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FORTRAN-IV COMPUTER PROGRAM
FOR CALCULATING TRANSIENT
HEAT TRANSFER COEFFICIENTS
FROM WALL TEMPERATURES

P. C. Owzarski

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FORTTRAN-IV COMPUTER PROGRAM
FOR CALCULATING TRANSIENT HEAT TRANSFER COEFFICIENTS
FROM WALL TEMPERATURES

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October 1967

PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

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FORTRAN-IV COMPUTER PROGRAM
FOR CALCULATING TRANSIENT HEAT TRANSFER COEFFICIENTS
FROM WALL TEMPERATURES

INTRODUCTION

Program Xingu has been developed to analyze transient wall and steam temperatures during a CSE blowdown or other analogous transient experiment. By calculating the temperature-time history in the containing walls, transient steamside heat transfer coefficients are estimated and total heat exchange per unit area is calculated.

The following sections respectively denote the capabilities of Program Xingu, explain the use of the program in detail, and explain the methods employed in the program.

PURPOSE AND CAPABILITIES OF PROGRAM XINGU

This Fortran-IV program was written to be used on UNIVAC-1108. It can be easily adapted to any Fortran-IV computer.

Program Xingu performs postmortem calculations on transient one dimensional ("1D") temperature-time data. Input data are three sets of a finite number of pairs of steam temperature-time points, steamside wall temperature time points, and far (outer) wall temperature-time points. Only one transient event is analyzed. Output consists of the steamside flux, a flux-time integral, a steamside temperature gradient in the wall, and a heat transfer coefficient based on the steam to steamside wall temperature difference. All are computed as functions of time. Adjustments to print other interior temperatures and gradients can be easily accomplished.

Multiple event analysis can be accomplished by using the program once for each individual event. Approximately one minute of UNIVAC-1108 machine time is required to analyze a ten-second event if a one-millisecond time interval is used in the finite difference employed in the program.

The original version, XINGU/A1R, can analyze an event only at a wall of one material. A modified version, XINGU/A2R, is capable of analyzing an event at a two-material composite wall. No restrictions exist on the choice of thermal conductivity and thermal diffusivity ratios.

PROGRAM DESCRIPTION

Program Xingu operates on temperature-time data input and fits a power series of equations to the data. Then it proceeds to establish initial conditions throughout the wall and initiates a time-marching solution of the finite difference heat equation until program completion.

Operations on Input Temperature - Time Data

1. Data is read in according to previously described data deck format. Immediately the data is printed for reference.
2. Each temperature and time datum is assigned a position in a vector, e.g., the vector TST(J) and TIMEST(J) have NST steam temperature and time components

$$TST(1) = xxx.x$$

$$TIMEST(1) = 0.$$

as initial conditions. NST-1 other vector component pairs exist for the steam data for $t > 0$.

3. For each of the three vector pairs, a set of linear simultaneous equations are set up. For example:

$$TST(J) - TST(1) = \sum_{K=1}^{NST-1} X(K) TIMEST(J)^K$$

4. The coefficients $X(K)$ are obtained using the Gauss-Seidel iteration method.⁽¹⁾
5. This technique enables a Laplace transformation correction scheme for thermocouple lag. If the thermocouples have a rise time of τ seconds, then the steam temperature at any time t is

$$TST = TST(1) + \sum_{K=1}^{NST-1} X(K)t^K(1 + K \cdot \frac{TAU}{t})$$

See Appendix II for development of this correction technique.

6. If the coefficients $X(K)$ do not converge or provide a poor fit to the input data, an alternate scheme for calculating a temperature at any time is initiated. This is a three-point interpolation that assumes three successive points lie on a parabola. Thermocouple lag is compensated for only in the first time interval, e.g., from $TIMEST(1) = 0.$ to $TIMEST(2)$. At this point operations on input data are complete.
7. The steamside wall temperature-time data $[TIW(J)$ and $TIMEIW(J)]$ and outer wall temperature-time data $[TOW(J)$ and $TIMEOW(J)]$ are handled similarly.

Solution of the Heat Equation in One Dimension

The heat equation in one dimension

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial X^2}$$

is solved using a simple marching technique with the finite difference form of the above:

$$T(n,m+1) - T(n,m) = \frac{\alpha \Delta t}{\Delta X^2} \left[T(n+1,m) - 2T(n,m) + T(n-1,m) \right]$$

for stability, $\alpha \Delta t / \Delta X^2 \leq \frac{1}{2}$.

The spacial grid consists of two series regions of 100 points. In the steamside region of the wall ΔX has been chosen to be very small, i.e., 1/500 of wall thickness and the far region 1/125 of the wall thickness. This insures a fair degree of accuracy in rapidly changing steamside region.

Boundary conditions are obtained from the input data where

$$T(1,M) = TIW(1,M), \text{ inner (steamside) wall temp}$$

$$T(201,M) = TOW(1,M), \text{ outer wall temp}$$

The initial conditions $T(N,1)$ are linear interpolations of the inner wall datum at $t = 0$ and outer wall datum at $t = 0$.

The time-marching is initiated using the initial conditions to calculate $T(N,2)$, $N=2$ to 201. $T(1,2)$ is the inner wall temperature at $t = \Delta t$. Once completed, $T(N,2)$ becomes $T(N,1)$ to save computer storage space, and the calculations are repeated for the next interval.

Calculated along with the temperature distribution and printed once every 100 time intervals are the steamside gradient and flux, the effective heat transfer coefficient defined as

$$HEFF = \frac{k [T(\text{steamside wall surface}) - T(\text{1st interior point})]}{[T(\text{steam}) - T(\text{steamside wall surface})] \cdot \Delta X}$$

and the flux integral

$$\int_0^t Q dt = \sum n Q(t_n) \Delta t.$$

The program execution ends when $n\Delta t \geq \text{TOTIME}$, an input variable.

INSTRUCTIONS FOR USING PROGRAM XINGU

The three means for using Program Xingu are Fortran-IV language deck, binary language deck, and magnetic tape. Control cards to use for each method will be described in detail following a description of that data deck.

Data Deck Format

Card #1. This card is an integer (without a decimal point) designating the number of steamside wall temperature-time data. The variable name is NIW. Punch the number to the far right of positions 1-5. Do not exceed 30.

Cards #2 to NIW + 1. These are the steamside temperature-time data. The NIW data have corresponding names. TIW (J) and TIMEIW (J) where the initial condition is TIW (1) (in °F) at TIMEIW (1) = 0.(seconds). TIW (J) must be punched in columns 1-10; TIMEIW (J) in Columns 11-20. An example is shown at the top of the following page.

*****1*****2*****3*****4*****5*****6*****7**

13

622. 0.

597.16 1.5

341.2 4.5

° °

° °

° °

109.15 6

Card #NIW + 2. This integer (NØW) is the number of far wall data.
Handle like card #1.

Card #NIW + 3 to NIW + NØW + 3. These are the far wall data. Handle
like the NIW data. Variable names are TØW (J) and TIMEØW (J).

Card #NIW + NØW + 3. This integer (NST) is the number of steam data.
Handle like card #1.

Cards #NIW + NØW + 4 to NIW + NØW + NST + 4. These are the steam data.
Handle like the NIW data. Variable names are TST (J) and TIMEST (J).

Following the temperature-time data are the following seven cards
(eight cards for XINGU/A2R).

1. k , thermal conductivity, Btu/hr ft^{2*} Columns 1-10
2. w , wall thickness, ft* Columns 1-10
3. ρC_p , density times heat capacity* Btu/ft³ Columns 1-10

*The values on cards 1, 2, and 3 refer to the homogeneous wall properties if XINGU/A1R is being used. They refer to the outer wall (away from the steamside wall) properties if XINGU/A2R is being used.

4. Δt , time increment, seconds* Columns 1-10
5. t , thermocouple response time, seconds Columns 1-10
6. Total duration of heat transfer time, seconds Columns 1-10
7. Total number of iterations for temperature-time curve fit. Keep less than 30. Place to far right of Columns 1-5.
8. (for XINGU/A2R only) In Columns 1-10 place the steamside composite wall thickness, (feet); in Columns 11-20 place the thermal conductivity of the same region, Btu/hr ft²F; and in Columns 21-30 place the thermal diffusivity of the same region (ft²/hr).

e.g.

*****1*****2*****3*****4*****5*****6*****7**

26.

.25

53.9

.0008

.01

6.

30

.025

9.4

.015

THE DATA DECK FOR XINGU/A1R SHOULD HAVE NIW + NØW + NST + 10 CARDS AND ONE MORE FOR XINGU/A2R.

* Δt must be chosen so that the dimensionless scale factor h^2 has the limit:

$$h^2 = \frac{(\Delta x)^2}{\frac{k}{\rho C_p} \Delta t} \geq 2$$

CONTROL CARD FORMATS:

From Fortran-IV Deck:*

*****1*****2*****3*****4*****5*****6*****7**

▽ RUN 5,CUB026,TIME,PAGES NAME, TITLE

▽IT FRN XINGU,XINGU,XINGU/AIR(OR A2R)

SOURCE DECK HERE (FORTRAN)

▽ XQT XINGU/AIR

DATA DECK HERE

▽ FIN

From Binary Deck:

*****1*****2*****3*****4*****5*****6*****7**

▽ RUN 5,CUB026,TIME,PAGES NAME, TITLE

BINARY DECK HERE

▽ XQT XINGU/AIR

DATA DECK HERE

▽FIN

*▽ in position 1 refers to a simultaneous 7-8 punch.

where

$$\Delta x = \text{wall thickness}/500 = w/500$$

and

$$\frac{k}{\rho C_p} = \alpha, \text{ thermal diffusivity}$$

Note: Apply this criterion to the material away from the steamside wall if XINGU/A2R is being applied to a composite wall.

From Tape:

*****1*****2*****3*****4*****5*****6*****7**

V RUN 5,CUB026,TIME,PAGES NAME, TITLE

R ASG A=U1133

V KQT CUR

IN A

TRI A

TOC EL,EP

V XQT XINGU/A1R

DATA DECK HERE

V FIN

To Put Fortran on tape use the following:

*****1*****2*****3*****4*****5*****6*****7**

V RUN 5,CUB026,TIME,PAGES NAME, TITLE

VR ASG B= (NAME OR NUMBER)

VIT FRN XINGU,XINGU,XINGU/A1R(OR A2R)

SOURCE DECK HERE (FORTRAN)

V XQT CUR

OUT B,1,3

TEF B

TRI B

TOC EL,EP

V XQT XINGU/A1R

DATA DECK HERE

VFIN

APPENDIX A

PROGRAM XINGU PRINTOUT

1. A1R Version
2. A2R Version

1. AIR Version

```

C
C
C
C   PROGRAM XINGU
C   THIS PROGRAM EVALUATES EFF H.T. COEFF(TIME) DURING BLOWDOWN IN CSE
C   INPUT VARIABLES
C   TST=STEAM TEMP,DEGREES FAHRENHEIT,NST INPUT POINTS  (NST=1,AT TIME=0.)
C   TIW(NIW),STEAMSIDE WALL TEMP,NIW PTS                (NIW=1,AT TIME=0.;
C   TOW(NOW),OUTSIDE WALL TEMP,NOW PTS                  (NOW=1,AT TIME=0.)
C   TOTIME,TOTAL DURATION OF COMPUTATION DESIRED,SECONDS
C   COND,THERMAL CONDUCTIVITY,BTU/HRFT-F
C   W,WALL THICKNESS,FT
C   RHOCp,WALL DENSITY*WALLHEATCAPACITY,BTU/(FT**3F)
C   DELT,DIFFERENTIAL TIME INTERVAL,SEC
C   TAU=THERMOCOUPLE RESPONSE TIME,SEC
C   NST(KEEP LESS THAN30)
C   NIW(   DITTO   )
C   NOW(   DITTO   )
C   ITL=NO. ITERATIONS TO GIVE GOOD DATA FIT TO POWER SERIES
C   TIMEIW(I),TIMEOW(J)= TIME CORRESP TO TIW(I),TOW(J) (I=1 MEANS TIME=0.ALWAYS)
C   OUTPUT  VARIABLES
C
C   IT,PARTICULAR ITERATION
C   X(I),Y(I),Z(I)=SOLUTION VECTORS FOR STEAM,INNERWALL,OUTER WALL TEMP SUCH
C   THAT  TST= TST(1) SUM(J=1,NST) 7(J)*TIME**(J)  ETC
C   TIME,TIW,TOW,TST
C   DIFFT=TEMPERATURE DIFFERENCE ACROSS FIRST INCREMENT W/500.,DEG F
C   DGAST=TST-TIW
C   Q=WALL FLUX,BTU/HRFT**2
C   HEFF=Q/DGAST,LOCAL EFFECTIVE H.T. COEFF.,BTU/HRFTFTDEGREESEF
C   SUMQDT=TOTAL HEAT PASSED THROUGH STEAM SIDE WALL, BTU/FT**2
C   GRAD=TEMP GRADIENT IN WALL AT SURFACE, DEGF/IN
C
C
C
C
C   DIMENSION A(30,30),B(30,30),C(30, 0),T(205,2),TIW(30),TIMEIW(30),T
2OW(30),TIMEOW(30),TST(30),TIMEST(30),X(30),Y(30),Z(30),XX(30,30)
C   DIMENSION VIW(30),VOW(30),VST(30)
C   READ(5,100) NIW
100  FORMAT(I5)
C   READ(5,300) (TIW(J),TIMEIW(J),J=1,NIW)
300  FORMAT(2F10.0)
C
C   READ(5,101) NOW
101  FORMAT(I5)
C   READ(5,301) (TOW(J),TIMEOW(J),J=1,NOW)
301  FORMAT(2F10.0)
C

```

```

      READ(5,102)NST
102  FORMAT(I5)
      READ(5,302) (TST(J),TIMEST(J),J=1,NST)
302  FORMAT(2F10.0)

```

C
C

```

      READ(5,103) COND,W,RHOCP,DELT,TAU,TOTIME,ITL
103  FORMAT(F10.0/F10.0/F10.0/F10.0 /F10.0/F10.0/I5)
      WRITE(6,17)
17   FORMAT(1H0,10X,20HINNER WALL TEMP DATA)
      WRITE(6,18) (TIW(J),TIMEIW(J),J=1,NIW)
18   FORMAT(1H0,10X,2E1 .5)
      WRITE(6,19)
19   FORMAT(1H0,10X,20HOUTER WALL TEMP DATA)
      WRITE(6,20) (TOW(J),TIMEOW(J),J=1,NOW)
20   FORMAT(1H0,10X,2E1 .5)
      WRITE(6,21)
21   FORMAT(1H0,10X,15HSTEAM TEMP DATA)
      WRITE(6,22) (TST(J),TIMEST(J),J=1,NST)
22   FORMAT(1H0,10X,2E1 .5)
      WRITE(6,23) COND,W,RHOCP,DELT,TAU,TOTIME,ITL
23   FORMAT(1H0,1X,11HOTHER INPUT,6E10.5,I5)

```

C
C
C
C
C
C
C
C
C
C
C

```

      FORM MATRICES A(I,J),B(I,J),C(I,J)
      VST(I)=TST(I+1)-TST(1)= SUM X(I)*TIMEST(I+1)**(J) I,J=1,NST-1
      A(I,J)=TIMEST(I+1)**J
      X(J) IS UNKNOWN,TO BE CALCULATED,  DITTO FOR B(I,J),Y(K)ETC

```

```

      NSTA=NST-1
      DO 105 M=1,NSTA
      DO 104 N=1,NSTA
104  A(M,N)= TIMEST(M+1)**N
105  CONTINUE
      NIWA=NIW-1
      DO 107 M=1,NIWA
      DO 106 N=1,NIWA
106  B(M,N)=TIMEIW(M+1)**N
107  CONTINUE
      NOWA=NOW-1
      DO 109 M=1,NOWA
      DO 108 N=1,NOWA
108  C(M,N)=TIMEOW(M+1)**N
109  CONTINUE
      MATRICES COMPLETE
      MAKE CONSTANT VECTORS,VST(I),VIW(I),VOW(I)

```

C
C
C

```

      DO 110 I=1,NSTA
110  VST(I)=TST(I+1)-TST(1)
      DO 111 I=1,NIWA
111  VIW(I)=TIW(I+1)-TIW(1)
      DO 112 I=1,NOWA
112  VOW(I)=VOW(I+1)-VOW(1)
C     VECTORS COMPLETE
C
C
C
C

```

SOLN OF SIMULT EQNS BY G-S METHOD (MCCORMICK AND SALVADORI,P209)

```

      WRITE(6,113)
113  FORMAT(1H0,15X,18HSIMULT EQN RESULTS)
      WRITE(6,114)
114  FORMAT(1H0,26HSTEAM TEMP EQN VECTOR,X(I))
      WRITE(6,115)
115  FORMAT(1H0,5X,44HTST=TST(1)+SUM(X(I)*TIME**I*(1.+I*TAU/TIME)))
C

```

```

      DO 116 J=1,NSTA
116  X(J)=0.
      IT=1
117  WRITE(6,118) IT
118  FORMAT(1H0,24X,9HITERATION I2)
      DO 121 I=1,NSTA
      P=VST(I)
      DO 120 J=1,NSTA
      IF(J-I) 119,120,119
119  P=P-A(I,J)*X(J)
120  CONTINUE
      X(I)=P/A(I,I)
121  WRITE(6,122) I,X(I)
122  FORMAT(20X,I2,E16.7)
      XX(NST-1,IT)=X(NST-1)
      IT=IT+1
      IF(IT-2) 117,117,8
800  CONTINUE
      X1=XX(NSTA,1)
      X2=XX(NSTA,2)
      IF(ABS(X2)-ABS(10.*X1)) 7,8,8
C

```

```

      7 IF(ABS((XX(NSTA,IT-1)-XX(NSTA,IT-2))/XX(NSTA,IT-1))-0.0001) 126
      2,126,125
125 IF(IT-ITL)117,117,24
C

```

```

      8 WRITE(6,9)
      9 FORMAT(1H0,10X,15HVECTOR UNSTABLE)
24  X1=1.
      X2=100.

```

```

126 CONTINUE
   DST=0.
   DO 31 J=2,NST
     TST2=TST(1)
     XIME=TIMEST(J)
     DO 30 K=1,NSTA
       TST2=TST2+X(K)*(XIME**K)
30  CONTINUE
     DST=DST+ABS(TST2-TST(J))
31  CONTINUE
     IF((DST/(FLOAT(NST)*(TST(1)+460.)))-.001) 35,33,33
33  X1=1.
     X2=100.
     WRITE(6,34)
34  FORMAT(1H0,10X,51H POWER SERIES FIT INACCURATE, USE 3PT INTERPOLAT
2ION)
35  CONTINUE
     WRITE(6,127)
127  FORMAT(///1X,28HINSIDE WALL TEMP VECTOR,Y(J))
     WRITE(6,128)
128  FORMAT(1H0,5X,44HTIW=TIW(1)+SUM(Y(I)*TIME**I*(1.+TAU*I/TIME)))
     DO 129 J=1,NIWA
129  Y(J)=0.
     IT=1
130  WRITE(6,131)IT
131  FORMAT(/24X,9HITERATION I2)
     DO 134 I=1,NIWA
       P=VIW(I)
       DO 133 J=1,NIWA
         IF(I-J) 132,133,132
132  P=P-B(I,J)*Y(J)
133  CONTINUE
       Y(I)=P/B(I,I)
134  WRITE(6,135) I,Y(I)
135  FORMAT(20X,I2,E16.7)
       XX(NIW-1,IT)=Y(NIW 1)
       IT=IT+1
       IF(IT-2) 130,130,8 1
801 CONTINUE
       Y1=XX(NIWA,1)
       Y2=XX(NIWA,2)
       IF(ABS(Y2)-ABS(10.*Y1)) 10,11,11
10  IF(ABS((XX(NIW-1,IT-1)-XX(NIW 1,IT-2))/XX(NIW-1,IT-1))-0.0001) 137
2,137,136
136 IF(IT-ITL) 130,130,25
11  WRITE(6,12)
12  FORMAT(1H0,10X,15HVECTOR UNSTABLE)
25  Y1=1.
     Y2=100.

```

```

137 CONTINUE
    DIW=0.
    DO 37 J=2,NIW
        TIW2=TIW(1)
        YIME=TIMEIW(J)
        DO 36 K=1,NIWA
            TIW2=TIW2+Y(K)*(YIME**K)
36 CONTINUE
        DIW=DIW+ABS(TIW2-TIW(J))
37 CONTINUE
        IF((DIW/(FLOAT(NIW)*(TIW(1)+460.)))-.001) 40,38,38
38 Y1=1.
        Y2=100.
        WRITE(6,39)
39 FORMAT(1H0,10X,51H POWER SERIES FIT INACCURATE, USE 3PT INTERPOLAT
        2ION)
40 CONTINUE
        WRITE(6,138)
138 FORMAT(///1X,29HOUTSIDE WALL TEMP VECTOR,Z(K))
        WRITE(6,139)
139 FORMAT(1H0,5X,44HTOW=TOW(1)+SUM(Z(K)*TIME**K*(1.+K*TAU/TIME)))

```

C

```

    DO 140 K=1,NOWA
140 Z(K)=0.
        IT=1
141 WRITE(6,142)IT
142 FORMAT(/24X,9HITERATION I2)
        DO 145 K=1,NOWA
            P=VOW(K)
            DO 144 J=1,NOWA
                IF(K-J) 143,144,143
143 P=P-C(K,J)*Z(J)
144 CONTINUE
            Z(K)=P/C(K,K)
145 WRITE(6,146) K,Z(K)
146 FORMAT(20X,I2,E16.7)
            XX(NOW-1,IT)=Z(NOW 1)
            IT=IT+1
            IF(IT-2) 141,141,8 2
802 CONTINUE
            IF(ABS((XX(NOW-1,IT-1)-XX(NOW 1,IT-2))/XX(NOW-1,IT-1))-0.0001) 148
            2,148,147
147 IF(IT-ITL) 141,141,148
148 CONTINUE

```

C

C AT THIS POINT THE HEAT EQN CAN BE SO-VED. THIS IS TO BE DONE IN
C TWO SPACE INTERVALS,100 POSITIONS INEACH. THE NARROWER REGION IS
C 20(OF THE LINEAR DIMENSION(WALL THICKKNSS W)AND CORRESP TO POS
C INDEX N=1TO101 ON THE STEAM SIDE AND CALLED REGION 1.

```

C
C      N=POSITION INDEX, N=1,101(REGION 1)  N=101,201(REGION 2)
C      M=TIME INDEX,M=1 OR 2
C      T(N,M)=WALL TEMP
C      T(1,M)=STEAM SIDE BOUNDARY CONDITION=TIW(1)+SUM Y(J)TIME**J
C      T(201,M)=OUTSIDE WALL BOUNDARY CONDITION
C      W1=.2*W,THICKNESS OF REGION 1
C      W2=.8*W,THICKNESS OF REGION 2
C      DW1=W1/100.,DIFFERENCE OF LINEAR DIMENSION-REGION 1
C      DW2=W2/100.,          DITTO REGION 2
C
C      HSQ=DW**2 * RHOC/COND*DELT, DIMENSIONLESS SCALE FACTOR SUCH THAT
C      T(N,M+1)= T(N,M)+ (T(N+1,M)-2T(N,M)+T(N-1,M))/HSQ,  HEAT EQN
C      STABILITY DEMANDS THAT HSQ BE GREATER THAN OR =2.
C
C
C      N1=1
C      N2=1
C      N1T=NST-2
C      N2T=NIW-2
C      KICKO=101
C      W1=.2*W
C      W2=.8*W
C      DW1=.002*W
C      DW2=.008*W
C      HSQ1=(DW1*DW1*RHOC*3600.)/(COND*DELT)
C      IF(HSQ1-2.) 999,15 ,150
C
150 HSQ2=16.*HSQ1
C
C      ESTABLISH INITIAL CONDITIONS NOW
C      KICK=1
C      T(1,1)=TIW(1)
C      T(201,1)=TOW(1)
C      T(101,1)= T(1,1)+ .2*(T(201,1)-T(1,1))
C      DO 151 N=2,100
151 T(N,1)=T(1,1)+          (T(101,1)-T(1,1))*FLOAT(N-1)/100.
C      DO 152 N=102,200
152 T(N,1)=T(101,1)+      (1./100.)*(T(201,1)-T(101,1))*FLOAT(N-101)
C
C      INITIAL CONDITIONS COMPLETE
C
153 CONTINUE
C      TIME=0.
C      SUMQDT=0.
C
C      BOUNDARY CONDITIONS
C
154 TIME=TIME +DELT

```

```

      TA2=TAU
      IF (ABS(Y2)-ABS(10.*Y1)) 15,21,210
C      3PT INERPOLATION WHEN MATRIX INVERSION IS UNSTABLE
210  IF (TIME-TIMEIW(2)) 211,212,212
212  IF (TIME-TIMEIW(N2+1)) 211,213,213
213  N2=N2+1
      TA2=0.
      IF (N2-N2T) 211,214,214
214  N2=N2T
211  S1=TIMEIW(N2+1)-TIMEIW(N2)
      S2=TIMEIW(N2+2)-TIMEIW(N2)
      V1=TIW(N2+1)-TIW(N2)
      V2=TIW(N2+2)-TIW(N2)
      S23=S1-S2
      T1=(TIME-TIMEIW(N2))*(1.+TA2/TIME)
      T2=((TIME-TIMEIW(N2))**2)*(1.+2.*TA2/TIME)
      T(1,2)=TIW(N2)+((V2*(S1**2)-V1*(S2**2))*T1+(V1*S2-V2*S1)*T2)/(S1
2*S2*S23)
      GO TO 16
15  T(1,2)=TIW(1)
      DO 155 I=1,NIWA
155  T(1,2)=T(1,2)+Y(I)*(TIME**(I))*(1.+FLOAT(I)*TAU/TIME)
16  T(201,2)=TOW(1)
      DO 156 J=1,NOWA
156  T(201,2)=T(201,2)+Z(J)*(TIME**(J))*(1.+FLOAT(J)*TAU/TIME)
C
C      COMPUTE T(N,2) NOW
C
      DO 157 N=2,100
157  T(N,2)=T(N,1)+(T(N-1,1)-2.*T(N,1)+T(N-1,1))/HSQ1
      DO 158 N=102,200
158  T(N,2)=T(N,1)+(T(N-1,1)-2.*T(N,1)+T(N-1,1))/HSQ2
      T(101,2)=.8*T(100,2)+.2*T(102,2)
C
      TA1=TAU
      IF (ABS(X2)-ABS(10.*X1)) 13,20,200
C      3PT INERPOLATION WHEN MATRIX INVERSION IS UNSTABLE
200  IF (TIME-TIMEST(2)) 201,202,202
202  IF (TIME-TIMEST(N1+1)) 201,203,203
203  N1=N1+1
      TA1=0.
      IF (N1-N1T) 201,204,204
204  N1=N1T
201  S1=TIMEST(N1+1)-TIMEST(N1)
      S2=TIMEST(N1+2)-TIMEST(N1)
      V1=TST(N1+1)-TST(N1)
      V2=TST(N1+2)-TST(N1)
      S23=S1-S2
      T1=(TIME-TIMEST(N1))*(1.+TA1/TIME)

```

```

      T2=((TIME-TIMEST(N1))*2)*(1. 2.*TA1/TIME)
      TS1=TST(N1)+((V2*(S1**2)-V1*(S2**2))*T1+(V1*S2-S1*V2)*T2)/(S1*S2*S
223)
      GO TO 14
13  TS1=TST(1)
      DO 159 I=1,NSTA
159 TS1=TS1+X(I)*(TIME**(I))*(1.+FLOAT(I)*TAU/TIME)
14  DIFFT=T(1,2)-T(2,2)
      GRAD=(ABS(DIFFT))/(DW1*12.)
      DGAST=TS1-T(1,2)
      Q=COND*DIFFT/DW1
      HEFF=ABS(Q/DGAST)
      SUMQDT=SUMQDT+Q*DELT/3600.

      KICK=KICK+1
      DO 160 J=1,201
160 T(J,1)=T(J,2)
      IF(KICK-2) 163,163,998

998 IF(TIME-TOTIME) 161,161,999
161 IF(KICK-KICK0) 154,162,162
162 KICK0=KICK0+100
163 WRITE(6,164) TIME,T(1,1),DIFFT,DGAST,Q
164 FORMAT(///10H TIME,SEC=,E10.5,11H TIW,DEGF,=,E13.7,7H DIFFT=,E10.5
2,7H DGAST=,E10.5,14H Q,BTU/HRFT2,=,E10.5)
      WRITE(6,165) HEFF
165 FORMAT(//30X,17HHEFF,BTU/HRFT2F,=,E13.7)
      WRITE(6,166) T(201,1),TS1,SUMQDT
166 FORMAT(1H0,5X,5H TOW=,E13.5,5H TST=,E13.5,8H SUMQDT=,E13.5,9HBTU/F
2T**2)
      WRITE(6,167) GRAD
167 FORMAT(1H0,36X,5HGRAD=,E10.5,7HDEGF/IN)
      GO TO 154
999 CONTINUE
      END

```


2. A2R Version

```

C
C
C
C   PROGRAM XINGU
C   XINGU/A2R
C   THIS PROGRAM EVALUATES EFF H.T. COEFF(TIME) DURING BLOWDOWN IN CSE
C   THIS PROGRAM CONSIDERS A 2 LAYER COMPOSITE WALL OF OTHER COND ON
C   THE STEAM SIDE( OTHERWISE IDENTICAL TO XINGU/AIR )
C   INPUT VARIABLES
C   TST=STEAM TEMP,DEGREES FAHRENHEIT,NST INPUT POINTS  (NST=1,AT TIME=0.)
C   TIW(NIW),STEAMSIDE WALL TEMP,NIW PTS                (NIW=1,AT TIME=0.)
C   TOW(NOW),OUTSIDE WALL TEMP,NOW PTS                  (NOW=1,AT TIME=0.)
C   TOTIME,TOTAL DURATION OF COMPUTATION DESIRED,SECONDS
C   COND,THERMAL CONDUCTIVITY,BTU/HRFT-F
C   W,WALL THICKNESS,FT
C   RHOCP,WALL DENSITY*WALLHEATCAPACITY,BTU/(FT**3F)
C   DELT,DIFFERENTIAL TIME INTERVAL,SEC
C   TAU=THERMOCOUPLE RESPONSE TIME,SEC
C   NST(KEEP LESS THAN30)
C   NIW(  DITTO      )
C   NOW(  DITTO      )
C   ITL=NO. ITERATIONS TO GIVE GOOD DATA FIT TO POWER SERIES
C   TIMEIW(I),TIMEOW(J)= TIME CORRESP TO TIW(I),TOW(J) (I=1 MEANS TIME=0.ALWAY
C   OUTPUT  VARIABLES
C
C   IT,PARTICULAR ITERATION
C   X(I),Y(I),Z(I)=SOLUTION VECTORS FOR STEAM,INNERWALL,OUTER WALL TEMP SUCH
C   THAT  TST= TST(1) SUM(J=1,NST)  X(J)*TIME**(J)  ETC
C   TIME,TIW,TOW,TST
C   DIFFT=TEMPERATURE DIFFERENCE ACROSS FIRST INCREMENT W/500.,DEG F
C   DGAST=TST-TIW
C   Q=WALL FLUX,BTU/HRFT**2
C   HEFF=Q/DGAST,LOCAL EFFECTIVE H.T. COEFF.,BTU/HRFTFTDEGREESF
C   SUMQDT=TOTAL HEAT PASSED THROUGH STEAM SIDE WALL, BTU/FT**2
C   GRAD=TEMP GRADIENT IN WALL AT SURFACE, DEGF/IN
C   WST=THICKNESS OF THE OTHER CONDUCTIVITY MATERIAL ON THE STEAM SIDE
C   ALPHST=THERMAL DIFFUSIVITY OF THAT REGION, FT**2/HR
C   CONDST=THERMAL CONDUCTIVITY OF THAT REGION, BTU/HR-FT-DEGF
C
C
C
C
C   DIMENSION A(30,30),B(30,30),C(30,30),T(205,2),TIW(30),TIMEIW(30),T
100 2OW(30),TIMEOW(30),TST(30),TIMEST(30),X(30),Y(30),Z(30),XX(30,30)
C   DIMENSION VIW(30),VOW(30),VST(30)
C   READ(5,100) NIW
100  FORMAT(I5)
C   READ(5,300) (TIW(J),TIMEIW(J),J=1,NIW)
300  FORMAT(2F10.0)

```

```

C      READ(5,101) NOW
101  FORMAT(I5)
      READ(5,301) (TOW(J),TIMEOW(J),J=1,NOW)
301  FORMAT(2F10.0)
C
      READ(5,102) NST
102  FORMAT(I5)
      READ(5,302) (TST(J),TIMEST(J),J=1,NST)
302  FORMAT(2F10.0)
C
C
      READ(5,103) COND,W,RHOC,P,DELT,TAU,TOTIME,ITL
103  FORMAT(F10.0/F10.0/F10.0/F10.0/F10.0/F10.0/I5)
      READ(5,303) WST,CONDST,ALPHST
303  FORMAT(3F10.0)
      WRITE(6,17)
17  FORMAT(1H0,10X,20HINNER WALL TEMP DATA)
      WRITE(6,18) (TIW(J),TIMEIW(J),J=1,NIW)
18  FORMAT(1H0,10X,2E1 .5)
      WRITE(6,19)
19  FORMAT(1H0,10X,20HOUTER WALL TEMP DATA)
      WRITE(6,20) (TOW(J),TIMEOW(J),J=1,NOW)
20  FORMAT(1H0,10X,2E1 .5)
      WRITE(6,21)
21  FORMAT(1H0,10X,15HSTEAM TEMP DATA)
      WRITE(6,22) (TST(J),TIMEST(J),J=1,NST)
22  FORMAT(1H0,10X,2E1 .5)
      WRITE(6,23) COND,W,RHOC,P,DELT,TAU,TOTIME,ITL
23  FORMAT(1H0,1X,11HOTHER INPUT,6E10.5,I5)
      WRITE(6,304) WST,CONDST,ALPHST
304  FORMAT(1H0,1X,29HOTH COND COMPOSITE LAYER DATA,3F10.5)
C
C
C      FORM MATRICES A(I,J),B(I,J),C(I,J)
C      VST(1)=TST(1)-TST(1)= SUM X(I)*TIMEST(I+1)**(J) I,J=1,NST-1
C      A(I,J)=TIMEST(I+1)**J
C      X(J) IS UNKNOWN,TO BE CALCULATED, DITTO FOR B(I,J),Y(K)ETC
C
C
C      NSTA=NST-1
      DO 105 M=1,NSTA
      DO 104 N=1,NSTA
104  A(M,N)= TIMEST(M+1)**N
105  CONTINUE
      NIWA=NIW-1
      DO 107 M=1,NIWA
      DO 106 N=1,NIWA

```

```

106 B(M,N)=TIMEIW(M+1)**N
107 CONTINUE
    NOWA=NOW-1
    DO 109 M=1,NOWA
    DO 108 N=1,NOWA
108 C(M,N)=TIMEOW(M+1)**N
109 CONTINUE
C   MATRICES COMPLETE
C   MAKE CONSTANT VECTORS,VST(I),VIW(I),VOW(I)
C
    DO 110 I=1,NSTA
110 VST(I)=TST(I+1)-TST(1)
    DO 111 I=1,NIWA
111 VIW(I)=TIW(I+1)-TIW(1)
    DO 112 I=1,NOWA
112 VOW(I)=VOW(I+1)-VOW(1)
C   VECTORS COMPLETE
C
C
C   SOLN OF SIMULT EQNS BY G-S METHOD (MCCORMICK AND SALVADORI,P209)
C
    WRITE(6,113)
113 FORMAT(1H0,15X,18H SIMULT EQN RESULTS)
    WRITE(6,114)
114 FORMAT(1H0,26H STEAM TEMP EQN VECTOR,X(I))
    WRITE(6,115)
115 FORMAT(1H0,5X,44HTST=TST(1)+SUM(X(I)*TIME**I*(1.+I*TAU/TIME)))
C
    DO 116 J=1,NSTA
116 X(J)=0.
    IT=1
117 WRITE(6,118) IT
118 FORMAT(1H0,24X,9H ITERATION I2)
    DO 121 I=1,NSTA
    P=VST(I)
    DO 120 J=1,NSTA
    IF(J-I) 119,120,119
119 P=P-A(I,J)*X(J)
120 CONTINUE
    X(I)=P/A(I,I)
121 WRITE(6,122) I,X(I)
122 FORMAT(20X,I2,E16.7)
    XX(NST-1,IT)=X(NST-1)
    IT=IT+1
    IF(IT-2) 117,117,8
800 CONTINUE
    X1=XX(NSTA,1)
    X2=XX(NSTA,2)

```

```

      IF (ABS(X2)-ABS(10.*X1)) 7,8,8
C
      7 IF (ABS((XX(NSTA,IT-1)-XX(NSTA,IT-2))/XX(NSTA,IT-1))-0.0001) 126
        2,126,125
125 IF (IT-ITL) 117,117,24
C
      8 WRITE(6,9)
      9 FORMAT(1H0,10X,15HVECTOR UNSTABLE)
24 X1=1.
   X2=100.
126 CONTINUE
   DST=0.
   DO 31 J=2,NST
     TST2=TST(1)
     XIME=TIMEST(J)
     DO 30 K=1,NSTA
       TST2=TST2+X(K)*(XIME**K)
30 CONTINUE
   DST=DST+ABS(TST2-TST(J))
31 CONTINUE
   IF ((DST/(FLOAT(NST)*(TST(1)+460.)))-0.001) 35,33,33
22 X1=1.
   X2=100.
   WRITE(6,34)
34 FORMAT(1H0,10X,51H POWER SERIES FIT INACCURATE, USE 3PT INTERPOLAT
  2ION)
35 CONTINUE
   WRITE(6,127)
127 FORMAT(///1X,28HINSIDE WALL TEMP VECTOR,Y(J))
   WRITE(6,128)
128 FORMAT(1H0,5X,44HTIW=TIW(1)+SUM(Y(I)*TIME**I*(1.+TAU*I/TIME)))
   DO 129 J=1,NIWA
129 Y(J)=0.
   IT=1
130 WRITE(6,131) IT
131 FORMAT(/24X,9HITERATION 12)
   DO 134 I=1,NIWA
     P=VIW(I)
     DO 133 J=1,NIWA
       IF (I-J) 132,133,132
132 P=P-B(I,J)*Y(J)
133 CONTINUE
     Y(I)=P/B(I,I)
134 WRITE(6,135) I,Y(I)
135 FORMAT(20X,I2,E16.7)
     XX(NIW-1,IT)=Y(NIW-1)
     IT=IT+1
     IF (IT-2) 130,130,8 1
801 CONTINUE

```

```

      Y1=XX(NIWA,1)
      Y2=XX(NIWA,2)
      IF(ABS(Y2)-ABS(10.*Y1)) 10,11,11
10  IF(ABS((XX(NIW-1,IT-1)-XX(NIW 1,IT-2))/XX(NIW-1,IT-1))-0.0001) 137
    2,137,136
136 IF(IT-ITL) 130,130,25
    11 WRITE(6,12)
    12 FORMAT(1H0,10X,15HVECTOR UNSTABLE)
    25 Y1=1.
      Y2=100.
137 CONTINUE
      DIW=0.
      DO 37 J=2,NIW
        TIW2=TIW(1)
        YIME=TIMEFIW(J)
        DO 36 K=1,NIWA
          TIW2=TIW2+Y(K)*(YIME**K)
36  CONTINUE
        DIW=DIW+ABS(TIW2-TIW(J))
37  CONTINUE
      IF((DIW/(FLOAT(NIW)*(TIW(1)+460.)))-.001) 40,38,38
38  Y1=1.
      Y2=100.
      WRITE(6,39)
39  FORMAT(1H0,10X,51H POWER SERIES FIT INACCURATE, USE 3PT INTERPOLAT
    2ION)
40  CONTINUE
      WRITE(6,138)
138  FORMAT(///1X,29HOUTSIDE WALL TEMP VECTOR,Z(K))
      WRITE(6,139)
139  FORMAT(1H0,5X,44HTOW=TOW(1)+SUM(Z(K)*TIME**K*(1.+K*TAU/TIME)))
C
      DO 140 K=1,NOWA
140  Z(K)=0.
      IT=1
141  WRITE(6,142)IT
142  FORMAT(/24X,9HITERATION I2)
      DO 145 K=1,NOWA
        P=VOW(K)
        DO 144 J=1,NOWA
          IF(K-J) 143,144,143
143  P=P-C(K,J)*Z(J)
144  CONTINUE
        Z(K)=P/C(K,K)
145  WRITE(6,146) K,Z(K)
146  FORMAT(20X,I2,E16.7)
      XX(NOW-1,IT)=Z(NOW 1)
      IT=IT+1
      IF(IT-2) 141,141,8 2

```

```

802 CONTINUE
  IF(ABS((XX(NOW-1,IT-1)-XX(NOW 1,IT-2))/XX(NOW-1,IT-1))-0.0001) 148
    2,148,147
147 IF(IT-ITL) 141,141,148
148 CONTINUE
C
C   AT THIS POINT THE HEAT EQN CAN BE SOLVED. THIS IS TO BE DONE IN
C   TWO SPACE INTERVALS,100 POSITIONS INEACH. THE NARROWER REGION IS
C   20( OF THE LINEAR DIMENSION(WALL THICKKNESS W)AND CORRESP TO POS
C   INDEX N=1TO101 ON THE STEAM SIDE AND CALLED REGION 1.
C
C   N=POSITION INDEX, N=1,101(REGION 1) N=101,201(REGION 2)
C   M=TIME INDEX,M=1 OR 2
C   T(N,M)=WALL TEMP
C   T(1,M)=STEAM SIDE BOUNDARY CONDITION=TIW(1)+SUM Y(J)TIME**J
C   DWJ(J=0, 1 OR 2) = A SPACIAL FINITE DIFFERENCE
C
C   HSQ=DW**2 * RHOCP/COND*DELT, DIMENSIONLESS SCALE FACTOR SUCH TIAT
C   T(N,M+1)= T(N,M)+ (T(N+1,M)-2T(N,M)+T(N-1,M))/HSQ, HEAT EQN
C   STABILITY DEMANDS THAT HSQ BE GREATER THAN OR =2.
C
C
C   N1=1
C   N2=1
C   N1T=NST-2
C   N2T=NIW-2
C   KICKO=101
C   ESTABLISH ADDITIONAL EQUIVALENT THICKNESS OF COMPOSITE LAYER
C   DW1=.004*W
C   DW2=.016*W
C   DW0=DW1*SQRT(ALPHST/(COND/RHOCP))
C   XN=WST/DW0
C   NX=1
700 NX=NX+1
  IF(FLOAT(NX-1)-XN) 700,701,701
701 CONTINUE
  HSQ1=(DW1*DW1*RHOCP*3600.)/(COND*DELT)
  IF(HSQ1-2.) 999,15 ,150
C
150 HSQ2=16.*HSQ1
C
C   ESTABLISH INITIAL CONDITIONS NOW
C   KICK=1
C   NA=NX+50
C   NB=NA+50
C   T(1,1)=TIW(1)
C   T(NB,1)=TOW(1)
C   T(NX,1)=(T(NB,1)+CONDST*W*T(1,1)/(COND*WST))/(1.+CONDST*W/(COND*WS
2T))

```

```

DO 702 J=2,NX
702 T(J,1)=T(1,1)+FLOAT(J-1)*(T(NX,1)-T(1,1))/FLOAT(NX-1)
DO 703 J=1,50
703 T(NX+J,1)=T(NX,1)+FLOAT(J)*(T(NA,1)-T(NX,1))/50.
DO 704 J=1,50
704 T(NA+J,1)=T(NA,1)+FLOAT(J)*(T(NB,1)-T(NA,1))/50.
C
C   INITIAL CONDITIONS COMPLETE
C
153 CONTINUE
    TIME=0.
    SUMQDT=0.
C
C   BOUNDARY CONDITIONS
C
154 TIME=TIME +DELT
    TA2=TAU
    IF(ABS(Y2)-ABS(10.*Y1)) 15,21,210
C   3PT INTERPOLATION WHEN MATRIX INVERSION IS UNSTABLE
210 IF(TIME-TIMEIW(2)) 211,212,212
212 IF(TIME-TIMEIW(N2+1)) 211,213,213
213 N2=N2+1
    TA2=0.
    IF(N2-N2T) 211,214,214
214 N2=N2T
211 S1=TIMEIW(N2+1)-TIMEIW(N2)
    S2=TIMEIW(N2+2)-TIMEIW(N2)
    V1=TIW(N2+1)-TIW(N2)
    V2=TIW(N2+2)-TIW(N2)
    S23=S1-S2
    T1=(TIME-TIMEIW(N2))*(1.+TA2/TIME)
    T2=((TIME-TIMEIW(N2))**2)*(1. 2.*TA2/TIME)
    T(1,2)=TIW(N2)+((V2*(S1**2)-V1*(S2**2))*T1+(V1*S2-V2*S1)*T2)/(S1
2*S2*S23)
    GO TO 16
15 T(1,2)=TIW(1)
    DO 155 I=1,NIWA
155 T(1,2)=T(1,2)+ Y(I)*(TIME**(I))*(1.+FLOAT(I)*TAU/TIME)
16 T(NB,2)=TOW(1)
    DO 156 J=1,NOWA
156 T(NB,2)=T(NB,2)+Z(J)*(TIME**(J))*(1.+FLOAT(J)*TAU/TIME)
C
C   COMPUTE T(N,2) NOW
C
DO 157 N=3,NA
157 T(N-1,2)=T(N-1,1)+(T(N,1)-2.*T(N-1,1)+T(N-2,1))/HSQ1
    NA2=NA+2
    DO 158 N=NA2,NB
158 T(N-1,2)=T(N-1,1)+(T(N,1)-2.*T(N-1,1)+T(N-2,1))/HSQ2

```

```

      T(NA,2)=.8*T(NA-1,2)+.2*T(NA+1,2)
C
      TA1=TAU
      IF(ABS(X2)-ABS(10.*X1)) 13,20,200
C
      3PT INTERPOLATION WHEN MATRIX INVERSION IS UNSTABLE
200  IF(TIME-TIMEST(2)) 201,202,202
202  IF(TIME-TIMEST(N1+1)) 201,203,203
203  N1=N1+1
      TA1=0.
      IF(N1-N1T) 201,204,204
204  N1=N1T
201  S1=TIMEST(N1+1)-TIMEST(N1)
      S2=TIMEST(N1+2)-TIMEST(N1)
      V1=TST(N1+1)-TST(N1)
      V2=TST(N1+2)-TST(N1)
      S23=S1-S2
      T1=(TIME-TIMEST(N1))*(1.+TA1/TIME)
      T2=((TIME-TIMEST(N1))**2)*(1. 2.*TA1/TIME)
      TS1=TST(N1)+((V2*(S1**2)-V1*(S2**2))*T1+(V1*S2-S1*V2)*T2)/(S1*S2*S
223)
      GO TO 14
13  TS1=TST(1)
      DO 159 I=1,NSTA
159  TS1=TS1+X(I)*(TIME**(I))*(1.+FLOAT(I)*TAU/TIME)
14  DIFFT=T(1,2)-T(2,2)
      GRAD=(ABS(DIFFT))/(DW0*12.)
      DGAST=TS1-T(1,2)
      Q=CONDST*DIFFT/DW0
      HEFF=ABS(Q/DGAST)
      SUMQDT=SUMQDT+Q*DELT/3600.
C
      KICK=KICK+1
      DO 160 J=1,NB
160  T(J,1)=T(J,2)
      IF(KICK-2) 163,163,998
C
C
C
C
C
998  IF(TIME-TOTIME) 161,161,999
161  IF(KICK-KICK0) 154,162,162
162  KICK0=KICK0+100
163  WRITE(6,164) TIME,T(1,1),DIFFT,DGAST,Q
164  FORMAT(///10H TIME,SEC=,E10.5,11H TIW,DEGF,=,E13.7,7H DIFFT=,E10.5
2,7H DGAST=,E10.5,14H Q,BTU/HRFT2,=,E10.5)
      WRITE(6,165) HEFF
165  FORMAT(//30X,17HHEFF,BTU/HRFT2F,=,E13.7)
      WRITE(6,166) T(NB,1),TS1,SUMQDT

```



```
166 FORMAT(1H0,5X,5H TOW=,E13.5,5H TST=,E13.5,8H SUMQDT=,E13.5,9HBTU/F
      2T**2)
      WRITE(6,167) GRAD
167 FORMAT(1H0,36X,5HGRAD=,E10.5,7HDEGF/IN)
      GO TO 154
999 CONTINUE
      FND
```

C

C

APPENDIX B

CORRECTION METHOD FOR THERMOCOUPLE RISETIME

APPENDIX B

Correction Method for Thermocouple Rise Time

A thermocouple's response to a step temperature change ΔT is exponential, i.e., $\Delta T[1 - \exp(-t/\tau)]$. The rise time, τ , is analogous to RC response where a corresponding resistance is $1/h A$ and capacitance is $\rho C_p V$. Thus the transfer (Laplace Transform) of a thermocouple, $G(s)$, is

$$G(s) = \frac{1}{\tau s + 1}$$

Thus for any input $I(t)$ [$I(s) = \mathcal{L}\{I(t)\}$], the corresponding output $O(t)$ is given by

$$O(t) = \mathcal{L}^{-1}[O(s)] = \mathcal{L}^{-1}[G(s)I(s)]$$

$I(t)$ is desired, hence

$$I(t) = \mathcal{L}^{-1}[O(s)/G(s)]$$

In Program Xingu, $O(t)$ is a power series

$$O(t) = \text{Temp}(t) - \text{Temp}(t=0)$$

$$O(t) = \sum_{n=1}^N a_n t^n = \sum_{m=2}^{N+1} a_{m-1} t^{m-1}$$

$$= \sum_{m=2}^{N+1} \frac{b_{m-1}}{(m-1)} t^{m-1}$$

Thus

$$O(s) = \sum_{m=2}^{N+1} b_{m-1} s^{-m}$$

$$I(s) = (\tau s + 1) \sum_{m=2}^{N+1} b_{m-1} s^{-m}$$

$$= O(s) + \tau \sum_{m=2}^{N+1} s^{-m+1}$$

$$I(t) = O(t) + \tau \sum_{n=1}^N a_n t^{n-1}$$

$$\text{Temp}(t) = \text{Temp}(0) + \sum_{n=1}^N a_n t^n (1 + n\tau/t)$$

The last equation is used to describe the true temperature at any time t .

APPENDIX C

TRIAL RUNS WITH PROGRAM XINGU

APPENDIX C

Trial Runs with Program Xingu

Program Xingu (A1R) has been successfully tested on several trial runs using data from B. M. Johnson's mathematical model of CSE pressure-temperature transients.⁽²⁾ Results are depicted graphically (Figures 1 and 2) and agree in magnitude to those of B. M. Johnson who used much larger spacing in the finite difference grid. An important conclusion is that temperature corrections for thermocouple rise time were insignificant in runs having this type of temperature-time history. This would not be true for more rapidly changing systems.

The modified version, XINGU/A2R, has been tested using the input temperature data of Figure 1. A composite region of stainless steel (.025 ft thick) was included on the steamside. The heat transfer coefficient-time curve was similar except the magnitude of the coefficient was attenuated by a time dependent function of thermal conductivity and diffusivity ratios and penetration thicknesses, e.g., this attenuation factor would be $\frac{k_{ss}}{k_{Fe}}$ in a steady state situation.

FIGURE 1
Effective Heat Transfer Coefficients at Primary Vessel Wall During
Blowdown
[Comparison of XINGU/A1R (and A2R) Computations
with the Calculated Variable HEFF of B. M. Johnson]

FIGURE 2
Effective Heat Transfer Coefficients at Primary Vessel Wall During
Blowdown
(Comparison of XINGU/AIR Computation with the Assumed
Constant $H_{EFF} = 1000 \text{ Btu/hr Ft}^2 \text{ } ^\circ\text{F}$ of B. M. Johnson)

NOMENCLATURE

C_p	Wall heat capacity, Btu/ft ³ °F
h	Dimensionless scale factor (page 6)
$HEFF$	Effective steamside heat transfer coefficient, Btu/hr ft ² °F
k	Wall thermal conductivity, Btu/hr ft °F
NIW	Number of inner wall temperature-time data
NOW	Number of outer wall temperature-time data
NST	Number of steam temperature-time data
Q	Heat flux at $x=0$ (inner wall)
s	Laplace transform variable
t	Time, seconds
$TIMEIW (J)$	J th time datum at the inner wall, seconds
$TIMEOW (J)$	J th time datum at the outer wall, seconds
$TIMEST (J)$	J th steam time datum, seconds
$TIW (J)$	J th temperature datum at the inner wall, °F
$TOW (J)$	J th temperature datum at the outer wall, °F
$TST (J)$	J th temperature steam datum, °F
$T(n,m)$	Finite difference temperature at position n (an integer) and time m (an integer)
x	Distance in the wall from the inside
w	Wall thickness, ft
α	Thermal diffusivity, ft ² /hr
Δ	Finite increment ($\Delta x = x_2 - x_1$)
ρ	Wall density, lb/ft ³
τ	Thermocouple time lag constant, seconds
$\mathcal{L}$	Laplace transformation operator

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