MASTER

**U. I. FUSION
STUDIES
LABORATORY**

Nuclear Engineering Program
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Urbana, Illinois 61801

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C00-2218-164

User's Guide for
RFPBRN, A One-Dimensional Transport and Stability Code

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June 1980

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RFPBRN USER'S GUIDE

RFPBRN is a one-dimensional, Lagrangian mesh, transport and stability code for Reverse Field Pinch reactors. The code employs the quasi-static approximation (ignores the inertial terms in the momentum transport equation) to follow the evolution of a plasma on a resistive time scale. The transport equations used are particle transport, energy transport and field diffusion. The model has three fluids (ions, electrons and alphas), two temperatures (ions and alphas are assumed to immediately equilibrate), and two field components (toroidal and poloidal).

The formulation assumes circularly concentric flux surfaces (i.e., large aspect ratio) and transport is calculated on radial mesh points. Pressure balance is treated as a constraint. The radial mesh is adjusted adiabatically until pressure balance is satisfied.

Ideal MHD stability of the profiles is checked for both global and local modes. Suydam's criterion¹ is used for localized interchange modes (which are assumed to saturate and result only in enhanced transport) while a Rayleigh-Ritz expansion of the ideal MHD energy principle² is used to monitor global modes. Global modes (i.e., modes with wide eigenfunctions) are assumed to disrupt the plasma.

RFPBRN is modular in design with each subroutine typically doing only one piece of physics. Consequently, RFPBRN could easily be modified to handle other plasma profiles (this has already been done for Spheromak). All that is involved is replacing the initialization subroutine, TINIT, with one that generates the desired profiles. Questions on how to do this should be referred to the author.

RFPBRN is written in Fortran and is available on the MFECC (Magnetic Fusion Energy Computer Center) computer system through filem. This guide

will assume the user is familiar with the system and only simple system commands will be given to show how to retrieve and execute the program. Further system documentation is available on line through the DOCUMENT utility.

The fortran source file and a data file is available through FILEM on the 7600 using the command

```
FILEM RDS 1346 RFPBRN RIN.
```

To send the files to the cray the NETOUT command is used:

```
NETOUT RFPBRN RIN U. XXXX
```

where XXXX is the desired user number. The source file is compiled using OLDCFT:

```
OLDCFT I=RFPBRN,L=0
```

which generates the compiled binary file \$BLD. The binary file is then loaded along with the fortran library (FORTLIB), the plotting library (TV80LIB), and a cray utility library (OMNILIB):

```
LDR B=$BLD, X=XRFPBRN, LIB=(FORTLIB, OMNILIB, TV80LIB).
```

The program is then executed by typing

```
XRFPBRN / T V
```

where "T" is the execution time desired and "V" is the point value. A typical burn takes about five minutes to execute although this time varies considerably depending on the options chosen.

The program runs in batch mode with no interaction from the terminal. Output is contained in a printed file named OUT and a plot file named F105xx0x where xx can be any two letters. Input is through the file RIN.

Input variables and their description are in Table I. These variables are principally used in subroutine TINIT to initialize the density, temperature and field profiles. A sample input file is shown in Table II.

Output variables and their description are in Table III. All printed output is put in file OUT and can be retrieved using the text editor or via the NETOUT command. Plotted output requires use of the NETPLOT command. A sample of the printed output is in Table IV (based on the same input of Table II). Figure 1 is an abbreviated flow chart.

RFPBRN has been used to simulate the RFPR design³ as well as a small compact RFP (CRFP)⁴. It has also simulated stable startup for an RFP using a plasma convection technique⁵. Gas puffing and pellet injection have been incorporated for refueling studies for the CRFP.⁶

References

1. B. R. Suydam, "Stability of a Linear Pinch," P1354, USA (1958).
2. I. B. Bernstein, et al., "An Energy Principle for Hydromagnetic Stability Problems," Proc. Roy. Soc., A244, 17-40 (1958).
3. R. A. Nebel, et al., "Comparison of Zero-Dimensional and One-Dimensional Thermonuclear Burn Calculations for the Reversed-Field Pinch Reactor (RFPR)," Los Alamos Internal Report LA-8185-MS (1980).
4. G. H. Miley and R. A. Nebel, "The Compact Reversed Field Pinch (CRFP) Reactor Concept," presented at Reversed Field Pinch Theory Workshop, Los Alamos, NM (1980).
5. R. A. Nebel, R. W. Moses, and G. H. Miley, "Ideal MHD Stable Startup," presented at Reversed Field Pinch Theory Workshop, Los Alamos, NM (1980).
6. R. A. Nebel, et al., "Compact Reverse-Field Pinch Reactor," Trans. Am. Nucl. Soc., 34, 39-40 (1980).

Table I. Input Variables for RFPBRN

Variable	Value	Remarks
A		Plasma radius + extrapolation length
RM		Field reversal radius
ATH		Toroidal field on centerline
TEMO		Initial temperature
DEMO		Initial average density
RR		Major radius
L	≤ 201	Number of mesh points
M		Maximum number of timesteps
DT		Initial timestep
TMAX		End of simulation time
JPT		Number of times plot routine is called
ISTAB		Ratio of number of mesh points to number of instability trial functions
FLUX	0	Plasma radius specified (B.C.)
	1	Toroidal flux conserved (B.C.)
FRA		Implicit fraction
WALLFT		(Plasma radius)/A
TWALL		Resistive diffusion time for wall
IFRAME	0	Lagrangian frame
	1	Convective frame
TSTAB		Time stability routine is first called
ALFACT		Tritium fraction
BOHMET	200	Bohm factor for energy transport
BOHMLC	0	No Bohm energy transport
	1	Bohm energy transport
BOHMPT		Perpendicular resistivity Bohm fraction

Table I. (continued)

Variable	Value	Remarks
IISTAB	1	Singular instability trial functions
	2	Finite instability trial functions
TREE		Refuel start time
	0	No refuel
REFPO	1	Gas puffing
	2	Pellet refuel
DTBIG		Maximum timestep
PELVEL		Pellet velocity
PELRAD		Pellet radius (cm)
PELINC		Inverse pellet injection rate

Table II. Input File

```

8.500E-01 6.500E-01 8.400E+00 1.400E+00 2.700E+20 6.35
201 999999 2.000E-6 1.800E+1 5 8
1 1 0.50.8624 1.00999.9E+140999.9E+140
1.00E+001.500 0.00 0.00 0 4.00E+02
0.50 1.00 1.00 1.00 1.00 1.00 1.00
2.00E+02 1.00 0.00E-08 2.00E+05 0.00E-04 1.
5.20 0.20 6.200E+04 1.950E-01 5.000E-01
-1.0

```

Table III. Output Variables for RFPBRN

Variable	Remarks
TIME	Time in burn simulation
L	Number of mesh points
BETAPL	Minimum average poloidal beta
LLL	Number of time steps
PFUS	Alpha particle fusion power
PIN	Ohmic heating power
Q	Fusion Energy (17.6 MeV)/Ohmic Energy
TI	Average ion temperature
TE	Average electron temperature
IMAXI	Mesh point of most rapidly changing ion temperature
FMAXI	Maximum fractional change in ion temperature
IMAXE	Mesh point of most rapidly changing electron temperature
FMAXE	Maximum fractional change in electron temperature
ERAD	Radiation energy lost from the plasma
ETH	Thermal conduction energy lost from the plasma
EC	Plasma energy lost by plasma convection
RINJ	Gas puffing line density source rate
EALOSS	Prompt alpha loss energy
EEM	Poynting's vector energy into plasma
EFUS	Alpha particle fusion energy
ELOSS	Energy lost from plasma
EGAIN	EEM + EFUS
PVWORK	$\int p dv$ work done by plasma

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Table III. (continued)

Variable	Remarks
WERR	Energy error
ENPER	Energy error fraction
ANLOSS	Fuel depletion rate
DAN	Total fuel depletion
ANERR	Line density error
DENPER	Line density error fraction
WB(3)	Field energy in plasma
WP(3)	Kinetic energy in plasma
DT	Time step size
THETA	Plasma theta value
FAVE	Plasma F value
PWALL	Total wall load
RATE	Startup gas feed rate
TEWALL	Electron temperature at wall
TIWALL	Ion temperature at wall
BZWALL	Toroidal field at wall
BTHWALL	Poloidal field at wall
RADIUS	Radius in plasma
NION	Ion density
NALPHA	Alpha particle density
TION	Ion temperature
TELECT	Electron temperature
U	$\left \frac{dx}{dr} \right $
BPOL	Poloidal field
BZ	Toroidal field
VXA	Mesh expansion parameter

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Table IV. Output Sample

ttime= 4.224e+00 l= 201 dt= 2.000e-01 betapl= 1.029e-01 lll= 100 pfus= 2.370e+06 pin= 4.105e+03 q= 7.259e+00 ti= 9.803e+00 ta= 1.037e+01 lmax= 198 fmax= 1.929e-02 lmax= 198 fmax= 1.880e-02 cred= 9.968e+05 eth= 5.745e+06 ac= 0. rinj= 0. ealoss= 0. ecm= 1.788e+05 efus= 5.204e+06 ealoss= 5.742e+06 egain= 5.383e+06 pvwork= 3.316e+02 werr= 5.330e+04 dnpwr= 1.850e-03 anloss= 8.433e+18 dan= 1.856e+19 anerr= -1.687e+18 dnpwr= -3.535e-05 wp(3)= 1.978e+07 wp(3)= 2.294e+06 theta= 1.561e+00 bthwall= 3.435e+00 feve= -6.469e-01 pwall= 2.578e+06 rate= 1.381e+14 tevall= 5.041e+00 tiwall= 4.747e+00 bzwall= -1.423e+00					
radius	nlon	alpha	tion	telect	u
0.00000	4.479e+20	2.165e+19	12.53977	13.12067	0.98492
0.03813	4.456e+20	2.132e+19	12.51852	13.09931	0.98310
0.07628	4.425e+20	2.074e+19	12.45475	13.03510	0.98318
0.11442	4.376e+20	1.982e+19	12.34949	12.92896	0.98318
0.15257	4.306e+20	1.858e+19	12.20412	12.78211	0.98318
0.19071	4.215e+20	1.709e+19	12.02054	12.59620	0.98323
0.22885	4.103e+20	1.541e+19	11.80096	12.37326	0.98337
0.26698	3.973e+20	1.361e+19	11.54768	12.11559	0.98367
0.30509	3.822e+20	1.177e+19	11.26388	11.82567	0.98422
0.34318	3.651e+20	9.944e+18	10.95147	11.50596	0.98515
0.38122	3.462e+20	8.198e+18	10.61289	11.15075	0.98654
0.41919	3.256e+20	6.561e+18	10.24967	10.78588	0.98894
0.45705	3.035e+20	5.130e+18	9.86341	10.38646	0.99243
0.49474	2.800e+20	3.869e+18	9.45343	9.96643	0.99757
0.53220	2.555e+20	2.808e+18	9.01635	9.51799	1.00537
0.56931	2.301e+20	1.946e+18	8.55424	9.03866	1.01622
0.60597	2.038e+20	1.271e+18	8.05298	8.51927	1.03028
0.64210	1.761e+20	7.823e+17	7.49815	7.94172	1.04567
0.67775	1.464e+20	4.004e+17	6.85457	7.28802	1.06064
0.71329	1.136e+20	1.661e+17	6.03647	6.40650	1.08684
0.71687	1.101e+20	1.490e+17	5.93790	6.30238	1.04556
0.72046	1.065e+20	1.330e+17	5.83486	6.19348	1.04168
0.72407	1.029e+20	1.181e+17	5.72679	6.07921	1.03743
0.72769	9.927e+19	1.042e+17	5.61303	5.95884	1.03212
0.73134	9.555e+19	9.132e+16	5.49275	5.83152	1.02581
0.73501	9.176e+19	7.943e+16	5.36497	5.69617	1.01831
0.73871	8.790e+19	6.851e+16	5.22842	5.55146	1.00939
0.74244	8.393e+19	5.854e+16	5.08151	5.39570	0.99072
0.74622	7.986e+19	4.947e+16	4.92213	5.22660	0.98581
0.75006	7.562e+19	4.128e+16	4.74731	5.04097	0.96984
radius	bpol	bz	vxa	slg	beta
0.00000	0.	7.640e+00	1.00064	0.00000	0.08508
0.03813	5.497e-01	7.602e+00	1.00061	121.03555	0.08485
0.07628	1.091e+00	7.487e+00	1.00062	29.19045	0.08497
0.11442	1.616e+00	7.299e+00	1.00063	12.69307	0.08516
0.15257	2.117e+00	7.039e+00	1.00063	7.16953	0.08541
0.19071	2.566e+00	6.712e+00	1.00064	4.50870	0.08570
0.22885	3.017e+00	6.324e+00	1.00065	3.05673	0.08600
0.26698	3.404e+00	5.879e+00	1.00065	2.17663	0.08627
0.30509	3.742e+00	5.386e+00	1.00064	1.60172	0.08647
0.34318	4.026e+00	4.850e+00	1.00063	1.20403	0.08652
0.38122	4.255e+00	4.279e+00	1.00059	0.91596	0.08633
0.41919	4.426e+00	3.660e+00	1.00052	0.69961	0.08578
0.45705	4.539e+00	3.059e+00	1.00041	0.53344	0.08472
0.49474	4.593e+00	2.420e+00	1.00022	0.40571	0.08296
0.53220	4.586e+00	1.770e+00	0.99995	0.31013	0.08024
0.56931	4.517e+00	1.118e+00	0.99961	0.24262	0.07628
0.60597	4.384e+00	4.808e-01	0.99925	0.19947	0.07057
0.64210	4.192e+00	-1.166e-01	0.99901	0.17720	0.06266
0.67775	3.954e+00	-6.471e-01	0.99906	0.17439	0.05203
0.71329	3.693e+00	-1.088e+00	0.99962	0.19550	0.03847
0.71687	3.667e+00	-1.126e+00	0.99971	0.19969	0.03694
0.72046	3.641e+00	-1.164e+00	0.99982	0.20445	0.03539
0.72407	3.614e+00	-1.200e+00	0.99994	0.20909	0.03379
0.72769	3.588e+00	-1.235e+00	1.00007	0.21611	0.03217
0.73134	3.562e+00	-1.269e+00	1.00020	0.22330	0.03051
0.73501	3.536e+00	-1.302e+00	1.00035	0.23160	0.02802
0.73871	3.511e+00	-1.334e+00	1.00051	0.24159	0.02708
0.74244	3.485e+00	-1.365e+00	1.00067	0.25359	0.02530
0.74622	3.460e+00	-1.395e+00	1.00082	0.26864	0.02348
0.75006	3.435e+00	-1.423e+00	1.00097	0.00000	0.02158

Table IV. (continued)

parts= 1.413e+21			
radius	polpar	pelden	
7.501e-01	1.138e+20	3.135e+20	
7.463e-01	2.271e+20	3.169e+20	
7.425e-01	2.179e+20	3.100e+20	
7.387e-01	2.043e+20	2.955e+20	
7.350e-01	1.860e+20	2.730e+20	
7.313e-01	1.626e+20	2.418e+20	
7.276e-01	1.337e+20	2.012e+20	
7.240e-01	9.063e+19	1.500e+20	
7.204e-01	5.676e+19	8.718e+19	
7.168e-01	1.265e+19	1.881e+19	
om2= -3.774e+08	nom1= 12	m= -1	ccs= 1.000e+00
0.	disp= 0.	ccs= 1.000e+00	squig= 0.
3.608e-03	disp= 1.595e-02	ccs= 0.	squig= 6.171e+00
7.618e-03	disp= 3.190e-02	ccs= 0.	squig= 3.987e+00
1.143e-02	disp= 4.786e-02	ccs= 0.	squig= 2.843e+00
1.525e-02	disp= 6.381e-02	ccs= 0.	squig= 2.106e+00
1.906e-02	disp= 7.974e-02	ccs= 0.	squig= 1.593e+00
2.287e-02	disp= 9.566e-02	ccs= 0.	squig= 1.224e+00
2.669e-02	disp= 1.115e-01	ccs= 0.	squig= 9.550e-01
3.050e-02	disp= 1.274e-01	ccs= 0.	squig= 7.563e-01
3.432e-02	disp= 1.432e-01	ccs= 0.	squig= 6.076e-01
3.813e-02	disp= 1.590e-01	ccs= 0.	squig= 4.946e-01
4.195e-02	disp= 1.748e-01	ccs= 0.	squig= 4.077e-01
4.576e-02	disp= 1.905e-01	ccs= 0.	squig= 3.399e-01
4.958e-02	disp= 2.062e-01	ccs= 0.	squig= 2.864e-01
5.339e-02	disp= 2.218e-01	ccs= 0.	squig= 2.436e-01
5.721e-02	disp= 2.373e-01	ccs= 0.	squig= 2.090e-01
6.102e-02	disp= 2.528e-01	ccs= 0.	squig= 1.800e-01
6.483e-02	disp= 2.682e-01	ccs= 0.	squig= 1.575e-01
6.865e-02	disp= 2.836e-01	ccs= 0.	squig= 1.381e-01
7.246e-02	disp= 2.989e-01	ccs= 0.	squig= 1.210e-01
7.628e-02	disp= 3.141e-01	ccs= 0.	squig= 1.081e-01
8.009e-02	disp= 3.292e-01	ccs= 0.	squig= 9.639e-02
8.391e-02	disp= 3.442e-01	ccs= 0.	squig= 8.636e-02
8.772e-02	disp= 3.592e-01	ccs= 0.	squig= 7.772e-02
9.154e-02	disp= 3.741e-01	ccs= 0.	squig= 7.023e-02
9.535e-02	disp= 3.888e-01	ccs= -1	squig= 6.370e-02
9.916e-02	disp= 4.035e-01	ccs= 0.	squig= 5.798e-02
1.030e-01	disp= 4.181e-01	ccs= 0.	squig= 5.295e-02
1.068e-01	disp= 4.325e-01	ccs= 0.	squig= 4.850e-02
1.106e-01	disp= 4.469e-01	ccs= 0.	squig= 4.456e-02
1.144e-01	disp= 4.611e-01	ccs= 0.	squig= 4.104e-02
1.182e-01	disp= 4.752e-01	ccs= 0.	squig= 3.790e-02
1.221e-01	disp= 4.892e-01	ccs= 0.	squig= 3.508e-02
1.259e-01	disp= 5.031e-01	ccs= 0.	squig= 3.255e-02
1.297e-01	disp= 5.168e-01	ccs= 0.	squig= 3.026e-02
1.335e-01	disp= 5.304e-01	ccs= 0.	squig= 2.819e-02
1.373e-01	disp= 5.439e-01	ccs= 0.	squig= 2.631e-02
1.411e-01	disp= 5.573e-01	ccs= 0.	squig= 2.460e-02
1.449e-01	disp= 5.704e-01	ccs= 0.	squig= 2.304e-02
1.488e-01	disp= 5.835e-01	ccs= 0.	squig= 2.161e-02
1.526e-01	disp= 5.964e-01	ccs= 0.	squig= 2.031e-02
1.564e-01	disp= 6.091e-01	ccs= 0.	squig= 1.911e-02
1.602e-01	disp= 6.217e-01	ccs= 0.	squig= 1.801e-02
1.640e-01	disp= 6.342e-01	ccs= 0.	squig= 1.699e-02
1.678e-01	disp= 6.464e-01	ccs= 0.	squig= 1.605e-02

Figure 1.

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