**HOTANK - A STEADY - STATE HEAT
TRANSFER PROGRAM FOR USE ON THE
UNIVAC 1107 / 1108**

W. E. WILLINGHAM

FEBRUARY 1968

**AEC RESEARCH &
DEVELOPMENT REPORT**

TIME IN	TIME OUT

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

PACIFIC NORTHWEST LABORATORY

RICHLAND, WASHINGTON

operated by

BATTELLE MEMORIAL INSTITUTE

for the

UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

PRINTED BY/ FOR THE U. S. ATOMIC ENERGY COMMISSION

3 3679 00060 7269

BNWL-616
UC-70, Waste Disposal
and Processing

HOTANK - A STEADY-STATE HEAT TRANSFER PROGRAM FOR
USE ON THE UNIVAC 1107/1108

By

W. E. Willingham
Chemical Development Section
Chemistry Department

February 1968

UNIVERSITY OF WASHINGTON
LIBRARY

PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

HOTANK - A STEADY-STATE HEAT TRANSFER PROGRAM FOR
USE ON THE UNIVAC 1107/1108

W. E. Willingham

ABSTRACT

A computer program is presented for the calculation of steady-state temperatures in heat and nonheat-generating systems suitable for a two-dimensional system of cylindrical geometry. The program is capable of handling problems with constant or temperature dependent thermal conductivities, internal heat generation, and constant film or contact coefficients. No attempt has been made to include radiation effects within the program. The results are calculated by an iterative process using the nodal or lumped parameter method of analysis.

TABLE OF CONTENTS

INTRODUCTION	1
DISCUSSION	2
Subroutine DATAIN	2
Card Listing	4
Subroutine DATABL	5
Card Listing	6
Main Program - HOTANK	6
Card Listing	6
Program Print-Out	10
ACKNOWLEDGEMENTS	11
REFERENCES	12
APPENDIX A - Simplified Block Diagram of Program HOTANK and Data Input Listing.	A-1
APPENDIX B - No. 1 Subroutine DATAIN	B-1
No. 2 Subroutine DATABL	B-5
No. 3 Program HOTANK	B-6
APPENDIX C - Typical Print-Out of Program HOTANK	C-1
DISTRIBUTION	.Distr-1

HOTANK - A STEADY-STATE HEAT TRANSFER PROGRAM FOR
USE ON THE UNIVAC 1107/1108

W. E. Willingham

INTRODUCTION

This report describes the use of a computer program for calculating steady-state temperatures in heat and nonheat-generating systems.

The program was undertaken in an effort to present a reasonably accurate method of estimating temperatures expected in and around underground storage tanks containing radioactive wastes. The iterative calculations presented in previous documents^(1,2) on heat transfer around underground waste tanks were made by this program.

These tanks are of large diameter, 75 x 36 ft high, and contain many thousands of gallons of radioactive waste products. The quantity of heat-generating fission products which may be stored in an underground tank is limited by the temperatures in and around the tank. It is important to know these temperatures to make certain that safety limits set by past experience are not exceeded.

Two subroutines are included within the main program to provide the necessary data on the physical system (DATAIN) and to print out certain fixed values of the input data (DATABL).

The program itself, HOTANK, is a modified version of Program-001,⁽³⁾ which is available from Computer Science Corporation, Richland, Washington. The modifications were minor and the reader is referred to the document by Mollerus⁽⁴⁾ for use of Program-001.

DISCUSSION

The new program, HOTANK, which operates in a cylindrical geometry, is capable of providing steady-state temperatures in a system having constant or temperature dependent thermal conductivities, internal heat generation (constant with time), constant film or contact coefficients (for convection), and heat transfer by conduction. The print-out of the program provides a thermal map on which isotherms may be drawn to give a temperature profile of the system. Figure 1 shows a typical thermal map drawn from the print-out. The thermal conductivity of soil is $0.33 \text{ Btu/hr(ft}^2)(^{\circ}\text{F/ft)}$.

The actual use of the program requires the division of the system into separate nodes, identifying the node geometry (linear or cylindrical), listing the thermal properties of all materials, listing the nodal dimensions, fixing the heat generation rate, the coefficients required, and the boundary conditions. Once these requisites are established, the program uses an iterative technique to calculate the temperature at the midpoint of each node. The various sections of the program will now be discussed in detail.

SUBROUTINE DATAIN

Subroutine DATAIN provides the necessary input data for the main program, HOTANK, and serves also as a modified version of a program from the Basic Fortran Library; Program-159, Punched Card Input for Program-001.⁽⁵⁾ The effect of this modified version is to eliminate the punched output and provide only for a cylindrical geometry system.

The subroutine calculates the nodal face areas, volumes, sequence number of adjacent node, face number of each node, and the distance to the centroid from each face (proportional to the log mean area).

FIGURE 1. Soil Temperatures Around an Underground Waste (Solid Cake) Storage Tank

The system is considered to be a segment of a right circular cylinder and is divided into individual nodes or segments (maximum 1000) from the centerline to the outside boundary, and from the top to bottom of the system. The present print-out configuration limits the program to a system 10 nodes wide. Use of a generalized print-out accommodating any number of nodes to the maximum of 1000, however, can make the selection of individual nodes rather awkward. The numbering sequence, either left to right or top to bottom, is selected after choosing the node arrangement. The numbering system is consecutive and remains fixed throughout the program.

Next, the thickness of the wedge is considered and may range from ~ 0 to 90° maximum; however, it may not be equal to 0° .

Since the problem is really one of sources and sinks, sink locations or no-flow interfaces must be specified for each case under consideration.

Finally, the actual thickness of each column from the centerline out and the thickness of each layer top to bottom must be given.

The calculation method is a straightforward procedure utilizing a log mean method to calculate the distances to the centroid from each face.

Card Listing

The necessary cards in order and format for the operation of Subroutine DATAIN are as follows:

Card Set (A) One card, FORMAT (3I5, 1E10.0, 6I5)

Field 1 • Number of concentric cylinders or horizontal columns (left to right).

Field 2 • Number of axial layers or vertical rows (top to bottom).

Printing out of all the information, although possible, would have reduced the flexibility of the program and was not considered necessary since this information is already known to the program user.

Card Listing

No card listing is given since this subroutine is only a writing sequence and the information comes from either the main program or the programmer.

MAIN PROGRAM - HOTANK

As previously mentioned the purpose of this program is to calculate the temperature distribution around an underground storage tank containing radioactive waste storage products.

The program itself is a straightforward procedure involving an iterative technique based on the Gauss-Seidel method of calculation.^(6,7,8)

Card Listing

To facilitate usage of the program, the various segments which comprise it and their purpose will be described in order of appearance.

Card Set (A) IDENTIFICATION, one card, FORMAT (4I5)

- Field 1 • Case identification number, not blank or zero.
- Field 2 • Number of nodes or segments in the system (maximum of 1000).
- Field 3 • Maximum number of minutes to calculate before printing the results.
- Field 4 • Method of calculation. Method 1 is used when a uniform temperature is assumed for the complete system, a single temperature being listed. Method 2 is used for a nodal temperature guess. A temperature is specified for

each node throughout the system. Method 3 is used when the initial temperature guess is specified by material type. One temperature is specified for each material type in the system.

Card Set (B) NODE SEQUENCE NUMBER, any number of cards, FORMAT (10I5)

Fields 1 to 10 • This lists the nodes in the order in which the calculations are to take place. The listing may be by column, by row, or random listing of each node number individually.

Card Set (C) INITIAL TEMPERATURE GUESS. This listing will depend on the value of METHOD in card set (A)

Field 1 • If METHOD = 1, one card, FORMAT (F5.0).

Fields 1 to 10 • If METHOD = 2, any number of cards, FORMAT (10F5.0).

Fields 1 to 12 • If METHOD = 3, one card, FORMAT (12F5.0).

Card Set (D) SINK TEMPERATURES, one card, FORMAT (6E5.2)

Fields 1 to 6 • The sink temperatures are listed, one value for each sink, starting with sink 1 in field 1. Leave blank if there is no sink.

Card Set (E) MATERIAL TYPE, any number of cards, FORMAT (10I5)

Fields 1 to 10 • This group of cards lists the material types for the system. The system may be divided into as many as 12 different types if necessary. A material type for each node must be listed.

Card Set (F) THERMAL CONDUCTIVITY, two cards, FORMAT (12E5.2)

Fields 1 to 12 • The thermal conductivity for each material type is listed separately. Since the value may be a function of temperature of the form $k = a + bt$, two fields will be required for each material type. If it is not a function of temperature, only the value of a is listed.

Field 1 • Value of $\underline{a}$ in $k = a + bt$

Field 2 • Value of $\underline{b}$ in $k = a + bt$

Card Set (G) HEAT GENERATION, one card, FORMAT (12E5.2)

Fields 1 to 12 • When the system contains heat-generating material, the value is listed in the field corresponding to the material type. One value is listed for each type or left blank.

Card Set (H) ALLOWABLE ERROR LIMIT, one card, FORMAT (2E5.2)

To prevent the program from continuing to run until the time limit is reached after having achieved an acceptable heat balance, an error limit is introduced in the program. If an acceptable limit is reached, the computation will stop and the results will be printed. If the acceptable limit is not reached, computations will continue until the previously set time limit is reached.

Field 1 • Allowable error for conductance calculations (deg F)

Field 2 • Allowable error in the temperature calculations (deg F)
or

Field 1 • Same as above

Field 2 • Allowable overall heat balance error (percent).
The error limits may be any reasonable values consistent with the work being done.

Card Set (I) NUMBER OF ITERATIONS, one card, FORMAT (I5)

Field 1 • This card is used to specify the number of iterative cycles to be made in the main portion of the program before transferring to the extrapolation section. Usually the value will be between 5 and 20. If the number is very large, the extrapolation portion of the program will not be used because of the time limit.

Card Set (J) ACCELERATION FACTOR, one card, FORMAT (F5.0)

Field 1 • A constant is introduced on this card for use in the extrapolation section of the program. It has a direct effect upon the size of adjustments within the section. By choosing different values, very large or small adjustments may be made in the new temperature profile.

Card Set (K) NODE NUMBER AND CONTACT COEFFICIENT, any number of cards, FORMAT (I5,6F5.0).

To allow for thermal convection and contact between dissimilar materials, provisions are made to introduce film or contact coefficients. These must be entered one to a card, i.e., if a node has a contact coefficient, then the node number and coefficient across the particular face in question must be entered on the same card.

These entries must be duplicated for the corresponding face of the adjacent node. When no coefficient is given, the resistance is considered infinite or the material is one homogeneous substance with no resistance to heat flow.

Coefficients may be assigned to any face of any node; however, corresponding coefficients must be assigned to adjacent node faces.

Field 1 • Node number

Fields 2 • Contact or film coefficient for faces left,
to 7 right, top, bottom, front, or back.

The last card in this set will have 1000 in Field 1 to signify the end of the set.

Card Set (L) BLANK. This is the last card in the deck to signify end of input data.

Provision has been made to include alternate cases in the same run if required. When alternate cases are included, the following applies:

Card Set (A) IDENTIFICATION, one card, FORMAT (4I5)

Field 1 • Case identification number, not blank or zero.

Field 2 • Number of nodes in the system.

Field 3 • Maximum number of minutes to calculate before printing results.

Field 4 • Change Case

Card Set (B) NUMBER OF CARDS TO BE READ, NCC, NCR, one card, FORMAT (2I5)

Field 1 • Used to tell the computer how many cards are to be expected for a node material type change (if any).

Field 2 • Used to tell the computer how many cards are to be expected for any additional changes.

Card Set (C) ALTERNATE DATA INPUT, any number of cards, FORMAT (2I5, 3E5.2)

Any changes will require the following information:

Field 1 • Node number.

Field 2 • Material type.

Fields 3 • Thermal conductivity.
to 4

Field 5 • Heat generation, if any.

Card Set (D) LAST CARD, one card, to have 99999 in columns 1-5 to signify the end of the data for this particular case.

PROGRAM PRINT-OUT

The print-out presently is limited to a system 10 nodes wide and provides a thermal display of the system from which a map may be drawn with the corresponding isotherms.

By suitable alteration, a general print-out can be obtained for a system as many nodes wide as necessary.

The present system permits an outline of the tank to be drawn directly on the output to provide information regarding temperature variation in any part of the system. A typical example is given in the Appendix showing the outline of the tank drawn on the print-out.

The information labelled "HEAT FROM NODES TO SINKS," printed just before the temperature maps, is correct for the wedge angle actually used in the calculations. These values must be multiplied by the ratio $360/\text{wedge angle}$ to obtain the heat value for the full 360° .

The "TOTAL HEAT LOAD IN TANK" given under "SUMMARY OF INPUT DATA FOR CASE NO." has already been converted to the value for 360° .

ACKNOWLEDGEMENTS

This work was performed under the guidance of B. M. Johnson, Manager, Engineering Analysis Unit, Chemical Development Section, Chemistry Department, Battelle-Northwest.

Acknowledgement is also given to W. V. DeMier, Chemical Development, for the help he provided in clearing up many of the questions encountered during modification of the original program.

REFERENCES

1. G. Jansen, Jr., W. E. Willingham, and W. V. DeMier. Buried Radioactive Waste Storage Tank Temperatures and Soil Temperatures Near Leaks, BNWL-181. Pacific Northwest Laboratory, Richland, Washington, 1966.
2. W. E. Willingham and G. Jansen, Jr. Heat Transfer from Solidified Wastes in Underground Storage Tanks, BNWL-262. Pacific Northwest Laboratory, Richland, Washington, 1966.
3. "Equilibrium Temperatures in a Generalized Heat Transfer System," Program-001, Fortran Library-IBM 7090. Computer Science Corporation, Richland, Washington.
4. F. J. Mollerus, Jr. Users Manual for SHTP - A Steady-State Heat Transfer Program for the IBM 7090 Computer, HW-73668. General Electric Company, Richland, Washington, 1962.
5. "Punched Card Input for Program-001," Program-159, Fortran Library-IBM 7090. Computer Science Corporation, Richland, Washington.
6. G. M. Dusinberre. Heat Transfer Calculations by Finite Differences, International Textbook Co., Scranton, Pa., 1961.
7. P. J. Schneider. Conduction Heat Transfer. Addison-Wesley Publishing Co., Inc., Reading, Mass., 1955.
8. M. Jakob. Heat Transfer. John Wiley and Sons, Inc., New York, N. Y., 1950.

APPENDIX A
SIMPLIFIED BLOCK DIAGRAM OF PROGRAM HOTANK
AND
DATA INPUT LISTING

FIGURE A-1. *Simplified Block Diagram of Program Hotank*

Field 3 • 1 if nodes are numbered vertically, 0 if numbered horizontally.

Field 4 • Angle of the wedge in degrees (not 0, maximum 90).

Fields 5 • Negative sink number at the left (axis),
to 10 right (circumference), top, bottom, front,
and back; or 0 at no-flow interfaces.

Card Set (B) Any number of cards, FORMAT (7E10.0)

Fields 1 • Actual thickness of each concentric layer.
to 7 Start with the thickness of the innermost
layer in Field 1.

Card Set (C) Any number of cards, FORMAT (7E10.0)

Fields 1 • Thickness of each axial layer or node row
to 7 (top to bottom). Start with thickness of
top layer or row in Field 1.

SUBROUTINE DATABL

This subroutine is used to print out preselected input data in tabular form at the end of the calculations. This information presently consists of the following:

- Material type number and thermal conductivity
- Sink temperatures
- Volumetric heat generation rate
- Total heat load in the tank

Also blank tables are set up, with the following headings to be filled in by the program user:

- Material type
- Film coefficients (values and locations)
- Sludge or cake thickness
- Soil cover depth
- Liquid layer depth
- Tank diameter
- Tank height

6666	290	1	1							ID
1	290	2	289	3	288	4	287	5	286	NSN
6	285	7	284	8	283	9	282	10	281	NSN
11	280	12	279	13	278	14	277	15	276	NSN
16	275	17	274	18	273	19	272	20	271	NSN
21	270	22	269	23	268	24	267	25	266	NSN
26	265	27	264	28	263	29	262	30	261	NSN
31	260	32	259	33	258	34	257	35	256	NSN
36	255	37	254	38	253	39	252	40	251	NSN
41	250	42	249	43	248	44	247	45	246	NSN
46	245	47	244	48	243	49	242	50	241	NSN
51	240	52	239	53	238	54	237	55	236	NSN
56	235	57	234	58	233	59	232	60	231	NSN
61	230	62	229	63	228	64	227	65	226	NSN
66	225	67	224	68	223	69	222	70	221	NSN
71	220	72	219	73	218	74	217	75	216	NSN
76	215	77	214	78	213	79	212	80	211	NSN
81	210	82	209	83	208	84	207	85	206	NSN
86	205	87	204	88	203	89	202	90	201	NSN
91	200	92	199	93	198	94	197	95	196	NSN
96	195	97	194	98	193	99	192	100	191	NSN
101	190	102	189	103	188	104	187	105	186	NSN
106	185	107	184	108	183	109	182	110	181	NSN
111	180	112	179	113	178	114	177	115	176	NSN
116	175	117	174	118	173	119	172	120	171	NSN
121	170	122	169	123	168	124	167	125	166	NSN
126	165	127	164	128	163	129	162	130	161	NSN
131	160	132	159	133	158	134	157	135	156	NSN
136	155	137	154	138	153	139	152	140	151	NSN
141	150	142	149	143	148	144	147	145	146	NSN
960.										TEMP
700+1	700+1									SNK
5	5	5	5	5	5	5	5	5	5	MAT 1
1	1	1	1	1	1	1	1	1	1	MAT 2
1	1	1	1	1	1	1	1	1	1	MAT 3
1	1	1	1	1	1	1	1	1	1	MAT 4

A-2

BNWL-616

APPENDIX B

NO. 1 SUBROUTINE DATAIN

NO. 2 SUBROUTINE DATABL

NO. 3 PROGRAM HOTANK

Appendix B, No. 1

```

C
C      * * * SUBROUTINE DATAIN * * *
C
C      PROVIDES INPUT DATA FOR HEAT TRANSFER PROGRAM ** HOTANK **
C      TWO DIMENSIONAL STEADY-STATE HEAT TRANSFER IN CYLINDRICAL COOR
C      DINATES
C      SINGLE NODE THICKNESS MODEL CONCENTRIC CYLINDERS
C      CALCULATES ADJACENT NODE NUMBER, DISTANCE FROM CENTROID TO NODE
C      FACE (PROPORTIONAL TO THE LOG MEAN AREA), FACE AREA, AND VOLUMES
C      FOR INDIVIDUAL NODES, WITH A WEDGE SHAPED (CENTER TO CIRCUMFERENCE)
C      GRID
C      NECESSARY INPUT DATA FOR EACH CASE
C      NUMBER OF CONCENTRIC CYLINDERS OR HORIZONTAL COLUMNS (LEFT TO
C      RIGHT)
C      NUMBER OF AXIAL LAYERS OR VERTICAL ROWS (TOP TO BOTTOM)
C      1 IF NUMBERED VERTICALLY (TOP TO BOTTOM), (N*T+L), 0 IF NUMBER-
C      ED HORIZONTALLY (LEFT TO RIGHT), (N*L+T)
C      ANGLE OF THE WEDGE IN DEGREES (NOT 0, MAX. 90)
C      NEGATIVE SINK NUMBER AT LEFT (AXIS), RIGHT (CIRCUMFERENCE),
C      TOP, BOTTOM, FRONT, BACK, OR 0 AT NOFLOW INTERFACES
C      FORMAT (3I5,1E10.0,6I5)
C      ACTUAL THICKNESS OF EACH CONCENTRIC LAYER, CENTERLINE TO OUTER
C      EDGE IN INCHES
C      FORMAT (7E10.0)
C      THICKNESS OF EACH AXIAL LAYER OR NODE ROW, TOP TO BOTTOM IN
C      INCHES
C      FORMAT (7E10.0)
C
C      DIMENSION X(1000,6),A(1000,6),U(1000,6),C(1000,6),THERM(1000,6),
C      1ADJ(1000,6),Q(1000),D(1000),VOL(1000),PRET(1000),SEQT(1000),
C      2OLDT(1000),MAT(1000),SINKQ(1000),TC(24),HEAT(24),SINK(6),
C      3RADIUS(1000),THICK(1000),NEXT(6)
C      COMMON X,C,E,D,Q,U,A,J,K,L,N,Z,R,S,ID,IZ,MO,TC,KA,BTU,ALL,ADJ,I,
C      1MAT,NON,VOL,HEAT,SEQT,OLDT,PRET,SINK,NLIM,TEMP,THERM,SINKQ,
C      2DELTA,NTIME,CERROR,TERROR
C      INTEGER WRITE,ADJ
C

```

```

C    RADIUS=THICKNESS OF EACH CONCENTRIC LAYER (HORIZONTAL)
C    THICK =THICKNESS OF EACH AXIAL LAYER (VERTICAL)
C    NEXT  =SINK OR NOFLOW INTERFACE LOCATION
C    ADJ    =ADJACENT NODE NUMBER
C    X      =DIMENSIONS OF EACH NODE
C    A      =FACE AREA OF EACH NODE
C    VOL    =VOLUME OF EACH NODE
C    1 FORMAT (3I5,1E10.0,6I5)
C    2 FORMAT (7E10.0)
C    3 FORMAT (16H1ERRONEOUS INPUT)
C    PI=3.14159
C    4 READ (2,1) NC,NR,NS,ANGLE,(NEXT(I), I=1,6)
C    NC     =NUMBER OF COLUMNS (LEFT TO RIGHT)
C    NR     =NUMBER OF LAYERS (TOP TO BOTTOM)
C    NS     =NUMBERING SEQUENCE (HORIZONTALLY OR VERTICALLY)
C    ANGLE  =ANGLE OF WEDGE USED
C
C    5 READ (2,2) (RADIUS(I), I=1,NC)
C    6 READ (2,2) (THICK(I), I=1,NR)
C    7 IF (ANGLE .GT. 0.0) GO TO 8
C    WRITE (3,3)
C    CALL EXIT
C    8 INTC=NS+NC*(1-NS)
C    INTR=(1-NS)+NR*NS
C    TO START THE PROGRAM AT THE FIRST NODE OF THE FIRST COLUMN AND ROW
C    NB=1-INTC
C    9 DO 20 IR=1,NR
C    RO=0.0
C    NB=NB+INTC
C    N =NB-INTR
C    10 DO 20 IC=1,NC
C    RO=RO+RADIUS(IC)
C    N=N+INTR
C    CALCULATION OF ADJACENT NODE NUMBERS
C    11 NF=1
C    ADJ(N,NF)=(N-1)*(1-NS)+(N-NR)*NS

```

```

    ADJ(N,NF+1)=(N+1)*(1-NS)+(N+NR)*NS
    ADJ(N,NF+2)=(N-NC)*(1-NS)+(N-1)*NS
    ADJ(N,NF+3)=(N+NC)*(1-NS)+(N+1)*NS
    ADJ(N,NF+4)=NEXT(5)
    ADJ(N,NF+5)=NEXT(6)
12  IF ((IC-1) .NE. 0) GO TO 13
    ADJ(N,NF)=NEXT(1)
13  IF ((IC-NC) .NE. 0) GO TO 14
    ADJ(N,NF+1)=NEXT(2)
14  IF ((IR-1) .NE. 0) GO TO 15
    ADJ(N,NF+2)=NEXT(3)
15  IF ((IR-NR) .NE. 0) GO TO 16
    ADJ(N,NF+3)=NEXT(4)
16  CONTINUE
C   CALCULATION OF NODE DIMENSIONS
17  ND=1
    RC=SQRT(0.5*(RO**2+(RO-RADIUS(IC))**2))
    IF (RO-RADIUS(IC)) 29,29,30
29  X(N,ND)=(2.0*RADIUS(IC)*SIN(ANGLE*0.01745))/(3.0*ANGLE*0.01745)
    X(N,ND+1)=RO-X(N,ND)
    GO TO 31
30  X(N,ND)=(RO-RADIUS(IC))*ALOG(RC/(RO-RADIUS(IC)))
    X(N,ND+1)=RO*ALOG(RO/RC)
31  X(N,ND+2)=0.5*THICK(IR)
    X(N,ND+3)=X(N,ND+2)
    X(N,ND+4)=RC*SIN(ANGLE/360.0*PI)
    X(N,ND+5)=X(N,ND+4)
    CONTINUE
C   CALCULATION OF FACE AREAS
18  NA=1
    A(N,NA)=(ANGLE/180.0*PI*THICK(IR))*(RO-RADIUS(IC))
    A(N,NA+1)=(ANGLE/180.0*PI*THICK(IR))*RO
    A(N,NA+2)=(ANGLE/360.0*PI*(RO**2-(RO-RADIUS(IC))**2))
    A(N,NA+3)=A(N,NA+2)
    A(N,NA+4)=RADIUS(IC)*THICK(IR)
    A(N,NA+5)=A(N,NA+4)

```



```

      CONTINUE
C     CALCULATION OF NODE VOLUME
      VOLA=A(N,NA+2)
19    VOL(N)=VOLA*THICK(IR)
20    CONTINUE
C     TO PRINTOUT ADJACENT NODE NUMBERS,AREAS,DIMENSIONS,VOLUMES
      READ (2,1) WRITE
      IF (WRITE .EQ. 3333) GO TO 21
      GO TO 28
22    FORMAT (1H0,50X,28H TITLE OF PROGRAM IS DATAIN )
23    FORMAT (1H0,10X,7HNODE NO,10X,11HADJ NODE NO,10X,10HDIMENSIONS,10X
1,4HAREA,10X,6HVOLUME)
24    FORMAT (1H ,10X,I5,14X,I5,14X,1PE10.2,7X,1E10.2,5X,1E10.2)
25    FORMAT (1H0)
21    WRITE (3,22)
      WRITE (3,23)
      DO 26 N=1,NON
      DO 27 J=1,6
      WRITE (3,24) N,ADJ(N,J),X(N,J),A(N,J),VOL(N)
27    CONTINUE
      WRITE (3,25)
26    CONTINUE
28    RETURN
      END

```

Appendix B, No. 2

*** SUBROUTINE DATABL ***

C
C

```

      THIS SUBROUTINE PROVIDES A PRINTOUT OF PRESELECTED INPUT DATA
      DIMENSION X(1000,6),A(1000,6),U(1000,6),C(1000,6),THERM(1000,6),
      1ADJ(1000,6),Q(1000),D(1000),VOL(1000),PRET(1000),SEQT(1000),
      2OLDT(1000),MAT(1000),SINKQ(1000),TC(24),HEAT(24),SINK(6)
      COMMON X,C,E,D,Q,U,A,J,K,L,N,Z,R,S,ID,IZ,MO,TC,KA,BTU,ALL,ADJ,I,
      1MAT,NON,VOL,HEAT,SEQT,OLDT,PRET,SINK,NLIM,TEMP,THERM,SINKQ,
      2DELTA,NTIME,CERROR,TERROR,ANGLE
      1 FORMAT (1H0,36X,38H*** SUMMARY OF INPUT DATA FOR CASE NO.,I5,4H **
      1*//2X,22HTHERMAL CONDUCTIVITIES,10X,17HSINK TEMPERATURES,10X,41HVO
      2LUMETRIC HEAT GEN RATE (BTU/HR CU FT) =,F7.3//2X,22HBTU/(HR SQFT D
      3EG F/FT),10X,18HDEGREES FAHRENHEIT,9X,41HTOTAL HEAT LOAD IN TANK
      4 (BTU/HR) =,1PE12.5///2X,11HMATERIAL 1 OPF8.4,15X,7HSINK 1 ,
      5F7.2,12X,33HSLUDGE OR CAKE THICKNESS (FEET) =/2X,11HMATERIAL 2 F8.
      64/2X,11HMATERIAL 3 F8.4,15X,7HSINK 2 ,F7.2,12X,33HSOIL COVER DEPTH
      7 (FEET) =/2X,11HMATERIAL 4 F8.4/2X,11HMATERIAL 5 F8.4,41X,
      833HLIQUID LAYER DEPTH (FEET) =/2X,11HMATERIAL 6 F8.4//2X,13
      9HMATERIAL TYPE,13X,17HFILM COEFFICIENTS,17X,33HTANK DIAMETER
      A (FEET) =/27X,19H(BTU/HR SQFT DEG F)/3X,1H1,58X,33HTANK HEIGH
      BT (FEET) =/3X,1H2,24X,4HNODE,10X,1HH/3X,1H3/3X,1H4/3X
      C,1H5/3X,1H6/)
      BTU=0.0
      DO 11 I=1,NON
      BTU=BTU+Q(I)
      11 CONTINUE
      BTU=BTU*360.0/ANGLE
      S=HEAT(2)*1728.
      WRITE(3,1) ID,S,BTU,TC(1),SINK(1),TC(3),TC(5),SINK(2),TC(7),
      1TC(9),TC(11)
      RETURN
      END

```

B-5

BNWL-616

[illegible]

INCLUDES HEAT TRANSFER BY CONDUCTION AND CONVECTION
SPECIAL PRINTOUT FORMAT INCLUDED
SYSTEM IS LIMITED TO NODES WITH A MAXIMUM OF 6 SIDES

EACH GROUP TO BE LISTED ON SEPARATE CARDS

- ```

(1) CASE IDENTIFICATION NOT BLANK OR ZERO
 NUMBER OF NODES (1000 MAXIMUM)
 MAXIMUM NUMBER OF MINUTES TO CALCULATE BEFORE
 PRINTING RESULTS
 METHOD OF CALCULATION
 FORMAT(4I5)
(2) NODE SEQUENCE NUMBER (NSN)
 ORDER IN WHICH THE NODES ARE TO BE CALCULATED
 FORMAT(10I5)
(3) INITIAL TEMPERATURE GUESS
 FORMAT(F5.0) OR (10F5.0) OR (12F5.0)
(4) TEMPERATURES (NOT ZERO) OF SINKS 1 TO 6, IF
 THERE IS NO SINK LEAVE BLANK (DEG F)
 FORMAT(6E5.2)
(5) MATERIAL TYPE FOR EACH NODE (INTEGERS, FROM 1 TO 12)
 FORMAT(10I5)
(6) THERMAL CONDUCTIVITY OF EACH MATERIAL TYPE
 TWO FIELDS FOR EACH TYPE (A1,B1,A2,B2,---)
 WHEN A FUNCTION OF TEMPERATURE (A+BT)
 (BTU/HR SQFT DEG F/FT)
 FORMAT(12E5.2)
(7) HEAT GENERATION BY MATERIAL TYPE, ONE VALUE OR
 BLANK FOR EACH TYPE, NOT ZERO (BTU/HR CU IN)
 FORMAT(12E5.2)
(8) ALLOWABLE ERROR FOR CONDUCTANCE CALCULATIONS (DEG F)
 AND ALLOWABLE ERROR IN THE TEMPERATURE CALCULATIONS
 (DEG F)

```

OR-

B-6

BNWL-616

C ALLOWABLE HEAT BALANCE ERROR (OVERALL) (IN PERCENT)  
 C FORMAT(2E5.2)  
 C (9) NUMBER OF ITERATIONS PER CYCLE BEFORE GOING TO  
 C THE EXTRAPOLATION SECTION OF THE PROGRAM (NIT)  
 C FORMAT(I5)  
 C (10) ACCELERATION FACTOR IN THE EXTRAPOLATION SECTION (ACF)  
 C FORMAT(F5.0)  
 C (11) NODE NUMBER AND FILM OR CONTACT COEFFICIENT AT  
 C EACH FACE, MUST BE DUPLICATED FOR ADJACENT FACES  
 C USE A BLANK OR ZERO FOR A HOMOGENEOUS INTERFACE  
 C FORMAT(I5,6F5.0)  
 C (12) LAST CARD OF EACH CASE (IN ADDITION TO DATA CARDS) IS  
 C BLANK

ALTERNATE INPUT FOR ADDITIONAL CASES ON THE SAME RUN

C (1) CASE IDENTIFICATION (NOT BLANK OR ZERO)  
 C NUMBER OF NODES  
 C TIME LIMIT ON CALCULATIONS  
 C CHANGE CASE (NEW)  
 C FORMAT (4I5)  
 C (2) NUMBER OF CARDS TO BE READ (NCC),(NCR)  
 C NCC REFERS TO A NODE MATERIAL TYPE CHANGE (IF ANY)  
 C NCR REFERS TO ANY ADDITIONAL CHANGES  
 C FORMAT (2I5)  
 C (3) NODE NUMBER  
 C MATERIAL TYPE  
 C FORMAT (2I5)  
 C (4) MATERIAL TYPE  
 C THERMAL CONDUCTIVITY (2 FIELDS)  
 C HEAT GENERATION BY MATERIAL TYPE  
 C FORMAT (I5,3E5.2)

1 FORMAT (4I5)

```

2 FORMAT (F5.0)
3 FORMAT (6E5.2)
4 FORMAT (10I5)
5 FORMAT (12E5.2)
6 FORMAT (15,6F5.0)
7 FORMAT (10F5.0)
8 FORMAT (46H1 CALCULATION OF STEADY STATE TEMPERATURES,48X,
115HPROGRAM HOTANK ///
214H CASE NO.16, 74H
3 HEAT BALANCE ERROR = F12.6,9H PERCENT //
440X, 10HMAX TEMP =1PE12.3,14H DEG F AT NODE 15///
514X, 1PE13.3,17H BTU/HR TO SINK 11PE13.3,17H BTU/HR TO SINK 2
61PE13.3,17H BTU/HR TO SINK 3/
714X, 1PE13.3,17H BTU/HR TO SINK 41PE13.3,17H BTU/HR TO SINK 5
81PE13.3,17H BTU/HR TO SINK 6)
9 FORMAT (30H0 HEAT FROM NODES TO SINK 111/)
10 FORMAT (6X, 5HHEAT=1PE11.3,10H FROM NODE 15)
11 FORMAT (1H+,40X 5HHEAT=1PE11.3,10H FROM NODE 15)
12 FORMAT (1H+,75X 5HHEAT=1PE11.3,10H FROM NODE 15)
13 FORMAT (1H0/1H 47X,24HNODE TEMPERATURES, DEG F)
14 FORMAT (15,3E5.2)
15 FORMAT (1H I3,1HX,1X,1P10E11.3)
16 FORMAT (1H1,31X, 52HSUPPLEMENTAL PROGRAM *** ERROR FIGURES FOR C
1ASE NO. 115///5X, 1P1E12.5, 74H BTU/HR = ERROR IN HEAT BALANC
2E BETWEEN HEAT IN AND HEAT OUT OF THE SYSTEM / 5X, 1P1E12.5,
370H BTU/HR = TOTAL HEAT ADDED TO THE SYSTEM (AND REMOVED FROM THE
4SYSTEM)
5///5X, 1P1E12.5, 58H BTU/HR = ERROR IN HEAT BALANCE AMONG ALL
6 INDIVIDUAL NODES / 5X, 1P1E12.5, 55H BTU/HR = SUM OF HEAT TRA
7NSFERRED ACROSS ALL NODE FACES / 5X, 1P1E12.5, 60H BTU/HR = ALGEBR
8AIC SUM OF THE HEAT FLOW OVER ALL NODE FACES)
17 FORMAT (1H0 10X,1H1,10X,1H2,10X,1H3,10X,1H4,10X,1H5,10X,1H6,10X,
11H7,10X,1H8,10X,1H9,9X,2H10/1H)
18 FORMAT (12F5.0)
19 FORMAT (1H1,31X, 36HTHERE IS AN ERROR IN THE INPUT DATA)
20 FORMAT (1H0,1X,27HTIME SPENT ON CALCULATION =1PE11.3,7H SECS)

```

```

 DIMENSION X(1000,6),A(1000,6),U(1000,6),C(1000,6),THERM(1000,6),
 1ADJ(1000,6),Q(1000),D(1000),VOL(1000),PRET(1000),SEQT(1000),
 2OLDT(1000),MAT(1000),SINKQ(1000),TGUESS(1000),NSN(1000),TC(24),
 3HEAT(24),TMAT(12),SINK(6)
 COMMON X,C,E,D,Q,U,A,J,K,L,N,Z,R,S,ID,IZ,MO,TC,KA,BTU,ALL,ADJ,I,
 1MAT,NON,VOL,HEAT,SEQT,OLDT,PRET,SINK,NLIM,TEMP,THERM,SINKQ,
 2DELTA,NTIME,CERROR,TERROR,ANGLE
 INTEGER ADJ
C
C IF STORAGE SPACE IS REQUIRED SET TGUESS EQUIVALENT TO SEQT
C
 CALL SETIO(2,1)
 CALL SETIO(3,2)
 DO 30 I=1,1000
 DO 30 J=1,6
 C(I,J)=0.0
30 CONTINUE
31 READ (2,1) ID,NON,NLIM,METHOD
 IF (ID .EQ. 0) GO TO 999
 IF (NON .EQ. 0) GO TO 999
 READ (2,4) (NSN(I),I=1,NON)
 DO 40 J=1,NON
 N=NSN(J)
40 CONTINUE
 GO TO (42,41,43), METHOD
C METHOD 1= UNIFORM TEMPERATURE GUESS
C METHOD 2= NODAL TEMPERATURE GUESS
C METHOD 3= MATERIAL TYPE TEMPERATURE GUESS
41 READ (2,7) (TGUESS(I),I=1,NON)
C SETTING UP TEMPERATURES FOR EACH NODE
 DO 50 N=1,NON
 SEQT(N)=TGUESS(N)
 OLDT(N)=SEQT(N)
50 CONTINUE
 GO TO 43
42 READ (2,2) TEMP

```

```

C SETTING ALL TEMPERATURES EQUAL
 DO 60 I=1,NON
 SEQT(I)=TEMP
 OLDT(I)=SEQT(I)
60 CONTINUE
61 IF (NON .NE. 0) GO TO 43
 GO TO 999
C THIS IS TO TAKE CARE OF CHANGE CASES
63 READ (2,1) ID,NON,NLIM,NEW
 IF (ID .EQ. 0) GO TO 999
 IF (ID .EQ. 99999) GO TO 888
 CALL ETIME
 IF (NEW .EQ. 0) GO TO 64
 GO TO 999
C NCC= NUMBER OF CARDS TO BE READ
C NCR= NUMBER OF CARDS TO BE READ
64 READ (2,1) NCC,NCR
 IF (NCC .LE. 0) GO TO 65
 DO 70 J=1,NCC
C NEW INPUT DATA
 READ (2,1) N,MAT(N)
70 CONTINUE
65 IF (NCR .LE. 0) GO TO 95
 DO 71 N=1,NCR
C NEW INPUT DATA
 READ (2,14) I,TC(2*I-1),TC(2*I),HEAT(I)
71 CONTINUE
66 GO TO 95
43 READ (2,3) (SINK(I),I=1,6)
 READ (2,4) (MAT(I),I=1,NON)
 READ (2,5) TC
 READ (2,5) (HEAT(I),I=1,12)
 READ (2,3) CERROR,TERROR
 READ (2,1) NIT
 READ (2,2) ACF
 CERROR=CERROR+(1.0-CERROR/CERROR)*1.0E+30

```

```

44 CONTINUE
 READ (2,6) N,(C(N,I), I=1,6)
 IF (N .EQ. 1000) GO TO 45
C WHEN N=1000 IT INDICATES END OF DATA SET
 GO TO 44
45 CONTINUE
 IF (METHOD .EQ. 3) GO TO 46
 GO TO 90
46 READ (2,18) (TMAT(I),I=1,12)
C SETTING UP TEMPERATURES BY MATERIAL TYPE
 DO 80 N=1,NON
 MT=MAT(N)
 GO TO (81,82,83,84,85,86,87,88,89,91,92,93), MT
81 SEQT(N)=TMAT(1)
 GO TO 80
82 SEQT(N)=TMAT(2)
 GO TO 80
83 SEQT(N)=TMAT(3)
 GO TO 80
84 SEQT(N)=TMAT(4)
 GO TO 80
85 SEQT(N)=TMAT(5)
 GO TO 80
86 SEQT(N)=TMAT(6)
 GO TO 80
87 SEQT(N)=TMAT(7)
 GO TO 80
88 SEQT(N)=TMAT(8)
 GO TO 80
89 SEQT(N)=TMAT(9)
 GO TO 80
91 SEQT(N)=TMAT(10)
 GO TO 80
92 SEQT(N)=TMAT(11)
 GO TO 80
93 SEQT(N)=TMAT(12)

```

B-11

BNWL-616



```

80 CONTINUE
90 CONTINUE
 CALL DATAIN
C SUBROUTINE DATAIN WILL CALCULATE THE NODE DIMENSIONS,FACE AREAS,
C VOLUMES,AND ADJACENT NODE NUMBERS FOR THE SYSTEM
C
 CONTINUE
95 HG=0.0
 CALL ETIME
 NLIM=NLIM+(1-NLIM/NLIM)*600
 NTIME=XLPTIM*2.0
 DO 100 N=1,NON
C CALCULATION OF HEAT FLOW (BTU/HR)
 MO=MAT(N)
96 Q(N)=VOL(N)*HEAT(MO)
97 HG=HG+Q(N)
100 CONTINUE
 DO 110 N=1,NON
 MESS=1
 DO 120 I=1,6
 IF (ADJ(N,I)) 122,121,122
121 U(N,I)=0.0
 GO TO 141
122 K=MAT(N)
 IF (TC(2*K-1)+TC(2*K)*(SEQT(N)-460.0)) 123,999,123
C CHECKING TO SEE IF THERE IS A THERMAL CONDUCTIVITY VALUE
C FOR NODE (N)
123 R=X(N,I)/(12.0*(TC(2*K-1)+TC(2*K)*(SEQT(N)-460.0)))
 IF (ADJ(N,I)) 124,121,125
125 L=ADJ(N,I)
 KA=MAT(L)
 IF ((TC(2*KA-1)+TC(2*KA)*(SEQT(N)-460.0)) .GT. 0.0) GO TO 126
 GO TO 999
126 GO TO (131,132,133,134), MESS
C CALCULATING THE CONDUCTANCE ACROSS EACH FACE(R ORIGINALLY
C HAS THE UNITS OF HR-FT**2-DEG F/BTU, THEN FINALLY

```

B-12

BNWL-616

```

C THE RECIPROCAL OF THIS, BTU/HR-FT**2-DEG F
C
131 R=R+X(L,2)/(12.0*(TC(2*KA-1)+TC(2*KA)*(SEQT(L)-460.0)))
 GO TO 130
132 R=R+X(L,1)/(12.0*(TC(2*KA-1)+TC(2*KA)*(SEQT(L)-460.0)))
 GO TO 130
133 R=R+X(L,4)/(12.0*(TC(2*KA-1)+TC(2*KA)*(SEQT(L)-460.0)))
 GO TO 130
134 R=R+X(L,3)/(12.0*(TC(2*KA-1)+TC(2*KA)*(SEQT(L)-460.0)))
130 CONTINUE
124 IF (C(N,I) .LT. 1.0E-4) GO TO 135
 GO TO 136
135 IF (R) 137,138,137
138 R=1.0E-30
137 R=1.0/R
 GO TO 139
136 R=1.0/(R+1.0/ABS(C(N,I)))
139 U(N,I)=R*(A(N,I)/144.0)
C U HAS THE UNITS OF BTU/HR-DEG F
141 MESS=MESS+1
120 CONTINUE
110 CONTINUE
 IF (NIT .NE. 0) GO TO 142
 NIT=5
C NIT = NUMBER OF ITERATIONS BEFORE GOING TO THE NEXT STEP
C START OF THE ACTUAL TEMPERATURE CALCULATIONS (ITERATIVE TYPE)
142 DO 150 K=1,NIT
 DO 150 N=1,NON
C SEQT = SEQUENTIAL TEMPERATURE
C OLDT = OLD TEMPERATURE
151 D(N)=SEQT(N)-OLDT(N)
 OLDT(N)=SEQT(N)
 TOP=0.0
 BOTTOM=0.0
 HOLD=0.0
 DO 160 I=1,6

```

B-13

BNWL-616

```

 L=ADJ(N,I)
 IF (L) 161,163,163
161 MO=-1*L
162 TOP=TOP+(460.0+SINK(MO))*U(N,I)
 GO TO 160
163 TOP=TOP+SEQT(L)*U(N,I)
160 BOTTOM=BOTTOM+U(N,I)
 IF (BOTTOM .GT. 0.0) GO TO 164
 BOTTOM=1.0E-04
164 SEQT(N)=(Q(N)+TOP)/BOTTOM
150 CONTINUE
C START OF THE HEAT BALANCE CALCULATIONS
C ERROR = ALGEBRAIC SUM OF THE HEAT FLOW FROM EACH NODE + THE
C HEAT GENERATED IN THE NODE
C ALL = ABSOLUTE SUM OF THE HEAT FLOW BETWEEN THE SYSTEM AND
C THE SINKS
C FLAME = BTU INTERCHANGE BETWEEN FACES OR BETWEEN A FACE AND
C A SINK
C DELTA = ALGEBRAIC SUM OF THE HEAT FLOW + THE HEAT GENERATED,
C OVER ALL THE NODES
C BTU = SUM OF THE HEAT FLOW ACROSS ALL THE NODES
C THF = ALGEBRAIC SUM OF THE HEAT FLUX OVER ALL THE NODE FACES
C HS=SUM OF THE HEAT TO THE SINKS
 ERROR=0.0
 ALL=0.0
 DELTA=0.0
 BTU=0.0
 THF=0.0
 HS=0.0
 DO 170 N=1,NON
 ERROR=ERROR+Q(N)
 ALL=ALL+Q(N)
 DELTA=DELTA+Q(N)
 DO 170 I=1,6
 K=ADJ(N,I)
 IF (K) 171,170,174

```

```

171 MO=-1*K
 FLAME=U(N,I)*(SEQT(N)-(460.0+SINK(MO)))
 ERROR=ERROR-FLAME
 DELTA=DELTA-FLAME
172 THF=THF+FLAME
 HS=HS+FLAME
 ALL=ALL+ABS(FLAME)
173 BTU=BTU+ABS(FLAME)
 GO TO 170
174 FLAME=U(N,I)*(SEQT(K)-SEQT(N))
 DELTA=DELTA+FLAME
175 THF=THF+FLAME
176 BTU=BTU+0.5*ABS(FLAME)
170 CONTINUE
 ALL=0.5*ALL
 IF (ABS((HG-HS)/HG)*100 .LE. ABS(TERROR)) GO TO 191
C CHECKING THE ELAPSED TIME
177 CALL ETIMEF(XLPTIM)
 NTIME=XLPTIM*2.0
 IF ((NTIME/120-NLIM) .GE. 0) GO TO 191
 DO 180 N=1,NON
C THIS IS THE EXTRAPOLATION SECTION OF THE PROGRAM (FOR
C TEMPERATURE ADJUSTMENTS)
 HOLD=SEQT(N)
 DIFF=(SEQT(N)-OLDT(N))
 FACS=SIGN(1.0,DIFF)
 CH=ACF*SEQT(N)*ABS((HG-HS)/HG)
C CH=CHANGE
C ACF = ACCELERATION FACTOR
 IF (25.0+CH) 181,183,182
182 IF (25.0-CH) 184,183,183
181 CH=-25.0
 GO TO 185
183 CH=CH
 GO TO 185
184 CH=+25.0

```

```

185 IF ((SEQT(N)-OLDT(N))/D(N)) 187,187,186
186 IF ((SEQT(N)-OLDT(N))/D(N)-0.85) 189,189,188
188 SEQT(N)=(SEQT(N)+(SEQT(N)-OLDT(N))*ACF)+(CH*FACS)
 GO TO 180
189 SEQT(N)=(SEQT(N)-(SEQT(N)-OLDT(N))/(1.0-(D(N)/(SEQT(N)-OLDT(N)))))
 1+(CH*FACS)
187 OLDT(N)=HOLD
180 CONTINUE
 GO TO 142
191 DO 190 L=1,NON
 DO 190 I=1,6
 K=ADJ(L,I)
 IF (K .GE. 0) GO TO 190
 MO=-1*K
C THERM = THE HEAT FLOW FROM A NODE TO A SINK
192 THERM(L,I)=U(L,I)*(SEQT(L)-(460.0+SINK(MO)))
190 CONTINUE
 Z=-460.0
 DO 200 I=1,NON
 SEQT(I)=SEQT(I)-460.0
 IF (SEQT(I)-Z) 200,200,193
193 Z=SEQT(I)
C PICKING OUT THE NODE WITH THE MAXIMUM TEMPERATURE
 IZ=I
200 CONTINUE
 DO 210 K=1,6
210 SINKQ(K)=0.0
 DO 220 N=1,NON
 DO 220 I=1,6
 IF (ADJ(N,I)) 211,220,220
211 L=-1*ADJ(N,I)
C SINKQ = THE SUM OF THE HEAT FLOW TO A SINK
 SINKQ(L)=SINKQ(L)+THERM(N,I)
220 CONTINUE
C ERRIS = HEAT BALANCE ERROR IN PERCENT, ((HEAT GENERATED-HEAT TO
C THE SINKS)/HEAT GENERATED)*100

```

```

ERRIS=((HG-HS)/HG)*100
NSK=3
IF (IFIX(SINK(4)+SINK(5)+SINK(6)) .GT. 0) NSK=6
C SETTING UP THE PRINTOUT INSTRUCTIONS
WRITE(3,8) ID,ERRIS,Z,IZ,(SINKQ(I),I=1,NSK)
DO 240 J=1,6
IF (SINK(J)) 241,240,241
241 WRITE(3,9) J
K=1
DO 230 N=1,NON
DO 230 I=1,6
IF (ADJ(N,I)+J) 230,231,230
231 GO TO (232,233,234), K
232 WRITE(3,10) THERM(N,I),N
K=2
GO TO 230
233 WRITE(3,11) THERM(N,I),N
K=3
GO TO 230
234 WRITE(3,12) THERM(N,I),N
K=1
230 CONTINUE
240 CONTINUE
WRITE(3,13)
WRITE(3,17)
NN=1
242 NNN=NN+9
NNN=MIN0(NON,NNN)
WRITE(3,15) NN,(SEQT(I),I=NN,NNN)
NN=NN+10
243 IF (NON-NN .LT. 0) GO TO 244
GO TO 242
244 WRITE (3,16) ID,ERROR,ALL,DELTA,BTU,THF
CALL DATABL
DO 245 I=1,NON
SEQT(I)=SEQT(I)+460.0

```

```
245 CONTINUE
 WRITE (3,20) XLPTIM
 GO TO 63
999 WRITE (3,19)
888 CALL EXIT
 END
```

B-18

BNWL-616

APPENDIX C

TYPICAL PRINT-OUT OF PROGRAM HOTANK





## CALCULATION OF STEADY STATE TEMPERATURES

PROGRAM HOTANK

CASE NO. 6666

HEAT BALANCE ERROR = -.110637 PERCENT

MAX TEMP = 5.340+02 DEG F AT NODE 231

1.114+02 BTU/HR TO SINK 1

2.771+01 BTU/HR TO SINK 2

0.000

BTU/HR TO SINK 3

## HEAT FROM NODES TO SINK 1

HEAT= 4.613-02 FROM NODE 1  
 HEAT= 7.294+00 FROM NODE 4  
 HEAT= 1.533+01 FROM NODE 7  
 HEAT= 2.366+01 FROM NODE 10

HEAT= 6.831-01 FROM NODE 2  
 HEAT= 1.058+01 FROM NODE 5  
 HEAT= 1.804+01 FROM NODE 8

HEAT= 1.803+00 FROM NODE 3  
 HEAT= 1.309+01 FROM NODE 6  
 HEAT= 2.086+01 FROM NODE 9

## HEAT FROM NODES TO SINK 2

HEAT= 8.377-03 FROM NODE 281  
 HEAT= 1.359+00 FROM NODE 284  
 HEAT= 3.920+00 FROM NODE 287  
 HEAT= 6.359+00 FROM NODE 290

HEAT= 1.246-01 FROM NODE 282  
 HEAT= 2.230+00 FROM NODE 285  
 HEAT= 4.744+00 FROM NODE 288

HEAT= 3.301-01 FROM NODE 283  
 HEAT= 3.082+00 FROM NODE 286  
 HEAT= 5.557+00 FROM NODE 289

## NODE TEMPERATURES, DEG F

|      | 1        | 2        | 3        | 4        | 5        | 6        | 7        | 8        | 9        | 10       |
|------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| 1X   | 7.001+01 | 7.001+01 | 7.001+01 | 7.001+01 | 7.001+01 | 7.001+01 | 7.001+01 | 7.001+01 | 7.001+01 | 7.001+01 |
| 11X  | 1.143+02 | 1.141+02 | 1.138+02 | 1.125+02 | 1.071+02 | 1.029+02 | 9.979+01 | 9.784+01 | 9.732+01 | 9.685+01 |
| 21X  | 1.841+02 | 1.844+02 | 1.843+02 | 1.822+02 | 1.675+02 | 1.562+02 | 1.475+02 | 1.408+02 | 1.393+02 | 1.381+02 |
| 31X  | 2.562+02 | 2.581+02 | 2.591+02 | 2.567+02 | 2.311+02 | 2.122+02 | 1.966+02 | 1.828+02 | 1.795+02 | 1.776+02 |
| 41X  | 3.342+02 | 3.372+02 | 3.393+02 | 3.374+02 | 2.994+02 | 2.715+02 | 2.474+02 | 2.245+02 | 2.176+02 | 2.147+02 |
| 51X  | 4.189+02 | 4.221+02 | 4.249+02 | 4.256+02 | 3.720+02 | 3.333+02 | 3.004+02 | 2.660+02 | 2.532+02 | 2.490+02 |
| 61X  | 4.698+02 | 4.725+02 | 4.753+02 | 4.790+02 | 4.462+02 | 3.971+02 | 3.553+02 | 3.068+02 | 2.866+02 | 2.803+02 |
| 71X  | 4.733+02 | 4.750+02 | 4.770+02 | 4.799+02 | 4.865+02 | 4.598+02 | 4.098+02 | 3.454+02 | 3.177+02 | 3.095+02 |
| 81X  | 4.776+02 | 4.778+02 | 4.784+02 | 4.801+02 | 4.859+02 | 4.920+02 | 4.627+02 | 3.802+02 | 3.463+02 | 3.371+02 |
| 91X  | 4.802+02 | 4.792+02 | 4.787+02 | 4.794+02 | 4.842+02 | 4.903+02 | 4.906+02 | 4.097+02 | 3.715+02 | 3.626+02 |
| 101X | 4.799+02 | 4.787+02 | 4.780+02 | 4.780+02 | 4.818+02 | 4.873+02 | 4.886+02 | 4.294+02 | 3.930+02 | 3.851+02 |
| 111X | 4.780+02 | 4.774+02 | 4.767+02 | 4.764+02 | 4.793+02 | 4.839+02 | 4.857+02 | 4.424+02 | 4.107+02 | 4.043+02 |
| 121X | 4.762+02 | 4.760+02 | 4.756+02 | 4.757+02 | 4.777+02 | 4.814+02 | 4.835+02 | 4.514+02 | 4.252+02 | 4.199+02 |
| 131X | 4.751+02 | 4.753+02 | 4.757+02 | 4.766+02 | 4.781+02 | 4.810+02 | 4.830+02 | 4.585+02 | 4.370+02 | 4.324+02 |
| 141X | 4.752+02 | 4.763+02 | 4.777+02 | 4.792+02 | 4.803+02 | 4.825+02 | 4.843+02 | 4.652+02 | 4.470+02 | 4.424+02 |
| 151X | 4.780+02 | 4.796+02 | 4.812+02 | 4.828+02 | 4.837+02 | 4.852+02 | 4.867+02 | 4.719+02 | 4.562+02 | 4.507+02 |
| 161X | 4.831+02 | 4.842+02 | 4.854+02 | 4.866+02 | 4.871+02 | 4.882+02 | 4.892+02 | 4.787+02 | 4.650+02 | 4.579+02 |
| 171X | 4.884+02 | 4.886+02 | 4.889+02 | 4.895+02 | 4.898+02 | 4.906+02 | 4.912+02 | 4.647+02 | 4.732+02 | 4.648+02 |
| 181X | 4.921+02 | 4.914+02 | 4.911+02 | 4.911+02 | 4.913+02 | 4.919+02 | 4.922+02 | 4.898+02 | 4.806+02 | 4.721+02 |
| 191X | 4.933+02 | 4.923+02 | 4.917+02 | 4.914+02 | 4.915+02 | 4.920+02 | 4.923+02 | 4.945+02 | 4.874+02 | 4.794+02 |
| 201X | 5.102+02 | 5.092+02 | 5.078+02 | 5.062+02 | 5.050+02 | 5.051+02 | 5.054+02 | 4.997+02 | 4.933+02 | 4.862+02 |
| 211X | 5.231+02 | 5.221+02 | 5.204+02 | 5.180+02 | 5.160+02 | 5.159+02 | 5.162+02 | 5.046+02 | 4.981+02 | 4.919+02 |
| 221X | 5.309+02 | 5.300+02 | 5.283+02 | 5.258+02 | 5.236+02 | 5.234+02 | 5.235+02 | 5.085+02 | 5.015+02 | 4.959+02 |
| 231X | 5.340+02 | 5.333+02 | 5.320+02 | 5.300+02 | 5.280+02 | 5.277+02 | 5.275+02 | 5.108+02 | 5.032+02 | 4.981+02 |
| 241X | 5.237+02 | 5.243+02 | 5.250+02 | 5.253+02 | 5.245+02 | 5.235+02 | 5.208+02 | 5.115+02 | 5.051+02 | 5.009+02 |
| 251X | 5.166+02 | 5.181+02 | 5.194+02 | 5.199+02 | 5.188+02 | 5.167+02 | 5.132+02 | 5.077+02 | 5.030+02 | 4.998+02 |
| 261X | 5.209+02 | 5.184+02 | 5.152+02 | 5.108+02 | 5.067+02 | 5.029+02 | 4.991+02 | 4.956+02 | 4.928+02 | 4.907+02 |
| 271X | 4.857+02 | 4.846+02 | 4.824+02 | 4.786+02 | 4.745+02 | 4.709+02 | 4.679+02 | 4.657+02 | 4.642+02 | 4.631+02 |
| 281X | 3.900+02 | 3.872+02 | 3.833+02 | 3.776+02 | 3.728+02 | 3.690+02 | 3.658+02 | 3.629+02 | 3.603+02 | 3.579+02 |

C-1

BNWL-616

SUPPLEMENTAL PROGRAM \*\*\* ERROR FIGURES FOR CASE NO. 6666

-1.53723-01 BTU/HR = ERROR IN HEAT BALANCE BETWEEN HEAT IN AND HEAT OUT OF THE SYSTEM  
 1.39017+02 BTU/HR = TOTAL HEAT ADDED TO THE SYSTEM (AND REMOVED FROM THE SYSTEM)

-1.53736-01 BTU/HR = ERROR IN HEAT BALANCE AMONG ALL INDIVIDUAL NODES  
 2.83708+04 BTU/HR = SUM OF HEAT TRANSFERRED ACROSS ALL NODE FACES  
 1.39094+02 BTU/HR = ALGEBRAIC SUM OF THE HEAT FLOW OVER ALL NODE FACES

\*\*\* SUMMARY OF INPUT DATA FOR CASE NO. 6666 \*\*\*

|                        |                     |                                           |              |
|------------------------|---------------------|-------------------------------------------|--------------|
| THERMAL CONDUCTIVITIES | SINK TEMPERATURES   | VOLUMETRIC HEAT GEN RATE (BTU/HR CU FT) = | 1.415        |
| BTU/(HR SQFT DEG F/FT) | DEGREES FAHRENHEIT  | TOTAL HEAT LOAD IN TANK (BTU/HR)          | = 5.00184+04 |
| MATERIAL 1 .1500       | SINK 1 70.00        | SLUDGE OR CAKE THICKNESS (FEET) =         |              |
| MATERIAL 2 1.2000      | SINK 2 70.00        | SOIL COVER DEPTH (FEET) =                 |              |
| MATERIAL 3 200.0000    |                     | LIQUID LAYER DEPTH (FEET) =               |              |
| MATERIAL 4 -.0000      |                     |                                           |              |
| MATERIAL 5 200.0000    |                     |                                           |              |
| MATERIAL 6 -.0000      |                     |                                           |              |
| MATERIAL TYPE          | FILM COEFFICIENTS   | TANK DIAMETER                             | (FEET) =     |
|                        | (BTU/HR SQFT DEG F) | TANK HEIGHT                               | (FEET) =     |
| 1                      | NODE H              |                                           |              |
| 2                      |                     |                                           |              |
| 3                      |                     |                                           |              |
| 4                      |                     |                                           |              |
| 5                      |                     |                                           |              |
| 6                      |                     |                                           |              |

DISTRIBUTIONNumber of  
Copies

|                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |              |                    |              |               |                 |              |              |              |                |             |                  |               |             |                       |             |                           |  |                            |
|------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|--------------------|--------------|---------------|-----------------|--------------|--------------|--------------|----------------|-------------|------------------|---------------|-------------|-----------------------|-------------|---------------------------|--|----------------------------|
| 2                | <u>AEC Chicago Patent Group</u><br>G. H. Lee<br>R. K. Sharp, Richland                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |              |                    |              |               |                 |              |              |              |                |             |                  |               |             |                       |             |                           |  |                            |
| 2                | <u>AEC Richland Operations Office</u><br>C. L. Robinson<br>Technical Information Library                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |              |                    |              |               |                 |              |              |              |                |             |                  |               |             |                       |             |                           |  |                            |
| 1                | <u>Argonne National Laboratory</u><br>John Loeding                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |              |                    |              |               |                 |              |              |              |                |             |                  |               |             |                       |             |                           |  |                            |
| 16               | <u>Atlantic Richfield Hanford Company</u><br>S. J. Beard<br>H. L. Brandt<br>J. B. Fecht<br>W. L. Godfrey<br>M. K. Harmon<br>W. M. Harty<br>P. Hatch<br>H. C. Rathvon<br>W. C. Schmidt<br>H. P. Shaw<br>R. J. Sloat<br>P. W. Smith<br>R. E. Smith<br>R. E. Tomlinson<br>L. L. Zahn<br>200 West Files                                                                                                                                                                                                                                                                                                                            |              |                    |              |               |                 |              |              |              |                |             |                  |               |             |                       |             |                           |  |                            |
| 3                | <u>Battelle Memorial Institute</u>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |              |                    |              |               |                 |              |              |              |                |             |                  |               |             |                       |             |                           |  |                            |
| 1                | <u>Union Carbide Corporation (ORNL)</u><br>R. L. Bradshaw                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |              |                    |              |               |                 |              |              |              |                |             |                  |               |             |                       |             |                           |  |                            |
| 36               | <u>Battelle-Northwest</u><br><table border="0"> <tbody> <tr> <td>G. J. Alkire</td> <td>G. Jansen, Jr. (5)</td> </tr> <tr> <td>J. M. Atwood</td> <td>B. M. Johnson</td> </tr> <tr> <td>A. G. Blasewitz</td> <td>R. W. Nelson</td> </tr> <tr> <td>C. R. Cooley</td> <td>D. W. Pearce</td> </tr> <tr> <td>D. R. de Halas</td> <td>A. M. Platt</td> </tr> <tr> <td>W. V. DeMier (2)</td> <td>C. J. Touhill</td> </tr> <tr> <td>W. A. Haney</td> <td>W. E. Willingham (10)</td> </tr> <tr> <td>B. F. Hajek</td> <td>Technical Information (5)</td> </tr> <tr> <td></td> <td>Technical Publications (2)</td> </tr> </tbody> </table> | G. J. Alkire | G. Jansen, Jr. (5) | J. M. Atwood | B. M. Johnson | A. G. Blasewitz | R. W. Nelson | C. R. Cooley | D. W. Pearce | D. R. de Halas | A. M. Platt | W. V. DeMier (2) | C. J. Touhill | W. A. Haney | W. E. Willingham (10) | B. F. Hajek | Technical Information (5) |  | Technical Publications (2) |
| G. J. Alkire     | G. Jansen, Jr. (5)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |              |                    |              |               |                 |              |              |              |                |             |                  |               |             |                       |             |                           |  |                            |
| J. M. Atwood     | B. M. Johnson                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |              |                    |              |               |                 |              |              |              |                |             |                  |               |             |                       |             |                           |  |                            |
| A. G. Blasewitz  | R. W. Nelson                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |              |                    |              |               |                 |              |              |              |                |             |                  |               |             |                       |             |                           |  |                            |
| C. R. Cooley     | D. W. Pearce                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |              |                    |              |               |                 |              |              |              |                |             |                  |               |             |                       |             |                           |  |                            |
| D. R. de Halas   | A. M. Platt                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |              |                    |              |               |                 |              |              |              |                |             |                  |               |             |                       |             |                           |  |                            |
| W. V. DeMier (2) | C. J. Touhill                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |              |                    |              |               |                 |              |              |              |                |             |                  |               |             |                       |             |                           |  |                            |
| W. A. Haney      | W. E. Willingham (10)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |              |                    |              |               |                 |              |              |              |                |             |                  |               |             |                       |             |                           |  |                            |
| B. F. Hajek      | Technical Information (5)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |              |                    |              |               |                 |              |              |              |                |             |                  |               |             |                       |             |                           |  |                            |
|                  | Technical Publications (2)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |              |                    |              |               |                 |              |              |              |                |             |                  |               |             |                       |             |                           |  |                            |
| 240              | <u>AEC Division of Technical Information</u>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |              |                    |              |               |                 |              |              |              |                |             |                  |               |             |                       |             |                           |  |                            |