325
10/13/64

LA-3115-MS

MASTER

LOS ALAMOS SCIENTIFIC LABORATORY
OF THE UNIVERSITY OF CALIFORNIA ○ LOS ALAMOS NEW MEXICO

NECKLACE

A COMPUTER PROGRAM CONCERNING THE TRANSIENT TEMPERATURES OF FISSIONING SPHERES IMBEDDED IN GRAPHITE

LEGAL NOTICE

Printed in USA. Price $~~1.75~~ 3.00 Available from the

Office of Technical Services
U. S. Department of Commerce
Washington 25, D. C.

DISCLAIMER

LA-3115-MS
UC-80, REACTOR TECHNOLOGY
TID-4500 (32nd Ed.)

LOS ALAMOS SCIENTIFIC LABORATORY

OF THE UNIVERSITY OF CALIFORNIA LOS ALAMOS NEW MEXICO

REPORT WRITTEN: March 1964

REPORT DISTRIBUTED: September 10, 1964

NECKLACE

A COMPUTER PROGRAM CONCERNING THE TRANSIENT TEMPERATURES OF FISSIONING SPHERES IMBEDDED IN GRAPHITE

by

C. G. Chezem and W. R. Stratton

Contract W-7405-ENG. 36 with the U. S. Atomic Energy Commission

ABSTRACT

The Necklace computer program describes the temperature-time-space relationship within a spherical volume in which contiguous spherical shells of graphite are heated by conduction from a central heat source. This source term may be in the central sphere and in an arbitrary number of adjacent spherical shells. Numbers and sizes of regions, specific heats, conductivities and the radial and time magnitudes of the heat source terms are arbitrary.

TABLE OF CONTENTS

I

INTRODUCTION

The Necklace code is one of several computer programs coded for the original RAC[1] series. This particular code is set up to solve the problem of an arbitrary energy input and heat conduction out of a fissile sphere which is surrounded by several contiguous spherical shells. Radii of regions, heat capacities, and thermal conductivities are arbitrary as well as the fission-energy source term. An additional objective is to create a structure in which the effects as may be caused by extreme energy source terms may be incorporated.

Within the limitations demanded by difference equations, values of heat capacities, and heat conductivities, the code as written is exact and output temperatures are accurate. However, the physics of pertinent phase changes, transient pressures, rapid diffusion of hot materials, etc., is either not known or not yet incorporated into the code.

Necklace (NEK) is coded in FØRTRAN-II (NEK-2) for the Los Alamos IBM-7094 computer and in FØRTRAN-IV (NEK-4) for the Los Alamos IBM-7030 (Stretch) computer. NEK-4 should be compatible with the FØRTRAN-IV assembly procedures for the 7094.

II

GENERAL DESCRIPTION

Physical Equations:

The fundamental equation that the code solves is

$$\iiint \frac{\partial}{\partial t} (\rho c u) dv = \iiint \frac{\partial E^f}{\partial t} \rho \, dv - \iint \vec{J} \cdot d\vec{s}, \qquad (1)$$

where ρ is the material density (gm/cm^3), c is the specific heat of the material (ergs/gm-$^\circ$K), and u the temperature in degrees Kelvin. E^f is the fission energy deposited (erg/gm), and $\vec{J} = - k \text{ grad } u$ is the heat current (erg/cm^2-sec) allowed by the thermal conductivity k. By application of the divergence theorem

$$\iint \vec{J} \cdot d\vec{s} = \iiint \text{div } \vec{J} \, dv, \qquad (2)$$

we can obtain

$$\frac{\partial}{\partial t}(\rho c u) = \rho \frac{\partial E^f}{\partial t} - \nabla \cdot \vec{J}. \qquad (3)$$

Since spherical symmetry has been assumed and noting that the volume element $dv = 4\pi r^2 dr$,

$$\nabla \cdot \vec{J} = \frac{1}{r^2} \frac{\partial}{\partial r} (r^2 J) = 4\pi \frac{\partial}{\partial v} (r^2 J).$$

By rearranging,

$$\frac{\partial u}{\partial t} = \frac{1}{c}\frac{\partial E^f}{\partial t} - \frac{4\pi}{c}\frac{\partial}{\partial m}(r^2 J) \tag{4}$$

can be obtained; note that the mass element ∂m is taken equal to density times the volume element, i.e., $\partial m = \rho\,\partial v$.

Difference Equations:

The several spherical regions may be divided into n sub-shells indexed i wherein the central shell (sphere) is labeled by $i = 1$. Equation 4 becomes

$$\frac{\partial u_i}{\partial t} = \frac{1}{c_i}\frac{\partial E_i^f}{\partial t} - \frac{4\pi}{m_i c_i}(r_i^2 J_i - r_{i-1}^2 J_{i-1}), \tag{5}$$

in which u_i, c_i, E_i^f, and m_i refer to the i-th region, and r_i and J_i refer to the i-th interface. An expression for the J_i is needed and by making use of the spherical symmetry of the heat flow equation may be written

$$J_i = -k_i \nabla u_i = -k_i \frac{\partial u_i}{\partial r_i} = -k_i 4\pi r_i^2 \frac{\partial u_i}{\partial v_i} \quad . \tag{6}$$

Finally, by combining Equations 5 and 6 and noting that $\Delta v = v_i$,

$$\frac{\partial u_i}{\partial t} = \frac{1}{c_i}\frac{\partial E_i^f}{\partial t} + \frac{16\pi^2}{c_i m_i}\left\{\frac{k_i r_i{}^4(u_{i+1}-u_i)}{v_i} - \frac{k_{i-1}r_{i-1}^4(u_i-u_{i-1})}{v_{i-1}}\right\}.$$

As noted above, the m_i, c_i, E_i^f, and u_i are associated with the i-th shell and the r_i are its outer boundaries. The k_i and v_i are associated with the shell boundaries. The k_i are the thermal conductivities associated with boundaries, and where the boundary marks a change in conductivity between regions k_i is a volume weighted average of the conductivities of the adjacent regions. The v_i are "boundary volumes" calculated from the half thicknesses of the adjacent shells.

The energy dumped into the central sphere during a time interval Δt is calculated on the basis of the mass of fissile material in the sphere. This energy is distributed between the several shells by choice of operator and by consideration of the range of fission fragments.

During a time cycle Δt, the fission energy is considered as dumped into the system at the beginning of the time interval and the temperature is raised accordingly. Throughout the time interval Δt heat is allowed to flow between shells as allowed by the temperatures and conductivities.

A de-bugging feature, which has been retained in the code because of its usefulness, is a check of conservation of energy. We should have, at any time,

energy input = energy retained + energy lost,

or

$$\sum_t E(t) = \sum_i \int_{u_o}^{u_i(t)} m_i c(u_i) du + \sum_i Q_i(t) + \sum_t Q_{loss} ,$$

where E(t) is the fission energy released into the fissionable material during Δt at time t, m and c are the masses and specific heats of the shells whose original temperature was u_o, Q is the heat energy stored in a non-solid state*, and Q_{loss} is the total loss across the outer boundary.

The question of heat radiation between shells was raised, and even though it seemed most unlikely that radiation transfer could be significant, the following scheme was incorporated into the NEK-2 version. The boundary conduction leakage term was modified by addition of the term (statement 179)

$$-4\pi r_i^2 \; p\epsilon \; (u_{i+1}^4 - u_i^4),$$

where $\epsilon = 5.6686 \times 10^{-5}$ erg/cm^2/°K^4/sec (the Stefan-Boltzmann constant) and p is the radiation efficiency $0 \leq p \leq 1$. The upper limit case, p = 1, yielded no significant change in the problem result. We conclude that radiation between shells is insignificant.

Analytic functions have been fitted by least squares methods to the known values of the specific heat. These values are illustrated in Figure 1.

Shell, shell boundary, and region indexing is illustrated in Figure 2.

---

*Because of uncertainties of some physical constants as mentioned above, one choice in the code limits all temperatures to 4000°K. Energy received in excess of that required to reach 4000°K is "stored" and released as demanded by temperature gradients.

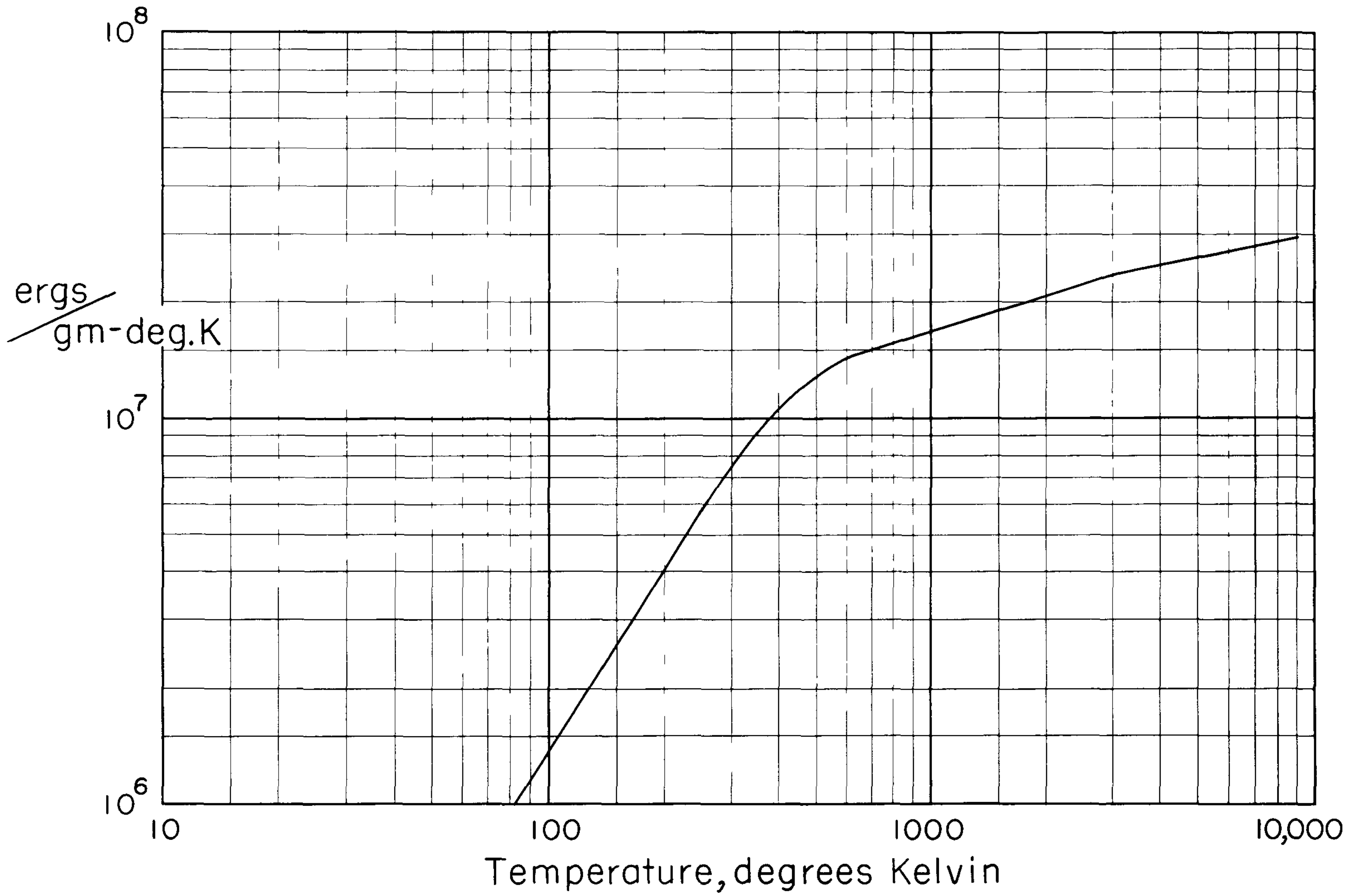


Figure 1
Graphite specific heats used in the NECKLACE code

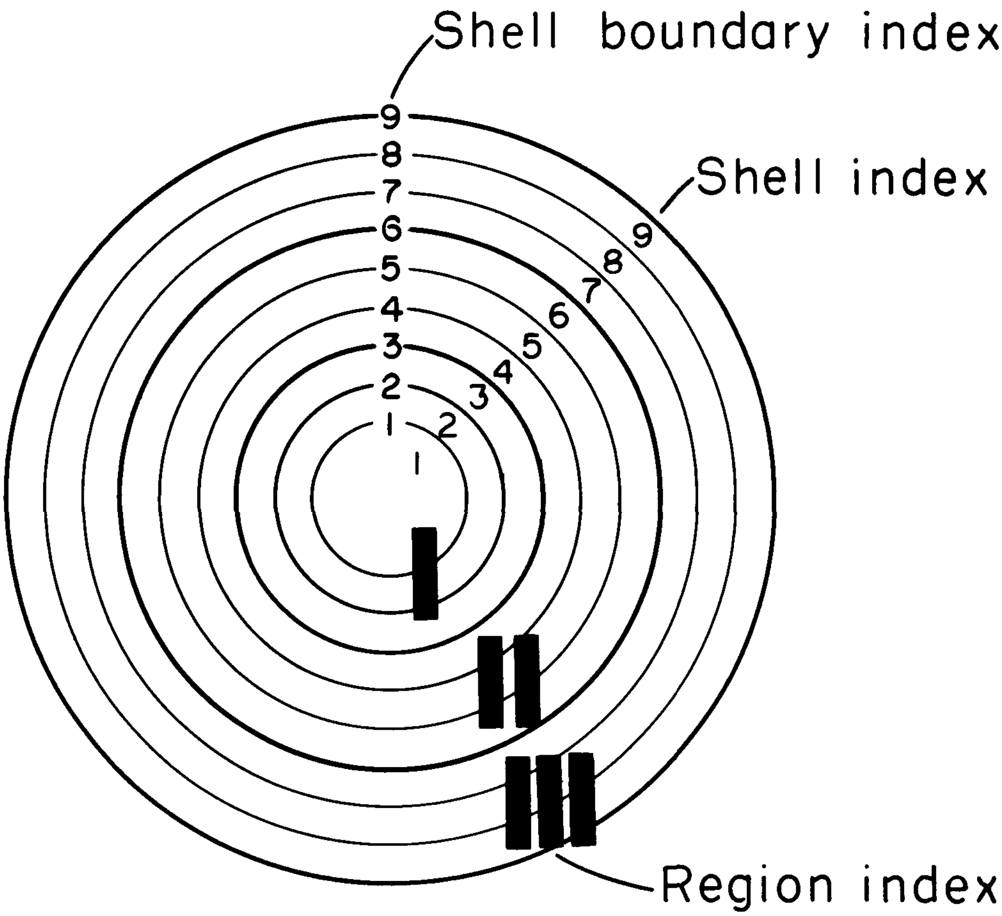


Figure 2

Typical shell, shell boundary, and region indexing

III

BASIC PHYSICAL UNITS USED IN NECKLACE

mass (m)	grams
length (r)	cm
time ($t, \Delta t$)	sec
temperature ($u, \Delta u$)	$^{\circ}$Kelvin
energy (E, Q)	ergs/gm
power ($\dot{E}$)	ergs/gm/sec
density (ρ)	gm/cm^3
specific heat (c)	ergs/$^{\circ}$K/gm

IV

SUBSCRIPTED SYMBOLS USED IN NECKLACE

FØRTRAN Symbol	Mathematical or Flow Diagram Symbol	Units	Definition
IR	Ir_i	--	shell index corresponding to the boundary of the i-th region
RIR	Rir_i	cm	outer radial boundary of the i-th region
RHØ	ρ_i	gm/cm^3	density of i-th region
XK	Xk_i	$\frac{erg}{cm^2 sec(^\circ K/cm)}$	thermal conductivity of i-th region
R	R_j	cm	outer radius of j-th shell
XMASS	$Xmass_j$	gm	mass of j-th shell
VR	Vr_j	cm^3	volume associated with j-th shell radius
FE	Fe_j	--	fraction of total energy dumped into j-th shell
DUDT	$(\partial u/\partial t)_j$	$^\circ K/sec$	time rate of change of temperature in j-th shell
DUSUM	$DUsum_j$	$^\circ K$	sum of temperature changes in the j-th shell

(CONT'D)

FØRTRAN Symbol	Mathematical or Flow Diagram Symbol	Units	Definition
U	U_j	$^\circ K$	temperature of shell
XKR	Xkr_j	$\frac{erg}{cm^2 sec(^\circ K/cm)}$	thermal conductivity across the j-th shell boundary
R4	$R4_j$	cm^4	--
DQ	DQ_j	ergs	energy dumped in a section during Δt
TPWR	--	--	factors used in RADMAS
DUPWR	$DUpwr_j$	$^\circ K$	change in temperature of a shell due to energy dump during Δt
DULEAK	$DUleak_j$	$^\circ K$	change in temperature of a shell due to leakage of heat during Δt
SPHT	$Spht_j$	erg/gm-$^\circ K$	specific heat of a shell
DQØUT	$DQout_j$	erg/sec	leakage rate out of a shell
IQ	Iq_j	--	logical flag. -1, raise temperature; +1, store heat in a shell
Q	Q_j	ergs	heat stored in a shell above vaporization temperature
QMAX	$Qmax_j$	ergs	largest amount of heat stored at any time in a shell
SDQ	SDq_j	ergs	$\sum_t \Delta Q_j$
QT	QT_j	ergs	$m_j \int_{u_o}^{u_j} cp(u)du$

V

NON-SUBSCRIPTED SYMBOLS USED IN NECKLACE OTHER THAN INPUT PARAMETERS, DEFINED DATA, FLAGS AND TEMPORARY STORAGE

FØRTRAN Symbol	Mathematical or Flow Diagram Symbol	Units	Definition
QPWR	Qpwr	ergs	total energy dumped into system
QLØSS	Qloss	ergs	total energy lost through outer boundary of system
UMAX	Umax	°K	maximum temperature reached by any shell during problem
IUMAX	IUmax	--	index of Umax
TUMAX	TUmax	sec	time of Umax
TEST	Test	°K	temperature level for problem termination
PRINT	Print	--	printout number
IRR	Irr	--	flow control index indicating region
SMC	Smc	gm	total mass of fissionable material in the system
XN	Xn	--	iteration number

(CONT'D)

FØRTRAN Symbol	Mathematical or Flow Diagram Symbol	Units	Definition
XKK	Xkk	--	counting index between printouts
TIME	t	sec	running time of iteration
ERGS	Ergs	ergs	total energy dumped in any Δt
DQIN	DQin	ergs/sec	leakage rate into a shell
UMEX	Umex	$^{\circ}K$	maximum temperature of shells during Δt
SSDQ	SSDq	ergs	$\sum_j SDq_j$
SQT	SQT	ergs	$\sum_j QT_j$
QSUM	Qsum	ergs	$\sum_j Q_j$
QCK	Qck	ergs	total energy stored in and lost from system. For conservation of energy: QCK=QPWR

VI

INPUT AND OPERATING INSTRUCTIONS FOR NECKLACE

The first two "DATA" cards are labeled CARD A and CARD B. These are labels for the printout and generally will not be changed and are entered only once per job. Problem input parameters are on cards labeled CARD 1 through CARD 10. An eleventh card CARD R is optional. Power vs time profile tables can be added under control of subroutine PWR.

CARD 1:

This is an identification card to label the problem. Column one must have a one (1) punched in it. Columns 2 through 72 may have any acceptable symbol. This will be the heading for the output print.

Cards 2 and 3 are punched on a 1216 format.

CARD 2:

1) JR Indicator for Subroutine RADMAS

JR = 1 Read radii of all shells from CARD R, calculate mass

JR = 2 Shells all of equal thickness, calculate mass

JR = 3 Shells all of equal mass within a region, calculate radii

2) NR Number of regions

3) LEAK Specifies behavior of leakage across outer boundary

4) KPWR for options see Function PWR

CARD 3:

IR_i Index numbers of region boundaries, e.g., if the inner region is required to have 3 shells, IR(1)=3, if region two has 4 shells, IR(2)=7, etc. NR words IR(NR) is the total number of shells in the system

The remaining input parameter cards use a 6E12.7 format.

CARD 4:

RIR_i Actual radii in cm of region (material) boundaries. NR words

CARD 5:

$RHØ_i$ Region densities (gm/cm^3) NR words

CARD 6:

XK_i (k_i) Region thermal conductivities $\left[erg/cm^2/sec/(^\circ K/cm)\right]$ NR words

CARD 7:

TPWR Six word vector defined in function PWR. See listing

CARD 8:

FE_j f_j Fraction of total energy deposited in system which is allotted to the j-th shell

$$\sum_{j=1}^{n} f_j = 1$$

CARD 9:

1)	UAI	U_o	initial temperature of system
2)	TIMEA	t_o	initial time in power profile
3)	DT	Δt	time increment per cycle
4)	TIMAX	t_{max}	maximum time of problem (not machine clock time)
5)	HTEST	Htest	program shutoff based on temperature dropping to a fraction, Htest, of its maximum value
6)	UVAP	Uvap	vaporization temperature assumed for all materials

CARD 10:

1)	XFIRST	initial number of printouts of cycles
2)	XKØUT	frequency of printouts, a print will be made every XKØUT iterations
3)	PNTMAX	maximum number of printouts allowed
4)	ØUTVEC	leakage vector from outer boundary (See LEAK on card 2 and text for explanation.)
5)	UQ	maximum allowable temperature, stores energy above this point
6)	EM	radiation efficiency between shells ($0 \leq EM \leq 1.0$)

CARD R: (Optional)

R_j — Actual radii of all shells when specified by JR=1 (CARD 1). N words

An additional set of data, a table of times and corresponding power levels, may be added under the control of Function PWR. This table is useful to force the problem to follow the time-power profile of a realistic reactor or experimental curve.

If the table is in erg/gm-sec, TPWR(1)=1.0. If not, TPWR(1) can be a correction factor to yield the proper units.

VII

LOS ALAMOS LIBRARY FUNCTIONS USED IN NEK-IV

SPLINE FIT (E202)

This routine may be used as a means of interpolation which produces smooth first derivatives and continuous second derivatives.

Programming Instructions

1. This routine has two entry points. Entry at SPLIN1 sets up a table of second derivatives evaluated at each of the N data points. The calling sequence is

CALL SPLIN1 (X,F,N,W,G,IND,XM1,XMN),

where

X is the origin of the table of abscissas (consecutively stored);

F is the origin of the table of ordinates (consecutively stored);

N is the number of data points (integer);

W is the origin of an array of length $\geq$ N in which the subroutine is to store the second derivatives;

G is the origin of an array of temporary storage of length $\geq$ N that can be used by the subroutine;

IND is an indicator defined below (integer);

XM1 is a value associated with the first data point. If IND = 1, XM1 is the value assigned to the derivative at the first point. If IND = 2, XM1 is the ratio of the second derivatives at the first and second points;

XMN is a value associated with the Nth data point. If IND = 1, XMN is the value assigned to the derivative at the Nth point. If IND = 2, XMN is the ratio of the second derivatives and the Nth and N-1st points.

2. Entry at SPLIN2 is for interpolation. Given a Y, where X(1) $\leq$ Y $\leq$ X(N), the subroutine returns the interpolated values of the ordinate at Y, and its first and second derivatives. The calling sequence is

CALL SPLIN2 (X,F,N,W,Y,TBL),

where

X, F, and W are the origins of the tables of abscissas, ordinates, and second derivatives as computed by SPLIN1;

N is the number of data points;

Y is the abscissa at which the interpolation is to be performed;

TBL is the origin of an array of length $\geq$ 3 in which the subroutine stores the value of the interpolated ordinate, its first and second derivatives, in that order.

3. The table of abscissas must be in increasing order. X(I-1) < X(I) < X(I+1), I = 2,3,...,N-1.

4. N must be $\geq$ 3 in SPLIN1; N must be $\geq$ 2 in SPLIN2.

5. SPLIN2 would usually be entered many times for each entry to SPLIN1.

Method

The "spline fit", which is essentially the numerical analogue of the draftsman's spline, consists of joining the assigned points by sections of cubics, requiring that slopes and curvatures be continuous at the junction points. For a complete description of the spline fit, see "Best Approximation Properties of the Spline Fit", by J. L. Walsh, J. H. Ahlberg, and E. N. Nilson in the Journal of Mathematics and Mechanics, Vol. II, No. 2 (1962).

MAXIMUM OR MINIMUM ELEMENTS OF A VECTOR (F115)

This program determines the maximum, minimum, absolute maximum, or absolute minimum element of a vector and the index of that element.

Programming Instructions

CALL MAXV (X, IX, N, I, Y) or MINV or MAXAV or MINAV depending on function desired, where

X is the origin of the vector;

IX is the spacing between elements of the vector, i.e., IX = X(2) - X(1);

N is the number of elements in the vector;

I is the index of the element selected, e.g., i = 1 for the first element, i = 2 for the second element, etc.;

Y is the element desired.

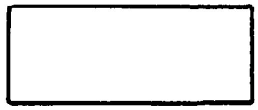
VIII

THE COMPLETE FLOW DIAGRAMS OF NEK-IV

Contents

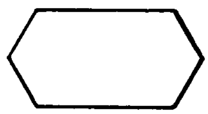
Interpretation of the flow diagrams requires some knowledge of FØRTRAN IV language. In some places it may be necessary that the reader check the listing to clarify the flow diagram.

We have used the IBM "diagramming template" No. X24-5884-6 and the Rapid-design "computer diagramming template" No. 54, both of which have the symbols we designate as follows:

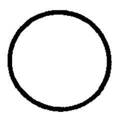


any non-arithmetic operation not covered by another symbol

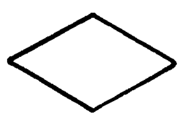
any operation written as an equation in FØRTRAN



any decision or branch operation

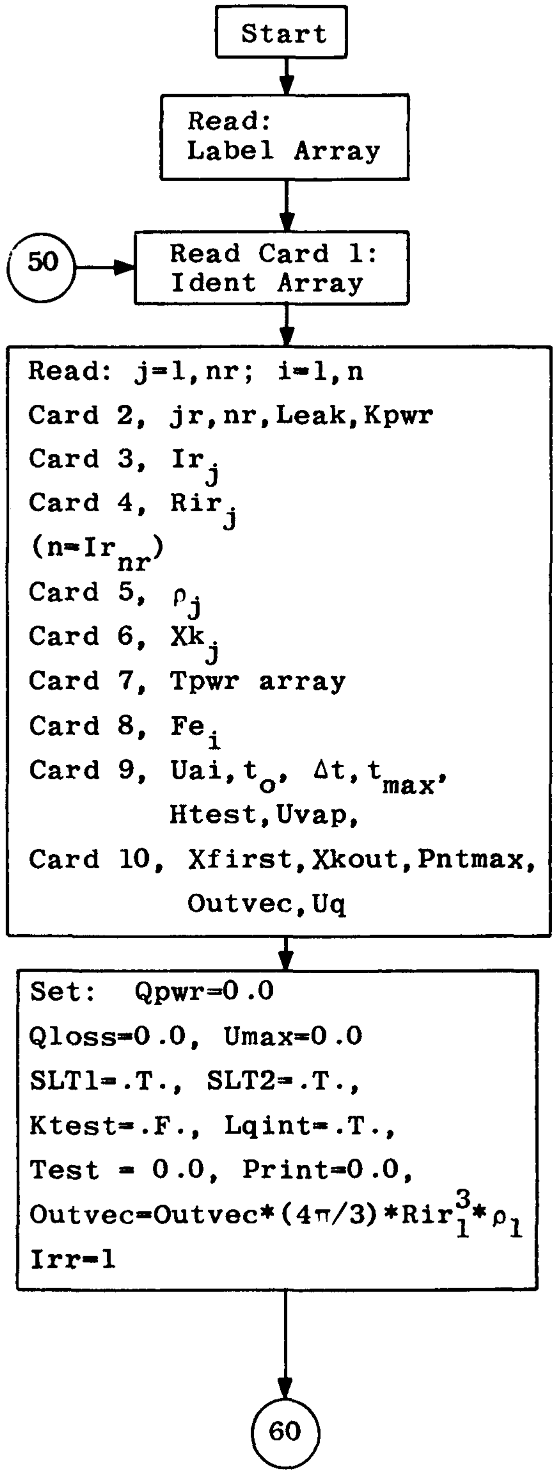


transfer point including a statement number

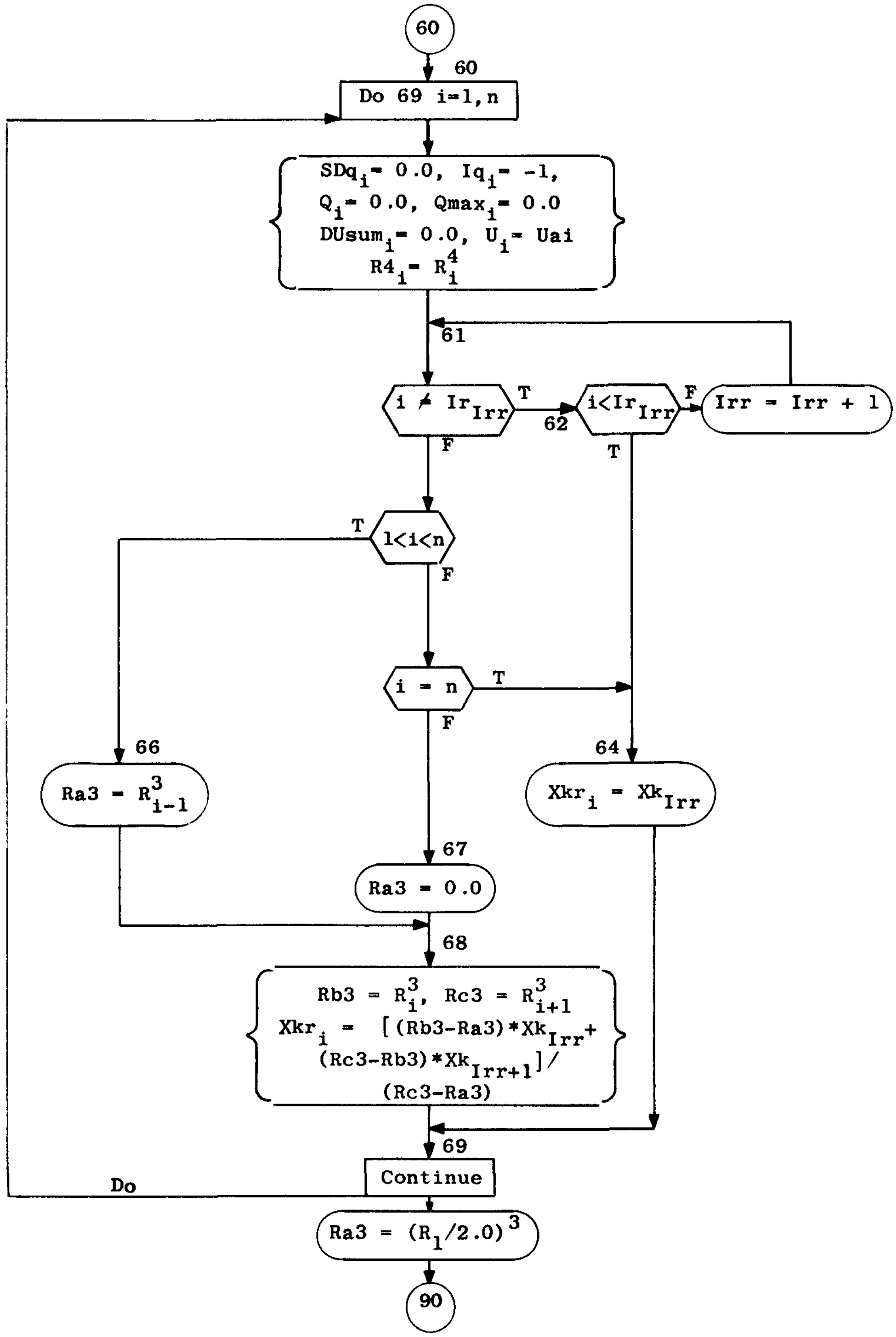


Entry, exit, or indication of a separately coded function or subroutine not in the IBM library

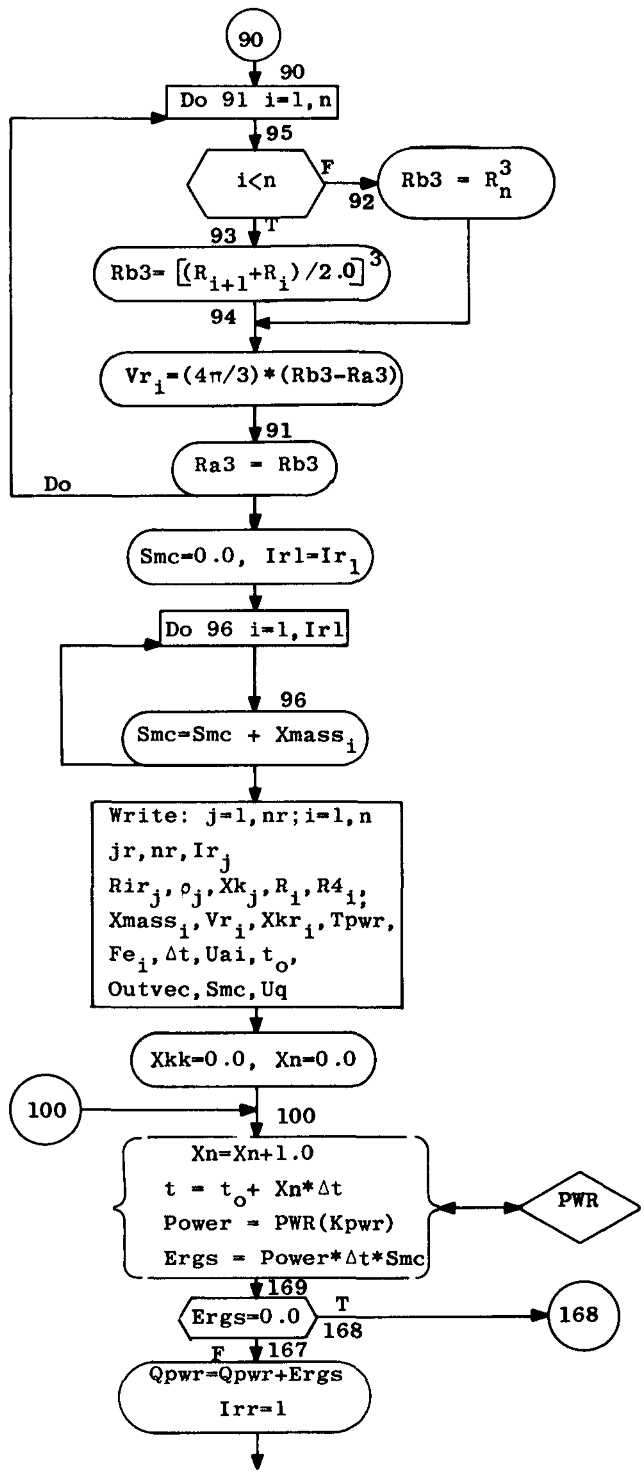
"Do-loop" flow lines always leave or enter the lower left hand corner of the extremes of the range.



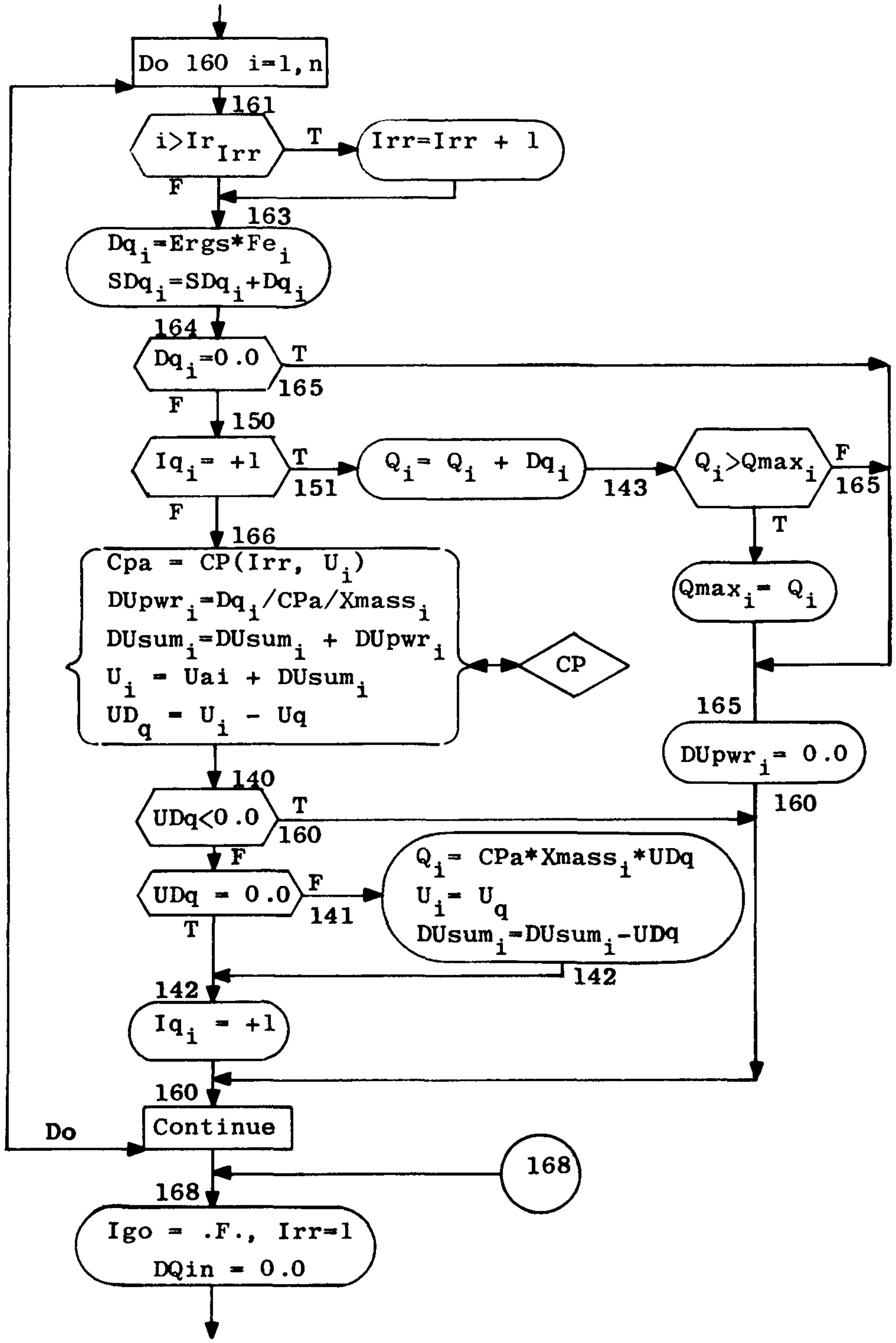
Flow diagram of the main program NEK-IV



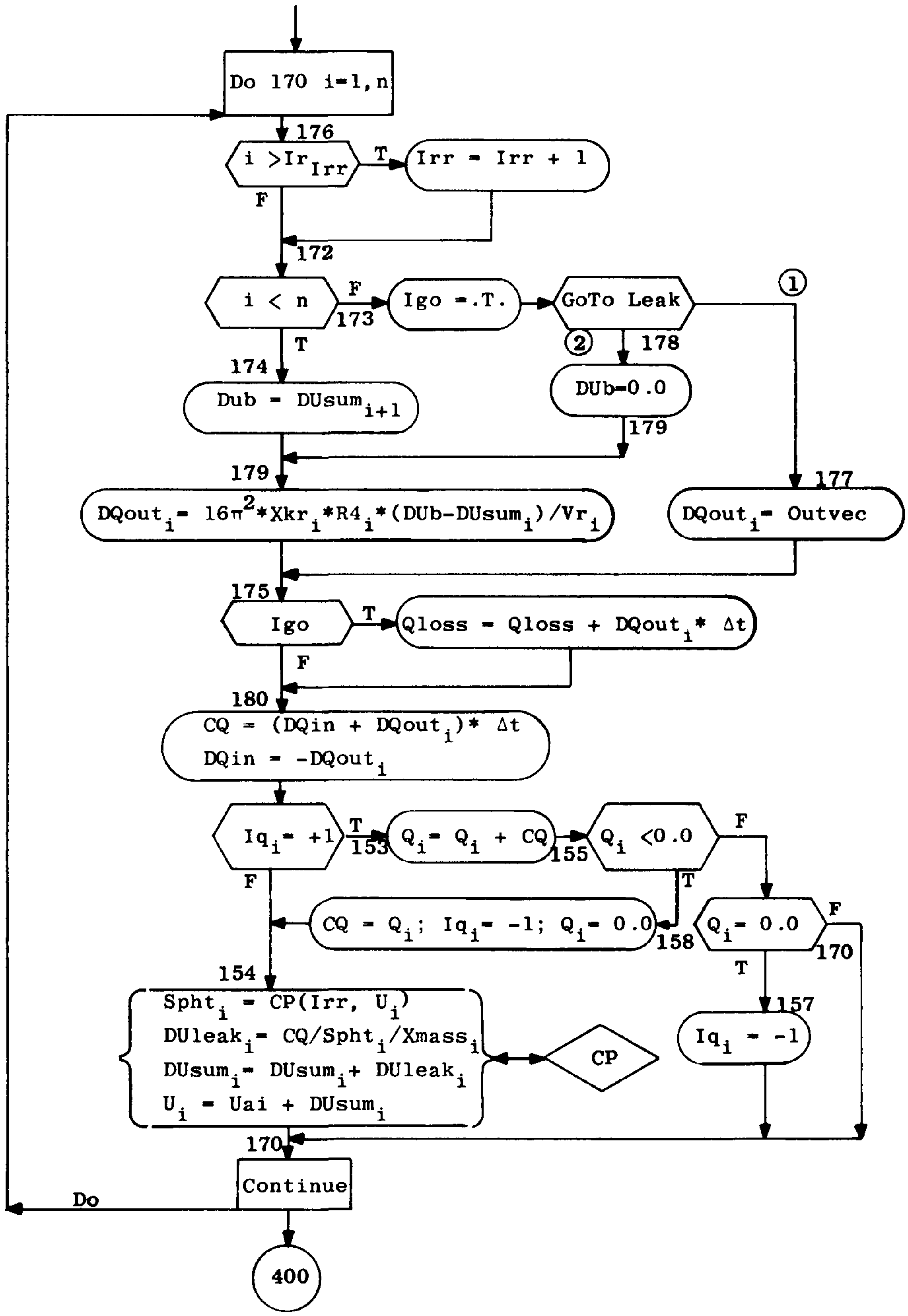
Flow diagram of the main program NEK-IV (continued)



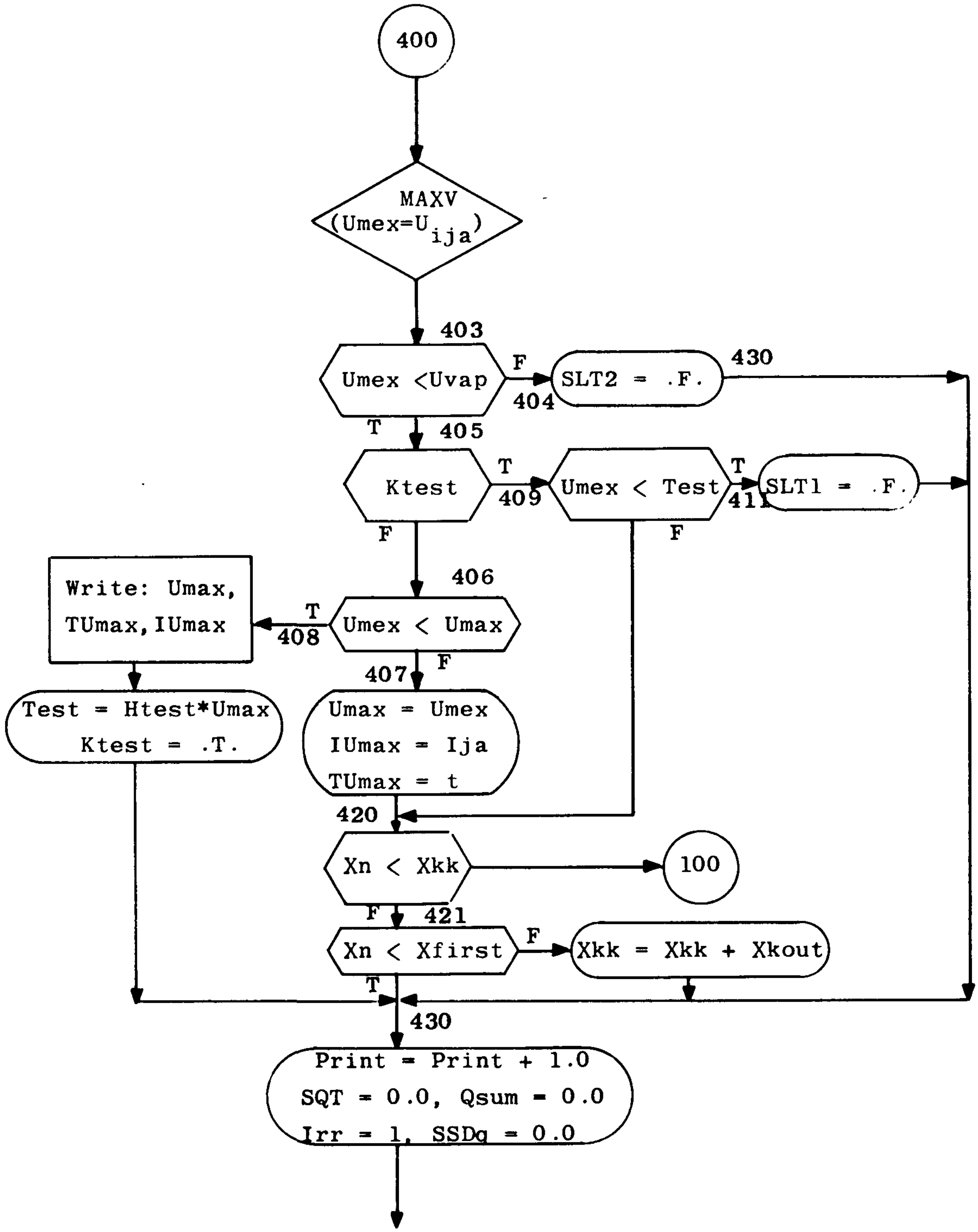
Flow diagram of the main program NEK-IV (continued)



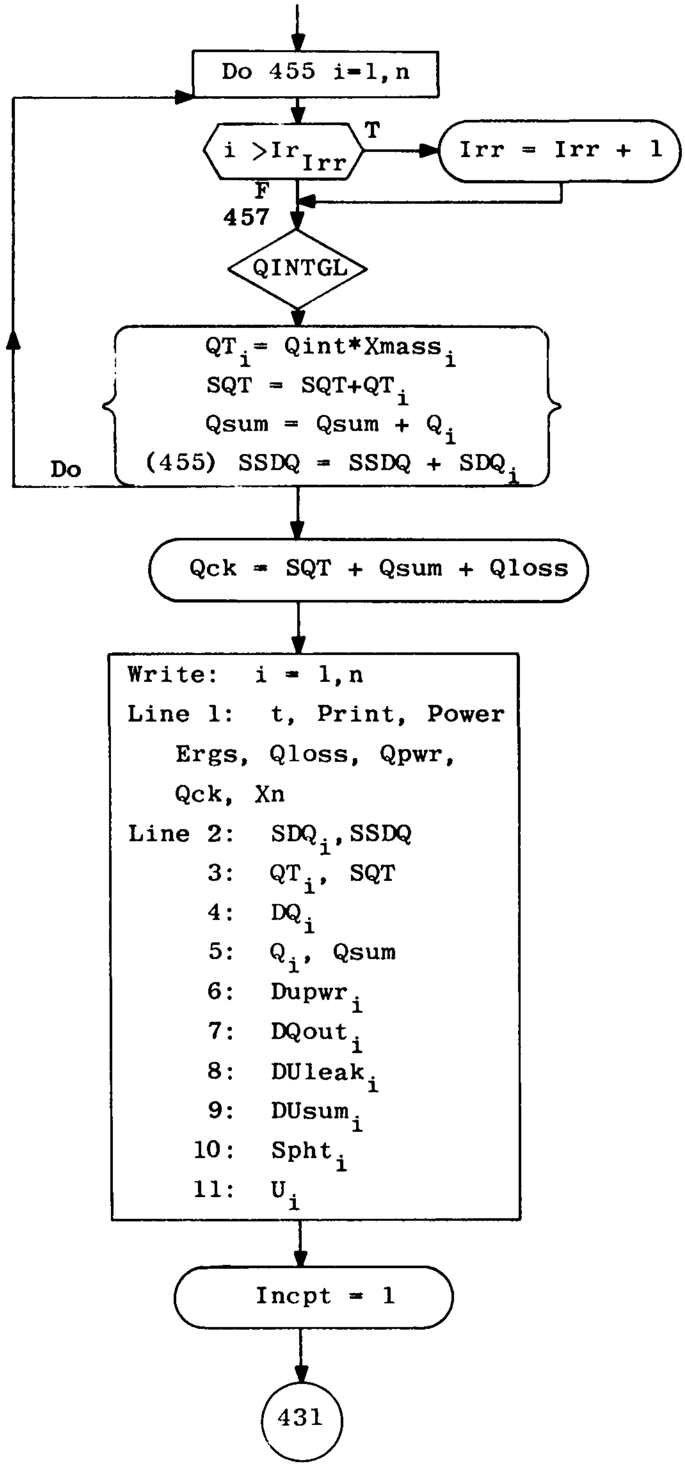
Flow diagram of the main program NEK-IV (continued)



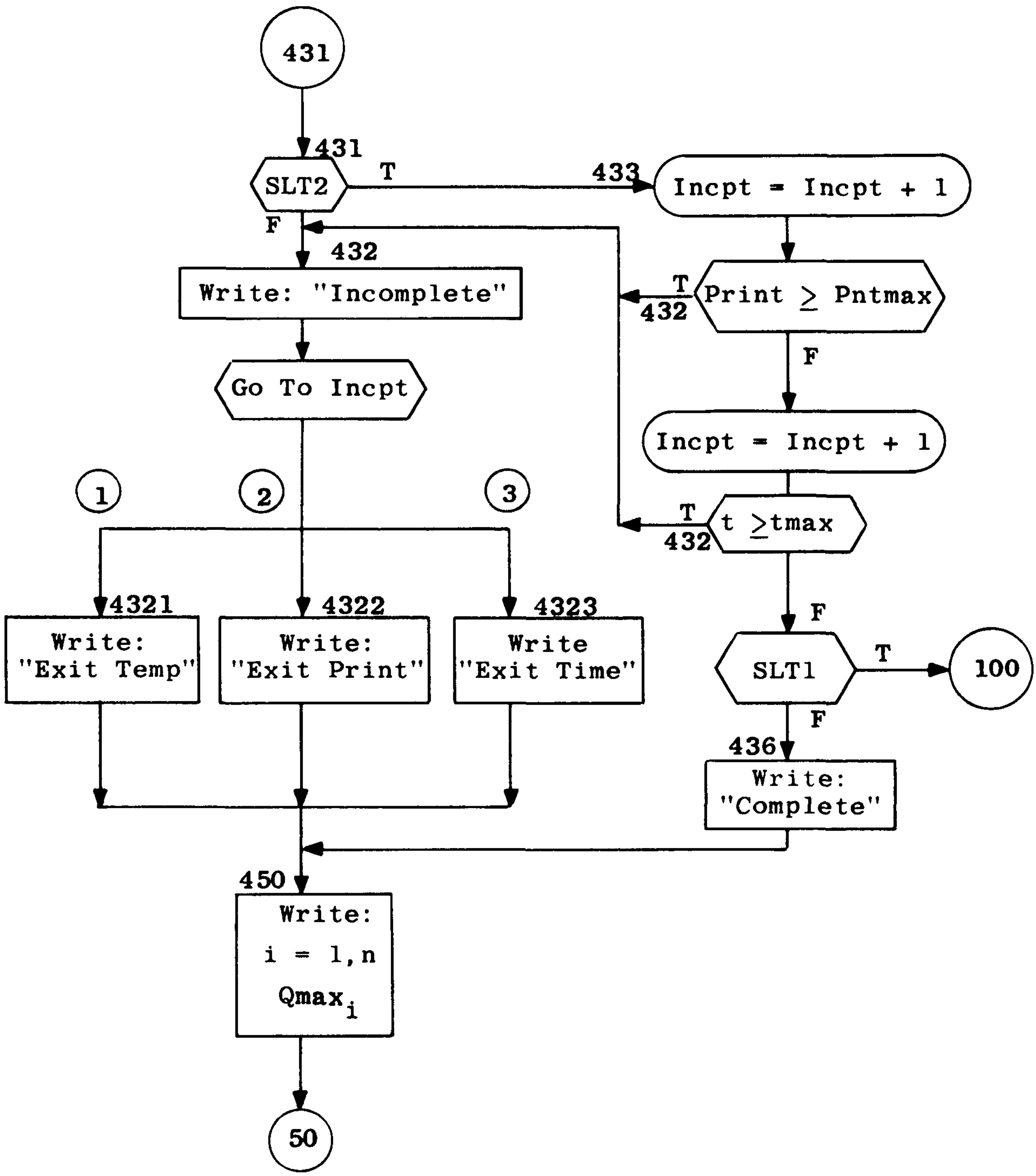
Flow diagram of the main program NEK-IV (continued)



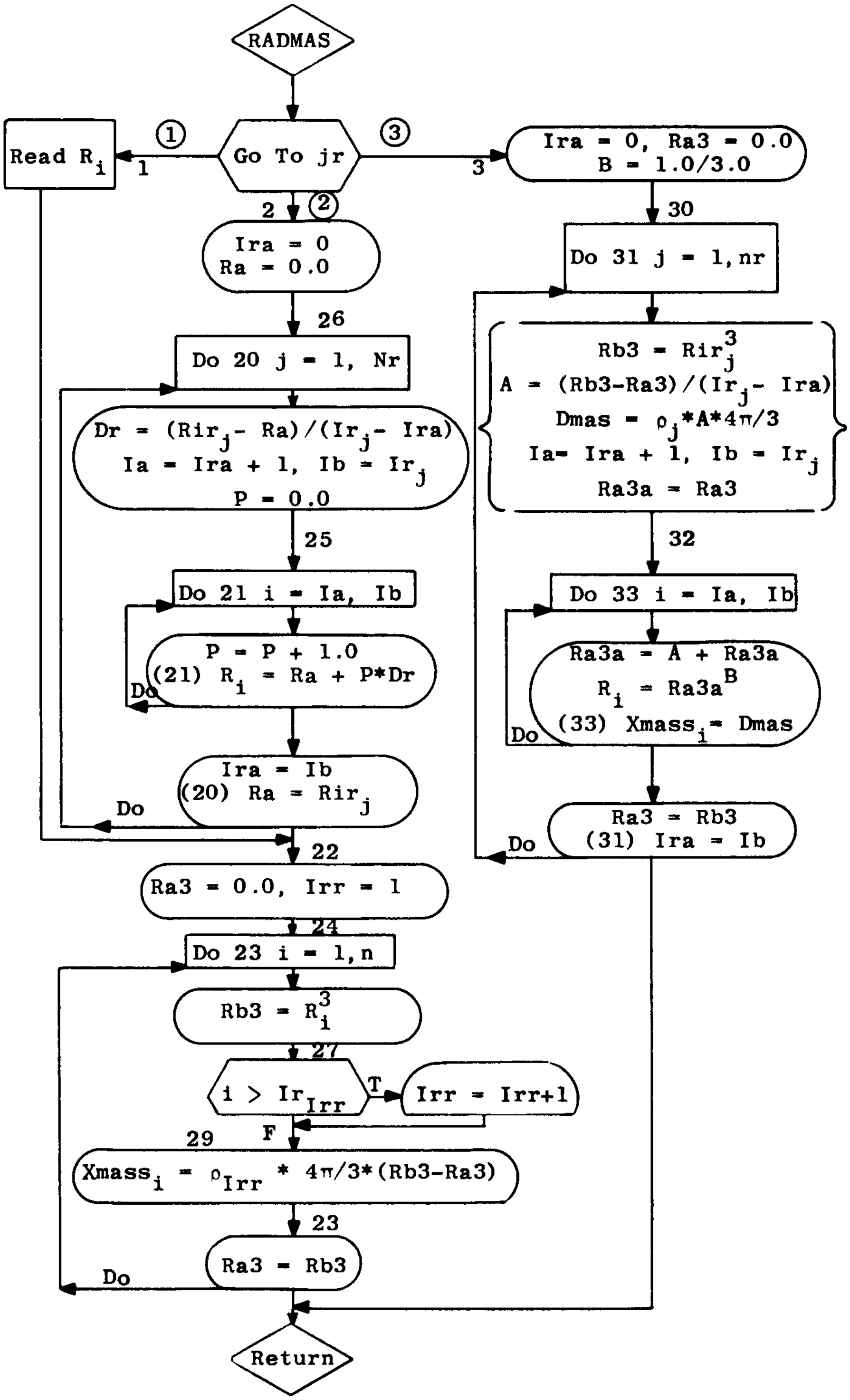
Flow diagram of the main program NEK-IV (continued)



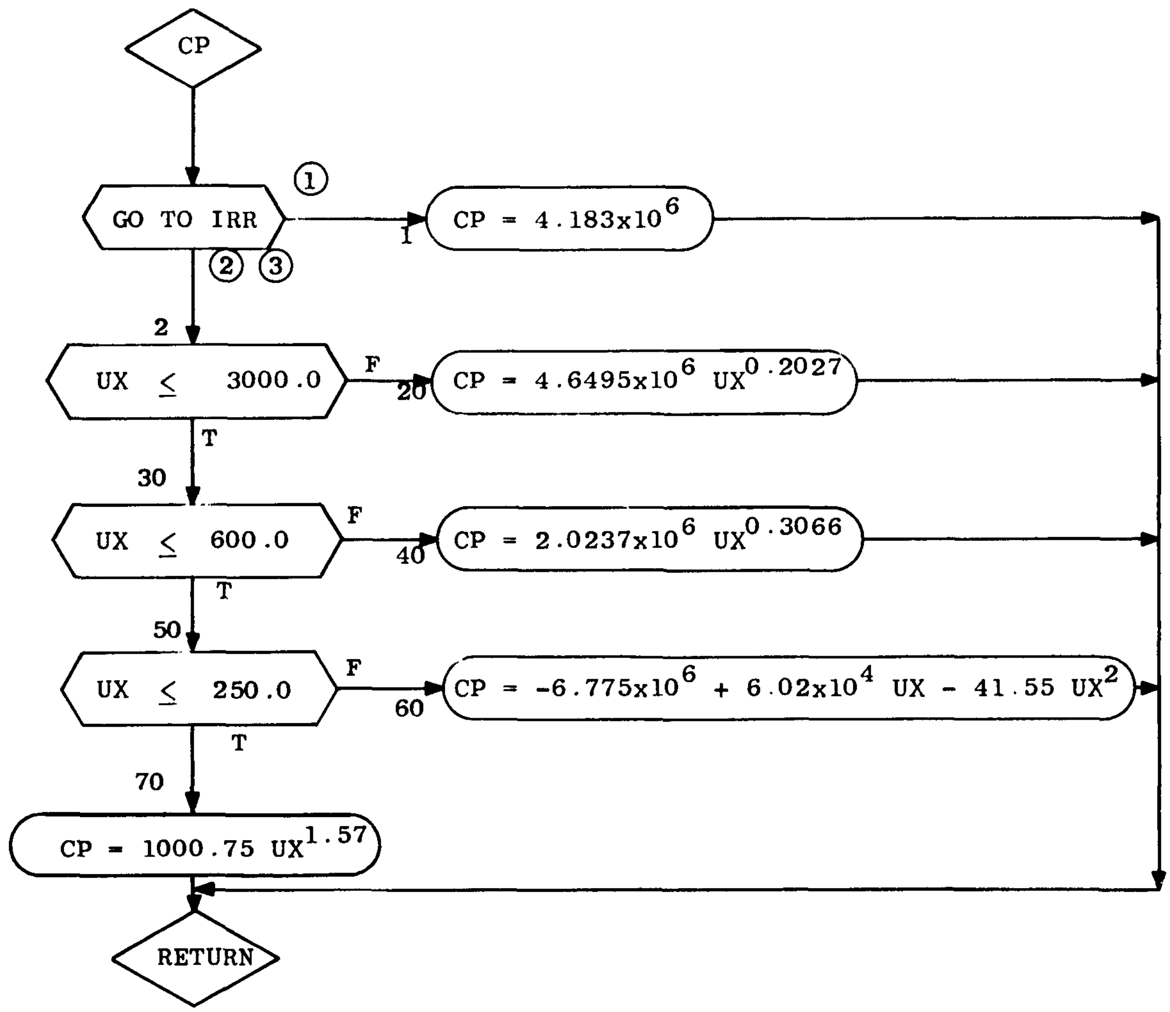
Flow diagram of the main program NEK-IV (continued)



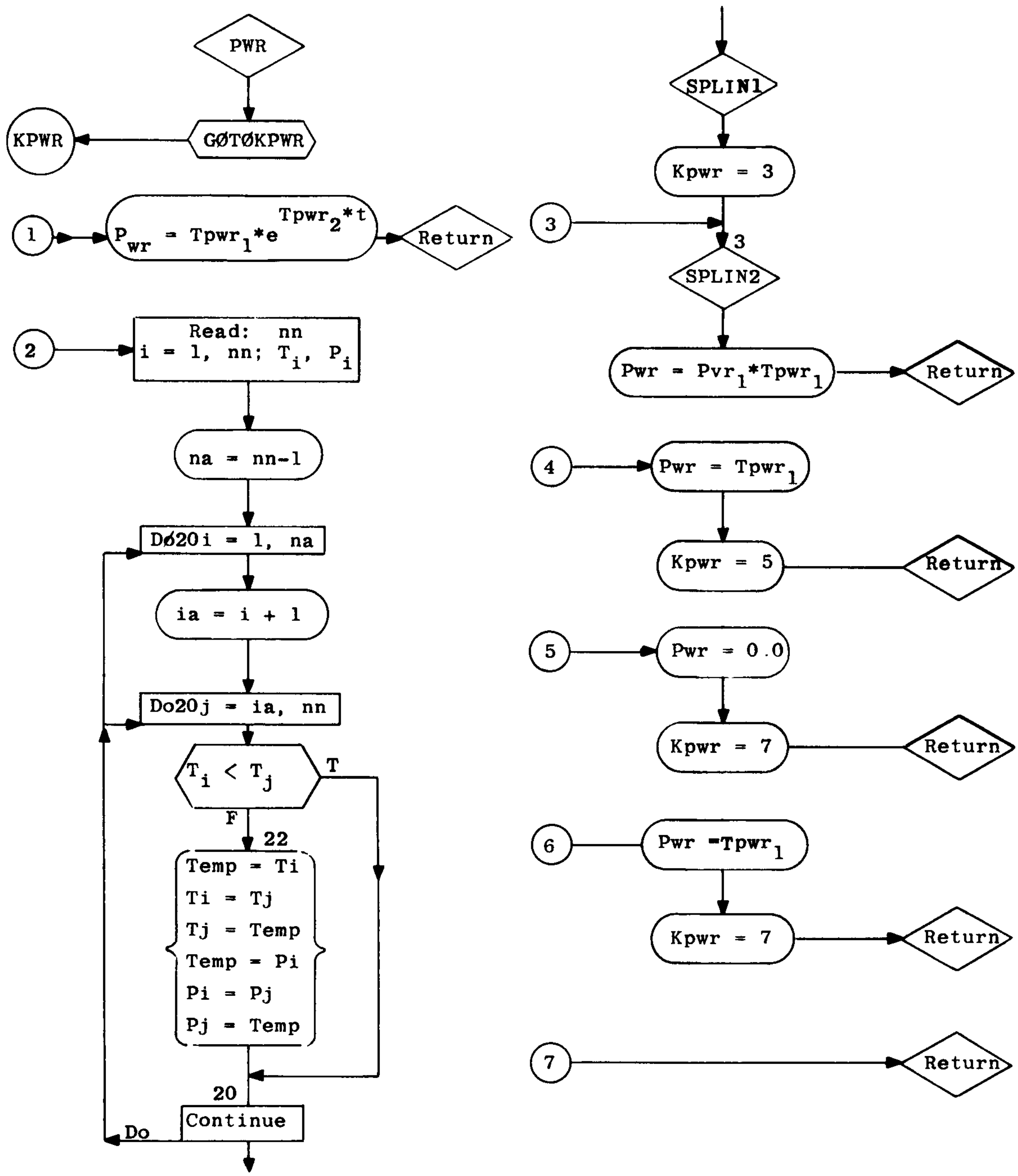
Flow diagram of the main program NEK-IV (continued)



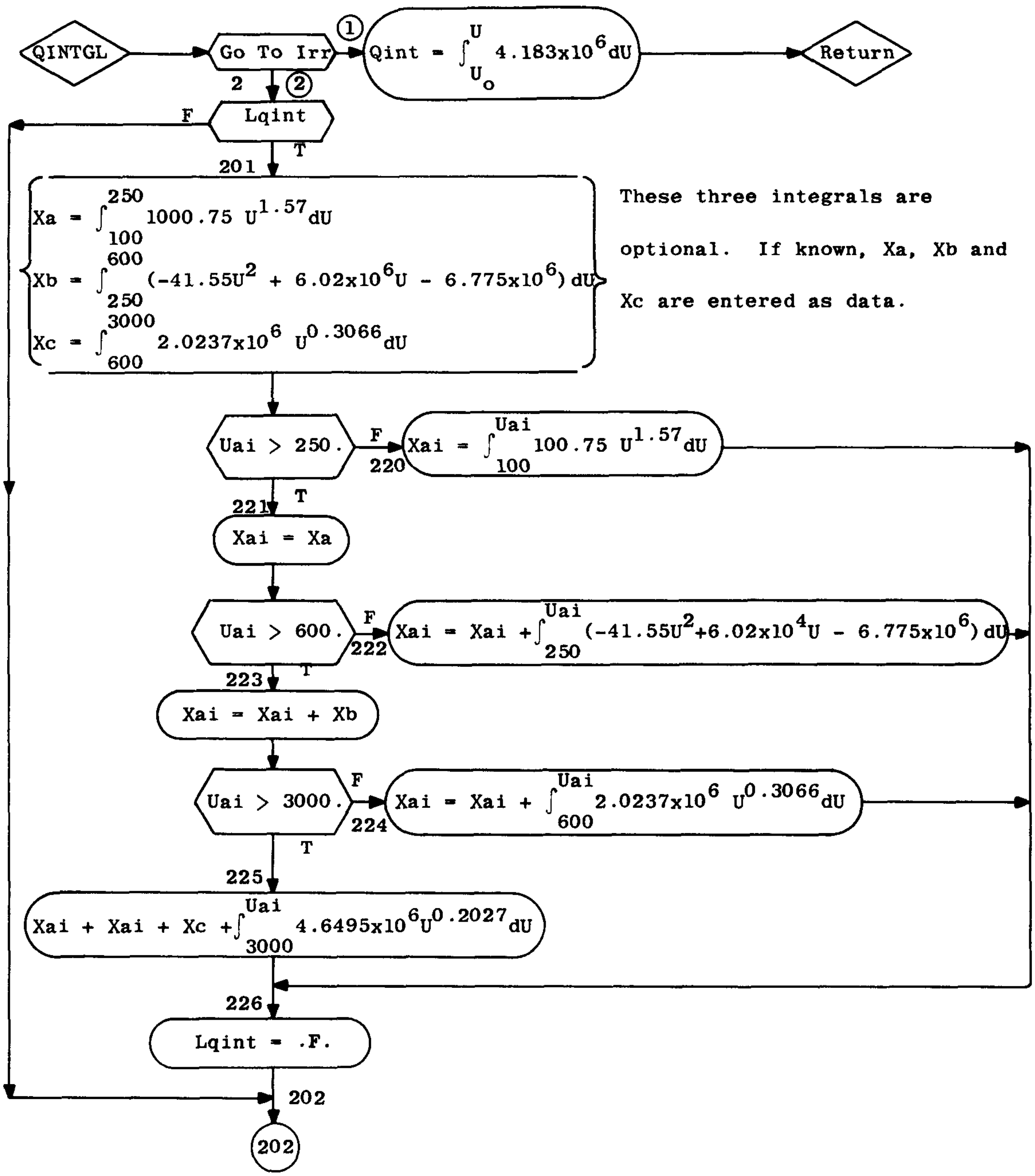
Flow diagram of the subroutine RADMAS



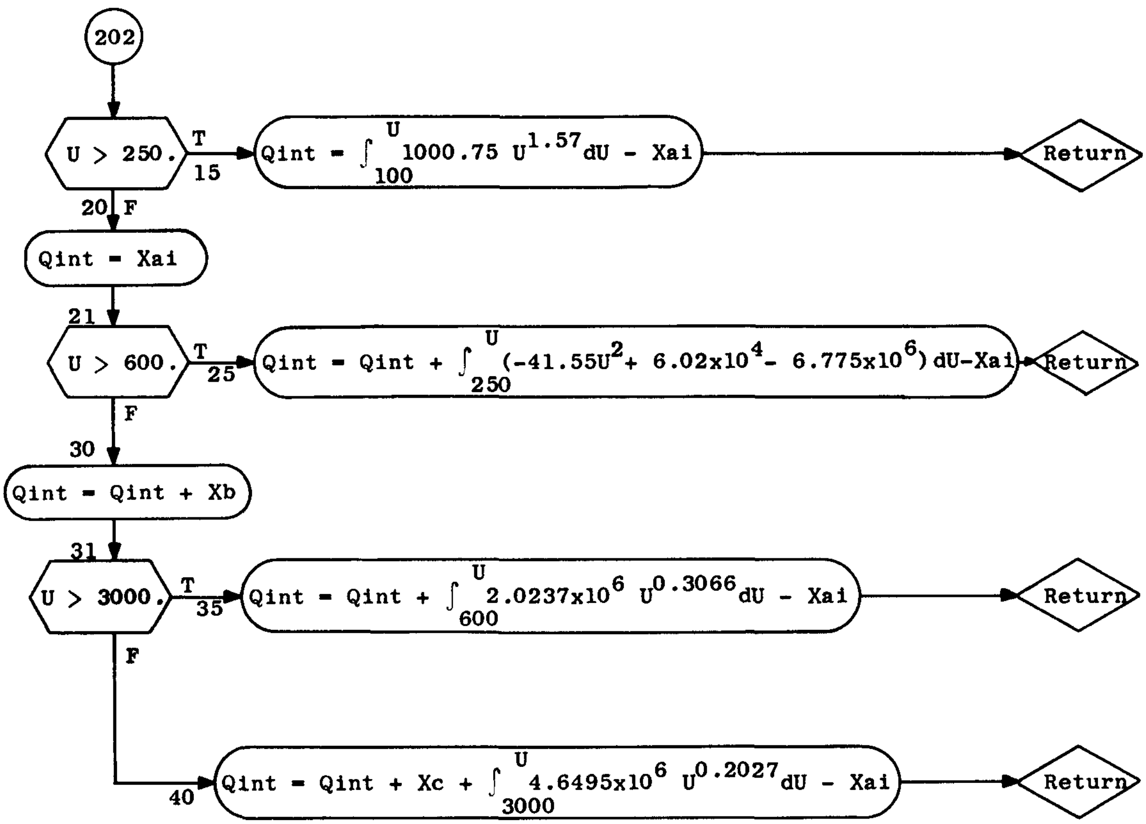
Flow diagram of the subroutine CP



Flow diagram of the subroutine PWR

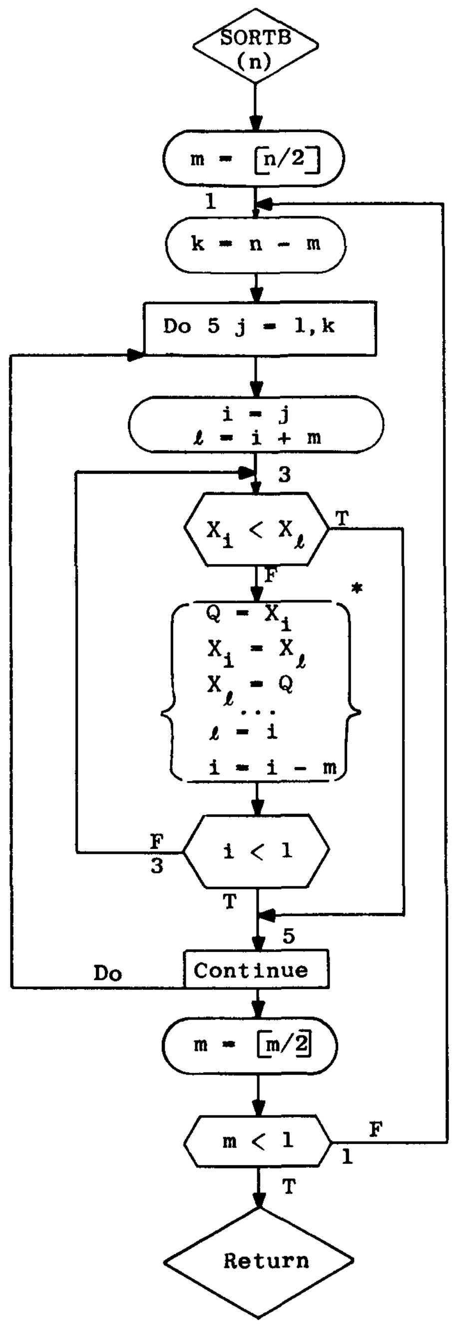


Flow diagram of the subroutine QINTGL



Note: The integrals in this Subroutine are evaluated and coded as Arithmetic Functions within the Subroutine.

Flow diagram of the subroutine QINTGL (continued)



*... indicates point of exchange of dependent variables or index vector.

This flow diagram is the Fortran IV equivalent of the same diagram in "A High-Speed Sorting Procedure", Communications of the ACM, July 1959 by D. L. Shell. It is assumed that a table is required where X is to be in ascending order and X is it's own key.

Flow diagram of the subroutine SORTB

IX

NEK-IV LISTINGS

```
T          SUBTYPE,FORTRAN
C      THIS IS THE FORTRAN IV DECK FOR NECKLACE       NEK-4
C
       DIMENSION  SDQ(200),QT(200)
C
       COMMON IDENT(12),LABEL(24),IR(8),RIR(8),RHO(8),XK(8),R(200),
      1 XMASS(200),VR(200),FE(200),DUDT(200),DUSUM(200),U(200),XKR(200),
      2 R4(200),DQ(200),TPWR(6),            DUPWR(200),DULEAK(200),
      3 SPHT(200),DQOUT(200),IQ(200),Q(200),QMAX(200),
      4 JR,NR,N,UAI,DT,UVAP,TIME,XN,UQ
C
       DATA ITP(10),JTP(9)
       LOGICAL SLT1,SLT2,IGO,KTEST,LQINT
C
C      LEAK=1 LEAK THRU OUTER BNDRY DEFINED BY OUTVEC (NEG).
C      LEAK=2 LEAKS INTO INF SINK.
C
     1 FORMAT(12A6)
     2 FORMAT(6E12.7)
     3 FORMAT(12I6)
     5 FORMAT(13HOINCOMPLETE.    )
     6 FORMAT(14H MAXIMUM TEMP.   1P2E14.6,I6,66X,6H******)
     7 FORMAT(20HCPROBLEM COMPLETED.      )
     8 FORMAT(1H+,74X,19HNEK-4, NECKLACE.      //)
     9 FORMAT(1H+,30X,12HRUNNING TIME, F8.2,9H MINUTES. )
    10 FORMAT(1X,A6,1P8E14.6/(1PE21.6,1P7E14.6))
    11 FORMAT(20I6)
    12 FORMAT(1HC)
    13 FORMAT(1H+,70X,19HEXIT ON TEMPERATURE   )
    14 FORMAT(1H+,70X,19HEXIT ON PRINT         )
    15 FORMAT(1H+,70X,19HEXIT ON TIME          )
C
       DATA  PISQ16(157.91367), FOR3PI(4.1887902)                       DATA
       READ       (ITP,1)LABEL                                          CARD A,B
C
    50 READ(ITP,1)IDENT                                                 CARD 1
       READ       (ITP,3)JR,NR,LEAK,KPWR                                CARD 2
       READ       (ITP,3)(IR(I),I=1,NR)                                 CARD 3
       N=IR(NR)
       READ       (ITP,2)(RIR(I),I=1,NR)                                CARD 4
       READ       (ITP,2)(RHO(I),I=1,NR)                                CARD 5
       READ       (ITP,2)(XK(I),I=1,NR)                                 CARD 6
       READ       (ITP,2)TPWR                                           CARD 7
       READ       (ITP,2)(FE(I),I=1;N)                                  CARD 8
       READ       (ITP,2)UAI,TIMEA,DT,TIMAX,HTEST,UVAP,                 CARD 9
      X XFIRST,XKOUT,PNTMAX,OUTVEC,UQ                                   CARD 10
       CALL RADMAS(FOR3PI)                                              CARD R
       QPWR=0.0
       QLOSS=0.0
       UMAX=0.0
       SLT1=.TRUE.
       SLT2=.TRUE.
       KTEST=.FALSE.
       LQINT=.TRUE.
       TEST=0.0
       PRINT=0.0
       OUTVEC=OUTVEC*FOR3PI*RHO(1)*RIR(1)**3
C
C      CALCULATE THERMAL CONDUCTIVITY ACROSS BOUNDARIES.
C
       IRR=1
    60 DO69I=1,N
```

```
      SDQ(I)=0.0
      IQ(I)=-1
      Q(I)=0.0
      QMAX(I)=0.0
      DUSUM(I)=0.0
      U(I)=UAI
      R4(I)=R(I)**4
   61 IF(I.NE.IR(IRR))GOTO62
      IF(I.LT.N.AND.I.GT.1)GOTO66
      IF(I.EQ.N)GOTO64
      GOTO67
   62 IF(I.LT.IR(IRR))GOTO64
      IRR=IRR+1
      GOTO61
   64 XKR(I)=XK(IRR)
      GOTO69
   66 RA3=R(I-1)**3
      GOTO68
   67 RA3=0.0
   68 RB3=R(I)**3
      RC3=R(I+1)**3
      XKR(I)=((RB3-RA3)*XK(IRR)+(RC3-RB3)*XK(IRR+1))/(RC3-RA3)
   69 CONTINUE
C
C     CALCULATE A VOLUME ASSOCIATED WITH EACH BOUNDARY.
C
      RA3=(R(1)/2.0)**3
   90 DO91I=1,N
   95 IF(I.LT.N)GOTO93
   92 RB3=R(N)**3
      GOTO94
   93 RB3=((R(I+1)+R(I))/2.0)**3
   94 VR(I)=FOR3PI*(RB3-RA3)
   91 RA3=RB3
C
C     CALCULATE MASS OF FISSIONABLE MATERIAL.
C
      SMC=0.0
      IR1=IR(1)
      DO96I=1,IR1
   96 SMC=SMC+XMASS(I)
C
C     WRITE PROBLEM PARAMETERS.
C
      WRITE        (JTP,1)IDENT
      WRITE        (JTP,8)
      WRITE        (JTP,11)JR,NR,(IR(I),I=1,NR)
      WRITE        (JTP,10)LABEL(7),(RIR(I),I=1,NR)
      WRITE        (JTP,10)LABEL(8),(RHO(I),I=1,NR)
      WRITE        (JTP,10)LABEL(9),(XK(I),I=1,NR)
      WRITE        (JTP,10)LABEL(10),(R(I),I=1,N)
      WRITE        (JTP,10)LABEL(15),(R4    (I),I=1,N)
      WRITE        (JTP,10)LABEL(11),(XMASS(I),I=1,N)
      WRITE        (JTP,10)LABEL(12),(VR(I),I=1,N)
      WRITE        (JTP,10)LABEL(6),(XKR(I),I=1,N)
      WRITE        (JTP,10)LABEL(17),TPWR
      WRITE        (JTP,10)LABEL(20),(FE(I),I=1,N)
      WRITE        (JTP,10)LABEL(16),DT,UAI,TIMEA,OUTVEC,SMC,UQ
      WRITE        (JTP,12)
C
C     BEGIN PROBLEM CYCLES.
C
```

```
      XKK=0.0
      XN=0.0
  100 XN=XN+1.0
      TIME=TIMEA+XN*DT                                                  TIMEA
      POWER=PWR(KPWR)                                                   PWR
      ERGS=POWER*DT*SMC
  169 IF(ERGS.EQ.0.0)GOTO168
  167 QPWR=QPWR+ERGS
C
C     CALCULATE HEAT CHANGE DUE TO ENERGY DUMP.
C
      IRR=1
      DO160I=1,N
  161 IF(I.GT.IR(IRR))IRR=IRR+1
  163 DQ(I)=ERGS*FE(I)
      SDQ(I)=SDQ(I)+DQ(I)
  164 IF(DQ(I).EQ.0.0)GOTO165
  150 IF(IQ(I))166,166,151
  151 Q(I)=Q(I)+DQ(I)
  143 IF(Q(I).GT.QMAX(I))QMAX(I)=Q(I)
  165 DUPWR(I)=0.0
      GOTO160
  166 CPA=CP(IRR,U(I))
      DUPWR(I)=DQ(I)/CPA/XMASS(I)
      DUSUM(I)=DUSUM(I)+DUPWR(I)
      U(I)=UAI+DUSUM(I)
      UDQ=U(I)-UQ
  140 IF(UDQ.LT.0.0)GOTO160
      IF(UDQ.EQ.0.0)GOTO142
  141 Q(I)=CPA*XMASS(I)*UDQ
      U(I)=UQ
      DUSUM(I)=DUSUM(I)-UDQ
  142 IQ(I)=1
  160 CONTINUE
C
C     CALCULATE HEAT CHANGE DUE TO LEAKAGE.
C
  168 IGO=.FALSE.
      IRR=1
      DQIN=0.0
      DO170I=1,N
  176 IF(I.GT.IR(IRR))IRR=IRR+1
  172 IF(I.LT.N)GOTO174
  173 IGO=.TRUE.
      GOTO(177,178),LEAK                                                LEAK
  177 DQOUT(I)=OUTVEC                                                   OUTVEC
      GOTO175
  178 DUB=0.0
      GOTO179
  174 DUB=DUSUM(I+1)
  179 DQOUT(I)=PISQ16   *XKR(I)*R4(I)*(DUB-DUSUM(I))/VR(I)
  175 IF(IGO)QLOSS=QLOSS+DQOUT(I)*DT
  180 CQ=(DQIN+DQOUT(I))*DT
      DQIN=-DQOUT(I)
  152 IF(IQ(I))154,154,153
  153 Q(I)=Q(I)+CQ
  155 IF(Q(I).LT.0.0)GOTO158
      IF(Q(I).EQ.0.0)IQ(I)=-1
      GOTO170
  158 CQ=Q(I)
      IQ(I)=-1
      Q(I)=0.0
```

```
  154 SPHT(I)=CP(IRR,U(I))
      DULEAK(I)=CQ/SPHT(I)/XMASS(I)
      DUSUM(I)=DUSUM(I)+DULEAK(I)
      U(I)=UAI+DUSUM(I)
  170 CONTINUE
C
C     LOCATE REGION OF MAXIMUM TEMPERATURE.
C
  400 CALL MAXV(U,1,N,IJA,UMEX)                                        F115MAXV
C
C     CHECK TIME OF MAXIMUM TEMPERATURE.  TEST PRINT AND TERMINATION.
C
  403 IF(UMEX.LT.UVAP)GOTO405
  404 SLT2=.FALSE.                                                     SLT2
      GOTO430
  405 IF(KTEST)GOTO409
  406 IF(UMEX.LT.UMAX)GOTO408
  407 UMAX=UMEX
      IUMAX=IJA
      TUMAX=TIME
      GOTO420
  408 WRITE(JTP,6)UMAX,TUMAX,IUMAX
      WRITE       (JTP,12)
      TEST=HTEST*UMAX
      KTEST=.TRUE.
      GOTO430
  409 IF(UMEX.LT.TEST)GOTO411
  420 IF(XN.LT.XKK)GOTO100
  421 IF(XN.LT.XFIRST)GOTO430
      XKK=XKK+XKOUT
      GOTO430
  411 SLT1=.FALSE.                                                     SLT1
  430 PRINT=PRINT+1.0
C
C     CALCULATE HEAT REMAINING IN SYSTEM.
C
      SQT=0.0
      QSUM=0.0
      IRR=1
      SSDQ=0.0
      DO455I=1,N
      IF(I.GT.IR(IRR))IRR=IRR+1
  457 CALL QINTGL(QINT,IRR,U(I),LQINT)
      QT(I)=QINT*XMASS(I)
      SQT=SQT+QT(I)
      QSUM=QSUM+Q(I)
  455 SSDQ=SSDQ+SDQ(I)
      QCK=SQT+QSUM+QLOSS
C
      WRITE       (JTP,10)LABEL(1),TIME,PRINT,POWER,ERGS,QLOSS,QPWR,QCK,
     X XN
      WRITE       (JTP,10)LABEL(23),(SDQ(I),I=1,N),SSDQ
      WRITE       (JTP,10)LABEL(24),(QT(I),I=1,N),SQT
      WRITE       (JTP,10)LABEL(5),(    DQ(I),I=1,N)
      WRITE       (JTP,10)LABEL(21),(Q(I),I=1,N),QSUM
      WRITE       (JTP,10)LABEL(13),(DUPWR(I),I=1,N)
      WRITE       (JTP,10)LABEL(19),(DQOUT(I),I=1,N)
      WRITE       (JTP,10)LABEL(3),(DULEAK(I),I=1,N)
      WRITE       (JTP,10)LABEL(4),(DUSUM(I),I=1,N)
      WRITE       (JTP,10)LABEL(18),(SPHT(I),I=1,N)
      WRITE       (JTP,10)LABEL(2),(U(I),I=1,N)
      WRITE       (JTP,12)
```

```
      INCPT=1
  431 IF(SLT2)GOTO433                                                    SLT2
  432 WRITE(JTP,5)
      GOTO(4321,4322,4323),INCPT
 4321 WRITE(JTP,13)
      GOTO450
 4322 WRITE(JTP,14)
      GOTO450
 4323 WRITE(JTP,15)
      GOTO450
  433 INCPT=INCPT+1
      IF(PRINT.GE.PNTMAX)GOTO432
      INCPT=INCPT+1
      IF(TIME.GE.TIMAX)GOTO432
  435 IF(SLT1)GOTO100
  436 WRITE       (JTP,7 )
  450 WRITE(JTP,12)
      WRITE       (JTP,10)LABEL(22),(QMAX(I),I=1,N)
      GOTO50
      END
```

```
T          SUBTYPE,FORTRAN
C     THIS IS THE FORTRAN IV DECK FOR NEK-4 FUNCTION PWR
C
      FUNCTION PWR(KPWR)
C
C     KPWR=1,  PWR RISES EXPONENTIALLY.  PWR(T)=TPWR(1)*EXP(TPWR(2)*T)
C     KPWR=2,  READ POWER PROFILE IN MW, INTERPOLATE AND CONVERT TO ERG/GM-SEC
C              CONVERSION FACTOR.. PWR=PWR*TPWR(1)
C     KPWR=3,  ALLOWED ONLY AFTER PROPER PROFILE IS IN STORAGE.
C     KPWR=4,  PULSE CENTER REGION AT TPWR(1)*DT THEN PWR(T)=0.0.
C     KPWR=5,  NOT AN INPUT PARAMETER, ASSOCIATED WITH KPWR=4.
C     KPWR=6,  POWER CONSTANT.  PWR(T)=TPWR(1).
C     KPWR=7,  NOT AN INPUT PARAMETER.  ASSOCIATED WITH KPWR=5 AND 6.
C
      DIMENSION T(500),P(500),W(500),G(500),PVR(3)
      COMMON IDENT(12),LABEL(24),IR(8),RIR(8),RHO(8),XK(8),R(200),
     1 XMASS(200),VR(200),FE(200),DUDT(200),DUSUM(200),U(200),XKR(200),
     2 R4(200),DQ(200),TPWR(6),          DUPWR(200),DULEAK(200),
     3 SPHT(200),DQOUT(200),IQ(200),Q(200),QMAX(200),
     4 JR,NR,N,UAI,DT,UVAP,TIME,XN,UQ
C
  101 FORMAT(I5)
  102 FORMAT(1X,5E14.7)
      DATA ITP(10),JTP(9)
C
C     KPWR=INTERNAL SIGNAL,  I=RADIUS,  IRR=REGION...
C
      GOTO(1,2,3,4,5,6,7),KPWR
C
    1 PWR=TPWR(1)*EXP (TPWR(2)*TIME)
      RETURN
    2 READ(ITP,101)NN
      READ(ITP,102)(T(I),I=1,NN)
      READ(ITP,102)(P(I),I=1,NN)
      CALL SORTB(NN,T,P)
      CALL SPLIN1(T,P,NN,W,G,2,1.0,1.0)
      KPWR=3
    3 CALL SPLIN2(T,P,NN,W,TIME,PVR)
      PWR=PVR(1)*TPWR(1)
      RETURN
    4 PWR=TPWR(1)
      KPWR=5
      RETURN
    5 PWR=0.0
      KPWR=7
      RETURN
    6 PWR=TPWR(1)
      KPWR=7
    7 RETURN
      END
```

```
T         SUBTYPE,FORTRAN
C      THIS IS THE FORTRAN IV DECK FOR NEK-4 SUBROUTINE QINTGL
       SUBROUTINE QINTGL(QINT,IRR,V,LQINT)
C
       FINTF(UL,UU,P,Q)=P*(UU**(Q+1.0)-UL**(Q+1.0))/(Q+1.0)
       GINTF(UU)=-6.775E6*(UU-250.0)+3.0095E4*((UU*UU)-6.25E4)-
      X 13.8483*((UU*UU)*UU-1.5625E7)
C
       COMMON IDENT(12),LABEL(24),IR(8),RIR(8),RHO(8),XK(8),R(200),
      1 XMASS(200),VR(200),FE(200),DUDT(200),DUSUM(200),U(200),XKR(200),
      2 R4(200),DQ(200),TPWR(6),          DUPWR(200),DULEAK(200),
      3 SPHT(200),DQOUT(200),IQ(200),Q(200),QMAX(200),
      4 JR,NR,N,UAI,DT,UVAP,TIME,XN,UQ
C
       LOGICAL LQINT
       DATA XA(5.1261573E8),XB(3.8071594E9),XC(4.7495641E10)
C
       GOTO(1,2,2),IRR
C
     1 QINT=4.183E6*(V-UAI)
       RETURN
C
     2 IF(LQINT)GOTO201
C
   202 IF(V.LT.250.0)GOTO15
    20 QINT=XA
    21 IF(V.LT.600.0)GOTO25
    30 QINT=QINT+XB
    31 IF(V.LT.3000.0)GOTO35
    40 QINT=QINT+XC+FINTF(3000.0,V,4.6495E6,0.2027)-XAI
       RETURN
    15 QINT=FINTF(100.0,V,1000.75,1.57)-XAI
       RETURN
    25 QINT=QINT+GINTF(V)-XAI
       RETURN
    35 QINT=QINT+FINTF(600.0,V,2.0237E6,0.3066)-XAI
       RETURN
C
C  201 XA=FINTF(100.0,250.0,1000.75,1.57)
C      XB=GINTF(600.0)
C      XC=FINTF(600.0,3000.0,2.0237E6,0.3066)
C
   201 CONTINUE
       IF(UAI.GT.250.0)GOTO221
   220 XAI=FINTF(100.0,UAI,1000.75,1.57)
       GOTO226
   221 XAI=XA
       IF(UAI.GT.600.0)GOTO223
   222 XAI=XAI+GINTF(UAI)
       GOTO226
   223 XAI=XAI+XB
       IF(UAI.GT.3000.0)GOTO225
   224 XAI=XAI+FINTF(600.0,UAI,2.0237E6,0.3066)
       GOTO226
   225 XAI=XAI+XC+FINTF(3000.0,UAI,4.6495E6,0.2027)
   226 LQINT=.FALSE.
       GOTO202
       END
```

```
T         SUBTYPE,FORTRAN
C      THIS IS THE FORTRAN IV DECK FOR NFK-4 SUBROUTINE RADMAS
C
       SUBROUTINE RADMAS(FOR3PI)
C
C      JR=1, READ R, CALCULATE MASS.
C      JR=2, DR=CONST. CALCULATE MASS.
C      JR=3, EQUAL MASS, CALCULATE R.
C
C
       COMMON IDENT(12),LABEL(24),IR(8),RIR(8),RHO(8),XK(8),R(200),
      1 XMASS(200),VR(200),FE(200),DUDT(200),DUSUM(200),U(200),XKR(200),
      2 R4(200),DQ(200),TPWR(6),           DUPWR(200),DULEAK(200),
      3 SPHT(200),DQOUT(200),IQ(200),Q(200),QMAX(200),
      4 JR,NR,N,UAI,DT,UVAP,TIME,XN,UQ
C
    11 FORMAT(6E12.7)
       DATA ITP(10),JTP(9)
C
       GOTO(1,2,3),JR
     1 READ(ITP,11)(R(I),I=1,N)
       GOTO22
     2 IRA=0
       RA=0.0
    26 DO20J=1,NR
       DR=(RIR(J)-RA)/FLOAT (IR(J)-IRA)
       IA=IRA+1
       IB=IR(J)
       P=0.0
    25 DO21I=IA,IB
       P=P+1.0
    21 R(I)=RA+P*DR
       IRA=IB
    20 RA=RIR(J)
    22 RA3=0.0
       IRR=1
    24 DO23I=1,N
       RB3=R(I)**3
    27 IF(I.GT.IR(IRR))IRR=IRR+1
    29 XMASS(I)=RHO(IRR)*FOR3PI*(RB3-RA3)
    23 RA3=RB3
       RETURN
     3 IRA=0
       RA3=0.0
       B=1.0/3.0
    30 DO31J=1,NR
       RB3=RIR(J)**3
       A=(RB3-RA3)/FLOAT (IR(J)-IRA)
       DMAS=RHO(J)*A*FOR3PI
       IA=IRA+1
       IB=IR(J)
       RA3A=RA3
    32 DO33I=IA,IB
       RA3A=A+RA3A
       R(I)=RA3A**B
    33 XMASS(I)=DMAS
       RA3=RB3
    31 IRA=IB
       RETURN
       END
```

```
T         SUBTYPE,FORTRAN
C      THIS IS THE FORTRAN IV DECK FOR NEK-4 FUNCTION CP
C
       FUNCTION    CP(IRR,UX)
C
       COMMON IDENT(12),LABEL(24),IR(8),RIR(8),RHO(8),XK(8),R(200),
     1 XMASS(200),VR(200),FE(200),DUDT(200),DUSUM(200),U(200),XKR(200),
     2 R4(200),DQ(200),TPWR(6),           DUPWR(200),DULEAK(200),
     3 SPHT(200),DQOUT(200),IQ(200),Q(200),QMAX(200),
     4 JR,NR,N,UAI,DT,UVAP,TIME,XN,UQ
C
C      IRR=REGION.                          ERG/GM-DEG(K)
C
       GOTO(1,2,2),IRR
C
     1 CP=4.183E6
       RETURN
     2 IF(UX.LE.3000.0)GOTO30
    20 CP=4.6495E6*UX**0.2027
       RETURN
    30 IF(UX.LT.600.0)GOTO50
    40 CP=2.0237E6*UX**0.3066
       RETURN
    50 IF(UX.LE.250.0)GOTO70
    60 CP=(6.02E4-41.55*UX)*UX-6.775E6
       RETURN
    70 CP=1000.75*UX**1.57
       RETURN
       END
```

X

NEK-II LISTINGS

Those statements flagged with "$" in column 80 are those which were modified for the radiation terms.

```
*     LABEL
CNEK-2
C     THIS IS THE FORTRAN II DECK FOR NECKLACE.
C     STATEMENTS FLAGGED $ CONTAIN RADIATION LEAKAGE MODIFICATIONS.
      DIMENSION IDENT(12),LABEL(24),IR(8),RIR(8),RHO(8),XK(8),
     1 R(200),XMASS(200),VR(200),    FE(200),DUDT(200),IQ(200),Q(200),
     2 DUSUM(200),U(200),TPWR(6),XKR(200),R4(200),           DQ(200),
     3 DUPWR(200),DULEAK(200),SPHT(200),DQOUT(200),QMAX(200)
      DIMENSION  SDQ(200),QT(200),DAY(2),AHE(200)
C
      COMMON IDENT,LABEL,IR,RIR,RHO,XK,R,XMASS,VR,
     1    FE,DUDT,DUSUM,U,JR,NR,N,UAI,     DT,UVAP,XKR,R4,DQ,
     2 TIME,XN,TPWR,       DUPWR,DULEAK,SPHT,DQOUT,IQ,Q,QMAX,UQ
C
      FREQUENCY 61(10,1,1),63(10,1,0),65(0,1,10),95(10,1,0),161(10,1,1),
     1 164(0,5,1),176(10,1,1),172(10,1,0),          403(100,0,1),
     2 405(0,10,1),406(1,0,100),409(1,0,100),437(100,1,1),420(100,1,0),
     3 421(2,1,1000),431(1,100),434(100,1,0),435(1,100),175(0,6,1),
     4 169(0,6,1),150(0,1,1),143(100,1,100),140(500,0,1)
C
C     LEAK=1 LEAK THRU OUTER BNDRY DEFINED BY OUTVEC (NEG).
C     LEAK=2 LEAKS INTO INF SINK.
C
    1 FORMAT(12A6)
    2 FORMAT(6E12.7)
    3 FORMAT(12I6)
    4 FORMAT(12A6)
    5 FORMAT(13HOINCOMPLETE.    )
    6 FORMAT(14H MAXIMUM TEMP.   1P2E14.6,I6,66X,6H******)
    7 FORMAT(20HOPROBLEM COMPLETED.      )
    8 FORMAT(1H+,74X,19HNEK-2, NECKLACE.          2A6//)
    9 FORMAT(1H+,30X,12HRUNNING TIME, F8.2,9H MINUTES. )
   10 FORMAT(1X,A6,1P8E14.6/(1PE21.6,1P7E14.6))
   11 FORMAT(20I6)
   12 FORMAT(1HO)
   13 FORMAT(1H+, 70X, 19HEXIT ON TEMPERATURE)
   14 FORMAT(1H+, 70X, 19HEXIT ON PRINT      )
   15 FORMAT(1H+, 70X, 19HEXIT ON TIME       )
C
      CALL DATE(DAY)
      READINPUTTAPE10,4,LABEL                                           CARD A,B
C
      PISQ16=157.91367                                                  16PI**2
      FOR3PI=4.1887902                                                  4PI/3
      CALL CLOCK (TEND,TBCD)
C                                          JR IN RADMAS
   50 TSTART=TEND
      READINPUTTAPE10,4,IDENT                                           CARD 1
      READINPUTTAPE10,3,JR,NR,LEAK,KPWR                                 CARD 2
      READINPUTTAPE10,3,(IR(I),I=1,NR)                                  CARD 3
      N=IR(NR)
      READINPUTTAPE10,2,(RIR(I),I=1,NR)                                 CARD 4
      READINPUTTAPE10,2,(RHO(I),I=1,NR)                                 CARD 5
      READINPUTTAPE10,2,(XK(I),I=1,NR)                                  CARD 6
      READINPUTTAPE10,2,TPWR                                            CARD 7
      READINPUTTAPE10,2,(FE(I),I=1,N)                                   CARD 8
      READINPUTTAPE10,2,UAI,TIMEA,DT,TIMAX,HTEST,UVAP,                  CARD 9
     X XFIRST,XKOUT,PNTMAX,OUTVEC,UQ,EM                                 CARD 10$
      CALL RADMAS(FOR3PI)                                               CARD R
      HEM=7.12337E-4*EM                                                      $
      QPWR=0.0
      QLEAK=0.0
```

```
      QLOSS=0.0
      UMAX=0.0
      KTEST=0
      TEST=0.0
      PRINT=0.0
      LQINT=1
      SENSELIGHTO
      OUTVEC=OUTVEC*FOR3PI*RHO(1)*RIR(1)**3
C
C     CALCULATE THERMAL CONDUCTIVITY ACROSS BOUNDARIES.
C
      IRR=1
   60 DO69I=1,N
      SDQ(I)=0.0
      IQ(I)=0
      Q(I)=0.0
      QMAX(I)=0.0
      DUSUM(I)=0.0
      U(I)=UAI
      R2=R(I)*R(I)
      AHE(I)=HEM*R2
      R4(I)=R2*R2
   61 IF(I-IR(IRR))64,63,62
   62 IRR=IRR+1
      GOTO61
   63 IF(I-N)65,64,64
   64 XKR(I)=XK(IRR)
      GOTO69
   65 IF(I-1)67,67,66
   66 RA3=R(I-1)**3
      GOTO68
   67 RA3=0.0
   68 RB3=R(I)**3
      RC3=R(I+1)**3
      XKR(I)=((RB3-RA3)*XK(IRR)+(RC3-RB3)*XK(IRR+1))/(RC3-RA3)
   69 CONTINUE
C
C     CALCULATE A VOLUME ASSOCIATED WITH EACH BOUNDARY.
C
      RA3=(R(1)/2.0)**3
   90 DO91I=1,N
   95 IF(I-N)93,92,92
   92 RB3=R(N)**3
      GOTO94
   93 RB3=((R(I+1)+R(I))/2.0)**3
   94 VR(I)=FOR3PI*(RB3-RA3)
   91 RA3=RB3
C
C     CALCULATE MASS OF FISSIONABLE MATERIAL.
C
      SMC=0.0
      IR1=IR(1)
      DO96I=1,IR1
   96 SMC=SMC+XMASS(I)
C
C     WRITE PROBLEM PARAMETERS.
C
      WRITEOUTPUTTAPE9,1,IDENT
      WRITEOUTPUTTAPE9,8,DAY
      WRITEOUTPUTTAPE9,11,JR,NR,(IR(I),I=1,NR)
      WRITEOUTPUTTAPE9,10,LABEL(7),(RIR(I),I=1,NR)
      WRITEOUTPUTTAPE9,10,LABEL(8),(RHO(I),I=1,NR)
```

```
      WRITEOUTPUTTAPE9,10,LABEL(9),(XK(I),I=1,NR)
      WRITEOUTPUTTAPE9,10,LABEL(10),(R(I),I=1,N)
      WRITEOUTPUTTAPE9,10,LABEL(15),(R4    (I),I=1,N)
      WRITEOUTPUTTAPE9,10,LABEL(11),(XMASS(I),I=1,N)
      WRITEOUTPUTTAPE9,10,LABEL(12),(VR(I),I=1,N)
      WRITEOUTPUTTAPE9,10,LABEL(6),(XKR(I),I=1,N)
      WRITEOUTPUTTAPE9,10,LABEL(17),TPWR
      WRITEOUTPUTTAPE9,10,LABEL(20),(FE(I),I=1,N)
      WRITEOUTPUTTAPE9,10,LABEL(16),(AHE(I),I=1,N)                          $
      WRITEOUTPUTTAPE9,10,LABEL(16),DT,UAI,TIMEA,OUTVEC,SMC,UQ
      WRITEOUTPUTTAPE9,12
      XKK=0.0
      XN=0.0
  100 XN=XN+1.0
      TIME=TIMEA+XN*DT                                                    TIMEA
      POWER=PWR(KPWR)
      ERGS=POWER*DT*SMC
  169 IF(ERGS)168,168,167
  167 QPWR=QPWR+ERGS
C
C     CALCULATE HEAT CHANGE DUE TO ENERGY DUMP.
C
      IRR=1
      DO160I=1,N
  161 IF(I-IR(IRR))163,163,162
  162 IRR=IRR+1
  163 DQ(I)=ERGS*FE(I)
      SDQ(I)=SDQ(I)+DQ(I)
  164 IF(DQ(I))165,165,150
  150 IF(IQ(I))166,166,151
  151 Q(I)=Q(I)+DQ(I)
  143 IF(Q(I)-QMAX(I))165,165,144
  144 QMAX(I)=Q(I)
  165 DUPWR(I)=0.0
      GOTO160
  166 CPA=CP(IRR,U(I))
      DUPWR(I)=DQ(I)/CPA/XMASS(I)
      DUSUM(I)=DUSUM(I)+DUPWR(I)
      U(I)=UAI+DUSUM(I)
      UDQ=U(I)-UQ
  140 IF(UDQ)160,142,141
  141 Q(I)=CPA*XMASS(I)*UDQ
      U(I)=UQ
      DUSUM(I)=DUSUM(I)-UDQ
  142 IQ(I)=1
  160 CONTINUE
C
C     CALCULATE HEAT CHANGE DUE TO LEAKAGE.
C
  168 IGO=0
      IRR=1
      DQIN=0.0
      DO170I=1,N
  176 IF(I-IR(IRR))172,172,171
  171 IRR=IRR+1
  172 IF(I-N)174,173,173
  173 IGO=1
      GOTO(177,178),LEAK                                                  LEAK
  177 DQOUT(I)=OUTVEC                                                     OUTVEC
      GOTO175
  178 DUB=0.0
      GOTO179
```

```
  174 DUB=DUSUM(I+1)
  179 DQOUT(I)=PISQ16   *XKR(I)*R4(I)*(DUB-DUSUM(I))/VR(I)
     X      -AHE(I)*(DUB**4-DUSUM(I)**4)                                  $
  175 IF(IGO)180,180,181
  181 QLOSS=QLOSS+DQOUT(I)*DT
  180 CQ=(DQIN+DQOUT(I))*DT
      DQIN=-DQOUT(I)
  152 IF(IQ(I))154,154,153
  153 Q(I)=Q(I)+CQ
  155 IF(Q(I))158,157,170
  157 IQ(I)=0
      GOTO170
  158 CQ=Q(I)
      IQ(I)=0
      Q(I)=0.0
  154 SPHT(I)=CP(IRR,U(I))
      DULEAK(I)=CQ/SPHT(I)/XMASS(I)
      DUSUM(I)=DUSUM(I)+DULEAK(I)
      U(I)=UAI+DUSUM(I)
  170 CONTINUE
C
C     LOCATE SHELL  OF MAXIMUM TEMPERATURE.
C
  400 CALL MAX3(U,-1,N,IJA,UMEX)                                   MAX3
C
C     CHECK TIME OF MAXIMUM TEMPERATURE.  TEST PRINT AND TERMINATION.
C
  403 IF(UMEX-UVAP)405,404,404
  404 SENSELIGHT2
      GOTO430
  405 IF(KTEST)406,406,409
  406 IF(UMEX-UMAX)408,407,407
  407 UMAX=UMEX
      IUMAX=IJA
      TUMAX=TIME
      GOTO420
  408 WRITEOUTPUTTAPE9,6,UMAX,TUMAX,IUMAX
      WRITEOUTPUTTAPE9,12
      TEST=HTEST*UMAX
      KTEST=1
      GOTO430
  409 IF(UMEX-TEST)411,411,420
  411 SENSELIGHT1
      GOTO430
  420 IF(XN-XKK)100,421,421
  421 IF(XN-XFIRST)430,423,423                                     XFIRST
  423 XKK=XKK+XKOUT                                                XKOUT
  430 PRINT=PRINT+1.0
C
C     CALCULATE HEAT REMAINING IN SYSTEM.
C
      SQT=0.0
      QSUM=0.0
      IRR=1
      SSDQ=0.0
      DO455I=1,N
      IF(I-IR(IRR))457,457,456
  456 IRR=IRR+1
  457 CALL QINTGL(QINT,IRR,U(I),LQINT)
      QT(I)=QINT*XMASS(I)
      SQT=SQT+QT(I)
      QSUM=QSUM+Q(I)
```

```
  455 SSDQ=SSDQ+SDQ(I)
      QCK=SQT+QSUM+QLOSS
C
      WRITEOUTPUTTAPE9,10,LABEL(1),TIME,PRINT,POWER,ERGS,QLOSS,QPWR,QCK,
     X XN
      WRITEOUTPUTTAPE9,10,LABEL(23),(SDQ(I),I=1,N),SSDQ
      WRITEOUTPUTTAPE9,10,LABEL(24),(QT(I),I=1,N),SQT
      WRITEOUTPUTTAPE9,10,LABEL(5),(    DQ(I),I=1,N)
      WRITEOUTPUTTAPE9,10,LABEL(21),(Q(I),I=1,N),QSUM
      WRITEOUTPUTTAPE9,10,LABEL(13),(DUPWR(I),I=1,N)
      WRITEOUTPUTTAPE9,10,LABEL(19),(DQOUT(I),I=1,N)
      WRITEOUTPUTTAPE9,10,LABEL(3),(DULEAK(I),I=1,N)
      WRITEOUTPUTTAPE9,10,LABEL(4),(DUSUM(I),I=1,N)
      WRITEOUTPUTTAPE9,10,LABEL(18),(SPHT(I),I=1,N)
      WRITEOUTPUTTAPE9,10,LABEL(2),(U(I),I=1,N)
      WRITEOUTPUTTAPE9,12
C
      INCPT=1
  431 IF(SENSELIGHT2)432,433
  432 WRITEOUTPUTTAPE9,5
      GOTO(4321,4322,4323),INCPT
 4321 WRITEOUTPUTTAPE9,13
      GOTO450
 4322 WRITEOUTPUTTAPE9,14
      GOTO450
 4323 WRITEOUTPUTTAPE9,15
      GOTO450
  433 INCPT=INCPT+1
  437 IF(PRINT-PNTMAX)434,432,432
  434 INCPT=INCPT+1
      IF(TIME-TIMAX)435,432,432
  435 IF(SENSELIGHT1)436,100
  436 WRITEOUTPUTTAPE9,7
  450 CALL CLOCK(TEND,TBCD)
      TRUN=TEND-TSTART
      WRITEOUTPUTTAPE9,9,TRUN
      WRITEOUTPUTTAPE9,12
      WRITEOUTPUTTAPE9,10,LABEL(22),(QMAX(I),I=1,N)
      GOTO50
      END
```

```
*     LABEL
CPWR2B
C     THIS IS THE FORTRAN II DECK FOR NEK-2 FUNCTION PWR.
      FUNCTION PWR(KPWR)
C
C     KPWR=1,  PWR RISES EXPONENTIALLY.  PWR(T)=TPWR(1)*EXP(TPWR(2)*T)
C     KPWR=2,  READ POWER PROFILE IN MW, INTERPOLATE AND CONVERT TO ERG/GM-SEC
C              CONVERSION FACTOR.. PWR=PWR*TPWR(1)
C     KPWR=3,  ALLOWED ONLY AFTER PROPER PROFILE IS IN STORAGE.
C     KPWR=4,  PULSE CENTER REGION AT TPWR(1)*DT THEN PWR(T)=0.0.
C     KPWR=5  NOT AN INPUT PARAMETER, ASSOCIATED WITH KPWR=4
C     KPWR=6,  POWER CONSTANT.  PWR(T)=TPWR(1).
C     KPWR=7,  NOT AN INPUT PARAMETER.  ASSOCIATED WITH KPWR=5 AND 6.
C
      DIMENSION IDENT(12),LABEL(24),IR(8),RIR(8),RHO(8),XK(8),
     1 R(200),XMASS(200),VR(200),   FE(200),DUDT(200),IQ(200),Q(200),
     2 DUSUM(200),U(200),TPWR(6),XKR(200),R4(200),          DQ(200),
     3 DUPWR(200),DULEAK(200),SPHT(200),DQOUT(200),QMAX(200)
      DIMENSION T(500),P(500),W(500),G(1000),PVR(3)
C
      COMMON IDENT,LABEL,IR,RIR,RHO,XK,R,XMASS,VR,
     1    FE,DUDT,DUSUM,U,JR,NR,N,UAI,     DT,UVAP,XKR,R4,DQ,
     2 TIME,XN,TPWR,       DUPWR,DULEAK,SPHT,DQOUT,IQ,Q,QMAX,UQ
C
  100 FORMAT(21HOPOWER TABLE FAILURE.  I4//)
C
C     KPWR=INTERNAL SIGNAL,  I=RADIUS,  IRR=REGION...
C
    1 GOTO(11,12,13,14,15,16,17),KPWR
   11 PWR=TPWR(1)*EXPF(TPWR(2)*TIME)
      RETURN
   12 CALL BINRD(1,JT,T,1,500)
      CALL BINRD(1,JP,P,1,500)
      IF(JT-JP)20,21,20
   20 IERR=3
   23 WRITEOUTPUTTAPE9,100,IERR
      SENSELIGHT2
      GOTO31
   21 IF(JT-501)24,22,22
   22 IERR=2
      JT=500
      GOTO23
   24 JX=JT-23
      DO30I=JX,JT
   25 IF(T(I))30,26,30
   26 NN=I-1
      GOTO32
   30 CONTINUE
   31 NN=JT
   32 KPWR=3
      CALL SORT1(NN,1,T,G,P)
      CALL SPLIN1(T,P,NN,W,G,2,1.0,1.0)
   13 CALL SPLIN2(T,P,NN,W,TIME,PVR)
      PWR=PVR(1)*TPWR(1)
      RETURN
   14 PWR=TPWR(1)
      KPWR=5
      RETURN
   15 PWR=0.0
      KPWR=7
      RETURN
   16 PWR=TPWR(1)
```

```
      KPWR=7
   17 RETURN
      END
```

```
*     LABEL
CRADMAS
C     THIS IS THE FORTRAN II DECK FOR NEK-2 SUBROUTINE RADMAS.
      SUBROUTINE RADMAS(FOR3PI)
C
C     JR=1, READ R, CALCULATE MASS.
C     JR=2, DR=CONST. CALCULATE MASS.
C     JR=3, EQUAL MASS, CALCULATE R.
C
      DIMENSION IDENT(12),LABEL(24),IR(8),RIR(8),RHO(8),XK(8),
     1 R(200),XMASS(200),VR(200),    FE(200),DUDT(200),IQ(200),Q(200),
     2 DUSUM(200),U(200),TPWR(6),XKR(200),R4(200),            DQ(200),
     3 DUPWR(200),DULEAK(200),SPHT(200),DQOUT(200),QMAX(200)
C
      COMMON IDENT,LABEL,IR,RIR,RHO,XK,R,XMASS,VR,
     1    FE,DUDT,DUSUM,U,JR,NR,N,UAI,     DT,UVAP,XKR,R4,DQ,
     2 TIME,XN,TPWR,       DUPWR,DULEAK,SPHT,DQOUT,IQ,Q,QMAX,UQ
C
   11 FORMAT(6E12.7)
C
      GOTO(1,2,3),JR
    1 READINPUTTAPE10,11,(R(I),I=1,N)
      GOTO22
    2 IRA=0
      RA=0.0
   26 DO20J=1,NR
      DR=(RIR(J)-RA)/FLOATF(IR(J)-IRA)
      IA=IRA+1
      IB=IR(J)
      P=0.0
   25 DO21I=IA,IB
      P=P+1.0
   21 R(I)=RA+P*DR
      IRA=IB
   20 RA=RIR(J)
   22 RA3=0.0
      IRR=1
   24 DO23I=1,N
      RB3=R(I)**3
   27 IF(I-IR(IRR))29,29,28
   28 IRR=IRR+1
   29 XMASS(I)=RHO(IRR)*FOR3PI*(RB3-RA3)
   23 RA3=RB3
      RETURN
    3 IRA=0
      RA3=0.0
      B=1.0/3.0
   30 DO31J=1,NR
      RB3=RIR(J)**3
      A=(RB3-RA3)/FLOATF(IR(J)-IRA)
      DMAS=RHO(J)*A*FOR3PI
      IA=IRA+1
      IB=IR(J)
      RA3A=RA3
   32 DO33I=IA,IB
      RA3A=A+RA3A
      R(I)=RA3A**B
   33 XMASS(I)=DMAS
      RA3=RB3
   31 IRA=IB
      RETURN
      END
```

```
*       LABEL
CCP-2
C       THIS IS THE FORTRAN II DECK FOR NEK-2 FUNCTION CP.
        FUNCTION    CP(IRR,UX)
C
        DIMENSION IDENT(12),LABEL(24),IR(8),RIR(8),RHO(8),XK(8),
       1 R(200),XMASS(200),VR(200),    FE(200),DUDT(200),IQ(200),Q(200),
       2 DUSUM(200),U(200),TPWR(6),XKR(200),R4(200),             DQ(200),
       3 DUPWR(200),DULEAK(200),SPHT(200),DQOUT(200),QMAX(200)
C
        COMMON IDENT,LABEL,IR,RIR,RHO,XK,R,XMASS,VR,
       1    FE,DUDT,DUSUM,U,JR,NR,N,UAI,     DT,UVAP,XKR,R4,DQ,
       2 TIME,XN,TPWR,       DUPWR,DULEAK,SPHT,DQOUT,IQ,Q,QMAX,UQ
C
C       IRR=REGION.                         ERG/GM-DEG(K)
C
        GOTO(1,2,2),IRR
      1 CP=4.183E6
        RETURN
      2 IF(UX-3000.0)30,30,20
     20 CP=4.6495E6*UX**0.2027
        RETURN
     30 IF(UX-600.0)50,40,40
     40 CP=2.0237E6*UX**0.3066
        RETURN
     50 IF(UX-250.0)70,70,60
     60 CP=(6.02E4-41.55*UX)*UX-6.775E6
        RETURN
     70 CP=1000.75*UX**1.57
        RETURN
        END
```

```
*       LABEL
CQINT
C       THIS IS THE FORTRAN II DECK FOR NEK-2 SUBROUTINE QINTGL
        SUBROUTINE QINTGL(QINT,IRR,U,LQINT)
        FINTF(UL,UU,P,Q)=P*(UU**(Q+1.0)-UL**(Q+1.0))/(Q+1.0)
        GINTF(UU)=-6.775E6*(UU-250.0)+3.0095E4*((UU*UU)-6.25E4)-
       X 13.8483*((UU*UU)*UU-1.5625E7)
C
        DIMENSION IDENT(12),LABEL(24),IR(8),RIR(8),RHO(8),XK(8),
       1 R(200),XMASS(200),VR(200),    FE(200),DUDT(200),IQ(200),Q(200),
       2 DUSUM(200),U(200),TPWR(6),XKR(200),R4(200),            DQ(200),
       3 DUPWR(200),DULEAK(200),SPHT(200),DQOUT(200),QMAX(200)
C
        COMMON IDENT,LABEL,IR,RIR,RHO,XK,R,XMASS,VR,
       1    FE,DUDT,DUSUM,U,JR,NR,N,UAI,     DT,UVAP,XKR,R4,DQ,
       2 TIME,XN,TPWR,       DUPWR,DULEAK,SPHT,DQOUT,IQ,Q,QMAX,UQ
C
        FREQUENCY 2(1,100),3(0,0,100),4(1,0,0),5(1,0,0),202(0,0,100),
       1 21(1,0,10),31(10,0,1)
C
        GOTO(1,2,2),IRR
      1 QINT=4.183E6*(U-UAI)
        RETURN
      2 GOTO(201,202),LQINT
    201 XA=FINTF(100.0,250.0,1000.75,1.57)
        XB=GINTF(600.0)
        XC=FINTF(600.0,3000.0,2.0237E6,0.3066)
      3 IF(UAI-250.0)220,220,221
    220 XAI=FINTF(100.0,UAI,1000.75,1.57)
        GOTO226
    221 XAI=XA
      4 IF(UAI-600.0)222,222,223
    222 XAI=XAI+GINTF(UAI)
        GOTO226
    223 XAI=XAI+XB
      5 IF(UAI-3000.0)224,224,225
    224 XAI=XAI+FINTF(600.0,UAI,2.0237E6,0.3066)
        GOTO226
    225 XAI=XAI+XC+FINTF(3000.0,UAI,4.6495E6,0.2027)
    226 LQINT=2
C
    202 IF(U-250.0)15,15,20
     15 QINT=FINTF(100.0,U,1000.75,1.57)-XAI
        RETURN
     20 QINT=XA
     21 IF(U-600.0)25,25,30
     25 QINT=QINT+GINTF(U)-XAI
        RETURN
     30 QINT=QINT+XB
     31 IF(U-3000.0)35,35,40
     35 QINT=QINT+FINTF(600.0,U,2.0237E6,0.3066)-XAI
        RETURN
     40 QINT=QINT+XC+FINTF(3000.0,U,4.6495E6,0.2027)-XAI
        RETURN
        END
```

XI

NEK-IV SAMPLE PROBLEM (UHTREX)

The problem here illustrated examines the behavior of the fuel beads of the UHTREX system at Los Alamos.* The fuel elements consist of an extruded mixture of graphite and fuel beads. The beads are coated spheres of UC_2. The UC_2 diameter varies from about 149 to 210 microns, and each bead is coated with about 100 microns of a pyrolytic carbon. The beads occupy about 20% of the fuel element volume.

To complete a spherical system for calculation we add enough graphite to an outer spherical shell of such dimensions as to be four times the fuel bead volume.

The power profile of this problem was generated by the L.A.S.L. RTS[2] code for a step input of about $10.0 over delayed critical. The magnitude of the "burst" was normalized to yield a Megawatts-total-power vs time curve for a homogeneous water-moderated reactor. The factor $TPWR_1$ converts

*The fuel elements are assumed to be subjected to abnormally high nuclear power transient conditions.

Megawatts-total-power to ergs/gm-sec in UC_2.

The various parameters of the problem are listed on the following pages as input data.

```
T        SUBTYPE,DATA
CUNST TEMP  DULEAKDUSUM E-DISTK-BNDYBNDRYSDENSTYK-MTRLR      MASS  VOL-R  CARD A } Labels
DUPWR 16PI/MR**4  MISC. PWR-CFSP HT DQ DUTE-FRACQ SUM Q-MAX SUM-Q Q-INTL CARD B }
IUHTREX FUEL PROBLEM.    APPROX $10.0 TRANSIENT                           CARD 1 }
    3     3     1     2                                                   CARD 2 }
    4     8    11                                                         CARD 3 }
 9       -03 190       -02 325       -02                                  CARD 4 }
 105     +01 2         +00 16        +00                                  CARD 5 }
 4       +06 4         +05 1         +07                                  CARD 6 } Input Parameters
 3632    +07                                                              CARD 7 }
 21      -01 21        -01 21        -01 21        -01 13        -01 2        -02 CARD 8A }
 1       -02 0         +00 0         +00 0         +00 0         +00 0        +00 CARD 8B }
 293     +02 8159      -03 1         -06 1789      -02 1         -01 4500     +04 CARD 9 }
 2       +00 1000      +03 300       +02 0         +00 4         +03          CARD 10 }
  176                                                                    Power  Profile (176 points)
  0.              9.5989834E-05 1.9197957E-04 2.8796920E-04 3.8395872E-04
  4.7994825E-04 5.7593777E-04 6.7192729E-04 7.6791682E-04 8.6390634E-04
  9.5989586E-04 1.0558848E-03 1.1518736E-03 1.2478624E-03 1.3438512E-03
  1.4398400E-03 1.5358288E-03 1.6318176E-03 1.7278064E-03 1.8237952E-03
  1.9197840E-03 2.0157718E-03 2.1117592E-03 2.2077465E-03 2.3037339E-03
  2.3997212E-03 2.4957086E-03 2.5916959E-03 2.6876832E-03 2.7836706E-03
  2.8796579E-03 2.9756452E-03 3.0716326E-03 3.1676199E-03 3.2636073E-03
  3.3595946E-03 3.4555820E-03 3.5515693E-03 3.6475567E-03 3.7435440E-03
  3.8395313E-03 3.9355177E-03 4.0315021E-03 4.1274865E-03 4.2234709E-03
  4.3194554E-03 4.4154400E-03 4.5114244E-03 4.6074088E-03 4.7033931E-03
  4.7993777E-03 4.8953620E-03 4.9913464E-03 5.0873309E-03 5.1833153E-03
  5.2792999E-03 5.3752843E-03 5.4712687E-03 5.5672530E-03 5.6632376E-03
  5.7592219E-03 5.8552063E-03 5.9511909E-03 6.0471752E-03 6.1431597E-03
  6.2391440E-03 6.3351285E-03 6.4311129E-03 6.5270975E-03 6.6230819E-03
  6.7190663E-03 6.8150508E-03 6.9110351F-03 7.0070196F-03 7.1030039E-03
  7.1989884E-03 7.2949728E-03 7.3909574E-03 7.4869418E-03 7.5829262E-03
  7.6789107F-03 7.7748950E-03 7.8708795E-03 7.9668636E-03 8.0628482E-03
  8.1588328F-03 8.2548169E-03 8.3508015E-03 8.4467859E-03 8.5427704E-03
  8.6387546E-03 8.7347392E-03 8.8307236F-03 8.9267081E-03 9.0226927E-03
  9.1186768E-03 9.2146614E-03 9.3106458E-03 9.4066303E-03 9.5026145E-03
  9.5985991E-03 9.6945835E-03 9.7905680E-03 9.8865526E-03 9.9825368E-03
  1.0078521E-02 1.0174506E-02 1.0270490E-02 1.0366475E-02 1.0462459E-02
  1.0558444E-02 1.0654428E-02 1.0750412E-02 1.0846397E-02 1.0942381E-02
  1.1038366E-02 1.1134350E-02 1.1230335E-02 1.1326319E-02 1.1422303E-02
  1.1518288E-02 1.1614272E-02 1.1710257E-02 1.1806241E-02 1.1902226E-02
  1.1998978E-02 1.2369312E-02 1.2566228E-02 1.2715231E-02 1.2848382E-02
  1.2963564F-02 1.3078745E-02 1.3193926E-02 1.3306030E-02 1.3402020E-02
  1.3498005E-02 1.3593989E-02 1.3689974F-02 1.3785959E-02 1.3881942E-02
  1.3977927E-02 1.4073911E-02 1.4169896E-02 1.4265880E-02 1.4361865E-02
  1.4457849E-02 1.4553834E-02 1.4649818E-02 1.4745802E-02 1.4841787E-02
  1.4937771E-02 1.5033756E-02 1.5129740E-02 1.5225725E-02 1.5321709E-02
  1.5417693F-02 1.5513678E-02 1.5609662E-02 1.5705637E-02 1.5801610E-02
  1.5897582F-02 1.5993555E-02 1.6089528E-02 1.6185501E-02 1.6281474E-02
  1.6377446E-02 1.6473419E-02 1.6569392E-02 1.6665365E-02 1.6761338E-02
  1.6866338E-02 1.7009207E-02 1.7235944E-02 1.7888001E-02 3.6212067E-02
  7.6249340E-02                                                          Time (seconds)
  4.8000000F-07 6.4102988E-07 8.5146466E-07 1.1264622E-06 1.4858309E-06
  1.9554564E-06 2.5691670E-06 3.3711688E-06 4.4192322E-06 5.7888494E-06
  7.5786785E-06 9.9176420E-06 1.2974221E-05 1.6968589E-05 2.2188459E-05
  2.9009840E-05 3.7924078E-05 4.9573289F-05 6.4796593E-05 8.4690518E-05
  1.1068812E-04 1.4466201E-04 1.8905939E-04 2.4707835E-04 3.2289795E-04
  4.2197980E-04 5.5146087E-04 7.2066787F-04 9.4178941E-04 1.2307527F-03
  1.6083729E-03 2.1018505E-03 2.7467313F-03 3.5894682E-03 4.6907638E-03
  6.1299471E-03 8.0106870E-03 1.0468452E-02 1.3680785E-02 1.7877537E-02
  2.3362544E-02 3.0530408E-02 3.9897425E-02 5.2138339E-02 6.8134882E-02
  8.9039298E-02 1.1635742E-01 1.5205695E-01 1.9870346E-01 2.5967542E-01
  3.3934619E-01 4.4346080E-01 5.7951871E-01 7.5732042E-01 9.8967358F-01  Power(megawatts)
```

Power(megawatts) (cont.)

1.2933145E 00	1.6901155E 00	2.2086587E 00	2.8862952E 00	3.7718379E 00
4.9290720E 00	6.4413574E 00	8.4176264E 00	1.1000231E 01	1.4375205E 01
1.8785650E 01	2.4549257E 01	3.2081200E 01	4.1923999E 01	5.4786667E 01
7.1595718E 01	9.3561908E 01	1.2226756E 02	1.5978030E 02	2.0880229E 02
2.7286462E 02	3.5658171E 02	4.6598386E 02	6.0895122E 02	7.9578171E 02
1.0399328E 03	1.3589897E 03	1.7759337E 03	2.3207952E 03	3.0328165E 03
3.9632798E 03	5.1791922E 03	6.7681183E 03	8.8444723E 03	1.1557750E 04
1.5103287E 04	1.9736277E 04	2.5790121E 04	3.3700331E 04	4.4035726E 04
5.7539181E 04	7.5180575E 04	9.8225913E 04	1.2832713E 05	1.6763856E 05
2.1896842E 05	2.8597384E 05	3.7341272E 05	4.8746687E 05	6.3615257E 05
8.2984177E 05	1.0819114E 06	1.4095422E 06	1.8346821E 06	2.3851630E 06
3.0959381E 06	4.0103295E 06	5.1810713E 06	6.6707730E 06	8.5511363E 06
1.0899963E 07	1.3794605E 07	1.7300179E 07	2.1451105E 07	2.6225578E 07
3.1515169E 07	3.7096432E 07	4.2616876E 07	4.7610984E 07	5.1558359E 07
5.3993695E 07	4.6338733E 07	3.5283647E 07	2.6863427E 07	2.0301945E 07
1.5602684E 07	1.1815153E 07	8.8474269E 06	6.6228331E 06	5.1438956E 06
3.9818667E 06	3.0744384E 06	2.3691697E 06	1.8230122E 06	1.4012479E 06
1.0762409E 06	8.2620517E 05	6.3408790E 05	4.8661525E 05	3.7349620E 05
2.8677706E 05	2.2032551E 05	1.6942149E 05	1.3043738E 05	1.0058769E 05
7.7735578E 04	6.0242581E 04	4.6853085E 04	3.6605161E 04	2.8762089E 04
2.2759743E 04	1.8166234E 04	1.4650956E 04	1.1960825E 04	9.9021573E 03
8.3267206E 03	7.1210681E 03	6.1983832E 03	5.4922299E 03	4.9517649E 03
4.5380847E 03	4.2214261E 03	3.9790113E 03	3.7933966E 03	3.6512440E 03
3.5348119E 03	3.4207595E 03	3.3111246E 03	3.2047222E 03	3.0940398E 03
2.9102135E 03				

```
UHTREX FUEL PROBLEM.   APPROX $10.0 TRANSIENT
                                                                        NEK-4, NECKLACE.

   3      3      4      8     11
BNDRYS  9.000000E-03  1.900000E-02  3.250000E-02
DENSTY  1.050C00E+01  2.000000E+00  1.600C0CE+00
K-MTRL  4.000000E+06  4.000000E+05  1.000C00E+07
R       5.669645E-03  7.143305E-03  8.177043E-03  9.000000E-03  1.312599E-02  1.559669E-02  1.746414E-02  1.900000E-02
        2.520649E-02  2.930698E-02  3.250000E-02
R**4    1.033293E-09  2.603735E-09  4.470798E-09  6.561000E-09  2.968444E-08  5.917384E-08  9.3C2276E-08  1.303210E-07
        4.036914E-07  7.377081E-07  1.115664E-06
MASS    8.015774E-06  8.015774E-06  8.015774E-06  8.015774E-06  1.283864E-05  1.283864E-05  1.283864E-05  1.283864E-05
        6.136661E-05  6.136661E-05  6.136661E-05
VOL-R   1.005976E-06  7.813989E-07  7.708498E-07  3.017967E-06  6.735579E-06  6.513627E-06  6.465318E-06  1.984700E-05
        3.958919E-05  3.880409E-05  2.016689E-05
K-BNDY  4.000000E+06  4.000000E+06  4.000000E+06  7.826214E+05  4.000000E+05  4.000000E+05  4.0C0000E+05  8.623616E+06
        1.000000E+07  1.000000E+07  1.000C00E+07
PWR-CF  3.632000E+07   .000000E 0C   .000C00E 00   .000000E 00   .000000E 00   .000000E 00
E-FRAC  2.100000E-01  2.100000E-01  2.100000E-01  2.100000E-01  1.300000E-01  2.000000E-02  1.0C0000E-02   .000000E 00
         .000000E 00   .000000E 00   .000C00E 0C
MISC.   1.000000E-06  2.930000E+02  8.159C00E-03   .000000E 00  3.206309E-05  4.000000E+03


CONST   8.160000E-03  1.000000E+00  1.444154E+11  4.630406E+00   .000000E 00  4.630406E+00  4.630161E+00  1.000000E+00

SUM-Q   9.723853E-01  9.723853E-01  9.723853E-01  9.723853E-01  6.019528E-01  9.260812E-02  4.630406E-02   .000000E 00
         .000000E 00   .000000E 00   .000000E 00  4.630406E+00
Q-INTL  9.723853E-01  9.723853E-01  9.723853E-01  9.663200E-01  6.063068E-01  9.380624E-02  4.612278E-02  4.490675E-04
         .000000E 00   .000000E 00   .000000E 00  4.630161E+00
E-DIST  9.723853E-01  9.723853E-01  9.723853E-01  9.723853E-01  6.019528E-01  9.260812E-02  4.630406E-02   .000000E 00
         .000000E 00   .000000E 00   .000C00E 00
Q SUM    .00000CE 00   .000000E 00   .000000E 00   .000000E 00   .000000E 00   .000000E 00   .0C0000E 00   .000000E 00
         .000000E 00   .000000E 00   .000C00E 00   .000000E 00
DUPWR   2.900047E-02  2.900047E-02  2.900C47E-02  2.900047E-02  6.425758E-03  9.885781E-04  4.942891E-04   .000000E 00
         .000C00E 00   .000000E 00   .000C00E 00
DQ OUT   .000000E 00   .C00000E 00   .000000E 00 -6.065257E+03 -1.513587E+03 -2.836401E+02 -4.492211E+02   .000C00E 00
         .000000E 00   .000000E 00   .000000E 0C
DULEAK   .00000CE 00  -.000000E 00  -.000CCCE 0C -1.808906E-04  4.858688E-05  1.312943E-05 -1.767548E-06  4.795369E-06
        -.000000E 00  -.000000E 00  -.000C0CE 00
DUSUM   2.900047E-02  2.900047E-02  2.900047E-02  2.881958E-02  6.474345E-03  1.001708E-03  4.925215E-04  4.795369E-06
         .000C00E 00   .000000E 00   .000000E 0C
SP HT   4.183C00E+06  4.183000E+06  4.183C0CE+06  4.183000E+06  7.296804E+06  7.296609E+06  7.296592E+06  7.296574E+06
        7.296574E+06  7.296574E+06  7.296574E+06
TEMP    2.930290E+02  2.930290E+02  2.930290E+02  2.930288E+02  2.930065E+02  2.930010E+02  2.930005E+02  2.930000E+02
        2.930000E+02  2.930000E+02  2.930000E+02


CONST   8.161000E-03  2.C00000E+00  1.448186E+11  4.643332E+00   .000000E 00  9.273738E+00  9.273245E+00  2.000000E+00

SUM-Q   1.947485E+00  1.947485E+00  1.947485F+0C  1.947485E+00  1.205586E+00  1.854748E-01  9.273738E-02   .000000E 00
         .000000E 00   .C0000E 00   .000000E 00  9.273738E+00
Q-INTL  1.947485E+00  1.947485E+00  1.946822E+00  1.929997E+00  1.218785E+00  1.891051E-01  9.222329E-02  1.299628E-03
        4.286374E-05   .000000E 00   .000000E 00  9.273245E+00
E-DIST  9.750997E-01  9.750997E-01  9.750997E-01  9.750997E-01  6.036331E-01  9.286664E-02  4.643332E-02   .000000E 00
         .C00000E 00   .000000E 00   .000C0CE 00
Q SUM    .00000CE 00   .C00000E 00   .000C00E 00   .000000E 00   .000000E 00   .000000E 00   .0C0000E 00   .000C00E 00
         .000C00E 00   .000000E 00   .000000E 00   .000000E 00
DUPWR   2.908143E-02  2.908143E-02  2.908143E-02  2.908143E-02  6.443490E-03  9.913328E-04  4.956677E-04   .000000E 00
         .000C0CE 00   .000000E 00   .000C00F 00
DQ OUT   .00000CE 00   .000000E 00 -6.626908E+02 -1.208585E+04 -3.041213E+03 -5.766182E+02 -8.937305E+02 -4.287960E+01
         .00000CE 0C   .000000E 00   .000C00E 0C
```

DULEAK	.000000E 00	-.000000E 00	-1.976413E-05	-3.406848E-04	9.654400E-05	2.630893E-05	-3.385110E-06	9.082708E-06
	9.576341E-08	-.000000E 00	-.000000E 00					
DUSUM	5.808190E-02	5.808190E-02	5.806213E-02	5.756032E-02	1.301438E-02	2.019349E-03	9.848041E-04	1.387808E-05
	9.576341E-08	.000000E 00	.000000E 00					
SP HT	4.183000E+06	4.183000E+06	4.183000E+06	4.183000F+06	7.297037E+06	7.296646E+06	7.296609F+06	7.296574E+06
	7.296574E+06	7.296574E+06	7.296574E+06					
TEMP	2.930581E+02	2.930581E+02	2.930581E+02	2.930576E+02	2.930130E+02	2.930020E+02	2.930010E+02	2.930000E+02
	2.930000E+02	2.930000E+02	2.930000E+02					
CONST	9.159000E-03	3.000000E+00	2.338286E+12	7.497267E+01	.000000E 00	2.527977E+04	2.527726E+04	1.000000E+03
SUM-Q	5.308752E+03	5.308752E+03	5.308752E+03	5.308752F+03	3.286370E+03	5.055954E+02	2.527977E+02	.000000E 00
	.000000E 00	.000000E 00	.000000E 00	2.527977E+04				
Q-INTL	4.245818E+03	4.063035E+03	3.941742E+03	3.831465E+03	5.477576E+03	1.700609E+03	6.520653E+02	1.433294E+02
	4.649677E+02	3.883696E+02	3.682829E+02	2.527726E+04				
E-DIST	1.574426E+01	1.574426E+01	1.574426E+01	1.574426E+01	9.746447E+00	1.499453E+00	7.497267E-01	.000000E 00
	.000000E 00	.000000E 00	.000000E 00					
Q SUM	.000000E 00	.000000E 00	.000000E 00	.000000E 00	.000000E 00	.000000E 00	.000000E 00	.000000E 00
	.000000E 00	.000000E 00	.000000E 00	.000000E 00				
DUPWR	4.695577E-01	4.695577E-01	4.695577E-01	4.695577E-01	8.391299E-02	1.477089E-02	7.745423E-03	.000000E 00
	.000000E 00	.000000E 00	.000000E 00					
DQ OUT	-3.526435E+06	-7.591430E+06	-1.201345E+07	-1.675986E+07	-9.643812E+06	-6.055607E+06	-4.831289E+06	-4.357224E+06
	-2.734717E+06	-1.337710E+06	.000000E 00					
DULEAK	-1.051726E-01	-1.212346E-01	-1.318825E-01	-1.415574E-01	6.124842E-02	3.534460E-02	1.264797E-02	5.023128E-03
	3.605291E-03	3.106793E-03	2.975570E-03					
DUSUM	1.266275E+02	1.211762E+02	1.175587E+02	1.142698E+02	5.209291E+01	1.742403E+01	6.848448E+00	1.524836E+00
	1.036136E+00	8.658051E-01	8.211149E-01					
SP HT	4.183000E+06	4.183000E+06	4.183000E+06	4.183000E+06	9.049509E+06	7.907425E+06	7.539708E+06	7.350566E+06
	7.333548E+06	7.327472E+06	7.325878E+06					
TEMP	4.196275E+02	4.141762E+02	4.105587E+02	4.072698E+02	3.450929E+02	3.104240E+02	2.998484E+02	2.945248E+02
	2.940361E+02	2.938658E+02	2.938211E+02					
CONST	1.015900E-02	4.000000E+00	3.764832E+13	1.207122E+03	.000000E 00	4.340152E+05	4.340043E+05	2.000000E+03
SUM-Q	9.114319E+04	9.114319E+04	9.114319E+04	9.114319E+04	5.642197E+04	8.680304E+03	4.340152E+03	.000000E 00
	.000000E 00	.000000E 00	.000000E 00	4.340152E+05				
Q-INTL	6.859388E+04	6.517674E+04	6.291357E+04	6.085876E+04	1.151806E+05	2.795428E+04	9.643747E+03	2.248348E+03
	7.889051E+03	6.901867E+03	6.643492E+03	4.340043E+05				
E-DIST	2.534956E+02	2.534956E+02	2.534956E+02	2.534956E+02	1.569258E+02	2.414243E+01	1.207122E+01	.000000E 00
	.000000E 00	.000000E 00	.000000E 00					
Q SUM	.000000E 00	.000000E 00	.000000E 00	.000000E 00	.000000E 00	.000000E 00	.000000E 00	.000000E 00
	.000000E 00	.000000E 00	.000000E 00	.000000E 00				
DUPWR	7.560265E+00	7.560265E+00	7.560265E+00	7.560265E+00	7.382806E-01	1.450873E-01	9.339394E-02	.000000E 00
	.000000E 00	.000000E 00	.000000E 00					
DQ OUT	-6.593232E+07	-1.416579E+08	-2.238663E+08	-3.119586E+08	-1.247636E+08	-7.028732E+07	-5.744267E+07	-5.200692E+07
	-3.290990E+07	-1.615078E+07	.000000E 00					
DULEAK	-1.966369E+00	-2.258445E+00	-2.451787E+00	-2.627270E+00	8.804763E-01	3.273150E-01	9.935145E-02	5.234001E-02
	3.944046E-02	3.492446E-02	3.373714E-02					
DUSUM	2.045748E+03	1.943835E+03	1.876338E+03	1.815055E+03	6.574615E+02	2.087264E+02	8.601129E+01	2.275869E+01
	1.692968E+01	1.488139E+01	1.434222E+01					
SP HT	4.183000E+06	4.183000E+06	4.183000E+06	4.183000E+06	1.655989E+07	1.296351E+07	1.006999E+07	8.089213E+06
	7.890264E+06	7.819687E+06	7.801051E+06					
TEMP	2.338748E+03	2.236835E+03	2.169338E+03	2.108055E+03	9.504615E+02	5.017264E+02	3.790113E+02	3.157587E+02
	3.099297E+02	3.078814E+02	3.073422E+02					
CONST	1.115900E-02	5.000000E+00	5.315272E+14	1.704241E+04	.000000E 00	6.595867E+06	6.596010E+06	3.000000E+03
SUM-Q	1.385132E+06	1.385132E+06	1.385132E+06	1.385132E+06	8.574628E+05	1.319173E+05	6.595867E+04	.000000E 00
	.000000E 00	.000000E 00	.000000E 00	6.595867E+06				

Q-INTL	1.242956E+05	1.242956E+05	1.242956E+05	1.242956E+05	9.519885E+05	2.860889E+05	1.056298E+05	2.097855E+04
	7.115055E+04	6.161411E+04	5.916630E+04	2.053799E+06				
E-DIST	3.578905E+03	3.578905E+03	3.578905E+03	3.578905E+03	2.215513E+03	3.408481E+02	1.704241E+02	.000000E 00
	.000000E 00	.000000E 00	.000000E 00					
Q SUM	1.217127E+06	1.205972E+06	1.191786E+06	9.273249E+05	.000000E 00	.000000E 00	.000000E 00	.000000E 00
	.000000E 00	.000000E 00	.000000E 00	4.542210E+06				
DUPWR	.000000E 00	.000000E 00	.000000E 00	.000000E 00	6.927246E+00	1.346436E+00	8.137137E-01	.000000E 00
	.000000E 00	.000000E 00	.000000E 00					
DQ OUT	.000000E 00	.000000E 00	.000000E 00	-1.207784E+07	-6.335418E+08	-4.442454E+08	-4.061603E+08	-3.648844E+08
	-2.285920E+08	-1.118161E+08	.000000E 00					
DULEAK	-3.661184E+00	-3.569662E+00	-3.601717E-01	-1.477189E+00	-1.942442E+00	7.475844E-01	1.817925E-01	2.660578E-01
	1.998782E-01	1.771664E-01	1.712364E-01					
DUSUM	3.707000E+03	3.707000E+03	3.707000E+03	3.707000E+03	3.660104E+03	1.386954E+03	6.122184E+02	1.653944E+02
	1.245220E+02	1.103032E+02	1.065727E+02					
SP HT	4.183000E+06	4.183000E+06	4.183000E+06	4.183000E+06	2.492005E+07	1.972255E+07	1.631774E+07	1.208375E+07
	1.111154E+07	1.074087E+07	1.064085E+07					
TEMP	4.000000E+03	4.000000E+03	4.000000E+03	4.000000E+03	3.953104E+03	1.679954E+03	9.052184E+02	4.583944E+02
	4.175220E+02	4.033032E+02	3.995727E+02					

CONST	1.215900E-02	6.000000E+00	1.948593E+15	6.247793E+04	.000000E 00	5.095553E+07	5.095589E+07	4.000000E+03
SUM-Q	1.070066E+07	1.070066E+07	1.070066E+07	1.070066E+07	6.624218E+06	1.019111E+06	5.095553E+05	.000000E 00
	.000000E 00	.000000E 00	.000000E 00	5.095553E+07				
Q-INTL	1.242956E+05	1.242956E+05	1.242956E+05	1.242956E+05	9.670088E+05	8.653397E+05	4.163901E+05	9.555961E+04
	3.382767E+05	2.971720E+05	2.864051E+05	3.763335E+06				
E-DIST	1.312036E+04	1.312036E+04	1.312036E+04	1.312036E+04	8.122130E+03	1.249559E+03	6.247793E+02	.000000E 00
	.000000E 00	.000000E 00	.000000E 00					
Q SUM	1.053266E+07	1.052150E+07	1.050731E+07	1.024281E+07	5.388279E+06	.000000E 00	.000000E 00	.000000E 00
	.000000E 00	.000000E 00	.000000E 00	4.719255E+07				
DUPWR	.000000E 00	.000000E 00	.000000E 00	.000000E 00	.000000E 00	3.963351E+00	2.280069E+00	.000000E 00
	.000000E 00	.000000E 00	.000000E 00					
DQ OUT	.000000E 00	.000000E 00	.000000E 00	.000000E 00	-8.830999E+07	-8.653208E+08	-1.198311E+09	-1.100532E+09
	-7.112173E+08	-3.516018E+08	.000000E 00					
DULEAK	-3.661184E+00	-3.569662E+00	-3.601717E-01	-1.477189E+00	-1.646110E+00	-2.463986E+00	-1.214822E+00	4.747213E-01
	4.147109E-01	3.904416E-01	3.837528E-01					
DUSUM	3.707000E+03	3.707000E+03	3.707000E+03	3.707000E+03	3.707000E+03	3.387305E+03	1.880591E+03	5.637500E+02
	4.406138E+02	3.964214E+02	3.847029E+02					
SP HT	4.183000E+06	4.183000E+06	4.183000E+06	4.183000E+06	2.497720E+07	2.456234E+07	2.135007E+07	1.604299E+07
	1.529760E+07	1.500894E+07	1.493026E+07					
TEMP	4.000000E+03	4.000000E+03	4.000000E+03	4.000000E+03	4.000000E+03	3.680305E+03	2.173591E+03	8.567500E+02
	7.336138E+02	6.894214E+02	6.777029E+02					

CONST	1.315900E-02	7.000000E+00	3.511478E+14	1.125888E+04	.000000E 00	8.695261E+07	8.695321E+07	5.000000E+03
SUM-Q	1.826005E+07	1.826005E+07	1.826005E+07	1.826005E+07	1.130384E+07	1.739052E+06	8.695261E+05	.000000E 00
	.000000E 00	.000000E 00	.000000E 00	8.695261E+07				
Q-INTL	1.242956E+05	1.242956E+05	1.242956E+05	1.242956E+05	9.670088E+05	8.009953E+05	4.364471E+05	1.704261E+05
	7.056279E+05	6.649713E+05	6.540447E+05	4.896704E+06				
E-DIST	2.364366E+03	2.364366E+03	2.364366E+03	2.364366E+03	1.463655E+03	2.251777E+02	1.125888E+02	.000000E 00
	.000000E 00	.000000E 00	.000000E 00					
Q SUM	1.809204E+07	1.808089E+07	1.806670E+07	1.780219E+07	1.001469E+07	.000000E 00	.000000E 00	.000000E 00
	.000000E 00	.000000E 00	.000000E 00	8.205651E+07				
DUPWR	.000000E 00	.000000E 00	.000000E 00	.000000E 00	.000000E 00	7.224701E-01	4.066637E-01	.000000E 00
	.000000E 00	.000000E 00	.000000E 00					
DQ OUT	.000000E 00	.000000E 00	.000000E 00	.000000E 00	-1.456324E+08	-7.055634E+08	-9.513598E+08	-9.048685E+08
	-6.196236E+08	-3.126444E+08	.000000E 00					
DULEAK	-3.661184E+00	-3.569662E+00	-3.601717E-01	-1.477189E+00	-1.646110E+00	-1.796432E+00	-8.877516E-01	2.035051E-01
	2.683701E-01	2.919912E-01	2.982806E-01					
DUSUM	3.707000E+03	3.707000E+03	3.707000E+03	3.707000E+03	3.707000E+03	3.182056E+03	1.953405E+03	9.076918E+02
	8.065622E+02	7.681058E+02	7.576979E+02					

```
SP HT    4.183000E+06  4.183000E+06  4.183000E+06  4.183000E+06  2.497720E+07  2.427754E+07  2.156577E+07  1.779415E+07
         1.732015E+07  1.713196E+07  1.708022E+07
TEMP     4.000000E+03  4.000000E+03  4.000000E+03  4.000000E+03  4.000000E+03  3.475056E+03  2.246405E+03  1.200692E+03
         1.099562E+03  1.061106E+03  1.050698E+03


CONST    1.415900E-02  8.000000E+00  2.373257E+13  7.609395E+02   .000000E 00  9.091218E+07  9.091283E+07  6.000000E+03

SUM-Q    1.909156E+07  1.909156E+07  1.909156E+07  1.909156E+07  1.181858E+07  1.818244E+06  9.091218E+05   .000000E 00
          .000000E 00   .000000E 00   .000000E 00  9.091218E+07
Q-INTL   1.242956E+05  1.242956E+05  1.242956E+05  1.242956E+05  9.670088E+05  5.768860E+05  3.467931E+05  2.041507E+05
         9.141978E+05  8.910504E+05  8.848102E+05  5.282080E+06
E-DIST   1.597973E+02  1.597973E+02  1.597973E+02  1.597973E+02  9.892214E+01  1.521879E+01  7.609395E+00   .000000E 00
          .000000E 00   .000000E 00   .000000E 00
Q SUM    1.892355E+07  1.891240E+07  1.889821E+07  1.863370E+07  1.026288E+07   .000000E 00   .000000E 00   .000000E 00
          .000000E 00   .000000E 00   .000000E 00  8.563075E+07
DUPWR     .000000E 00   .000000E 00   .000000E 00   .000000E 00   .000000E 00  5.173468E-02  2.886538E-02   .000000E 00
          .000000E 00   .000000E 00   .000000E 00
DQ OUT    .000000E 00   .000000E 00   .000000E 00   .000000E 00 -3.512056E+08 -4.725128E+08 -5.174589E+08 -4.904668E+08
        -3.348164E+08 -1.688183E+08   .000000E 00
DULEAK  -3.661184E+00 -3.569662E+00 -3.601717E-01 -1.477189E+00 -1.646110E+00 -4.123689E-01 -1.704969E-01  1.140900E-01
         1.394087E-01  1.494189E-01  1.521643E-01
DUSUM    3.707000E+03  3.707000E+03  3.707000E+03  3.707000E+03  3.707000E+03  2.444970E+03  1.621781E+03  1.052693E+03
         9.978676E+02  9.770847E+02  9.714642E+02
SP HT    4.183000E+06  4.183000E+06  4.183000E+06  4.183000E+06  2.497720E+07  2.291299E+07  2.053316E+07  1.842764E+07
         1.819400E+07  1.810363E+07  1.807901E+07
TEMP     4.000000E+03  4.000000E+03  4.000000E+03  4.000000E+03  4.000000E+03  2.737970E+03  1.914781E+03  1.345693E+03
         1.290868E+03  1.270085E+03  1.264464E+03


CONST    1.515900E-02  9.000000E+00  1.577513E+12  5.057993E+01   .000000E 00  9.117114E+07  9.117179E+07  7.000000E+03

SUM-Q    1.914594E+07  1.914594E+07  1.914594E+07  1.914594E+07  1.185225E+07  1.823423E+06  9.117114E+05   .000000E 00
          .000000E 00   .000000E 00   .000000E 00  9.117114E+07
Q-INTL   1.242956E+05  1.242956E+05  1.242956E+05  1.242956E+05  9.670088E+05  5.321567E+05  3.385482E+05  2.293299E+05
         1.048609E+06  1.030984E+06  1.026255E+06  5.670074E+06
E-DIST   1.062179E+01  1.062179E+01  1.062179E+01  1.062179E+01  6.575391E+00  1.011599E+00  5.057993E-01   .000000E 00
          .000000E 00   .000000E 00   .000000E 00
Q SUM    1.897793E+07  1.896678E+07  1.895259E+07  1.868808E+07  9.916328E+06   .000000E 00   .000000E 00   .000000E 00
          .000000E 00   .000000E 00   .000000E 00  8.550172E+07
DUPWR     .000000E 00   .000000E 00   .000000E 00   .000000E 00   .000000E 00  3.500283E-03  1.928486E-03   .000000E 00
          .000000E 00   .000000E 00   .000000E 00
DQ OUT    .000000E 00   .000000E 00   .000000E 00   .000000E 00 -3.940136E+08 -4.023813E+08 -3.931664E+08 -3.690813E+08
        -2.478762E+08 -1.242677E+08   .000000E 00
DULEAK  -3.661184E+00 -3.569662E+00 -3.601717E-01 -1.477189E+00 -1.646110E+00 -2.895364E-02  3.513428E-02  9.948010E-02
         1.056669E-01  1.081256E-01  1.088014E-01
DUSUM    3.707000E+03  3.707000E+03  3.707000E+03  3.707000E+03  3.707000E+03  2.291576E+03  1.590425E+03  1.157879E+03
         1.116609E+03  1.101218E+03  1.097080E+03
SP HT    4.183000E+06  4.183000E+06  4.183000E+06  4.183000E+06  2.497720E+07  2.251055E+07  2.042880E+07  1.885789E+07
         1.869174E+07  1.862892E+07  1.861194E+07
TEMP     4.000000E+03  4.000000E+03  4.000000E+03  4.000000E+03  4.000000E+03  2.584576E+03  1.883425E+03  1.450879E+03
         1.409609E+03  1.394218E+03  1.390080E+03


CONST    1.615900E-02  1.000000E+01  2.058880E+11  6.601405E+00   .000000E 00  9.119061E+07  9.119127E+07  8.000000E+03

SUM-Q    1.915003E+07  1.915003E+07  1.915003E+07  1.915003E+07  1.185478E+07  1.823812E+06  9.119061E+05   .000000E 00
          .000000E 00   .000000E 00   .000000E 00  9.119061E+07
Q-INTL   1.242956E+05  1.242956E+05  1.242956E+05  1.242956E+05  9.670088E+05  5.369589E+05  3.540984E+05  2.528310E+05
         1.164255E+06  1.147927E+06  1.143553E+06  6.063815E+06
E-DIST   1.386295E+00  1.386295E+00  1.386295E+00  1.386295E+00  8.581826E-01  1.320281E-01  6.601405E-02   .000000E 00
          .000000E 00   .000000E 00   .000000E 00
```

Q SUM	1.898202E+07	1.897087E+07	1.895668E+07	1.869217E+07	9.525707E+06	.000000E 00	.000000E 00	.000000E 00
	.000000E 00	.000000E 00	.000000E 00	8.512745E+07				
DUPWR	.000000E 00	.000000E 00	.000000E 00	.000000E 00	.000000E 00	4.559446E-04	2.493269E-04	.000000E 00
	.000000E 00	.000000E 00	.000000E 00					
DQ OUT	.000000E 00	.000000E 00	.000000E 00	.000000E 00	-3.894115E+08	-3.780276E+08	-3.594139E+08	-3.364217E+08
	-2.247844E+08	-1.124824E+08	.000000E 00					
DULEAK	-3.661184E+00	-3.569662E+00	-3.601717E-01	-1.477189E+00	-1.646110E+00	3.931306E-02	7.030164E-02	9.311655E-02
	9.530622E-02	9.614726E-02	9.637578E-02					
DUSUM	3.707000E+03	3.707000E+03	3.707000E+03	3.707000E+03	3.707000E+03	2.308176E+03	1.649433E+03	1.253983E+03
	1.216363E+03	1.202404E+03	1.198657E+03					
SP HT	4.183000E+06	4.183000E+06	4.183000E+06	4.183000E+06	2.497720E+07	2.255460E+07	2.062283E+07	1.923244E+07
	1.908780E+07	1.903349E+07	1.901886E+07					
TEMP	4.000000E+03	4.000000E+03	4.000000E+03	4.000000E+03	4.000000E+03	2.601176E+03	1.942433E+03	1.546983E+03
	1.509363E+03	1.495404E+03	1.491657E+03					

CONST	1.715900E-02	1.100000E+01	1.213419E+11	3.890595E+00	.000000E 00	9.119530E+07	9.119596E+07	9.000000E+03
SUM-Q	1.915101E+07	1.915101E+07	1.915101E+07	1.915101E+07	1.185539E+07	1.823906E+06	9.119530E+05	.000000E 00
	.000000E 00	.000000E 00	.000000E 00	9.119530E+07				
Q-INTL	1.242956E+05	1.242956E+05	1.242956E+05	1.242956E+05	9.670088E+05	5.502521E+05	3.734354E+05	2.753785E+05
	1.273294E+06	1.257439E+06	1.253192E+06	6.447183E+06				
E-DIST	8.170250E-01	8.170250E-01	8.170250E-01	8.170250E-01	5.057774E-01	7.781191E-02	3.890595E-02	.000000E 00
	.000000E 00	.000000E 00	.000000E 00					
Q SUM	1.898301E+07	1.897185E+07	1.895767E+07	1.869316E+07	9.143092E+06	.000000E 00	.000000E 00	.000000E 00
	.000000E 00	.000000E 00	.000000E 00	8.474877E+07				
DUPWR	.000000E 00	.000000E 00	.000000E 00	.000000E 00	.000000E 00	2.672815E-04	1.452986E-04	.000000E 00
	.000000E 00	.000000E 00	.000000E 00					
DQ OUT	.000000E 00	.000000E 00	.000000E 00	.000000E 00	-3.766689E+08	-3.626241E+08	-3.431457E+08	-3.210274E+08
	-2.142974E+08	-1.071981E+08	.000000E 00					
DULEAK	-3.661184E+00	-3.569662E+00	-3.601717E-01	-1.477189E+00	-1.646110E+00	4.824374E-02	7.274413E-02	8.802915E-02
	8.947452E-02	9.001422E-02	9.015942E-02					
DUSUM	3.707000E+03	3.707000E+03	3.707000E+03	3.707000E+03	3.707000E+03	2.353960E+03	1.722053E+03	1.344496E+03
	1.308596E+03	1.295288E+03	1.291718E+03					
SP HT	4.183000E+06	4.183000E+06	4.183000E+06	4.183000E+06	2.497720E+07	2.267556E+07	2.085622E+07	1.957071E+07
	1.943814E+07	1.938847E+07	1.937509E+07					
TEMP	4.000000E+03	4.000000E+03	4.000000E+03	4.000000E+03	4.000000E+03	2.646960E+03	2.015053E+03	1.637496E+03
	1.601596E+03	1.588288E+03	1.584718E+03					

CONST	1.815900E-02	1.200000E+01	1.157439E+11	3.711108E+00	.000000E 00	9.119906E+07	9.119973E+07	1.000000E+04
SUM-Q	1.915180E+07	1.915180E+07	1.915180E+07	1.915180E+07	1.185588E+07	1.823981E+06	9.119906E+05	.000000E 00
	.000000E 00	.000000E 00	.000000E 00	9.119906E+07				
Q-INTL	1.242956E+05	1.242956E+05	1.242956E+05	1.242956E+05	9.670088E+05	5.643801E+05	3.927206E+05	2.970879E+05
	1.378002E+06	1.362490E+06	1.358334E+06	6.817205E+06				
E-DIST	7.793327E-01	7.793327E-01	7.793327E-01	7.793327E-01	4.824441E-01	7.422217E-02	3.711108E-02	.000000E 00
	.000000E 00	.000000E 00	.000000E 00					
Q SUM	1.898380E+07	1.897264E+07	1.895846E+07	1.869395E+07	8.773675E+06	.000000E 00	.000000E 00	.000000E 00
	.000000E 00	.000000E 00	.000000E 00	8.438252E+07				
DUPWR	.000000E 00	.000000E 00	.000000E 00	.000000E 00	.000000E 00	2.535385E-04	1.371189E-04	.000000E 00
	.000000E 00	.000000E 00	.000000E 00					
DQ OUT	.000000E 00	.000000E 00	.000000E 00	.000000E 00	-3.631970E+08	-3.492867E+08	-3.303424E+08	-3.090335E+08
	-2.062712E+08	-1.031794E+08	.000000E 00					
DULEAK	-3.661184E+00	-3.569662E+00	-3.601717E-01	-1.477189E+00	-1.646110E+00	4.751688E-02	6.999551E-02	8.349152E-02
	8.476136E-02	8.523186E-02	8.535808E-02					
DUSUM	3.707000E+03	3.707000E+03	3.707000E+03	3.707000E+03	3.707000E+03	2.402354E+03	1.793687E+03	1.430217E+03
	1.395658E+03	1.382848E+03	1.379411E+03					
SP HT	4.183000E+06	4.183000E+06	4.183000E+06	4.183000E+06	2.497720E+07	2.280188E+07	2.108081E+07	1.987932E+07
	1.975621E+07	1.971014E+07	1.969774E+07					
TEMP	4.000000E+03	4.000000E+03	4.000000E+03	4.000000E+03	4.000000E+03	2.695354E+03	2.086687E+03	1.723217E+03
	1.688658E+03	1.675848E+03	1.672411E+03					

INCOMPLETE.

EXIT ON TIME

```
Q-MAX    1.898380E+07  1.897264E+07  1.895846E+07  1.869395E+07  1.032159E+07   .000000E 00   .000000E 00   .000000E 00
          .000000E 00   .000000E 00   .000000E 00
B         JOB NO2-CHEZEM   FOX    NO2      5      22462249 1         0806 NO2-CHEZ
```

REFERENCES

1. C. G. Chezem and W. R. Stratton, "RAC, A Computer Program for Reactor Accident Calculations", Los Alamos Scientific Laboratory Report LAMS-2920, January 1963.
2. G. R. Keepin and C. W. Cox, "General Solution of the Reactor Kinetic Equations", Nuclear Science and Engineering, 8, 670-690 (1960).