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Compendium of Computer Codes for the Researcher
in Magnetic Fusion Energy

Edited by Gary D. Porter

March 10, 1989

Lawrence
Livermore
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March 10, 1989

Compendium of Computer Codes For the Researcher in Magnetic Fusion Energy

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Abstract This is a compendium of computer codes, which are available to the fusion researcher. It is intended to be a document that permits a quick evaluation of the tools available to the experimenter who wants to both analyze his data, and compare the results of his analysis with the predictions of available theories. This document will be updated frequently to maintain its usefulness. I would appreciate receiving further information about codes not included here from anyone who has used them. The information required includes a *brief* description of the code (including any special features), a bibliography of the documentation available for the code and/or the underlying physics, a list of people to contact for help in running the code, instructions on how to access the code, and a description of the output from the code. Wherever possible, the code contacts should include people from each of the fusion facilities so that the novice can talk to someone "down the hall" when he first tries to use a code. I would also appreciate any comments about possible additions and improvements in the index. I encourage any additional criticism of this document.

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Contents

1	Introduction	6
2	General Utility Codes	6
2.1	BASIS	6
2.2	MPPL	7
2.3	GRAFL-III	7
2.4	XPOSTPLT	8
3	General Physics Codes	8
3.1	Cross-Sections	8
3.1.1	ALADDIN	8
3.1.2	SIGV	9
3.2	Neutron and Photon Transport	10
3.2.1	MCNP	10
3.3	Vacuum Field Calculation	11
3.3.1	EFFI	11
3.3.2	GFUN3D	11
3.3.3	MAFCO	12
4	Data Analysis Codes	12
4.1	General Data Analysis	12
4.1.1	CHIREG	12
4.1.2	DATAPLOT	12
4.1.3	IDL	13
4.1.4	LOCUS	14
4.1.5	PROFREG	14
4.1.6	SIG	15
4.2	Machine Specific Data Analysis	15
4.2.1	ENERGY	15
4.2.2	REVIEW	16
5	Design Codes	16
5.1	Tokamaks	16
5.1.1	MUMAK	16
5.1.2	POPCON	17
5.1.3	TADDPACK	17
5.1.4	TETRA	17
6	MHD Equilibrium Codes	18
6.1	Open Geometry	18
6.1.1	TEBASCO	18
6.1.2	LTE	18
6.2	Toroidal Geometry	18

6.2.1	ACCOMME	18
6.2.2	AD	19
6.2.3	BETA	20
6.2.4	EFIT	20
6.2.5	EPFC	20
6.2.6	EQPD	21
6.2.7	NEQ/HEQ/VEQ	21
6.2.8	VMEC	21
6.2.9	VMOMS	22
7	Particle Following Codes	23
7.1	Single Particle	23
7.1.1	TIBRO	23
7.2	Monte-Carlo	23
7.2.1	MCGO	23
7.2.2	MCPAT	24
7.3	Particle-in-cell Simulation codes with self-consistent fields	25
7.3.1	DART	25
7.3.2	DIPSI	25
7.3.3	EMONE	25
7.3.4	ES1	26
7.3.5	PDW1	26
7.3.6	PDW2	27
7.3.7	PDWZ	27
7.3.8	TESS	28
7.3.9	VSI	28
7.3.10	ZOHAR	28
8	Plasma Transport Codes	29
8.1	Cross-Field Transport	29
8.1.1	BALDUR	29
8.1.2	BETA MC (Monte Carlo)	29
8.1.3	CFRX	30
8.1.4	CHAPO	30
8.1.5	HPFB	31
8.1.6	IHTMDC	31
8.1.7	MINERVA	32
8.1.8	MIRTH	32
8.1.9	ONETWO	32
8.1.10	RFPBURN	33
8.1.11	SNAP	34
8.1.12	TRACK	34
8.1.13	THEORY	35

8.1.14	TRANSP	35
8.1.15	TSC	36
8.1.16	WHIST	36
8.1.17	ZERO	37
8.1.18	CROSS-REFERENCE	37
8.2	2-D Transport	38
8.2.1	B2	38
8.2.2	PLANET	38
8.3	Parallel Transport	38
8.3.1	PHLOW	38
8.3.2	ZCODE	39
8.3.3	CROSS-REFERENCE	39
8.4	Impurity Transport	40
8.4.1	MIST	40
9	Sources and Sinks	41
9.1	Electron-Cyclotron Frequency	41
9.1.1	TORCH	41
9.1.2	TORAY	41
9.2	Ion-Cyclotron Frequency	42
9.2.1	ANTENA	42
9.2.2	ICRH	42
9.2.3	FIRC	43
9.2.4	MFIRC	43
9.2.5	SHIRC	43
9.2.6	IHRC	44
9.2.7	THIRC	44
9.2.8	GARFIELD	45
9.3	Neutral Beams	45
9.3.1	NFREYA	45
9.3.2	BEAM	46
9.4	Neutral Particle Transport	46
9.4.1	DEGAS	46
9.4.2	FENAT	47
9.4.3	PELLET	47
9.5	Impurity Radiation Codes	48
9.6	Cyclotron Emission Codes	48
9.6.1	CYTRAN	48
9.6.2	HORACE	48
9.6.3	OPAKE2	49
9.7	Lower Hybrid	49
9.7.1	WPCP38	49

10 Fokker-Planck Codes	50
10.1 Single Flux Tube	50
10.1.1 BAV/BACON	50
10.1.2 CQL	50
10.1.3 HYBRID-II	51
10.1.4 SFP	51
10.1.5 SMOKE	52
10.2 Multiple Flux Tubes	53
10.2.1 CQL3D	53
10.2.2 FPT	53
11 Stability Codes	54
11.1 Magnetohydrodynamic Stability	54
11.1.1 FLORA	54
11.1.2 GATO	54
11.1.3 <i>PEST</i>	54
11.1.4 <i>TEARING</i>	54
11.2 Resistive MHD	55
11.2.1 CART	55
11.2.2 HIB-G	55
11.2.3 RPD	56
11.3 Microstability	56
11.3.1 ALFWVS	56
11.3.2 MICE	57
11.4 Turbulence	57
11.4.1 DIA	57
11.4.2 DRIFT	58
11.4.3 TWOFLD	58
11.5 CROSS-REFERENCE	59

1. Introduction

When starting the search for computational tools to address a question about plasma physics, a person may be quickly overwhelmed by the number that are available. This compendium is intended to make it somewhat easier to determine what already exists. I hope that the list of computer codes will enable the experimentalist to find the tools necessary to both thoroughly analyze his data and to determine how those data compare with theoretical models. The National Fusion Program is dominated by research in toroidal geometry, hence most of the codes listed here are useful for this research. However, some work continues in open geometry, e.g. neutron sources and edge physics studies, so I have also included those codes that I think will be useful for research in these areas.

Since I am directing this listing toward the needs of the experimentalist, I have tried to provide the information that is likely to be of value to him. Specifically, I expect that he is likely to need several different codes to fully analyze his data. Hence, it becomes valuable to be able to transfer data from one code to another. One powerful tool for this job is described in Sec. 2.1.

Many codes are available on the NMFECC's Crays. A description of these codes can be obtained on-line [123]. I have included some of these codes in this compendium, but by no means all. In general, I have tried to provide a summary of the information available in Ref. 123. Other code descriptions that are included in this document have been copied verbatim from references describing the codes.

This compendium is intended to be a live document. Computer codes change frequently, and new ones are added regularly. I have written this document using $\text{\LaTeX}$ to facilitate updates and additions. I anticipate updating the document every few months. Please send information regarding new codes, or suggested changes to G. D. Porter, Lawrence Livermore National Laboratory, P.O. Box 5511, L-637, Livermore, CA, 94550 or via electronic mail to PORTER@LLL.MFENET.

2. General Utility Codes

2.1. BASIS

Description BASIS is the name of a system for developing computer programs and running them. It consists of two parts: the development system, which is used to write the user's part of the program; and the runtime system, which combines with the user-written modules to form the complete program. BASIS is designed to assist in the production of programs with sophisticated user interfaces and to solve many of the problems connected with program development, especially for multiple-author programs.

BASIS is the name of the program that results from loading the BASIS runtime system by itself, with no user-written modules. It is an interpreter for the BASIS Language. Like any interpreter, it has enormous advantages over FORTRAN for doing interactive calculations and plots, and for developing and debugging small programs or modules. It is an excellent environment for algorithm development [25].

Availability BASIS is a public file and can be accessed by typing `basis / t v` on the MFECC.

Users A. Friedman, L. LoDestro, G. Smith, M. Rensink, P.F. Dubois, M. Fenstermacher, S.K. Ho, P. Willmann, J. Perkins (LLNL); R.B. Campbell, D.T. Blackfield (TRW@LLNL); J. Galambos (FEDC)

Documentation See Refs. 25,24. To obtain a copy of the most recent BASIS manual type:

```
cfs filem
read 374 .basisdoc alwith. j2
end
allout nip alwith. j2 gr. ind. box ann id

while on the MFECC's Cray.
```

2.2. MPPL

Description MPPL, (a More Productive Programming Language), is a source code preprocessor. On the Crays, it is an alternative to precomp. This language allows programmers to write in a c-like language that is more convenient and powerful than Fortran 77. MPPL then transforms statements written in the MPPL language into standard Fortran 77. This language is essentially an extension to Fortran 77 that provides free-form input and many structured constructs such as "while" and "for" loops. MPPL's macro preprocessor file-inclusion facility encourages the creation of structured, easy-to-read programs that contain fewer labels. MPPL provides a more productive programming environment for Fortran 77 users on Unix, VAX and Cray machines.

Special Features MPPL can be used independently as well as with Basis.

Availability MPPL is a public file and can be accessed by typing `mppl / t v` on the MFECC.

Users P. Willman (LLNL)

Documentation The MPPL documentation is included in the BASIS manual, which can be obtained as described in Sec. 2.1.

2.3. GRAFL-III

Description GRAFL-III consists of a small set of routines that can produce the vast majority of the figures and plots in the scientific literature. The 38 routines and their arguments have been designed to give the user extensive control over scientific graphs with minimum coding. Versions of GRAFL-III have been implemented on the NMFECC and Octopus computer systems based on the GRAFLIB and TV80LIB graphics libraries developed at LLNL. A GRAFLIB version is also resident on the LLL Vax. Although some of the coding uses low-level GRAFCORE routines, GRAFL-III contains enough comments to permit easy modification or rewriting to drive other graphics libraries. Variations of GRAFL have been written to drive DIGLIB on a Vax, the CERN graphics system and DISSPLA. A version for the Sun is being developed and a GKS version is planned. The NMFECC implementation gives good quality output on every medium - slides, videos, and graphics printers - and the 'hardcopy' option provides publication-quality output. The main plotting routines insist on labels to make the output intelligible. These labels can be decoded by GRAFL-III to produce Greek and math symbols and to make professional looking science graphics. All control flags have English names to give clarity to the coding. Alternative numeric values for the flags have been eliminated for simplicity and clarity. Graphs can be produced in many colors simply by sending the output to the color camera. This process may be expensive but is useful for presentations. We eliminated interactivity in GRAFL-III because the trend is to use test-bed systems such as Basis for developing

physics codes. These systems already contain sophisticated interactive capabilities. The objective of a good graphics library like GRAFLIB is to provide total control over every pixel of a drawing, whereas GRAFL-III lets physicists and engineers create complete graphs with minimum coding. However, GRAFL-III contains many comments, and most of the internal parameter choices are in common blocks. These two features permit easy revision for those users who need more detailed plotting capabilities.

Users Many programs use this graphics package, including BASIS (Sect. 2.1).

Documentation See Ref. 137.

2.4. XPOSTPLT

Description XPOSTPLT is an interactive plotting program for use in conjunction with DDT and its PRINT command. XPOSTPLT can produce plots of either curves or contours from a data file produced by DDT. How to use XPOSTPLT is described in file POSTRPT. The controllee for the CRAY-2 is called XPOSTB.

Availability The files are in filem 374 .plo

Users P. Willmann (LLNL)

Documentation See Ref. 123

3. General Physics Codes

3.1. Cross-Sections

3.1.1. ALADDIN

Description The ALADDIN atomic physics database system has been developed in order to provide a standard tool for the exchange of atomic data for fusion applications. ALADDIN is designed to support a wide range of users in the international atomic physics and fusion modeling communities, and includes a data format definition together with supporting software for both interactive searches as well as access to the database by fusion modeling and other codes. ALADDIN has been accepted as the standard atomic physics data exchange format for fusion applications by the IAEA, which will coordinate entry of critically evaluated atomic data into ALADDIN form.

Special Features ALADDIN is designed to offer maximum flexibility in the choice of data representations and labeling schemes, so as to support a wide range of atomic physics data types and allow natural evolution and modification of the database as needs change. Support for the widest possible user community was also a prime ALADDIN objective, leading to the use of straightforward ASCII text files with concatenated data entries as the standard data file format, and the adoption of strict FORTRAN 77 code for the supporting software. This will allow ready access to the ALADDIN system on the wide range of scientific computers, and easy interfacing with FORTRAN fusion modeling codes, user developed atomic physics codes, databases, etc. The supporting software consists of the ALADDIN interactive searching and data retrieval capabilities to subroutine

package, which provides ALADDIN datafile searching and data retrieval capabilities to user's codes. Associated dictionary files are included in the ALADDIN system for data documentation.

Availability ALADDIN is in its final development stages, with "beta test" versions of the software and associated documentation available from Russell Hulse (PPPL, (609) 243-2621, email HULSE@PPCL.MIT.EDU), as well as from the IAEA atomic and molecular data unit (R. Janev, J. Smith), the ORNL atomic data center (R. Phaneuf, et al.), and various international atomic data centers. Final database format and software enhancements are presently anticipated for mid-1989 publication and general release. Entry of critically evaluated atomic data sets into ALADDIN format is to be coordinated by IAEA atomic and molecular data unit, which will also coordinate long-term development and distribution of updated software and documentation.

Users Present ALADDIN beta test sites include the IAEA atomic and molecular data unit (R. Janev and J. Smith), the ORNL atomic data center (R. Phaneuf, et al.), and various international atomic data centers.

Documentation Reference 48 contains the present IAEA atomic data labeling scheme in addition to the ALADDIN presentation. The commented source code and sample data files are also useful for reference. A paper containing a full description of the ALADDIN database format and supporting software is in preparation by R. Hulse for journal publication.

3.1.2. SIGV

Description SIGV is a modular code on the VAX that is used to compute $\langle \sigma v \rangle$ for a variety of interaction pairs involving e^- , H, H_2 , He for numerical input with several types of distribution functions.

Special Features

- Allowance for anisotropic plasma distribution function with non-normal beam injection.
- Estimation of the accuracy of the integration, with the choice of the number of quadrature points then governed by the desired accuracy.
- Provision for use of a 32-point Gauss-Laguerre formula for Maxwellian distribution functions.
- A structure to facilitate modification or incorporation into a larger code.
- A "driver" program that enables the code to be easily run from the terminal of the VAX.

Users R. S. Devoto (LLNL)

Documentation See Ref. 21.

3.2. Neutron and Photon Transport

3.2.1. MCNP

Description MCNP is a general-purpose Monte Carlo code that can be used for neutron, photon, or coupled neutron-photon transport, including the capability to calculate eigenvalues for critical systems. The code treats an arbitrary three-dimensional configuration of materials in geometric cells bounded by first- and second degree surfaces and some special fourth-degree surfaces (elliptical tori).

Pointwise cross-section data are used. For neutrons, all reactions given in a particular cross-section evaluation (such as ENDF.B-V) are accounted for. Thermal neutrons are described by both the free gas and S(a,b) models. For photons, the code takes account of incoherent and coherent scattering, the possibility of fluorescent emission following photoelectric absorption, and absorption in pair production with local emission of annihilation radiation [123].

Special Features Important standard features that make MCNP very versatile and easy to use include a variety of standard sources, a geometry plotter, a very rich collection of variance reduction techniques, and elaborate tally structure and user interface that allow a user to easily calculate almost anything conceivable, and an extensive collection of cross-section data. A post processing code, MCPLOT, is available to graphically display the MCNP tally output [123].

Availability MCNP version 3 is available in FILEM under user 514 in the directories as follows:

directory	name	description
.crayrun	mcnp	executable binary for version 3
	wind	required for plotting
	mcplot	executable binary for post processor
	fr80con	converter for FILMF file
.crayupd	cft	LANL CFT 110 compiler
	cftlib	
	craymath	LANL libraries needed for MCNP and MCPLOT
	cgscft	
	sccft	libraries needed for MCPLOT loading
	disclib	
	mcnppl	old program library
	mcnp3	original source code for MCNP
.crayinfo	mcnp1t	source code for mcplot
	mcnpid	source listing with identifiers
	mcnpix	master index of variables
	mcnpex	LIB file of sample input files
.ver3xs		cross section libraries

Documentation See Ref. 123.

3.3. Vacuum Field Calculation

3.3.1. EFFI

Description EFFI calculates magnetic flux lines, fields, forces, and inductance for an arbitrary system of coils made from circular arc and/or straight segments of rectangular cross section conductor. This is a packaged code that includes a users manual and sample test cases online [123].

Special Features

- Auxiliary codes are EIG for generating EFFI input, and EFIMAF for translating EFFI input to MAFCO citenumr:49 input.
- EFFI produces both printed and graphical output. Each page of output is labeled with the problem title, the time, machine, and date of the run, and the version number and compile date for EFFI. In addition, each column of numbers on each page is appropriately labeled. Plots of field contours can all be obtained at the option of the user. On field contour and flux line plots, lines of intersection between the coils and the plotting plane are also shown [123].

Availability The EFFI files are located in FILEM in user number 3011 as follows: `filem rds 3011 .effic effi effirpt` where EFFI and EFFIRPT are the Cray controllee and users manual, respectively.

Users R. Bulmer (LLNL)

Documentation See Refs. 123,109,110.

3.3.2. GFUN3D

Description The GFUN3D computer program is primarily a design tool for calculating the magnetic fields for a system of conductors and non-linear (variable permeability) magnetic materials in three dimensions. The technique used considers the magnet as a system of known current and unknown induced magnetization sources. This leads to an integral equation in terms of the unknown magnetization (dipole strength and direction per unit volume). In order to solve this equation only the iron needs to be discretised and the need for false boundaries is avoided [123].

Special Features John Kerns has written a program, XFRM, which converts EFFI coil input into GFUN coil input.

Availability GFUN3D can be found in FILEM as follows:
`filem read 3011 .gfunc xgfun gfunins.`

Users J. Foote (LLNL)

Documentation See Refs. 123,4.

3.3.3. MAFCO

Description MAFCO calculates magnetic field ($\vec{B}$) with filamentary approximation for current elements.

Special Features

- Input is derived from EFFI input using EFIMAF.
- Fast code for calculating fields away from conductor bundles.

Availability Contact Bulmer@LLN.MFENET

Users R. Bulmer (LLNL)

Documentation See Ref. 100.

4. Data Analysis Codes

4.1. General Data Analysis

4.1.1. CHIREG

Description CHIREG is a general purpose regression code for tokamak analysis. To reduce the effects of colinearity, principle components, ridge regression and latent roots analysis are used. Influence diagnostics automatically determine statistical outliers and discard them.

Documentation Results from CHIREG are described in P. McCarthy, K.S. Riedel, and O. Kardaun, et al., in progress.

Availability The code is available on request: contact K.S. Riedel; Courant Institute of Mathematical Sciences; New York University; New York, NY 10012.

4.1.2. DATAPLOT

Description The DATAPLOT language was designed and developed in 1976 in response to data analysis problems encountered in the scientific/research environment at the National Bureau of Standards. At such time it became increasingly evident that the 3 highest priority computing activities of the scientist/engineer were

1. graphics (especially continuous)
2. fitting (especially non-linear)
3. operations with functions.

DATAPLOT was developed to provide these capabilities [28].

Special Features The language has extensive capabilities in

1. graphics (continuous or discrete)
2. fitting (non-linear or linear)
3. general data analysis
4. mathematics.

DATAPLOT commands are high-level, English-syntax, and self-descriptive.

Availability A license for the use of this software can be obtained for a small charge from:

U.S. Department of Commerce
Attn: Walter Finch
National Technical Information Service
Office of Data Base Services
5285 Port Royal Road
Springfield, VA 22151

Users G. D. Porter, J. Barter, G. Dimonte (LLNL)

Documentation See Ref. 28.

4.1.3. IDL

Description IDL is a software system for the interactive analysis, reduction and display of scientific data. It is designed to help scientists to quickly and accurately analyze their data [56].

Special Features [56]

- Operators and functions work on entire arrays simplifying interactive analyses and reducing programming time.
- Immediate mode statements provide instant feedback and "hands-on" interaction eliminating tedious edit, compile and link steps.
- The integrated display of graphs, curves and images for most popular graphic and image display devices speeds analysis and aid in the understanding of complex data.
- IDL is a complete structured language.
- Programs may be written in any language supported by the VAX/VMS operating system and called interactively from IDL.
- Built-in image, spectral and signal processing capabilities aid the speedy development of applications programs.

Availability IDL is available commercially

Users S. Allen (LLNL)

Documentation See Ref. 56.

4.1.4. LOCUS

Description LOCUS is a database system for creating, manipulating, and interactively investigating databases. LOCUS was written in response to the need to study the data from the experimental devices at PPPL and is now also used extensively at other fusion laboratories. An example of its use is the determination of scaling laws. To do this, LOCUS allows the user to enter and modify data, define subsidiary variables as arbitrary functions of original data, plot and fit such variables, and perform multiple linear regression analysis. Through a flexible interactive interface the program is easy to learn and largely self-documenting.

There are two implementations of LOCUS: one that manipulates data in VAX VMS ISAM files and another that manipulates data in the commercial relational database management system, INGRES.

Special Features LOCUS allows plotting profiles and time evolving data by specifying the appropriate constraints. It also allows storing frequently used expressions.

Availability Contact MURPHY@PPC.MFENET or WIELAND@PPC.MFENET

Users P.C. Efthimion, R.J. Goldston, Hill, J.D. Strachan, Zarnstorff, and many others (PPPL), G.A. Barnes, G.A. Wurden, P.G. Weber (Los Alamos), H.C. Howe, M. Murakami (Oak Ridge), Bosch (Garching), W.A. Morris, T.E. Edlington (Culham).

Documentation In Ref. 88, there is an overview of the programs and a users manual for each of the LOCUS versions (INGRES and ISAM).

4.1.5. PROFREG

Description PROFREG parametrized temperature and density profile shapes in terms of plasma *parameters* such as line averaged density and edge q_a . The normalized profiles are represented by splines or polynomial, with the coefficients being functions of the discharge parameters $a_i(\bar{n}q_a, I_p, \dots)$.

The parametric dependencies are determined by generalized least squares. Spatial correlations in the error structure are calculated iteratively. Related SAS routines performed stepwise regressions and calculate influence diagnostics.

Documentation The method is described in O. Kardaun, K. Riedel, P. McCarthy, and K. Lackner (in preparation). Applications of the code to ASDEX Ohmic profiles are described in P. McCarthy, K. Riedel, O. Kardaun, et al. (in preparation).

Availability PROFREG is available on request: contact Kurt S. Riedel, Courant Institute of Mathematical Sciences, New York University, New York, NY 10012

4.1.6. SIG

Description SIG is a general-purpose signal processing, analysis, and display program. Its main purpose is to perform manipulations on time- and frequency-domain signals. However, it has been designed to ultimately accommodate other representations for data such as multiplexed signals and complex matrices. Many of the basic operations one would perform on digitized data are contained in the core SIG package. Out of these core commands, more powerful signal processing algorithms may be built [69].

Special Features Two user interfaces:

- menu mode
- command mode

Availability Contact D. L. Payne, L-156, Lawrence Livermore National Laboratory, P.O. Box 5504, Livermore, CA 94550.

Users T. A. Casper, G. D. Porter, A. W. Molvik (LLNL)

Documentation See Ref. 69.

4.2. Machine Specific Data Analysis

4.2.1. ENERGY

Description The ENERGY code is a diagnostics analysis program used on DIII-D at GA. Given appropriate experimental data the code generates least squares best fit profiles for electron and ion temperatures, electron densities, radiated power, soft x-ray intensity, Z_{eff} , and plasma rotation profiles.

Special Features Linear, nonlinear, constrained and non-negative fitting methods are used to generate the profiles. The profiles are assumed to be flux surface functions and are modeled using variable knot cubic spline techniques. Diagnostic data can be combined in various ways to generate new or non-measured data. The code is intended primarily for interactive use, output is in graphic form.

Availability Information on the techniques used in this code can be obtained from H. St. John at General Atomics.

Users H. St. John (GA), G. Porter (LLNL)

Documentation A users manual can be obtained on the General Atomics User Service Center VAX. The numerical techniques used are discussed in Ref. 111.

4.2.2 REVIEW

Description REVIEW is a program to display time traces of data taken on the GA VAX cluster. It can display any pointname versus time in addition to a variety of pseudo-pointnames. These include diamagnetic beta and related quantities as calculated in a simple way from diamagnetic loop data, CO₂ interferometer data, charge exchange data, and discharge shape parameters as calculated by the outer flux surface code MFIT [118].

Special Features This is an interactive code.

Code Output During the run, much of the code output is to the terminal (must be a graphics terminal to be useful). In addition, versatec and/or QMS files can be written.

Availability This code is used for data analysis on the DIII-D tokamak. Information on the techniques used can be obtained from T. Strait at General Atomics (GA).

Users T. Strait (GA), S. Allen (LLNL)

Documentation See Ref. 118.

5. Design Codes

5.1. Tokamaks

5.1.1. MUMAK

Description MUMAK is a zero-dimensional (volume averaged), time-independent, power balance code for modeling plasma particle and energy flow in tokamaks. The equations describing the steady-state power balance include terms for alpha power from D-T burning plasmas, inductive (ohmic) as well as non-inductive current drive power, conduction power losses described by empirical energy confinement scaling laws, and radiation power losses. Radial profiles of plasma density and temperature are controlled by input parameters and are assumed fixed for the power balance calculations. MUMAK also performs calculations of non-inductive current drive efficiencies for electron cyclotron harmonic (ECH), neutral beam injection (NBI), lower hybrid (LH) slow wave, and fast wave (FW) current drive. The NBI models also include the effects of electron trapping as well as the beam energy dependence. The LH models take into account both the accessibility limit and the condition for avoiding strong electron Landau damping of the wave to determine the radius of maximum penetration for the waves [27].

Special Features MUMAK operates in the BASIS code control system (see Sec. 2.1).

Availability Contact Fenstermacher, user=30347 on the MFECC

Users L. J. Perkins, M. E. Fenstermacher, S. K. Ho (LLNL); R. B. Campbell, D. T. Blackfield, (TRW@LLNL)

Documentation See Ref. 27

5.1.2. POPCON

DRAFT

Description

Special Features

Code Benchmarking

Availability

Users

Documentation See Ref. 7

5.1.3. TADDPACK

Description The computer code **Thermal Analysis Divertor during Disruption PAcKage** (TAD-DPACK) provides three-dimensional graphic presentations of time and position dependent thermal effects on a poloidal cross section of the double-null-divertor configured reactor. These thermal effects include incident heat flux, surface temperature, vaporization rate, total vaporization, and melting depth. The dependence of these thermal effects on material choice, pulse shape, and the characteristic thickness of the plasma scrape-off layer is determined through parametric analysis with TADDPACK.

Special Features This computer code is designed to be a convenient, rapid, and user-friendly modeling tool, which can be easily adapted to most tokamak double-null divertor reactor designs.

Availability Contact L. J. Perkins (LLNL)

Users L. J. Perkins(LLNL)

Documentation See Refs. 13,12.

5.1.4. TETRA

Description The code **Tokamak Engineering Test Reactor Analysis** (TETRA) consists of a series of modules, each describing a tokamak system or component, controlled by an optimizer/driver. The code has been used to simulate the **TIBER II** design. A feature of this code is the ability to perform optimization studies through the use of a numerical software package that iterates prescribed variables to satisfy a set of prescribed equations or constraints.

Special Features This code operates under the BASIS code control system (see Sec. 2.1).

Availability To obtain on the MFEC, contact J. D. Galambos (FEDC), or L. J. Perkins (LLNL)

Users M. E. Fenstermacher, S. K. Ho, M. L. Brown, L. J. Perkins (LLNL); J. D. Galambos (FEDC); R. L. Miller (LANL)

Documentation See Ref. 103

6. MHD Equilibrium Codes

6.1. Open Geometry

6.1.1. *TEBASCO*

Description *TEBASCO* is a Tandem mirror Equilibrium and Ballooning Stability COde. It allows you to compute tandem mirror MHD equilibria [62,99] and to analyze both the flute-averaged and ballooning mode stability (infinite- m , and $m = 1$) of these equilibria. This stability analysis is directed toward the computation of marginal stability boundaries [98].

Special Features *TEBASCO* is designed to be an interactive code. Much useful output (equilibrium parameters, points on the marginal stability boundary, etc.) will appear on your terminal. In addition, all of this information, along with any plots that are made in a *TEBASCO* run are stored in an FR80 output file [98].

Availability Contact Lodestro@LLN.MFENET

Users L. Lodestro (LLNL)

Documentation See Refs. 62,99,61,98.

6.1.2. *LTE*

Description *LTE* code calculates quadrupole mirror equilibrium in the paraxial limit. The equilibrium is assumed to be isorhopic and FLR is included. The field geometry is input from EFFI, Sec. 3.3.1.

Availability Contact L. D. Pearlstein @LLN.MFENET.

Users L. D. Pearlstein (LLNL)

Documentation None exists.

6.2. Toroidal Geometry

6.2.1. *ACCOME*

Description *ACCOME* is primarily a code for computing the current drive by neutral beams, neoclassical (bootstrap) effects and Ohmic current, but includes an MHD code (*SELENE*) to solve for the free or fixed boundary equilibrium from the Grad-Shafranov equation. Neutral beam deposition is carried out with a Monte Carlo technique. The fast ion distribution function is found

from the numerical computation of the eigenfunctions of the bounce-average Fokker-Planck equation (J.G. Cordey [19]). Neoclassical currents come from the expressions in the review paper of Hinton and Hazeltine [41]. The MHD equilibrium is made self consistent with the driven current in an iterative process. It has been used to simulate experiments in DIII-D and to predict performance of ITER when operating in steady state. It is currently being modified to include lower hybrid current drive.

Availability Permission to obtain copies of this code must be obtained from JAERI.

Users R. S. Devoto (LLNL)

Documentation See Refs. [20,22].

6.2.2 AD

Description AD is a large class of codes employing Grad's technique of iterative alternation between solving for the 2-D or 3-D geometry of flux surfaces and for transport as defined by a set of profiles. The codes are applicable to slow-evolution problems for which the time to equilibrate within flux surfaces is short compared to the time scale of the phenomena studied. They solve the fully nonlinear macroscopic MHD equations dropping the momentum term, either with dissipation [32] or adiabatic [33]. An important feature of AD codes is their ability to handle complicated topologies and free boundaries with high precision.

The most fully elaborated code of the AD family is the 3D code employing anisotropic Braginskii transport [8]. This code (and a non-Braginskii variation) has been applied to study the "anomalous" coupling of plasma diffusion and heat flow [44,45]. Kress [68] has devised and implemented techniques to accelerate convergence in the low resistivity regime. The following 2D and axisymmetric implementations of AD are referenced in [34]:

- 2D adiabatic Tokamak, Belt Pinch, and Doublet
- Axisymmetric adiabatic Doublet
- 2D adiabatic tearing (Lens)
- 2D resistive Tokamak and Doublet
- Divertor
- Mirror Machine, Simple and Reversed Field.

Availability All codes are available on request: contact M. Kress and A. Blank; Magnetofluid Dynamics Division; Courant Institute of Mathematical Sciences; New York University, New York, NY 10012.

Documentation See Refs. [32], [33], [8], [44], [45], [68], and [34].

6.2.3. BETA

Description The BETA code is a well known research tool for two- and three-dimensional magnetohydrodynamic equilibrium. MHD equilibria are calculated in flux coordinates using an accelerated iteration procedure. The nonlinear stability of this equilibrium is analyzed using a variational procedure.

The BETA code has been extensively used in the design of all major stellarator experiments. Tokamak applications include modeling magnetic field ripple, helical shaping coils, and divertor configurations.

Availability The BETA code is currently listed on the NMFECC at Livermore.

Documentation All aspects of the code are described in [5] and [6].

6.2.4. EFIT

Description The equilibrium-fitting code EFIT was developed to perform magnetic analyses for Doublet III. It can be run in either the fitting mode or the equilibrium mode. EFIT exists on the GA VAX's and the MFECC. In the equilibrium mode, it acts as an equilibrium solver. In the fitting mode, it performs magnetic fittings. The magnetic data needed for fitting can either be retrieved from the data bank directly or from an input file. There are two versions: EFIT for Doublet III (D-III), and EFITD for Doublet III D (DIII-D). Additionally, EFIT can also perform fixed boundary calculations [72].

Users L. Lau (GA); G. Porter (LLNL)

Documentation See Ref. 72.

6.2.5. EPFC

Description EPFC calculates an approximate fixed boundary toroidal equilibrium using variational techniques. Single null, double null, and limited tokamak configurations with finite aspect ratio and arbitrary p' and FF' profiles can be modeled. A version of the code capable of handling RFP configurations also exists. Despite the approximate nature of the method, flux surface topology along with local and integrated plasma parameters computed by EPFC have been shown to agree well with those computed by exact equilibrium codes (even for strongly shaped plasmas as is found for ITER).

Special Features The code is quite fast. Execution times on various computers include: Cray-2-0.01 - 0.06 sec, Vax 11/780-0.5 - 2.0 sec, Macintosh II-4.0 - 15.0 sec.

Availability EPFC currently runs on Cray, Vax, and Macintosh computers. Contact S. W. Haney (MFECC user 30273, (415)422-6715) for copies of the code.

Users S. W. Haney (LLNL)

Documentation A manual accompanies the code.

6.2.6. EQPD

Description EQPD finds axisymmetric MHD equilibria in non-diverted and four-node poloidal divertor tokamaks with square cross sections. Uses the 2-D Chodura-Schlüter method in which 2-D magneto-hydro-friction equations are advanced numerically with conjugate gradient term. Up-down symmetry assumed. A small but finite resistivity introduced to obtain smooth plasma profiles near the divertor separatrix and internal divertor rings. Can change the number of divertor rings with moderate amount of code modifications. The code used primarily to initialize the 3-D resistive MHD simulation code, RPD, but can be used as the basis of transport calculations in poloidal divertor as well as non-diverted tokamaks.

Code Developers Eijiro Uchimoto (Courant Institute, New York University), and James D. Callen (University of Wisconsin-Madison).

Special Features Language: FORTRAN77. Compiler: CIVIC or CFT77.

Documentation E. Uchimoto, Ph.D. Thesis, Dept of Physics, Univ. of Wisconsin-Madison (1988).

Availability Contact Eijiro Uchimoto, Courant Institute, New York University, 251 Mercer St., New York, NY 10012; Tel. No. (212)-998-3273; MFE user No. 1556.

6.2.7. NEQ/HEQ/VEQ

Description These codes solve the equilibrium equations for axisymmetric ($R-Z$), free boundary problems. The output includes an eqdsk file suitable for input to stability codes. NEQ solves for poloidal field coil currents required to achieve zero pressure at a number of specifiable points with optional coil current minimization. HEQ solves in addition for coil currents and profile parameters required to fix X-point or limiter strike point locations and volt-seconds. VEQ can in addition minimize the magnetic energy. TEQ is a BASIS (see Sec. 2.1) version of these codes. It allows a very flexible runtime specification of the equation set, can do multiple runs, and includes all the N/H/VEQ features.

Availability On the NMFEC the files needed to run HEQ can be obtained from FILEM in directory .heqpub of user 1054. Contact Dennis Strickler to obtain NEQ or VEQ. To obtain the LLNL version (TEQ), contact R. Bulmer (bulmer@lln.mfenet).

Users D. Strickler (ORNL), L. L. LoDestro (LLNL).

Documentation See Ref. 119.

6.2.8. VMEC

Description VMEC is a code that solves for MHD equilibria in toroidal plasmas (tokamaks, rippled tokamaks, stellarators, torsatrons, and heliacs).

Special Features VMEC uses a steepest descent moments approach to determine the spectral representation of R , Z , and a renormalization parameter for the poloidal angle. It can be run in both free-boundary and fixed boundary modes. Options exist to specify either no net current (steady-state stellarator condition, solve for the rotational transform) or the rotational transform profile (solve for the net toroidal current). Options also exist for specification of the adiabatic pressure constraint. At present VMEC cannot handle magnetic islands.

Integration with Other Codes VMEC has been used in 2-D form as a module in the TRANSP transport code (Sec. 8.1.14) and is being incorporated into the WHIST transport code (Sec. 8.1.16). The TRACK code (Sec. 8.1.12) can be used to evaluate geometric information from the spectral coefficients. The STELOPT code uses VMEC in an optimization loop to obtain configurations with suitable transport and stability properties.

Availability A stand-alone version of VMEC demonstrates some of its capabilities and is available in either VAX or Cray forms. The stand-alone version uses DISSPLA graphics. Contacts at ORNL (FTS prefix 624): S.P. Hirshman (615)-574-1289, NMFECC user 251; W.I. Van Rij (615)-574-0639, NMFECC user 27770; Stan Attenberger (615)-574-0613, NMECC user 21070; Wayne Houlberg (615)-574-1350, NMFECC user 2357.

Users ORNL: S.E. Attenberger, N. Dominguez, S.P. Hirshman, L.M. Hively, W.A. Houlberg, D.K. Lee, R.N. Morris, W.I. Van Rij. PPPL: D.C. McCune, R. M. Wieland.

Documentation See Ref. 43.

6.2.9. VMOMS

Description VMOMS is a code that solves for fixed boundary MHD equilibria in tokamak plasmas.

Special Features VMOMS uses a shooting method to determine the spectral representation of R and Z , and assumes up-down symmetry. Results are presented in terms of the shift, elongation, and triangularity. The toroidal current profile and plasma pressure must be specified. VMOMS cannot handle magnetic islands.

Integration with Other Codes VMOMS has been used as a module in the WHIST (Sec. 8.1.16) and PROCTR (Sec. ??) transport codes. The TRACK code (Sec. 8.1.12) can be used to evaluate geometric information from the spectral coefficients.

Availability A stand-alone version of VMOMS demonstrates some of its capabilities and is available in either VAX or Cray forms. The stand-alone version uses DISSPLA graphics. Contacts at ORNL (FTS prefix 624): Stan Attenberger (615)-574-0613, NMECC user 21070; Wayne Houlberg (615)-574-1350, NMFECC user 2357.

Users ORNL: W.A. Houlberg, E.A. Lazarus, W.I. Van Rij.

Documentation See Refs. 73-75,71.

7. Particle Following Codes

7.1. Single Particle

7.1.1. TIBRO

Description TIBRO follows single particles in magnetic fields computed with MAFCO-style filamentary approximation.

Special Features Long-used code (mature).

Availability The Cray source, compiled version, data, examples, and description may be obtained from Steve Devoto on the Cray by typing `filem rds .317 .tibroc tibro`. The file *tibro* is a lib file containing all relevant files.

Users R. S. Devoto, J. H. Foote (LLNL)

Documentation [35]

7.2. Monte-Carlo

7.2.1. MCGO

Description MCGO follows single charged particles in 3-D magnetic fields either supplied analytically or on a grid. When supplied on a grid, the fields are represented by tri-cubic spline coefficients. Orbit code for studying fast ion behavior in tokamaks. Individual particle orbits may be calculated from appropriate initial conditions. Neutral beam injection may be simulated with NFREYA (Sec. 9.3.1) and the resulting steady-state, fast-ion distribution is obtained. Magnetic equilibria are specified with either concentric circular models or from EQDSK-type axisymmetric equilibrium data files. Processes simulated include, finite banana-width, charge exchange (primary, secondary, and resonant), electron and ion drag, energy diffusion, and limiter impact.

Code Output Extensive graphical output is generated. Time-dependent quantities (e.g. B , w , W) as well as orbit projections are depicted for single particle orbit calculations. Representations of neutral beam deposition and steady state fast ion distribution (e.g. heating, current, pressure) are determined in the neutral beam mode.

Availability Contact Glenn Sager (619) 455-3789 or R. W. Harvey (619) 455-3761 at General Atomics (GA).

Users G. Sager (GA), A. Molvik (LLNL)

Documentation Some documentation is self-contained in the source.

7.2.2 MCPAT

Description MCPAT, a Monte Carlo code for Particle Axial Transport, evolves an ensemble of test electrons or ions in prescribed axial electric and magnetic fields using relativistic guiding-center equations of motion [106]. The particle gyrophase is calculated, and rf heating can be modeled directly by equations of motion [106] or by using a quasilinear model. Collisions with electrons and ions are modeled by a Monte Carlo technique where Maxwellian background distribution functions with varying densities and temperatures are specified, and Spitzer scattering coefficients are used [108]. The code usually solves steady-state problems where the profiles of the background distributions may be updated from the test-particle information by a iteration procedure. The code can also be run in a quasi-time-dependent mode where an ensemble of particles are followed for a moderate number (10 to 50) of macro time-steps. The code's primary use is in calculating density and energy profiles along a magnetic field line either in open-end geometry or in periodic geometry for toroidal devices. The code has been used to study parallel electron heat transport in a tokamak divertor region when the mean free path is comparable to the distance to the divertor plate. Electrostatic potential variations can be determined by assuming a Boltzmann distribution of electrons for test ion problems or using ion fluid equations for test electron problems.

Special Features

- MCPAT uses magnetic field profiles generated by EFFI or from a cubic spline representation.
- The code can be restarted so an iteration series can be continued.
- Improved efficiency is provided by particle splitting techniques and by accelerated collisional and rf diffusion processes.
- Output is available on an FR80 plot file, which gives test-particle profile data and momentum space distribution functions. The confinement time and energy flow are also given. A printed output file has more detailed diagnostic information.

Availability Contact Rognlien@LLNL.MFENET

Users T. D. Rognlien (LLNL)

Code Benchmarking The code has been benchmarked on a number of problems. The collisional relaxation of test particles to a background Maxwellian has been verified. It yields the Pastukov rate for long mean-free-path confinement in a magnetic mirror and flow confinement for a short mean-free-path. Spitzer thermal conduction has been reproduced for a highly collisional plasma. The calculation of rf heating using the equations of motion gives the same results as the quasilinear model in the appropriate parameter regime, and super adiabatic reduction of rf heating agrees with theory for a simple quadratic magnetic well. With the quasilinear model of rf heating, the code compares well with Fokker-Planck codes.

Documentation See Refs. 106,108.

7.3. Particle-in-cell Simulation codes with self-consistent fields

2000-2001

7.3.1. DART

Description This is a recently modified version of the DART code designed to simulate the behavior of a beam of charged particles whose paths are affected by electric and magnetic fields. This code is used to design laboratory scale and full-scale beam direct converters. The code in its modified version has been generalized to treat a wide variety of problems in addition to direct converters. The simulation technique includes space charge, secondary electron effects, and neutral gas ionization, and charge exchange. Calculations of electrode placement and energy conversion efficiency are described [136].

Availability Contact Moir@LLNLMFENET

Users R. W. Moir (LLNL)

Documentation See Ref. 136.

7.3.2. DIPSI

Description DIPSI is a $1\frac{1}{2}$ -D (1D, 2V) electrostatic PIC code that is applied to the study of plasma-surface interactions in bounded plasma systems, such as divertors or plasma etching systems. DIPSI was derived from the TESS code (Sec. 7.3.8).

Special Features

- Planar or Volume Source Particle Injection
- Particle absorption or reflection at the collector plate
- Coulomb Collision Model

Availability Contact Procassini @LLNLMFENET

Users R.J. Procassini (UCB)

Documentation See Refs. 126,18.

7.3.3. EMONE

Description EMONE is a $1\frac{1}{2}$ -D relativistic, electromagnetic PIC code.

Special Features

- parametric instabilities
- RF heating
- current drive

DRAFT

Availability Contact BCOHEN@LLNL.MFENET

Users B. I. Cohen (LLNL)

Documentation See Refs. 17,10.

7.3.4. ESI

Description ESI is a basic 1-1/2 D PIC many-particle code, periodic, can be magnetized or not, with a great variety of initial conditions for $f(x, v_x)$.

Special Features A PC version of this codes is also available.

Availability Contact C.K. Birdsall at UC, Berkeley: MFE user number 1200.

Users C.K. Birdsall (UC Berkeley)

Documentation See Ref. 10, Chapters 1-5.

7.3.5. PDW1

Description PDW1 is a 1-1/2 D PIC many-particle bounded code, electrodes at either end, with external circuit.

PDW1 operates on the principles espoused in Ref. 10 with some additional features described in Ref. 77. Injection of particles from the boundaries is supported, as is initial loading, for a drifting Maxwellian distribution. (The injection parameters for PDW1 are actually painfully complete, so a modification called PDWMAX is also available for those who don't need the full generality.) Other distributions and particle sources are minor modifications. The external circuit is a series RLC circuit with both AC and DC voltage sources. A constant magnetic field in any direction is allowed.

Transportability has been made as easy as possible by limiting system-dependent subroutine calls (such as graphics and other I/O) to a very few of the main routines in the code. The only compiler-dependent features are the use of a precompiler and one use of a compiler directive. These should be easy to translate to another system.

This code was intended for use both as a research and teaching tool. Because of this, it was written with some care toward clarity and, therefore, *should* be relatively easy to learn and use.

Special Features

- electrodes emit drifting cut-off Maxwellian velocities
- electrodes may be absorbing, reflecting, secondary emitting, etc.
- useful for 1-D sheath particle and energy transport
- PC version also available

Availability Contact William Lawson, Courant Inst., 251 Mercer St., New York, NY 10012, (212)-998-3260; Prof. C.K. (Ned) Birdsall, EECS Dept., U. of Calif., Berkeley, CA 94720, (415)-643-6631; Perry Gray, Dept. of Physics, Dartmouth College, Hanover, NH 03755, (603)-646-3969

Users C.K. Birdsall (UC, Berkeley)

Documentation See Refs. 10, 76, and 77.

7.3.6. PDW2

Description PDW2 is a particle, electrostatic, 2-1/2 D, bounded in X with external circuit, periodic in Y code.

PDW2 is intended as a directly upward compatible two dimensional extension of PWD1. PDW2 operates on the principles espoused in Ref. 10 with some additional features described in Ref. 77. Fields are solved with a combined finite difference Fourier technique with rectangular grids [10]. Injection of particles from the boundaries is supported, as is initial loading, for a Maxwellian distribution. Other distributions and particle sources are minor modifications. The external circuit, in the bounded dimension, is a series RLC circuit with both AC and DC voltage sources. A constant magnetic field in any direction is allowed.

Transportability has been made as easy as possible by limiting system-dependent subroutine calls (such as graphics and other I/O) to a very few of the main routines in the code. The only compiler-dependent features are the use of a precompiler and one use of a compiler directive. These should be easy to translate to another system.

This code was intended for use both as a research and teaching tool. Because of this, it was written with some care toward clarity and, therefore, *should* be relatively easy to learn and use.

Availability Contact Perry Gray, Dept. of Physics, Dartmouth College, Hanover, NH 03755, (603)-646-3969; Prof. M.K. Hudson, Dept. of Physics, Dartmouth College, Hanover, NH 03755, (603)-646-2976; Prof. C.K. (Ned) Birdsall, EECS Dept., U. of Calif., Berkeley, CA 94720, (415)-643-6631; William Lawson, Courant Inst., 251 Mercer St., New York, NY 10012. (212)-998-3260.

Users C.K. Birdsall (UC, Berkeley)

Documentation See Ref. 76,10,77.

7.3.7. PDWZ

Description PDWZ is the same as PDW1 (Sec. 7.3.5) but in 2-1/2 D, where *x* is the bounded direction and *y* is the periodic direction.

Special Features

- allows wave along bounding walls, like Kelvin Helmholtz instability for magnetized plasma (see PRL 13, Feb, 1989).

7.3.8. TESS

Description TESS is a $1\frac{1}{2}$ -D guiding center, open-field line electrostatic PIC code.

Special Features

- ECRH
- ICRH
- Neutral beam injection
- Ambipolar potential
- Coulomb Collision Model

Availability Contact BCOHEN@LLNL.MFENET

Users B. I. Cohen (LLNL), R.J. Procassini (UCB)

Documentation See Refs. 126,18.

7.3.9. VSI

Description VSI is a basic 1-D electrostatic code in which the perturbed part of the Vlasov equation is solved along the particle trajectories. The Vlasov equation may or may not be linearized. The code has reduced particle noise, especially in the linearized case.

Availability Contact E. Morse; MFE user number 30155

Users G. DiYen, U.C. Berkeley

Documentation Forthcoming.

7.3.10. ZOHAR

Description ZOHAR is a $2\frac{1}{2}$ -D relativistic, electromagnetic PIC code.

Special Features

- Parametric instabilities
- RF heating

Availability Contact BCOHEN@LLNL.MFENET

Users A. B. Langdon, B. I. Cohen (LLNL)

Documentation See Ref. 70.

8. Plasma Transport Codes

8.1. Cross-Field Transport

8.1.1. BALDUR

Description BALDUR is a $1\frac{1}{2}$ -D transport code designed to simulate a wide variety of plasma conditions in tokamaks. The code follows the time evolution of particle densities (up to two hydrogenic species and up to four impurity species), electron and ion temperature, and poloidal magnetic flux density as a function of flux surface. The shapes of the flux surfaces are determined by solving axisymmetric equilibrium force balance equations, given conditions that may be changing with time. BALDUR provides a detailed treatment of neutral hydrogen transport, auxiliary heating, multispecies effects (including an extensive atomic physics package), orbits of α -particles, plasma compression, ripple transport, and edge processes such as "scrape-off" losses. There are a wide variety of transport models available as options, and different transport models can be combined additively. In addition, there are various options to treat the axisymmetric effects resulting from sawtooth oscillations, saturated tearing modes, and high- n ballooning modes. The code has been used to aid interpretation of data from tokamak experiments and for evaluating designs of future tokamak devices.

Special Features Most of the BALDUR code follows OLYMPUS conventions. The 1-D version of the code used the OLYMPUS preprocessor. NAMELIST is used for specifying the input parameters, with a provision for inline comments in the input file. Choices among a variety of graphical and printed output options are provided.

Availability Contact Redi@PPC.MFENET or Bateman@PPC.MFENET. Recent versions of the code are available on the US Magnetic Fusion Energy Computer Center. The 1-D version of the code described in Ref. 114 is in the CPC Program Library, Queen's University of Belfast, N. Ireland.

Users M. Redi, Glenn Bateman, D. P. Stotler (PPPL), C. E. Singer (U. Illinois), R. Engle (MIT), M. Hughes (Grumman), S. Sabbagh (Columbia)

Documentation A 1-D version of the code is documented in Ref. 114. Additional documentation for the $1\frac{1}{2}$ -D version of BALDUR is available online at the US Magnetic Fusion Energy Computer Center.

8.1.2. BETA MC (Monte Carlo)

Description The BETA MC code calculates particle and heat losses through Monte Carlo simulations of particle orbits. The guiding centers of particle trajectories are calculated in Boozer coordinates and discrete particle effects are simulated using a model collision operator. The electric-field potential is calculated self-consistently from quasineutrality instead of Ohm's law.

The BETA MC code uses a number of advanced numerical techniques that significantly enhance its performance above the standard scheme. The input data is automatically produced in the BETA equilibrium code

The major physical results is that the electron-loss rate becomes comparable to the ion-loss rate. Magnetic field ripple and electromagnetic perturbation produce this effect in tokamaks. To model three dimensions and perturbations in tokamaks, small helical perturbations have been added to the plasma.

Availability The BETA MC code is available on request: contact Frances Bauer, Octavio Betancourt and Paul Garabedian: Courant Institute of Mathematical Sciences: New York University: New York, NY 10012.

Documentation It is documented in [7].

8.1.3 CFRX

Description CFRX is a 1-1/4-D fluid transport code designed to simulate a wide variety of plasma conditions in the Field-Reversed Configuration (FRC). The code follows the temporal evolution of ion density, ion and electron temperature, and axial magnetic field as a function of flux surface in both the closed- and open-field-line regions. The FRC equilibrium is assumed to be highly elongated, and equilibrium is enforced through a radial pressure balance equation and a radially-averaged axial tension balance constraint. Cross-field transport is followed using classical or Bohm transport scalings. The extra 1/4 dimension arises through the inclusion of three multi-dimensional effects: (1) flux-surface averaging within the closed-field region; (2) axial contraction of the closed-field region mandated by the equilibrium constraints; and (3) parallel transport loss terms included on open field lines. CFRX has been used to aid interpretation of data from FRC experiments at Los Alamos.

Availability The code is available on the US NMFECC Network, contact K.-M. Ling, K.A. Werley (LANL) or M.-Y. Hsiao (Penn State). The code will also soon be available in the CPC Program Library, Queen's University of Belfast, N. Ireland (Ref. 47).

Users K.-M. Ling, D. Rej, K.A. Werley (LANL), M.-Y. Hsiao (Penn State)

Documentation The formulation of the model is described in Ref. 15. The numerical embodiment and application of the model are described in Ref. 135. A user's guide is provided by Ref. 47.

1.4 CHAPO

Description CHAPO is a predictive one-dimensional transport code. It has several modules that can be activated or deactivated individually. The primary module integrates the radial diffusion equations for the parallel current, the electron and ion energies, and the density of the working gas. There is a neutral particle module and two impurity modules, each of which allows for all the charge states of an impurity element to be evolved. The code is designed for the comparison of theoretically based transport models with experimental data in a context that is geometrically simple, but includes a description of all relevant subsidiary physics (sources and sinks).

Special Features Implementation of a large number of theoretical models, including off-diagonal elements; links to the TEXT and MFE experimental databases; flexibility and ease of use.

Availability Contact James C. Wiley, Fusion Research Center, The University of Texas at Austin, Wiley@UTA

Users J.C. Wiley, W.H. Miner, Jr., D.W. Ross, and members of TEXT staff, U. of Texas.

Documentation A draft report describing the code has been prepared. It is available to prospective users upon request.

8.1.5. HPFB

Description The Heat Pulse Forced Boundary (HPFB) is a predictive transport code used to calculate the thermal diffusivity from time-dependent perturbations. The advantage of HPFB over traditional predictive codes is that the actual experimentally measured diagnostic data is input into the computation through time-dependent boundary conditions. No theoretical assumptions about input power or thermal diffusivity in the region outside the heat pulse region are necessary; thus, a more accurate determination of χ_e is possible.

Both convective and diffusive terms are included in the density and electron-and-ion temperature equations. Neoclassical resistivity and ion heat conductivity are used. To reduce experimental noise, a sawtooth-averaging model is included.

Documentation The method and results obtained in ASDEX are documented in Ref. 104.

Availability Copies of the code are available on request: contact Kurt S. Riedel, Courant Institute of Mathematical Sciences, New York University, New York, NY 10012; and L. Gianone, Max-Planck Institute for Plasma Physics, Garching, West Germany.

8.1.6. IHTMDC

Description IHTMDC is a 2-dimensional heat transport code for calculating ion heat transport in a model divertor configuration. The geometry is simplified by replacing the true magnetic-divertor geometry with a circular cross-section model and a toroidally symmetric limiter. The ion-energy balance equation is solved for the ion temperature in a boundary layer containing the separatrix, defined as the magnetic surface that is tangent to the limiter, neglecting particle transport and energy exchange with electrons. Both neoclassical and anomalous transport are included. The standard neoclassical transport is generalized near the separatrix to include the significantly larger poloidal temperature gradient there. The anomalous transport is modeled with a larger poloidal temperature gradient there. The anomalous transport is modeled with a simple term containing an anomalous thermal conductivity whose value is an input parameter. The ion temperature and the neoclassical and anomalous heat fluxes, averaged over a magnetic surface are obtained as functions of minor radius, for various values of the input parameters, which include the temperature gradient well inside the separatrix, the magnitude and poloidal dependence of the anomalous thermal conductivity, the aspect ratio, and the poloidal field of the divertor.

Availability Contact F.L. Hinton at General Atomics (GA).

Users F.L. Hinton

Documentation None

DRAFT

8.1.7. MINERVA

Description MINERVA is a 1-1/2 D transport code designed to simulate low beta Spheromak transport. The separatrix is allowed to touch the geometric axis and special attention is given to including the resultant singularities correctly. The code can presently calculate the magnetic field diffusion (which decouples from the equations for the evolution of the density and temperatures). Classical transport is assumed, but not hardwired in. Other transport models may be included as subroutines. Inclusion of the evolution of the density and temperatures is underway.

Availability The code is presently under development. An experimental version (no guarantees) may be had from 517mfe.

Users A.G. Sgro

Documentation See Ref. 112.

8.1.8. MIRTH

Description MIRTH, (Multigroup Ion Radial transport and THERmalization), is a code that solves an approximation to the Fokker-Panck equation appropriate for thermalization of fast ions from neutral beam injection or fusion reactions.

Special Features The MIRTH code uses a simple approximation to the time-dependent Fokker-Planck equation to calculate downscattering in energy. The pitch angle dependence is integrated out of the equations. The downscattering includes that due to classical Coulomb collisions plus an option for a user-supplied energy loss term. Another option exists to include radial diffusion in real space replacing the usual pitch angle terms.

Integration with Other Codes MIRTH is a module of the WHIST (Sec. 8.1.16) transport code, and is used for both fast beam ions and fast alphas.

Availability Contacts at ORNL (FTS prefix 624): Stan Attenberger (615)-574-0613, NMFECC user 21070; Wayne Houlberg (615)-574-1350, NMFECC user 2357.

Users ORNL. S.E. Attenberger, W.A. Houlberg.

Documentation See Ref. 1.

8.1.9. ONETWO

Description ONETWO is the 1-1/2 D time-dependent main transport code developed and used at General Atomics since the mid-70's for modeling plasmas in tokamaks. Both circular and noncircular cross section plasma can be modeled with specified currents in field shaping coils. Electrons and several ion species are treated as fluids and neutrals are treated kinetically. Neoclassical and

model anomalous transport mechanism are treated. Important physical process that produces sources and sink of particles and energies are treated with various subroutines: NEUCG for wall recycled neutrals, NFREYA (Sec. 9.3.1) for neutral beams, TORAY (Sec. 9.1.2) for electron cyclotron heating and current drive to name a few examples. Models for pellet fueling, fusion, ohmic heating fast ion to name a few examples. Models for pellet fueling, fusion, ohmic heating fast ion storage are also included. Short circuit transport processes for sawteeth and low- m tearing modes (DELSOL) ?? are included.

There are two ways of treating MHD equilibria: A 1D mode in which simple ellipsoidal flux surfaces or externally generated and arbitrary equilibria are used; and a 1-1/2 D mode in which magnetic flux surfaces are determined and updated with calls to a 2D MHD equilibrium code.

Special Features There are two modes of operation. In the simulation mode the primary quantities such as particle densities, temperatures and current density are transported with prescribed diffusion coefficients using the particle and energy conservation equations and Faraday's law. In the analysis mode experimental density and temperature profiles are inverted from calculated sources to find the diffusion coefficients.

Code Output The code output is both numerical and graphical. Graphical output is created by running post-processors on files created during the run. Separate processors are used for equilibrium, transport, and neutral beam plots. Control of the quantities actually plotted is provided by plot flags and scale parameters in the input file.

Availability Contact H. St. John at General Atomics (GA) StJohn@GAV.MFENET

Users R.E. Waltz, R.R. Dominguez, R. Stockdale, R.W. Harvey, K. Matsuda, K.H. Burrell, D.P. Schuessel, R. Groebner (GA); G.D. Porter (LLNL); and S. Wolfe (MIT).

Documentation The code is described in Ref. 101. Sample publications of work done with the code include Refs. 23, 94, and 39.

8.1.10. RFPBURN

Description RFPBURN is a 1-D (cylindrical) transport code designed to simulate a wide variety of plasma conditions in the Reversed Field Pinch (RFP) and in the High Density Z-Pinch (HDZP). The code follows the radial and temporal evolution of fuel and alpha-particle density, ion and electron temperature, and poloidal and axial (toroidal) magnetic field. Equilibrium is enforced through a radial pressure balance equation. There is a variety of transport models available including density- or pressure-gradient driven diffusion, as well as thermal force terms; and, it is a trivial exercise to add new transport coefficients. The code includes a 1-D neutral-hydrogen transport description, an impurity-density-specified coronal equilibrium radiation model, an up-to-date pellet injection model, a mean-field dynamo model required to permit steady RFP equilibria, and a fusion-product alpha-particle slowing-down model. RFPBURN has been used to examine a wide range of specific phenomena including sawtooth oscillations, oscillating-field current drive, dynamo, quasi-linear effects of Alfvén waves and pressure- and current-driven instabilities, pellet injection, impurity injection, radiation collapse, soft beta limits, ignition, and reactor operation. The code also provides profiles for linear stability calculations and for self-consistent coupling with edge-plasma transport models. Additionally, a separate version (RFPEDGE) treats a cylindrical

annulus and include axial loss terms for simulating edge plasmas. Another version (ZAP) treats a cylindrical annulus with a moving inner boundary of solid hydrogen, also including the external circuit equations, for simulating HDZP start-up.

Availability Recent versions are available on the MFECC Network, contact K. Werley or R. Nebel at Los Alamos.

Users K.A. Werley, R.A. Nebel (LANL), R. Veerasingam (Penn State), R. Scardovelli (Wendelstein), J. DeVaux (Phillips Petroleum)

Documentation Older versions of the code are documented through a series of U. of Illinois reports and theses, contact K. Werley or R. Nebel at Los Alamos.

8.1.11. SNAP

Description

Special Features

- For rapid analysis of experimental data
- Time-independent, shifted circles
- Input includes measured profiles, radiation and neutron emission, ...
- Output includes confinement times, power balance, and profiles not measured
- 125 SNAP runs available in Texas data base

Documentation See Ref. ?

8.1.12. TRACK

Description TRACK is a suite of routines for computing the intersections of a trajectory with a set of nested flux surfaces, finding magnetic field components at a given point, and transforming between flux coordinates and Cartesian or cylindrical coordinates of toroidal plasmas.

Special Features The TRACK routines are applicable to any toroidal device (axisymmetric or non-axisymmetric plasmas) and contains several entry points for different problems. The geometry and magnetic field must be represented in spectral form (i.e., sine and cosine expansions of R, Z, and B)

Integration with Other Codes TRACK requires spectral coefficients as input —these may be provided by VMOM9 (Sec. 6.2.9) or VMEC (Sec. 6.2.8) equilibria or by simple approximation. It has been integrated into the WHIST (Sec. 8.1.16) and PROCTR (Sec. ??) transport codes to provide chordal information for neutral beam and pellet injection, and interpretation of chordal density and charge exchange signals, etc.

Availability A stand-alone version of TRACK demonstrates some of its capabilities and is available in either VAX or Cray forms. The stand-alone version uses DISSPLA graphics. Contacts at ORNL (FTS prefix 624): Stan Attenberger (615)-574-0613, NMFECC user 21070; Wayne Houlberg (615)-574-1350, NMFECC user 2357.

Users ORNL: S.E. Attenberger, L.D. Horton, W.A. Houlberg, H.C. Howe.

Documentation See Ref. 2.

8.1.13. THEORY

Description THEORY computes the microinstability-theory-based transport coefficients given in Ref. 113. Transport from the following modes is included:

- Drift waves, including trapped electron and η_i
- Rippling
- Resistive ballooning
- kinetic ballooning
- high frequency (η_e)

Special Features This code is written to be a subroutine within the BALDUR code (Sec. 8.1.1), but can also be used as a stand-alone code to calculate fluxes from various transport mechanisms.

Availability The subroutine can be obtained on the NMFECC by typing:

```
cfs
get /004121/bald88/wbaldn1
end
```

This produces a *lib* file, which contains the required codes.

Users Singer (U. Ill.)

Documentation See Ref. 31.

8.1.14. TRANSP

Description TRANSP is a time-dependent, $1\frac{1}{2}$ -D transport analysis code. The data inputs to the code include plasma current I_p , surface voltage, V , and spectroscopic measurements of hydrogen and impurity confinement times (τ_p^H , and τ_p^O) in addition to profile measurements of electron density $n_e(r, t)$, and electron temperature, $T_e(r, t)$, ion temperature, $T_i(r, t)$, and the radiated power, $P_{rad}(r, t)$. On the basis of the measurements, the code solves the magnetic field diffusion equation for the poloidal magnetic field, $B_\theta(r, t)$ in order to evaluate $Z_{eff}(t)$, and the current density: $j(r, t)$ [38].

Users M. Zarnstorff (PPPL)

Documentation See Ref. 38.

8.1.15. TSC

Description TSC is the Tokamak Simulation Code developed at PPPL and used extensively in Princeton and throughout the world. It can model the evolution of a free-boundary axisymmetric tokamak plasma on several different time scales. The plasma equilibrium and field evolution equations are solved on a 2D Cartesian grid, while the surface averaged transport equations for the pressures and densities are solved in magnetic flux coordinates. An arbitrary transport model can be used, but the Coppi-Tang model is used most frequently. Neo-classical resistivity, bootstrap current, auxiliary heating, current drive, alpha-heating, radiation, pellet injection, sawtooth, and ballooning mode transport models are all included. As an option, circuit equations are solved for all the poloidal field coil systems with the effects of induced currents in passive conductors included. Realistic feedback systems can be defined to control the time evolution of the plasma current, position, and shape. Required voltages for each coil system can be output as part of a calculation. Vertical stability and control can be studied, and a disrupting plasma can be modeled.

Special Features TSC can be run in a "data comparison" mode in which case it reads specially prepared data files for the PBX-M, TFTR, or DIII-D experiments. For each of these, a special post-processor exists, which directly compares TSC predictions with both magnetics and kinetics data for particular shots from these experiments. In all modes, TSC calculates the ballooning mode stability criteria internally, and also writes files that are read by the PEST code to calculate low-n mode ideal and resistive stability.

Availability The FORTRAN source file is called TSCPUB7 and is stored in CFS FILEM directory 431.PUBLIC. It compiles under CIVIC, CFT77, or CFT2, uses TV80LIB and NAG, and runs only on the BMA and FMA. Versions are available in CRPP/EPFL (Switzerland), IPP (Germany), and JAERI (Japan). Contact S. Jardin (PPPL).

Users T. Kaiser, D. Shumaker (LLNL); S. Jardin, N. Pomphrey, C. Kessel, D. Ward (PPPL); R. Sayer, J. Whitson (ORNL); K.M. Ling, C. Bathke (LANL); J. Ramos, T. Yang (MIT); B. Merrill (EG&G); M. Shoucri (IREQ, Canada); R. Weiner (IPP, Garching); F. Marcus (CRPP/EPFL, Switzerland); Y. Mizuno (IPP, Nagoya); T. Tsunematsu, Y. Nakamura, Tsutsui (JAERI, Japan).

Documentation A 58-page users manual is available from either Jardin at PPPL. The computational model is described in Ref. 57, and benchmarking of the code against experiment in Ref. 60.

8.1.16. WHIST

Description WHIST (Wayne Houlberg Implicit Space Time), is a time-dependent, 1 1/2-D transport code. Many parts of the code are able to accommodate stellarator geometry, and work is in progress to make the code fully compatible with both stellarators and tokamaks. The code has been written with the intent of making it available to all interested persons. It is expected that users will have some familiarity with transport theory. Documentation is primarily internal (FORTRAN comments). Typical cases take a minute or two of Cray execution time.

Special Features Some of the modules of WHIST are available as free-standing codes with example input and output files. These include a pellet ablation package, the VMOMS equilibrium solver (Sec. 6.2.9), a general purpose geometry package (TRACK, Sec. 8.1.12), and a neutral beam package. These packages and the complete WHIST code are fully supported: i.e., help with their use and fixing of bugs is provided by the code developers.

Availability An automated procedure exists to generate Vax or Cray code for the WHIST code or any of its modules. The code is easily adapted to IBM or other computers. Contact the code developers below for a version adapted to your needs.

Users W.A. Houlberg, S.E. Attenberger (ORNL)

Documentation The WHIST code is documented with comment lines within the source.

8.1.17. ZERO

Description ZERO is primarily a 0D transport code for fitting confinement-time models to data and extrapolating to ignition. Using prescribed parabolic profiles or density and temperature sources for ohmic heating, bremsstrahlung, and impurity radiation, alpha fusion power are readily calculated. These global power sources and sinks are balanced against semi-empirical theoretical models for transport power losses from the trapped electron and ion-temperature gradient modes. The code can be run in a two-temperature, time-dependent mode to fit the models to data on confinement time. The code can run scans over current and density or take input from large-global, confinement-time data bases. The fitted power losses are then used to generate density-temperature power contours to ignition (POPCON Sec. 5.1.2 plots). Options permit the use of Kaye-Goldston empirical models as well.

The code also contains an option for 1D one-temperature steady-state calculations with fixed density profiles and prescribed theoretical models for heat diffusivity. Model auxiliary heating profiles are prescribed but ohmic heating is self consistently calculated with Spitzer's law. The code operates by "shooting" from the outer radius to the $q = 1$ surface where a sawteeth short circuit is prescribed. This is followed by iteration to obtain a current profile consistent with Spitzer's law. The code is stable to operation near marginal stability for temperature gradient mode thresholds. It is 10-30 times more efficient than the standard 1D time-dependent codes for this limited class of problems.

Availability Contact R.E. Waltz at General Atomics (GA).

Users R.E. Waltz and R.R. Dominguez (GA)

Documentation There is no detailed documentation of this code; however, a publication that has used this code can be found in Ref. 132.

8.1.18. CROSS-REFERENCE

Other codes that are useful for studying cross-field transport are found in Sections 10.2.1 and 10.2.2.

8.2. 2-D Transport

8.2.1. B2

Description B2 is a multi-fluid code for study of the two-dimensional structure of the tokamak edge plasma. The code models an electrically neutral and current-free plasma containing several ion species and electrons. Each ion fluid is governed by a Navier-Stokes system of equations. Coupling between the plasma species occurs through ionization and recombination processes, interspecies friction, electric and thermal forces, and temperature equilibration. Parallel transport is assumed classical, while radial transport is anomalous. A simple neutral gas model is included in B2.

Special Features The code consists of a large number of files on the VAX, which are concatenated and shipped to the Cray for compilation and loading. Several of the files are problem-dependent routines; sample problem setups are available for ASDEX, DIII-D, JET, NET, INTOR and ITER.

Availability Source files and the tools necessary to assemble the code are stored in CFS under user number 30137 (Rensink). Also, the code author (Bas Braams) can be reached on the MFENET with the name BBRAAMS@PPC.MFENET and has been very willing to help new users.

Users M.E. Rensink (LLNL), B. Braams (PPPL)

Documentation The most complete code documentation is in Ref. 11. Copies may be available from the author (temporarily at PPPL). Several publications referenced in Ref. 11 describe specific applications of the code.

8.2.2. PLANET

Special Features

- 2-D transport in divertor and scrape-off layer
- Advective transport due to drift effects
- Realistic geometry
- Coupled to DEGAS

8.3. Parallel Transport

8.3.1. PHLOW

Description PHLOW is a time-dependent, one-dimensional code for ion transport along a single magnetic flux tube. The equations used are essentially the double-adiabatic equations of Chew, Goldberger, and Low but collision coupling between the perpendicular and parallel temperatures is used [107]. The ion equations are advanced using an explicit two-step Lax-Wendroff scheme. Either open-end or periodic boundary conditions can be used. The electrons are represented by a pressure balance equation allowing anisotropic pressure. The electron temperature profiles can be specified or calculated using a Spitzer thermal conduction model that is finite-differenced implicitly.

Special Features

- PHLOW can be coupled to the Monte Carlo code MCPAT (Sec. 7.2.2) such that MCPAT calculates the electron profiles and PHLOW calculates the ion profiles. PHLOW can also be used to give initial profiles for ion Monte Carlo calculations.
- Code output is in the form of an FR80 plot file showing profiles of ion density, drift velocity, perpendicular pressure, and parallel pressure. Magnetic field profiles can be read from EFFI output (Sec. 3.3.1) or specified using cubic splines.

Availability Contact Rognlien@LLL.MFECC

Users T. D. Rognlien (LLNL)

Code Benchmarking The code reproduces analytic stagnant flow solutions for the symmetric penetration of warm plasma into a mirror cell. It also shows the expected transition to supersonic flow at the mirror throat for the asymmetric, finite flow velocity case.

Documentation See Ref. 107.

8.3.2. ZCODE

Description ZCODE contains a 1-D (parallel to the magnetic field) steady-state, fluid description of ion density, ion momentum, and ion and electron temperature. The transport model assumes classical parallel conductivities with free streaming heat flux limits enforced on both the ions and the electrons, and applies sheath boundary conditions at one side. A 1-D neutral-hydrogen transport description is included, as well as flux-surface expansion effects. ZCODE is used to help simulate edge-plasma conditions.

Special Features ZCODE is set up to interface directly with a series of other codes useful for describing edge conditions, including a radial cross-field transport code, RFPEDGE; a 2-D magnetic equilibrium code geometry from either NEQ (Sec. 6.2.7) or TORSIDO; a divertor-plate locator and shape-optimizer code, DIVLOC; and finally, a 2-D neutral-atom transport code, DEGAS (Sec. 9.4.1).

Availability The code is available on the MFECC Network, contact K.A. Werley.

Users K.A. Werley (LANL)

Documentation Documentation consists of a viewgraph package, contact K.A. Werley

8.3.3. CROSS-REFERENCE

Other codes that are useful for studying parallel transport are found in Sections 7.2.2 and 7.3.5.

8.4. Impurity Transport

8.4.1. MIST

Description MIST is a time-dependent, 1-D multi-species impurity transport code that solves the coupled continuity equations for each charge state of a given impurity element in cylindrical geometry. The radial impurity ion transport particle flux is taken together with source and sink terms, and the atomic processes of ionization and recombination to determine the evolution of the radial distribution of each impurity ion charge state in the plasma, along with other associated quantities.

Special Features MIST takes as input either fixed or time-dependent profiles of the plasma electron temperature, electron density, neutral hydrogen density and energy, etc., along with choices for the impurity transport coefficients and atomic physics to be used for a particular run. Complete (though approximate) atomic rate data is presently available in MIST to allow calculations for any impurity element, with plans to include ALADDIN (Sec. 3.1.1) atomic physics database interface capability to access IAEA standardized evaluated atomic data as it becomes available. The code uses an implicit finite-difference numerical scheme, which is embedded in a predictor-corrector loop to handle nonlinear transport coefficients, edge sources with finite "recycling" coefficients, etc. Dynamic time-step control allows the calculation to adapt to changing time scales in the solutions. Among the advantages of the implicit numerical method is that it allows transport equilibrium (time-independent) solutions to be obtained directly (for linear transport models). Such equilibrium solutions can be obtained via a single input switch setting.

MIST output is available in both tabular as well as plotted form. The tabular output can be read by various databases, post-processors, pasted into Macintosh graphics and spreadsheet programs, etc., for flexible manipulation and plotting of results in customized applications. MIST versions are available for the DEC VAX as well as MFECC's Cray computers. The VAX version does not generate plotted output.

MIST code development has been primarily oriented towards providing support for experimental data analysis and modeling, with straightforward setups for these applications and output emphasizing experimentally relevant quantities such as spectral line brightnesses, radiated power profiles, and Z_{eff} profiles. Transport equilibrium runs are routinely used for basic interpretation of impurity-related diagnostic data such as VUV and X-ray spectra, and can be obtained in 10-20 seconds of VAX-8600 time. Time-dependent runs are used primarily for analysis of impurity injection experiments and interpretation of shots with strongly time-varying plasma profiles. Such cases are usually run using the faster original MFECC's Cray implementation of the code, and typically take 1-3 minutes on Cray-1.

Availability Contact Russell Hulse (PPPL, (609)243-2621, email HULSE@PPC.MFENET)

Users PPPL/TFTR (R. Hulse, B. Stratton, et al.), GA/DIII-D (M.A. Mahdavi, N. Brooks, et al.), LLNL/DIII-D (S. Allen), John Hopkins University/DIII-D (M. Perry), Université du Québec Tokamak de Varennes (K. Parbhakar, K. Dimoff, et al.), LASL/ZT-40 (T. Cayton), JAERI JFT-2M (H. Ogawa)

Documentation The basic published MIST reference is Ref. 49. The VSOP pre-processor used for MIST code generation (R. Hulse, author) automatically generates documentation on common

block and input variables, and this documentation is provided for user reference along with sample input files, etc.

9. Sources and Sinks

9.1. Electron-Cyclotron Frequency

9.1.1. TORCH

Description The TORCH, (Toroidal Ray-tracing Current Drive and Heating), code traces rays that represent a microwave beam in the electron-cyclotron frequency range. Equilibrium quantities ($\bar{B}$, n_e , and T_e) can be obtained from analytic models or from MHD codes via an EQDSK file. TORCH calculates radial profiles of power deposited and current driven. The code can also calculate profiles of power deposition on a calorimeter. Rays can be reflected by mirrors in the region exterior to the plasma. TORCH can also simulate a cyclotron-emission diagnostic by computing the power emitted and reabsorbed along rays that are accepted by the diagnostic.

Special Features TORCH is organized as a set of packages that are configured by the BASIS system (see Sec. 2.1). The BASIS interpreter handles all input and output and provides access to internal documentation about the packages and variables.

Availability TORCH can be obtained on the NMFEC Cray-2's in a lib file that contains sample input files. Type `cfs get /3030/torch2/torch`.

Users G. Smith (LLNL)

Documentation

9.1.2. TORAY

Description TORAY is primarily a 3-D, time-independent, ray-tracing code for electron-cyclotron waves, and computes single-pass absorption rates, current-drive efficiencies, energy-deposition profiles, and driven-current profiles. By interfacing to ONETWO (Sec. 8.1.9), TORAY can be used for time-dependent problems. There are many options to run the code, such as a noncircular cross-section with numerically given density and temperature profiles, a circular cross-section with prescribed parabolic profiles, etc. The code uses the cold-plasma dispersion relation to trace rays, but uses solutions of a relativistic dispersion relation for absorption, and includes a relativistic current-drive theory.

The main frame of TORAY was developed by Arnold Kritz (Hunter College) and Gary R. Smith (LLNL). At General Atomics, the code has been improved by installing a computation of relativistic absorption that includes a capability to model non-Maxwellian electrons by a two-temperature distribution, and also improved in the efficiency by a factor $10 \sim 40$.

Availability Contact K. Matsuda at General Atomics (GA).

Users K. Matsuda, V. Chan, R.H. Harvey (GA), R. James (LLNL, GA)

Documentation There is no detailed documentation for this code; however, one publication that has used the code can be found in Ref. 89.

9.2. Ion-Cyclotron Frequency

9.2.1. ANTENA

Description ANTENA (McVey Code) calculates the time-harmonic self-consistent plasma fields from a variety of antenna types, to an infinitely long cylindrical plasma within a cylindrical conducting boundary. Single antennas or phased arrays can be handled. Antenna types include full and partial turn loops, Nagoya type III (Kharkov), rectangular apertures, saddle coils, and line currents. Radial profiles of density and temperature are approximated by steps for Gaussian, parabolic or arbitrary user input profiles. The warm plasma dispersion relation is used to compute Landau and cyclotron absorption, with a Krook operator to simulate collisional absorption. It has been particularly useful for calculating the loading resistance, and studying ponderomotive stabilization effects.

Special Features The following parameters can be scanned: radius, azimuthal angle, axial position, frequency, density, magnetic field, temperature, and parallel wave number. A second scan can be nested in the first.

Availability ANTENA can be obtained on the NMFEC's Crays. Type files `rds 1437 .icrf xantenc4 xplota4`. XANTENC4 is the executable file, and XPLOTA4 is the plot package. The file ANTNEWS contains information on the latest updates to the code. ANTENA is also available as part of the BASIS package.

Users G. Smith (LLNL)

Documentation

9.2.2. ICRH

Description See D. Bachelor!

Special Features

Code Benchmarking

Availability

Users

Documentation See Ref. ?

9.2.3. FIRC

Description FIRC is a 1-D Fundamental Ion Resonance Code (FIRC). Propagation, transmission, reflection, absorption of the magnetosonic mode across the fundamental ion cyclotron resonance layer are computed. Solution of the three basic scattering problems are obtained: (1) Fast-mode incidence from high-field side, (2) Fast-mode incidence from low field side, and (3) Slow mode incidence. The component of E along equilibrium magnetic field is ignored. Warm plasma electric current is derived from linearized Vlasov equation within a boundary layer near the resonance surface.

Special Features ODE solver DVERK is used from IMSL package to construct linearly independent solutions of the field equation. Appropriate linear combinations of these solutions are matched to WKB solutions yielding full wave solutions. Asymptotically growing solutions are suppressed by reduction of order method.

Availability Contact Kaya Imre or Harold Weitzner, Courant Institute of Mathematical Sciences, New York University, New York, NY 10012.

Documentation See Refs. 50, 50, and 58.

9.2.4. MFIRC

Description MFIRC is a 1-D Minority Fundamental Ion Resonance Code with poloidal field. We allow the poloidal component of the equilibrium magnetic field to be non-zero and show that the field equations become an integrodifferential system. We compute the propagation, transmission, reflection, absorption of the incident fast mode across the fundamental ion cyclotron resonance layer. Solutions of the basic scattering problems are obtained: (1) Fast-mode incidence from high-field side and (2) Fast-Mode incidence from low-field side. Warm plasma electric current is derived from the linearized Vlasov equation within a boundary layer near the resonance surface.

Special Features The integral operator is truncated and discretized. We obtain linearly-independent solutions for this system. Appropriate linear combinations of these solutions are matched to WKB solutions yielding full wave solutions.

Availability Contact Kaya Imre, Harold Weitzner, and D.C. Stevens, Courant Institute of Mathematical Sciences, New York University, New York, NY 10012.

Documentation See Refs. 134, 53, and 59

9.2.5. SHIRC

Description SHIRC is a Second Harmonic Ion Resonance Code with poloidal field. We allow the poloidal component of the equilibrium magnetic field to be non-zero and show that the field equations become a fourth-order integrodifferential system. We compute the propagation, mode conversion, transmission, reflection, and absorption of the incident waves across the second harmonic ion-cyclotron resonance layer. Solution of the three basic scattering problems are obtained:

(1) Fast-mode incidence from high-field side, (2) Fast-mode incidence from low-field side, (3) Slow-mode incidence. Warm plasma electric current is derived from linearized Vlasov equation within a boundary layer near the resonance surface, as a linear functional of the equilibrium magnetic field.

Special Features We obtain the solutions of the integrodifferential system by constructing an appropriate right-hand side for the ODE corresponding to the perpendicularly stratified case. The integral operator is truncated and discretized to obtain this right-hand side. We obtain linearly independent solutions for this system. Appropriate linear combinations of these solutions are matched to WKB solutions yielding full wave solutions.

Availability Contact Kaya Inre, Harold Weitzner, and D.C. Stevens: Courant Institute of Mathematical Sciences, New York University, New York, NY 10012.

Documentation See Refs. 134, 54, and 59.

9.2.6. *IIHRC*

Description IIHRC is a 1-D Ion-Ion Hybrid Resonance Code. Mode conversion, transmission, reflection, absorption of the electromagnetic and Bernstein modes are calculated across the ion-cyclotron resonance layer where there are two resonant ion species. The majority species is at second harmonic and the minority species is at fundamental resonance on the same resonance surface. Solutions of the three basic scattering problems are obtained: (1) Fast-mode incidence from high-field side, (2) Fast-Mode incidence from low-field side, (3) Bernstein-mode incidence. The component of E along equilibrium magnetic field is ignored. Warm plasma electric current is derived from the linearized Vlasov equation within a boundary layer near the resonance surface.

Special Features ODE solver DVERK is used from IMSL package to construct linearly independent solutions of the field equation. Appropriate linear combinations of these solutions are matched to WKB solutions yielding full wave solutions. We use reduction of order method to eliminate growing solutions.

Availability Contact Kaya Inre and Harold Weitzner, Courant Institute of Mathematical Sciences, New York University, New York, NY 10012.

Documentation See Refs. 52, 55, and 58.

9.2.7. *THIRC*

Description THIRC is a 1-D Third Harmonic Ion Resonance Code. Mode conversion, transmission, reflection, absorption of the electromagnetic and Bernstein modes across the third harmonic ion-cyclotron resonance layer are computed. Solutions of the three basic scattering problems are obtained: (1) Fast-mode incidence from high-field side, (2) Fast-Mode incidence from low-field side, and (3) Bernstein-mode incidence. Component of E along equilibrium magnetic field is ignored. Warm plasma electric current is derived from the linearized Vlasov equation within a boundary layer near the resonance surface.

Special Features ODE solver DVERK is used from IMSL package to construct linearly independent solutions of the field equation. Appropriate linear combinations of these solutions are matched to WKB solutions yielding full wave solutions. Double reduction of order technique is used to suppress growing solutions.

Availability Contact Kaya Imre and Harold Weitzner, Courant Institute of Mathematical Sciences, New York University, New York, NY 10012.

Documentation See Refs. 51, 55, and 58.

9.2.8. GARFIELD

Description Grumman Aerospace **RF FIELD** code (GARFIELD) is designed to calculate the three-dimensional structure of ICRF fields in axisymmetric mirrors. The code solves the electromagnetic wave equation for the electric field using a cold plasma dispersion relation with a small collision term to simulate absorption. The full wave solution including $\vec{E} \cdot \vec{B}$ is computed. The fields are Fourier analyzed in the poloidal direction and solved on a grid in the axial and radial directions. A two-dimensional equilibrium can be used as the source of equilibrium data. ICRF wave propagation and absorption in mirrors thus includes the effect of axial variation of the magnetic field and density [102].

Users G. Smith (LLNL)

Documentation See Ref. 102.

9.3. Neutral Beams

9.3.1. NFREYA

Description NFREYA is a Monte Carlo code that computes the fast ion birth deposition for neutral beam injection into tokamaks and stellarators.

Special Features NFREYA carefully treats the geometry of the vacuum vessel and includes beam divergence, focussing, and aperture losses. Bounce averaging over the initial ion orbits is optional. The magnetic fields are obtained from 2-D (tokamak) or 3-D (stellarator) codes. The beam geometry is modeled in detail.

Integration with Other Codes NFREYA exists as a stand-alone code. It has been incorporated as a module of the nonlinear multispecies Fokker-Planck code CQL/CQL3D (Sec. 10.2.1).

Availability Contacts at ORNL (FTS prefix 624): R.H. Fowler (615)-574-0629, NMFECC user; J.A. Rome (615)-574-1306; R.N. Morris (615)-574-0620, NMFECC user.

Users ORNL: R.H. Fowler, J.A. Rome, R.N. Morris, LLNL: G.D. Kerbel

Documentation See Refs. 29,97.

9.3.2 BEAM

Description BEAM is a code that computes the profile of birth points for neutral beam deposition, using a multiple beamlet formulation that does not include divergence or focussing effects.

Special Features The BEAM code is applicable to any toroidal device (axisymmetric or non-axisymmetric plasmas), and includes arbitrary beam orientation with respect to the plasma. It calculates the flux surface average of the birth current profile, $\langle v \cdot B \rangle$, as well as the usual particle source profile $H(r)$. The toroidal momentum source could easily be added as a calculation that parallels the birth current calculation. Options include circular or rectangular beam cross-sections.

Integration with Other Codes BEAM requires auxiliary routines for geometry and cross-sections, and the output must be processed by a Fokker-Planck code to obtain thermal electron and ion heating and current source profiles. BEAM has been integrated into the WHIST transport code (Sec. 8.1.16). In this implementation, BEAM uses the TRACK code (Sec. 8.1.12) for the plasma and beamlet geometry, and the MIRTH (Sec. 8.1.8) code for the thermalization of the fast ions. The driven current is computed using expressions from Hirshman and Sigmar in an auxiliary routine.

Availability A stand-alone version of BEAM that computes particle and current birth profiles and includes coupling to the TRACK routines is available in either VAX or Cray forms. Any other auxiliary routines, as implemented in the WHIST code, are also available. The stand-alone version uses DISSPLA graphics. Contacts at ORNL (FTS prefix 624): Stan Attenberger (615)-574-0613. NMFEEC user 21070; Wayne Houlberg (615)-574-1350. NMFEEC user 2357.

Users ORNL: S. E. Attenberger, W. A. Houlberg.

Documentation See Refs. 3.42.

9.4. Neutral Particle Transport

9.4.1 DEGAS

Description The DEGAS code solves the linearized Boltzmann equation for neutral particle transport in a fixed plasma. The solution is obtained via a Monte Carlo method employing the pseudo-collision algorithm (PCA) for tracking particles. It includes all relevant neutral-plasma interactions for hydrogenic atoms and molecules, and for helium. Wall reflection and sputtering is modelled by a combination of data from experiments and from the TRIM and MARLOWE computer codes. Wall composition can be specified from a list of materials commonly used in fusion experiments and reactor designs. Arbitrary three-dimensional geometric configurations can be treated, with special options available for cylindrical and toroidal symmetry. A full set of diagnostics is available from a post-processing graphics package, including 3-D and contour plots. Particle, momentum, and energy fluxes to the walls are also computed. The definition of the grid, plasma, and walls for DEGAS is time-consuming and very problem-dependent; the user should write a separate code to perform this task.

Special Features DEGAS can be run on the CRAY-2 in a multi-tasking mode. The Monte Carlo algorithm includes particle splitting and Russian roulette options to more effectively use computational resources.

Availability Access to the code is described in a user's manual available on the NMFECC's Cray T.

Users T.B. Kaiser, M.E. Rensink (LLNL); L. Owen (ORNL); A. Ehrhardt (PPPL)

Code Benchmarking The code has been used to model several fusion experiments, including TFTR, PDX, DIII-D and TMX-U. Published references to these applications are in the article by Heifetz [40].

Documentation See Ref. 40. An unfinished draft of a user's manual is available on MFECC by typing filem rds 4575 .d.doc deguser.

9.4.2 FENAT

Description Solution of the energy dependent diffusion equation in two dimensions is formulated by multigroup approximation of the energy variable and general triangular mesh, finite element discretization of the spatial domain. Finite element formulation is done by Galerkin's method. Based on this formulation, a two-dimensional multigroup finite element diffusion theory code, FENAT, has been developed for the transport of neutral atoms in fusion plasmas. FENAT solves the multigroup diffusion equation in X-Y cartesian and R-Z cylindrical/toroidal geometries. Use of the finite element method allows solution of problems in which the plasma cross-section has an arbitrary shape. The accuracy of FENAT has been verified by comparing results to those obtained using the two-dimensional discrete ordinate transport theory code, DOT-4.3 [36].

Users T. Kaiser (LLNL)

Documentation See Refs. 36,37.

9.4.3 PELLET

Description PELLET is a code that computes the mass deposition of frozen hydrogenic pellets in magnetically confined toroidal plasmas.

Special Features The PELLET code calculates ablation from plasma electrons and fast ions using the neutral shielding model. Additional shielding is included from the cold ablatant plasma flowing along the magnetic field. The energy distribution of incident electrons and fast ions (from neutral beam injection or fusion alphas) is handled with a multiple energy group formalism. Several options on detail of the model are included. The geometry is applicable to any toroidal device (axisymmetric or non-axisymmetric plasmas), and includes arbitrary pellet orientation with respect to the plasma. The flux surface average of the particle source profile is calculated.

Integration with Other Codes PELLET requires auxiliary routines for the plasma geometry. PELLET has been integrated into many transport codes (BALDUR (Sec. 8.1.1), PROCTR (Sec. ??), TRANSP (Sec. 8.1.14), TSC (Sec. 8.1.15), WHIST (Sec. 8.1.16), plus several outside the U.S.). The TRACK code can be used to provide the required geometric information.

Availability A stand-alone version of PELLET that computes the particle source profile and includes coupling to the TRACK (Sec. 8.1.12) routines is available in either VAX or Cray forms. The stand-alone version uses DISSPLA graphics. Contacts at ORNL (FTS prefix 624): Stan Attenberger (615)-574-0613, NMFECC user 21070; Wayne Houlberg (615)-574-1350, NMFECC user 2357.

Users ORNL: S.E. Attenberger, M.J. Gouge, W. Houlberg, H.C. Howe. PPPL: G. Bateman, D.R. Mikkelsen, D.K. Owens, M. H. Redi.

Documentation See Ref. 46.

9.5. *Impurity Radiation Codes*

9.6. *Cyclotron Emission Codes*

9.6.1. CYTRAN

Description CYTRAN is a code that computes synchrotron radiation transport (emission and reabsorption), using a cylindrical approximation for the plasma.

Special Features The CYTRAN code approximates non-circular plasmas by a cylinder of equal cross-sectional area. Diffuse reflection from the walls is assumed. The plasma is divided in optically thin and thick regions. In the presence of reflection the plasma appears thick at frequencies range where most of the energy is carried, even though it is optically thin. Net flux surface-averaged power emission/adsorption profiles are obtained.

Integration with Other Codes CYTRAN is run as a module in the WHIST transport code (Sec. 8.1.16).

Availability Written by S. Tamor. Contacts at ORNL (FTS prefix 624): Stan Attenberger (615)-574-0613, NMFECC user 21070; Wayne Houlberg (615)-574-1350, NMFECC user 2357.

Users ORNL: S. E. Attenberger, W. A. Houlberg.

Documentation See Refs. 122,121.

9.6.2. HORACE

Description HORACE was written by Bob Harvey (GA) and Martin O'Brien (Culham) and incorporates Ray tracing and Absorption to calculate the net cyclotron emission to a detector. It calculates the power per unit frequency observed by an antenna, along *n* rays rays, for a specified frequency range, and for a specified range of cyclotron harmonics. The specific intensity

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(ergs/sec)/(cm²-steradian-radian frequency) along each ray is weighted by $wt(i : i = 1, n_{rays})$, the product of the solid angle element and antenna gain factor, appropriate to the ray. Multiplying further by the antenna area gives the power per radian frequency into the antenna.

Availability Contact C. Lasnier@LLNL.MFENET.

Users C. Lasnier (LLNL)

Documentation See Ref. 9.

9.6.3. OPAKE2

Description OPAKE2 is a code for calculation of the emission and absorption coefficients for cyclotron radiation in a magnetized plasma. It is not intended to be a subroutine, but is a stand-alone code for producing a table for permanent reference.

The user specifies a plasma temperature, a direction of propagation, the highest and lowest frequencies desired, and the number of frequency entries. The code returns absorption coefficients and emissivities vs frequency for the ordinary and extraordinary modes. A relativistic Maxwellian distribution is assumed, and the plasma modes are defined via the low density limit of the Appleton-Hartree dispersion relation [123].

Special Features A number of options are available:

1. It will provide emission (not absorption) coefficients for a loss cone distribution.
2. The distribution can be a drifting Maxwellian.
3. The code can return the correlation matrix for the emitted electric field components.

Availability Complete instructions for preparation of input are contained in the program listing. The output generated is prefaced by an explanation of the table headings and definitions. The program can be obtained by executing: `filem rds 604 opake2`.

Users T. Samec (TRW)

Documentation See Ref. 123.

9.7. Lower Hybrid

9.7.1. WPCP38

Description The WPCP38 code solves the equations given by Weitzner Ref. 133 for wave propagation in a plasma based on the cold plasma model. The principal use of the code is for the detailed study of the heating of a plasma at lower hybrid frequencies.

Availability The code is available from Donald Stevens (NYU, MFEC user 1540) on request.

10. Fokker-Planck Codes

10.1. Single Flux Tube

10.1.1. BAV/BACON

Description BAV is a **B**ounce **A**veraged 2-D Fokker-Planck code for Coulomb collisions that includes neutral beam injection, charge exchange, a simple rf heating model, and finite-transit loss. This single-species, single region, non-relativistic code is implicitly finite differenced on a (v, θ) velocity grid, and the resulting matrix equation solved with ICCG. The nonlinear collisional diffusion operator is determined by solving for the Rosenbluth potentials, in which a specified number of terms in a Legendre polynomial expansion are kept. The original version of the code by Cutler, et al. [20] is in non-conservation form. Subsequently, the code was rewritten so that the line density is conserved [105]; the name has correspondingly been modified to BACON. Even more recently, L.D. Pearlstein has improved the code by using more accurate bounce-average evaluations and made the code much faster by vectorization.

Special Features

- The code can optionally and reliably calculate the self-consistent electrostatic potential profiles along the magnetic field.
- The code has a reliable option for choosing the maximum time step.
- The code can be run in a manner to terminate upon achieving steady state.
- The code can calculate $B(s)$ including long-thin equilibrium, and has dB/dt terms.

Availability Contact Rognlien@LLNL.MFENET

Users T. D. Rognlien (LLNL)

Code Benchmarking BAV has been benchmarked with several other Fokker-Planck codes such as Hybrid-II (Sect. 10.1.3), SMOKE (Sect. 10.1.5), and CQL (Sect. 10.1.2). Also, it agrees with analytic calculations such as Pastukov confinement in mirrors.

Documentation See Refs. 20,105.

10.1.2. CQL

Description The bounce-averaged Fokker-Planck code CQL-(Collisional QuasiLinear)-has been in development for a number of years and is now available in package form. The theoretical basis for most of the physics incorporated in the CQL program is presented in the article by Kerbel and McCoy [63]. The code has been applied to solve a variety of problems demonstrating its range of versatility. A few of these applications have been reported in the recent literature, including such varied subjects as ICRF reactivity enhancement, runaway rates and resistivity for arbitrary inverse aspect ratios, relativistic corrections to runaway rates and resistivity, ECH in tokamaks, the effects of collisions and finite spectral width on resonant diffusion, and neutral beam current drive efficiency [65].

Special Features The computer code CQL is designed to solve the multi-species bounce-averaged Fokker-Planck equation complete with

- non-linear (and/or linear) collisional terms
- multi-mode RF quasilinear terms
- source terms (e.g., charge-exchange, fusion, neutral beams)
- loss terms (e.g., non-confinement boundaries, charge-exchange phenomenological models).

Availability The source code may be accessed through FILEM in directory .cql02 of user 714. Details of what is available in this directory, and how to compile the code is found in Refs. 63,64.

Users G. Kerbel (MFECC)

Documentation See Refs. 63,65,64.

10.1.3. HYBRID-II

Description The computer program HYBRID-II solves the time-dependent, two-dimensional, nonlinear Fokker-Planck equations for an arbitrary number of ion species. It makes use of the general purpose Fokker-Planck package FPPAC [123]. The two velocity dimensions are speed and pitch angle, and it is assumed that the electrons are Maxwellian.

The program may be applied to problems in the areas of both mirror confinement and toroidal confinement. In the former case, a self-consistent ambipolar potential profile may be computed to assure charge neutrality, and it is also possible to model both the plugs and the solenoid in a tandem mirror device [123].

Availability Relevant files are located in directory public under user number 723. File HYBRID2 is the source file. Precompile using PRECOMP with the CRAY option, compile using CFT, and load TV80LIB and OMNLIB.

Users A. Futch (LLNL), A. Mirin (MFECC)

Documentation See Refs. 123,67,96.

10.1.4. SFP

Description SFP is a simplified, easily modifiable code has been developed to determine the Alfvén wave of neutral beam driven toroidal plasmas [14].

Special Features

1. Kennel-Englemann infinite medium quasilinear theory examining particle-wave power transfer for the shear, compressional and anomalous Doppler mode.
2. Linearized collision operator.
3. Expansion in Legendre polynomials, result in a set of coupled ODE's in the speed coordinate.
4. Beam growth and electron damping terms computed for the collisional distribution.
5. Useful for parameter surveys.
6. Code driven by BASIS.

Availability Contact Campbell @ LLL.MFENET

Users R. B. Campbell (LLNL)

Documentation See Ref. 14.

10.1.5. SMOKE

Description SMOKE is a relativistic, bounce-averaged, multi-region Fokker-Planck code for studying the physics of plasmas on a collisional time scale. It is capable of treating a plasma trapped in magnetic and potential wells of general shape as in a tandem mirror or a tokamak. The numerical method used is a combination of mapping technique and a Galerkin finite element method.

Special Features The code includes:

- nonlinear nonrelativistic collision operator
- linear non-relativistic collision operator
- linear relativistic collision operator
- quasilinear rf diffusion operator
- synchrotron radiation effects
- neutral beam injection terms

Availability Contact Y. Matsuda@LLL.MFENET

Users Y. Matsuda (LLNL)

Documentation See Ref. 90.

10.2. Multiple Flux Tubes

10.2.1. CQL3D

Description CQL3D is a multi-flux-surface version of the Fokker-Planck code CQL (Sec. 10.1.2). The code solves the Fokker-Planck equation simultaneously on a large number of flux surfaces. Depending on the type of problem, modules couple the various flux surfaces. For instance, for ECH a wave damping calculation computes the energy density in space (and thus the electric field strength), and the Fokker-Planck code computes the local power absorption. The code iterates to steady state. For neutral beams, a Monte Carlo neutral beam injection code is used to determine the local fast ion source. An MHD equilibrium code module allows CQL3D to utilize non-circular flux surfaces, if desired.

Special Features

- non-circular cross sections
- multi-flux surface
- ECH, Neutral Beams
- Fast-CRAY-2 only

Availability Contact G.D. Kerbel.

Users M. G. McCov and G. D. Kerbel (NMFECC); R. Harvey (GA)

Documentation See Ref. 91.

10.2.2. FPT

Description The differential equations of plasma transport in a toroidal confinement system are solved. Several energetic ion species are described by velocity space distribution functions (depending on speed, pitch angle and distance from the magnetic axis), and their slowing down and scattering are modeled numerically by the complete nonlinear Fokker-Planck operator. The plasma ions and electrons are described by a multi-fluid transport model.

The poloidal flux is taken to be a function only of r (the distance from the magnetic axis), so that constant flux surfaces are circular tori. Each plasma species is described by a separate radial density profile, and the plasma ions are all assumed to be at the same local temperature. (The electrons have their own temperature profile.) Only the poloidal component of the magnetic field varies with time.

Neutral transport is calculated using a multispecies generalization of the Hughes-Post Monte Carlo code. Beam deposition is calculated using the NFREYA code of Lister, et al. 123 (Sec. 9.3.1).

Availability Relevant files are located in directory .public under user number 723. File FPT is the source file, BBEAMS and BNEUT are binary files, and SPLDAT is a data file. Precompile using PRECOMP with the CRAY option, compile using CFT, and load BBEAMS, BNEUT, TV80LIB, and OMNLIB. APLDAT should be on disc when executing '123'.

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Users Mirin (MFECC)

Documentation See Refs. 123,95,66.

11. Stability Codes

11.1. Magnetohydrodynamic Stability

11.1.1. FLORA

Description FLORA solves, in a 2-D domain (z, ψ) , for the linearized stability of a long thin axisymmetric equilibrium. It uses an initial-value method in which an equilibrium is given an initial perturbation to its magnetic B field, and the time behavior of the perturbation is followed. The perturbation has been Fourier expanded in the azimuthal (θ) direction and each mode (m) must be examined separately. The values of m can be arbitrary with an upper limit around $O(10^3)$ because of accuracy consideration as the modes become more highly localized.

Users B.I. Cohen (LLNL)

Documentation See Ref. 30,16.

11.1.2. GATO

Description GA low-n Toroidal stability code (GATO), which is similar to PEST, but never misses an unstable mode. It uses "EQDSK" format file for input, and treats limited or diverted plasmas, with or without a flux-conserving wall.

Users T. Kaiser (LLNL), L. Lao (GA).

Documentation

11.1.3. PEST

Description

Special Features

Availability

Users

Documentation

11.1.4. TEARING

Description see G. Bateman!

Special Features

Code Benchmarking

Availability

Users

Documentation See Ref. ?

11.2. Resistive MHD

11.2.1. CART

Description CART is the 3-D nonlinear resistive MHD code, employing a reduced set of tokamak equations with Cartesian coordinate mesh in the poloidal plane and spectral representation in the toroidal direction. This code is particularly suited for treating up-down asymmetric noncircular cross section with or without a magnetic separatrix, all of which characterize realistic DIII-D single-null divertor discharges with high pressure or high current.

Past applications have been to the global mode cascade and magnetic fluctuation simulations using actual DIII-D discharge equilibria (generated by EFIT [86,81]) to the effects of magnetic separatrix and pressure pedestal on finite beta kink-tearing modes [79], and to the stabilization of external kink and axisymmetric modes in a highly elongated tokamak [78].

Possible future applications might be the transport study of multi-helicity global ideal and resistive MHD modes especially with high current and/or high pressure.

Availability Contact J.K. Lee at General Atomics (GA).

Users J.K. Lee, L.L. Lao, W. Howl (GA)

Documentation There is no detailed documentation for this code. Some publications that have used the code include Refs. 86, 81, 79, and 78.

11.2.2. HIB-G

Description HIB-G is the GA version of PPPL's 3-D resistive-MHD code HIB (by W. Park) with various extensions. Being spectral both in poloidal and toroidal directions, this code has been applied to almost circular cross-section tokamaks (theoretical and D-III equilibria).

An important extension was made for simulations of 3-D MHD turbulence driven by resistive ballooning modes [87], adopting various pressure evolution methods to facilitate the steady state or saturation of these nonlocal modes.

Another extension was to the linkage to realistic experimental D-III equilibria [82] with many useful code diagnostics such as the efficient calculation of various magnetic island sizes with time.

Availability Contact J.K. Lee at General Atomics (GA).

1.537

Users J.K. Lee, J.S. Kim, R.E. Waltz, M.S. Chu (GA).

Documentation There is no detailed documentation for this code. Some publications that have used the code include Refs. 87, 82, 80, and 83.

11.2.3. RPD

Description RPD is a 3-D, full-resistive MHD initial value code for a poloidal divertor tokamak with a non-diverted option available. RPD advances 3-D, full-resistive MHD equations in a four-node poloidal divertor tokamak with square cross section. The divertor separatrix and scrape off region are included as part of computational domain. The code is fully toroidal and compressible. The equations are Fourier-analyzed in the toroidal direction only and finite-differenced in two Cartesian directions of constant toroidal angle plane. A new, semi-implicit time-advancement scheme is employed for higher code efficiency. Both linear and nonlinear options are available. The number of divertor rings can be changed with moderate amounts of code modifications. The code can be extended to couple transport effects with resistive-MHD instabilities in such devices.

Code Developers Ejiri Uchimoto (Courant Institute, New York University) and James D. Callen (University of Wisconsin-Madison).

Special Features Language: FORTRAN77. Compiler: CIVIC

Availability Contact Ejiri Uchimoto, Courant Institute, New York University, 251 Mercer St., New York, NY 10012; Tel. No. (212)-998-3273; MFE user No. 1556.

Users Ejiri Uchimoto and Zuoyang Chang (University of Wisconsin-Madison)

Documentation See Ref. 124.

11.3. Microstability

11.3.1. ALFWVS

Description The Alfvén-Waves code ALFWVS produces stability results for Alfvén-ion-cyclotron (AIC) instability in

1. a uniform magnetic field ($k_z = 0$)
2. a mirror magnetic field ($k_z = 0$)
3. a sharp-boundary, cylindrical, DT plasma ($k_z \neq 0$; instability is driven by α particles)

For the first two configurations, a large variety of ion distribution functions is available. For the third, the α distribution is computed.

Special Features In addition to microstability constraints, the code calculates mirror-mode (equilibrium) limits, a wall-stabilized MHD limit, and the adiabaticity limit.

Availability Type filem rds 3030 .alfwvs xalfwvs.

Users G. Smith (LLNL)

Documentation A document is available that gives steps for running the code, descriptions of the variables, and an extensive example run (with commentary). Type filem rds 3030 .alfwvs alfwvs/d. See also Refs. 115,117,116.

11.3.2. MICE

Description MICE code calculates microstability to ion-cyclotron (and harmonics) loss-cone and anisotropy driven (not AIC) modes in mirror geometry. The code considers, in detail the inhomogeneous medium and the 3-D nature of the geometry. The formalism leads to a balloon equation which is solved using LSODE. Resonant denominators are treated kinetically.

Special Features The code will track marginal stability or equivalently the most unstable case.

Availability Contact L. D. Pearlstein @LLNL.MFENET.

Users L. D. Pearlstein (LLNL)

Documentation None exists.

11.4. Turbulence

11.4.1. DIA

Description DIA treats the direct interaction approximation statistical closure scheme for electrostatic electron drift-wave turbulence in sheared slab geometry. Nearly Boltzmann electrons are treated with an δf model. The code solves for the correlation function of the electrostatic potential, I , in a 3D k_x, k_y, k_z representation. The frequency spectrum is represented by the pole approximation suitable for domination by a single branch (also called Lorentz model). There are separate dynamical equations for I (wave-kinetic equation) and the nonlinear dispersion relation for the nonlinear frequency shift and decorrelation rate (line broadening). Thus not only wave-wave nonlinear coupling effects are included but also wave-particle nonlinear resonance broadening and polarization shielding (Ion Compton scattering effect). 3D spectra for the correlation function and resonance broadening as well as $\vec{E} \times \vec{B}$ diffusion are calculated via an iterative procedure.

Availability Contact R.E. Waltz at General Atomics (GA).

Users R.E. Waltz and R.R. Dominguez at General Atomics (GA).

Documentation There is no documentation for this code; however, a publication that has used the code can be found at Ref. 127.

11.4.2. DRIFT

Description DRIFT is a 3D-electrostatic, nonlinear drift-wave code used to study drift-wave turbulence in tokamak geometry. It is a mixed space-spectral (r, m, n) code with global boundary conditions numerically similar to standard nonlinear resistive MHD (Sec. 11.2) codes. It time advances the ion-continuity equation or generalized-vorticity equation to obtain the electrostatic potential perturbations. The parallel ion-motion and $\vec{E} \times \vec{B}$ convection of adiabatic ion-pressure perturbations are advanced as well. The code runs on a single or multiple helicity m, n grid to treat ion-temperature gradient-mode turbulence in a sheared slab or tokamak geometry (with sheared and curved magnetic field) as well as electron drift-mode turbulence driven by a model (*id*) non-adiabaticity for the nearly Boltzmann electrons. The background gradients are fixed and the $\vec{E} \times \vec{B}$ diffusion of density or ion pressure is computed. FLR effects are included and ion Landau damping is modeled with a parallel viscosity.

There is a numerically similar code TEAR ??, which treats nonlinear simulations of low- m (MHD) tearing modes.

Availability Contact R.E. Waltz at General Atomics (GA).

Users R.E. Waltz.

Documentation There is no documentation for this code; however, a publication that has used the code can be found in Ref. 130.

11.4.3. TWOFLD

Description TWOFLD is a nonlinear-electromagnetic drift-wave code used for studying turbulence relevant to tokamaks. Perturbations are represented on a k_x, k_y grid, and the effective curvature drift and parallel wave-number are taken as fixed parameters. The code can treat a hierarchy of collisional two-fluid models starting with the two-field (TWOFLD) vorticity and electron-continuity equations for the electric-field potential and density perturbations. This system describes isothermal electrostatic resistive interchange modes. Adding the ion parallel-motion equation couples the ion sound branch and adding an explicit Ohm's law to advance the parallel magnetic-vector potential allows electromagnetic effects including the ideal MHD (Sec. 11.2) ballooning modes. A trapped electron three-fluid model obtains by the addition of a trapped electron collisional-continuity equation and modifying Ohm's law to respond only to untrapped electrons. In these models, only $\vec{E} \times \vec{B}$ particle transport is significant. Further, electron-temperature perturbations can be advanced by a collisional heat-conduction equation and the adiabatic pressure convection equations. The temperature perturbations allow simulation of electric and ion heat flows while introducing a stabilizing element to the electron-drift branch and destabilizing the ion-drift (η_i) branch. The most complicated case involves the time advancement of six fields.

Availability Contact R.E. Waltz at General Atomics (GA).

Users R.E. Waltz

Documentation There is no detailed documentation for this code; however, some publications that have used the code can be found in Refs. 128, 129, and 131

11.5. CROSS-REFERENCE

Other codes that are useful for stability analysis include Sections 8.1.15 and 8.1.15.

References

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Index

- ACCOMME, 18
- AD, 19
- ALADDIN, 8
- ALFWVS, 56
- ambipolar potential, 24, 28, 50, 51
- ANTENA, 42
- B2, 38
- balance
 - particle, 16
 - power, 16
- BALDUR, 29
- BASIS, 6
- BAV/BACON, 50
- BEAM, 46
- BETA, 20
- BETA MC, 29
- CART, 55
- CFRX, 30
- CHAPO, 30
- CHIREG, 12
- CQL, 50
- CQL3D, 53
- current drive
 - bootstrap, 18, 35
 - ech, 16, 25, 33, 41
 - lower hybrid, 16, 19
 - neutral beam, 16, 18, 23, 33, 35, 50, 53
- CYTRAN, 48
- DART, 25
- data analysis, 12, 15
 - DIII-D, 15
 - Fourier, 15
 - statistical, 12, 15
 - time series, 15
- DATAPLOT, 12
- DEGAS, 46
- DIA, 57
- DIPSI, 25
- disruption
 - thermal effects, 17
- DRIFT, 58
- edge physics, 24, 38
- EFFI, 11
- EFIT, 20
- electrode design, 25
- EMONE, 25
- ENERGY, 15
- EPFC, 20
- EQPD, 21
- ES1, 26
- FENAT, 47
- FIRC, 43
- FLORA, 54
- Fokker-Planck, 50-53
 - multi-region, 52
 - multispecies, 51
- FPT, 53
- GARFIELD, 45
- GATO, 54
- GFUN3D, 11
- GRAFL-III, 7
- Graphics, 7, 8
- heating
 - alpha, 16, 37
 - ech, 24, 25, 28, 33, 41, 50, 52, 53
 - ich, 24, 25, 28, 42, 45, 50
 - neutral beam, 23, 28, 33, 50-53
 - ohmic, 16, 33, 37
- HEQ, 21
- HIB-G, 55
- HORACE, 48
- HPFB, 31
- HYBRID-II, 51
- ICRH, 42
- IDL, 13
- IHTMDC, 31
- IJHRC, 44
- LOCUS, 14
- LTE, 18
- MAFCO, 12
- magnetic field
 - equilibrium
 - DIII-D, 20

- open geometry, 18
- toroidal geometry, 18, 20, 21, 32
- permeable material, 11
- vacuum, 11, 12
- MCGO, 23
- MCNP, 10
- MCPAT, 24
- MFIRC, 43
- MICE, 57
- MINERVA, 32
- MIRTH, 32
- MIST, 40
- MPPL, 7
- MUMAK, 16
- NEQ, 21
- NFREYA, 45
- ONETWO, 32
- OPAKE2, 49
- particle trajectory, 23, 25
- PDW1, 26
- PDW2, 27
- PDWZ, 27
- PELLET, 47
- PEST, 54
- PHLOW, 38
- PLANET, 38
- plasma absorption
 - electron cyclotron, 41, 48, 49
- plasma simulation, 25, 28
- POPCON, 17
- PROFREG, 14
- Programming Language, 7
- radiation
 - bremstrahlung, 37
 - electron cyclotron, 16, 41, 48, 49
 - impurity, 16, 37
- REVIEW, 16
- rf fields
 - electron cyclotron frequency, 41
 - ion cyclotron frequency, 42, 45
- RFPBURN, 33
- RPD, 56
- SFP, 51
- SHIRC, 43
- SIG, 15
- SIGV, 9
- simulation, 25
- SMOKE, 52
- SNAP, 34
- stability
 - aic, 56
 - Alfvén, 51
 - mhd
 - open geometry, 18, 54
 - toroidal geometry, 54
 - parametric, 25, 28
- stellarator, 36
- TADDPACK, 17
- TEARING, 54
- TEBASCO, 18
- TESS, 28
- TETRA, 17
- THEORY, 35
- THIRC, 44
- TIBRO, 23
- tokamak design, 16, 17
- TORAY, 41
- TORCH, 41
- TRACK, 34
- TRANSP, 35
- transport
 - axial, 24, 38
 - cross-field, 29, 30, 35, 38, 53
 - impurity, 40
 - multispecies, 29
 - neutral particle, 29, 46, 47
 - neutron, 10
 - photon, 10
 - velocity space, 50, 52
- TSC, 36
- TWOFLD, 58
- VEQ, 21
- VMEC, 21
- VMOMS, 22
- VSI, 28
- WHIST, 36
- WPCP38, 49
- XPOSTPLT, 8

SECRET

ZCODE, 39
ZERO, 37
ZOHAR, 28