LA-3347-MS

OCT 1

MASTER

# LOS ALAMOS SCIENTIFIC LABORATORY
## of the
## University of California

LOS ALAMOS • NEW MEXICO

# Computer Program for Solution of the Energy Balance and Heat Transfer of a Pulsed Thermonuclear Reactor



UNITED STATES
ATOMIC ENERGY COMMISSION
CONTRACT W-7405-ENG. 36

Printed in USA. Price $1.00. Available from the Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, United States Department of Commerce, Springfield, Virginia

LA-3347-MS
UC-20, CONTROLLED
THERMONUCLEAR PROCESSES
TID-4500 (43rd Ed.)

**LOS ALAMOS SCIENTIFIC LABORATORY**
**of the**
**University of California**

LOS ALAMOS • NEW MEXICO

Report written: June 1, 1965

Report distributed: September 10, 1965

# Computer Program for Solution of the Energy Balance and Heat Transfer of a Pulsed Thermonuclear Reactor

by

J. E. Powers and F. L. Ribe

ABSTRACT

A summary is given of the function and use of a Fortran program for use on the IBM-7094. The program is used to solve the energy balance and heat transfer of the pulsed reactor discussed in LA-3294-MS, "Feasibility Study of a Pulsed Thermonuclear Reactor."

## CONTENTS


| | | Page |
|---|---|---|
| | ABSTRACT | 3 |
| I. | FUNCTION OF THE PROGRAM | 7 |
| II. | USE OF THE PROGRAM | 7 |
| III. | SUMMARY OF PROGRAM INPUT | 8 |
| IV. | SUMMARY OF PROGRAM OUTPUT | 10 |
| V. | LISTING OF THE PROGRAM | 11 |
| VI. | SAMPLE CALCULATION | 12 |


## TABLES


| | | |
|---|---|---|
| I. | Fortran Code Listing | 13 |
| II. | Listing of Problem | 18 |

## I. FUNCTION OF THE PROGRAM

The basic function of the program is to solve the energy-balance equation (83) of the Los Alamos Scientific Laboratory report No. LA-3294-MS, "Feasibility Study of a Pulsed Thermonuclear Reactor," (1965), with a pump-power ($P_p$) term corresponding to realistic heat transfer. A set of burning times, corresponding to various kT's, are assumed. These are called T GUESS in the program. Then, the energy-balance equation is iterated to obtain the final values of $\tau_T$(TAU), which are roots of Eq. (83).

For each value of $\tau_T$, the heat-transfer equations (68) through (82) of LA-3294-MS are solved under the constraint that $\Delta p_\Sigma = \Delta p_B$ and $L_{c\Sigma} = L_{cB}$.

## II. USE OF THE PROGRAM

The program is written in Fortran II, Version III.

Submit as a monitor job with first card an ID card (orange)

Deck RIBE (Binary deck)

Deck LASPLN (Binary deck)

Data cards:

Control card for table input: N, JJ, Epsi — Format: 2I6, 1E12.7

- N - length of G(TAU) table
- JJ - number of XKT's
- Epsi - convergence test

Cards containing XKT, SIGV (Number of cards: JJ) — Format: 2E12.7

Cards containing X, Y (Number of cards: N) — Format: 2E12.7
[where X is TAU and Y is G(TAU)]

Card containing B Format: 1E12.7

Cards containing XKT, T GUESS Format: 2E12.7
(Number of cards: JJ)

Sets of cards containing the following:

U, UE, UB, XS, XE, XB, DTS, DTE, DPS, DPE Format: 6E12.7
(Six words per card for a total of JJ words, and with each set beginning on a new card.)

The following six cards contain data for a particular case. Any number of cases may be run by repeating these six cards for each case.

Card No. 1. "1" punch in Column 1 and Columns 2 to 72 used for identification of the case.

Card No. 2. KK, LL, MM Format: 3I6

KK - maximum number of iterations

LL - 0 for regular run

1 for one iteration only on TAU

MM - 0 for no print-out of iterations

1 for printing iterations

Card No. 3. IR, IM, IE, IS, IH, IQ, J2 Format: 7I6

Card No. 4. RC, RP, EP, EPR, ETA, CAPC Format: 6E12.7

Card No. 5. RHO, QI, XMU, CAPLC, Z, TY Format: 6E12.7

Card No. 6. CN, STE, CVV, VKK Format: 4E12.7

## III. SUMMARY OF PROGRAM INPUT

| Code | Symbol LA-3294-MS | Explanation | Unit |
|---|---|---|---|
| XKT | kT | Plasma temperature | keV |
| SIGV | $\sigma v$ | d-t cross section times velocity | $cm^3\ sec^{-1}$ |
| G($\tau$) | | Factor in resistive energy loss. Not in Eq. (27). Use G = 1.267 for hot copper coil. G = 0 for sustained-field case. | |
| B | B | Magnetic field | G |
| U | $u_\Sigma$ | Fluid velocity-$\Sigma$ case | ft/sec |

| Symbol Code | Symbol LA-3294-MS | Explanation | Unit |
|---|---|---|---|
| UE | $u_E$ | Fluid velocity-E case | ft/sec |
| UB | $u_B$ | Fluid velocity-B case | ft/sec |
| XS | $x_\Sigma$ | Fractional channel spacing-$\Sigma$ case | |
| XE | $x_E$ | Fractional channel spacing-E case | |
| XB | $x_B$ | Fractional channel spacing-B case | |
| DTS | $\Delta T_\Sigma$ | Temperature difference between conductor and coolant | $^oC$ |
| DTE | $\Delta T_E$ | Temperature difference between conductor and coolant | $^oC$ |
| DPS | $\Delta p_\Sigma$ | Pressure drop in channels-$\Sigma$ case | psi |
| DPE | $\Delta p_E$ | Pressure drop in channels-E case | psi |

Energy-Balance Indices for Eq. (83)

| | | | |
|---|---|---|---|
| IR | r | Index: r = 1 gives cryogenic case | |
| IM | m | Index: m = 1 gives hot-conductor case | |
| IE | e | Index: e = 1 includes $w_p$ in $P_\Sigma$ | |
| IS | s | Index: s = 1 includes $w_p$ in energy balance | |
| IH | H | Index: H = 1 includes $P_p$ in energy balance | |
| IQ | q | Index: q = 1 includes $P_B$ in $P_\Sigma$ | |
| XJ2 | J2 | Index: J2 = 1 includes $P_{pE}$ and $P_{pB}$ in $P_p$ | |
| RC | $R_c$ | Coil inner radius | cm |
| RP | $R_p$ | Plasma radius | cm |
| EP | $\epsilon$ | Thermal efficiency | |
| EPR | $\epsilon r$ | Refrigeration efficiency | |
| Z | $\xi$ | Duty factor | |
| ETA | $\eta$ | Resistivity of coil conductor | ohm-cm |
| CAPC | C | Thermal capacity of coolant | $Btu/lb^oF$ |
| RHØ | $\rho_c$ | Density of coolant | $lb/ft^3$ |
| QI | Q | Energy release in d-t reaction | keV |

| Code | Symbol LA-3294-MS | Explanation | Unit |
|---|---|---|---|
| XMU | $\mu_c$ | Viscosity of coolant | lb/hr ft |
| CAPKC | $k_c$ | Thermal conductivity of coolant | Btu/ hr ft$^{o}$F |
| TY | $\tau_y$ | Tensile yield strength of conductor | psi |
| CN | $n_c$ | Number density of conductor atoms | cm$^{-3}$ |
| STE | $\sigma_t E$ | Cross section times energy loss per conductor atom | cm$^2$-keV |
| CVV | $C_v$ | Thermal capacity per unit volume of conductor | J/cm$^3$ $^{o}$C |
| VKK | $k_v$ | Thermal conductivity of conductor | w/cm$^{o}$C |

## IV. SUMMARY OF PROGRAM OUTPUT

| Code | Symbol LA-3294-MS | Explanation | Unit |
|---|---|---|---|
| PS | $P_\Sigma$ | Total power removed from conductor $\Sigma$-case | w/cm |
| PT | $P_T$ | Thermonuclear power | w/cm |
| PN | $P_N$ | Power loss by neutrons in conductor | w/cm |
| PB | $P_B$ | Bremsstrahlung power | w/cm |
| N | n | Plasma number density | cm$^{-3}$ |
| K | Number of iterations required to meet convergence test on energy balance | | |
| LCS | $L_{c\Sigma}$ | Coolant channel length for $\Sigma$ heat transfer | cm |
| LCE | $L_{cE}$ | Coolant channel length for electrical heat transfer | cm |
| LCB | $L_{cB}$ | Coolant channel length for bremsstrahlung heat transfer | cm |
| DS | $d_\Sigma$ | Coolant channel diameter, $\Sigma$-case | cm |
| DE | $d_E$ | Coolant channel diameter, E-case | cm |

| Code | Symbol LA-3294-MS | Explanation | Unit |
|---|---|---|---|
| DB | $d_B$ | Coolant channel diameter, B-case | cm |
| DPB | $\Delta P_B$ | Coolant pressure drop, B-case | psi |
| DTB | $\Delta T_B$ | Pressure difference between conductor and coolant, B-case | $^oC$ |
| XSDT | $x_\Sigma \delta_t$ | Spacing of coolant channels, Σ-case | cm |
| XEDT | $x_E \delta_t$ | Spacing of coolant channels, E-case | cm |
| XBDT | $x_B \delta_t$ | Spacing of coolant channels, B-case | cm |
| TRS | $T_{R\Sigma}$ | Temperature rise of coolant, Σ-case | $^oC$ |
| TRE | $T_{RE}$ | Temperature rise of coolant, E-case | $^oC$ |
| TRB | $T_{RB}$ | Temperature rise of coolant, B-case | |
| WP/TAU | $W_p/\tau$ | Plasma energy per half cycle | w/cm |
| WE/TAU | $W_E/\tau$ | Electrical energy dissipation per half cycle | w/cm |
| PPS | $P_{p\Sigma}$ | Coolant pump power, Σ-case | w/cm |
| PPE | $P_{pE}$ | Coolant pump power, E-case | w/cm |
| PPB | $P_{pB}$ | Coolant pump power, B-case | w/cm |
| PPPP | $P_{p\Sigma} + J2(P_{pE} + P_{pB})$ | Total coolant pump power | w/cm |
| NTAU | $n\tau_T$ | Product of number density times burning time | $cm^{-3}$ sec |

## V. LISTING OF THE PROGRAM

Table I is a listing of the symbolic Fortran code. Note that the treatments of heat transfer in the Σ case and the E and B cases are somewhat different. In the Σ case, use is made of the basic Eqs. (57) through (67). In the E and B cases, the reduced forms, Eqs. (73) through (82), are used.

The energy-balance equation (83) of LA-3294-MS is the same as Eq. (42) of LA-3289-MS, "Scylla Theta-Pinch Experiments: Status, Plans, and Proposal for a Closed Toroidal Theta Pinch (Scyllac)," (1965). The latter report also treats energy balance for a cryogenic coil, e.g., Eq. (43). In the present code, the energy balance includes both the hot-coil and cryogenic cases for m = 1, r = 0, and m = 0, r = 1, respectively.

## VI. SAMPLE CALCULATION

Table II is a listing of the problem corresponding to the graph of Fig. 4 in LA-3294-MS. The energy balance with heat transfer for this case of a hot Be-Cu coil at a magnetic field of 200 kG requires a plasma burning time of 13.5 msec at the optimum plasma temperature of 12 keV.

TABLE I. Fortran Code Listing.

```
C RIBE
      DIMENSIONXKT(50),TGUESS(50),SIGV(50),GY(50),NK(50),
     1PT(50),PN(50),PB(50),PS(50),D(50),CL(50),PP(50),TAU(50),XDT(50),
     2TR(50),TNN(50),WPT(50),WET(50),XNN(50),U(50)
      DIMENSIONX(50),Y(50),W(50),G(50),TAB(3)
      DIMENSIONV1(50),V2(50)
      DIMENSIONUE(50),UB(50),XS(50),XE(50),XB(50),DTS(50),DTE(50),
     1DTB(50),DPS(50),DPE(50),DPB(50),PPPP(50)
      DIMENSIONDE(50),CLE(50),TRE(50),PPE(50),XEDT(50)
      DIMENSIONDB(50),CLB(50),TRB(50),PPB(50),XBDT(50)
    1 FORMAT(72H
     1              )
    2 FORMAT(3I6)
    3 FORMAT(2I6,1E12.7)
    4 FORMAT(7I6)
    5 FORMAT(6E12.7)
    6 FORMAT(4E12.7)
    7 FORMAT(2E12.7)
   18 FORMAT(22H      ONLY ONE ITERATION,//)
   19 FORMAT(15H      REGULAR RUN,//)
   20 FORMAT(10X,3H R=I4,6H     M=I4,6H     E=I4,6H     S=I4,6H     H=I4,6H
     1   QQ=I4,6H    J2=I4)
   21 FORMAT(10X,3H B=1PE14.5)
   23 FORMAT(1P9E12.3,I6)
   24 FORMAT(1H2)
   26 FORMAT(1P9E12.3)
   28 FORMAT(1P2E12.3)
   99 FORMAT(1H0,3X,A6,1PE14.5)
  222 FORMAT(I6,1P7E12.3)
  223 FORMAT(I6,1P8E12.3)
  500 FORMAT(84H          KT          US          UE          UB
     1   XS          XE          XB)
  501 FORMAT(1P7E12.3)
  502 FORMAT(60H          KT          DPS          DPE          DTS
     1 DTE)
  503 FORMAT(1P5E12.3)
  504 FORMAT(114H          KT       TGUESS          TAU       G(TAU)
     1   PS          PT          PN          PB           N      K)
  505 FORMAT(108H          KT          LCS          LCE          LCB
     1   DS          DE          DB          DPB          DTB)
  506 FORMAT(108H          KT         XSDT          XEDT         XBDT
     1   TRS          TRE          TRB       WP/TAU       WE/TAU)
  507 FORMAT(72H          KT          PPS          PPE          PPB
     1PPPP        NTAU)
  508 FORMAT(1P6E12.3)
      V1(1)=6H    RC=
      V1(2)=6H    RP=
      V1(3)=6H    EP=
      V1(4)=6H   EPR=
      V1(5)=6H   ETA=
      V1(6)=6H  CAPC=
      V1(7)=6H   RHO=
      V1(8)=6H     Q=
      V1(9)=6H    MU=
```

```
      V1(10)=6HCAPKC=
      V1(11)=6H     Z=
      V1(12)=6H  TAUY=
      V1(13)=6H    NC=
      V1(14)=6H   STE=
      V1(15)=6H    CV=
      V1(16)=6H    KV=
      READ INPUT TAPE 10,3,N,JJ,EPSI
      READ INPUT TAPE 10,7,(XKT(J),SIGV(J),J=1,JJ)
      READ INPUT TAPE 10,7,(X(I),Y(I),I=1,N)
      READ INPUT TAPE 10,6,B
      READ INPUT TAPE 10,7,(XKT(J),TGUESS(J),J=1,JJ)
      READ INPUT TAPE 10,5,(U(J),J=1,JJ)
      READ INPUT TAPE 10,5,(UE(J),J=1,JJ)
      READ INPUT TAPE 10,5,(UB(J),J=1,JJ)
      READ INPUT TAPE 10,5,(XS(J),J=1,JJ)
      READ INPUT TAPE 10,5,(XE(J),J=1,JJ)
      READ INPUT TAPE 10,5,(XB(J),J=1,JJ)
      READ INPUT TAPE 10,5,(DTS(J),J=1,JJ)
      READ INPUT TAPE 10,5,(DTE(J),J=1,JJ)
      READ INPUT TAPE 10,5,(DPS(J),J=1,JJ)
      READ INPUT TAPE 10,5,(DPE(J),J=1,JJ)
      DO200I=1,N
  200 X(I)=LOG10F(X(I))
   55 READ INPUT TAPE 10,1
      READ INPUT TAPE 10,2,KK,LL,MM
      READ INPUT TAPE 10,4,IR,IM,IE,IS,IH,IQ,J2
      READ INPUT TAPE 10,5,RC,RP,EP,EPR,ETA,CAPC
      READ INPUT TAPE 10,5,RHO,QI,XMU,CAPKC,Z,TY
      READ INPUT TAPE 10,6,CN,STE,CVV,VKK
      V2(1)=RC
      V2(2)=RP
      V2(3)=EP
      V2(4)=EPR
      V2(5)=ETA
      V2(6)=CAPC
      V2(7)=RHO
      V2(8)=QI
      V2(9)=XMU
      V2(10)=CAPKC
      V2(11)=Z
      V2(12)=TY
      V2(13)=CN
      V2(14)=STE
      V2(15)=CVV
      V2(16)=VKK
      CALL SPLIN1(X,Y,N,W,G,2,0.,0.)
      IF(IM)300,301,300
  300 BIGE=1.-EP
      GOTO302
  301 BIGE=1./EPR
  302 R=IR
      XM=IM
      E=IE
```

TABLE I. (Continued).

```
S=IS
H=IH
QQ=IQ
XJ2=J2
C1=SQRTF(2.*VKK*Z/(3.1415926*CVV))
C2=19.76*RC
C3=CN*STE/QI
C4=.01941*RP**2
C5=1.875E-8*RP**2
C6=8.72E-4*RC*SQRTF(ETA)
C7=29.53*RHO/XMU
C8=XMU*CAPC/CAPKC
C9=2.336E3/RHO
C10=5.296E-3*RC
C11=Z*H*(1.+.2*XM)
C12=1.762E3/Z
C13=EP+.0745*(1.+EP)
C14=BIGE*R*(1.+EP*EPR)
C15=(1.+.2*R)+R*BIGE-XM*EP
C20=(VKK/CVV)**.25*(XMU**.625/CAPKC**.875)/CAPC**.375
C21=1./(CAPC*RHO*C20)
C22=(VKK/CVV)*C20/RHO
C23=C22/RHO
C25=.706E-9*C22
C27=1.65E-6*C23
C28=7.38E3*C21
C29=8.10E-9*C20
C40=(VKK/CVV)**.125*(XMU**.625/CAPKC**.875)/CAPC**.375
C41=1./(CAPC*RHO*C40)
C42=(VKK/CVV)**.5*C40/RHO
C43=C42/RHO
C45=1.93*C42
C47=4.51E3*C43
C48=.957E2*C41
C49=1.07E-3*C40
DRC=5.77E-7*B**2*RC/TY
WP=C5*B**2
PARTW=C6*B**2
CZ=S*(1.-EP)*WP
DO100J=1,JJ
DENOM=QI*SIGV(J)
Y1=XKT(J)**2/DENOM
Y2=SQRTF(XKT(J))/DENOM
PT(J)=C4*B**4/Y1
PN(J)=C3*DRC*PT(J)
PB(J)=1.37E-14*Y2*PT(J)
XNN(J)=1.242E7*B**2/XKT(J)
PART1=C13*PT(J)-C14*(PN(J)+PB(J))
RDD=(C7*U(J))**.8
DEN2=2.804*CAPKC*RDD*C8**.3
B20=B**2.5
B21=XE(J)**2.5
B22=B20*B21
B23=DPE(J)/UE(J)**2
B24=B22*B23/UE(J)
B25=B23/(B**.5*XE(J)**.5)
B26=RC*ETA**.5*UE(J)**2/Z
B27=B20*XE(J)**.5*B26
```

```
      K=0
      T=TGUESS(J)
   30 K=K+1
      DT=C1*SQRTF(T)
      SND=C2*DRC/(XS(J)**2*DT**2)
      CALL SPLIN2(X,Y,N,W,LOG10F(T),TAB)
      GY(J)=TAB(1)
      WE=PARTW*GY(J)*SQRTF(T)
      PS(J)=QQ*PB(J)+PN(J)+.3333333*(WE/T)+(.375*E*(WP/T))
      DHS=C12*PS(J)/(SND*DTS(J))
      D(J)=(DHS/DEN2)**1.25
      AN=C10*D(J)**2*DRC/(XS(J)**2*DT**2)
      BG=RHO*U(J)*AN
      RS=C7*U(J)*D(J)
      FS=6.6E-2/RS**.233
      CL(J)=C9*D(J)*DPS(J)/(U(J)**2*FS)
      PP(J)=195.3*BG*DPS(J)/(CL(J)*RHO)
      A20=(GY(J)/DTE(J))**1.25
      A21=DTE(J)**1.25/(GY(J)**.25)
      EUD=A20*B22*C25
      DE(J)=EUD/UE(J)
      RE=C7*EUD
      FE=.066/RE**.233
      CLE(J)=A20*B24*C27/FE
      PPE(J)=A20*B27*C29*FE/T**.5
      DPB(J)=DPS(J)
      CLB(J)=CL(J)
      B40=.066*C45*CLB(J)*UB(J)**1.767
      B41=DPB(J)*C7**.233
      DB(J)=(B40/(B41*C47))**.81103
      FB=.066/(C7*UB(J)*DB(J))**.233
      A40=XB(J)*T**.5/RC
      A41=A40**.25
      A42=A40*PB(J)/Z**.5
      A43=A42**1.25
      A44=UB(J)**2*PB(J)**.25*FB
      RECP=UB(J)**3*CLB(J)*FB/(C47*A43*DPB(J))
      DTB(J)=1./RECP**.8
      PPB(J)=C49*A41*A44*PB(J)*RECP/Z**1.125
      PPPP(J)=PP(J)+XJ2*(PPE(J)+PPB(J))
      AZ=PART1-C11*C15*PPPP(J)
      BZ=BIGE*WE/SQRTF(T)
      RAD=BZ**2+4.*AZ*CZ
      IF(RAD)80,40,40
   80 WRITE OUTPUT TAPE 9,1
      WRITE OUTPUT TAPE 9,222,K,XKT(J),T,GY(J),AZ,BZ,CZ,RAD
      TAU(J)=0.
      NK(J)=K
      XDT(J)=0.
      TR(J)=0.
      TNN(J)=0.
      WPT(J)=0.
      WET(J)=0.
      GO TO 100
   40 T2=((BZ+SQRTF(RAD))/(2.*AZ))**2
      IF(MM)86,86,85
   85 WRITE OUTPUT TAPE 9,1
      WRITE OUTPUT TAPE 9,223,K,XKT(J),T,GY(J),AZ,BZ,CZ,RAD,T2
```

TABLE I. (Continued).

```
   86 IF(LL)41,41,45
   41 TEST=(T-T2)/T
      IF(ABSF(TEST)-EPSI)60,60,50
   50 IF(K-KK)95,60,60
   95 T=T2
      GOTO30
   45 NK(J)=K
      TAU(J)=T2
      GO TO 61
   60 NK(J)=K
      TAU(J)=T
   61 XDT(J)=XS(J)*DT
      XEDT(J)=XE(J)*DT
      XBDT(J)=XB(J)*DT
      TR(J)=5.267E-4*CL(J)*PS(J)/(BG*CAPC*Z)
      TRE(J)=A21*B25*C28/FE
      TRB(J)=C48*Z**1.125*DPB(J)*DTB(J)**1.25/(A41*A44)
      TNN(J)=XNN(J)*T
      WPT(J)=WP/T
      WET(J)=WE/T
  100 CONTINUE
      WRITE OUTPUT TAPE 9,1
      IF(LL)69,70,69
   69 WRITE OUTPUT TAPE 9,18
      GOTO71
   70 WRITE OUTPUT TAPE 9,19
   71 WRITE OUTPUT TAPE 9,20,IR,IM,IE,IS,IH,IQ,J2
      WRITE OUTPUT TAPE 9,21,B
 1000 WRITE OUTPUT TAPE 9,99,(V1(I),V2(I),I=1,16)
      WRITE OUTPUT TAPE 9,1
      WRITE OUTPUT TAPE 9,500
      WRITE OUTPUT TAPE 9,501,(XKT(J),U(J),UE(J),UB(J),XS(J),
     1XE(J),XB(J),J=1,JJ)
      WRITE OUTPUT TAPE 9,24
      WRITE OUTPUT TAPE 9,502
      WRITE OUTPUT TAPE 9,503,(XKT(J),DPS(J),DPE(J),DTS(J),
     1DTE(J),J=1,JJ)
      WRITE OUTPUT TAPE 9,1
      WRITE OUTPUT TAPE 9,504
      WRITE OUTPUT TAPE 9,23,(XKT(J),TGUESS(J),TAU(J),
     1GY(J),PS(J),PT(J),PN(J),PB(J),XNN(J),NK(J),J=1,JJ)
      WRITE OUTPUT TAPE 9,24
      WRITE OUTPUT TAPE 9,505
      WRITE OUTPUT TAPE9,26,(XKT(J),CL(J),CLE(J),CLB(J),
     1D(J),DE(J),DB(J),DPB(J),DTB(J),J=1,JJ)
      WRITE OUTPUT TAPE 9,1
      WRITE OUTPUT TAPE 9,506
      WRITE OUTPUT TAPE 9,26,(XKT(J),XDT(J),XEDT(J),XBDT(J),
     1TR(J),TRE(J),TRB(J),WPT(J),WET(J),J=1,JJ)
      WRITE OUTPUT TAPE 9,24
      WRITE OUTPUT TAPE 9,507
      WRITE OUTPUT TAPE 9,508,(XKT(J),PP(J),PPE(J),PPB(J),
     1PPPP(J),TNN(J),J=1,JJ)
      GOTO55
      END
```

TABLE II. Listing of Problem Corresponding to the Graph of Fig. 4 in LA-3294-MS.

```
     B       2JOB, J POWERS     RIBE    P15                                        JPOWERSR     103536    8/24/65   MACH 6
     *     XEQ

LIBRARY ENTRY POINTS,
     (FPT)       (TSHM)       (RTN)       LOG10       SQRT        EXP(3       (STHM)       (FIL)

103554 EXECUTION



RIBE,  G(TAU)=1.267,  B=200 KG,  PULSE FIELD
REGULAR RUN

        R=   0    M=   1    E=   0    S=   1    H=   1   QQ=   0   J2=   1
        B=   2.00000E 05

    RC=    1.00000E 01

    RP=    5.00000E 00

    EP=    4.00000E-01

   EPR=    5.20000E 01

   ETA=    7.90000E-06

  CAPC=    8.50000E-01

   RHO=    1.60000E 00

     Q=    1.89000E 04

    MU=    5.50000E-02

 CAPKC=    2.70000E-01

     Z=    5.33333E 00

  TAUY=    7.00000E 04

    NC=    8.42000E 22

   STE=    4.12000E-21

    CV=    3.70000E 00

    KV=    1.60000E 00
```

TABLE II. (Continued).

RIBE, G(TAU)=1.267, B=200 KG, PULSE FIELD

| KT | US | UE | UB | XS | XE | XB |
|---|---|---|---|---|---|---|
| 5.000E 00 | 1.275E 03 | 1.196E 03 | 2.000E 03 | 1.849E 00 | 1.890E 00 | 1.800E 00 |
| 8.000E 00 | 1.275E 03 | 1.196E 03 | 1.900E 03 | 1.849E 00 | 1.890E 00 | 1.800E 00 |
| 1.000E 01 | 1.275E 03 | 1.196E 03 | 1.800E 03 | 1.849E 00 | 1.890E 00 | 1.800E 00 |
| 1.200E 01 | 1.275E 03 | 1.196E 03 | 1.700E 03 | 1.849E 00 | 1.890E 00 | 1.800E 00 |
| 1.500E 01 | 1.275E 03 | 1.196E 03 | 1.639E 03 | 1.849E 00 | 1.890E 00 | 1.800E 00 |
| 1.700E 01 | 1.275E 03 | 1.196E 03 | 1.639E 03 | 1.849E 00 | 1.890E 00 | 1.800E 00 |
| 2.000E 01 | 1.275E 03 | 1.196E 03 | 1.639E 03 | 1.849E 00 | 1.890E 00 | 1.800E 00 |
| 2.500E 01 | 1.275E 03 | 1.196E 03 | 1.639E 03 | 1.849E 00 | 1.890E 00 | 1.800E 00 |
| 3.000E 01 | 1.275E 03 | 1.196E 03 | 1.639E 03 | 1.849E 00 | 1.890E 00 | 1.800E 00 |
| 3.500E 01 | 1.275E 03 | 1.196E 03 | 1.639E 03 | 1.849E 00 | 1.890E 00 | 1.800E 00 |
| 4.000E 01 | 1.275E 03 | 1.196E 03 | 1.639E 03 | 1.849E 00 | 1.890E 00 | 1.800E 00 |
| 5.000E 01 | 1.275E 03 | 1.196E 03 | 1.639E 03 | 1.849E 00 | 1.890E 00 | 1.800E 00 |
| 6.000E 01 | 1.275E 03 | 1.196E 03 | 1.639E 03 | 1.849E 00 | 1.890E 00 | 1.800E 00 |
| 7.000E 01 | 1.275E 03 | 1.196E 03 | 1.639E 03 | 1.849E 00 | 1.890E 00 | 1.800E 00 |
| 8.000E 01 | 1.275E 03 | 1.196E 03 | 1.639E 03 | 1.849E 00 | 1.890E 00 | 1.800E 00 |

| KT | DPS | DPE | DTS | DTE |
|---|---|---|---|---|
| 5.000E 00 | 1.100E 03 | 1.100E 03 | 3.641E 01 | 3.442E 01 |
| 8.000E 00 | 1.100E 03 | 1.100E 03 | 3.641E 01 | 3.442E 01 |
| 1.000E 01 | 1.100E 03 | 1.100E 03 | 3.641E 01 | 3.442E 01 |
| 1.200E 01 | 1.100E 03 | 1.100E 03 | 3.641E 01 | 3.442E 01 |
| 1.500E 01 | 1.100E 03 | 1.100E 03 | 3.641E 01 | 3.442E 01 |
| 1.700E 01 | 1.100E 03 | 1.100E 03 | 3.641E 01 | 3.442E 01 |
| 2.000E 01 | 1.100E 03 | 1.100E 03 | 3.641E 01 | 3.442E 01 |
| 2.500E 01 | 1.100E 03 | 1.100E 03 | 3.641E 01 | 3.442E 01 |
| 3.000E 01 | 1.100E 03 | 1.100E 03 | 3.641E 01 | 3.442E 01 |
| 3.500E 01 | 1.100E 03 | 1.100E 03 | 3.641E 01 | 3.442E 01 |
| 4.000E 01 | 1.100E 03 | 1.100E 03 | 3.641E 01 | 3.442E 01 |
| 5.000E 01 | 1.100E 03 | 1.100E 03 | 3.641E 01 | 3.442E 01 |
| 6.000E 01 | 1.100E 03 | 1.100E 03 | 3.641E 01 | 3.442E 01 |
| 7.000E 01 | 1.100E 03 | 1.100E 03 | 3.641E 01 | 3.442E 01 |
| 8.000E 01 | 1.100E 03 | 1.100E 03 | 3.641E 01 | 3.442E 01 |

RIBE, G(TAU)=1.267, B=200 KG, PULSE FIELD

| KT | TGUESS | TAU | G(TAU) | PS | PT | PN | PB | N | K |
|---|---|---|---|---|---|---|---|---|---|
| 5.000E 00 | 2.000E-01 | 7.847E-02 | 1.267E 00 | 2.011E 06 | 8.804E 06 | 5.328E 05 | 9.514E 05 | 9.936E 16 | 7 |
| 8.000E 00 | 2.740E-02 | 2.550E-02 | 1.267E 00 | 3.495E 06 | 1.490E 07 | 9.019E 05 | 4.701E 05 | 6.210E 16 | 5 |
| 1.000E 01 | 2.000E-02 | 1.956E-02 | 1.267E 00 | 3.981E 06 | 1.688E 07 | 1.021E 06 | 3.364E 05 | 4.968E 16 | 4 |
| 1.200E 01 | 2.000E-02 | 1.346E-02 | 1.267E 00 | 4.802E 06 | 2.038E 07 | 1.233E 06 | 2.559E 05 | 4.140E 16 | 7 |
| 1.500E 01 | 2.000E-02 | 1.760E-02 | 1.267E 00 | 4.186E 06 | 1.761E 07 | 1.066E 06 | 1.831E 05 | 3.312E 16 | 6 |
| 1.700E 01 | 2.160E-02 | 2.079E-02 | 1.267E 00 | 3.849E 06 | 1.615E 07 | 9.772E 05 | 1.518E 05 | 2.922E 16 | 5 |
| 2.000E 01 | 2.400E-02 | 2.381E-02 | 1.267E 00 | 3.594E 06 | 1.504E 07 | 9.102E 05 | 1.189E 05 | 2.484E 16 | 4 |
| 2.500E 01 | 3.160E-02 | 3.088E-02 | 1.267E 00 | 3.152E 06 | 1.315E 07 | 7.957E 05 | 8.509E 04 | 1.987E 16 | 4 |
| 3.000E 01 | 1.000E-01 | 4.800E-02 | 1.267E 00 | 2.526E 06 | 1.052E 07 | 6.364E 05 | 6.473E 04 | 1.656E 16 | 7 |
| 3.500E 01 | 3.000E-01 | 7.341E-02 | 1.267E 00 | 2.043E 06 | 8.505E 06 | 5.147E 05 | 5.137E 04 | 1.419E 16 | 8 |
| 4.000E 01 | 5.000E-01 | 1.018E-01 | 1.267E 00 | 1.736E 06 | 7.245E 06 | 4.385E 05 | 4.205E 04 | 1.242E 16 | 8 |
| 5.000E 01 | 8.000E-01 | 2.344E-01 | 1.267E 00 | 1.150E 06 | 4.872E 06 | 2.948E 05 | 3.009E 04 | 9.936E 15 | 8 |
| 6.000E 01 | 1.000E 00 | 4.715E-01 | 1.267E 00 | 8.176E 05 | 3.546E 06 | 2.146E 05 | 2.289E 04 | 8.280E 15 | 7 |
| 7.000E 01 | 2.000E 00 | 9.375E-01 | 1.267E 00 | 5.871E 05 | 2.635E 06 | 1.595E 05 | 1.816E 04 | 7.097E 15 | 7 |
| 8.000E 01 | 4.000E 00 | 1.872E 00 | 1.267E 00 | 4.234E 05 | 1.995E 06 | 1.207E 05 | 1.487E 04 | 6.210E 15 | 7 |

TABLE II. (Continued).

| KT | LCS | LCE | LCB | DS | DE | DB | DPB | DTB |
|---|---|---|---|---|---|---|---|---|
| 5.000E 00 | 8.031E 01 | 2.503E 01 | 8.031E 01 | 2.821E-01 | 9.995E-02 | 5.377E-01 | 1.100E 03 | 3.671E 01 |
| 8.000E 00 | 3.329E 01 | 2.503E 01 | 3.329E 01 | 1.381E-01 | 9.995E-02 | 2.446E-01 | 1.100E 03 | 2.023E 01 |
| 1.000E 01 | 2.705E 01 | 2.503E 01 | 2.705E 01 | 1.167E-01 | 9.995E-02 | 1.913E-01 | 1.100E 03 | 1.612E 01 |
| 1.200E 01 | 2.029E 01 | 2.503E 01 | 2.029E 01 | 9.245E-02 | 9.995E-02 | 1.396E-01 | 1.100E 03 | 1.370E 01 |
| 1.500E 01 | 2.484E 01 | 2.503E 01 | 2.484E 01 | 1.089E-01 | 9.995E-02 | 1.561E-01 | 1.100E 03 | 1.056E 01 |
| 1.700E 01 | 2.819E 01 | 2.503E 01 | 2.819E 01 | 1.207E-01 | 9.995E-02 | 1.729E-01 | 1.100E 03 | 8.757E 00 |
| 2.000E 01 | 3.126E 01 | 2.503E 01 | 3.126E 01 | 1.312E-01 | 9.995E-02 | 1.881E-01 | 1.100E 03 | 6.868E 00 |
| 2.500E 01 | 3.814E 01 | 2.503E 01 | 3.814E 01 | 1.542E-01 | 9.995E-02 | 2.210E-01 | 1.100E 03 | 4.919E 00 |
| 3.000E 01 | 5.352E 01 | 2.503E 01 | 5.352E 01 | 2.030E-01 | 9.995E-02 | 2.908E-01 | 1.100E 03 | 3.745E 00 |
| 3.500E 01 | 7.425E 01 | 2.503E 01 | 7.425E 01 | 2.647E-01 | 9.995E-02 | 3.793E-01 | 1.100E 03 | 2.972E 00 |
| 4.000E 01 | 9.566E 01 | 2.503E 01 | 9.566E 01 | 3.251E-01 | 9.995E-02 | 4.658E-01 | 1.100E 03 | 2.430E 00 |
| 5.000E 01 | 1.833E 02 | 2.503E 01 | 1.833E 02 | 5.510E-01 | 9.995E-02 | 7.895E-01 | 1.100E 03 | 1.730E 00 |
| 6.000E 01 | 3.182E 02 | 2.503E 01 | 3.182E 02 | 8.616E-01 | 9.995E-02 | 1.235E 00 | 1.100E 03 | 1.305E 00 |
| 7.000E 01 | 5.509E 02 | 2.503E 01 | 5.509E 02 | 1.345E 00 | 9.995E-02 | 1.927E 00 | 1.100E 03 | 1.023E 00 |
| 8.000E 01 | 9.659E 02 | 2.503E 01 | 9.659E 02 | 2.121E 00 | 9.995E-02 | 3.039E 00 | 1.100E 03 | 8.218E-01 |

RIBE, G(TAU)=1.267, B=200 KG, PULSE FIELD

| KT | XSDT | XEDT | XBDT | TRS | TRE | TRB | WP/TAU | WE/TAU |
|---|---|---|---|---|---|---|---|---|
| 5.000E 00 | 6.276E-01 | 6.415E-01 | 6.110E-01 | 2.607E 02 | 2.688E 02 | 5.881E 02 | 2.389E 05 | 4.434E 06 |
| 8.000E 00 | 3.578E-01 | 3.657E-01 | 3.483E-01 | 2.546E 02 | 2.688E 02 | 3.493E 02 | 7.352E 05 | 7.778E 06 |
| 1.000E 01 | 3.134E-01 | 3.203E-01 | 3.051E-01 | 2.532E 02 | 2.688E 02 | 3.070E 02 | 9.584E 05 | 8.881E 06 |
| 1.200E 01 | 2.599E-01 | 2.657E-01 | 2.530E-01 | 2.513E 02 | 2.688E 02 | 2.890E 02 | 1.393E 06 | 1.071E 07 |
| 1.500E 01 | 2.973E-01 | 3.039E-01 | 2.894E-01 | 2.526E 02 | 2.688E 02 | 2.402E 02 | 1.065E 06 | 9.362E 06 |
| 1.700E 01 | 3.230E-01 | 3.302E-01 | 3.145E-01 | 2.535E 02 | 2.688E 02 | 1.999E 02 | 9.021E 05 | 8.616E 06 |
| 2.000E 01 | 3.457E-01 | 3.533E-01 | 3.365E-01 | 2.542E 02 | 2.688E 02 | 1.572E 02 | 7.876E 05 | 8.051E 06 |
| 2.500E 01 | 3.937E-01 | 4.025E-01 | 3.833E-01 | 2.555E 02 | 2.688E 02 | 1.132E 02 | 6.071E 05 | 7.068E 06 |
| 3.000E 01 | 4.909E-01 | 5.018E-01 | 4.779E-01 | 2.579E 02 | 2.688E 02 | 8.698E 01 | 3.906E 05 | 5.669E 06 |
| 3.500E 01 | 6.070E-01 | 6.205E-01 | 5.909E-01 | 2.601E 02 | 2.688E 02 | 6.963E 01 | 2.554E 05 | 4.584E 06 |
| 4.000E 01 | 7.149E-01 | 7.308E-01 | 6.960E-01 | 2.619E 02 | 2.688E 02 | 5.733E 01 | 1.841E 05 | 3.893E 06 |
| 5.000E 01 | 1.085E 00 | 1.109E 00 | 1.056E 00 | 2.665E 02 | 2.688E 02 | 4.153E 01 | 7.999E 04 | 2.566E 06 |
| 6.000E 01 | 1.538E 00 | 1.573E 00 | 1.498E 00 | 2.705E 02 | 2.688E 02 | 3.180E 01 | 3.977E 04 | 1.809E 06 |
| 7.000E 01 | 2.169E 00 | 2.217E 00 | 2.112E 00 | 2.745E 02 | 2.688E 02 | 2.529E 01 | 2.000E 04 | 1.283E 06 |
| 8.000E 01 | 3.065E 00 | 3.133E 00 | 2.984E 00 | 2.786E 02 | 2.688E 02 | 2.062E 01 | 1.002E 04 | 9.079E 05 |

| KT | PPS | PPE | PPB | PPPP | NTAU |
|---|---|---|---|---|---|
| 5.000E 00 | 1.203E 05 | 1.715E 05 | 1.340E 05 | 4.258E 05 | 7.797E 15 |
| 8.000E 00 | 2.141E 05 | 3.008E 05 | 1.115E 05 | 6.264E 05 | 1.584E 15 |
| 1.000E 01 | 2.453E 05 | 3.435E 05 | 9.074E 04 | 6.795E 05 | 9.719E 14 |
| 1.200E 01 | 2.982E 05 | 4.141E 05 | 7.334E 04 | 7.856E 05 | 5.572E 14 |
| 1.500E 01 | 2.585E 05 | 3.621E 05 | 6.314E 04 | 6.837E 05 | 5.830E 14 |
| 1.700E 01 | 2.369E 05 | 3.332E 05 | 6.287E 04 | 6.330E 05 | 6.074E 14 |
| 2.000E 01 | 2.206E 05 | 3.114E 05 | 6.265E 04 | 5.946E 05 | 5.913E 14 |
| 2.500E 01 | 1.924E 05 | 2.734E 05 | 6.225E 04 | 5.280E 05 | 6.137E 14 |
| 3.000E 01 | 1.528E 05 | 2.193E 05 | 6.164E 04 | 4.337E 05 | 7.949E 14 |
| 3.500E 01 | 1.225E 05 | 1.773E 05 | 6.110E 04 | 3.609E 05 | 1.042E 15 |
| 4.000E 01 | 1.034E 05 | 1.506E 05 | 6.074E 04 | 3.147E 05 | 1.265E 15 |
| 5.000E 01 | 6.731E 04 | 9.923E 04 | 6.000E 04 | 2.265E 05 | 2.329E 15 |
| 6.000E 01 | 4.716E 04 | 6.996E 04 | 5.961E 04 | 1.767E 05 | 3.904E 15 |
| 7.000E 01 | 3.337E 04 | 4.962E 04 | 5.948E 04 | 1.425E 05 | 6.654E 15 |
| 8.000E 01 | 2.370E 04 | 3.512E 04 | 5.970E 04 | 1.185E 05 | 1.162E 16 |

END OF FILE TAPE A 2

127 LINES OUTPUT.

103568