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User's Guide for

FRMOD, a Zero Dimensional FRM Burn Code

Prepared for the

Fusion Studies Laboratory
Nuclear Engineering Program
University of Illinois
Urbana, Illinois 61801

by

D. Driemeyer
G. H. Miley†

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†Persons interested in further details should contact this author at the Laboratory address or via 217-333-3772 (FTS 958-5533).

FRMOD User's Guide

The zero-dimensional FRM plasma burn code, FRMOD, described in this work is written in the FORTRAN language and is currently available on the Control Data Corporation (CDC) 7600 computer at the Magnetic Fusion Energy Computer Center (MFECC), sponsered by the U. S. Department of Energy, in Livermore, CA. This guide will assume that the user is familiar with the system architecture and some of the utility programs available on the MFE-7600 machine, since online documentation is available for system routines through the use of the DOCUMENT utility. Users may therefore refer to it for answers to system related questions.

The files associated with the FRMOD code are available through the FILEM utility, using the command:

FILEM .RDS 1345 .DRIEM <list> / t v,

where <list> is a string of file names chosen from Table A1, t is the user allocated time limit, and v is the priority value. For execution of the already compiled version of FRMOD, XFRMOD, the following command would then be issued:

XFRMOD D=data,H=output / t v.

Here the data and output files (see Tables A3 and A5 for examples) may have any name except NEWDAT, which is a temporary scratch file used for outputting the converged values of the five dependant variables for each case (see Table A6). These values can thus be copied into new data files and used as an initial guess for additional parametric calculations involving related FRM plasmas. A value of t equal to one should normally be sufficient for completing a series of parametric studies; however the code can be restarted by typing:

+XFRMOD? / t v,

where ? is a letter corresponding to the channel being used, if the initial time allocation runs out.

The program is currently set up to be run in an interactive mode with periodic action required of the user if the code is having problems converging. When such action is needed the code will prompt the user at the terminal. This interaction feature was included because the set of algebraic equations describing the steady-state plasma parameters is highly non-linear, and numerical convergence is consequently difficult in some cases. Thus, when a solution has not converged after some maximum number of iterations (typically 100) control returns to the user and a revised guess for the five dependant parameters may be entered. (Continuation using the existing values of the parameters is also possible if zeroes are entered for the new guess.) Control also returns to the user if the solver begins to search for a solution where the values of the dependant parameters are no longer physical (i.e., negative), and a revised guess should always be entered in that case.

To illustrate the use of the FRMOD code, a typical data file, and the first portion of its corresponding output file are given in Tables A3 and A5. They are for an elongated D-^{3}He study vs the stability factor, S. As Table A3 indicates, the input to the code is specified in NAMELIST format; except for the initial guess for the five dependant variables, which may be entered in a free format style (where the values are terminated by commas) when the guess is typed in from the terminal, or in a fixed G10.0 format mode when the guess is specified as part of the data file. The output file can then be examined by disposing it, using the ALLOUT or NETOUT utilities, or by printing it at the terminal, using the TRIX AC editor, if it is short. Because the input is in NAMELIST format extremely compact data files are normally possible. The user does, however, have the freedom to specify other values for many parameters; thus a summary of all user specifiable variables, and their default values, is given in Table A2. Similarly, because the code represents a large amount of information symbolically in its output summary, a key to the output file is also included in Table A4.

Finally, for those individuals who are interested in a bit more detail, a brief flow chart for the FRMOD code is provided in Fig. A1. This should aid in locating general sections of the code; however specific questions regarding more subtle modifications should be referred to the author. In any case, when changes are made in the FRMOD code the new FORTRAN source file must be recompiled and loaded along with the FORTLIB libraries. The command for this process is:

```
CHATR I=FRMOD,L=0,LIB=(F') / t v,
```

and the new version of XFRMOD can then be executed in the above manner.

TABLE A1

Files Associated with the FRMOD Code.

File Name	Type	Remarks
FRMOD	F	FORTRAN source for the FRMOD code.
XFRMOD	B	Compiled version of the FRMOD code.
DATHE1	D	Data file for a study of reference D-^{3}He plasmas with no heat conduction losses.
DATHE2	D	Data file for a study of reference, spherical D-^{3}He plasmas with heat conduction losses.
DATHE3	D	Data file for a study of elongated D-^{3}He plasmas.
DATHE4	D	Data file for a study of spherical D-^{3}He plasmas with different magnetic field strengths.
DATHE5	D	Data file for a study of spherical D-^{3}He plasmas with anomalous diffusion losses.
DATCD2	D	Data file for a study of spherical Cat-D plasmas.
DATCD3	D	Data file for a study of elongated Cat-D plasmas.
DATDT2	D	Data file for a study of spherical D-T plasmas.
DATDT5	D	Data file for a study of spherical D-T plasmas with anomalous diffusion losses.

TABLE A2

Input Variables for the FRMOD Code

Block	Variable Name	Default Value	Remarks
IN1	N	5	The number of dependant variables.
IN1	ITMAX	100	The maximum number of iterations used by QNWT before control returns to the user.
IN1	FPRNT	20	The number of iterations between intermediate printouts by QNWT.
IN1	EPS	10	Convergence criterion for QNWT.
IN1	IPRNT	1	Detailed printout occurs every IPRNT-th iteration.
IN2	ZKAP	1	The plasma elongation factor, κ.
IN2	IDIF	1	The diffusion coefficient control: 0 -> Classical diffusion. 1 -> For near-classical diffusion. 2 -> Anomalous diffusion.
IN2	ICD	0	The Cat-D system flag: 0 -> Fixed fuel fractions. 1 -> Cat-D fueled system.
IN2	RHO	9.7E-7	The resistivity of the first wall (Ω-m), used in calculating the cyclotron losses.

Block	Variable Name	Default Value	Remarks
IN2	FH	0.1	The hole fraction of the first wall, used in calculating the cyclotron losses.
IN2	EC	1.0	The extraneous cyclotron loss factor.
IN2	GAMED	0.8	The correction for the electron drag reduction in the circulating current.
IN3	FB(1)	0.5	Fraction of the fuel that is deuterium.
	FB(2)	0.0	Fraction of the fuel that is tritium.
	FB(3)	0.5	Fraction of the fuel that is helium-3.
Note: For Cat-D systems, these fractions are chosen by the code.			
IN3	C3	0.7	The sensitivity parameter for attempting to converge on an improved initial guess.
IN3	ETATH	0.4	The thermal conversion efficiency.
IN3	ETADC	0.6	The direct conversion efficiency.
IN3	ETAI	0.8	The beam injection efficiency.
IN3	ETAIC	0.8	The ion cyclotron coupling efficiency.
IN3	DIST	500.0	The distance from the beam source to the plasma (cm).
IN3	TANY	.017452	The tangent of the beam divergence angle in the y-direction.
IN3	TANZ	.017452	The tangent of the beam divergence angle in the z-direction.
IN3	BBETA	$\pi/8$	The beam orientation angle relative to the coordinate frame used to describe the background plasma.

Block	Variable Name	Default Value	Remarks
IN3	BMAX	10.0	The cutoff value for the beam shaping factor.
IN3	NBΓ	20	The number of grid divisions used to integrate the beam trapping.
IN4	EAV(1)	650.0	The average energy (in keV) of the six
	EAV(2)	750.0	fps found in a deuterium fueled system.
	EAV(3)	1600.0	Namely, the ^{3}He, T, and p produced by
	EAV(4)	2000.0	D-D fusion; the α produced by D-T
	EAV(5)	2100.0	fusion; and the α and p produced by
	EAV(6)	5500.0	D-^{3}He fusion.

Note: The next four values are used in calculating the fraction of the marginally confined fps and their energy that is deposited in the closed field region.

Block	Variable Name	Default Value	Remarks
IN4	AE	-0.42887	The slope of the correlation line for energy deposition.
IN4	BE	0.25044	The intercept of the correlation line for energy deposition.
IN4	AP	-0.35011	The slope of the correlation line for particle deposition.
IN4	BP	0.34500	The intercept of the correlation line for particle deposition.

Block	Variable Name	Default Value	Remarks
IN4	TC	0.05	The temperature of the plasma on the open field lines (keV).
IN4	XNC	0.02	The density of the plasma on the open field lines ($x10^{15}cm^{-3}$).
IN4	TBL	1.0	The temperature of the boundary layer region (keV).
IN4	GAMW	1.0	The thickness of the boundary layer in units of the average ion gyroradius in the vacuum magnetic field. If GAMW=0, there are no heat conduction losses.
IN4	IFED	0	Control over the fp energy and particle deposition: 0 -> FRMOD approximation is used. 1 -> No fp heating or ash buildup. 2 -> Closed-field confinement limit. 3 -> Absolute confinement limit. 4 -> Input values are used.
IN5	E(k,j)	24*0.0	The energy of the k-th energy group of the j-th injected species (keV). The first group is a temperature, not an energy, and the species are: 1 -> Electrons. 2 -> Deuterium.

Block	Variable Name	Default Value	Remarks
			3 -> Tritium.
			4 -> Helium-3.
			5 -> Alpnas.
			6 -> Protons.
IN5	EINC(j)	6*0.0	The beam energy increment between cases for the j-th injected species (kev).
IN5	TINC	20.0	The ion temperature increment between cases (keV).
IN5	XNG	1.0E+8	The density of cold neutrals at the surface of the closed field region (cm^{-3}).
IN5	S	10.0	Tne plasma stability factor.
IN5	BO	60.0	The vacuum magnetic field strength (kG).
IN5	GAMC	1.0	A factor used to destroy the confinement in order to study the effects of enhanced diffusion.
IN5	FRE	6*0.0	The fraction of the six charged fps' energy retained in the closed field region. Normally, these fractions are found using the correlations.
IN5	FRP	6*0.0	The fraction of the six charged fps deposited in the closed field region. Normally, these fractions are also found using the correlations.

Block	Variable Name	Default Value	Remarks
IN5	NPT	3	The number of different background temperatures calculated for each set of input parameters. If only beam heating is used this value corresponds to the number of different injection energies for each set of parameters.
IN5	IDAT	1	The control over whether the input is from disk or from the terminal.
IN5	NG	2	The number of energy groups. This number should be increased if the beam power is large.
	ICMAX	none	Chosen when inputting an initial guess for the five dependant variables. If ICMAX>1, this number of iterations is used in an attempt to improve the initial guess and enhance the probability of finding a solution. (If this value is set larger than one a large amount of intermediate output is generated at the terminal. Also, ICMAX=5 should be sufficient to allow a reasonable guess to be evaluated.

Block	Variable Name	Default Value	Remarks
	X(1)	none	Initial guess for either the background ion temperature (keV), if X(1)>1, or the relative ICRH input, if X(1)<1. For the first case the ICRH input is zero, neutral beams are the only energy input to the plasma, and the ion temperature thus becomes a dependant variable. When X(1)<1, however, the ion temperature is fixed, and the ICRH input becomes a dependant variable.
	X(2)	none	Initial guess for the temperature of the background electrons (keV).
	X(3)	none	Initial guess for the peak density of the background ions ($x10^{15}cm^{-3}$).
	X(4)	none	Initial guess for the ratio of the electron to ion density.
	X(5)	none	Initial guess for the fraction of the background that is fuel.

TABLE A4

Definition of Symbols Found in the Output File

Symbol	Meaning
TI	Ion temperature (keV).
TE	Electron temperature (keV).
P/AV	Peak to average temperature.
XNBO	Peak background ion density (cm^{-3}).
XNEO	Peak background electron density (cm^{-3}).
TAUPN	Particle confinement time for anomalous diffusion (sec).
TAUE	Energy confinement time (sec).
TAUPC	Particle confinement time for classical diffusion (sec).
GAMC	Anomalous loss factor.
PHIO	Neutron flux at the plasma surface ($\#/cm^2/sec$).
RHV	The spherical vortex radius (cm).
RHO	The average ion gyroradius in the vacuum field (cm).
IDIF	The type of diffusion for this case:
	0 -> Classical.
	1 -> Near-classical.
	2 -> Anomalous.
PMAG	The magnetic pressure.
PPLAS	The plasma kinetic pressure.
BETA	The plasma beta value.
IR-MA	The plasma current required to maintain the equilibrium.
ID-MA	The diamagnetic plasma current contribution.

Symbol	Meaning
II-MA	The injected plasma current contribution.
F-E	The ratio of the electron to the ion density.
F-D	The fractional density of thermal deuterium.
F-T	The fractional density of thermal tritium.
F-He	The fractional density of thermal helium-3.
F-AL	The fractional density of thermal alphas.
F-PR	The fractional density of thermal protons.
FAI	Fraction of the ion input power from injected beams.
FCFI	Fraction of the ion input power from charged fps.
FIC	Fraction of the ion input power from ICRH.
FLI	Fraction of the ion power losses in leakage.
FIE	Fraction of the ion power losses to the electrons.
FHC	Fraction of the ion power losses in heat conduction.
FAE	Fraction of the electron input power from NB injection.
FCFE	Fraction of the electron input power from charged fps.
FIE	Fraction of the electron input power from the ions.
FLE	Fraction of the electron power losses in leakage.
FBR	Fraction of the electron power losses in bremsstrahlung radiation.
FCY	Fraction of the electron power losses in cyclotron radiation.
AKCY	Fraction of the cyclotron radiation absorbed by the first wall.

Symbol	Meaning
RHO	The resistivity of the first wall (Ω-m).
FH	Fraction of the first wall that is holes.
FI	Fraction of the charged fusion power that is given to the ions.
FE	Fraction of the charged fusion power that is given to the electrons.
FL	The fraction of the charged fusion power that is not deposited in the closed field region.
FRDDH	Fraction of the 820-keV, D-D, ^{3}He's energy retained in the closed field region.
FRDDT	Fraction of the 1010-keV, D-D, T's energy retained in the closed field region.
FRDDP	Fraction of the 3020-keV, D-D, p's energy retained in the closed field region.
FRDTA	Fraction of the 3520-keV, D-T, α's energy retained in the closed field region.
FRDHA	Fraction of the 3670-kev, D-^{3}He, α's energy retained in the closed field region.
FRDHP	Fraction of the 14680-keV, D-^{3}He, p's energy retained in the closed field region.
FHC	Fraction of the total plasma output power in heat conduction losses.

Symbol	Meaning
FBR	Fraction of the total plasma output power in bremsstrahlung radiation losses.
FCY	Fraction of the total plasma output power in cyclotron radiation losses.
FLP	Fraction of the total poasma output power in particle leakage losses.
FCF	Fraction of the total plasma output power in charged fp losses.
FNF	Fraction of the total plasma output power in neutrons.
PI-MW	The total injection power (MW).
PF-MW	The total fusion power (MW).
QVAL	The energy multip?lication factor.
PN-MW	The net electrical power output (MW).
ETAI	The neutral beam injection effiency.
FVAL	The ratio of total to background fusion power.
ETATH	The thermal conversion efficiency.
ETADC	The direct conversion efficiency.
ETAIC	The ion cyclotron heating efficiency.
EO-D,T,H	The beam injection energy for each species (keV).
IBD,T,H-A	The beam injection current for each species (amps).
PI-D,T,H	The beam power for each injected species (MW).
TAUF	The average fusion time for each species (sec).
SGVEI	Electron ionization rate for each species (cm^3/sec).

Symbol	Meaning
SGVPI	Proton ionization rate for each species (cm^3/sec).
SGVCX	Charge exchange rate for each species (cm^3/sec).
AT	The beam attenuation for each injected species.
TBL	Boundary layer temperature (keV).
XNBL	Boundary layer density (cm^{-3}).
KPRP	Cross field thermal conductivity in the boundary layer (ergs/keV/cm).
GAMW	Thickness of the boundary layer in units of the hot ion gyroradius.
XO-CM	Thickness of the boundary layer (cm).
SAREA	The surface area of the plasma (cm^2).