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**ETFOD, A Point Model
Physics Code with Arbitrary Input**

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ETFOD, A POINT MODEL PHYSICS CODE WITH ARBITRARY INPUT

K. E. Rothe

S. E. Attenberger

ABSTRACT

ETFOD is a zero-dimensional code which solves a set of physics equations by minimization. The technique used is different than normally used, in that the input is arbitrary. The user is supplied with a set of variables from which he specifies which variables are input (unchanging). The remaining variables become the output. Presently the code is being used for ETF reactor design studies. The code was written in a manner to allow easy modification of equations, variables, and physics calculations. The solution technique is presented along with hints for using the code.

1. INTRODUCTION

For many years the fusion physics community has used point model codes to do Tokamak reactor designs. One or more physical equations are written either in terms of variables defined at a point in the center of the plasma, or else in terms of variables averaged over the plasma volume. Depending on the needs of the users, certain of the variables are selected as input and the rest are output variables which define a self-consistent solution.

Now that reactor design studies are beginning in earnest, the point model codes are being pushed to the limit of their accuracy. The most sophisticated techniques and the most advanced physics models available are being incorporated, whenever fast methods are available. As a result, it becomes a nontrivial task to use a program to solve any problem other than the one for which it was originally written. When the input variables are changed, either the code must be extensively rewritten, or else the code must be used to generate reams of graphic output from which the desired data points may be read by hand.

ETFOOD has overcome these problems to a very great extent. The user is furnished with a generous list of variables, any subset of which may be identified as input variables. The physics equations may be changed at the whim of the user without fear of destroying the program logic. The secret is to treat the problem as a minimization problem, so that a self-consistent solution is found iteratively. The solution technique will be described in detail in this report.

2. PROGRAM OVERVIEW

Given a set of equations of the form $y_i = F_i(y_1, y_2, \dots, y_n)$ where the y_i are arbitrary variables and the F_i are arbitrary functions, one can always write $R_i = \frac{y_i - F_i}{y_{oi}}$ where the y_{oi} are the initial values of the variables and the R_i are residuals. The set of equations is then solved by minimizing the residuals. In this fashion ETFOD is designed to solve a set of O-D equations written in residual form. The minimization package used is EO4FAF from the NAG¹ library. EO4FAF minimizes the sum of the squares of the residuals.

The residual equations need initial guesses which are supplied by the user. From the list of eligible variables (see section 3.8) some of the variables may be designated "fixed" while others are free or "active". In general there will be more active variables than there are functions F_i . In order to fully determine the solution, an additional set of equations is constructed, also cast in residual form, i.e. $R_i = \frac{y_{oi} - y_i}{y_{oi}}$ where y_{oi} is the initial guess for the variable and y_i is the current value. Thus the solution obtained will be that solution of the original equations which is closest to the initial guess.

Since the solution of the physics equations is of primary importance, weights are assigned to the residuals with a relatively large weight given to the physics equations and small weights given to the other equations.

In order to increase the speed and flexibility of the code, the variables are normalized. This allows uniform restrictions on the variables regardless of their magnitudes. Each variable is normalized

by its initial guess. Thus the initial guess given to EO4FAF is a vector of 1's. When the residuals are to be calculated using the new solution generated by EO4FAF, each element of the solution vector is multiplied by its respective normalization factor, since the physics equations use the actual value of a variable instead of its normalized value.

A flowchart of the program is listed in Appendix A. The names of the subroutines wherein the calculations occur are listed to the right of the description. A program listing can be found in Appendix D. Two sample cases are included (Appendix E) to show the effect of changing the weight of an initial guess.

ETFOD runs on the FED PDP-10 and contains calls to machine-dependent I/O buffering routines.

3. DESCRIPTION

3.1 MAIN

The main program initializes the I/O units, opens the data input files and output files, and reads all the input data. The input files are ETFOD.DAT and INPUT.DAT. These files are described in detail in sections 3.8 and 3.9. The output files are ETFOD.OUT and SPECS.ETF. The number of input variables from ETFOD.DAT is counted to facilitate changing the variable list. If there are fewer active variables from ETFOD.DAT than physics equations, the problem is overconstrained. A warning is written to unit 5 and ETFOD.OUT. Each active variable in ETFOD.DAT has an associated index number (referring to its relative position in the variable list), weight factor (see section 3.8), and initial value stored in arrays which are passed in common INDEXP to subroutines FIZICS, RESID, and SEARCH. All the information from file ETFOD.DAT is written to file ETFOD.OUT. The normalized solution vector is initialized to 1.0. At the end of the run certain plasma parameters are written to ETFOD.OUT. This routine calls SEARCH.

The following variables are used in MAIN:

EQNWT	weight given to physics residuals.
IND	array containing the indices of the variables read from ETFOD.DAT.
INDP	array containing the indices of the active variables.
IOUT	causes the calculation and output of design specifications when set to 1. (Initially 0.)
IX	array containing the weighting flag letters 'F' (fixed), 'P' (preferred), and 'U' (unknown); used in assigning numerical weights to initial guesses.
MEQ	number of physics equations, read from ETFOD.DAT.

N number of active variables, counted as they are read from
ETFOD.DAT. If $MEQ > N$, the problem is overconstrained.

NAMVAR array holding five-letter names of variables, read from
ETFOD.DAT.

NIN unit used when reading ETFOD.DAT, defined 6.

NIN2 unit used when reading INPUT.DAT, defined 28.

NOUT unit used when outputting messages to user, defined 5
(defaults to terminal).

NOUT2 unit used when outputting to ETFOD.OUT, defined 20.

NOUT3 unit used when outputting to SPECS.ETF, defined 27.

NVAR total number of variables from ETFOD.DAT.

UNITS array holding 20 letter unit descriptions of variables in
ETFOD.DAT.

WW array holding the weight factors for the active variables.

WWX array holding the weight factors corresponding to 'F'
(fixed), 'P' (preferred), 'U' (unknown); read from INPUT.DAT.

3.2 SEARCH

Subroutine SEARCH defines the parameters and limits used in EO4FAF. All array sizes which are calculated are tested to ensure sufficient space has been allocated. If not, warnings are printed on unit 5 (terminal by default). The initial guess of the solution is checked, and warnings are written to unit 5 if the residuals are greater than 0.5. The final solution is also tested for accuracy. A warning is written to unit 5 and also to ETPOD.OUT and SPECS.ETF if the physics equations are not accurate within a specified limit. This subroutine is called by the main program and calls RESID, EO4FAF, and PRTOUT.

The following variables are used in SEARCH:

APER	percent accuracy desired of physics equations. $APER = 100 * FRAACC$.
F	the sum of the squares of the residuals; returned by EO4FAF.
FRAACC	the fractional accuracy desired for the physics equations.
FTOL	the tolerance criterion used by EO4FAF on F. Currently FTOL is initialized to $1.0E-6$. On return $FTOL = 0.0$ if the value of $F < FTOL$. $FTOL = 1.0$ if a relative test on the range of F is satisfied. $FTOL = -1.0$ if the XTOL tolerance test is satisfied (see XTOL, below). FTOL and XTOL were chosen such that $FTOL = -1.0$ would usually be the tolerance criterion satisfied. This insures that the solution is near a minimum.
IFAIL	on return from EO4FAF designates the reason for exit from EO4FAF. IFAIL = 1 signals incorrect input parameters. IFAIL = 2 indicates that the maximum number of iterations has been reached but no tolerance conditions are satisfied.
IPRINT	specifies the frequency of calls to MONIT, a printout routine. IPRINT = 1 causes MONIT to be called every iteration. IPRINT = 2 causes MONIT to be called only when F is reduced. If $IPRINT \leq 0$ MONIT is not called.
IRC, IW, IX, IST	dimensions of RC, W, X, STEPMX, respectively (see below).
LTEST	minimum allowable size of array W required by EO4FAF. $LTEST = 2*M + 4*N + M*N + N*(N+1)/2 + (N+3+N/3)*(M+2+2*N)$.
M	total number of residuals. $M = MEQ + N$.

MAXCAL maximum number of iterations attempted before EO4FAF is forced to exit.

RC array containing the residuals.

STPMX array containing restraint values. In a given iteration no active variable can change an amount greater than its associated restraint value in STEPMX. This prevents sudden, large fluctuations of variables which could lead to solutions far from the initial estimates. Every element initialized to 0.5.

W workspace needed by EO4FAF.

X array containing the current normalized solution. Every element is initialized to 1.0.

XTOL relative accuracy to which the position of the minimum is required. For two successive iterations whose solution vectors are $\underline{Y}$ and $\underline{Z}$, the XTOL criterion is satisfied when $|Y_i - Z_i| < XTOL * STEPMX_i$, $i = 1, 2, \dots, N$ (see FTOL above).

3.3 RESID

Subroutine RESID takes the normalized solution generated by EO4FAF and multiplies by the normalizing factors (the initial guesses). This yields the actual values of the eligible variables which are needed when calculating the physics residuals. The variables must appear in the data file ETFOD.DAT in the same order as they appear in commons VARBLS (containing the current values of the variables), INITL (containing the normalizing factors), and INDEX (containing the index numbers which locate values in the other commons). RESID is called by SEARCH and the EO4FAF package, and calls FIZICS.

The following variables are used in RESID:

M	the total number of residuals.
N	the number of active variables.
XC	array containing EO4FAF's current solution (normalized).
XX	array containing current solution of all eligible variables, both active and fixed (normalized; hence those not changing are 1.0).

3.4 FIZICS

SUBROUTINE FIZICS contains the physics equations of the 0-D model. The input is primarily from common block VARBL5, which contains the natural values (not normalized) of the eligible variables. All values are in MKS units unless otherwise noted. FIZICS is called by RESID, and calls the physics packages ALFETA, COULM, INJETA, OHMIC, RADIAT, RATE, RFETA, and TAUS.

FIZICS computes all the residuals, both for the physics equations and the initial value equations. (See the description in section 2.) The physics equations are subject to constant revision and improvement, but the following set of equations is representative. (Refer to the table of variables for identification of symbols.)

$$R_1 = \frac{1}{N_{i0}} [N_i - N_e (1 - Z\xi)] \quad (1)$$

$$R_2 = \frac{1}{N_{i0}} [N_i - N_e (Z_{eff} - Z^2\xi)] \quad (2)$$

where $\xi = N_Z / N_e$

$$R_3 = \frac{1}{\beta_0} \left[\beta - \frac{(N_i T_i + N_e T_e + N_Z T_i) 1.602 \times 10^{-16}}{2\mu_0 B_t^2} \right] \quad (3)$$

$$R_4 = \frac{1}{P_{\alpha 0}} \left[P_{\alpha} - \frac{3}{2} \frac{(N_i T_i + N_e T_e + N_Z T_i)}{\tau_E} 1.602 \times 10^{-16} \right] \quad (4)$$

$$R_5 = \frac{1}{P_{\alpha o}} \left[P_{\alpha} - \frac{N_1^2 \langle \sigma v \rangle Q_{\alpha}}{4} \right] \quad (5)$$

where $Q_{\alpha} = 5.607 \times 10^{-13}$ joule (3.52 MeV)

$$R_6 = \frac{1}{P_{\alpha o}} \left[P_{\alpha} n_{\alpha} + P_{inj} n_{inj} + P_{rf} n_{rf} + P_{coul} \right. \\ \left. - \frac{3}{2} \frac{T_1 (1.602 \times 10^{-16})}{C_1} \left(\frac{1}{C_{TP}^T TP} + \frac{1}{C_{NC}^T NC} + \frac{1}{C_{RT}^T RT} \right) \right] \quad (6)$$

$$R_7 = \frac{1}{P_{\alpha o}} \left[P_{\alpha} (1 - n_{\alpha}) + P_{inj} (1 - n_{inj}) + P (1 - n_{rf}) - P_{coul} \right. \\ \left. - P_{rad} + P_{\Omega} - \frac{3}{2} \frac{T_e (1.602 \times 10^{-16})}{C_e} \frac{1}{C_{EMP}^T EMP} \right] \quad (7)$$

$$R_8 = \frac{1}{P_{fo}} \left[P_f - 5 P_{\alpha} V \right] \quad (8)$$

$$R_9 = \frac{1}{w_{\alpha o}} \left[w_{\alpha} - \frac{4}{5} \frac{P_f}{S} \right] \quad (9)$$

$$R_{10} = \frac{1}{I_{po}} \left[I_p - \frac{5.6 \times 10^6 a B_t (1 + \sigma^2) 1.11}{2g A \left(1 - \frac{1}{A^2} \right)^2} \right] \quad (10)$$

The following variables are used in FIZICS:

A	(Symbol a) Minor radius of the plasma (m).
ALEXT	External inductance (H).
ALPI	Internal inductance (H).
AR	(Symbol A) Aspect ratio.
AREA	(Symbol S) Surface area of first wall (m^2).
BP	Poloidal magnetic field (T).
BT	Toroidal magnetic field (T).
CC	(Symbol R) The array of residual values. The first MEQ values are the physics residuals. The last M-MEQ values are the initial value residuals.
CE	(Symbol C_e) Multiplier for electron conduction and convection confinement time.
CEMP	(Symbol C_{EMP}) Multiplier for empirical confinement time.
CI	(Symbol C_i) Multiplier for ion conduction and convection confinement time.
CNC	(Symbol C_{NC}) Multiplier for neoclassical confinement time.
CRT	(Symbol C_{RT}) Multiplier for Ripple Trapping confinement time.
CTP	(Symbol C_{TP}) Multiplier for Trapped Particle confinement time.
EB	Neutral beam energy (primary component, in keV).
EQNWT	A weighting factor used to give the physics residuals more weight than the initial value residuals.
ETAALF	(Symbol η_α) The fraction of alpha power absorbed by the ions.
ETAINJ	(Symbol η_{inj}) The fraction of injected power absorbed by the ions.
ETARF	(Symbol η_{rf}) The fraction of rf power absorbed by the ions.
IP	(Symbol I_p) Plasma current (A).
NE	(Symbol N_e) Electron density (m^{-3}).
NI	(Symbol N_i) Ion density (m^{-3}).
NZ	(Symbol N_Z) Impurity density (m^{-3}).

PALFV	(Symbol p_α) Alpha power per unit volume (W/m^3).
PCOULV	(Symbol p_{coul}) Power per unit volume transferred from electrons to ions (W/m^3).
PFUS	(Symbol P_f) Total alpha + neutron power at 17.6 Mev per reaction.
PINJ	(Symbol $P_{\text{inj}} = p_{\text{inj}} V$) Total injected power (W).
POHMV	(Symbol p_Ω) Ohmic heating power per unit volume (W).
PRADV	(Symbol p_{rad}) Power per unit volume lost due to radiation (W/m^3).
PRF	(Symbol $P_{\text{rf}} = p_{\text{rf}} V$) Total rf power (W).
Q	(Symbol q) Safety factor.
REFL	Reflection coefficient for synchrotron radiation. (If REFL = 1, no power is lost to the wall.)
RIPPLE	Peak-to-average magnetic ripple depth (dimensionless).
RP	Plasma resistance (Ohms).
SIGMA	(Symbol σ) Plasma elongation.
SIGMAV	(Symbol $\langle \sigma v \rangle$) D-T reaction rate (m^3/s).
TAUE	(Symbol τ_E) Global energy confinement time (s).
TAUEMP	(Symbol τ_{EMP}) Empirical electron conduction time (s).
TAUNC	(Symbol τ_{NC}) Neoclassical ion conduction time (s).
TAURT	(Symbol τ_{RT}) Ripple trapping ion conduction time (s).
TAUTP	(Symbol τ_{TP}) Trapped particle ion conduction and convection time (s).
TE	(Symbol T_e) Electron temperature, in keV.
TI	(Symbol T_i) Ion temperature, in keV.
VOL	(Symbol V) Plasma volume.
WPA	(Symbol w_α) Neutron wall loading (W/m^2).
ZEFF	(Symbol Z_{eff}) Effective charge on plasma.
ZETA	(Symbol ξ) Impurity fraction.
ZMUO	(Symbol μ_0) Permeability constant (H/m).

3.5 Physics Packages

The physics portion of the ETFOD code is highly modularized to permit upgrading of the physics models as new models become available. Where possible, the physics packages are borrowed from or benchmarked against those of the WHIST 1-D transport code.²

The following subroutines are among the current physics packages:

<u>ALFETA</u>	Computes the fraction of the alpha power which is absorbed by the ions.
<u>COULM</u>	Computes the electron-ion power transfer due to Coulomb collisions.
<u>INJETA</u>	Computes the fraction of neutral beam energy absorbed by the ions.
<u>OHMIC</u>	Computes the Ohmic heating rate.
<u>RADIAT</u>	Computes the power loss due to radiation.
<u>RATE</u>	Computes the D-T fusion reaction rate.
<u>RFETA</u>	Computes the fraction of rf power absorbed by the ions.
<u>TAUS</u>	Computes confinement times predicted by theoretical and empirical models.

The above routines are very primitive at the present time. They will be described in detail in a later memo, after the code has been upgraded to include shape factors and more sophisticated physics models.

3.6 MONIT

Subroutine MONIT allows the user to follow the iterative process of E04FAF and prints warnings in file ETFOD.OUT when certain kinds of problems occur during an iteration. It is called from E04FAF and calls PRTOUT.

The following variables are used in MONIT:

- F sum of the squares of the residuals.
- LIM if true, the value of a normalized variable was constrained by STEPMX for this iteration. (See SEARCH for definition of STEPMX.)
- M the total number of residuals.
- N the number of active variables.
- SING if true, the solution has become degenerate. A random number has been generated and incorporated in the solution.
- X current normalized solution array.

3.7 PRTOUT

Subroutine PRTOUT writes out the variable names and their current values. The values of the fixed variables are followed by an 'F'. PRTOUT is called from SEARCH and MONIT.

3.8 ETFOD.DAT

ETFOD.DAT contains the number of physics equations coded in FIZICS and the eligible variables from which one can choose input (fixed) variables and output (active) variables. As seen in the listing in Appendix B, each variable has a five-letter name under the heading VARIABLE, the units of the variable under the heading UNITS, an initial value under the heading VALUE, and either an F, P, or U under the heading WEIGHT. These weights indicate whether the variable is fixed (F) or active (P, U), and for active variables the weights indicate how sure one is of the value. Thus, the value of a variable marked preferred (P) will remain fairly close to the initial value, while a variable marked unknown (U) can more easily be changed significantly. However, even preferred values can change significantly if necessary to find a solution to the physics equations.

At present the following variables are in ETFOD.DAT:

TI	ion temperature (keV)
TE	electron temperature (keV)
ZEFF	effective charge of plasma
NI	density of ions (m^{-3})
NE	density of electrons (m^{-3})
NZ	density of impurities (m^{-3})
Q	safety factor
BETA	plasma pressure relative to the magnetic pressure
BT	toroidal magnetic field (T)
TAUE	total energy confinement time (s)
PALFV	alpha power per unit volume (W/m^3)
PFUS	total alpha + neutron power (W)
WPA	wall loading due to neutrons (W/m^2)

A	minor radius of the plasma (m)
AR	aspect ratio
SIGMA	plasma elongation
PINJ	injected power (W)
PRF	rf power (W)
CI	multiplier for ion conduction and convection time
CE	multiplier for electron conduction and convection time
IP	plasma current (A)

3.9 INPUT.DAT

The data in INPUT.DAT is read in from MAIN and stored in common INP. See Appendix C for a listing of the file. The values remain unchanged.

The following variables are in INPUT.DAT:

WWX(1)	the weight given to fixed variables in ETFOD.DAT
WWX(2)	the weight given to preferred variables in ETFOD.DAT
WWX(3)	the weight given to unknown variables in ETFOD.DAT
EQNWT	the weight given to the physics residuals in FIZICS
Z	charge of impurity ion
CTP	multiplier for trapped particle confinement time
CNC	multiplier for neoclassical confinement time
CRT	multiplier for ripple trapping confinement time
CEMP	multiplier for empirical confinement time
AMU	mass of plasma ions (AMU)
AMZ	mass of impurity ions (AMU)
EB	neutral beam energy (primary component, in keV)
LI	internal inductance parameter (dimensionless)
REFL	reflection coefficient for synchrotron radiation
RIPPLE	peak-to-average magnetic ripple depth (dimensionless)
FACTOR	low beta multiplier for plasma current
GAMMA	resistive loss factor
SCAPL	scrape off layer width (m)
PBURN	burn pressure (TORR)
PQNCH	quench pressure (TORR)

4. ADDITIONAL HINTS FOR USING ETFOD

Occasionally the code will find a solution to the least squares problem which is not a solution to the physics equations. (If so, there is an error message in the output file.) When this occurs, we have found it to be due to one of two things: either the equations are overconstrained or else they are badly underconstrained.

4.1 Overconstrained Equations

If there are fewer free variables than physics equations, the program prints an error message but solves the problem anyway. If the initial guess is very good, the solution to the physics equations may still be found. It is also possible that a certain subset of the physics equations is overconstrained. The program cannot tell you whether this has happened, but you should suspect that it has if all the output values seem very reasonable, but nevertheless the physics equations do not quite balance. The remedy is to float another variable or two. If this fails to work, then one or more of your initial guesses is much too low.

4.2 Badly Underconstrained Equations

This problem tends to occur when developing a brand new data set. The initial guesses are frequently poor, and there are usually a large number of free variables (free + "preferred" or "unknown"). The solution will contain values that are way out of line with the values expected. Also the execution time may be very long, especially if the initial guesses are too low (it is better to guess large values if unsure). The remedy is to tighten constraints on wayward variables.

REFERENCES

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2. A. T. Mense, W. A. Houlberg, S. E. Attenberger, "A 1-D Transport Model for Analysis of Expanding Radius and Full Bore Startup of Tokamak Plasmas," ORNL/TM-6841.

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Appendix A Flowchart

Appendix B ETF0D.DAT

TEST INPUT DATA. TNS REF. DESIGN ORNL/TM-6721

10 = NUMBER OF CONSTRAINT EQUATIONS

NVAR	VALUE	WEIGHT	VARIABLE	UNITS
1	12.00E0	F	TI	(KEV)
2	12.00E0	F	TE	(KEV)
3	1.500	P	ZEFF	
4	1.70E20	P	NI	(M**3)
5	1.70E20	P	NE	(M**3)
6	0.54E19	P	NZ	(M**3)
7	3.8	F	Q	(SAFETY FACTOR)
8	7.E-2	F	BETA	
9	5.01E0	F	BT	(TESLA)
10	1.500	U	TAUE	(SEC)
11	0.920E7	U	PALFV	(W/M**3)
12	1.042E10	U	PFUS	(W)
13	3.300E7	P	WPA	(W/M**2)
14	1.34	F	A	(M)
15	4.179	F	AR	
16	1.6	F	SIGMA	
17	0.E-00	F	PINJ	(W)
18	1.E-24	P	PRF	(W)
19	1.00	P	CI	
20	1.00	P	CE	
21	5.0E6	U	IP	(AMPS)

END

F=FIXED
P=PREFERRED VALUE
U=UNKNOWN

Appendix C INPUT.DAT

WWX(1)	WWX(2)	WWX(3)	EQNWT	
1.000	0.040	0.010	10.0	
Z	CTP	CNC	CRT	CEMP
8.0	1 0E20	1.0	6.0E03	1.0
AMU	AMZ	EB	LI	REFL
2.5	42.	150.0	1.50	0.9
RIPPLE	FACTOR	GAMMA	SCRAPL	PBURN
.0155	0.8	0.1	0.250	0.1E-5
FQCH				
0.10E-3				

Appendix D Program Listing

```

SUBROUTINE FIZICS(CC,M)
  DIMENSION CC(M),AK(100),BK(100)
COMMON/XS/XX(100)
COMMON/INDEXP/EQNWT,WW(100),INDP(100),MEQ,MAXDIM
COMMON/INITL/TIO,TEO,ZEFO,NIO,NEO,NZO,QO,BETAO,
# BTO,TAUEO,PALFVO,PFUSO,WPAO,AO,ARO,SIGMAO,PINJO,PRFO,CIO,
# CEO,IPO,
# DUMINI(79)
COMMON/INP/Z,CTP,CNC,CRT,CEMP,AMU,AMZ,EB,REFL,RIPPLE,
1 FACTOR,GAMMA,SCRAPL,PBURN,PONCH,LI
COMMON/SPECS/ETAALF,PCOULV,ETAINJ,POHNV,PRADV,SIGMAV,ETARF,
1 TAUTP,TAUEMP,TAURT,TAUNC
COMMON/VARBL/TE,TE,ZEFF,NI,NE,NZ,C,BETA,BT,TAUE
# ,PALFV,PFUS,WPA,A,AR,SIGMA,PINJ,PRF,CI,CE,IP
# ,DUMVAR(79)
COMMON/OUTFL/IOUT
COMMON/IO/NIN,NIN2,NOUT,NOUT2,NOUT3
REAL NIC,NEO,NZO,IPO,LI,NI,NE,NZ,IP,ILBTA,LP,LW,NTAU,LPI
EQUIVALENCE(AK(1),TI),(BK(1),TIO)
DATA ZMUO/1.2566E-6/
DATA QALPHA/5.607E-13/
C*****DEFINE INTERNAL VARIABLES*****
EI=1.5*(1.602E-16)*TI
EE=1.5*(1.602E-16)*TE
ZETA=NZ/NE
VOL=2.*3.14159**2*A**3*AR*SIGMA
AREA=4.*3.14159**2*A**2*AR*SQRT((1.+SIGMA**2)*.5)
C*****PHYSICS PACKAGES*****
CALL ALFETA(TE,ETAALF)
CALL COULM(NE,NI,AMU,TE,TI,PCOULV)
CALL INJETA(NI,NZ,Z,AMU,AMZ,TE,EB,ETAINJ)
CALL OHMIC(NE,TE,ZEFF,A,IP,POHNV)
CALL RADIAT(NE,ZEFF,TE,REFL,BT,BETA,A,NZ,PRADV)
CALL RATE(TI,SIGMAV)
CALL RFETA(ETARF)
CALL TAUS(NE,A,BT,BETA,ZEFF,AR,TI,SIGMA,
# AMU,RIPPLE,Q,TE,NI,TAUTP,TAUEMP,TAURT,TAUNC)
TAUTP=CTP*TAUTP
TAUNC=CNC*TAUNC
TAURT=CRT*TAURT
C*****CONSTRAINT EQUATIONS*****
CC(1)=(NI-NE*(1.-Z*ZETA))/NIO
CC(2)=(NI-NE*(ZEFF-Z**2*ZETA))/NIO
CC(3)=(BETA-(NI*TI+NE*TE+NZ*TI)*1.602E-16
# /(BT**2/(2.*ZMUO)))/BETAO
CC(4)=(PALFV-(NI*EI+NE*EE+NZ*EI)/TAUE)/PALFVO
CC(5)=(PALFV-NI*SIGMAV*NI*QALPHA/4.0)/PALFVO
CC(6)=(PALFV*ETAALF+ETAINJ*PINJ/VOL+ETARF*PRF/VOL+PCOULV
# -(NI*EI)/CI * (1./TAUTP+1./TAUNC
# +1./TAURT))/PALFVO
CC(7)=(PALFV*(1.-ETAALF)+(1.-ETAINJ)*PINJ/VOL+(1.-ETARF)*PRF/VOL
# -PCOULV+POHNV-PRADV-(NE*EE)/CE * (1./(CEMP*TAUEMP)))

```

```

#          /PALFV0
CC(8)=(PFUS-5.0286*PALFV*VOL)/PFUS0
CC(9)=(WPA-(PFUS*0.79213/AREA))/WPA0
CC(10)=(IP-5.6E6*A*BT*(1.0+SIGMA**2)*1.11/
1      (2.0*Q*AR*(1.0-1.0/AR**2)**2))/IPO
DO 143 I=1,MEQ
143      CC(I)=CC(I)*EQNWT
C
C  SINCE WE DON'T CALCULATE F OURSELVES, THE WEIGHTED VARIABLES
C  MUST BE TREATED AS CONSTRAINTS
C
NN=M-MEQ
DO 100 II=1,NN
I=INDP(II)
100      CC(II+MEQ)=WW(II)*(AK(I)-BK(I))/BK(I)
C*****COMPUTE OUTPUT VARIABLES*****
      IF(IOUT.NE.1) RETURN
      PALF=PALFV*VOL*1.0E-6
      RO=A*AR
      LPI=ZMUO*RO*LI/2.0
      ALEXT=ZMUO*RO*(ALOG(8.0*RO/(A*SQRT(SIGMA)))-2.0)
      LP=ALEXT+LPI
      RP=2.0*RO*1.638E-9*2.0*ZEFF*(24.0-ALOG(SQRT(NI/1.0E6)/
1      (TE*1000.0)))/(TE**1.5*A**2*SIGMA)
      V=RP*IP
      DRATEB=PALFV*VOL/QALPHA
      TAUP=TAUE
      DRATEL=NI*VOL/(2.0*TAU)
      FB=DRATEB/(DRATEL+DRATEB)
      B=SIGMA*A
      NTAU=NE*TAUE
      PB=PINJ*1.0E-6
      LW=WPA*1.0E-6
      POWFUS=PFUS*1.0E-6
      ALPPOW=PALFV*VOL*1.0E-6
      RADPOW=PRADV*VOL*1.0E-6
      POWEQV=PFUS*0.35*1.0E-6
      IP=IP*1.0E-6
      ILBTA=FACTOR*IP
      VSIND=LP*ILBTA
C
C  WRITE OUT SPECIFICATIONS
C
      WRITE(NOUT2,140)PALF,RO,LPI,ALEXT,VSIND,RP,V,DRATEB,DRATEL,FB
140      FORMAT(/' TOTAL ALPHA POWER',13X,E14.6,5X,'MAJOR RADIUS',18X,
1      E14.6/' INTERNAL INDUCTANCE',11X,E14.6,5X,'EXTERNAL ',
2      'INDUCTANCE',11X,E14.6/' INDUCTIVE VOLT-SECONDS',8X,E14.6,5X,
3      'PLASMA RESISTANCE',13X,E14.6/' PLASMA VOLTAGE',16X,E14.6,5X,
4      'DEUTERIUM BURN-UP RATE',8X,E14.6/' DEUTERIUM DIFFUSION ',
5      'LOSS RATE',1X,E14.6,5X,'FRACTION OF FUEL BURNED',7X,E14.6)
      RIPPLE=RIPPLE*100.0
      WRITE(NOUT3,180)A,Q,AR,Z,SIGMA,ZEFF,BETA,GAMMA,BT,
1      LI,TI,SCRAPL,TE,FACTOR,RIPPLE,PBURN,PONCH
180      FORMAT(2X,'PLASMA RADIUS (M)  =' ,F10.3,7X,'Q',21X,'=' ,F10.3/
1      2X,'ASPECT RATIO          =' ,F10.3,7X,'IMPURITY Z          =' ,

```

```

2      F10.3/2X,'ELONGATION'          =',F10.3,7X,'ZEFF',18X,'=',
3      F10.3/2X,'BETA',15X,'=',F10.3,7X,'GAMMA (RES LOSS)  =',
4      F10.3/2X,'FIELD ON AXIS(T)    =',F10.3,7X,'PLASMA INT IND ',
5      '(LI)  =',F10.3/2X,'ION TEMP (KEV)    =',F10.3,7X,
6      'SCRAPE OFF LAYER (M) =',F10.3/2X,'ELE TEMP (KEV)    =',
7      F10.3,7X,'IP FACTOR',13X,'=',F10.3/2X,'RIPPLE (%)',9X,'=',
A      F10.3,7X,
8      'BURN PRESS (TORR)    =',E10.4/39X,'QUENCH PRESS (TORR)  =',
9      E10.4)
WRITE(NOUT3,200)RO,IP,B,ILBTA,VOL,V,LP,RP,NI,NE
200    FORMAT(/2X,'MAJOR RADIUS (M)  =',F10.3,
1      7X,'PLASMA-CRNT-HB (MA)  =',F10.3/
2      2X,'PLASMA HEIGHT (M)  =',F10.3,
B      7X,'PLASMA-CRNT-LB (MA)  =',F10.3/
C      2X,'PLASMA VOLUM (M**3)=',F10.3,7X,
3      'PLASMA VOLT-BURN (V)  =',F10.3/
D      2X,'PLASMA IND (H)      =',E10.4,
4      7X,'PLASMA RES-BURN (OHM) =',E10.4/2X,'ION DENSITY (/M**3)=',
5      E10.4/2X,'ELE DENSITY (/M**3)=',E10.4)
WRITE(NOUT3,220)ZETA,Z,ZEFF
220    FORMAT(/2X,'IMPURITY CONCENT. =',F10.3/2X,'IMPURITY Z',9X,'=',
1      F10.3/2X,'ZEFF',15X,'=',F10.3)
WRITE(NOUT3,240)NTAU,TAUE,TAUEMP,TAUTP,TAUP
240    FORMAT(/2X,'NTAU (SEC/M**3)    =',E10.4/2X,'TAUE (SEC)',9X,'=',
1      F10.3/2X,'TAUE-EMP (SEC)    =',F10.3/2X,'TAUE-TP (SEC)',6X,
2      '= ',F10.3/2X,'TAUP (SEC)',9X,'=',F10.3)
WRITE(NOUT3,260)PB,EB,LW,POWFUS,ALPPOW,RADPOW,POWEQV
260    FORMAT(/2X,'BEAM POWER (MW)    =',F10.3/2X,'BEAM ENERGY (KEV)  '
1      ',=',F10.3//2X,'PLASMA EDGE NEU. LOAD (MW/M**2) =',F12.2/2X,
2      'FUSION POWER (MW)',15X,'=',F12.2/2X,'ALPHA (MW)',22X,'=',
3      F12.2/2X,'RADIATION (MW)',18X,'=',F12.2/2X,'ELEC. POWER',
4      '(MW)',16X,'=',F12.2)
RETURN
END

```

C

C-----

C

```

SUBROUTINE RESID(M,N,XC,RC)
C--THE CC ELEMENTS ARE RESIDUALS OF THE CONSTRAINT EQUATIONS.
C--CONSTRAINTS HAVE THE FORM CC=F(X) WHERE CC=0 FOR ALLOWED
C--VALUES OF X.

```

```

COMMON/INDEXP/EQNWT,WW(100),INDP(100),MEQ,MAXDIM
COMMON/VARBL/ TI,TE,ZEFF,NI,NE,NZ,Q,BETA,BT,TAUE
# ,PALFV,PFUS,WPA,A,AR,SIGMA,PINJ,PRF,CI,CE,IP
# ,DUMVAR(79)
COMMON/INDEX/ITI,ITE,IZEFF,INI,INE,
# INZ,IQ,IBETA,IBT,ITAUE,IPALFV,IPFUS,IWPA,IA,IAR,ISIGMA,
# IPINJ,IPRF,ICI,ICE,IIP,
# DUMIND(79)
COMMON/INITL/TIO,TEO,ZEFO,NIO,NEO,NZO,QO,BETAO,
# BTO,TAUEO,PALFVO,PFUSO,WPAO,AO,ARO,SIGMAO,PINJO,PRFO,CIO,
# CEO,IPO,
# DUMINI(79)
COMMON/XS/XX(100)
DIMENSION XC(N),RC(M)

```

REAL NIO,NEO,NZO,IPO,LI,NI,NE,NZ,IP,ILBTA,LP,LW,NTAU,LPI
 C--VARIABLES MUST APPEAR IN THE DATA FILE IN THE SAME ORDER
 C--AS THEY APPEAR IN COMMON.

```

C
      DO 100 I=1,MAXDIM
100   XX(I)=1.0
      DO 105 II=1,N
      I=INDP(II)
105   XX(I)=XC(II)
C--ALL OTHER XX(I)=1.
      TI  =XX(ITI  )*TIO
      TE  =XX(ITE  )*TEO
      ZEFF =XX(IZEFF)*ZEFFO
      NI  =XX(INI  )*NIO
      NE  =XX(INE  )*NEO
      NZ  =XX(INZ  )*NZO
      Q   =XX(IQ   )*QO
      BETA =XX(IBETA)*BETAO
      BT   =XX(IBT  )*BTO
      TAUE =XX(ITAUE)*TAUEO
      PALFV =XX(IPALFV)*PALFVO
      PFUS  =XX(IPFUS)*PFUSO
      WPA   =XX(IWPA)*WPAO
      A     =XX(IA   )*AO
      AR    =XX(IAR  )*ARO
      SIGMA =XX(ISIGMA)*SIGMAO
      PINJ  =XX(IPINJ)*PINJO
      PRF   =XX(IPRF)*PRFO
      CI    =XX(ICI  )*CIO
      CE    =XX(ICE  )*CEO
      IP    =XX(IIP  )*IPO

```

```

C
      CALL FIZICS(RC,M)
      RETURN
      END

```

C

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EX ETFO.D.PHYSUB.REL:NAG/SEA

AUTHORS: S. E. ATTENBERGER, K. E. ROTHE
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 4-0613 4-0637

```

      MAIN ROUTINE
COMMON/INDEX/IND(100)
      COMMON/INDEXP/EQNWT,WW(100),INDP(100),MEQ,MAXDIM
COMMON/SPECS/ETAALF,PCOULV,ETAINJ,POHNV,PRADV,SIGMAV,ETARF,
1      TAUTP,TAUEMP,TAURT,TAUNC
      COMMON/INITL/VARO(100)
      COMMON/INP/Z,CTP,CNC,CRT,CEMP,AMU,AMZ,EB,REFL,RIPPLE,
1      FACTOR,GAMMA,SCRAPL,PPURN,PQCH,LI
      COMMON/IO/NIN,NIN2,NOUT,NOU12,NOUT3
      COMMON/NAMES/NAMVAR(100),IFPU(100)
      COMMON/PRT/NVAR

```

```

COMMON/XS/  XX(100)
REAL NIO,NEO,NZO,IPO,LI,NI,NE,NZ,IP,ILBTA,LP,LW,NTAU,LPI
DIMENSION UNITS(4),IX(3),WWX(3)

C
C THE WEIGHTS ARE READ IN FROM INPUT.DAT AND ARE DETERMINED FROM
C TEST RUNS TO BE GENERALLY WORKABLE
C F=FIXED P=PREFERRED U=UNKNOWN
C
DATA IEND/4H END/,IX/'F','P','U',IOUT/0/,MAXDIM/100/
DATA IFPU/100*'F',IBLNK/' '/

C
NIN=6
NIN2=28
NOUT=5
NOUT2=20
NOUT3=27
OPEN(UNIT=NIN,DEVICE='DSK',ACCESS='SEQIN',FILE='ETFOD.DAT')
OPEN(UNIT=NIN2,DEVICE='DSK',ACCESS='SEQIN',FILE='INPUT.DAT')
OPEN(UNIT=NOUT2,DEVICE='DSK',ACCESS='SEQOUT',FILE='ETFOD.OUT')
OPEN(UNIT=NOUT3,DEVICE='DSK',ACCESS='SEQOUT',FILE='SPECS.ETF')
DUM=0.
1  FORMAT(80A1)
2  FORMAT(8I10)
3  FORMAT(A4,E12.4,9X,A1,5X,A5,4A5)
READ(NIN2,10)WWX,EQNWT
READ(NIN2,10)Z,CTP,CNC,CRT,CEMP,AMU,AMZ,EB,LI,REFL,RIPPLE,
1  FACTOR,GAMMA,SCRAPL,PBURN,PQNCN
10 FORMAT(/5E12.4)
C
READ(NIN,1)DUM
READ(NIN,2)MEQ
READ(NIN,1)DUM
C
N=0
NVAR=0
DO 100 I=1,MAXDIM
READ(NIN,3)IVAR,VARO(I),LX,NAMVAR(I),UNITS
IF(IVAR.EQ.IEND) GO TO 150
WRITE(NOUT2,3)IVAR,VARO(I),LX,NAMVAR(I),UNITS
NVAR=NVAR+1
IND(I)=NVAR
DO 80 J=1,3
IF(LX.EQ.IX(J))WX=WWX(J)
80 CONTINUE
IF(WX.EQ.1.0) GO TO 100
N=N+1
INDP(N)=I
IFPU(I)=IBLNK
WW(N)=WX
100 CONTINUE
C
150 WRITE(NOUT2,160)
160 FORMAT(/' WHERE: F=FIXED VALUE'/7X,' P=PREFERRED VALUE'/
1  7X,' U=UNKNOWN VALUE')
IF(MEQ.GT.N) WRITE(NOUT,4)

```



```

      IF(MEQ.GT.N) WRITE(NOUT2,4)
4     FORMAT(47H WARNING      NUMBER OF CONSTRAINTS EXCEEDS NUMBER,
      # 19H OF FREE VARIABLES      )
C
      TYPE 10,(WW(I),I=1,N)
C
      CALL SEARCH(N,MEQ)
      WRITE(NOUT2,240)ETAALF,PCOULV,ETAINJ,POHNV,PRADV,SIGMAV,ETARF,
1      TAUTP,TAUEMP,TAURT,TAUNC
240     FORMAT(' ETAALF',20X,E13.6// ' PCOULV',20X,E13.6// ' ETAINJ',20X,
1      E13.6// ' POHNV ',20X,E13.6// ' PRADV ',20X,E13.6// ' SIGMAV',
2      20X,E13.6// ' ETARF ',20X,E13.6// ' TAUTP ',20X,E13.6// ' TAUEMP',
3      20X,E13.6// ' TAURT ',20X,E13.6// ' TAUNC ',20X,E13.6)
C
      STOP
      END
C
C-----
C
      SUBROUTINE SEARCH(N,MEQ)
C
C  DIMENSIONS
C
C  X(N)      GUESS AT SOLUTION
C  R(M)      RESIDUALS
C  W(IW)     WORK SPACE
C  STEPMX(N) RANGE LIMITS ON X
C
      DIMENSION X(100),W(1500),RC(100),STPEMX(100)
      COMMON/INDEXP/EQNWT,WW(100),INDP(100),MDUM,MAXDIM
      COMMON/PARAMS/COND1,ACCURC,CNORM
      COMMON/IO/NIN,NIN2,NOUT,NOUT2,NOUT3
      COMMON/OUTFL/IOUT
      REAL NIO,NEO,NZO,IPO,LI,NI,NE,NZ,IP,ILBTA,LP,LW,NTAU,LPI
      EXTERNAL RESID,MONIT
      DATA FRAACC/0.01/
      DATA X,W,RC/100*1.0,1500*0.0/
      DATA IX,IW,IRC,ISTP/100,1500,100,100/
C--ALL VARIABLES ARE NORMALIZED TO 1 AT THE INITIAL VALUE.
      M=MEQ+N
C--IPRINT MUST BE .GE.0,CAUSING MONIT TO BE CALLED AND VALUES
C--IN COMMON PARAMS TO BE DEFINED
      IPRINT=1
      MAXCAL=1500
C      MAXCAL=100*(N+5)*NX
C  XTOL=8.631675E-03
      XTOL=0.1
      FTOL=1.0E-6
      WRITE(NOUT2,40)XTOL,FTOL
40  FORMAT('/', XTOL = ',1PE13.6,6X,'FTOL = ',1PE13.6)
      DO 50 I=1,N
50  STEPMX(I)=0.5
      WRITE(NOUT2,52)STPEMX(1)
52  FORMAT(' STEPMX = ',1PE13.6)
      III=N+3+N/3

```

```

      LTEST=2*M+4*N+M*N+N*(N+1)/2+III*(M+2+2*N)
      IF(IW.LT.LTEST) WRITE(NOUT,2) LTEST
      IF(IW.LT.LTEST) WRITE(NOUT2,2) LTEST
2      FORMAT(36H INCREASE DIMENSION OF W TO AT LEAST,I10)
C
      IF(N.LE.IX)GO TO 120
      WRITE(NOUT,115)N
      WRITE(NOUT2,115)N
115      FORMAT(/' INCREASE X DIMENSION TO AT LEAST',I5)
120      IF(M.LE.IRC)GO TO 130
      WRITE(NOUT,125)M
      WRITE(NOUT2,125)M
125      FORMAT(/' INCREASE RC DIMENSION TO AT LEAST',I5)
130      IFAIL=0
C--TEST OF INITIAL VALUES
      CALL RESID(M,N,X,RC)
      DO 150 I=1,M
150      IF(ABS(RC(I)).GT.0.5)WRITE(NOUT,155)I
155      FORMAT(' BAD GUESS AT SOLUTION FOR EQUATION',I3)
      F=0.0
      WRITE(NOUT2,23)F,(RC(I),I=1,M)
23  FORMAT(/' SUM OF SQUARES =',F10.4/' RESIDUALS: '/(1P10E10.3))
      DO 160 I=1,IRC
160      RC(I)=0.0
C
      CALL E04FAF(M,N,X,RC,F,FTOL,XTOL,STPMX,W,IW,RESID,MONIT,
1      IPRINT,MAXCAL,IFAIL)
C
      IF(IFAIL.EQ.0) WRITE(NOUT,20)
      IF(IFAIL.EQ.0) WRITE(NOUT2,20)
20  FORMAT(27H A SOLUTION HAS BEEN FOUND.)
C--CALL RESID TO UPDATE VALUES OF VARBLs.
      IOUT=1
      CALL RESID(M,N,X,RC)
      WRITE(NOUT2,170)F,FTOL,IFAIL,(RC(I),I=1,M)
170      FORMAT(/' SUM OF SQUARES =',E10.4,4X,'FTOL =',F4.1,4X,
1      'IFAIL =',I2/' RESIDUALS: '/(1P10E11.4))
      PERCNT=FRAACC*100.0
      DO 200 I=1,MEQ
      RC(I)=RC(I)/EQNWT
      IF(ABS(RC(I)).GT.FRAACC)GO TO 220
200      CONTINUE
      GO TO 250
220      WRITE(NOUT2,240)PERCNT
      WRITE(NOUT,240)PERCNT
      WRITE(NOUT3,240)PERCNT
240      FORMAT(/' THIS SOLUTION DOES NOT SATISFY PHYSICS EQUATIONS',
1      ' WITHIN ',F3.1,'%')
      GO TO 270
250      WRITE(NOUT2,260)PERCNT
      WRITE(NOUT,260)PERCNT
260      FORMAT(/' THIS SOLUTION DOES SATISFY PHYSICS EQUATIONS',
1      ' WITHIN ',F3.1,'%')
270      WRITE(NOUT2,271)
271      FORMAT(1X)

```

```

DO 272 I=1,MEQ
RC(I)=RC(I)*100.0
272 WRITE(NOUT2,274)I,RC(I)
274 FORMAT(' EQUATION ',I2,' IS BALANCED WITHIN ',F5.2,'%')
WRITE(NOUT2,280)(X(I),I=1,N)
280 FORMAT('/ NORMALIZED X: '/(1P10E11.4))
TYPE 290,FTOL
290 FORMAT(' FTOL=',F4.1)
CALL PRTOUT
RETURN
END
C
C-----
C
SUBROUTINE MONIT(M,N,X,F,NITER,SING,LIM)
LOGICAL SING,LIM
DIMENSION X(N)
COMMON/IO/NIN,NIN2,NOUT,NOUT2,NOUT3
C--IF IPRINT .GT. 0, THIS ROUTINE IS CALLED TO MONITOR THE
C--PROGRESS OF THE CONVERGENCE.
C
WRITE(NOUT2,10)F,NITER,SING,(X(I),I=1,N)
10 FORMAT('/ SUM OF SQUARES =',E10.4,' AFTER ',I10,
1 ' ITERATIONS'/' SING =',L10,' (IF TRUE, RANDOM POINT HAS',
2 ' BEEN USED)'/' CURRENT SOLUTION: '/(1P10E10.3))
IF(LIM)WRITE(NOUT2,15)
15 FORMAT('/ THE VALUE OF AN X WAS CONSTRAINED BY STEPMX')
CALL PRTOUT
RETURN
END
C
C-----
C
SUBROUTINE PRTOUT
COMMON/IO/NIN,NIN2,NOUT,NOUT2,NOUT3
COMMON/NAMES/NAMVAR(100),IFPU(100)
COMMON/OUTFL/IOUT
COMMON/PRT/NVAR
COMMON/VARBL/VALUE(100)
C
WRITE(NOUT2,90)
90 FORMAT(1X)
DO 100 I=1,NVAR
100 WRITE(NOUT2,1) NAMVAR(I),VALUE(I),IFPU(I)
1 FORMAT(2X,A5,3H = ,E15.3,2X,A1)
IF(IOUT.NE.1) RETURN
RETURN
END

```

```

      SUBROUTINE ALFETA(TEKEV,ETAALF)
C--REF ORNL/TM-5509
C--(NOT ACCURATE FOR TE ABOVE 20 KEV)
      ETAALF=TEKEV/50.
      IF(ETAALF.GT.1.) ETAALF=1.
      RETURN
      END

C
      SUBROUTINE COULM(DENE,DENI,AMU,TEKEV,TIKEV,PCOULV)
C--REF. ORNL/TM-5509
C--(PCOULV IS POSITIVE WHEN POWER IS TRANSFERRED TO IONS)
      ALOGLM=24.6-ALOG((1.E-6)*SQRT(DENE)/TEKEV)
      PCOULV=(1.5E-19*DENE)/TEKEV**1.5
      #      *DENI/AMU *ALOGLM *(TEKEV-TIKEV)*1.6E-16
      RETURN
      END

C
      SUBROUTINE INJETA(DENI,DENZ,Z,AMU,AMZ,TEKEV,EBEAM,ETAINJ)
C--REF ORNL/TM-5509
C--EBEAM IS IN KEV
      ZBR=(DENI+DENZ*Z**2*(AMU/AMZ))/(DENI+Z*DENZ)
C      ASSUME BEAM SPECIES MIX = PLASMA SPECIES MIX
      AMB=AMU
      ECRIT=14.8*TEKEV*(AMB*(ZBR*AMB/AMU)**2)**(1./3.)
      GI=0.5*EXP(-0.0916*EBEAM/ECRIT)+0.5*EXP(-0.635*EBEAM/ECRIT)
C--GE=1.-GI
      ETAINJ=GI
      RETURN
      END

C
      SUBROUTINE OHMIC(DENE,TEKEV,ZEFF,AMINOR,CURRT,POHMOV)
C--REF ORNL/TM-5509
      ALOGLM=24.6-ALOG((1.E-6)*SQRT(DENE)/TEKEV)
      RSPITZ=ALOGLM*1.65E-9*ZEFF/(TEKEV**1.5)
C--APPROPRIATE FOR HYDROGEN
      CURDEN=CURRT/(3.14159*AMINOR**2)
      POHMOV=RSPITZ*CURDEN**2
      RETURN
      END

C
      SUBROUTINE RADIAT(DENE,ZEFF,TKEV,REFL,BT,BETA,AMINOR,DENZ,PRADV)
C--REF ORNL/TM-5509
      PBREMV=(0.3E-20*DENE)*DENE*ZEFF*SQRT(TKEV)*1.6E-16
      PSYNCV=1.5E5*TKEV**3*(1.-REFL)*(1.+TKEV/204.)*1.6E-16
      # *SQRT(DENE*(BT*SQRT(1.-BETA))**5/(AMINOR*TKEV))
      PLINEV=(.32E-32*DENE)*DENZ
C--THIS LINE RADIATION IS APPROPRIATE FOR IRON ABOVE 2 KEV.
      PLINEV=0.
      PRADV=PBREMV+PSYNCV+PLINEV
      RETURN
      END

C
      SUBROUTINE RATE(TKEV,SIGMAV)
C      SIGMAV=(3.14*TKEV-20.6)*1.E-23
C      IF(SIGMAV.LT.1.E-35) SIGMAV=0.0

```

```

TIEV=TKEV*1.E3
SIGMAV=1.E-6*SVFUSE(TIEV,3)
RETURN
END

```

C

```

SUBROUTINE RFETA(ETARF)

```

```

C--FOR NOW, ASSUME ALL RF POWER GOES TO IONS

```

```

ETARF=1.0
RETURN
END

```

C

```

SUBROUTINE TAUS(DENE,AMINOR,BT,BETA,ZEFF,ASP,TIKEV,ELONG,
# AMU,DELTA,QS,TEKEV,DENI,TAUTP,TAUEMP,TAURT,TAUNC)

```

```

C--TRAPPED PARTICLE MODE FROM MARTIN PENG

```

```

TAUTP=(2.4E20/DENE)
#      *(AMINOR/1.2)**4.
#      *(BT/5.3)**6
#      *(BETA/0.07)**2
#      *(ZEFF/1.1)
#      *(ASP/4.17)**2.5
#      *(12./TIKEV)**5.5
#      *(1.+ELONG**2)/(2.*1.78)

```

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C--EMPIRICAL SCALING FROM MARTIN PENG

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TAUEMP=(5.E-21*DENE)*AMINOR**2

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C--RIPPLE TRAPPING DERIVED FROM STRINGER'S DIFF. COEFF.

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```

RO=ASP*AMINOR
ZNUE=1.6E4*ZEFF*(DENE/1.E19)*(TIKEV)**-1.5
SQRAM=SQRT(AMU*1836.)
BTKG=BT*10.
VD=1.E6*TIKEV/(BTKG*RO)
XRT=46.5*DELTA**1.5*SQRAM*VD**2/(ZNUE*ELONG**2)
TAURT=AMINOR**2/(4.*XRT*1.E-4)

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C--NEOCLASSICAL DIFFUSION DERIVED FROM DIAGONAL TERMS OF

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C--HINTON-MOORE MODEL FOR ION THERMAL CONDUCTIVITY.

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BP=BT*((1.+ELONG**2)/2.)/(QS*ASP)
EPS=1./ASP
ZL=24.-ALOG((1.E-6)*SQRT(DENE)/TEKEV)
ZNUI=6.71E-14*DENI*ZL/(TIKEV*1.E3)**1.5
OMEGBI=9.78E3*BP/(BT*RO)*SQRT(1.E3*TIKEV/(EPS*AMU))
SNI=ZNUI/(EPS*OMEGBI)
RHOIT=144.25E-04*SQRT(AMU*1.E3*TIKEV)/BP
XK2=.66*(1./(1.+1.03*SQRT(SNI))+.31*SNI)
#      +EPS**3*1.77*SNI/(1.+74*SNI*EPS**1.5)
XINC=SQRT(EPS)*ZNUI*RHOIT**2*XK2
TAUNC=AMINOR**2/(4.*XINC*1.E-4)
RETURN
END
FUNCTION SVFUSE(TI,IRATE)

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```

C*****

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```

C*****W.A.HOULBERG ORNL 2/79.

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C*****TABULATED DATA PROVIDED BY J.R.MCNALLY, JR.

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C*****

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C*****SVFUSE IS <SIGMA*VEL> AVERAGED OVER TWO MAXWELLIAN DISTRIBUTIONS

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```

C*****WITH TEMPERATURE TI. UNITS ARE IN CM**3/SEC FOR SVFUSE.

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```

C*****IRATE=INDEX DENOTING REACTION

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```

C***** = 1   D+D = 3HE( 817KEV) +N( 2450KEV)          REF 1 *
C***** = 2   D+D =   T( 1008KEV) +P( 3024KEV)          REF 1 *
C***** = 3   D+T =   A( 3517KEV) +N(14069KEV)          REF 1 *
C***** = 4   T+T =   A( 1259KEV) +N( 5034KEV) +N( 5034KEV) REF 1 *
C***** = 5 3HE+T = D( 9546KEV) +A( 4773KEV)          41% REF 2 *
C*****      = P( 5374KEV) +A( 1344KEV) -N( 5374KEV) 55% REF 2 *
C*****      = P(10077KEV) +A( 403KEV) +N( 1612KEV) 4% REF 2 *
C***** = 6 3HE+D = P(14681KEV) +A( 3670KEV)          REF 1 *
C*****THE ENERGIES FOR THE PRODUCTS ARE INVERSELY PROPORTIONAL TO THE *
C*****MASS OF EACH PRODUCT. *
C*****THE BRANCHING RATIO FOR REACTION 5 IS ENERGY SENSITIVE. *
C*****REF 1: UCRL-70552 (1967) *
C*****REF 2: BNWL-1685 (1975) P. 75 *
C*****      SOV PHYS JETP 12 (1961) P. 163 *
C*****TI=MAXWELLIAN TEMPERATURE IN EV. *
C*****CROSS-SECTIONS TABULATED IN STEPS OF .2 KEV FOR 1.<T< 10. KEV *
C*****      2. KEV FOR 10.<T<100. KEV *
C*****      20. KEV FOR 100.<T<200. KEV *
C*****

```

```

DIMENSION SV(96,6),SV1(96),SV2(96),SV3(96),SV4(96),SV5(96),SV6(96)
EQUIVALENCE (SV(1,1),SV1(1)),(SV(1,2),SV2(1)),(SV(1,3),SV3(1))
EQUIVALENCE (SV(1,4),SV4(1)),(SV(1,5),SV5(1)),(SV(1,6),SV6(1))

```

```

DATA SV1/9.65E-23,2.61E-22,5.75E-22,1.10E-21,1.90E-21,
#      3.04E-21,4.58E-21,6.57E-21,9.06E-21,1.21E-20,
#      1.57E-20,2.00E-20,2.49E-20,3.04E-20,3.67E-20,
#      4.37E-20,5.14E-20,5.98E-20,6.90E-20,7.90E-20,
#      8.97E-20,1.01E-19,1.13E-19,1.26E-19,1.40E-19,
#      1.55E-19,1.70E-19,1.86E-19,2.03E-19,2.21E-19,
#      2.39E-19,2.58E-19,2.78E-19,2.99E-19,3.20E-19,
#      3.42E-19,3.64E-19,3.88E-19,4.12E-19,4.37E-19,
#      4.62E-19,4.88E-19,5.15E-19,5.42E-19,5.70E-19,
#      5.99E-19,6.28E-19,6.57E-19,6.86E-19,7.16E-19,
#      7.46E-19,7.76E-19,8.06E-19,8.36E-19,8.66E-19,
#      8.96E-19,9.26E-19,9.56E-19,9.86E-19,1.01E-18,
#      1.04E-18,1.07E-18,1.10E-18,1.13E-18,1.16E-18,
#      1.19E-18,1.22E-18,1.25E-18,1.28E-18,1.31E-18,
#      1.34E-18,1.37E-18,1.40E-18,1.43E-18,1.46E-18,
#      1.49E-18,1.52E-18,1.55E-18,1.58E-18,1.61E-18,
#      1.64E-18,1.67E-18,1.70E-18,1.73E-18,1.76E-18,
#      1.79E-18,1.82E-18,1.85E-18,1.88E-18,1.91E-18,
#      1.94E-18,1.97E-18,2.00E-18,2.03E-18,2.06E-18,
#      2.09E-18,2.12E-18,2.15E-18,2.18E-18,2.21E-18,
#      2.24E-18,2.27E-18,2.30E-18,2.33E-18,2.36E-18,
#      2.39E-18,2.42E-18,2.45E-18,2.48E-18,2.51E-18,
#      2.54E-18,2.57E-18,2.60E-18,2.63E-18,2.66E-18,
#      2.69E-18,2.72E-18,2.75E-18,2.78E-18,2.81E-18,
#      2.84E-18,2.87E-18,2.90E-18,2.93E-18,2.96E-18,
#      2.99E-18,3.02E-18,3.05E-18,3.08E-18,3.11E-18,
#      3.14E-18,3.17E-18,3.20E-18,3.23E-18,3.26E-18,
#      3.29E-18,3.32E-18,3.35E-18,3.38E-18,3.41E-18,
#      3.44E-18,3.47E-18,3.50E-18,3.53E-18,3.56E-18,
#      3.59E-18,3.62E-18,3.65E-18,3.68E-18,3.71E-18,
#      3.74E-18,3.77E-18,3.80E-18,3.83E-18,3.86E-18,
#      3.89E-18,3.92E-18,3.95E-18,3.98E-18,4.01E-18,
#      4.04E-18,4.07E-18,4.10E-18,4.13E-18,4.16E-18,
#      4.19E-18,4.22E-18,4.25E-18,4.28E-18,4.31E-18,
#      4.34E-18,4.37E-18,4.40E-18,4.43E-18,4.46E-18,
#      4.49E-18,4.52E-18,4.55E-18,4.58E-18,4.61E-18,
#      4.64E-18,4.67E-18,4.70E-18,4.73E-18,4.76E-18,
#      4.79E-18,4.82E-18,4.85E-18,4.88E-18,4.91E-18,
#      4.94E-18,4.97E-18,5.00E-18,5.03E-18,5.06E-18,
#      5.09E-18,5.12E-18,5.15E-18,5.18E-18,5.21E-18,
#      5.24E-18,5.27E-18,5.30E-18,5.33E-18,5.36E-18,
#      5.39E-18,5.42E-18,5.45E-18,5.48E-18,5.51E-18,
#      5.54E-18,5.57E-18,5.60E-18,5.63E-18,5.66E-18,
#      5.69E-18,5.72E-18,5.75E-18,5.78E-18,5.81E-18,
#      5.84E-18,5.87E-18,5.90E-18,5.93E-18,5.96E-18,
#      5.99E-18,6.02E-18,6.05E-18,6.08E-18,6.11E-18,
#      6.14E-18,6.17E-18,6.20E-18,6.23E-18,6.26E-18,
#      6.29E-18,6.32E-18,6.35E-18,6.38E-18,6.41E-18,
#      6.44E-18,6.47E-18,6.50E-18,6.53E-18,6.56E-18,
#      6.59E-18,6.62E-18,6.65E-18,6.68E-18,6.71E-18,
#      6.74E-18,6.77E-18,6.80E-18,6.83E-18,6.86E-18,
#      6.89E-18,6.92E-18,6.95E-18,6.98E-18,7.01E-18,
#      7.04E-18,7.07E-18,7.10E-18,7.13E-18,7.16E-18,
#      7.19E-18,7.22E-18,7.25E-18,7.28E-18,7.31E-18,
#      7.34E-18,7.37E-18,7.40E-18,7.43E-18,7.46E-18,
#      7.49E-18,7.52E-18,7.55E-18,7.58E-18,7.61E-18,
#      7.64E-18,7.67E-18,7.70E-18,7.73E-18,7.76E-18,
#      7.79E-18,7.82E-18,7.85E-18,7.88E-18,7.91E-18,
#      7.94E-18,7.97E-18,8.00E-18,8.03E-18,8.06E-18,
#      8.09E-18,8.12E-18,8.15E-18,8.18E-18,8.21E-18,
#      8.24E-18,8.27E-18,8.30E-18,8.33E-18,8.36E-18,
#      8.39E-18,8.42E-18,8.45E-18,8.48E-18,8.51E-18,
#      8.54E-18,8.57E-18,8.60E-18,8.63E-18,8.66E-18,
#      8.69E-18,8.72E-18,8.75E-18,8.78E-18,8.81E-18,
#      8.84E-18,8.87E-18,8.90E-18,8.93E-18,8.96E-18,
#      8.99E-18,9.02E-18,9.05E-18,9.08E-18,9.11E-18,
#      9.14E-18,9.17E-18,9.20E-18,9.23E-18,9.26E-18,
#      9.29E-18,9.32E-18,9.35E-18,9.38E-18,9.41E-18,
#      9.44E-18,9.47E-18,9.50E-18,9.53E-18,9.56E-18,
#      9.59E-18,9.62E-18,9.65E-18,9.68E-18,9.71E-18,
#      9.74E-18,9.77E-18,9.80E-18,9.83E-18,9.86E-18,
#      9.89E-18,9.92E-18,9.95E-18,9.98E-18,1.01E-17,
#      1.04E-17,1.07E-17,1.10E-17,1.13E-17,1.16E-17,
#      1.19E-17,1.22E-17,1.25E-17,1.28E-17,1.31E-17,
#      1.34E-17,1.37E-17,1.40E-17,1.43E-17,1.46E-17,
#      1.49E-17,1.52E-17,1.55E-17,1.58E-17,1.61E-17,
#      1.64E-17,1.67E-17,1.70E-17,1.73E-17,1.76E-17,
#      1.79E-17,1.82E-17,1.85E-17,1.88E-17,1.91E-17,
#      1.94E-17,1.97E-17,2.00E-17,2.03E-17,2.06E-17,
#      2.09E-17,2.12E-17,2.15E-17,2.18E-17,2.21E-17,
#      2.24E-17,2.27E-17,2.30E-17,2.33E-17,2.36E-17,
#      2.39E-17,2.42E-17,2.45E-17,2.48E-17,2.51E-17,
#      2.54E-17,2.57E-17,2.60E-17,2.63E-17,2.66E-17,
#      2.69E-17,2.72E-17,2.75E-17,2.78E-17,2.81E-17,
#      2.84E-17,2.87E-17,2.90E-17,2.93E-17,2.96E-17,
#      2.99E-17,3.02E-17,3.05E-17,3.08E-17,3.11E-17,
#      3.14E-17,3.17E-17,3.20E-17,3.23E-17,3.26E-17,
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#      3.44E-17,3.47E-17,3.50E-17,3.53E-17,3.56E-17,
#      3.59E-17,3.62E-17,3.65E-17,3.68E-17,3.71E-17,
#      3.74E-17,3.77E-17,3.80E-17,3.83E-17,3.86E-17,
#      3.89E-17,3.92E-17,3.95E-17,3.98E-17,4.01E-17,
#      4.04E-17,4.07E-17,4.10E-17,4.13E-17,4.16E-17,
#      4.19E-17,4.22E-17,4.25E-17,4.28E-17,4.31E-17,
#      4.34E-17,4.37E-17,4.40E-17,4.43E-17,4.46E-17,
#      4.49E-17,4.52E-17,4.55E-17,4.58E-17,4.61E-17,
#      4.64E-17,4.67E-17,4.70E-17,4.73E-17,4.76E-17,
#      4.79E-17,4.82E-17,4.85E-17,4.88E-17,4.91E-17,
#      4.94E-17,4.97E-17,5.00E-17,5.03E-17,5.06E-17,
#      5.09E-17,5.12E-17,5.15E-17,5.18E-17,5.21E-17,
#      5.24E-17,5.27E-17,5.30E-17,5.33E-17,5.36E-17,
#      5.39E-17,5.42E-17,5.45E-17,5.48E-17,5.51E-17,
#      5.54E-17,5.57E-17,5.60E-17,5.63E-17,5.66E-17,
#      5.69E-17,5.72E-17,5.75E-17,5.78E-17,5.81E-17,
#      5.84E-17,5.87E-17,5.90E-17,5.93E-17,5.96E-17,
#      5.99E-17,6.02E-17,6.05E-17,6.08E-17,6.11E-17,
#      6.14E-17,6.17E-17,6.20E-17,6.23E-17,6.26E-17,
#      6.29E-17,6.32E-17,6.35E-17,6.38E-17,6.41E-17,
#      6.44E-17,6.47E-17,6.50E-17,6.53E-17,6.56E-17,
#      6.59E-17,6.62E-17,6.65E-17,6.68E-17,6.71E-17,
#      6.74E-17,6.77E-17,6.80E-17,6.83E-17,6.86E-17,
#      6.89E-17,6.92E-17,6.95E-17,6.98E-17,7.01E-17,
#      7.04E-17,7.07E-17,7.10E-17,7.13E-17,7.16E-17,
#      7.19E-17,7.22E-17,7.25E-17,7.28E-17,7.31E-17,
#      7.34E-17,7.37E-17,7.40E-17,7.43E-17,7.46E-17,
#      7.49E-17,7.52E-17,7.55E-17,7.58E-17,7.61E-17,
#      7.64E-17,7.67E-17,7.70E-17,7.73E-17,7.76E-17,
#      7.79E-17,7.82E-17,7.85E-17,7.88E-17,7.91E-17,
#      7.94E-17,7.97E-17,8.00E-17,8.03E-17,8.06E-17,
#      8.09E-17,8.12E-17,8.15E-17,8.18E-17,8.21E-17,
#      8.24E-17,8.27E-17,8.30E-17,8.33E-17,8.36E-17,
#      8.39E-17,8.42E-17,8.45E-17,8.48E-17,8.51E-17,
#      8.54E-17,8.57E-17,8.60E-17,8.63E-17,8.66E-17,
#      8.69E-17,8.72E-17,8.75E-17,8.78E-17,8.81E-17,
#      8.84E-17,8.87E-17,8.90E-17,8.93E-17,8.96E-17,
#      8.99E-17,9.02E-17,9.05E-17,9.08E-17,9.11E-17,
#      9.14E-17,9.17E-17,9.20E-17,9.23E-17,9.26E-17,
#      9.29E-17,9.32E-17,9.35E-17,9.38E-17,9.41E-17,
#      9.44E-17,9.47E-17,9.50E-17,9.53E-17,9.56E-17,
#      9.59E-17,9.62E-17,9.65E-17,9.68E-17,9.71E-17,
#      9.74E-17,9.77E-17,9.80E-17,9.83E-17,9.86E-17,
#      9.89E-17,9.92E-17,9.95E-17,9.98E-17,1.01E-16,
#      1.04E-16,1.07E-16,1.10E-16,1.13E-16,1.16E-16,
#      1.19E-16,1.22E-16,1.25E-16,1.28E-16,1.31E-16,
#      1.34E-16,1.37E-16,1.40E-16,1.43E-16,1.46E-16,
#      1.49E-16,1.52E-16,1.55E-16,1.58E-16,1.61E-16,
#      1.64E-16,1.67E-16,1.70E-16,1.73E-16,1.76E-16,
#      1.79E-16,1.82E-16,1.85E-16,1.88E-16,1.91E-16,
#      1.94E-16,1.97E-16,2.00E-16,2.03E-16,2.06E-16,
#      2.09E-16,2.12E-16,2.15E-16,2.18E-16,2.21E-16,
#      2.24E-16,2.27E-16,2.30E-16,2.33E-16,2.36E-16,
#      2.39E-16,2.42E-16,2.45E-16,2.48E-16,2.51E-16,
#      2.54E-16,2.57E-16,2.60E-16,2.63E-16,2.66E-16,
#      2.69E-16,2.72E-16,2.75E-16,2.78E-16,2.81E-16,
#      2.84E-16,2.87E-16,2.90E-16,2.93E-16,2.96E-16,
#      2.99E-16,3.02E-16,3.05E-16,3.08E-16,3.11E-16,
#      3.14E-16,3.17E-16,3.20E-16,3.23E-16,3.26E-16,
#      3.29E-16,3.32E-16,3.35E-16,3.38E-16,3.41E-16,
#      3.44E-16,3.47E-16,3.50E-16,3.53E-16,3.56E-16,
#      3.59E-16,3.62E-16,3.65E-16,3.68E-16,3.71E-16,
#      3.74E-16,3.77E-16,3.80E-16,3.83E-16,3.86E-16,
#      3.89E-16,3.92E-16,3.95E-16,3.98E-16,4.01E-16,
#      4.04E-16,4.07E-16,4.10E-16,4.13E-16,4.16E-16,
#      4.19E-16,4.22E-16,4.25E-16,4.28E-16,4.31E-16,
#      4.34E-16,4.37E-16,4.40E-16,4.43E-16,4.46E-16,
#      4.49E-16,4.52E-16,4.55E-16,4.58E-16,4.61E-16,
#      4.64E-16,4.67E-16,4.70E-16,4.73E-16,4.76E-16,
#      4.79E-16,4.82E-16,4.85E-16,4.88E-16,4.91E-16,
#      4.94E-16,4.97E-16,5.00E-16,5.03E-16,5.06E-16,
#      5.09E-16,5.12E-16,5.15E-16,5.18E-16,5.21E-16,
#      5.24E-16,5.27E-16,5.30E-16,5.33E-16,5.36E-16,
#      5.39E-16,5.42E-16,5.45E-16,5.48E-16,5.51E-16,
#      5.54E-16,5.57E-16,5.60E-16,5.63E-16,5.66E-16,
#      5.69E-16,5.72E-16,5.75E-16,5.78E-16,5.81E-16,
#      5.84E-16,5.87E-16,5.90E-16,5.93E-16,5.96E-16,
#      5.99E-16,6.02E-16,6.05E-16,6.08E-16,6.11E-16,
#      6.14E-16,6.17E-16,6.20E-16,6.23E-16,6.26E-16,
#      6.29E-16,6.32E-16,6.35E-16,6.38E-16,6.41E-16,
#      6.44E-16,6.47E-16,6.50E-16,6.53E-16,6.56E-16,
#      6.59E-16,6.62E-16,6.65E-16,6.68E-16,6.71E-16,
#      6.74E-16,6.77E-16,6.80E-16,6.83E-16,6.86E-16,
#      6.89E-16,6.92E-16,6.95E-16,6.98E-16,7.01E-16,
#      7.04E-16,7.07E-16,7.10E-16,7.13E-16,7.16E-16,
#      7.19E-16,7.22E-16,7.25E-16,7.28E-16,7.31E-16,
#      7.34E-16,7.37E-16,7.40E-16,7.43E-16,7.46E-16,
#      7.49E-16,7.52E-16,7.55E-16,7.58E-16,7.61E-16,
#      7.64E-16,7.67E-16,7.70E-16,7.73E-16,7.76E-16,
#      7.79E-16,7.82E-16,7.85E-16,7.88E-16,7.91E-16,
#      7.94E-16,7.97E-16,8.00E-16,8.03E-16,8.06E-16,
#      8.09E-16,8.12E-16,8.15E-16,8.18E-16,8.21E-16,
#      8.24E-16,8.27E-16,8.30E-16,8.33E-16,8.36E-16,
#      8.39E-16,8.42E-16,8.45E-16,8.48E-16,8.51E-16,
#      8.54E-16,8.57E-16,8.60E-16,8.63E-16,8.66E-16,
#      8.69E-16,8.72E-16,8.75E-16,8.78E-16,8.81E-16,
#      8.84E-16,8.87E-16,8.90E-16,8.93E-16,8.96E-16,
#      8.99E-16,9.02E-16,9.05E-16,9.08E-16,9.11E-16,
#      9.14E-16,9.17E-16,9.20E-16,9.23E-16,9.26E-16,
#      9.29E-16,9.32E-16,9.35E-16,9.38E-16,9.41E-16,
#      9.44E-16,9.47E-16,9.50E-16,9.53E-16,9.56E-16,
#      9.59E-16,9.62E-16,9.65E-16,9.68E-16,9.71E-16,
#      9.74E-16,9.77E-16,9.80E-16,9.83E-16,9.86E-16,
#      9.89E-16,9.92E-16,9.95E-16,9.98E-16,1.01E-15,
#      1.04E-15,1.07E-15,1.10E-15,1.13E-15,1.16E-15,
#      1.19E-15,1.22E-15,1.25E-15,1.28E-15,1.31E-15,
#      1.34E-15,1.37E-15,1.40E-15,1.43E-15,1.46E-15,
#      1.49E-15,1.52E-15,1.55E-15,1.58E-15,1.61E-15,
#      1.64E-15,1.67E-15,1.70E-15,1.73E-15,1.76E-15,
#      1.79E-15,1.82E-15,1.85E-15,1.88E-15,1.91E-15,
#      1.94E-15,1.97E-15,2.00E-15,2.03E-15,2.06E-15,
#      2.09E-15,2.12E-15,2.15E-15,2.18E-15,2.21E-15,
#      2.24E-15,2.27E-15,2.30E-15,2.33E-15,2.36E-15,
#      2.39E-15,2.42E-15,2.45E-15,2.48E-15,2.51E-15,
#      2.54E-15,2.57E-15,2.60E-15,2.63E-15,2.66E-15,
#      2.69E-15,2.72E-15,2.75E-15,2.78E-15,2.81E-15,
#      2.84E-15,2.87E-15,2.90E-15,2.93E-15,2.96E-15,
#      2.99E-15,3.02E-15,3.05E-15,3.08E-15,3.11E-15,
#      3.14E-15,3.17E-15,3.20E-15,3.23E-15,3.26E-15,
#      3.29E-15,3.32E-15,3.35E-15,3.38E-15,3.41E-15,
#      3.44E-15,3.47E-15,3.50E-15,3.53E-15,3.56E-15,
#      3.59E-15,3.62E-15,3.65E-15,3.68E-15,3.71E-15,
#      3.74E-15,3.77E-15,3.80E-15,3.83E-15,3.86E-15,
#      3.89E-15,3.92E-15,3.95E-15,3.98E-15,4.01E-15,
#      4.04E-15,4.07E-15,4.10E-15,4.13E-15,4.16E-15,
#      4.19E-15,4.22E-15,4.25E-15,4.28E-15,4.31E-15,
#      4.34E-15,4.37E-15,4.40E-15,4.43E-15,4.46E-15,
#      4.49E-15,4.52E-15,4.55E-15,4.58E-15,4.61E-15,
#      4.64E-15,4.67E-15,4.70E-15,4.73E-15,4.76E-15,
#      4.79E-15,4.82E-15,4.85E-15,4.88E-15,4.91E-15,
#      4.94E-15,4.97E-15,5.00E-15,5.03E-15,5.06E-15,
#      5.09E-15,5.12E-15,5.15E-15,5.18E-15,5.21E-15,
#      5.24E-15,5.27E-15,5.30E-15,5.33E-15,5.36E-15,
#      5.39E-15,5.42E-15,5.45E-15,5.48E-15,5.51E-15,
#      5.54E-15,5.57E-15,5.60E-15,5.63E-15,5.66E-15,
#      5.69E-15,5.72E-15,5.75E-15,5.78E-15,5.81E-15,
#      5.84E-15,5.87E-15,5.90E-15,5.93E-15,5.96E-15,
#      5.99E-15,6.02E-15,6.05E-15,6.08E-15,6.11E-15,
#      6.14E-15,6.17E-15,6.20E-15,6.23E-15,6.26E-15,
#      6.29E-15,6.32E-15,6.35E-15,6.38E-15,6.41E-15,
#      6.44E-15,6.47E-15,6.50E-15,6.53E-15,6.56E-15,
#      6.59E-15,6.62E-15,6.65E-15,6.68E-15,6.71E-15,
#      6.74E-15,6.77E-15,6.80E-15,6.83E-15,6.86E-15,
#      6.89E-15,6.92E-15,6.95E-15,6.98E-15,7.01E-15,
#      7.04E-15,7.07E-15,7.10E-15,7.13E-15,7.16E-15,
#      7.19E-15,7.22E-15,7.25E-15,7.28E-15,7.31E-15,
#      7.34E-15,7.37E-15,7.40E-15,7.43E-15,7.46E-15,
#      7.49E-15,7.52E-15,7.55E-15,7.58E-15
```

9.84E-18, 1.03E-17, 1.09E-17, 1.14E-17, 1.19E-17,
1.24E-17, 1.29E-17, 1.34E-17, 1.39E-17, 1.44E-17,
1.49E-17, 1.54E-17, 1.59E-17, 1.64E-17, 1.69E-17,
1.73E-17, 1.78E-17, 1.83E-17, 1.88E-17, 1.93E-17,
1.97E-17, 2.02E-17, 2.07E-17, 2.12E-17, 2.16E-17,
2.21E-17, 2.66E-17, 3.09E-17, 3.51E-17, 3.90E-17,
4.29E-17/

DATA SV3/6.27E-21,1.86E-20,4.44E-20,9.11E-20,1.57E-19,
2.83E-19,4.47E-19,6.72E-19,9.67E-19,1.34E-18,
1.81E-18,2.38E-18,3.06E-18,3.86E-18,4.79E-18,
5.86E-18,7.07E-18,8.43E-18,9.95E-18,1.16E-17,
1.35E-17,1.55E-17,1.77E-17,2.00E-17,2.26E-17,
2.53E-17,2.81E-17,3.12E-17,3.44E-17,3.78E-17,
4.14E-17,4.52E-17,4.91E-17,5.31E-17,5.74E-17,
6.17E-17,6.63E-17,7.09E-17,7.57E-17,8.07E-17,
8.57E-17,9.09E-17,9.62E-17,1.02E-16,1.07E-16,
1.13E-16,1.74E-16,2.39E-16,3.06E-16,3.70E-16,
4.31E-16,4.88E-16,5.39E-16,5.86E-16,6.28E-16,
6.65E-16,6.98E-16,7.27E-16,7.52E-16,7.74E-16,
7.93E-16,8.09E-16,8.23E-16,8.35E-16,8.45E-16,
8.54E-16,8.61E-16,8.66E-16,8.70E-16,8.74E-16,
8.76E-16,8.77E-16,8.78E-16,8.78E-16,8.77E-16,
8.76E-16,8.77E-16,8.72E-16,8.70E-16,8.67E-16,
8.64E-16,8.61E-16,8.57E-16,8.54E-16,8.50E-16,
8.46E-16,8.42E-16,8.37E-16,8.33E-16,8.29E-16,
8.24E-16,7.77E-16,7.31E-16,6.89E-16,6.50E-16,
6.16E-16/

```
DATA SV4/3.28E-23,1.02E-22,2.52E-22,5.29E-22,9.84E-22,  
# 1.68E-21,2.66E-21,4.00E-21,5.75E-21,7.96E-21,  
# 1.07E-20,1.40E-20,1.79E-20,2.24E-20,2.76E-20,  
# 3.35E-20,4.01E-20,4.75E-20,5.56E-20,6.45E-20,  
# 7.42E-20,8.47E-20,9.60E-20,1.08E-19,1.21E-19,  
# 1.35E-19,1.49E-19,1.64E-19,1.80E-19,1.97E-19,  
# 2.14E-19,2.32E-19,2.51E-19,2.71E-19,2.91E-19,  
# 3.12E-19,3.34E-19,3.56E-19,3.79E-19,4.03E-19,  
# 4.27E-19,4.52E-19,4.77E-19,5.03E-19,5.30E-19,  
# 5.57E-19,5.84E-19,6.19E-19,6.56E-18,6.96E-18,  
# 7.37E-18,7.80E-18,8.24E-18,8.68E-18,9.13E-18,  
# 9.59E-18,1.00E-17,1.04E-17,1.09E-17,1.13E-17,  
# 1.17E-17,1.22E-17,1.26E-17,1.30E-17,1.34E-17,  
# 1.39E-17,1.43E-17,1.47E-17,1.51E-17,1.55E-17,  
# 1.59E-17,1.63E-17,1.67E-17,1.71E-17,1.75E-17,  
# 1.79E-17,1.83E-17,1.87E-17,1.91E-17,1.95E-17,  
# 2.32E-17,2.66E-17,2.97E-17,3.25E-17,  
# 3.48E-17/
```

[illegible]

```

#      0.00E-00,0.00E-00,0.00E-00,0.00E-00,0.00E-00,
#      1.16E-20,6.17E-20,1.12E-19,1.62E-19,2.12E-19,
#      2.62E-19,4.37E-19,6.11E-19,7.85E-19,9.60E-19,
#      1.13E-18,1.47E-18,1.80E-18,2.14E-18,2.47E-18,
#      2.81E-18,3.30E-18,3.80E-18,4.29E-18,4.79E-18,
#      5.29E-18,5.93E-18,6.58E-18,7.22E-18,7.87E-18,
#      8.52E-18,9.29E-18,1.01E-17,1.09E-17,1.16E-17,
#      1.24E-17,1.33E-17,1.42E-17,1.51E-17,1.60E-17,
#      1.69E-17,1.78E-17,1.88E-17,1.98E-17,2.08E-17,
#      2.18E-17,2.29E-17,2.39E-17,2.50E-17,2.61E-17,
#      2.71E-17,4.01E-17,5.30E-17,6.59E-17,7.88E-17,
#      9.18E-17/
DATA SV6/3.10E-26,1.80E-25,7.28E-25,2.31E-24,6.11E-24,
#      1.41E-23,2.94E-23,5.63E-23,1.01E-22,1.70E-22,
#      2.73E-22,4.22E-22,6.29E-22,9.09E-22,1.28E-21,
#      1.75E-21,2.36E-21,3.11E-21,4.03E-21,5.14E-21,
#      6.46E-21,8.03E-21,9.87E-21,1.20E-20,1.45E-20,
#      1.73E-20,2.05E-20,2.41E-20,2.81E-20,3.26E-20,
#      3.76E-20,4.32E-20,4.93E-20,5.61E-20,6.35E-20,
#      7.15E-20,8.03E-20,8.98E-20,1.00E-19,1.11E-19,
#      1.23E-19,1.36E-19,1.50E-19,1.65E-19,1.81E-19,
#      1.97E-19,4.33E-19,8.17E-19,1.39E-18,2.19E-18,
#      3.26E-18,4.61E-18,6.28E-18,8.27E-18,1.06E-17,
#      1.32E-17,1.62E-17,1.95E-17,2.30E-17,2.68E-17,
#      3.09E-17,3.52E-17,3.96E-17,4.42E-17,4.89E-17,
#      5.37E-17,5.87E-17,6.36E-17,6.87E-17,7.37E-17,
#      7.88E-17,8.38E-17,8.88E-17,9.38E-17,9.87E-17,
#      1.04E-16,1.08E-16,1.13E-16,1.18E-16,1.22E-16,
#      1.27E-16,1.31E-16,1.36E-16,1.40E-16,1.44E-16,
#      1.48E-16,1.52E-16,1.56E-16,1.60E-16,1.63E-16,
#      1.67E-16,1.97E-16,2.19E-16,2.34E-16,2.45E-16,
#      2.52E-16/
SVFUSE=0.
T=TI/1000.
IF(T.LT.1. .AND. IRATE.EQ.3) GO TO 20
IF(T.LT.1. .OR. T.GT. 200.) RETURN
DTX=.2
IPT=-4
IF(T.LT.10.) GOTO 10
DTX=2.
IPT=41
IF(T.LT.100.) GOTO 10
DTX=20.
IPT=86
10 IX=IFIX(T/DTX)+IPT
TX=DTX*(IX-IPT)
SVFUSE=SV(IX,IRATE)+(SV(IX+1,IRATE)-SV(IX,IRATE))*(T-TX)/DTX
RETURN
20 TL=ALOG10(TI)
SVL=(-1.110333*TL+12.26350)*TL-49.01817)*TL+86.86500
IF(SVL.LT.37.) SVFUSE=10.**(-SVL)
C THIS FIT IS GOOD TO SVL=50. BUT DEC MACHINES CAN'T HANDLE 1.E-50
RETURN
END

```


Appendix E Sample Cases

Following are two test runs. The first example is obtained with the impurity density, NZ, flagged as unknown. In the second example NZ is flagged as a preferred value. A comparison of the two shows that NZ stayed closer to its initial value when marked preferred.

The file ETFOD.OUT contains the input data from ETFOD.DAT followed by three parameters fixed in the code. The initial residuals of the physics equations are listed next. Following those is the trace of the iterative process in E04FAF as output by MONIT. Upon exit from E04FAF, a statement is written in this file indicating whether a solution has or has not been found. Following this are some plasma parameters, the final residuals of all the equations, the accuracy of the physics equations, the normalized solution vector, and the final values of the input variables.

In these examples some of the intermediate printout from MONIT has been left out due to the length of the listing.

The file SPECS.ETF contains the final design specifications.

File ETFOD.OUT (Example 1)

1	0.1200E+02	F	TI	(KEV)
2	0.1200E+02	F	TE	(KEV)
3	0.1500E+01	P	ZEFF	
4	0.1700E+21	P	NI	(M ⁰⁰ -3)
5	0.1700E+21	P	NE	(M ⁰⁰ -3)
6	0.5400E+19	U	NZ	(M ⁰⁰ -3)
7	0.3800E+01	F	Q	(SAFETY FACTOR)
8	0.7000E-01	F	BETA	
9	0.5010E+01	F	BT	(TESLA)
10	0.1500E+01	U	TAUE	(SEC)
11	0.9200E+07	U	PALFV	(W/M ⁰⁰ 3)
12	0.1042E+11	U	PFUS	(W)
13	0.3300E+08	P	WPA	(W/M ⁰⁰ 2)
14	0.1340E+01	F	A	(H)
15	0.4179E+01	F	AR	
16	0.1600E+01	F	SIGMA	
17	0.0000E+00	F	PINJ	(W)
18	0.1000E-23	P	PRF	(W)
19	0.1000E+01	P	CI	
20	0.1000E+01	P	CE	
21	0.5000E+07	U	IP	(AMPS)

WHERE: F=FIXED VALUE
P=PREFERRED VALUE
U=UNKNOWN VALUE

XTOL = 1.000000E-01 FTOL = 1.000000E-06
STEPMX = 5.000000E-01

SUM OF SQUARES = 0.0000

RESIDUALS:

2.541E+00 1.533E+00 5.023E-01 9.278E+00 9.234E+00 2.213E+00 7.173E+00 -4.099E+00 3.672E+00 -5.260E-01
0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
0.000E+00 0.000E+00

SUM OF SQUARES = .5003E+03 AFTER 0 ITERATIONS

SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:

1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00
1.000E+00 1.000E+00

T1	=	0.120E+02	F
TE	=	0.120E+02	F
ZEFF	=	0.150E+01	
N1	=	0.170E+21	
NE	=	0.170E+21	
NZ	=	0.540E+19	
Q	=	0.380E+01	F
BETA	=	0.700E-01	F
BT	=	0.501E+01	F
TAUE	=	0.150E+01	
PALFV	=	0.920E+07	
PFUS	=	0.104E+11	
WPA	=	0.330E+08	
A	=	0.134E+01	F
AR	=	0.418E+01	F
SIGMA	=	0.160E+01	F
PINJ	=	0.000E+00	F
PRF	=	0.100E-23	
CI	=	0.100E+01	
CG	=	0.100E+01	
IP	=	0.500E+07	

SUM OF SQUARES = .24465+03 AFTER 0 ITERATIONS
 SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:

1.500E+00	1.000E+00	1.500E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
1.000E+00	1.000E+00								

T1	=	0.120E+02	F
TE	=	0.120E+02	F
ZEFF	=	0.225E+01	
N1	=	0.170E+21	
NE	=	0.255E+21	
NZ	=	0.540E+19	
Q	=	0.380E+01	F
BETA	=	0.700E-01	F
BT	=	0.501E+01	F
TAUE	=	0.150E+01	
PALFV	=	0.920E+07	

PFUS = 0.156E+11
WPA = 0.330E+08
A = 0.134E+01 F
AR = 0.418E+01 F
SIGMA = 0.160E+01 F
PINJ = 0.000E+00 F
PRF = 0.100E-23
CI = 0.100E+01
CE = 0.100E+01
IP = 0.750E+07

SUM OF SQUARES = .1003E+03 AFTER 1 ITERATIONS
SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:

1.461E+00 9.884E-01 1.375E+00 8.982E-01 1.036E+00 6.682E-01 1.000E+00 6.655E-01 9.996E-01 7.174E-01
9.556E-01 1.019E+00

THE VALUE OF AN X WAS CONSTRAINED BY STEPMX

TI = 0.120E+02 F
TE = 0.120E+02 F
ZEFF = 0.219E+01
NI = 0.164E+21
NE = 0.234E+21
NZ = 0.485E+19
Q = 0.380E+01 F
BETA = 0.700E-01 F
BT = 0.501E+01 F
TAUE = 0.135E+01
PALPV = 0.615E+07
PFUS = 0.104E+11
WPA = 0.220E+08
A = 0.134E+01 F
AR = 0.418E+01 F
SIGMA = 0.160E+01 F
PINJ = 0.000E+00 F
PRF = 0.100E-23
CI = 0.717E+00
CE = 0.956E+00
IP = 0.509E+07

SUM OF SQUARES = .1950E+02 AFTER 2 ITERATIONS
 SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)
 CURRENT SOLUTION:
 1.396E+00 9.823E-01 1.245E+00 7.564E-01 1.027E+00 3.364E-01 5.000E-01 3.309E-01 9.833E-01 6.733E-01
 8.291E-01 1.038E+00

THE VALUE OF AN X WAS CONSTRAINED BY STEPMX

TI	=	0.120E+02	F
TE	=	0.120E+02	F
ZEFF	=	0.209E+01	
NI	=	0.167E+21	
NE	=	0.212E+21	
NZ	=	0.408E+19	
Q	=	0.380E+01	F
BETA	=	0.700E-01	F
BT	=	0.501E+01	F
TAUE	=	0.154E+01	
PALFY	=	0.310E+07	
PFUS	=	0.521E+10	
WPA	=	0.109E+08	
A	=	0.134E+01	F
AR	=	0.418E+01	F
SIGMA	=	0.160E+01	F
PINJ	=	0.000E+00	F
PRF	=	0.983E-24	
CI	=	0.673E+00	
CE	=	0.829E+00	
IP	=	0.519E+07	

SUM OF SQUARES = .7881E-02 AFTER 3 ITERATIONS
 SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)
 CURRENT SOLUTION:
 1.268E+00 9.880E-01 1.133E+00 5.709E-01 1.006E+00 7.501E-02 1.058E-01 6.695E-02 9.302E-01 5.103E-01
 7.823E-01 1.053E+00

TI	=	0.120E+02	F
TE	=	0.120E+02	F

ZEFF	=	0.190E+01
NI	=	0.168E+21
NE	=	0.193E+21
NZ	=	0.308E+19
Q	=	0.380E+01
BETA	=	0.700E-01
BT	=	0.501E+01
TAUE	=	0.151E+01
PALFV	=	0.690E+06
PFUS	=	0.110E+10
WPA	=	0.221E+07
A	=	0.134E+01
AR	=	0.418E+01
SIGNA	=	0.160E+01
PINJ	=	0.000E+00
PRF	=	0.930E-24
CI	=	0.510E+00
CE	=	0.762E+00
IP	=	0.526E+07

SUM OF SQUARES = .6987E-01 AFTER 4 ITERATIONS
 SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:

1.170E+00	9.99E-01	1.124E+00	4.907E-01	1.007E+00	7.636E-02	1.077E-01	6.815E-02	1.028E+00	9.683E-01
7.812E-01	1.053E+00								

TI	=	0.120E+02
TE	=	0.120E+02
ZEFF	=	0.175E+01
NI	=	0.170E+21
NE	=	0.191E+21
NZ	=	0.265E+19
Q	=	0.380E+01
BETA	=	0.700E-01
BT	=	0.501E+01
TAUE	=	0.151E+01
PALFV	=	0.702E+06
PFUS	=	0.112E+10
WPA	=	0.225E+07
A	=	0.134E+01

AR = 0.418E+01 F
 SIGMA = 0.160E+01 F
 PINJ = 0.000E+00 F
 PRF = 0.103E-23
 CI = 0.968E+00
 CE = 0.781E+00
 IP = 0.526E+07

SUM OF SQUARES = .1224E-01 AFTER 5 ITERATIONS

SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:

1 179E+00 9.994E-01 1.124E+00 4.911E-01 9.883E-01 7.662E-02 1.080E-01 6.839E-02 8.864E-01 6.675E-01
 7.146E-01 1.053E+00

TI = 0.120E+02 F
 TE = 0.120E+02 F
 ZEFF = 0.177E+01
 NI = 0.170E+21
 NE = 0.191E+21
 NZ = 0.265E+19
 Q = 0.380E+01 F
 BETA = 0.700E-01 F
 BT = 0.501E+01 F
 TAUS = 0.148E+01
 PALPV = 0.705E+06
 PFUS = 0.113E+10
 WPA = 0.226E+07
 A = 0.134E+01 F
 AR = 0.418E+01 F
 SIGMA = 0.160E+01 F
 PINJ = 0.000E+00 F
 PRF = 0.886E-24
 CI = 0.667E+00
 CE = 0.715E+00
 IP = 0.526E+07

SUM OF SQUARES = .1076E+02 AFTER 6 ITERATIONS

SING = T (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:

1.197E+00 1.145E+00 1.091E+00 4.964E-01 1.164E+00 8.944E-02 2.576E-01 2.159E-01 9.445E-01 6.090E-01
 9.270E-01 1.182E+00

TI	=	0.120E+02	F
TE	=	0.120E+02	F
ZEFF	=	0.180E+01	
NI	=	0.195E+21	
NE	=	0.166E+21	
NZ	=	0.268E+19	
Q	=	0.380E+01	F
BETA	=	0.700E-01	F
BT	=	0.501E+01	F
TAUE	=	0.175E+01	
PALFY	=	0.823E+06	
PFUS	=	0.268E+10	
WPA	=	0.712E+07	
A	=	0.134E+01	F
AR	=	0.418E+01	F
SIGNA	=	0.160E+01	F
PINJ	=	0.000E+00	F
PRF	=	0.944E-24	
CI	=	0.609E+00	
CE	=	0.927E+00	
IP	=	0.591E+07	

SUM OF SQUARES = .2514E-02 AFTER 19 ITERATIONS
 SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:
 1.120E+00 1.008E+00 1.117E+00 4.285E-01 9.771E-01 7.784E-02 1.097E-01 6.958E-02 9.093E-01 5.753E-01
 7.286E-01 1.052E+00

TI	=	0.120E+02	F
TE	=	0.120E+02	F
ZEFF	=	0.168E+01	
NI	=	0.171E+21	

NE	=	0.190E+21
NZ	=	0.231E+19
Q	=	0.380E+01
BETA	=	0.700E-01
BT	=	0.501E+01
TAUE	=	0.147E+01
PALFY	=	0.716E+06
PFUS	=	0.114E+10
WPA	=	0.230E+07
A	=	0.134E+01
AR	=	0.418E+01
SIGMA	=	0.160E+01
PINJ	=	0.000E+00
PRF	=	0.909E-24
CI	=	0.575E+00
CE	=	0.729E+00
IP	=	0.526E+07

SUM OF SQUARES = -2134E-02 AFTER 20 ITERATIONS
 SINGO = F (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:

1.117E+00 1.009E+00 1.117E+00 4.239E-01 9.755E-01 7.792E-02 1.098E-01 6.973E-02 9.071E-01 5.960E-01
 7.237E-01 1.052E+00

TI	=	0.120E+02
TE	=	0.120E+02
ZEFF	=	0.168E+01
NI	=	0.172E+21
NE	=	0.190E+21
NZ	=	0.229E+19
Q	=	0.380E+01
BETA	=	0.700E-01
BT	=	0.501E+01
TAUE	=	0.146E+01
PALFY	=	0.717E+06
PFUS	=	0.114E+10
WPA	=	0.230E+07
A	=	0.134E+01
AR	=	0.418E+01
SIGMA	=	0.160E+01

PINJ = 0.000E+00 F
 PRF = 0.907E-24
 CI = 0.596E+00
 CE = 0.724E+00
 IP = 0.526E+07

SUM OF SQUARES = .2105E-02 AFTER 21 ITERATIONS

SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:

1.123E+00 1.008E+00 1.117E+00 4.306E-01 9.769E-01 7.779E-02 1.097E-01 6.947E-02 9.106E-01 5.731E-01
 7.270E-01 1.052E+00

TI = 0.120E+02 F
 TE = 0.120E+02 F
 ZEFF = 0.169E+01
 NI = 0.171E+21
 NE = 0.190E+21
 NZ = 0.233E+19
 Q = 0.380E+01 F
 BETA = 0.700E-01 F
 BT = 0.501E+01 F
 TAUE = 0.147E+01
 PALFY = 0.716E+06
 PFUS = 0.114E+10
 WPA = 0.229E+07
 A = 0.134E+01 F
 AR = 0.418E+01 F
 SIGMA = 0.160E+01 F
 PINJ = 0.000E+00 F
 PRF = 0.911E-24
 CI = 0.573E+00
 CE = 0.727E+00
 IP = 0.526E+07

A SOLUTION HAS BEEN FOUND.

TOTAL ALPHA POWER	0.227280E+03	MAJOR RADIUS	0.559986E+01
INTERNAL INDUCTANCE	0.527759E-05	EXTERNAL INDUCTANCE	0.896846E-05
INDUCTIVE VOLT-SECONDS	0.599751E-04	PLASMA RESISTANCE	0.880346E-08
PLASMA VOLTAGE	0.463276E-01	DEUTERIUM BURN-UP RATE	0.405351E+21
DEUTERIUM DIFFUSION LOSS RATE	0.185700E+23	FRACTION OF FUEL BURNED	0.213620E-01

SUM OF SQUARES = .2105E-02 FTOL =-1.0 IFAIL = 0

RESIDUALS:

1.2410E-03 6.6227E-03 5.6278E-04 6.9217E-05-6.4212E-04 1.4226E-03 1.3775E-03-3.0541E-04 7.3326E-04-1.1500E-03
4.9355E-03 3.2210E-04 4.6944E-03-5.6937E-03-2.3134E-04-9.2221E-03-8.9035E-03-3.7221E-02-3.5760E-03-1.7076E-02
-1.0921E-02 5.2487E-04

THIS SOLUTION DOES SATISFY PHYSICS EQUATIONS WITHIN 1.0%

EQUATION 1 IS BALANCED WITHIN 0.01%
EQUATION 2 IS BALANCED WITHIN 0.07%
EQUATION 3 IS BALANCED WITHIN 0.01%
EQUATION 4 IS BALANCED WITHIN 0.00%
EQUATION 5 IS BALANCED WITHIN -0.01%
EQUATION 6 IS BALANCED WITHIN 0.01%
EQUATION 7 IS BALANCED WITHIN 0.01%
EQUATION 8 IS BALANCED WITHIN -0.00%
EQUATION 9 IS BALANCED WITHIN 0.01%
EQUATION 10 IS BALANCED WITHIN -0.01%

NORMALIZED X:

1.1234E+00 1.0081E+00 1.1174E+00 4.3063E-01 9.7687E-01 7.7793E-02 1.0965E-01 6.9467E-02 9.1060E-01 5.7310E-01
7.2698E-01 1.0525E+00

TI = 0.120E+02 F
TE = 0.120E+02 F
ZEFF = 0.169E+01
NI = 0.171E+21
NE = 0.190E+21
NZ = 0.233E+19
Q = 0.380E+01 F
BETA = 0.700E-01 F
BT = 0.501E+01 F
TAUE = 0.147E+01
PALFV = 0.716E+06
PFUS = 0.114E+10
WPA = 0.229E+07
A = 0.134E+01 F
AR = 0.418E+01 F
SIGMA = 0.160E+01 F

PINJ =	0.000E+00	F
PRF =	0.911E-24	
CI =	0.573E+00	
CE =	0.727E+00	
IP =	0.526E+01	
ETAALF	0.240000E+00	
PCOULV	0.000000E+00	
ETA1NJ	0.803399E+00	
POHVV	0.102178E+04	
PRADV	0.101871E+06	
SIGNAV	0.174000E-21	
ETARF	0.100000E+01	
TAUTP	0.215876E+21	
TAUSMP	0.170538E+01	
TAURT	0.763769E+02	
TAUNC	0.541728E+01	

File SPECS.ETF (Example 1)

PLASMA RADIUS (M)	=	1.340	Q	=	3.800
ASPECT RATIO	=	4.179	IMPURITY Z	=	8.000
ELONGATION	=	1.600	ZEFF	=	1.685
BETA	=	0.070	GAMMA (RES LOSS)	=	0.100
FIELD ON AXIS(T)	=	5.010	PLASMA INT IND (LI)	=	1.500
ION TEMP (KEV)	=	12.000	SCRAPE OFF LAYER (M)	=	0.250
ELE TEMP (KEV)	=	12.000	IP FACTOR	=	0.800
RIPPLE (%)	=	1.550	BURN PRESS (TORR)	=	.1000E-05
			QUENCH PRESS (TORR)	=	.1000E-03

MAJOR RADIUS (M)	=	5.600	PLASMA-CRNT-HB (MA)	=	5.262
PLASMA HEIGHT (M)	=	2.144	PLASMA-CRNT-LB (MA)	=	4.210
PLASMA VOLUM (M**3)	=	317.567	PLASMA VOLT-BURN (V)	=	0.046
PLASMA IND (H)	=	.1425E-04	PLASMA RES-BURN (OHM)	=	.8803E-08
ION DENSITY (/M**3)	=	.1714E+21			
ELE DENSITY (/M**3)	=	.1900E+21			

IMPURITY CONCENT.	=	0.012
IMPURITY Z	=	8.000
ZEFF	=	1.685

NTAU (SEC/M**3)	=	.2783E+21
TAUE (SEC)	=	1.465
TAUE-EMP (SEC)	=	1.705
TAUE-TP (SEC)	=	*****
TAUP (SEC)	=	1.465

BEAM POWER (MW)	=	0.000
BEAM ENERGY (KEV)	=	150.000

PLASMA EDGE NEU. LOAD (MW/M**2)	=	2.29
FUSION POWER (MW)	=	1142.58
ALPHA (MW)	=	227.28
RADIATION (MW)	=	32.35
ELEC. POWER (MW)	=	399.90

File ETFOD.OUT (Example 2)

1	0.1200E+02	F	TI	(KEV)
2	0.1200E+02	F	TE	(KEV)
3	0.1500E+01	P	ZEFF	
4	0.1700E+21	P	NI	(M ² -3)
5	0.1700E+21	P	NE	(M ² -3)
6	0.5400E+19	P	NZ	(M ² -3)
7	0.3800E+01	F	Q	(SAFETY FACTOR)
8	0.7000E-01	F	BETA	
9	0.5010E+01	F	BT	(TESLA)
10	0.1500E+01	U	TAUE	(SEC)
11	0.9200E+07	U	PALFV	(W/M ² -3)
12	0.1042E+11	U	PFUS	(W)
13	0.3300E+08	P	WPA	(W/M ² -2)
14	0.1340E+01	F	A	(M)
15	0.4179E+01	F	AR	
16	0.1670E+01	F	SIGMA	
17	0.0000E+00	F	PINJ	(W)
18	0.1000E-23	P	PRF	(W)
19	0.1000E+01	P	CI	
20	0.1000E+01	P	CE	
21	0.5000E+07	U	IP	(AMPS)

WHERE: F=FIXED VALUE
P=PREFERRED VALUE
U=UNKNOWN VALUE

XTOL = 1.000000E-01 FTOL = 1.000000E-06
STEPMX = 5.000000E-01

SUM OF SQUARES = 0.0000

RESIDUALS:

2.541E+00 1.533E+01 5.023E-01 9.278E+00 9.234E+00 2.293E+00 7.173E+00-4.099E+00 3.672E+00-5.260E-01
0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
0.000E+00 0.000E+00

SUM OF SQUARES = 5003E+03 AFTER 0 ITERATIONS

SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:

1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00
1.000E+00 1.000E+00

TI	=	0.120E+02	F
TE	=	0.120E+02	F
ZEFF	=	0.150E+01	
NI	=	0.170E+21	
NE	=	0.170E+21	
NZ	=	0.540E+19	
Q	=	0.380E+01	F
BETA	=	0.700E-01	F
BT	=	0.501E+01	F
TAUE	=	0.150E+01	
PALFV	=	0.920E+07	
PFUS	=	0.104E+11	
WPA	=	0.330E+08	
A	=	0.134E+01	F
AR	=	0.418E+01	F
SIGMA	=	0.160E+01	F
PINJ	=	0.000E+00	F
PRF	=	0.100E-23	
CI	=	0.100E+01	
CE	=	0.100E+01	
IP	=	0.500E+07	

SUM OF SQUARES = .2446E+03 AFTER 0 ITERATIONS

SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:

1.500E+00	1.000E+00	1.500E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
1.000E+00	1.000E+00								

TI	=	0.120E+02	F
TE	=	0.120E+02	F
ZEFF	=	0.225E+01	
NI	=	0.170E+21	
NE	=	0.255E+21	
NZ	=	0.540E+19	
Q	=	0.380E+01	F
BETA	=	0.700E-01	F
BT	=	0.501E+01	F
TAUE	=	0.150E+01	
PALFV	=	0.920E+07	

PFUS = 0.156E+11
 WPA = 0.330E+08
 A = 0.134E+01 F
 AR = 0.418E+01 F
 SIGMA = 0.160E+01 F
 PINJ = 0.000E+00 F
 PRF = 0.100E-23
 CI = 0.100E+01
 CE = 0.100E+01
 IP = 0.750E+07

SUM OF SQUARES = .1011E+03 AFTER : ITERATIONS

SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:

1.486E+00 9.851E-01 1.378E+00 9.212E-01 1.046E+00 6.611E-01 1.000E+00 6.655E-01 1.000E+00 7.237E-01
 9.862E-01 1.019E+00

THE VALUE OF AN X WAS CONSTRAINED BY STEPMX

TI = 0.120E+02 F
 TE = 0.120E+02 F
 ZEFF = 0.223E+01
 NI = 0.167E+21
 NE = 0.234E+21
 NZ = 0.497E+19
 Q = 0.380E+01 F
 BETA = 0.700E-01 F
 BT = 0.501E+01 F
 TAUE = 0.157E+01
 PALFY = 0.615E+07
 PFUS = 0.104E+11
 WPA = 0.220E+08
 A = 0.134E+01 F
 AR = 0.418E+01 F
 SIGMA = 0.160E+01 F
 PINJ = 0.000E+00 F
 PRF = 0.100E-23
 CI = 0.724E+00
 CE = 0.186E+00
 IP = 0.109E+07

SUM OF SQUARES = .1984E+02 AFTER 2 ITERATIONS
 SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)
 CURRENT SOLUTION:
 1.457E+00 9.729E-01 1.253E+00 8.231E-01 1.050E+00 3.363E-01 5.000E-01 3.310E-01 9.835E-01 6.731E-01
 8.976E-01 1.038E+00

THE VALUE OF AN X WAS CONSTRAINED BY STEPMX

TI	=	0.120E+02	F
TE	=	0.120E+02	F
ZEFF	=	0.219E+01	
NI	=	0.165E+21	
NE	=	0.213E+21	
NZ	=	0.444E+19	
Q	=	0.380E+01	F
BETA	=	0.700E-01	F
BT	=	0.501E+01	F
TAUR	=	0.158E+01	
PALPV	=	0.309E+07	
PFUS	=	0.521E+10	
WPA	=	0.109E+08	
A	=	0.134E+01	F
AR	=	0.418E+01	F
SIGMA	=	0.160E+01	F
PINJ	=	0.000E+00	F
PRF	=	0.984E-24	
CI	=	0.673E+00	
CE	=	0.898E+00	
IP	=	0.519E+07	

SUM OF SQUARES = .3025E-02 AFTER 3 ITERATIONS
 SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)
 CURRENT SOLUTION:
 1.409E+00 9.669E-01 1.149E+00 7.183E-01 1.057E+00 7.155E-02 1.009E-01 6.386E-02 9.554E-01 5.282E-01
 8.740E-01 1.053E+00

TI	=	0.120E+02	F
TE	=	0.120E+02	F

ZEFF	=	0.211E+01
NI	=	0.164E+21
NE	=	0.195E+21
NZ	=	0.388E+19
Q	=	0.380E+01 F
BETA	=	0.700E-01 F
BT	=	0.501E+01 F
TAUE	=	0.159E+01
PALFV	=	0.658E+06
PFUS	=	0.105E+10
WPA	=	0.211E+07
A	=	0.138E+01 F
AR	=	0.418E+01 F
SIGNA	=	0.160E+01 F
PIRJ	=	0.000E+00 F
PRF	=	0.955E-24
CI	=	0.528E+00
CE	=	0.874E+00
IP	=	0.526E+07

SUM OF SQUARES = .1104E-01 AFTER 4 ITERATIONS
 STOP = F (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:

1.34E+00	9.69E-01	1.147E+00	6.976E-01	1.069E+00	7.183E-02	1.013E-01	6.412E-02	1.062E+00	8.517E-01
8.928E-01	1.053E+00								

TI	=	0.120E+02 F
TE	=	0.120E+02 F
ZEFF	=	0.208E+01
NI	=	0.165E+21
NE	=	0.195E+21
NZ	=	0.377E+19
Q	=	0.380E+01 F
BETA	=	0.700E-01 F
BT	=	0.501E+01 F
TAUE	=	0.160E+01
PALFV	=	0.661E+06
PFUS	=	0.106E+10
WPA	=	0.212E+07
A	=	0.138E+01 F

AR = 0.418E+01 F
 SIGMA = 0.160E+01 F
 PINJ = 0.000E+00 F
 PRF = 0.106E-23
 CI = 0.852E+00
 CE = 0.893E+00
 IP = 0.526E+07

SUM OF SQUARES = .1167E-01 AFTER 5 ITERATIONS
 SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:

1.358E+00 9.734E-01 1.144E+00 6.728E-01 1.041E+00 7.278E-02 1.026E-01 6.496E-02 8.662E-01 6.488E-01
 8.170E-01 1.053E+00

TI = 0.120E+02 F
 TE = 0.120E+02 F
 ZEFT = 0.204E+01
 NI = 0.165E+21
 NE = 0.195E+21
 NZ = 0.363E+19
 Q = 0.380E+01 F
 BETA = 0.700E-01 F
 BT = 0.501E+01 F
 TAUE = 0.156E+01
 PALFV = 0.670E+06
 PFUS = 0.107E+10
 WPA = 0.214E+07
 A = 0.134E+01 F
 AR = 0.418E+01 F
 SIGMA = 0.160E+01 F
 PINJ = 0.000E+00 F
 PRF = 0.866E-24
 CI = 0.649E+00
 CE = 0.817E+00
 IP = 0.526E+07

SUM OF SQUARES = .2378E+02 AFTER 6 ITERATIONS
 SING = T (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:

1.306E+00 1.195E+00 1.093E+00 6.102E-01 1.285E+00 9.250E-02 3.212E-01 2.800E-01 9.760E-01 6.712E-01
 1.084E+00 1.240E+00

TI = 0.120E+02 F
 TE = 0.120E+02 F
 ZEFF = 0.196E+01
 NI = 0.203E+21
 NE = 0.186E+21
 NZ = 0.329E+19
 Q = 0.380E+01 F
 BETA = 0.700E-01 F
 BT = 0.501E-01 F
 TAUE = 0.193E+01
 PALPV = 0.851E+06
 PFUS = 0.335E+10
 WPA = 0.924E+07
 A = 0.134E+01 F
 AR = 0.418E+01 F
 SIGMA = 0.160E+01 F
 PINJ = 0.000E+00 F
 PRF = 0.976E-24
 CI = 0.671E+00
 CE = 0.108E+01
 IP = 0.620E+07

;
 ;
 ;

SUM OF SQUARES = .5602E-02 AFTER 25 ITERATIONS
 SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:

1.388E+00 9.700E-01 1.147E+00 6.965E-01 1.057E+00 7.138E-02 1.005E-01 6.369E-02 1.001E+00 8.499E-01
 8.626E-01 1.053E+00

TI = 0.120E+02 F
 TE = 0.120E+02 F
 ZEFF = 0.208E+01
 NI = 0.165E+21

NE	=	0.195E+21	
NZ	=	0.376E+19	
Q	=	0.380E+01	F
BETA	=	0.700E-01	F
BT	=	0.501E+01	F
TAUE	=	0.159E+01	
PALFV	=	0.657E+06	
PFUS	=	0.105E+10	
WPA	=	0.210E+07	
A	=	0.134E+01	F
AR	=	0.418E+01	F
SIGMA	=	0.160E+01	F
PINJ	=	0.000E+00	F
PRF	=	0.100E-23	
CI	=	0.850E+00	
CE	=	0.863E+00	
IP	=	0.526E+07	

SUM OF SQUARES = .4619E-02 AFTER 26 ITERATIONS

SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:

1.379E+00 9.711E-01 1.146E+00 6.888E-01 1.052E+00 7.217E-02 1.019E-01 6.453E-02 9.740E-01 7.868E-01
8.596E-01 1.053E+00

TI	=	0.120E+02	F
TE	=	0.120E+02	F
ZEFF	=	0.207E+01	
NI	=	0.165E+21	
NE	=	0.195E+21	
NZ	=	0.372E+19	
Q	=	0.380E+01	F
BETA	=	0.700E-01	F
BT	=	0.501E+01	F
TAUE	=	0.158E+01	
PALFV	=	0.664E+06	
PFUS	=	0.106E+10	
WPA	=	0.213E+07	
A	=	0.134E+01	F
AR	=	0.418E+01	F
SIGMA	=	0.160E+01	F

PINJ = 0.000E+00 F
 PRF = 0.974E-24
 CI = 0.787E+00
 CE = 0.860E+00
 IP = 0.527E+07

SUM OF SQUARES = .2525E-02 AFTER 27 ITERATIONS
 SING = F (IF TRUE, RANDOM POINT HAS BEEN USED)

CURRENT SOLUTION:

1.389E+00 9.694E-01 1.148E+00 6.993E-01 1.056E+00 7.198E-02 1.014E-01 6.410E-02 9.550E-01 6.162E-01
 8.667E-01 1.052E+00

TI = 0.120E+02 F
 TE = 0.120E+02 F
 ZEFF = 0.208E+01
 NI = 0.165E+21
 NE = 0.195E+21
 NZ = 0.378E+19
 Q = 0.380E+01 F
 BETA = 0.700E-01 F
 BT = 0.501E+01 F
 TAU = 0.158E+01
 PALFV = 0.662E+06
 PFUS = 0.106E+10
 WPA = 0.712E+07
 A = 0.134E+01 F
 AR = 0.418E+01 F
 SIGMA = 0.160E+01 F
 PINJ = 0.000E+00 F
 PRF = 0.955E-24
 CI = 0.616E+00
 CE = 0.867E+00
 IP = 0.526E+07

A SOLUTION HAS BEEN FOUND.

TOTAL ALPHA POWER	0.209814E+03	MAJOR RADIUS	0.559986E+01
INTERNAL INDUCTANCE	0.527759E-05	EXTERNAL INDUCTANCE	0.896846E-05
INDUCTIVE VOLT-SECONDS	0.599820E-04	PLASMA RESISTANCE	0.109192E-07
PLASMA VOLTAGE	0.574682E-01	DEUTERIUM BURN-UP RATE	0.374200E+21
DEUTERIUM DIFFUSION LOSS RATE	0.165004E+23	FRACTION OF FUEL BURNED	0.221753E-01

SUM OF SQUARES = .2334E-02 PTOL =-1.0 IFAIL = 0

RESIDUALS:

-1.0218E-03 1.0623E-03-2.5944E-04-7.4855E-04-1.6471E-03 1.9612E-03 1.3849E-03 1.2088E-03 6.2465E-04 5.5625E-05
1.5671E-02-1.2298E-03 5.9087E-03-1.1925E-02 5.7077E-04-9.2819E-03-8.9862E-03-3.7431E-02-2.2454E-03-1.7202E-02
-5.2006E-03 5.2607E-04

THIS SOLUTION DOES SATISFY PHYSICS EQUATIONS WITHIN 1.0%

EQUATION 1 IS BALANCED WITHIN -0.01%
EQUATION 2 IS BALANCED WITHIN 0.01%
EQUATION 3 IS BALANCED WITHIN -0.00%
EQUATION 4 IS BALANCED WITHIN -0.01%
EQUATION 5 IS BALANCED WITHIN -0.02%
EQUATION 6 IS BALANCED WITHIN 0.02%
EQUATION 7 IS BALANCED WITHIN 0.01%
EQUATION 8 IS BALANCED WITHIN 0.01%
EQUATION 9 IS BALANCED WITHIN 0.01%
EQUATION 10 IS BALANCED WITHIN 0.00%

NORMALIZED X:

1.3918E+00 9.6925E-01 1.1477E+00 7.0188E-01 1.0571E+00 7.1814E-02 1.0138E-01 6.4218E-02 9.4386E-01 5.6995E-01
8.6999E-01 1.0526E+00

TI = 0.120E+02 F
TE = 0.120E+02 F
ZEFF = 0.209E+01
NI = 0.165E+21
NE = 0.195E+21
NZ = 0.379E+19
Q = 0.380E+01 F
BETA = 0.700E-01 F
BT = 0.501E+01 F
TAUE = 0.159E+01
PALFV = 0.661E+06
PFUS = 0.106E+10
WPA = 0.212E+07
A = 0.134E+01 F
AR = 0.418E+01 F
SIGMA = 0.160E+01 F

PINJ	=	0.000E+00	F
PNF	=	0.944E-24	
CI	=	0.570E+00	
CE	=	0.870E+00	
IP	=	0.526E+01	
ETALF			0.240000E+00
PCOULV			0.000000E+00
ETAINJ			0.799853E+00
POHVV			0.126521E+04
PHADV			0.132932E+06
SIGHAV			0.174000E-21
ETARF			0.100000E+01
TAUTP			0.260375E+21
TAUHP			0.175172E+01
TAURT			0.971944E+02
TAUNC			0.562575E+01

File SPECS.ETF (Example 2)

PLASMA RADIUS (M)	=	1.340	Q	=	3.800
ASPECT RATIO	=	4.179	IMPURITY Z	=	8.000
ELONGATION	=	1.600	ZEFF	=	2.088
BETA	=	0.070	GAMMA (RES LOSS)	=	0.100
FIELD ON AXIS(T)	=	5.010	PLASMA INT IND (LI)	=	1.500
ION TEMP (KEV)	=	12.000	SCRAPE OFF LAYER (M)	=	0.250
ELE TEMP (KEV)	=	12.000	IP FACTOR	=	0.800
RIPPLE (%)	=	1.550	BURN PRESS (TORR)	=	.1000E-05
			QUENCH PRESS (TORR)	=	.1000E-03

MAJOR RADIUS (M)	=	5.600	PLASMA-CRNT-HB (MA)	=	5.263
PLASMA HEIGHT (M)	=	2.144	PLASMA-CRNT-LB (MA)	=	4.210
PLASMA VOLUM (M**3)	=	317.567	PLASMA VOLT-BURN (V)	=	0.057
PLASMA IND (H)	=	.1425E-04	PLASMA RES-BURN (OHM)	=	.1092E-07
ION DENSITY (/M**3)	=	.1648E+21			
ELE DENSITY (/M**3)	=	.1951E+21			

IMPURITY CONCENT.	=	0.019
IMPURITY Z	=	8.000
ZEFF	=	2.088

NTAU (SEC/M**3)	=	.3094E+21
TAUE (SEC)	=	1.586
TAUE-EMP (SEC)	=	1.752
TAUE-TP (SEC)	=	*****
TAUP (SEC)	=	1.586

BEAM POWER (MW)	=	0.000
BEAM ENERGY (KEV)	=	150.000

PLASMA EDGE NEU. LOAD (MW/M**2)	=	2.12
FUSION POWER (MW)	=	1056.33
ALPHA (MW)	=	209.81
RADIATION (MW)	=	42.21
ELEC. POWER (MW)	=	369.72