1.0E-02
C
C          DEN0D=SDCOLD/(DENE*SIGVIO)
C          Y(6)=DEN0D
C
C      1020 IF(X.LE.TTSTAR) GO TO 1030
C
C          IF(DENT.GT.DENDTF.AND.DERIV(2).GT.0.0) STCOLD=0.9*STCOLD
C          C**** IF(DENT.GT.DENDTF.AND.DERIV(2).GT.0.0) H0=1.0E-02
C          IF(DENT.LT.DENDTF.AND.DERIV(2).LT.0.0) STCOLD=1.1*ABS(TLOSS)
C          C**** IF(DENT.LT.DENDTF.AND.DERIV(2).LT.0.0) H0=1.0E-02
C
C          DEN0T=STCOLD/(DENE*SIGVIO)
C          Y(7)=DEN0T
C
C-----SHUT OFF MICROWAVE POWER AFTER IGNITION
C
C      1030 IF(PMICRO.LT.1.0E-06) PMICRO=0.0

```



```

      IF (TI.GT.TIF.AND.DENI.GT.(DENDTF+DENDTF).AND.
      &      (CPALP-CPLOSS).GT.CIGNIT) PMICRO=0.1*PMICRO
C
C
      IF(X.LT.XFINAL) GO TO 150
C
C
C-----CLOSE FILES
C
      CLOSE(UNIT=22,FILE='EBT7EQ.IN')
      CLOSE(UNIT=23,FILE=PRTFIL)
      CLOSE(UNIT=20,FILE=PLTFIL)
C
C
      STOP
      END

```

```

C
C
C      SUBROUTINE INIT
C
C      REAL*8 PRTFIL,PLTFIL
C
C      COMMON/VARBLE/DEND,DENT,DENA,DENIM,DENHIM,DENOD,DENOT,
&      PE,PI,DENE,DENI,DENO,TE,TI
C      COMMON/INPUT/ZI,AI,ZHI,AHI,PMICRO,UDBEAM,UALPHA,PBEAM,
&      VOLUME,AREA,RCURVA,RMAJOR,RMINOR,ERATIO,BFIELD
C      COMMON/SIGMAS/SIGVDT,SIGVIO,SIGVCX,SIGVXD,SIGVXT
C      COMMON/INRATE/SDBEAM,SDCOLD,STCOLD,DENDTF,DENODF,DENOTF,TEF,
&      TDSTAR,TTSTAR,DLOSS,TLOSS
C      COMMON/GLOBAL/PALPHA,PLOSS,CPALP,CPLOSS,TAGLOB,ENTAU,C
C      COMMON/IGNITE/CIGNIT,TIF
C      COMMON/CLOG/COULOG
C      COMMON/PARAM/FCCOUNT,EPS0
C      COMMON/ERRCOM/EPS,S(100),Y(100),NMAX,MMAX
C      COMMON/CONTRL/XSTART,H0,XFINAL,PRTRQ
C      COMMON/PRTLAB/LABEL(20),PRTFIL,PLTFIL
C
C
C-----SET UP PARAMETERS FOR EXTINT AND ERROR ROUTINES
C
C      NMAX=9
C      DO 5 I=1,100
C      S(I)=0.1E18
C      5   Y(I)=0.0
C
C
C-----OPEN INPUT FILE AND READ CONTROL PARAMETERS
C
C      OPEN (UNIT=22,FILE='EBT7EQ.IN')
C
C      READ (22,40) (LABEL(I),I=1,20)
C      READ (22,20) PRTFIL
C      READ (22,20) PLTFIL
C      READ (22,50) EPS
C      READ (22,60) MMAX
C      READ (22,50) XSTART
C      READ (22,50) H0
C      READ (22,50) XFINAL
C      READ (22,50) PRTRQ
C
C
C      EPS0 IS ERROR CONDITION FOR NEUTRAL EQUATIONS
C      CIGNIT IS THE CRITERION FOR WHEN (PALPHA-PLOSS) MEANS IGNITION
C
C      READ (22,50) EPS0
C      READ (22,50) CIGNIT
C
C
C      20  FORMAT (8X,A10)
C      40  FORMAT (20A4)
C      50  FORMAT (8X,E13.6)
C      60  FORMAT (9X,I2)

```

```

C
C
C-----READ INPUT PARAMETERS
C
C      ZI IS LOW-Z IMPURITY CHARGE NUMBER
C      AI IS LOW-Z IMPURITY ATOMIC NUMBER
C      ZHI IS HIGH-Z IMPURITY CHARGE NUMBER
C      AHI IS HIGH-Z IMPURITY ATOMIC NUMBER
C      PMICRO IS THE MICRO-WAVE POWER, INPUT AS MEGAWATTS/1000
C      UDBEAM IS THE DEUTERIUM BEAM ENERGY
C      UALPHA IS THE ALPHA PARTICLE BEAM ENERGY
C      PBEAM IS THE TOTAL BEAM POWER
C      VOLUME IS THE PLASMA VOLUME IN THE EBT
C      AREA IS THE SURFACE AREA
C      RCURVA IS THE RADIUS OF CURVATURE (GRAD(BFIELD)/BFIELD)
C      RMAJOR IS THE MAJOR RADIUS
C      RMINOR IS THE MINOR RADIUS
C      ERATIO IS THE RATIO OF THE CHARGE*RADIAL ELECTRIC FIELD
C              *AREA TO THE ELECTRON TEMPERATURE
C
C      READ (22.50) ZI
C      READ (22.50) AI
C      READ (22.50) ZHI
C      READ (22.50) AHI
C      READ (22.50) PMICRO
C      READ (22.50) UDBEAM
C      READ (22.50) UALPHA
C      READ (22.50) PBEAM
C      READ (22.50) RCURVA
C      READ (22.50) RMAJOR
C      READ (22.50) RMINOR
C      READ (22.50) ERATIO
C      READ (22.50) BFIELD
C
C      READ (22.50) DENDTF
C      READ (22.50) DENODF
C      READ (22.50) DENOTF
C      READ (22.50) TEF
C      READ (22.50) TIF
C
C
C-----READ INITIAL CONDITIONS
C
C      READ (22.50) DEND
C      READ (22.50) DENT
C      READ (22.50) DENA
C      READ (22.50) DENIM
C      READ (22.50) DENHIM
C      READ (22.50) DENOD
C      READ (22.50) DENOT
C      READ (22.50) TE
C      READ (22.50) TI
C
C
C-----CALCULATE OTHER NEEDED QUANTITIES
C
C      DENE=DEND+DENT+2.0*DENA+ZI*DENIM+ZHI*DENHIM

```

```

DENI=DEND+DENT
DENI=DENØD+DENØT
PE=1.5*TE*DENE
PI=1.5*TI*DENI

C
C
C-----TDSTAR,TTSTAR ARE TIMES (SEC) FOR NEUTRALS (D,T RESPECTIVELY)
C          TO REACH EQUILIBRIUM --> SET TO INFINITY
C          (USED AS CHECK FOR NEUTRAL EQUATIONS IN F)
C
C
C          TDSTAR=1.00E+05
C          TTSTAR=1.00E+05
C
C          VOLUME=2.0*9.869604*RAJOR*MINOR*MINOR
C
C-----SDBEAM=6.25E21*PBEAM/(VOLUME*UDPEAM)
C          SDBEAM=0.00
C
C
C-----CALL SIGION WITH TE=TEF TO GET SIGVIO TO
C          CALCULATE SDCOLD,STCOLD
C
C          TE=TEF
C          CALL SIGION
C          TE=(2.0*PE)/(3.0*DENE)
C
C          SDCOLD=2.0*DENDTF*(DENØDF*SIGVIO)
C          STCOLD=2.0*DENDTF*(DENØTF*SIGVIO)
C
C
C-----C IS POWER CONVERSION FACTOR FROM KEV/SEC/M**3 TO MEGAWATTS
C          (TOTAL POWER, NOT NORMALIZED TO VOLUME)
C
C          C=1.602E-22*VOLUME
C
C
C-----SET UP Y-ARRAY OF DEPENDENT VARIABLES
C
C          Y(1)=DEND
C          Y(2)=DENT
C          Y(3)=DENA
C          Y(4)=DENIM
C          Y(5)=DENHIM
C          Y(6)=DENØD
C          Y(7)=DENØT
C          Y(8)=PE
C          Y(9)=PI
C
C
C-----OPEN PRINT AND PLOT FILES
C
C          OPEN(UNIT=23,FILE=PRTFIL)
C          OPEN(UNIT=20,FILE=PLTFIL)
C
C
C          RETURN
C          END

```

```

C
C
SUBROUTINE PRINT1
C
C-----WRITE INPUT PARAMETERS AND INITIAL CONDITIONS
C
COMMON/VARIABLE/DENT, DENA, DENIM, DENHIM, DENØD, DENØT,
& PE, PI, DENE, DENI, DENØ, TE, TI
COMMON/INPUT/ZI, AI, ZHI, AHI, PMICRO, UDBEAM, UALPHA, PBEAM,
& VOLUME, AREA, RCURVA, RMAJOR, RMINOR, ERATIO, BFIELD
COMMON/PARAM/FCOUNT, EPSØ
COMMON/ERRCOM/EPS, S(100), Y(100), NMAX, MMAX
COMMON/CONTROL/XSTART, HØ, XF FINAL, PRTRQ
COMMON/PRTLAB/LABEL(20), PRTFIL, PLTFIL
C
C
WRITE (23,106)
100 FORMAT(' ',30X,'EBT REACTOR STUDIES',//)
WRITE (23,102) (LABEL(I),I=1,20)
102 FORMAT(' ',26X,20(A4),//)
WRITE (23,103) (LABEL(I),I=1,20)
103 FORMAT(' ',20(A4))
WRITE (23,105)
105 FORMAT(' ',3X,'INPUT PARAMETERS:',//)
WRITE (23,106) ZI, AI, ZHI, AHI, PMICRO
106 FORMAT(' ',16X,'ZI=',E11.4,10X,'AI=',E11.4,9X,'ZHI=',E11.4,9X,
& 'AHI=',E11.4,6X,'PMICRO=',E11.4)
WRITE (23,107) UDBEAM, UALPHA, PBEAM, VOLUME, AREA
107 FORMAT(' ',12X,'UDBEAM=',E11.4,6X,'UALPHA=',E11.4,7X,'PBEAM=',
& E11.4,5X,'VOLUME=',E11.4,8X,'AREA=',E11.4)
WRITE (23,108) RCURVA, RMAJOR, RMINOR, ERATIO, BFIELD
108 FORMAT(' ',12X,'RCURVA=',E11.4,6X,'RMAJOR=',E11.4,6X,'RMINOR=',
& E11.4,6X,'ERATIO=',E11.4,6X,'BFIELD=',E11.4,//)
WRITE (23,110)
110 FORMAT(' ',3X,'INITIAL CONDITIONS:',//)
WRITE (23,120) DEND, DENT, DENE, DENIM, DENHIM
120 FORMAT(' ',14X,'DEND=',E11.4,8X,'DENT=',E11.4,8X,'DENA=',
& E11.4,7X,'DENIM=',E11.4,6X,'DENHIM=',E11.4)
WRITE (23,125) DENØD, DENØT, DENE, DENI, DENØ
125 FORMAT(' ',13X,'DENØD=',E11.4,7X,'DENØT=',E11.4,8X,'DENE=',
& E11.4,8X,'DENI=',E11.4,8X,'DENØ=',E11.4)
WRITE (23,130) TE, TI
130 FORMAT(' ',16X,'TE=',E11.4,10X,'TI=',E11.4)
WRITE (23,135)
135 FORMAT(' ',3X,'CONTROL PARAMETERS:',//)
WRITE (23,140) XSTART, HØ, XF FINAL, EPS, MMAX
140 FORMAT(' ',12X,'XSTART=',E11.4,10X,'HØ=',E11.4,6X,'XF FINAL=',
& E11.4,9X,'EPS=',E11.4,8X,'MMAX=',E12,//)
WRITE (23,115)
115 FORMAT(' ',3X,'TIME INTEGRATIONS:',//)
C
C
RETURN
END

```

```

C
C
C      SUBROUTINE PRINT2(X,H0)
C
C-----PRINT VARIABLES, DERIVATIVES, AND VARIOUS EXPRESSIONS
C          AS A FUNCTION OF TIME, DURING INTEGRATION
C
COMMON/VARIABLE/DEND,DENT,DENA,DENIM,DENHIM,DEN0D,DEN0T,
      &      PE,PI,DENE,DENI,DEN0,TE,TI
COMMON/INPUT/ZI,AI,ZHI,AHI,PMICRO,UDBEAM,UALPHA,PBEAM,
      &      VOLUME,AREA,RCURVA,RAJOR,RMINGR,ERATIO,BFIELD
COMMON/SIGMAS/SIGVDT,SIGVIO,SIGVCX,SIGVXD,SIGVXT
COMMON/TIMEP/TAPD,TAPT,TAPA,TAPIM,TAPHIM,TAPION
COMMON/TIMEE/TAEI,TAEI,TACOND
COMMON/TIMEX/TAS,TACX
COMMON/FAC/FDBE,FDBI,FAE,FAI,FRD,FRT,FH,FD
COMMON/POWER/PSYNC,PHSYNC,FHSYNC,PLINE,PBREM,PRAD,PCOLMB
COMMON/INRATE/SDBEAM,SDCOLD,STCOLD,DENDTF,DEN0DF,DEN0TF,TE*,
      &      TDSTAR,TTSTAR,DLOSS,TLOSS
COMMON/RATE/RATEDT,RATE0D,RATE0I,BDFUSN
COMMON/DIFLOS/DIFD,DIFT,DIFA,DIFIM,DIFHIM
COMMON/SPUT/SPUTN,SPUTD,SPUTT,SPUTA,SPUTI,SPUTHI
COMMON/SRATES/SRATEN,SRATED,SRATEI,SRATEA,SSRIM,SSRHIM
COMMON/RECYCL/RECYLD,RECYLT
COMMON/FJWTRN/DBEAME,DBEAMI,BFUSNE,BFUSNI,TBEAME,TBEAMI,TRANE,
      &      TRANI
COMMON/ALF/ALFAE,ALFAI,TALFAE,TALFAI
COMMON/GLOBAL/PALPHA,PLOSS,CPALP,CPLOSS,TAGLOB,ENTAU,C
COMMON/IGNITE/IGNIT,TIF
COMMON/CLOG/COULOG
COMMON/PARAM/FCOUNT,EPS0
COMMON/DEYDT/DERIV(9)
COMMON/PRTLAB/LABEL(20),PRTFIL,PLTFIL
C
C
      WRITE(20,600) X,DENE,DENI,DENA,DEN0,TE,TI,CPALP,CPLOSS,TAGLOB,
      &      ENTAU,H0,SDCOLD,STCOLD
600  FORMAT(' ',11E11.4)
      WRITE(23,800) X,FCOUNT
800  FORMAT(' TIME=',E11.4,10X,'FCOUNT=',I4,/)
      WRITE(23,900) DERIV(1),DERIV(2),DERIV(3),DERIV(4),DERIV(5)
900  FORMAT(' ',13X,'DY(1)=' ,E11.4,7X,'DY(2)=' ,E11.4,7X,'DY(3)=' ,
      &      E11.4,7X,'DY(4)=' ,E11.4,7X,'DY(5)=' ,E11.4,
      &      WRITE(23,905) DERIV(6),DERIV(7),DERIV(8),DERIV(9)
905  FORMAT(' ',13X,'DY(6)=' ,E11.4,7X,'DY(7)=' ,E11.4,7X,'DY(8)=' ,
      &      E11.4,7X,'DY(9)=' ,E11.4,7X)
      WRITE(23,920) DEND,DENT,DENA,DENIM,DENHIM
920  FORMAT(' ',14X,'DEND=' ,E11.4,8X,'DENT=' ,E11.4,8X,'DENA=' ,
      &      E11.4,7X,'DENIM=' ,E11.4,6X,'DENHIM=' ,E11.4)
      WRITE(23,925) DEN0D,DEN0T,DENE,DENI,DEN0
925  FORMAT(' ',13X,'DEN0D=' ,E11.4,7X,'DEN0T=' ,E11.4,8X,'DENE=' ,
      &      E11.4,8X,'DENI=' ,E11.4,8X,'DEN0=' ,E11.4)
      WRITE(23,930) TE,TI,PE,PI
930  FORMAT(' ',16X,'TE=' ,E11.4,10X,'TI=' ,E11.4,10X,'PE=' ,E11.4,10X,
      &      'PI=' ,E11.4)
      WRITE(23,935) SDBEAM,SDCOLD,STCOLD,TDSTAR,TTSTAR
935  FORMAT(' ',12X,'SDBEAM=' ,E11.4,6X,'SDCOLD=' ,E11.4,6X,
      &      'STCOLD=' ,E11.4,6X,'TDSTAR=' ,E11.4,6X,'TTSTAR=' ,E11.4)

```

```

WRITE(23,940) RATEDT,RATE0D,RATE0T,BDFUSN
940 FORMAT(' ',12X,'RATEDT=',E11.4,5X,'RATE0D=',E11.4,6X,
& 'RATE0T=',E11.4,6X,'BDFUSN=',E11.4)
WRITE(23,945) SIGVDT,SIGVIO,SIGVCX,SIGVXD,SIGVXT
945 FORMAT(' ',12X,'SIGVDT=',E11.4,6X,'SIGVIO=',E11.4,6X,
& 'SIGVCX=',E11.4,6X,'SIGVXD=',E11.4,6X,'SIGVXT=',E11.4)
WRITE(23,950) TAPD,TAPT,TAPA,TAPIM,TAPHIM
950 FORMAT(' ',14X,'TAPD=',E11.4,8X,'TAPT=',E11.4,8X,'TAPA=',
& E11.4,7X,'TAPIM=',E11.4,6X,'TAPHIM=',E11.4)
WRITE(23,955) TAPION,TAEI,TACOND
955 FORMAT(' ',12X,'TAPION=',E11.4,8X,'TAEI=',E11.4,8X,'TACOND=',
& E11.4,6X,'TACOND=',E11.4)
WRITE(23,960) TAS,TACX
960 FORMAT(' ',15X,'TAS=',E11.4,8X,'TACX=',E11.4)
WRITE(23,965) PSYNC,PHSYNC,FHSYNC,PLINE,PBREM,PCOLMB,PRAD,PMICRO
965 FORMAT(' ',13X,'PSYNC=',E11.4,6X,'PHSYNC=',E11.4,6X,'FHSYNC=',
& E11.4,7X,'PLINE=',E11.4,7X,'PBREM=',E11.4,7X,13X,
& 'PCOLMB=',E11.4,8X,'PRAD=',E11.4,6X,'PMICRO=',E11.4)
WRITE(23,970) DBEAME,BFUSNE,TBEAME,TRANE,DBEAMI,BFUSNI,
& TBEAMI,TRANI
970 FORMAT(' ',12X,'DBEAME=',E11.4,6X,'BFUSNE=',E11.4,6X,
& 'TBEAME=',E11.4,7X,'TRANE=',E11.4,7X,13X,'DBEAMI=',
& E11.4,6X,'BFUSNI=',E11.4,
& 6X,'TBEAMI=',E11.4,7X,'TRANI=',E11.4)
WRITE(23,975) ALFAE,ALFAI
975 FORMAT(' ',13X,'ALFAE=',E11.4,7X,'ALFAI=',E11.4)
WRITE(23,980) PALPHA,PLOSS,TAGLOB,ENTAU
980 FORMAT(' ',12X,'PALPHA=',E11.4,7X,'PLOSS=',E11.4,6X,'TAGLOB=',
& E11.4,7X,'ENTAU=',E11.4)
WRITE(23,985) CPALP,CPLOSS
985 FORMAT(' ',10X,'PALPHA*C=',E11.4,5X,'PLOSS*C=',E11.4,///)
C
RETURN
END

```

```

C
C
C      SUBROUTINE GETVAR(Y)
C
C-----SUBROUTINE TO TAKE TIME-DEPENDENT VARIABLES OUT OF ARRAY Y
C          (USED FOR EXTINT) AND PUT THEM IN COMMON BLOCK VARBLE
C          FOR MNEMONIC REFERENCE IN OTHER SUBROUTINES
C
C      DIMENSION Y(1)
C
C      COMMON/VARBLE/DEND,DENT,DENA,DENIM,DENHIM,DENØD,DENØT,
C      &          PE,PI,DENE,DENI,DENØ,TE,TI
C      COMMON/INPUT/ZI,AI,ZHI,AHI,PMICRO,UDBEAM,UALPHA,PBEAM,
C      &          VOLUME,AREA,RCURVA,RMAJOR,RMINOR,ERATIO,BFIELD
C
C      DEND=Y(1)
C      DENT=Y(2)
C      DENA=Y(3)
C      DENIM=Y(4)
C      DENHIM=Y(5)
C      DENØD=Y(6)
C      DENØT=Y(7)
C      PE=Y(8)
C      PI=Y(9)
C
C      DENE=DEND+DENT+2.0*DENA+ZI*DENIM+ZHI*DENHIM
C      DENI=DEND+DENT
C      DENØ=DENØD+DENØT
C      TE=(2.0*PE)/(3.0*DENE)
C      TI=(2.0*PI)/(3.0*DENI)
C
C      RETURN
C      END

```


**SOURCE SUBROUTINE TO DEFINE THE RIGHT-HAND SIDES OF THE
DIFFERENTIAL EQUATIONS FOR THE PARTICLE-BALANCE MODEL
FOR EBT REACTOR STUDIES**

X IS THE INDEPENDENT VARIABLE (TIME)
Y(100) IS ARRAY OF DEPENDENT VARIABLES
DY(100) IS ARRAY TO RETURN RIGHT-HAND-SIDES OF
DIFFERENTIAL EQUATIONS TO EXTINT

DY(1)=D/DT(DEND)
DY(2)=D/DT(DENT)
DY(3)=D/DT(DENA)
DY(4)=D/DT(DENIM)
DY(5)=D/DT(DENHIM)
DY(6)=D/DT(DENOD)
DY(7)=D/DT(DENOT)
DY(8)=D/DT(PE)
DY(9)=D/DT(PI)

DEND=Y(1)
DENT=Y(2)
DENA=Y(3)
DENIM=Y(4)
DENHIM=Y(5)
DENØD=Y(6)
DENØT=Y(7)
PE=Y(8)
PI=Y(9)

```

IMPLICIT REAL (A-H,O-Z), INTEGER(I-N)
INTEGER ECOUNT

```

```
COMMON/VARBLE/DEND,DENT,DENA,DENIM,DENHIM,DENØD,DENØT,  
PE,PI,DENE,DENI,DENØ,TE,TI  
COMMON/INPUT/ZI,AI,ZHI,AHI,PMICRO,UDBEAM,UALPHA,PBEAM,  
VOLUME,AREA,RCURVA,RMAJOR,RMINOR,ERATIO,BFIELD  
COMMON/SIGMAS/SIGVDT,SIGVIO,SIGVCX,SIGVXD,SIGVXT  
COMMON/TIMEP/TAPD,TAPT,TAPA,TAPIM,TAPHIM,TAPION  
COMMON/TIMEE/TAE,TAEI,TACOND  
COMMON/TIMEX/TAS,TACX  
COMMON/FRAC/FDBE,FDBI,FAE,FAI,FRD,FRT,FH,FD  
COMMON/POWER/PSYNC,PHSYNC,FHSYNC,PLINE,PBREM,PRAD,PCOLMB  
COMMON/INRATE/SDBEAM,SDCOLD,STCOLD,DENDTF,DENØDF,DENØTF,TEF,  
TOSTAR,TTSTAR,DLOSS,TLLOSS
```

```

COMMON/RATE/RATEDT,RATE0D,RATE0T,BDFUSH
COMMON/DIFLOS/DIFD,DIFT,DIFA,DIFIM,DIFHM
COMMON/SPUT/SPUTN,SPUTD,SPUTT,SPUTA,SPUTI,SPUTHI
COMMON/SRATES/SRATEN,SRATED,SRATET,SRATEA,SSRIM,SSRHIM
COMMON/RECYCL/RECYLD,RECYLT
COMMON/POWTRN/DBEAME,DBEAMI,BFUSNE,BFUSNI,TBEAME,TBEAMI,TRANE,
      TRANI
COMMON/ALF/ALFAE,ALFAI,TALFAE,TALFAI
COMMON/CLOG/COULOG
COMMON/PARAM/FCOUNT,EPSE
COMMON/DBYDT/DERIV(9)

C
C      DIMENSION DY(1),Y(1)
C
C      CALL GETVAR(Y)
C
C-----CALCULATE NEEDED FUNCTIONAL QUANTITIES (SUBROUTINES)
C
C      CALL SIGDT
C      CALL SIGION
C      CALL COLMB
C      CALL TAUS
C***  CALL FUFRAC
C***  CALL SPUTR
C      CALL FRACT
C      CALL POWRAD
C
C-----CALCULATE D/DT(DEND)
C
C      BDFUSH IS THE RATE OF FUSION OF THE DEUTERIUM BEAM WITH
C          PLASMA TRITONS (#/M**3/SEC)
C      RATEDT IS THE DEUTERIUM-TRITIUM FUSION RATE
C      RATE0D IS THE DEUTERIUM-NEUTRAL IONIZATION RATE
C      DIFD IS THE DEUTERIUM PARTICLE DIFFUSION (CONVECTION) LOSS
C      SDCOLD IS THE DEUTERIUM INJECTION RATE FROM COLD FUEL
C
C***  BDFUSH=SDBEAM*FD
100  BDFUSH=0.0
      RATEDT=DEND*(DENT*SIGVDT)
      RATE0D=DENE*(DENO*SIGVIO)
      IF (X.GT.TDSTAR) RATE0D=SDCOLD
      DIFD=DEND/TAPD
      DLOSS=SDBEAM-BDFUSH-RATEDT-DIFD
120  DY(1)=RATE0D+DLOSS
C
C-----CALCULATE D/DT(DENT)
C
C      RATE0T IS THE TRITIUM-NEUTRAL IONIZATION RATE
C      DIFT IS THE TRITIUM-PARTICLE DIFFUSION (CONVECTION) LOSS
C      STCOLD IS THE TRITIUM-INJECTION RATE FROM COLD FUEL

```

ה

DIFA IS THE ALPHA PARTICLE DIFFUSION (CONNECTION) LOSS

cc

388 DIFA=DENA/TAPA
359 DY(3)=BDFUSN+RATEDT-DIF.

החלטה

-----CALCULATE D/DT(DENIM)

```

SRATEN IS THE SPUTTERING RATE FOR NEUTRONS
SRATED IS THE SPUTTERING RATE FOR DEUTERONS
SRATED IS THE SPUTTERING RATE FOR TRITONS
SRATEA IS THE SPUTTERING RATE FOR ALPHA PARTICLES
DIFIM IS THE LOW-Z IMPURITY PARTICLE DIFFUSION (CONVECTION) LOSS
SSRIM IS THE SELF-SPUTTERING RATE FOR LOW-Z IMPURITIES

```

C
C
C
C
C
C
C

```

C***** SRATEN=(RATEDT+BDFUSN)*SPUTN
C***** SRATED=DIFD*SPUTD
C***** SRATET=DIFT*SPUTT
C***** SRATEA=DIFA*SPUTA
C***** DIFIM=DENIM/TAPIM
C***** SSRIM=DIFIM*SPUTI
C***** 400 DY(4)=SRATEN+SRATED+SRATET+SRATEA+SSRIM-DIFIM
400 DY(4)=0.0

```

התאחדות

C-----CALCULATE D/DT(DENHIM)

DIFHIM IS THE HI-2 IMPURITY PARTICLE DIFFUSION (CONVECTION) LOSS
SSRHIM IS THE SELF-SPUTTERING RATE FOR HIGH-Z IMPURITIES

CC
CC
CC
CC

```

C=SSRHHM-DIFHHM/SPUTHI
C=SSRHHM-DIFHHM/SPUTHI
C=SSRHHM-DIFHHM/SPUTHI
500 DY(5)=SRATEN+SRATED+SRATE+SRATE+SSRHHM-DIFHHM
500 DY(5)=0.0

```

[illegible]

C-----CALCULATE D/DT(DENØD)

RECYLD IS THE RATE OF RECYCLED DEUTERONS

C
C
C

```

C***** RECYLD=DIFD*FRD
C***** DY(6)=RECYLD-RATE00
        600 IF (X.GT.TDSTAR) GO TO 630

```

```

610 DY(6)=SCOLD-RATE0
615 IF (ABS(DY(6)).LT.EPS0) TDSTAR=X
620 GO TO 700
630 DY(6)=0.0
C
C
C-----CALCULATE D/DT(DEN2)
C
C
C      RECYLT IS THE RATE OF RECYCLED TRITONS
C
C
C***** RECYLT=DIFT*FRT
C***** 700      DY(7)=RECYLT-RATE0T
700      IF (X.GT.TTSTAR) GO TO 730
710      DY(7)=SCOLD-RATE0T
715      IF (ABS(DY(6)).LT.EPS0) TTSTAR=X
720      GO TO 800
730      DY(7)=0.0
C
C
C-----CALCULATE D/DT(PE)
C
C
C      DBEAME IS THE SPECIFIC POWER DELIVERED DIRECTLY TO THE ELECTRONS
C      FROM THE DEUTERIUM BEAM
C      BFUSNE IS THE SPECIFIC POWER DELIVERED DIRECTLY TO THE ELECTRONS
C      BY THE 3.5 MEV ALPHA PARTICLES FROM SUPRATHERMAL FUSION
C      TBEAME IS THE TOTAL POWER DELIVERED TO THE ELECTRONS FROM THE
C      DEUTERIUM BEAM AND ALPHA PARTICLES
C      ALFAE IS POWER DELIVERED FROM THE ALPHA PARTICLES TO ELECTRONS
C      TALFAE IS NET POWER DELIVERED FROM ALPHA PARTICLES TO ELECTRONS
C      TRANE IS THE SPECIFIC POWER LOSS FROM THE ELECTRONS DUE TO
C      DIFFERENT TRANSPORT PROCESSES
C
C
C      800      DBEAME=SDBEAM*UDBEAM*FDBE
C      BFUSNE=BDFUSN*UALPHA*FAE
C      TBEAME=DBEAME+BFUSNE
C      ALFAE=RATEDT*UALPHA*FAE
C      TALFAE=ALFAE-3.0*TE*RATEDT
C      TRANE=PE/TAE
C      890      DY(8)=PMICRO+TBEAME+TALFAE-TRANE-PCOLMB-PRAD
C
C
C-----CALCULATE D/DT(PI)
C
C
C      DBEAMI IS THE SPECIFIC POWER DELIVERED DIRECTLY TO THE IONS
C      FROM THE DEUTERIUM BEAM
C      BFUSNI IS THE SPECIFIC POWER DELIVERED DIRECTLY TO THE IONS
C      BY THE 3.5 MEV ALPHA PARTICLES FROM SUPRATHERMAL FUSION
C      TBEAMI IS THE TOTAL POWER DELIVERED TO THE IONS FROM THE
C      DEUTERIUM BEAM AND ALPHA PARTICLES
C      ALFAI IS POWER DELIVERED FROM THE ALPHA PARTICLES TO THE IONS
C      TALFAI IS NET POWER DELIVERED FROM THE ALPHA PARTICLES TO IONS
C      TRANI IS THE SPECIFIC POWER LOSS FROM THE IONS DUE TO
C      DIFFERENT TRANSPORT PROCESSES

```

```

900 DBEAMI=SDBEAM+UDBEAM*FDBI
    BFUSNI=8DFUSN*UALPHA*FAI
    TBEAMI=DBEAMI+BFUSNI
    ALFAI=RATEDT*UALPHA*FAI
    TALFAI=ALFAI-3.0*TI*RATEDT
    TRANI=PI/TAEI
990 DY(9)=TALFAI+TBEAMI+PCOLMB-TRANI
C
C
C
30 FCOUNT=FCOUNT+1
C
DO 950 I=1,9
950 DERIV(I)=DY(I)
C
C
    RETURN
    END

```

```

C
C
C      SUBROUTINE SIGDT
C
C-----FIND SIGVDT, THE MAXWELLIAN-AVERAGED DEUTERIUM-TRITIUM
C      FUSION CROSS-SECTION, BY INTERPOLATING FROM ARRAYS WHERE
C      CROSS-SECTION VALUES ARE STORED AS A FUNCTION OF THE
C      ION TEMPERATURE, TI.
C
C      COMMON/VARBLE/DEND,DENT,DENA,DENIM,DENHIM,DENBD,DENBT,
C      &      PE,PI,DENE,DENI,DENB,TE,TI
C      COMMON/SIGMAS/SIGVDT,SIGVIO,SIGVCX,SIGVXD,SIGVXT
C
C      DIMENSION TEMP(150),SV(150)
C      DATA ICALL/1/
C
C      IF (TI.GT.1.0) GO TO 5
C      SIGVDT=2.80E-29*EXP(5.4*TI)
C      RETURN
C
C      5      GO TO (10,20),ICALL
C-----READ IN ARRAYS OF SIGVDT VERSUS TEMPERATURE FROM
C      SIG7EQ.DAT THE FIRST TIME ROUTINE IS CALLED
C
C      10      OPEN(UNIT=21,FILE='SIGVDT.DAT')
C      READ(21,1) DUM
C      READ(21,2) (TE,P(1),SV(1),1=1,141)
C      1      FORMAT(A4)
C      2      FORMAT(F25.3,E25.16)
C      ICALL=2
C      CLOSE(UNIT=21,FILE='SIGVDT.DAT')
C
C-----BINARY SEARCH TO FIND TEMP(I) < TI < TEMP(I+1)
C      OR TEMP(I)=TI
C
C      20      INDEX=0
C      INC=141
C      100      MODINC=MOD(INC,2)
C      INC=INC/2
C      INC=INC+MODINC
C      I=INDEX+INC
C      IF (I.GT.141) I=141
C      IF (TEMP(I)-TI) 200,500,125
C      125      IF (TEMP(I-1).LT.TI) GO TO 300
C      IF (INC.EQ.1) GO TO 1000
C      GO TO 100
C
C-----CHANGE INDEX TO SEARCH 2ND HALF OF REMAINING TEMPERATURES
C
C      200      IF (TEMP(I+1).GT.TI) GO TO 400
C      INDEX=I

```

```

      IF(INC.EQ.1) GO TO 1000
      GO TO 100
C-----
C-----TEMP(I-1) < TI < TEMP(I)
C
300   I=I-1
C-----
C-----NOW TEMP(I) < TI < TEMP(I+1)
C-----DO LINEAR INTERPOLATION TO FIND SIGVDT FOR TI
C
400   SIGVDT=SV(I)+(SV(I+1)-SV(I))*(TI-TEMP(I))/(TEMP(I+1)-TEMP(I))
      RETURN
C-----
C-----TEMP(I)=TI
C
500   SIGVDT=SV(I)
      RETURN
C-----
C-----IF GET HERE TI IS OUT OF RANGE OF TABLED VALUES
C
1000  WRITE(6,5000) TI
5000  FORMAT(' TEMPERATURE ',E14.7,' IS NOT IN RANGE FOR SIGVDT')
      SIGVDT=0.0
      RETURN
      END

```



```

C
C
C
C      SUBROUTINE TAUS
C
C-----CALCULATE THE PARTICLE AND ENERGY CONFINEMENT TIMES
C      (USING KOVRIZHNYKH'S RESULTS)
C      AND CHARGE-EXCHANGE AND MOMENTUM-EXCHANGE TIMES
C
C      COMMON/VARBLE/DEND,DENT,DENA,DENIM,DENHIM,DENND,DENNT,
C      &      PE,PI,DENE,DENI,DEND,TE,TI
C      COMMON/INPUT/ZI,AI,ZHI,AHI,PMICRO,UDBEAM,UALPHA,PBEAM,
C      &      VOLUME,AREA,RCURVA,RMAJOR,RMINOR,ERATIO,BFIELD
C      COMMON/SIGMAS/SIGVDT,SIGVIO,SIGVCX,SIGVXD,SIGVXT
C      COMMON/TIMEP/TAPD,TAPT,TAPA,TAPIM,TAPHIM,TAPION
C      COMMON/TIMEE/TAEI,TACOND
C      COMMON/TIMEX/TAS,TACX
C      COMMON/CLOG/COULOG
C
C-----SET UP ARRAYS TO CALCULATE PARTICLE CONFINEMENT TIMES
C      I=1 FOR DEUTERON
C      I=2 FOR TRITON
C      I=3 FOR ALPHA PARTICLE
C      I=4 FOR LOW-Z IMPURITY NUCLEUS
C      I=5 FOR HIGH-Z IMPURITY NUCLEUS
C
C      DIMENSION Z(5),A(5),DEN(5),TAU(5)
C      EQUIVALENCE (DEND,DEN(1))
C      EQUIVALENCE (TAPD,TAU(1))
C      DATA Z/1.0,1.0,2.0,0.0,0.0/
C      DATA A/2.0,3.0,4.0,0.0,0.0/
C      DATA IFIRST/1/
C
C      GO TO (4,5),IFIRST
C
C-----SET IMPURITY CHARGE NUMBERS AND ATOMIC NUMBERS
C      THE FIRST TIME THIS ROUTINE IS CALLED
C
C      4  Z(4)=ZI
C        Z(5)=ZHI
C        A(4)=AI
C        A(5)=AHI
C        IFIRST=2
C
C-----LOOP CALCULATES PARTICLE CONFINEMENT TIMES
C
C      IMAX IS NUMBER OF PARTICLE CONFINEMENT TIMES TO CALCULATE
C      IMAX=3 FOR 7 EQUATIONS (D,T,A,NEUTRALS - NO IMPURITIES)
C
C      IMAX=3
C
C      5  DO 50 I=1,IMAX
C        COLFRJ=2.218E-18*COULOG*DEN(I)*Z(I)*Z(I)/SQRT(A(I)*TI**3)
C        ALPHA=Z(I)*ERATIO
C        C=.75*((RMAJOR/RCURVA)**2)*(1.0+(2.0+ALPHA)*ALPHA)
C        OMEGAJ=1.0E3*TI*(1.0+ALPHA)/(Z(I)*BFIELD*RCURVA*RMINOR)
C        COLOM=COLFRJ/OMGAJ

```

```

      TAU(1)=(C/COLFRJ)*(1.0+COLOM*COLOM)
50  CONTINUE
C
C-----TAPION IS THE ION PARTICLE CONFINEMENT TIME
C
      TPION1=DEND/(DENI*TAPD)+DENT/(DENI*TAPT)
      TAPION=1.0/TPION1
C
C      TACX IS THE CHARGE EXCHANGE TIME
C
      TACX1=(SIGVCX/DENI)*(DEND*DENO0+DENT*DENO1)
100  TACX=1.0/TACX1
C
C-----TACOND IS THE ENERGY CONFINEMENT TIME
C
C**** TACOND=3.0*TAPION/7.0
      TACOND=0.0
C
C-----TAS IS THE SPITZER ION-ELECTRON MOMENTUM EXCHANGE TIME
C      (NOTE:THIS EXPRESSION FOR DEUTERIUM BEAM)
C
C**** TAS=(0.24E19/DENE)*SORT(TE**3)
      TAS=0.0
C
C-----TAEI IS THE ION ENERGY CONFINEMENT TIME
C
C**** TAEI1=TPION1+TACX1+1.0/TACOND
      TAEI1=TPION1+TACX1
      TAEI=1.0/TAEI1
C
C-----TAE, THE ELECTRON ENERGY CONFINEMENT TIME, IS TEMPORARILY SET
C      EQUAL TO THE ION PARTICLE CONFINEMENT TIME
C
200  TAE=TAPION
C
      RETURN
      END

```

CCCCC

CCC

CC

C
C

CC

2

00

000

0

CC

U
r
c

00

00

00

0

000

U
C

00

00

9

C
C
CRADIATION TRANSFERRED TO BACKGROUND ELECTRONS
(TEMPORARILY SET TO ZERO)FH=0.0
RETURN
END

```

C
C
C
      SUBROUTINE POWRAD
C
C-----CALCULATE TOTAL POWER LOSS FROM RADIATION, PRAD
C
C      IMPLICIT REAL (A-H,O-Z), INTEGER(I-N)
C
C      COMMON/VARBLE/DEND,DENT,DENA,DENIM,DENHIM,DENBD,DENBT,
      &      PE,PI,DENE,DENI,DENB,TE,TI
C      COMMON/INPUT/ZI,AI,ZHI,AHI,PMICRO,UDBEAM,UALPHA,PBEAM,
      &      VOLUME,AREA,RCURVA,RMAJOR,RMINOR,ERATIO,BFIELD
C      COMMON/FRAC/FDSE,FDBI,FAE,FAI,FRD,FRT,FH,FD
C      COMMON/POWER/PSYNC,PHSYNC,FHSYNC,PLINE,PBREM,PRAD,PCOLMB
C
C-----ZEFF IS THE EFFECTIVE CHARGE
C
C      ZEFF=(DEND+DENT+4.0*DENA+ZI*ZI*DENIM+ZHI*ZHI*DENHIM)/DENE
C
C-----PBREM IS THE POWER LOSS DUE TO BRAMSTRAHLUNG RADIATION
C
C      PBREM=3.0E-21*ZEFF*DENE*DENE*SQRT(TE)
C
C-----PLINE IS THE POWER LOSS DUE TO LINE RADIATION
C
C      PLINE=2.0D-17*DENHIM*DENE
      PLINE=0.0
C
C-----PSYNC IS THE POWER LOSS DUE TO SYNCHROTRON RADIATION
C      FROM THE BACKGROUND PLASMA
C      (RE IS THE REFLECTION COEFFICIENT)
C
C      RE=0.9
C
C      100 PSYNC=1.5E+5*SQRT(DENE*(BFIELD**5)/RMINOR)*(TE**2.75)*(1.0-RE)*
      &      (1.0+TE/204.0)
C
C-----PHSYNC IS THE POWER LOSS DUE TO SYNCHROTRON RADIATION
C      FROM THE HOT-ELECTRON ANNULI
C      (TEMPORARILY ZERO)
C
C      PHSYNC=0.0
C
C-----ISYNC IS THE POWER GAIN DUE TO THE SYNCHTRON RADIATION
C      FROM HOT-ELECTRON ANNULI TRANSFERRED TO THE
C      BACKGROUND ELECTRONS
C
C      FHSYNC=FH*PSYNC
      FHSYNC=0.0
C
C      200 PRAD=PBREM+PSYNC-FHSYNC+PLINE
      RETURN
      END

```

```

C
C
C
C      SUBROUTINE SPUTR
C
C-----CALCULATE SPUTN, SPUTT, SPUTA, SPUTI, AND SPUTHI, THE
C      SPUTTERING RATES FOR NEUTRON, DEUTERON, TRITON, ALPHA, AND
C      LOW-Z AND HIGH-Z IMPURITIES, RESPECTIVELY
C
C      IMPLICIT REAL (A-H,O-Z), INTEGER(I-N)
C
C      COMMON/VARBLE/DEND,DENT,DENA,DENIM,DENHIM,DENBD,DENBT,
C      &      PE,PI,DENE,DENI,DENB,TE,TI
C      COMMON/INPUT/ZI,AI,ZHI,AHI,PMICRO,UDBEAM,UALPHA,PBEAM,
C      &      VOLUME,AREA,RCURVA,RMAJOR,RMINOR,ERATIO,BFIELD
C      COMMON/SPUT/SPUTN,SPUTD,SPUTT,SPUTA,SPUTI,SPUTHI
C
C-----TEMPORARILY ALL SPUTTERING RATES ARE SET TO ZERO
C
C      SPUTN=0.0
C      SPUTD=0.0
C      SPUTT=0.0
C      SPUTA=0.0
C      SPUTI=0.0
C      SPUTHI=0.0
C
C      RETURN
C      END

```

```
C
C
SUBROUTINE FUFAC
C
C-----CALCULATE FD, THE FRACTION OF THE DEUTERIUM BEAM WHICH
C          UNDERGOES SUPRATHERMAL FUSION
C
C      IMPLICIT REAL    (A-H,O-Z), INTEGER(I-N)
C
COMMON/VARBLE/DEND,DENT,DENA,DENIM,DENHIM,DENBD,DENBT,
&              PE,PI,DENE,DENI,DENO,TE,TI
COMMON/INPUT/ZI,AI,ZHI,AHI,PMICRO,UDBEAM,UALIMA,PBEAM,
&              VOLUME,AREA,RCURVA,RMAJOR,RMINOR,ERATIO,BFIELD
COMMON/FAC/FDBE,FDBI,FAE,FAI,FRD,FRT,FH,FD
C
C      IF (ABS(UDBEAM-150.0).LT.5.0) GO TO 150
C      IF (ABS(UDBEAM-200.0).LT.5.0) GO TO 200
C      IF (ABS(UDBEAM-225.0).LT.5.0) GO TO 225
C
150   FUN=-0.13075+0.27820*TE-0.00928*TE*TE
      !F (TE.GT.15.0) FUN=2.0
      GO TO 500
C
200   FUN=-0.12890+0.2747*TE-0.00752*TE*TE
      IF (TE.GT.18.0) FUN=2.3
      GO TO 500
C
225   FUN=-0.13612+0.28177*TE-0.0074*TE*TE
      IF (TE.GT.19.0) FUN=2.5
C
500   IF (FUN.LT.0.0) FUN=0.0
C
      FD=UDBEAM*DENT*FUN/(1.76E+04*DENE)
C
      RETURN
      END
```


EXTINT.F4 - Source Listing for EXTINT, ERROR

```

C
C SUBROUTINE EXTINT (NMAX, X, Y, F, H0, M MAX, ERROR)
C

```

```

C   IMPLICIT REAL  (A-H,O-Z), INTEGER (I-N)
C   INTEGER N MAX, M MAX
C   REAL  X, H0, Y(NMAX)
C

```

```

C   A DEFERRED-LIMIT INTEGRATOR (J.P. BORIS AND N.K. WINSOR)
C

```

```

C   THIS SUBROUTINE INTEGRATES UP TO 100 SIMULTANEOUS FIRST ORDER
C   ORDINARY DIFFERENTIAL EQUATIONS FROM X TO X + H0 BY REPEATED EX-
C   TRAPOLATIONS ON A MIDPOINT RULE. UP TO 10 EXTRAPOLATIONS MAY BE
C   REQUESTED BEFORE REDUCTION OF THE INITIAL STEPSIZE IS CARRIED OUT.
C   (REF. R. BULIRSCH AND J. STOER - NUMERISCHE MATHEMATIK 8,1 (1966))
C

```

```

C   NMAX      THE TOTAL NUMBER OF DEPENDENT VARIABLES BEING INTE-
C              GRATED. THERE WILL BE ONE FIRST ORDER EQUATION FOR
C              EACH DEPENDENT VARIABLE.
C

```

```

C   X          THE INDEPENDENT VARIABLE, X IS TREATED AS REAL AND
C              MONOTONIC DURING THE INTEGRATION STEP. THE VALUE OF
C              X ON RETURN FROM "EXT INT" CONTAINS THE VALUE WHICH
C              IS APPROPRIATE TO THE LENGTH OF THE INTEGRATION ACTU-
C              ALLY PERFORMED. IF CONVERGENCE HAS BEEN OBSERVED IN
C              M MAX OF FEWER EXTRAPOLATIONS, X (AT EXIT) = X (AT
C              ENTRY) + H0. ON ENTRY X MUST BE SET TO THE INITIAL
C              VALUE OF THE INDEPENDENT VARIABLE FOR THE INTEGRATION
C              STEP BEING CONTEMPLATED.
C

```

```

C   Y          THE DEPENDENT VARIABLES. EACH DEPENDENT VARIABLE Y(N)
C              (FOR N = 1, 2, ..., NMAX) IS INTEGRATED FROM X TO X+H0
C              IF ADEQUATE CONVERGENCE, AS DEFINED BY THE "ERROR"
C              SUBROUTINE, OCCURS IN M MAX OR FEWER EXTRAPOLATIONS.
C

```

```

C   F          THE DERIVATIVE SUBROUTINE SUPPLIED BY THE USER FOR
C              HIS PARTICULAR PROBLEM. IT MUST BE OF THE FORM
C              F (X, Y, DY) WHERE THE ARRAY DY(N) (FOR N = 1,2, ...,
C              NMAX) IS RETURNED CONTAINING THE NMAX DERIVATIVES
C              (DY(N)/DX)(X,Y).
C

```

```

C   H0         IS THE BASIC STEPSIZE OF THE INTEGRATION. IN CONVER-
C              GENCE OCCURS WITHIN MMAX EXTRAPOLATIONS, X RETURNS
C              FROM EXT INT WITH THE VALUE X + H0. THE VALUES IN THE
C              ARRAY Y ARE THE VALUES OF THE DEPENDENT VARIABLES AT
C              THIS VALUE OF X. IF CONVERGENCE DOES NOT OCCUR, H0 IS
C              HALVED AND THE ENTIRE EXTRAPOLATION PROCEDURE IS
C              REPEATED AND REPEATED AGAIN UNTIL CONVERGENCE OCCURS.
C              AN ATTEMPT HAS BEEN MADE TO UTILIZE AS MUCH PREVIOUS-
C              LY COMPUTED INFORMATION AS POSSIBLE WHEN H0 MUST BE
C              HALVED FOR CONVERGENCE.
C

```

```

C   M MAX      CONTAINS THE NUMBER OF TIMES EXTRAPOLATION IS ATTEM-
C              PTED BEFORE H0 IS HALVED. THIS VALUE WILL VARY WITH
C              COMPUTER ROUND-OFF ERROR AND WITH THE TYPE AND NUMBER
C              OF EQUATIONS BEING INTEGRATED. IN ALL CASES, HOWEVER,
C              ONE SHOULD SPECIFY AN M MAX 'GO' 2. THE STEPSIZE FOR
C              FUTURE ITERATIONS IS SELECTED AND RETURNED IN H0.
C              THIS NEW VALUE IS CHOSEN SO THAT CONVERGENCE WILL BE
C              OBSERVED AT ABOUT THE 0.65*MMAX-TH EXTRAPOLATION.
C              AS WRITTEN, MMAX.LE.10.
C

```

```

C
C      ERROR      IS A SUBROUTINE WHICH IS USED TO DETERMINE THE SATIS-
C                  FACTORY CONVERGENCE OF EACH INDIVIDUAL EQUATION BEING
C                  INTEGRATED. AN EXAMPLE IS GIVEN WHICH CORRESPONDS TO
C                  THE ERROR CRITERION USED BY BULIRSCH AND STOER.
C                  THE CALLING SEQUENCE IS
C                  ERROR (M, DY, CONV, FINISH) WHERE M IS THE ORDER OF
C                  EXTRAPOLATION, DY IS THE VECTOR OF INCREMENTS TO THE
C                  DEPENDENT VARIABLES Y, CONV IS A VECTOR OF LOGICALS
C                  WHICH ARE .TRUE. COMPONENTWISE WHEN THE CORRESPONDING
C                  DEPENDENT VARIABLE HAS CONVERGED, AND FINISH IS
C                  RETURNED .TRUE. WHEN THE ENTIRE SYSTEM OF EQUATIONS
C                  HAS SATISFIED THE CONVERGENCE CRITERION.
C
C      LOGICAL LATERL, CONV(100), PREVIN, FINISH
C      REAL   STEPFC, X0, U, SUM, Y1, BETA, H, DEN, SORT2, YP
C      INTEGER J, K, L, M, N, L MAX, K ASIDE, PTS, MM, MMAXP
C      INTEGER KMIN
C      REAL   HM(11), S(11), P(11), YBAR(100,11), Y0(100)
C      REAL   Y NEW(100), Y OLD(100), DY(100), DY0(100), Y HOLD(7,10,100)
C
C
C      C INITIALIZE..100
C      MMAXP = MMAX + 1
C      SORT2 = SORT(2.00)
C      FINISH = .FALSE.
C      LATERL = .FALSE.
C      X0 = X
C      DO 100 N = 1, NMAX
100   Y0(N) = Y(N)
C      LMAX = (MMAX + 1)/2 + 1
C      CALL F (X0, Y, DY0)
C
C      C START A NEW LEVEL..200
C      204 X = X0 + H0
C      KMIN = 1
C      STEPFC = 2.0**((MMAX/3.0+0.5)
C      DO 205 N = 1, NMAX
205   CONV(N) = .FALSE.
C      IF (.NOT.LATERL .OR. (MMAX.LT.1)) GO TO 203
C      ELSE BEGIN SHIFTING OLD INFORMATION INTO POSITION..
C      DO 202 N = 1, NMAX
C      Y(N) = Y HOLD(2,1,N)
C      YBAR(N,1) = Y(N)
C      DO 202 L = 1, LMAX
C      MM2 = MMAX - 2
C      MMIN = IABS(2*L-3)
C      DO 202 M = MMIN, MM2
202   Y HOLD(L,M,N) = Y HOLD (L+1, M+2, N)
C
C      C COMPUTING BETA AND ASSOCIATED QUANTITIES..300
C      203 H = H0/2
C      HM(1) = H0/2.0
C      HM(2) = H0/4.0
C      HM(3) = H0/6.0
C      BETA = 0.25/(H0*H0)
C
C      C EXTRAPOLATIONS OF HIGHER ORDER EXPANSIONS..400
C      DO 400 MM = 1, MMAXP
C      BEGINNING THE LOOP OVER MMAX EXTRAPOLATIONS IN THIS LEVEL..

```

```

M = MM - 1
STEPFC = STEPFC/SORT2
PREVIN = .FALSE.
IF (LATERL.AND.(M.LT.NMAX - 1)) PREVIN = .TRUE.
KASIDE = 2
IF (2*(M/2).EQ.M) KASIDE = 3
L = (M + 1)/2 + 1
IF (M.GT.2) HM(MM) = HM(MM-2)/2
H = HM(MM)
S(MM) = 1 - EXP(-BETA*H*H)
IF (PREVIN) GO TO 503
C ELSE GENERATE THE M-TH MIDPOINT INTEGRAL..
DO 404 N = 1, NMAX
  Y OLD(N) = Y0(N)
  404 Y NEW(N) = Y0(N) + H*DY0(N)
  CALL F (X0+H, YNEW, DY)
  FTS = (H0*1.000001)/H
DO 405 K = 2, PTS
  C BEGIN THE MIDPOINT INTEGRATION..
  DO 406 N = 1, NMAX
    U = Y OLD(N) + 2*H*DY(N)
    Y OLD(N) = Y NEW (N)
    406 Y NEW (N) = U
    CALL F (X0 + K*H, Y NEW, DY)
    IF ((K.NE.KASIDE).OR.(L.LT.2)) GO TO 405
  C ELSE BEGIN PUTTING INFORMATION ASIDE..
  DO 408 N = 1, NMAX
    408 Y HOLD (L, M, N) = (YNEW(N) + YOLD(N) + H*DY(N))/2.0
    L = L - 1
    KASIDE = 2*KASIDE
  C END OF PUTTING INFORMATION ASIDE
  405 CONTINUE
  C END OF THE MIDPOINT INTEGRATION
  C
  C NOW ADVANCE THE DEPENDENT VARIABLES..500
  503 IF (M.GT.0) GO TO 504
  DO 505 N = 1, NMAX
    YBAR(N,1) = (YNEW(N) + YOLD(N) + H*DY(N))/2
    505 Y(N) = YBAR(N,1)
  IF (NMAX.EQ.0) GO TO 700
  GO TO 400
  C NOW DETERMINE THE INTERPOLATIONAL POLYNOMIALS..
  504 IF (STEPFC.LT.1.1) KMIN = KMIN + 1
  DEN = 1
  DO 401 K = KMIN, M
    P(K) = ((H/HM(K))**2)
    DO 410 J = KMIN, M
      IF (J.NE.K) P(K) = P(K)*(S(J) - S(MM))/(S(J) - S(K))
    410 CONTINUE
    401 DEN = DEN + P(K)
  C END DETERMINATION OF THE INTERPOLATIONAL POLYNOMIALS
  DO 500 N=1, N MAX
    IF (CONV(N)) GO TO 500
    YP = Y(N)
    YH = Y HOLD (1,M,N)
    IF (.NOT.PREVIN) YH = (YNEW(N) + YOLD(N) + H*DY(N))/2.0
    SUM = 0.0
    IF (M.LT.2) GO TO 501
    DO 502 J = KMIN, M
      502 SUM = SUM + (YBAR(N,J) - YP)*P(J)

```

```

501    DY(N) = 0.0
      IF (DEN.NE.0.0) DY(N) = ((YM - YP) - SUM/DEN
      Y(N) = YP + DY(N)
      YBAR(N,MM) = YM
500    CONTINUE
      CALL ERROR (M, DY, CONV, FINISH)
      IF (FINISH) GO TO 700
400    CONTINUE
C
C PREPARE FOR THE NEXT LEVEL IF NECESSARY..600
      LATRL = .TRUE.
      H0 = H0/2
      GO TO 204
C
C RETURN..700
700    H0 = H0 * STEPFC
      RETURN
      END

```

```

C
C
SUBROUTINE ERROR (M, DY, CONV, FINISH)
C
C   THIS VERSION OF THE ERROR ROUTINE CORRESPONDS CLOSELY TO THE
C   VERSION EMPLOYED BY BULIRSCHKE AND STORER. THE DIFFERENCES, HOWEVER,
C   ARE NOTeworthy. THIS VERSION IS CALLED ONLY AFTER ALL UNCONVERGED
C   DEPENDENT VARIABLES HAVE BEEN EXTRAPOLATED AT ORDER M. THUS AN
C   EXCESSIVE NUMBER OF SUBROUTINE REFERENCES ARE MADE UNNECESSARY.
C   NEW VALUES FOR ANY PARTICULAR DEPENDENT VARIABLE ARE NOT CAL-
C   CULATED AFTER CONVERGENCE, AS DEFINED BY THIS SUBROUTINE, HAS BEEN
C   OBSERVED FOR THAT VARIABLE. THUS POSSIBLE INSTABILITIES ASSOCIATED
C   WITH ATTEMPTS AT OVERCONVERGENCE CAN BE ELIMINATED. ONE OF THESE
C   INSTABILITIES, ARISING FROM RESETTING THE MAGNITUDE VECTOR S AT
C   EVERY EXTRAPOLATION AS DOES THE B - S PROGRAM, IS ELIMINATED BY
C   RESETTING S ONLY AFTER THE CORRESPONDING DEPENDENT VARIABLE HAS
C   CONVERGED ACCORDING TO THE CRITERIA CHOSEN.
C   IMPLICIT REAL (A-H,O-Z), INTEGER (I-N)
C   INTEGER M
C   REAL DY(M)
C   LOGICAL CONV(M), FINISH
C   COMMON /ERRCOM/ EPS, S(100), Y(100), NMAX
C   REAL EPS, S, Y
C   INTEGER NMAX, NTIMES (100)
C
  IF (M.NE.1) GO TO 1
  DO 3 N = 1, NMAX
    3 NTIMES(N) = 0
    NCONV = 0
  1 DO 2 N = 1, NMAX
    IF (Y(N).NE.0.0) S(N)=ABS(Y(N))
    IF (.NOT.(ABS(DY(N))/S(N).LT.EPS).OR. CONV(N)) GO TO 2
    NTIMES(N) = NTIMES(N) + 1
    IF (NTIMES(N).EQ. 1) NCONV = NCONV + 1
    IF (NTIMES(N).EQ. 2) CONV(N) = .TRUE.
    IF (ABS(Y(N)).GT. S(N)) S(N) = ABS(Y(N))
  2 CONTINUE
  IF (NCONV.EQ.NMAX) FINISH = .TRUE.
  RETURN
END

```

TEMPERATURE, KEV SIGMAV FOR DT. M=3/SEC (MAR. 24.75)

1.000	0.626999999000000E-26
1.200	0.186000001000000E-25
1.400	0.443999999000000E-25
1.600	0.911000000000000E-25
1.800	0.167000000000000E-24
2.000	0.283000001000000E-24
2.200	0.447000002000000E-24
2.400	0.672000000000000E-24
2.600	0.966999996000000E-24
2.800	0.133999999000000E-23
3.000	0.181000001000000E-23
3.200	0.238000001000000E-23
3.400	0.306000001000000E-23
3.600	0.386000000000000E-23
3.800	0.479000000000000E-23
4.000	0.585999999000000E-23
4.200	0.707000001000000E-23
4.400	0.842999995000000E-23
4.600	0.995000002000000E-23
4.800	0.116000000000000E-22
5.000	0.134999999000000E-22
5.200	0.155000000000000E-22
5.400	0.176999999000000E-22
5.600	0.200000000000000E-22
5.800	0.226000000000000E-22
6.000	0.253000001000000E-22
6.200	0.281000001000000E-22
6.400	0.311999998000000E-22
6.600	0.343999999000000E-22
6.800	0.377999999000000E-22
7.000	0.414000001000000E-22
7.200	0.451999999000000E-22
7.400	0.491000000000000E-22
7.600	0.531000001000000E-22
7.800	0.573999996000000E-22
8.000	0.617000000000000E-22
8.200	0.663000002000000E-22
8.400	0.709000004000000E-22
8.600	0.756999997000000E-22
8.800	0.806999997000000E-22
9.000	0.856999997000000E-22
9.200	0.909000004000000E-22
9.400	0.962000002000000E-22
9.600	0.102000000000000E-21
9.800	0.107000000000000E-21
10.000	0.113000000000000E-21
12.000	0.174000000000000E-21
14.000	0.238999999000000E-21
16.000	0.306000000000000E-21
18.000	0.370000002000000E-21
20.000	0.430999999000000E-21
22.000	0.488000002000000E-21
24.000	0.538999999000000E-21
26.000	0.585999997000000E-21
28.000	0.627999999000000E-21
30.000	0.664999999000000E-21
32.000	0.698000001000000E-21
34.000	0.726999998000000E-21

0.7519999970000000E-21	36.000
0.7740000036000000E-21	38.000
0.7930000020000000E-21	40.000
0.8090000000000000E-21	42.000
0.8229999970000000E-21	44.000
0.8349999980000000E-21	46.000
0.8450000020000000E-21	49.000
0.8540000030000000E-21	50.000
0.8610000010000000E-21	52.000
0.8660000030000000E-21	54.000
0.8699999950000000E-21	56.000
0.8740000000000000E-21	58.000
0.8759999960000000E-21	60.000
0.8770000060000000E-21	62.000
0.8780000040000000E-21	64.000
0.8780000040000000E-21	66.000
0.8770000060000000E-21	68.000
0.8759999960000000E-21	70.000
0.8740000000000000E-21	72.000
0.8720000040000000E-21	74.000
0.8699999950000000E-21	76.000
0.8670000010000000E-21	78.000
0.8639999950000000E-21	80.000
0.8610000010000000E-21	82.000
0.8569999970000000E-21	84.000
0.8540000030000000E-21	86.000
0.8499999980000000E-21	88.000
0.8420000020000000E-21	92.000
0.8370000000000000E-21	94.000
0.8330000020000000E-21	96.000
0.8289999970000000E-21	98.000
0.8240000010000000E-21	100.000
0.7770000030000000E-21	120.000
0.7310000030000000E-21	140.000
0.6890000000000000E-21	160.000
0.6499999980000000E-21	180.000
0.6159999990000000E-21	200.000
0.5849999990000000E-21	220.000
0.5570000000000000E-21	240.000
0.5320000010000000E-21	260.000
0.5100000020000000E-21	280.000
0.4899999980000000E-21	300.000
0.4719999970000000E-21	320.000
0.4550000010000000E-21	340.000
0.4400000000000000E-21	360.000
0.4259999970000000E-21	380.000
0.4129999990000000E-21	400.000
0.4010000010000000E-21	420.000
0.3910000000000000E-21	440.000
0.3810000010000000E-21	460.000
0.3710000000000000E-21	480.000
0.3630000000000000E-21	500.000
0.3550000010000000E-21	520.000
0.3470000010000000E-21	540.000
0.3400000000000000E-21	560.000
0.3340000000000000E-21	580.000
0.3279999990000000E-21	600.000
0.3219999990000000E-21	620.000
0.3159999990000000E-21	640.000

660.000	0.311000000000000E-21
680.000	0.3070000010000000E-21
700.000	0.3019999990000000E-21
720.000	0.2980000010000000E-21
740.000	0.2940000000000000E-21
760.000	0.2900000020000000E-21
780.000	0.2860000000000000E-21
800.000	0.2830000000000000E-21
820.000	0.2789999990000000E-21
840.000	0.2759999990000000E-21
860.000	0.2729999990000000E-21
880.000	0.2700000020000000E-21
900.000	0.2679999990000000E-21
920.000	0.2649999990000000E-21
940.000	0.2619999990000000E-21
960.000	0.2600000000000000E-21
980.000	0.2580000010000000E-21
1000.000	0.2550000010000000E-21
1020.000	0.2549996284006031D-21
1040.000	0.2549996284006031D-21
1060.000	0.2549996284006031D-21
1080.000	0.2549996284006031D-21
1100.000	0.2549996284006031D-21


```
C
C
C PROGRAM TO PLOT VARIABLES VS. TIME (SEM-LOG)
C FROM PLOT DATA FILE FOR A SINGLE RUN OF EBT7EQ.F4
C USING DISPLA -- ON VERSATEK PLOTTER ON PDP-10
C (USER NEEDS TO EXECUTE POST-PROCESSOR VECVER)
C OR ON TEKTRONIX CRT TERMINAL
C
C
C DIMENSION LABEL(16)
C DIMENSION TIME(500),DENE(500),DENI(500),DENA(500),DEN0(500),
8 TE(500),TI(500),CPALPH(500),CPLOSS(500),TAGLOP(500),
8 ENTAU(500),H0(500),SDCOLD(500),STCOLD(500)
C DIMENSION IPAR(40)
C
C DATA IDIM/500/
C
C -----SET PLOTTING PARAMETERS
C
C XINCH=10.0
C YINCH=6.0
C IPRK=+2
C
C -----SET DEFAULT PLOT AXIS LIMITS
C
C DENMIN=1.0E+18
C DENMAX=1.0E+21
C TMIN=1.0
C TMAX=100.0
C POWMIN=1.0
C POWMAX=1000.0
C SDCMIN=1.0E+18
C SDCMAX=1.0E+19
C TSMIN=0.01
C TS MAX=10.0
C
C -----GET DATA FROM PLOT FILE AND CHECK PLOT AXIS LIMITS
C
C OPEN(UNIT=20,FILE='PLOT.7EQ')
C
C READ(20,100) (LABEL(I),I=1,16)
100 FORMAT(' ',16A5)
C
C NPTS=0
C DO 250 I=1,IDIM
C READ(20,200,END=260) TIME(I),DENE(I),DENI(I),DENA(I),DEN0(I),
8 TE(I),TI(I),CPALPH(I),CPLOSS(I),TAGLOB(I),
8 ENTAU(I),H0(I),SDCOLD(I),STCOLD(I)
200 FORMAT(' ',11E11.4,' ',3E11.4)
NPTS=NPTS+1
IF(DENA(I).LT.DENMIN) DENMIN=DENA(I)
IF(DENE(I).GT.DENMAX) DENMAX=DENE(I)
IF(TE(I).LT.TMIN) TMIN=TE(I)
IF(TI(I).LT.TMIN) TMIN=TI(I)
IF(TE(I).GT.TMAX) TMAX=TE(I)
IF(TI(I).GT.TMAX) TMAX=TI(I)
IF(CPALPH(I).LT.POWMIN) POWMIN=CPALPH(I)
IF(CPALPH(I).GT.POWMAX) POWMAX=CPALPH(I)
IF(CPLOSS(I).GT.POWMAX) POWMAX=CPLOSS(I)
IF(SDCOLD(I).LT.SDCMIN) SDCMIN=SDCOLD(I)
```

```

      IF (SDCOLD(I).GT.SDCMAX) SDCMAX=SDCOLD(I)
250  CONTINUE
260  CONTINUE
C
C-----PUT '$' IN LABEL FOR SELF-COUNTING TITLE
C
      DO 300 I=1,16
      IF (LABEL(I).EQ.' ') GO TO 310
300  CONTINUE
310  LABEL(I)='$'
C
C
C***** TEKTRONIX OR VERSATEK? *****
C
C
      ICPS=120
      IMODE=0
C***** CALL TKTRN(ICPS,IMODE)
      CALL VRSTEC
C
C
C-----PLOT DENSITIES VS. TIME
C
      CALL BGNPL(1)
      J=INEST(IPAK,40,25)
      CALL AXSPLT(TIME(1),TIME(NPTS),XINCH,XOR,XSTEP,XAXIS)
      CALL ALGPLT(DENMIN,DENMAX,YINCH,YOR,YCYCLE)
      CALL CARTOG
      CALL TITLE(LABEL,-100,'TIME (SEC)',10,'DENSITIES (#/CM3)',
        & 18,XAXIS,YINCH)
      CALL YLOG(XOR,XSTEP,YOR,YCYCLE)
      CALL RESET('CARTOG')
      BLNK1=XAXIS-3.0
      BLNKR=BLNK1+2.5
      BLNKB=1.0
      BLNKT=BLNKB+1.0
      CALL BLNK1(BLNK1,BLNKR,BLNKB,BLNKT,1)
      CALL CURVE(TIME,DENI,NPTS,IMARK)
      CALL CURVE(TIME,DENT,NPTS,IMARK)
      CALL CURVE(TIME,DENA,NPTS,IMARK)
      CALL GRID(2,1)
      CALL RESET('BLNK1')
      CALL LINES('ELECTRON DENSITY$',IPAK,1)
      CALL LINES('ION DENSITY$',IPAK,2)
      CALL LINES('ALPHA DENSITY$',IPAK,3)
      XLEGND=BLNK1+0.1
      YLEGND=BLNKB+0.1
      CALL LEGEND(IPAK,3,XLEGND,YLEGND)
      CALL ENDPL(1)
C
C-----PLOT TEMPERATURES VS. TIME
C
      CALL BGNPL(2)
      J=INEST(IPAK,40,25)
      CALL ALGPLT(TMPMIN,TMPMAX,YINCH,YOR,YCYCLE)
      CALL CARTOG
      CALL TITLE(LABEL,-100,'TIME (SEC)',10,'TEMPERATURES (KEV)',18,
        & XAXIS,YINCH)
      CALL RESET('CARTOG')
      CALL YLOG(XOR,XSTEP,YOR,YCYCLE)

```

```

BLNKR=BLNKL+3.0
BLNKT=BLNKB+0.75
CALL BLNK1(BLNKL,BLNKR,BLNKB,BLNKT,1)
CALL CURVE(TIME,TE,NPTS,IMARK)
CALL CURVE(TIME,TI,NPTS,IMARK)
CALL GRID(2,1)
CALL RESET('BLNK1')
CALL LINES('ELECTRON TEMPERATURE$',IPAK,1)
CALL LINES('ION TEMPERATURE$',IPAK,2)
CALL LEGEND(IPAK,2,XLEGND,YLEGND)
CALL ENDPL(2)

```

```

C
C-----PLOT TOTAL POWERS VS. TIME
C

```

```

CALL BGNPL(3)
J=LINEST(IPAK,40,25)
CALL ALGPLT(POLMIN,POLMAX,YINCH,YOR,YCYCLE)
CALL CARTOG
CALL TITLE(LABEL,-100,'TIME (SEC)',10,'POWERS (MW)',11,
           & XAXIS,YINCH)
CALL RESET('CARTOG')
CALL YLOG(XOR,XSTEP,YOR,YCYCLE)
BLNKR=BLNKL+2.75
CALL BLNK1(BLNKL,BLNKR,BLNKB,BLNKT,1)
CALL CURVE(TIME,CPALPH,NPTS,IMARK)
CALL CURVE(TIME,CPLOSS,NPTS,IMARK)
CALL GRID(2,1)
CALL RESET('BLNK1')
CALL LINES('TOTAL ALPHA POWERS$',IPAK,1)
CALL LINES('TOTAL POWER LOSSES$',IPAK,2)
CALL LEGEND(IPAK,2,XLEGND,YLEGND)
CALL ENDPL(3)

```

```

C
C-----PLOT COLD FUELING RATES VS. TIME
C

```

```

CALL BGNPL(4)
J=LINEST(IPAK,40,25)
CALL ALGPLT(SDCMIN,SDCMAX,YINCH,YOR,YCYCLE)
CALL CARTOG
CALL TITLE(LABEL,-100,'TIME (SEC)',10,
           & 'FUELING RATES (g/m2/SEC)',26,XAXIS,YINCH)
CALL YLOG(XOR,XSTEP,YOR,YCYCLE)
CALL RESET('CARTOG')
BLNKL=XAXIS-3.5
BLNKR=BLNKL+3.25
CALL BLNK1(BLNKL,BLNKR,BLNKB,BLNKT,1)
CALL CURVE(TIME,SDCOLD,NPTS,IMARK)
CALL CURVE(TIME,STCOLD,NPTS,IMARK)
CALL GRID(2,1)
CALL RESET('BLNK1')
CALL LINES('DEUTERIUM FUELING RATES$',IPAK,1)
CALL LINES('TRITIUM FUELING RATES$',IPAK,2)
XLEGND=BLNKL+0.1
CALL LEGEND(IPAK,2,XLEGND,YLEGND)
CALL ENDPL(4)

```

```

C
C-----PLOT TIME-STEP VS. TIME
C

```

```

CALL BGNPL(5)
CALL ALGPLT(TSMIN,TSMAX,YINCH,YOR,YCYCLE)

```

```

CALL CARTOG
CALL TITLE(LABEL,-100,'TIME (SEC)',10,'TIME-STEP (SEC)',15,
      &      XAXIS,YINCH)
CALL RESET('CARTOG')
CALL YLOG(XOR,XSTEP,YOR,YCYCLE)
CALL CURVE(TIME,H0,NPTS,IMARK)
CALL GRID(2,1)
CALL ENDPL(5)

C
C
C 500  CALL DONEPL
C
C  CLOSE(UNIT=20,FILE='PLOT.7EQ')
C
C  STOP
C  EN*

```

DISVEC.CMD - Linkage Command File for Versatek Plots

DSKC:PLOTS.REL[10,100],DSKC:PLOT.REL[10,100],DSKC:VECW.REL[10,100],DSKC:
FFED.REL[10,100],DSKC:QVYTEC.REL[10,100],DSKC:LIB.REL[10,100]/SEA,DSKC:
LIB.REL[10,100]/SEA,DSKC:LIB.REL[10,100]/SEA,DSKC:LIB.REL[10,100]/SEA,DS
KC:LIB.REL[10,100]/SEA,DSKC:LIB.REL[10,100]/SEA,PUB:CALVEC.REL/LIB

DISTEK.CMD - Linkage Command File for Tektronix Plots

78

DSKC:TSEND.REL[10,100],DSKC:LIB.REL[10,100]/SEA,DSKC:LIB.REL[10,100]/SEA
,DSKC:LIB.REL[10,100]/SEA,DSKC:LIB.REL[10,100]/SEA,DSKC:LIB.REL[10,100]/
SEA,DSKC:LIB.REL[10,100]/SEA,PUB:A64010.REL/LIB

7EQ.CMD - Batch Command File

```
.EX EBT7EQ.F4.EXTINT.F4
.IF (NOERROR) .GOTO C
A::CLOSE
.IF (ERROR) .GOTO C
C::PRINT PRINT.7EQ/DISPOSE:RENAME
.IF (ERROR) .GOTO D
D::EX DIS7EQ.F4.#DISVEC.CMD
.IF (ERROR) .GOTO E
E::CLOSE
.IF (ERROR) .GOTO F
F::R VECVER
*
.IF (ERROR) .GOTO G
G::DEL *.BAK,*.REL,*.VEC,*.LPT
XTERR::DEL *.BAK,*.REL,*.VEC,*.LPT
XCERR::CLOSE
```

Appendix D

SAMPLE OUTPUT

PRINT.7EQ

PLOT.7EQ

SEGMENT.EPL

BLANK PAGE

PRINT.7EQ - Partial Listing of Printer Output from Sample Run

OUT REACTOR STUDIES

#05 REACTOR(40 C0RLS) - PYNCH SHUTOFF - 12/18/76

INPUT PARAMETERS:

Z1= 0.000E+00	Q1= 0.000E+00	ZH1= 0.000E+00	QH1= 0.000E+00	PYNCH= 0.200E+00
UNPCH= 0.100E+00	UNPCH= 0.100E+00	PCH= 0.000E+00	VOLUME= 0.110E+04	AREA= 0.000E+00
RCOR= 0.270E+01	RCOR= 0.000E+02	RYCOR= 0.100E+01	ENTR= 0.100E+00	OF FELD= 0.200E+01

INITIAL CONDITIONS:

DEMO= 0.500E+00	DEMT= 0.500E+00	DEMO= 0.100E+16	DEMT= 0.100E+09	DEMT= 0.100E+09
DEMO= 0.100E+15	DEMT= 0.100E+15	DEMO= 0.100E+21	DEMT= 0.100E+21	DEMT= 0.200E+15
YE= 0.100E+01	YI= 0.100E+01			

CENTRAL PARAMETERS:

XTST= 0.000E+00	XB= 0.100E+05	XTML= 0.100E+03	EPS= 0.100E+05	TTM= 4
-----------------	---------------	-----------------	----------------	--------

TIME INTEGRATIONS:

TIME= 0.510E+00

PCORNT= 13

BY(1)= 0.170E+19	BY(2)= 0.000E+16	BY(3)= 0.200E+16	BY(4)= 0.000E+00	BY(5)= 0.000E+00
BY(6)= 0.000E+00	BY(7)= 0.000E+00	BY(8)= 0.402E+21	BY(9)= 0.342E+21	BY(10)= 0.100E+00
DEMO= 0.500E+00	DEMT= 0.500E+00	DEMO= 0.130E+16	DEMT= 0.100E+09	DEMT= 0.270E+14
DEMO= 1.00E+14	DEMT= 0.130E+14	DEMO= 0.100E+21	DEMT= 0.100E+21	
YE= 0.270E+01	YI= 0.200E+01	PE= 0.410E+21	PI= 0.377E+21	
SOCOLD= 0.000E+00	SOCOLD= 0.340E+00	SOCOLD= 0.210E+20	TOSTAR= 0.106E+04	TOSTAR= 0.106E+04
RYTEST= 0.200E+16	RYTEST= 0.240E+20	RYTEST= 0.210E+20	ROPUSH= 0.000E+00	SICVKT= 0.000E+00
SICVKT= 0.0310E+24	SICVKT= 0.161E+13	SICVKT= 0.210E+13	SICVKT= 0.000E+00	TRPHIT= 0.000E+00
TUP= 0.223E+01	TUP= 0.220E+01	TUP= 0.200E+05	TUPIT= 0.000E+00	TACOR= 0.000E+00
TUPIT= 0.223E+01	TUP= 0.223E+01	THEI= 0.135E+01		
TUP= 0.000E+00	TUP= 0.135E+01			
PYNCH= 0.200E+17	PYNCH= 0.000E+00	PYNCH= 0.000E+00	PLINE= 0.000E+00	PCORNT= 0.504E+20
PCORNT= 0.200E+21	PCORNT= 0.000E+00	PCORNT= 0.124E+22	THANE= 0.102E+21	
DEMO= 0.000E+00	DEMO= 0.000E+00	DEMO= 0.000E+00	THANI= 0.275E+21	
DEMO= 0.000E+00	DEMO= 0.000E+00	DEMO= 0.000E+00		
ALPHA= 0.000E+19	ALPHA= 0.300E+10	ALPHA= 0.511E+21	ENTR= 0.106E+21	
ALPHA= 0.754E+19	ALPHA= 0.511E+21	ALPHA= 0.130E+01		
ALPHA= 0.130E+01	ALPHA= 0.500E+02			

58

[illegible]

TIME= 0.4259E+01 FCOUNT= 2!

BY(1) = 0.735E+19	BY(2) = 0.7991E+19	BY(3) = 0.2237E+18	BY(4) = 0.0000E+00	BY(5) = 0.0000E+00
BY(6) = 0.0000E+00	BY(7) = 0.0000E+00	BY(8) = 0.4047E+21	BY(9) = 0.4047E+21	
DEMT = 0.7202E+20	DEMT = 0.7596E+20	DEMT = 0.2673E+18	DEMT = 0.1000E+09	DEMT = 0.1000E+09
DEMD = 0.1532E+14	DEMD = 0.1677E+14	DEMD = 0.1405E+21	DEMD = 0.1405E+21	DEMD = 0.3011E+14
TE = 0.7700E+01	TE = 0.6977E+01	TE = 0.1734E+22	TE = 0.1540E+22	
SOCALD = 0.0000E+00	SOCALD = 0.2420E+20	STCOLD = 0.2333E+20	TBSTNR = 0.1063E-04	TTSTNR = 0.1063E-04
RASTET = 0.2242E+10	RASTET = 0.2420E+20	RASTET = 0.2333E+20	OPUSH = 0.0000E+00	
SIGV = 0.4059E+21	SIGVIO = 0.1071E+13	SIGVCA = 0.0944E+14	SIGVCH = 0.0000E+00	SIGVCH = 0.0000E+00
TRFLOH = 0.4652E+01	TRFLOH = 0.4652E+01	TRFLOH = 0.4652E+01	TRFLOH = 0.0000E+00	TRFLOH = 0.0000E+00
TRFLOH = 0.0000E+00	TRFLOH = 0.4652E+01	TRFLOH = 0.4652E+01	TRFLOH = 0.0000E+00	
PSYCH = 0.5239E+10	PSYCH = 0.0000E+00	PSYCH = 0.0000E+00	PLINE = 0.0000E+00	PMRETN = 0.1053E+21
PCOLPR = 0.0647E+21	PMRETN = 0.1053E+21	PMRETN = 0.1240E+22		
WREAFI = 0.0000E+00	WREAFI = 0.0000E+00	WREAFI = 0.0000E+00	TRWRE = 0.3710E+21	
WREAFI = 0.0000E+00	WREAFI = 0.0000E+00	WREAFI = 0.0000E+00	TRWRE = 0.5403E+21	
ALFAE = 0.6730E+21	ALFAE = 0.1110E+21			
PLPFRM = 0.7040E+21	PLPFRM = 0.1100E+22	TRFLOH = 0.2964E+01	ENTRU = 0.4052E+21	
PLPFRM = 0.1405E+03	PLPFRM = 0.2102E+03			

TIME= 0.404E+01 FCOUNT= 13

BY(1) = 0.443E+19	BY(2) = -0.240E+10	BY(3) = 0.376E+10	BY(4) = 0.000E+00	BY(5) = 0.000E+00
BY(6) = 0.000E+00	BY(7) = 0.000E+00	BY(8) = 0.632E+21	BY(9) = 0.637E+21	
DEMO = 0.765E+20	DEMT = 0.765E+20	DEMO = 0.437E+20	DEMT = 0.437E+20	DEDMIN = 0.100E+00
DEMO = 0.123E+10	DEMT = 0.793E+13	DEMO = 0.153E+21	DEMT = 0.157E+21	DEMO = 0.204E+14
TE = 0.915E+01	TI = 0.013E+01	PI = 0.211E+22	PI = 0.106E+22	
SDEAP = 0.000E+00	SDCOL = 0.1961E+20	STCOL = 0.1240E+20	TSSTAN = 0.1063E-04	TSSTAN = 0.1063E-04
RATST = 0.377E+20	RATESD = 0.1961E+20	RATST = 0.1240E+20	SDFUSH = 0.000E+00	
SIGVIT = 0.647E-22	SIGVIG = 0.100E-13	SIGVCK = 0.373E-14	SIGVIO = 0.000E+00	SIGVKT = 0.000E+00
THP = 0.515E+01	THPT = 0.624E+01	THP = 0.374E+01	THPI = 0.000E+00	THPIH = 0.000E+00
THPIH = 0.564E+01	THRE = 0.564E+01	THRE = 0.395E+01	TACNO = 0.000E+00	
THS = 0.000E+00	THVC = 0.1324E+02	FHSVHT = 0.000E+00	PLINE = 0.000E+00	PMENH = 0.2153E+21
PCOLP = 0.047E-09	PHYS = 0.000E+00	PHYCR = 0.124E+22		
PCOLP = 0.920E+21	THW = 0.216E+21	TREAP = 0.000E+00		
DEAPTE = 0.000E+00	BFUSHT = 0.000E+00	TREAP = 0.000E+00	TRANE = 0.373E+21	
DEAPTI = 0.000E+00	BFUSHI = 0.000E+00	TREAP = 0.000E+00	TRANI = 0.473E+21	

PLOT.7EQ - Partial Listing of Intermediate Plot File from Sample Run

```

*35 REACTOR(40 COILS) - PHYSICS OUTPUT - 12/10/76
0.5100E+00 0.1000E+21 0.1000E+21 0.1301E+16 0.2700E+14 0.2770E+01 0.2300E+01 0.1300E+01 0.9700E+02 0.1300E+01 0.1300E+21
0.2910E+01 0.2400E+20 0.2100E+20 0.1031E+21 0.1031E+21 0.4017E+16 0.3300E+14 0.3020E+01 0.3470E+01 0.9040E+01 0.1240E+03 0.1740E+01 0.1790E+21
0.3670E+01 0.2400E+20 0.2300E+20 0.1000E+21 0.1000E+21 0.1100E+17 0.3300E+14 0.4770E+01 0.4210E+01 0.1400E+02 0.1371E+03 0.2027E+01 0.2202E+21
0.2910E+01 0.2400E+20 0.2300E+20 0.1000E+21 0.1000E+21 0.2790E+17 0.3300E+14 0.5400E+01 0.4020E+01 0.2647E+02 0.1900E+03 0.2257E+01 0.2617E+21
0.3277E+01 0.2400E+20 0.2300E+20 0.1000E+21 0.1000E+21 0.2620E+17 0.3300E+14 0.5097E+01 0.5340E+01 0.4313E+02 0.1630E+03 0.2430E+01 0.3000E+21
0.1311E+00 0.2400E+20 0.2300E+20 0.1000E+21 0.1000E+21 0.9510E+17 0.3190E+14 0.6404E+01 0.9007E+01 0.6400E+02 0.1772E+03 0.2390E+01 0.3302E+21
0.5030E+01 0.2400E+20 0.2300E+20 0.1000E+21 0.1000E+21 0.1967E+10 0.3070E+14 0.7032E+01 0.6304E+01 0.9402E+02 0.1917E+03 0.2740E+01 0.3012E+21
0.7350E+01 0.2400E+20 0.2300E+20 0.1000E+21 0.1000E+21 0.2670E+10 0.3010E+14 0.7700E+01 0.6977E+01 0.1400E+03 0.2102E+03 0.2364E+01 0.4000E+21
0.4230E+01 0.1400E+21 0.1400E+21 0.1000E+21 0.1000E+21 0.4040E+01 0.1530E+21 0.1527E+21 0.4370E+10 0.2040E+14 0.9190E+01 0.0130E+01 0.2907E+03 0.2040E+03 0.3670E+01 0.5617E+21
0.1311E+00 0.1961E+20 0.1240E+20 0.5390E+01 0.1540E+21 0.1520E+21 0.7200E+10 0.1440E+14 0.1100E+02 0.1010E+02 0.4000E+03 0.1954E+03 0.4030E+01 0.7537E+21
0.1040E+00 0.1150E+20 0.5400E+19 0.5912E+01 0.1540E+21 0.1520E+21 0.1100E+19 0.1167E+14 0.1422E+02 0.1263E+02 0.7391E+03 0.1030E+03 0.6207E+01 0.9400E+21
0.1160E+00 0.0440E+19 0.7321E+19 0.6447E+01 0.1540E+21 0.1520E+21 0.1991E+19 0.1030E+14 0.1950E+02 0.1700E+02 0.1300E+04 0.2001E+03 0.7734E+01 0.1170E+22
0.5030E+01 0.0430E+19 0.5930E+19 0.6000E+01 0.1500E+21 0.1521E+21 0.3304E+19 0.1011E+14 0.2072E+02 0.2577E+02 0.2230E+04 0.2652E+03 0.0967E+01 0.1364E+22
0.4634E+01 0.5537E+19 0.5337E+19 0.7531E+01 0.1630E+21 0.1517E+21 0.5620E+19 0.1100E+14 0.4100E+02 0.4223E+02 0.3099E+04 0.3542E+03 0.9402E+01 0.1434E+22
0.7350E+01 0.5537E+19 0.5337E+19 0.0114E+01 0.1604E+21 0.1514E+21 0.0400E+19 0.1167E+14 0.5292E+02 0.6500E+02 0.3341E+04 0.5360E+03 0.1000E+02 0.1519E+22
0.1311E+00 0.5537E+19 0.5337E+19 0.0700E+01 0.1740E+21 0.1511E+21 0.1142E+20 0.1001E+14 0.6247E+02 0.9002E+02 0.3200E+04 0.6400E+03 0.1073E+02 0.1622E+22
0.1054E+00 0.4000E+19 0.4004E+19 0.9261E+01 0.1700E+21 0.1509E+21 0.1400E+20 0.1041E+14 0.6950E+02 0.1100E+03 0.3021E+04 0.7307E+03 0.1130E+02 0.1713E+22
0.2001E+00 0.4400E+19 0.4004E+19 0.1000E+02 0.1050E+21 0.1307E+21 0.1740E+20 0.9902E+13 0.7790E+02 0.1370E+03 0.2700E+04 0.0200E+03 0.1207E+02 0.1010E+22
0.4161E+00 0.4400E+19 0.4023E+19 0.1057E+02 0.1050E+21 0.1504E+21 0.1951E+20 0.9030E+13 0.0254E+02 0.1514E+03 0.2657E+04 0.0019E+03 0.1240E+02 0.1063E+22
0.2001E+00 0.4037E+19 0.3091E+19 0.1137E+02 0.1954E+21 0.1502E+21 0.2290E+20 0.0990E+13 0.0000E+02 0.1711E+03 0.2300E+04 0.9603E+03 0.1270E+02 0.1917E+22
0.4161E+00 0.3633E+19 0.3091E+19 0.1231E+02 0.2022E+21 0.1500E+21 0.2600E+20 0.0426E+13 0.9900E+02 0.1901E+03 0.2370E+04 0.1047E+04 0.1290E+02 0.1900E+22
0.6000E+00 0.3074E+19 0.3000E+19 0.1297E+02 0.2066E+21 0.1500E+21 0.2030E+20 0.7970E+13 0.9097E+02 0.2010E+03 0.2290E+04 0.1104E+04 0.1307E+02 0.1961E+22
0.4161E+00 0.3407E+19 0.3000E+19 0.1201E+02 0.2131E+21 0.1500E+21 0.3140E+20 0.7947E+13 0.1030E+03 0.2140E+03 0.2220E+04 0.1103E+04 0.1300E+02 0.1964E+22
0.6400E+00 0.3407E+19 0.3010E+19 0.1407E+02 0.2171E+21 0.1400E+21 0.3304E+20 0.7120E+13 0.1067E+03 0.2234E+03 0.2164E+04 0.1233E+04 0.1307E+02 0.1999E+22
0.0223E+00 0.3130E+19 0.3162E+19 0.1407E+02 0.2171E+21 0.1400E+21 0.3624E+20 0.7731E+13 0.1090E+03 0.2317E+03 0.2120E+04 0.1297E+04 0.1299E+02 0.1940E+22
0.1540E+02 0.2290E+21 0.1900E+21 0.1040E+01 0.3130E+19 0.3162E+19 0.1640E+02 0.2290E+21 0.1900E+21 0.1040E+01 0.3130E+19 0.3162E+19 0.1640E+02 0.2290E+21 0.1900E+21 0.1040E+01
0.1321E+01 0.3130E+19 0.3162E+19 0.1777E+02 0.2374E+21 0.1900E+21 0.4090E+20 0.6067E+13 0.1160E+03 0.2400E+03 0.2047E+04 0.1461E+04 0.1267E+02 0.1900E+22
0.1177E+01 0.2992E+19 0.3240E+19 0.1099E+02 0.2440E+21 0.1904E+21 0.4707E+20 0.6930E+13 0.1107E+03 0.2540E+03 0.2025E+04 0.1533E+04 0.1240E+02 0.1079E+22
0.1403E+01 0.3404E+19 0.2921E+19 0.2040E+02 0.2531E+21 0.1902E+21 0.5140E+20 0.6400E+13 0.1200E+03 0.2990E+03 0.1999E+04 0.1612E+04 0.1220E+02 0.1040E+22
0.1321E+01 0.3130E+19 0.2921E+19 0.2179E+02 0.2600E+21 0.1900E+21 0.9500E+20 0.6400E+13 0.1210E+03 0.2621E+03 0.1907E+04 0.1670E+04 0.1200E+02 0.1010E+22

```

SEGMENT.EPL - Versatek Printer Plots from DIS7EQ.F4 from Sample Run