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Beam-Plasma Heating Model Code and Commentary

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Plasma Physics Division

May 8, 1979

NAVAL RESEARCH LABORATORY
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A computer code listing, definition of terms, and CSN step commentary are presented as a supplement to the paper "Beam-Plasma Heating Model", by D. A. Hammer, A. W. Ali and myself. Together, these papers should allow application of our heating code to a wide and varied range of beam and plasma parameters and resistivity models.

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CONTENTS

BEAM-PLASMA HEATING MODEL CODE AND COMMENTARY

INTRODUCTION

This code listing and commentary is intended to supplement the paper, "Beam-Plasma Heating Model," by D. A. Hammer, A. W. Ali and myself.[1] Briefly, the paper describes a one-dimensional ionization and heating model as it applies to results of several electron beam-plasma interaction experiments. Beam energy is deposited resistively in the plasma at a rate ηj^2, where j is the return current density and η the plasma resistivity, both classical and anomalous, due to ion-acoustic or electron-electron mode turbulence. Principle energy losses include ionization, line radiation, inelastic electron impact excitation, bremmstrahlung and radiative recombination. The level of ionization and plasma heating are computed as a function of neutral gas pressure, beam rise-time, pulse width and current density, and resistivity model. Plasma dynamic and kinetic effects such as expansion and end loss are not explicitly included in the model.

The computational model assumes that the avalanche breakdown process driven by the large electrostatic and inductive electric fields at the beam front has been completed. Previous theoretical studies[2] have determined that the resultant plasma has a density of the order of 10^{14} cm^{-3} and a temperature of a few eV. Plasma conductivity is then

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sufficiently high that neutralization of the beam front inductive electric field drives a backstreaming plasma "return current" within the beam channel.[3] When the beam is present, the plasma current density j_p is given by $j_p \approx - j_b$, where j_b is the beam current density. When the beam pulse is over $j_p = 0$.

The remainder of this paper consists of a listing, a definition of terms, and a CSN step commentary of the beam-plasma heating code set forth in Section II of Ref. 1. This report, along with Ref. 1, should be sufficient to allow further application of this heating code to a wide and varied range of beam and plasma parameters and resistivity models.

CODE LISTING

This code calculates the density and temperature in a "return current" heated plasma in the presence of a large initial neutral fraction. Avalanching is assumed completed when the calculation starts (i.e., no electric field is applied). The energy equations (Eqs. (9) and (11), Ref. 1) calculated in subroutine FINI, ENTRY F, include Spitzer and electron neutral resistivities and three-body recombination as heat sources. Loss mechanisms are line radiation and ionization. The density equation (Eq. (10), Ref. 1) also calculated in ENTRY F, includes collisional ionization and two and three-body recombination. Integration of the energy and density equations is carried out by subroutine INT (Boris and Windsor).[4]

MAIN PROGRAM

```
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION Y(3)
      REAL*4    TIME(100),TEMP(100),DENSE(100),CNEUT(100)
      COMMON/CALLS/NOCALL
      EXTERNAL F
       CALL PDSTOP
      READ (5,13,END=1000) IMAX,JMAX,TE0,Y20,DENMAX,H0,TPULSE,BKG
 13   FORMAT (2I3,6D10.2)
      C1=3.D0+22
      DO 101 J=1,JMAX
      TE=TE0
      Y(1)=1.5*Y20*TE0
      Y(2)=Y20
      Y(3)=Y(1)
      T=0.D+00
      H01=H0
      IH01=H01*1.D+09
      ITIME=0
      ENERGY=0.D0
      READ (5,14) CURDEN
 14   FORMAT (1D10.2)
      WRITE (6,111)
 111  FORMAT (//30X, ' INITIAL VALUES ARE '/5X, 'TIME STEP', 7X,
     1  '1.SNKT',9X, 'DENSITY',6X, 'TEMPERATURE', 5X,'MAX J-BEAM     ',
     2  1X, 'NEUTRAL DENSITY', 5X, 'B(KG)')
      WRITE (6,11) H0,Y(1),Y(2),TE ,CURDEN,DENMAX,BKG
 11   FORMAT(7E15.5/)
      WRITE (6,112)
 112  FORMAT (1X,'T(NS) DENSITY TE    TI  CRDNT RATIO IONIZ RAD',
     1 1X,'LINE RAD CL ION HT  IAC RES  LHHYB RES  CLAS RES',
     2 1X,'BREMS  CUM ENERGY  EE RES')
      CALL FINT (CURDEN,DENMAX,TPULSE,BKG,H01)
      DO 100 I=1,IMAX
      NOCALL=0
      CALL INT(3,T,Y,F,H01)
      IF(T.LE.TPULSE) GO TO 32
      CRDENT=CURDEN*DEXP(-(T-TPULSE)/1.D-08)
      GO TO 9
 32   CRDENT=CURDEN*(1.D0-DEXP(-T/1.D-08))
 9    CONTINUE
      IF (Y(2).GE.DENMAX) Y(2)=DENMAX
      TE=2.*Y(1)/(3.*Y(2))
      DENEUT=DENMAX-Y(2)
      SQTE=DSQRT(TE)
      VE=4.20D*SQTE
      SQNE=DSQRT(Y(2))
      A=13.6D+00/TE
      DENE=Y(2)
      DENI=DENE
      TI=Y(3)/(1.5D0*DENI)
      SQTI=DSQRT(TI)
      COULOG=24.D0 - DLOG(SQNE/TE)
      CLASSR=C1*(COULOG/TE + 0.014D0*DENEUT/DENE)/SQTE
      QI=4.53D-09*COULOG*(TE-TI)*DENE**2/(TE*SQTE)
      CS=9.8D+05*(SQTE+SQTI)
      VTHI=9.8D+05*SQTI
       VD=6.D+21*CRDENT/Y(2)
      ANOMLH=(1.3D+37*BKG/DENE ) *(1.D0/(1.D0+(VTHI/VD)**2))
      ANOMLH=0.D0
      VCRIT=9.8D+05*SQTE*(1.D0+3.D0*(SQTE/SQTI)*DEXP(-1.5D0-0.5D0*TE
     1    /TI))
      RATIO=VD/VCRIT
      IF (RATIO.LT.0.3D+00) RATIO=0.3D+00
       ANOMIA=0.
 20    ANOMIA=(3.6D+30/SQNE)*DEXP(-1.0+00/(0.7D0*RATIO**3))
      STABLJ=7.6D-23*DENE**1.5*COULOG/TE**1.5
      CUTOFF=CRDENT/STABLJ
      IF(CUTOFF.LE.0.3D0) CUTOFF=0.3D0
      ANOMEE=0.
 21   ANOMEE=1.D+44*CRDENT/(DENE*SQNE)
      ANOMEE=ANOMEE*DEXP(-1./CUTOFF**3)
      ANOMWV=4.D+29*TE/SQNE*DEXP(-TE/1000.)
      ANOMWV=ANOMWV*DEXP(-1./CUTOFF**3)
      ANOMWV=0.
      S=5.4D-08*SQTE*DEXP(-A)/(4.88D+00+1.D+00/A)
      S=1.85D+00*DEXP(3.6D+00/TE) * S
      S1=1.6D-6*DEXP(-10.2/TE)/SQTE
      S1=S1/(1.D0+4.7D-14*DENEUT)
      RADION=DENEUT*Y(2)*13.6*S
      RADLIN=DENEUT*Y(2)*S1
      BREMS=3.33D-13*SQTE*Y(2)**2
      RESIST=CLASSR+ANOMLH+ANOMIA +ANOMEE +ANOMWV
      ENERGY=ENERGY+H01*RESIST*CRDENT**2
      ITIME=ITIME+IH01
      EDENS=1.D-15*DENE
      WRITE(6,12)ITIME,EDENS,TE,TI,CRDENT,RATIO,RADION,RADLIN,QI,ANOMIA,
     1 ANOMLH,CLASSR,BREMS,ENERGY,ANOMEE
 12   FORMAT(I5,F6.2,F7.1,F5.1,F6.2,F5.1,9D10.2)
      II=I
      IF (I.GT.50) II=I-50
      IF (I.GT.100) II=I-100
      TIME(II)=T
      TEMP(II)=TE
      DENSE(II)=Y(2)
```

```
      DNEUT(III)=DENEUT
      IF (MOD(I,50).EQ.0) GO TO 50
      GO TO 100
 50   CONTINUE
      IF(I.EQ.100) GO TO 99
      H01=10.D+00*H0
      TH01=H01*1.D+09 +1.00
      CALL FINI (CURDEN,DENMAX,TPULSE,BKG,H01)
      GO TO 100
 99   H01=25.D0*H0
      TH01=H01*1.D+09
      CALL FINI (CURDEN,DENMAX,TPULSE,BKG,H01)
 100  CONTINUE
 101  CONTINUE
      GO TO 1
 1000 STOP
      END
```

SUBROUTINE FINI

```
      SUBROUTINE FINI (CURDEN, DENMAX,TPULSE,BKG,H01)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/CALLS/NOCALL
      DSQ=DSQRT(13.6D00)
      RETURN
      ENTRY F(T,Y,DY)
      DIMENSION DY(3)
      DIMENSION Y(3)
      NOCALL=NOCALL+1
      IF(T.LE.TPULSE) GO TO 32
      CRDENT=CURDEN*DEXP(-(T-TPULSE)/1.D-08)
      GO TO 9
 32   CRDENT=CURDEN*(1.D0-DEXP(-T/1.D-08))
 9    CONTINUE
      C1=3.0D+22
      DENE=Y(2)
      DENI=DENE
 101   SQNE=DSQRT(DABS(DENE))
      DENEUT=DENMAX-Y(2)
      IF (DENE.GE.DENMAX) DENE=DENMAX
      IF (DENE.GE.DENMAX) DENEUT=0.0D+00
      TE=Y(1)/(1.5*DENE)
       TE=DABS(TE)
      TI=Y(3)/(1.5D0*DENI)
 11    SQTE=DSQRT(DABS(TE))
      SQTI=DSQRT(TI)
      A=13.6D+00/TE
      S=5.4D-08*SQTE*DEXP(-A)/(4.88D+00+1.D+00/A)
      S=1.85D+00*DEXP(3.6D+00/TE) * S
      S1=1.6D-6*DEXP(-10./TE)/SQTE
      S1=S1/(1.D0+4.7D-14*DENEUT)
      TWOBOD=(5.2D-14*DSQ/SQTE)*(0.43+0.5*DLOG(13.6D+00/TE)+0.469D+00*
     1 (13.6D+00/TE)**(1./3.))
      THREEB=8.75D-27/TE**4.5
      COULOG=24.D0 - DLOG(SQNE/TE)
      CLASSR=C1*(COULOG/TE + 0.014D0*DENEUT/DENE)/SQTE
      CS=9.9D+05*(SQTE+SQTI)
       IF(T.LT.2.D-09) CRDENT=0.005
       VD=6.D+21*CRDENT/Y(2)
      VCRIT=9.8D+05*SQTE*(1.D0+36.D0*(SQTE/SQTI)*DEXP(-1.5D0-0.5D0*TE
     1 /TI))
      RATIO=VD/VCRIT
      IF (RATIO.LT.0.3D+00) RATIO=0.3D+00
      VTHI=9.8D+05*SQTI
      ANOMLH=(1.3D+37*BKG/DENE ) *(1.D0/(1.D0+(VTHI/VD)**2))
      ANOMLH=0.D0
      STABLJ=7.2D-23*DENE**1.5*COULOG/TE**1.5
      CUTOFF=CRDENT/STABLJ
      IF(CUTOFF.LE.0.3D0) CUTOFF=0.3D0
      ANOMEE=0.
 19   ANOMEE=1.D+44*CRDENT/(DENE*SQNE)
      ANOMEE=ANOMEE*DEXP(-1./CUTOFF**3)
      VE=4.2D7*SQTE
       ANOMIA=0.
 20    ANOMIA=(3.6D+30/SQNE)*DEXP(-1.0+00/(0.7D0*RATIO**3))
      ANOMWV=4.D+29*TE/SQNE*DEXP(-TE/1000.)
      ANOMWV=ANOMWV*DEXP(-1./CUTOFF**3)
      ANOMWV=0.
      ANOME=DABS((VD-CS)/VD)*ANOMIA + 0.5D0*ANOMLH  + ANOMEE +ANOMWV
      ANOMI=(CS/VD)*ANOMIA + 0.5D0*ANOMLH
      QI=4.59D-09*COULOG*(TE-TI)*DENE**2/(TE*SQTE)
      BREMS=3.35D-13*SQTE*Y(2)**2
      RESIST=CLASSR+ANOME
      DY(1)=RESIST*CRDENT**2-DENEUT*DENE*(13.6D+00*S+S1)-BREMS -CI
     1  +THREEB*DENE**3*(1.5D+00*TE+3.D+01)-TWOBOD*DENE**2*1.5D+00*TE
      DY(2)=S*DENE*DENEUT-TWOBOD*DENE**2-THREEB  *DENE**3
      DY(3)=QI+ANOMI*CRDENT**2
      RETURN
        END
```

SUBROUTINE INT

```
      SUBROUTINE INT (NMAX, X, Y, F, HO)
      INTEGER NMAX
      DOUBLE PRECISION X, HO, Y
      DIMENSION Y(NMAX)
      EXTERNAL F, ERROR
      DOUBLE PRECISION EPS, H, TRUNC, XO, X1, S, YO, DABS
      INTEGER N, NCONV, NMAX1
      REAL*8 EPSV1
      COMMON /ERRCOM/ YO(  6), S(  6), EPS, NMAX1
      COMMON/CALLS/NOCALL
      EPS=1.E-5
      NMAX1 = NMAX
      XO = X
      H = HO
      DO 100 N = 1, NMAX
        YO(N) = Y(N)
        S(N) = -1
  100   IF (YO(N) .NE. 0.) S(N) = DABS(YO(N))
      EPSV1=EPS
      EPS=.1
      CALL EXTINT (NMAX, X, Y, F, H, 1, ERROR)
      EPS=EPSV1
      X = XO
      X1 = X + HO
      DO 300 N = 1, NMAX
  300   Y(N) = YO(N)
  310 IF (DABS((X1-X)/H) .LE. EPS) GO TO 400
      IF ( (X1-X) * (X1-X-1.4*H) .LE. 0. ) H = X1-X
      IF ( (X1-X-1.4*H) * (X1-X-2.0*H) .LT. 0. ) H = (X1-X) / 2.0
      CALL EXTINT (NMAX, X, Y, F, H, 6, ERROR)
      GO TO 310
  400 RETURN
      END
```

SUBROUTINE EXTINT

```
      SUBROUTINE EXTINT (NMAX, X, Y, F, HO, M MAX, ERROR)
      INTEGER N MAX, M MAX
      DOUBLE PRECISION X, HO, Y(NMAX)
      LOGICAL FIRSTL, CONV(  6), PREVIN, FINISH
      INTEGER J, K, L, M, N, L MAX, K ASIDE, PTS, MM, MMAXP, KMIN
      INTEGER MM2, MMIN, IABS
      REAL FLOAT
      DOUBLE PRECISION XO, U, SUP, YM, BETA, H, DEN, SQRT2, YP, FK,
     1         ONE, TWO, FOUR, SIX, DEXP, DSQRT
      DOUBLE PRECISION HM(11), S(11), P(11,11), YBAR(  6, 7),YO(  6),
     1         Y NEW(  6), Y OLD(  6), DY(  6), DYO(  6), Y HOLD(4, 7,  6)
      ONE = 1.0
      TWO = 2.0
      FOUR = 4.0
      SIX = 6.0
      MMAXP = MMAX + 1
      SQRT2 = DSQRT(TWO)
      FINISH = .FALSE.
      FIRSTL = .TRUE.
      XO = X
      DO 100 N = 1, NMAX
  100   YO(N) = Y(N)
      LMAX = (MMAX + 1)/2 + 1
      CALL F (XO, YO, DYO)
  200 X = XO + HO
      HM(1) = HO/TWO
      HM(2) = HO/FOUR
      HM(3) = HO/SIX
      DO 210 N = 1, NMAX
  210   CONV(N) = .FALSE.
      DO 600 MM = 1, MMAXP
        M = MM - 1
        KASIDE = 2
        IF (2*(M/2).EQ.M) KASIDE = 3
        L = (M + 1)/2 + 1
        IF (M.GT.2) HM(MM) = HM(MM-2)/TWO
        H = HM(MM)
        IF (FIRSTL .OR. M.EQ.0 .OR. M.GE.MMAX-1) GO TO 420
          DO 410 N=1, NMAX
  410       Y BAR(N,MM) = Y HOLD(1,M,N)
          GO TO 500
  420     DO 430 N = 1, NMAX
            Y OLD(N) = YO(N)
  430       Y NEW(N) = YO(N) + H*DYO(N)
          CALL F (XO+H, YNEW, DY)
          PTS = HO/H + 0.1
          DO 460 K = 2, PTS
```

```
         DO 440 N = 1, NMAX
            U = Y OLD(N) + TWO*H*DY(N)
            Y OLD(N) = Y NEW (N)
  440       Y NEW (N) = U
         CALL F (X0 + FLOAT(K)*H, Y NEW, DY)
         IF ((K.NE.KASIDE).OR.(L.LT.2)) GO TO 460
            DO 450 N = 1, NMAX
  450          Y HOLD (L, M, N) = (YNEW(N) + YOLD(N) + H*DY(N))/TWO
            L = L - 1
            KASIDE = 2*KASIDE
  460    CONTINUE
         DO 490 N = 1, NMAX
  490       Y BAR(N,MM) = (YNEW(N) + YOLD(N) + H*DY(N))/TWO
  500 IF (M.GT.0) GO TO 520
      DO 510 N = 1, NMAX
  510    Y(N) = YBAR(N,1)
      IF (NMAX.EQ.0) GO TO 700
      KMIN = 1
      IF (.NOT.FIRSTL) GO TO 600
         BETA = 0.25/(H0*H0)
         S(1) = ONE - DEXP(-BETA*H*H)
      GO TO 600
  520 IF ((3*M)/2 .GT. NMAX) KMIN = KMIN + 1
      IF (.NOT.FIRSTL) GO TO 550
         DEN = ONE
         S(MM) = ONE - DEXP(-BETA*H*H)
         DO 540 K = KMIN, M
            PK = (H/HH(K))**2
            DO 530 J = KMIN, M
               IF (J.NE.K) PK     = PK   *(S(J) - S(MM))/(S(J) - S(K))
  530       CONTINUE
            P(MM,K) = PK
  540       DEN = DEN - PK
         P(MM,MMAXP) = DEN
  550 DO 590 N=1, N MAX
         IF (CONV(N)) GO TO 590
         YP = Y(N)
         YM = Y BAR(N,MM)
         SUM = 0.0
         DEN = P(MM,MMAXP)
         IF (M.LT.2) GO TO 570
         DO 560 J = KMIN, M
  560       SUM = SUM + (YBAR(N,J) - YP)*P(MM,J)
  570    DY(N) = YM - YP
         IF (DEN.NE.0.0) DY(N) = ((YM - YP) - SUM)/DEN
         Y(N) = YP + DY(N)
  590 CONTINUE
  599 CALL ERROR (M, DY, CONV, FINISH)
      IF (FINISH) GO TO 700
  600 CONTINUE
      H0 = H0/TWO
      FIRSTL = .FALSE.
      DO 620 N = 1, NMAX
         Y BAR(N,1) = Y HOLD(2,1,N)
         DO 620 L = 1, LMAX
            MM2 = MMAX - 2
            MMIN = IABS(2*L-3)
            IF (MMIN.GT.MM2) GO TO 620
            DO 610 M = MMIN, MM2
  610          Y HOLD(L, M, N) = Y HOLD (L+1, M+2, N)
  620    CONTINUE
      GO TO 200
  700 HU = H0 * SQRT2 ** (FLOAT(MMAX)*TWO/3.0 - FLOAT(M))
      RETURN
      END
```

SUBROUTINE ERROR

```
      SUBROUTINE ERROR (M, DY, CONV, FINISH)
      INTEGER M
      INTEGER NMAX, NTIMES(  6), NCONV, N
      DOUBLE PRECISION Y, S, EPS, DABS
      COMMON /ERRCOM/ Y(  6), S(  6), EPS, NMAX
      REAL*8 DY(NMAX)
      LOGICAL CONV(NMAX),FINISH
      IF (M.NE.1) GO TO 1
         DO 3 N = 1, NMAX
    3       NTIMES(N) = 0
         NCONV = 0
    1 DO 2 N = 1, NMAX
         IF (.NOT.( DABS(DY(N))/S(N).LT.EPS .OR. CONV(N) )) GO TO 2
         NTIMES(N) = NTIMES(N) + 1
         IF (NTIMES(N).EQ. 1) NCONV = NCONV + 1
         IF (NTIMES(N).EQ. 2) CONV(N) = .TRUE.
         IF (DABS(Y(N)).GT. S(N)) S(N) = DABS(Y(N))
         IF (Y(N).EQ.0.0D0 .AND. S(N).EQ.0.0D0) S(N) = -1
    2 CONTINUE
      IF (NCONV.EQ.NMAX) FINISH = .TRUE.
      RETURN
      END
```

COMPUTATION PRINT OUT SAMPLE

INITIAL VALUES ARE

TIME STEP	I.SHOT	DENSITY	TEMPERATURE	MAX J-BEAM	NEUTRAL DENSITY	R(CG)
0.200000-08	0.112500 16	0.300000 15	0.250000 01	0.150000 02	0.100000 17	0.200000 01

T(NS)	DENSITY	TE	TI	CRONI	RATIO	IONIZ RAD	LINE RAD	CL ION HT	IAC RES	LAMYR RES	CLAS RES	BREMS	CUM ENERGY	EE RES
2	0.30	2.6	7.5	2.77	6.1	0.180 23	0.100 21	-0.860 20	0.210 24	0.960 23	0.750 23	0.470 17	0.540 16	0.000 00
4	0.39	12.2	4.6	4.95	4.9	0.160 25	0.170 22	0.120 22	0.180 24	0.440 23	0.980 22	0.180 18	0.180 17	0.000 00
6	0.77	14.2	5.1	6.77	3.6	0.280 25	0.313 22	0.370 22	0.130 24	0.370 23	0.680 22	0.620 18	0.340 17	0.000 00
8	1.19	12.2	4.7	8.26	2.7	0.380 25	0.510 22	0.110 23	0.970 23	0.220 23	0.730 22	0.170 19	0.510 17	0.000 00
10	1.80	10.2	4.6	9.48	2.1	0.430 25	0.720 22	0.230 23	0.730 23	0.160 23	0.850 22	0.350 19	0.680 17	0.000 00
12	2.43	8.9	4.2	10.44	1.7	0.440 25	0.903 22	0.410 23	0.560 23	0.113 23	0.103 23	0.590 19	0.850 17	0.000 00
14	3.07	8.0	4.1	11.30	1.5	0.420 25	0.110 23	0.410 23	0.430 23	0.940 22	0.110 23	0.890 19	0.100 18	0.000 00
16	3.68	7.3	4.1	11.97	1.4	0.400 25	0.123 23	0.820 23	0.340 23	0.700 22	0.120 23	0.120 20	0.120 18	0.000 00
18	4.25	6.9	4.1	12.52	1.3	0.380 25	0.133 23	0.100 24	0.270 23	0.600 22	0.130 23	0.160 20	0.130 18	0.000 00
20	4.80	6.6	4.0	12.97	1.2	0.360 25	0.140 23	0.120 24	0.210 23	0.530 22	0.140 23	0.200 20	0.140 18	0.000 00
22	5.30	6.4	4.0	13.34	1.1	0.330 25	0.153 23	0.153 24	0.170 23	0.483 22	0.150 23	0.240 20	0.150 18	0.000 00
24	5.78	6.2	4.0	13.64	1.0	0.310 25	0.160 23	0.173 24	0.130 23	0.440 22	0.150 23	0.280 20	0.170 18	0.000 00
26	6.22	6.1	4.0	13.89	1.0	0.290 25	0.170 23	0.190 24	0.100 23	0.410 22	0.150 23	0.320 20	0.180 18	0.000 00
28	6.63	6.0	4.0	14.09	0.9	0.270 25	0.173 23	0.213 24	0.790 22	0.390 22	0.150 23	0.360 20	0.190 18	0.000 00
30	7.01	6.0	4.0	14.25	0.9	0.250 25	0.180 23	0.233 24	0.610 22	0.360 22	0.153 23	0.400 20	0.200 18	0.000 00
32	7.36	6.0	4.0	14.39	0.9	0.230 25	0.190 23	0.260 24	0.460 22	0.340 22	0.150 23	0.440 20	0.210 18	0.000 00
34	7.68	6.0	4.0	14.50	0.8	0.210 25	0.203 23	0.289 24	0.350 22	0.330 22	0.150 23	0.490 20	0.220 18	0.000 00
36	7.98	6.1	4.0	14.59	0.8	0.190 25	0.213 23	0.310 24	0.270 22	0.320 22	0.150 23	0.530 20	0.230 18	0.000 00
38	8.26	6.1	4.0	14.66	0.8	0.180 25	0.220 23	0.330 24	0.200 22	0.300 22	0.150 23	0.570 20	0.240 18	0.000 00
40	8.51	6.2	4.0	14.73	0.8	0.160 25	0.233 23	0.363 24	0.150 22	0.300 22	0.150 23	0.600 20	0.250 18	0.000 00
42	8.73	6.3	4.0	14.78	0.7	0.140 25	0.240 23	0.380 24	0.110 22	0.290 22	0.140 23	0.640 20	0.250 18	0.000 00
44	8.93	6.4	4.0	14.82	0.7	0.130 25	0.250 23	0.400 24	0.810 21	0.280 22	0.140 23	0.680 20	0.240 18	0.000 00
46	9.11	6.5	4.1	14.85	0.7	0.110 25	0.263 23	0.420 24	0.600 21	0.270 22	0.130 23	0.710 20	0.270 18	0.000 00
48	9.27	6.7	4.1	14.88	0.7	0.100 25	0.270 23	0.440 24	0.440 21	0.270 22	0.130 23	0.740 20	0.280 18	0.000 00
50	9.40	6.8	4.2	14.90	0.7	0.860 24	0.270 23	0.460 24	0.320 21	0.260 22	0.133 23	0.780 20	0.290 18	0.000 00
52	9.53	7.0	4.2	14.92	0.7	0.733 24	0.283 23	0.470 24	0.240 21	0.260 22	0.120 23	0.800 20	0.290 18	0.000 00
54	9.62	7.2	4.3	14.93	0.6	0.610 24	0.290 23	0.480 24	0.180 21	0.260 22	0.120 23	0.830 20	0.300 18	0.000 00
56	9.70	7.4	4.4	14.94	0.6	0.510 24	0.290 23	0.493 24	0.130 21	0.260 22	0.110 23	0.860 20	0.300 18	0.000 00
58	9.77	7.6	4.4	14.95	0.6	0.410 24	0.303 23	0.500 24	0.963 20	0.250 22	0.113 23	0.880 20	0.310 18	0.000 00
60	9.82	7.8	4.5	14.96	0.6	0.330 24	0.300 23	0.510 24	0.720 20	0.250 22	0.110 23	0.900 20	0.310 18	0.000 00
62	9.87	8.0	4.6	14.97	0.6	0.260 24	0.290 23	0.513 24	0.540 20	0.250 22	0.100 23	0.920 20	0.320 18	0.000 00
64	9.90	8.2	4.7	14.98	0.6	0.205 24	0.290 23	0.513 24	0.410 20	0.250 22	0.980 22	0.940 20	0.330 18	0.000 00
66	9.93	8.4	4.8	14.99	0.6	0.160 24	0.270 23	0.520 24	0.310 20	0.250 22	0.950 22	0.960 20	0.330 18	0.000 00
68	9.95	8.6	4.9	14.99	0.6	0.120 24	0.260 23	0.520 24	0.233 20	0.253 22	0.920 22	0.970 20	0.340 18	0.000 00
70	9.96	8.8	5.0	14.99	0.6	0.870 23	0.230 23	0.520 24	0.180 20	0.250 22	0.890 22	0.990 20	0.340 18	0.000 00
72	9.97	9.0	5.1	12.28	0.5	0.630 23	0.210 23	0.510 24	0.230 17	0.240 22	0.870 22	0.100 21	0.350 18	0.000 00
74	9.99	9.1	5.2	10.05	0.4	0.450 23	0.173 23	0.513 24	0.100 12	0.233 22	0.840 22	0.100 21	0.350 18	0.000 00
76	9.99	9.1	5.3	8.23	0.3	0.310 23	0.143 23	0.503 24	0.140 02	0.220 22	0.850 22	0.100 21	0.350 18	0.000 00
78	9.99	9.1	5.3	6.74	0.3	0.220 23	0.110 23	0.490 24	0.380 00	0.200 22	0.850 22	0.100 21	0.350 18	0.000 00
80	9.99	9.1	5.4	5.52	0.3	0.150 23	0.850 22	0.480 24	0.380 00	0.180 22	0.860 22	0.100 21	0.350 18	0.000 00
82	10.00	9.0	5.5	4.52	0.3	0.110 21	0.640 22	0.470 24	0.383 00	0.150 22	0.860 22	0.100 21	0.350 18	0.000 00
84	10.00	9.0	5.5	3.70	0.3	0.740 22	0.473 22	0.460 24	0.380 00	0.130 22	0.870 22	0.100 21	0.350 18	0.000 00
86	10.00	8.9	5.6	3.03	0.3	0.520 22	0.343 22	0.453 24	0.380 00	0.990 21	0.870 22	0.100 21	0.350 18	0.000 00
88	10.00	8.9	5.6	2.48	0.3	0.370 22	0.250 22	0.440 24	0.380 00	0.750 21	0.880 22	0.100 21	0.350 18	0.000 00
90	10.00	8.8	5.7	2.03	0.3	0.260 22	0.180 22	0.420 24	0.380 00	0.550 21	0.890 22	0.100 21	0.350 18	0.000 00
92	10.00	8.8	5.8	1.66	0.3	0.183 22	0.133 22	0.410 24	0.380 00	0.400 21	0.890 22	0.990 20	0.350 18	0.000 00
94	10.00	8.7	5.8	1.36	0.3	0.130 22	0.960 21	0.400 24	0.380 00	0.280 21	0.900 22	0.990 20	0.350 18	0.000 00
96	10.00	8.7	5.9	1.11	0.3	0.970 21	0.710 21	0.390 24	0.380 00	0.190 21	0.910 22	0.990 20	0.350 18	0.000 00
98	10.00	8.6	5.9	0.91	0.3	0.710 21	0.533 21	0.380 24	0.380 00	0.130 21	0.920 22	0.980 20	0.350 18	0.000 00
100	10.00	8.6	6.0	0.75	0.3	0.530 21	0.400 21	0.370 24	0.380 00	0.880 20	0.920 22	0.980 20	0.350 18	0.000 00
110	10.00	8.3	6.2	0.27	0.3	0.180 21	0.140 21	0.320 24	0.380 00	0.120 20	0.940 22	0.970 20	0.350 18	0.000 00
120	10.00	8.2	6.4	0.10	0.3	0.120 21	0.920 20	0.270 24	0.380 00	0.160 19	0.990 22	0.960 20	0.350 18	0.000 00
130	10.00	8.0	6.5	0.04	0.3	0.110 21	0.850 20	0.220 24	0.380 00	0.210 18	0.100 23	0.950 20	0.350 18	0.000 00
140	10.00	7.9	6.7	0.01	0.3	0.113 21	0.863 20	0.193 24	0.380 00	0.270 17	0.100 23	0.940 20	0.350 18	0.000 00
150	10.00	7.7	6.9	0.01	0.3	0.120 21	0.880 20	0.150 24	0.380 00	0.363 16	0.113 23	0.930 20	0.350 18	0.000 00
160	10.00	7.6	6.9	0.00	0.3	0.110 21	0.910 20	0.120 24	0.380 00	0.480 15	0.110 23	0.930 20	0.350 18	0.000 00
170	10.00	7.6	7.0	0.00	0.3	0.110 21	0.933 20	0.103 24	0.380 00	0.650 14	0.110 23	0.920 20	0.350 18	0.000 00
180	10.00	7.5	7.0	0.00	0.3	0.113 21	0.950 20	0.823 23	0.380 00	0.873 13	0.110 23	0.920 20	0.350 18	0.000 00
190	10.00	7.5	7.1	0.00	0.3	0.110 21	0.960 20	0.680 23	0.380 00	0.120 13	0.110 23	0.910 20	0.350 18	0.000 00
200	10.00	7.4	7.1	0.00	0.3	0.110 21	0.973 20	0.533 23	0.380 00	0.160 12	0.110 23	0.910 20	0.350 18	0.000 00
210	10.00	7.4	7.1	0.00	0.3	0.110 21	0.980 20	0.420 23	0.380 00	0.217 11	0.110 23	0.910 20	0.350 18	0.000 00
220	10.00	7.4	7.2	0.00	0.3	0.110 21	0.990 20	0.330 23	0.380 00	0.290 10	0.110 23	0.910 20	0.350 18	0.000 00
230	10.00	7.3	7.2	0.00	0.3	0.120 21	0.103 21	0.270 23	0.380 00	0.390 09	0.110 23	0.910 20	0.350 18	0.000 00
240	10.00	7.3	7.2	0.00	0.3	0.120 21	0.100 21	0.213 23	0.380 00	0.520 08	0.110 23	0.910 20	0.350 18	0.000 00
250	10.00	7.3	7.2	0.00	0.3	0.120 21	0.100 21	0.170 23	0.380 00	0.700 07	0.110 23	0.910 20	0.350 18	0.000 00
260	10.00	7.3	7.2	0.00	0.3	0.120 21	0.103 21	0.130 23	0.380 00	0.953 06	0.120 23	0.910 20	0.350 18	0.000 00
270	10.00	7.3	7.2	0.00	0.3	0.120 21	0.100 21	0.100 23	0.380 00	0.130 06	0.120 23	0.900 20	0.350 18	0.000 00
280	10.00	7.3	7.2	0.00	0.3	0.120 21	0.100 21	0.920 22	0.380 00	0.170 05	0.120 23	0.900 20	0.350 18	0.000 00
290	10.00	7.3	7.2	0.00	0.3	0.123 21	0.103 21	0.640 22	0.380 00	0.243 04	0.120 23	0.900 20	0.350 18	0.000 00
300	10.00	7.3	7.3	0.00	0.3	0.120 21	0.100 21	0.500 22	0.380 00	0.320 03	0.120 23	0.900 20	0.350 18	0.000 00
310	10.00	7.3	7.3	0.00	0.3	0.120 21	0.100 21	0.393 22	0.380 00	0.430 02	0.120 23	0.900 20	0.350 18	0.000 00
320	10.00	7.3	7.3	0.00	0.3	0.123 21	0.103 21	0.310 22	0.380 00	0.580 01	0.123 23	0.900 20	0.350 18	0.000 00
330	10.00	7.3	7.3	0.00	0.3	0.120 21	0.100 21	0.240 22	0.380 00	0.790 00	0.120 23	0.900 20	0.350 18	0.000 00
340	10.00	7.3	7.3	0.00	0.3	0.120 21	0.103 21	0.189 22	0.380 00	0.110 00	0.120 23	0.900 20	0.350 18	0.000 00
350	10.00	7.3	7.3	0.00	0.3	0.123 21	0.100 21	0.143 22	0.380 00	0.140-01	0.120 23	0.900 20	0.350 18	0.000 00
360	10.00	7.3	7.3	0.00	0.3	0.120 21	0.100 21	0.110 22	0.380 00	0.200-02	0.120 23	0.900 20	0.350 18	0.000 00
370	10.00	7.3	7.3	0.00	0.3	0.120 21	0.100 21	0.810 21	0.380 00	0.263-03	0.120 23	0.900 20	0.350 18	0.000 00
380	10.00	7.3	7.3	0.00	0.3	0.120 21	0.100 21	0.603 21	0.380 00	0.360-04	0.123 23	0.900 20	0.350 18	0.000 00
390	10.00	7.3	7.3	0.00	0.3	0.120 21	0.100 21	0.430 21	0.380 00	0.480-05	0.120 23	0.900 20	0.350 18	0.000 00
400	10.00	7.3	7.3	0.00	0.3	0.123 21	0.103 21	0.300 21	0.380 00	0.660-06	0.120 23	0.900 20	0.350 18	0.000 00
410	10.00	7.3	7.3	0.00	0.3	0.120 21	0.103 21	0.200 21	0.380 00	0.890-07	0.123 23	0.900 20	0.350 18	0.000 00
420	10.00	7.3	7.3	0.00	0.3	0.120 21	0.100 21	0.110 21	0.380 00	0.120-07	0.120 23	0.900 20	0.350 18	0.000 00
430	10.00	7.3	7.3	0.00	0.3	0.120 21	0.103 21	0.490 20	0.380 00	0.160-08	0.120 23	0.900 20	0.350 18	0.000 00
440	10.00	7.3	7.3	0.00	0.3	0.120 21	0.103 21	-0.200 19	0.380 00	0.220-09	0.120 23	0.900 20	0.350 18	0.000 00
450	10.00	7.3	7.3	0.00	0.3	0.120 21	0.100 21	-0.420 20	0.380 00	0.300-10	0.120 23	0.900 20	0.350 18	0.000 00
460	10.00	7.3	7.3	0.00	0.3	0.120 21	0.103 21	-0.740 20	0.380 00	0.400-11	0.120 23	0.900 20	0.350 18	0.000 00
470	10.00	7.3	7.3	0.00	0.3	0.123 21	0.100 21	-0.100 21	0.380 00	0.540-12	0.120 23	0.900 20	0.350 18	0.000 00
480	10.00	7.3	7.3	0.00	0.3	0.120 21	0.100 21	-0.120 21	0.380 00	0.740-13	0.120 23	0.900 20	0.350 18	0.000 00
490	10.00	7.3	7.3	0.00	0.3	0.123 21	0.103 21	-0.143 21	0.380 00	0.100-13	0.120 23	0.900 20	0.350 18	0.000 00
500	10.00	7.3	7.3	0.00	0.3	0.120 21	0.100 21	-0.150 21	0.380 00	0.140-14	0.120 23	0.900 20	0.350 18	0.000 00
510	10.00	7.3	7.3	0.00	0.3	0.120 21	0.103 21	-0.163 21	0.380 00	0.180-15	0.120 23	0.900 20	0.350 18	0.000 00
520	10.00	7.3	7.3	0.00	0.3	0.120 21	0.103 21	-0.170 21	0.380 00	0.253-16	0.120 23	0.900 20	0.350 18	0.000 00
530	10.00	7.3	7.3	0.00	0.3	0.120 21	0.100 21	-0.170 21	0.380 00	0.330-17	0.120 23	0.900 20	0.350 18	0.000 00
540	10.00	7.3	7.3	0.00	0.3	0.120 21	0.100 21	-0.180 21	0.380 00	0.450-18	0.120 23	0.900 20	0.350 18	0.000 00
550	10.00	7.3	7.3	0.00	0.3	0.120 21	0.103 21	-0.180 21	0.380 00	0.613-19	0.120 23	0.900 20	0.350 18	0.000 00
560	10.00	7.3	7.3	0.00	0.3	0.120 21	0.100 21	-0.180 21	0.380 00	0.830-20	0.120 23	0.900 20	0.350 18	0.000 00
570	10.00	7.3	7.3	0.00	0.3	0.120 21	0.103 21	-0.190 21	0.380 00	0.110-20	0.120 23	0.900 20	0.350 18	0.000 00
580	10.00	7.3	7.3	0.00	0.3	0.120 21	0.100 21	-0.190 21	0.380 00	0.150-21	0.120 23	0.900 20	0.350 18	0.000 00
590	10.00	7.3	7.3	0.00	0.3	0.120 21	0.100 21	-0.190 21	0.380 00	0.210-22	0.120 23	0.900 20	0.350 18	0.000 00
600	10.00	7.3	7.3	0.00	0.3	0.120 21	0.103 21	-0.190 21	0.380 00	0.280-23	0.120 23	0.900 20	0.350 18	0.000 00

DEFINITION OF TERMS

ANOME	Electron portion of resistivity as expressed in Eq. (12a), Section II, of Ref. 1.
ANOMEE	Electron-electron resistivity as expressed in Eq. (4).
ANOMI	Ion portion of resistivity as expressed in Eq. (12b).
ANOMIA	Ion-acoustic resistivity as expressed in Eq. (3).
ANOMLH	Lower hybrid resistivity not specifically given in Ref. 1, but operative in some of the runs.
ANOMWV	Wave resistivity as expressed in Eq. (8).
BKG	Applied, axial, magnetic guide field in kG.
B(KG)	Format designating printout of initial value of magnetic field BKG.
BREMS	P_B in Ref. 1, the plasma power density in eV/cm^3 sec lost to bremsstrahlung.
CLAS RES	Format designating printout of instantaneous classical resistivity value.
CLASSR	Classical resistivity, as expressed in Eqs. (1a), (1b) and (2).
CL ION HT	Format designating printout of power density used for classical ion heating.
COULOG	Coulomb logarithm, $\ln\Lambda$.
CRDENT	Instantaneous beam current density in kA/cm^2.
CRDNT	Format designating printout of instantaneous beam current density in kA/cm^2.
CS	Ion sound velocity.
CUM ENERGY	Format designating printout of total accumulated energy density transferred from the beam to the plasma system, in $eV/cm.^3$
CURDEN	Assymptotic beam current density in kA/cm^2.

CUTOFF	Ratio of instantaneous beam current density (CRDENT) and a minimum current density (STABLJ) or j_{min} as expressed in Eq. (6).
DENE	Instantaneous value of the electron density cm^{-3}.
DENEUT	Instantaneous value of the neutral density cm^{-3}.
DENI	Instantaneous value of the ion density, equal to DENE for a hydrogen plasma.
DENMAX	Neutral hydrogen fill density cm^{-3}. Equal to DENE plus DENEUT.
DENSITY	Format designating printout of initial value of electron density (Y20) in cm^{-3}.
DY(1)	Electron energy equation as expressed in Eq. (9).
DY(2)	Electron (and ion) density equation as expressed in Eq. (10).
DY(3)	Ion energy equation as expressed in Eq. (11).
EDENS	Instantaneous value of electron density times 1×10^{-15}.
EE RES	Format designating printout of electron-electron resistivity.
ENERGY	Total beam energy density in eV/cm^3 deposited resistively in the plasma at a rate ηj^2.
HO,HO1	Calculation time step length.
IAC RES	Format designating printout of ion acoustic resistivity.
IHO1	Time step length times 1×10^9.
IMAX	The number of time steps printed out.
IONIZ RAD	Format designating printout of beam power density in eV/cm^3 sec used for ionization.
ITIME	Time step length.
JMAX	The number of different current densities to be calculated.

LINE RAD	Format designating printout of the plasma power density in eV/cm^3 sec lost through line radiation.
LWHYB RES	Format designating printout of the lower hybrid resistivity.
MAX J-BEAM	Format designating printout of initial value of the peak beam current density in kA/cm^2.
NEUTRAL DENSITY	Format designating printout of initial value of the neutral hydrogen fill density cm^{-3}.
QI	The classical collisional electron-ion energy transfer rate.
RADION	Beam power density in eV/cm^3 sec used for ionization.
RADLIN	Plasma power density in eV/cm^3 sec lost through line radiation.
RATIO	Ratio of plasma electron drift velocity VD to the critical velocity VCRIT. RATIO is a measure of whether the ion acoustic instability is expected. Yes, if RATIO > 1.
RESIST	Sum of all the resistivities employed in the model.
S	Ionization rate coefficient as expressed in Eq. (13).
S1	Excitation rate coefficient as expressed in Eq. (14).
STABLJ	Minimum current density, j_{min} as expressed in Eq. (6).
T,T(NS)	Format designating printout of time in nsec of the calculation.
TEMPERATURE	Format designating printout of initial value of the electron temperature in eV.
TE	Format designating printout of electron temperature in eV.
TEO	Initial electron temperature in eV.

THREEB	Three-body recombination rate coefficient, α_3 as expressed in Eq. (16).
TI	Format designating printout of ion temperature in eV.
TIME STEP	Format designating printout of initial value of time step length (HO) in nsec.
T PULSE	Beam pulse width in nsec.
TWOBOD	Two-body recombination rate coefficient, α_2 as expressed in Eq. (15).
VCRIT	Critical velocity as expressed in Eq. (5). (See RATIO).
VD	Plasma electron drift velocity.
VE	Plasma electron thermal velocity.
VTHI	Ion thermal velocity.
Y(1),3/2NKT	Defined as 3/2 the initial electron density (Y20) times the initial electron temperature (TEO), in eV/cm^3.
Y 20,Y(2)	Initial electron density, cm^{-3}.

CSN STEP COMMENTARY

The following commentary is intended to point out specific areas of importance in understanding and utilizing this computational program. References are made to CSN numbers listed down the left hand side of the code listing.

A. Main Program:

CSN 0007 — Initial data is read in at this statement. The present number of time steps (IMAX) is 100. The total number of beam current densities (JMAX) is presently 6, (2,3,4,6,10 and 15 kA/cm^2). The initial electron temperature (TEO) is taken as 2.5 eV, and is determined beforehand. The initial electron density (Y20) is also estimated beforehand, and is usually between 0.1 and 5% of DENMAX, the neutral hydrogen fill density. Present values of Y20 range between $3 \times 10^{13} cm^{-3}$ and $3 \times 10^{14} cm^{-3}$. Values of DENMAX range between $6.7 \times 10^{15} cm^{-3}$ (100mT) and $3.3 \times 10^{16} cm^{-3}$ (500mT). The calculation time step length (HO) is presently 2×10^{-9} sec. The first 50 steps are taken at 5HO or 10 nsec increments. See CSN 0083 through 0099, especially 0094 and 0098, for setting the time increments. The time of calculation T(NS) is printed out down the left hand side of the computation printout, see CSN 0027 for this format statement. The beam pulse width (TPULSE) is presently set at 70 nsec for our accelerator. The rise and fall times are set in CSN 0032-0036. They are presently 10 nsec. It is also possible to employ a step function beam pulse by specifying just the rise time. In that case, TPULSE is disregarded. The applied, axial, magnetic guide field (BKG) is set at 2 kG.

CSN 0020 — The assymptotic beam current densities are read in at this statement. One data card is required for each value of CURDEN.

CSN 0023 — This is the format statement for the display of the initial values of the run as they are listed across the top of each section of the computation printout. These include TIME STEP, or HO in nsec, 1.5NKT or Y(1) in eV/cm^3, DENSITY, the initial electron density Y20 or Y(2) in cm^{-3}, TEMPERATURE, the initial electron temperature TEO in eV, MAX J-BEAM, the initial value of the peak beam current density CURDEN in kA/cm^2, NEUTRAL DENSITY, the initial value of the neutral hydrogen fill density DENMAX, in cm^{-3}, and B(KG) the initial value of the magnetic guide field BKG in kG.

CSN 0027 This is the format statement for the headings of the columns of computational results listed in the printout. From left to right we have: T(NS) in nsec, the time from the start of the beam pulse to the time of the calculation, the electron density, DENSITY, in units of 10^{15}cm^{-3}, the electron and ion temperatures, TE and TI, respectively, the instantaneous beam current density, CRDNT, in kA/cm^2, RATIO, the ratio of plasma electron drift velocity, VD, to the critical velocity, VCRIT, as defined in Eq. (5) of Ref. 1. RATIO is a measure of whether the ion acoustic instability is expected. If RATIO > 1, the ion acoustic mode is operative. IONIZ RAD is the beam power density in eV/cm^{3}sec used for ionization. LINE RAD is the plasma power density lost through line radiation. CL ION HT is the power density used for classical ion heating. IAC RES, LWHYB RES, CLAS RES, and EE RES in the last column, are the ion acoustic, lower hybrid, classical and electron-electron resistivities respectively as described in Section II of Ref. 1. They have the units of (eV/cm^{3}sec)/(kA/cm^2)^2, so that power density is in eV/cm^3 sec when current density is in kA/cm^2. BREMS is the plasma power density, P_B in Ref. 1, lost to bremsstrahlung. CUM ENERGY is the total accumulated energy density transferred from the beam to the plasma system, in eV/cm^3.

CSN 0028 This statement calls for subroutine FINI which calculates the energy equations given in Eqs. (9) and (11) and the density equation given in Eq. (10) in Ref. 1. The common variables are listed within the parenthesis.

CSN 0032-0036 These statements specify the beam pulse rise (0035) and fall (0033) time, in this case being 10 nsec. To specify a step function pulse, only statement 0035 would be necessary.

CSN 0038-0080 Here begins the calculation of quantities for the printout. All of these quantities are defined in Section III of this paper. Note the order of CSN 0054 and 0055. Since the computer "remembers" the last statement it reads, it takes ANOMLH as zero in this case; ANOMIA, statements 0059 and 0060, on the other hand, is operative, at least within the range of RATIO > 1. In a similar manner, the exponential factor in ANOMEE, statement 0066, and given in Eq. (4), is written in statement 0062 as CUTOFF. The electron-electron resistivity is turned off when the beam current density CRDENT drops below the minimum value required for the electron-electron two stream instability, STABLJ or j_{min} as given in Eq. (6). This same cutoff also limits the wave resistivity, ANOMWV, CSN 0067-0069, although in this run it is set at zero.

CSN 0083-0099 — Within these statements are set the time increments for which the computations are performed. The calculation time step length H0, is set at 2 nsec initially. The first 50 time steps have 2 nsec increments, the next 50 steps have 5H0 or 10 nsec increments, (CSN 0090 and 0094). Additional steps, if more than 100 were called for, would have increments of 25H0 or 50 nsec. (CSN 0093 and 0098).

B. Subroutine FINI:

CSN 0032, 0033 — TWOBOD and TRHEEB are the two and three-body recombination rate coefficients respectively. These are expressed as α_2 and α_3 in Eqs. (15) and (16) in Ref. 1.

CSN 0057, 0058 — ANOME and ANOMI are the electron and ion portions of the resistivity as expressed in Eqs. (12a) and (12b), Ref. 1, respectively.

CSN 0062-0064 — The equations calculated in subroutine FINI, ENTRY F, are listed in statements 0062, 0063 and 0064, being the electron energy, electron and ion density, and ion energy equations respectively. These are expressed in Eqs. (9), (10) and (11) in Ref. 1.

C. Subroutines, INT, EXTINT and ERROR:

CSN 0005 (INT) — INT chooses an integration accuracy appropriate to the machine on which it is computing, or 1 part in 10^5, whichever is greater. Then it involves subroutine EXTINT, as necessary to integrate the energy and density equations from X to X + HO. A description of the arguments of INT appears at the beginning of EXTINT. COMMON/ERRCOM provides subroutine ERROR with variables it needs.

CSN 0010 (INT) Initialize "S" and the local variables.

CSN 0018 (INT) Determine an appropriate H.

CSN 0022 (INT) Perform the required integration.

D. Computation Print Out:

A sample computation printout section has been reproduced to illustrate the existing format of calculation display. Initial values, as previously defined, are listed across the top of each section, and beneath these are the 15 columns of calculations. The sample calculation has initial values as follows: time step 2 nsec, initial electron density $3 \times 10^{14} cm^{-3}$, initial temperature 2.5 eV, maximum beam current density 15 kA/cm^2, neutral fill density $1 \times 10^{16} cm^{-3}$ or 150 mT, and applied magnetic field 2 kG. Note that all the resistivities are operative except the electron-electron. Also note how the ion acoustic resistivity is "turned off" at about 75 nsec when RATIO falls below 0.3.

REFERENCES

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