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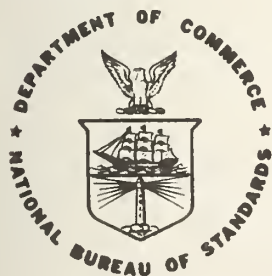
A Computer Program for the Thermal Analysis of the Fire Endurance of Construction Walls

Francis C. W. Fung

Center for Fire Research
Institute for Applied Technology
National Bureau of Standards
Washington, D.C. 20234

May 1977

Final Report
Issued June 1977



**U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS**

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A COMPUTER PROGRAM FOR THE THERMAL ANALYSIS OF THE
FIRE ENDURANCE OF CONSTRUCTION WALLS

Francis C. W. Fung

Abstract

A general one-dimensional transient heat and mass transfer numerical program has been developed for composite building constructions. Since typical building constructions consist of a series of composite layers and intermediate air layers, transient heat transfer is modeled by conduction through solids and by radiation and convection through air spaces. In addition the program has built-in features for ease of application to building constructions where various combinations of solid-to-solid and solid-to-air interfaces are encountered. The complete Fortran language program as used on the NBS Univac 1108 computer is given. A discussion of the program and instruction for its use are facilitated by the aid of examples. Numerical solutions using the present program compare favorably with experimental data in standard fire endurance tests.

Key words: Composite building constructions; convection; experimental data; fire endurance; heat generation or absorption; numerical solutions; radiation; one-dimensional; thermal conduction; transient heat transfer.

1. INTRODUCTION

The fire performance of building constructions is generally evaluated by a large scale laboratory fire endurance test (ASTM E 119) in which one surface is exposed to furnace gases with a prescribed increasing temperature history simulating the burnout of combustibles. The fire endurance rating of the construction is the time period during which it withstands the fire exposure without (a) structural failure, (b) the development of cracks through which flames or hot gases can pass, or (c) the temperature rise on the unexposed surface exceeding, a prescribed limit (250 °F average rise or 325 °F rise at a single point). Where the failure criterion is due to heat transmission alone, heat transfer analysis can provide a means for prediction and design.

Since typical building constructions consist of a series of composite layers and intermediate air layers, transient heat transfer is modeled by conduction through solids and by radiation and convection through air spaces. In addition, the program has built-in features for ease of application to building constructions where various combinations of solid-to-solid and solid-to-air interfaces are encountered. For each solid layer, the present program has provisions for phase changes, heat generation and absorption, and thermal property variation with temperature commonly found in building materials. Through the air spaces the modes of heat transfer include radiation and convection with temperature-dependent air properties.

A number of special analog and numerical programs for fire endurance evaluation have been in existence for some time [1-4]¹. A more flexible and general finite difference program was developed by Krokosky as recently as 1970 [5], which also contains a review of the existing thermal analysis programs for fire endurance evaluation.

The present numerical program was also developed to incorporate into fire endurance analyses the following features which are desirable and yet not readily available in existing programs:

1. Options to handle heat exposure on one or both sides of a structure.
2. Allowance for air infiltration, and heat generation and absorption in air spaces.
3. For ease of application to building structures, a single input card, using digits 1 and 0, is sufficient to instruct the computer the specified number of solid layers and air spaces arranged in a given problem.
4. Temperature-dependent thermal properties and known heat effects due to chemical reactions of some common building materials are stored in a subroutine and called by an input card, punched as 2331, indicate coded materials stored in the subroutine.
5. The duration as well as the amount of heat represented by a phase change or chemical reaction can be varied in any material.

¹ Numbers in brackets refer to the literature references listed at the end of this paper.

2. GOVERNING EQUATION AND BOUNDARY CONDITIONS

The governing equation for one-dimensional transient heat flow is the well known heat diffusion equation. Including a term for internal heat generation, this can be expressed as:

$$\frac{\partial}{\partial x} \left(k \frac{\partial T}{\partial x} \right) + g = \rho c \frac{\partial T}{\partial \theta} \quad (1)$$

where

- T = absolute temperature in solid
- x = coordinate in direction of heat flow
- k = heat conduction coefficient
- g = time rate of heat generation per unit volume in solid
- ρ = density of solid
- c = specific heat capacity of solid
- θ = time.

Boundary Conditions [6,7]:

The following types of boundary conditions need to be evaluated for the general problem:

- (a) solid to air
- (b) energy balance in air space
- (c) air to solid
- (d) solid to surrounding
- (e) solid to symmetry plane
- (f) solid to solid
- (g) furnace gases to first surface layer.

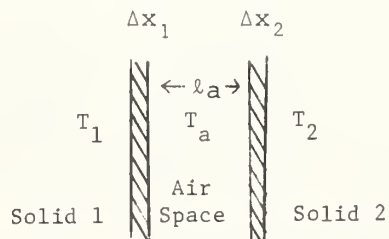


Figure 1. Solid-Air-Solid Interface

(a) Solid to Air (see fig. 1) [7]

$$\frac{\rho_1 c_1 \Delta x}{2} \frac{\Delta T_1}{\Delta \theta} = -k_1 \frac{\Delta T_1}{\Delta x_1} - \sigma \epsilon_{12} \left(T_1^4 - T_2^4 \right) - h(T_1 - T_a)^{5/4} + g_1 \frac{\Delta x_1}{2} \quad (2)$$

(b) Energy Balance in Air Space (see fig. 1)

$$\rho_a c_{pa} \frac{\Delta T_a}{\Delta \theta} = h(T_1 - T_a)^{5/4} - h(T_a - T_2)^{5/4} + \dot{m} c_{pa} (T_1 - T_2) + \ell_a g_a \quad (3)$$

(c) Air to Solid (see fig. 1)

$$\frac{\rho_2 c_2 \Delta x_2}{2} \frac{\Delta T_2}{\Delta \theta} = k_2 \frac{\Delta T_2}{\Delta x_2} + \sigma \epsilon_{12} \left(T_a^4 - T_2^4 \right) + h(T_a - T_2)^{5/4} + g_2 \frac{\Delta x_2}{2} \quad (4)$$

In the above equations the subscripts 1 and 2 indicate solid 1 and solid 2, respectively, as shown in figure 1, and where

$$\epsilon_{12} = \frac{1}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1}$$

and

- ϵ_1, ϵ_2 are emissivity of surface 1 and of surface 2
- T_2, T_1 : surface temperatures as shown in figure 1
- $\Delta x_1, \Delta x_2$: incremental length in x direction in solid 1 and solid 2
- σ : Stefan Boltzmann constant
- T_a : temperature of air
- k_1, k_2 : heat conduction coefficient in solid 1, and 2
- g_1, g_2 : time rate of heat generation or absorption per unit volume in solid 1 and 2
- ℓ_a : air gap spacing
- c_{pa} : specific heat capacity of air
- ρ_a : density of air

- \dot{m} : rate of mass transfer per unit area due to pressure difference
 g_a : rate of heat generation per unit volume in air space due to combustibles
 h : an empirical convection heat transfer constant,
 $h = .27$ for vertical surface, and $h = .38$ for horizontal surfaces [8].

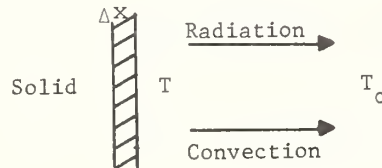


Figure 2. Solid-to-Surrounding Interface

(d) Solid to Ambient (see fig. 2)

$$\frac{\rho c \Delta x}{2} \frac{\Delta T}{\Delta \theta} = -k \frac{\Delta T}{\Delta \theta} - \sigma \epsilon (T^4 - T_o^4) - h(T - T_o)^{5/4} + g \frac{\Delta x}{2} \quad (5)$$

where the additional variables are:

- T_o : ambient temperature
 ϵ : emissivity of surface
 T : surface temperature of solid

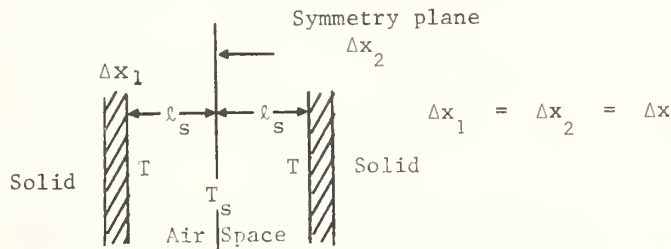


Figure 3. Symmetry Plane

(e) Solid to Symmetry Plane (see fig. 3)

By symmetry, temperature on both solid surfaces that face each other are equal, however $T \geq T_s$. So there will be heat transfer from solid to air. At the interface we have:

$$\frac{\rho c \Delta x}{2} \frac{\Delta T}{\Delta \theta} = -k \frac{\Delta T}{\Delta x} - h(T - T_s)^{5/4} + g \frac{\Delta x}{2} \quad (6a)$$

At the air space we have,

$$\rho_s c_p a \frac{\Delta T_s}{\Delta \theta} = h(T - T_s)^{5/4} \quad (6b)$$

where

- T: surface temperature of solids
- T_s : temperature of air in symmetry plane
- ℓ_s : distance from solid to symmetry plane

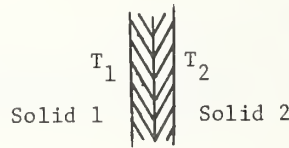


Figure 4. Solid-to-Solid Interface

(f) Solid to Solid (see fig. 4)

Consider interface between Solid 1 and Solid 2 as shown in figure 4. Let T_1 and T_2 be the interface temperature in each solid respectively. A heat balance for the interface node can be expressed as $T_2 = T_1$, and

$$\rho_1 c_1 \frac{\Delta x_1}{2} \frac{\Delta T_1}{\Delta \theta} + \rho_2 c_2 \frac{\Delta x_2}{2} \frac{\Delta T_2}{\Delta \theta} = g_1 \frac{\Delta x_1}{2} + g_2 \frac{\Delta x_2}{2} - k_1 \frac{\Delta T_1}{\Delta x} + k_2 \frac{\Delta T_2}{\Delta x} \quad (7)$$

where subscript indicates conditions in solid layer 1 or 2.

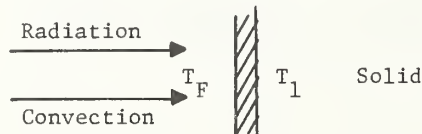


Figure 5. Furnace-to-First-Solid Interface

(g) Furnace Gases to First Solid Surface (see fig. 5)

Consider heat transfer from furnace gases to first solid surface. The main modes of heat transfer will be radiation and convection. A good approximation of ASTM E 119 fire curve is given by the following three formulas:

$$T = 1692 \frac{\theta}{\theta + 4} + 68 \quad 0 < \theta < 50 \text{ min (error } \pm 2\%)$$

$$T = 1667 + 1.26\theta - 0.0236(120-\theta)^2 \quad 50 \text{ min} < \theta < 115 \text{ min}$$

(no appreciable error)

$$T = 1667 + 1.26\theta \quad 115 \text{ min} < \theta < 480 \text{ min}$$

(linear exact)

Heat balance from furnace to first solid surface,

$$\frac{\rho c \Delta x}{2} \frac{\Delta T_1}{\Delta \theta} = k \frac{\Delta T}{\Delta x} + \sigma \epsilon (T_F^4 - T_1^4) + h(T_F - T_1)^{5/4} + g \frac{\Delta x}{2} \quad (8)$$

where T_F is absolute furnace temperature.

3. PROBLEM FORMULATION AND FINITE DIFFERENCE EQUATIONS

Consider general one-dimensional heat transfer problem containing N solid layers and m air spaces in any order. To facilitate formulation and discussion we introduce $i, j,$ and $k,$ three running indices.

Let:

- $T_{i,j}$: Temperature of j th node in i th solid
- i : $1 \dots N$ (number of solid layers)
- j : $1 \dots n$ (number of nodes in solid layer)
- k : $1 \dots m$ (number of air spaces)

In figure 6, a general multi-layer configuration is shown, where numbers in circles indicate the applicable equation at the given node as discussed in the previous section.

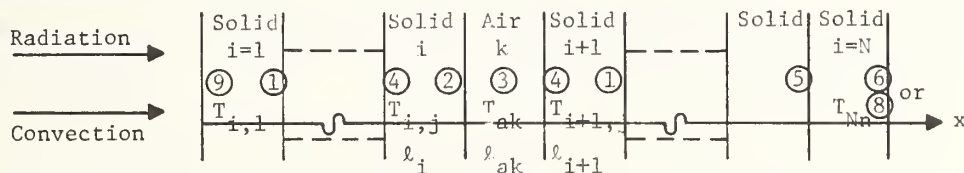


Figure 6. A Composite Wall with N Layers, m Air Spaces
(Numbers in circles indicate applicable equation as discussed in section 2.)

To solve our problem numerically with the nonlinear heat diffusion equation and associated complex system of boundary conditions we shall use forward time differencing and central space differencing scheme. Figure 7 shows the finite differencing network inside a solid layer.

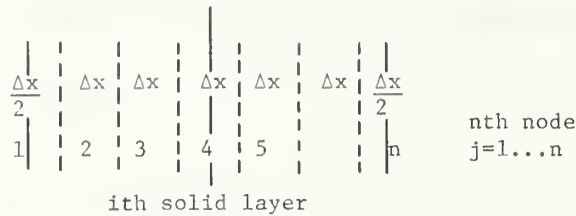


Figure 7. Sketch of Finite Differencing Network in a Solid Layer

Furthermore, let

T_{ak} : Temperature of kth air spacing

θ : Time

$\Delta\theta$: Time increment

$T'_{i,j}$: Temperature at $(\theta + \Delta\theta)$ of jth node in ith solid

l_i : Thickness of ith solid

l_{ak} : Thickness of kth air spacing

$\Delta x_i = \frac{l_i}{n-1}$: Difference spacing for ith solid

$g_{i,j}$: Rate of heat generation per unit volume

$k_{i,j}$: Heat conduction coefficient

α_i : Heat diffusion coefficient

g_{ak} : Rate of heat generation per unit volume in air space

$\overset{\circ}{m}_k$: Rate of mass transfer per unit area

Applying our finite differencing scheme we have the following general finite difference expressions corresponding to the previously discussed governing equation and boundary conditions [6,7 and 9].

Governing Equation

$$T'_{i,j} = \frac{1}{M_i} \left(T_{i(j-1)} + T_{i(j+1)} \right) + \left(1 - \frac{2}{M_i} \right) T_{ij} + \frac{g_{ij} \Delta x_i^2}{k_{ij} M_i} \quad (9)$$

where

$$M_i = \frac{(\Delta x_i)^2}{\alpha_i \Delta \theta}$$

From equation (9) we require $M_i > 2$ for stability.

Solid to Air

$$T'_{i,n} = T_{i,n} + \frac{2}{M_i} \left(T_{i,n-1} - T_{i,n} \right) - R_i \left[(T_{i,n})^4 - (T_{i+1,1})^4 \right] - H_i (T_{i,n} - T_{ak})^{5/4} + \frac{g_{i,n} \Delta x_i^2}{k_{i,n} M_i} \quad (10)$$

where

$$R_i = \frac{2 \Delta \theta \sigma \epsilon_{12}}{\Delta x_i \rho_i c_i}$$

c_i : Specific heat of i th layer

$$H_i = \frac{2 \Delta \theta h}{\rho_i c_i \Delta x_i}$$

Air Space Heat Balance

$$T'_{ak} = T_{ak} + P_k (T_{i,n} - T_{ak})^{5/4} - Q_K (T_{ak} - T_{i+1,1})^{5/4} + S_k (T_{i,n} - T_{i+1,1}) + G_{ak} \quad (11)$$

where

$$P_k = \frac{h \Delta \theta}{\rho_{ak} c_{pa} a}$$

ρ_a : air density function of temperature

c_{pa} : specific heat of air

$$Q_K = \frac{h\Delta\theta}{\ell_{ak} c_{pa} \rho_a}$$

$$S_k = \frac{\overset{\circ}{m}\Delta\theta}{\ell_{ak} \rho_a}$$

$$G_{ak} = \frac{g_{ak} \Delta\theta}{c_{pa} \rho_a}$$

Air to Solid

$$T'_{i+1,1} = T_{i+1,1} + R_i \left[(T_{in})^4 - (T_{i+1,1})^4 \right] - \frac{2}{M_{i+1}} (T_{i+1,1} - T_{i+1,2}) + H_{i+1} (T_{ak} - T_{i+1,1})^{5/4} \quad (12)$$

R_i, M_{i+1}, H_{i+1} as defined before.

Solid to Ambient

$$T'_{N,n} = T_{N,n} + \frac{2}{M_n} (T_{N,n-1} - T_{N,n}) - R_N (T_{N,n}^4 - T_O^4) - H_N (T_{N,n} - T_O)^{5/4} + \frac{G_{N,n} (\Delta x_N)^2}{k_{N,n} M_N} \quad (13)$$

where

$$R_N = \frac{2\Delta\theta\sigma\epsilon_N}{\Delta x_N \rho_N c_N}$$

ϵ_N : emissivity of solid (last node to ambient)

$H_N, k_{N,n}$ and M_N as defined before

T_O : ambient temperature

Solid to Symmetry Plane

$$T'_{N,n} = T_{N,n} + \frac{2}{M_N} (T_{N,n-1} - T_{N,n}) - H_N (T_{N,n} - T_S)^{5/4} + \frac{G_{N,n} (\Delta x_N)^2}{k_{N,n} M_n} - R_N (T_{N,n}^4 - T_S^4) \quad (14a)$$

$$T'_S = T_S + P_S (T_{N,n} - T_S)^{5/4} + R_N (T_{N,n}^4 - T_S^4) \quad (14b)$$

where

T_S : temperature at symmetry plane

$$P_S = \frac{h \Delta \theta}{\ell_s c_p \rho_a}$$

ℓ_s : distance between solid surface and symmetry plane.

Solid to Solid

$$T'_{i+1,1} = T'_{i,n}$$

$$T'_{i,n} = \left[A_i T_{i,n} + A_{i+1} T_{i+1,1} + B_i g_{i,n} + B_{i+1} g_{i+1,1} + D_{i,n} (T_{i,n-1} - T_{i,n}) - D_{i+1,1} (T_{i+1,1} - T_{i+1,2}) \right] (A_i + A_{i+1}) \quad (15)$$

where

$$A_i = \frac{\rho_i c_i \Delta x_i}{2}$$

$$B_i = \frac{\Delta x_i \Delta \theta}{2}$$

$$D_{i,n} = \frac{k_{i,n} \Delta \theta}{\Delta x_i}$$

$$D_{i+1,1} = \frac{k_{i+1,1} \Delta \theta}{\Delta x_{i+1}}$$

$g_{i,j}$: rate of heat generation per unit volume in i th solid.

Furnace Gases to First Solid Surface

$$T'_{1,1} = T_{1,1} + R_1 (T_F^4 - T_{1,1}^4) + H_1 (T_F - T_{1,1}) + \frac{G_{1,1} \Delta x_1}{k_{1,1} M_1} - \frac{2}{M_1} (T_{1,1} - T_{1,2}) \quad (16)$$

where

$$R_1 = \frac{2 \Delta \theta \sigma \epsilon_o}{x_{1,1} c_1}$$

ϵ_o : emissivity of first surface (furnace gases to 1st solid).

T_F : furnace temperature, and

H_1 : as defined before

4. DISCUSSION OF NUMERICAL PROGRAM

A flow chart of the main program is presented in figure 16. A listing of the complete numerical program is also presented at the end of this report. The logical sequence of the main program can be grasped readily by first considering the flow chart.

The following is a list of input parameters as read in on data cards (examples of which are shown at section 5.3).

NN: number of solid layers

N: number of nodes in each layer

M: number of air spaces

ID: sequence of numbers 1 or 0, specifying the sequence of solid layers and air spaces, e.g., 101011101 means solid-air-solid-air-solid-solid-solid-air-solid.

IDD: sequence of numbers specifying the material of each solid layer, e.g., 122321 means the six solid layers of the problem are of materials 1, 2, 2, 3, 2, 1 in that order. Various temperature dependent material properties are stored in Subroutine PROP.

AL(i): thickness of ith solid layer in feet

AI(i): thickness of air gap spacing in feet

GA(k): rate of heat generation per unit volume due to combustibles in kth air space, Btu/ft³-hr.

DTHETA: Time increment in fraction of hour.

AMO: Volume rate of airflow through walls per unit area in ft³/ft²-hr (m/ρ).

GM1, GM2, GM3, etc: Heat absorption or release due to phase change in material 1, 2 or 3 etc., Btu/ft³hr.

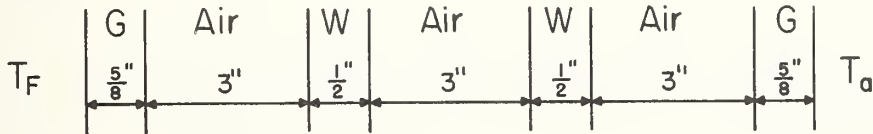
Subroutine PROP stores temperature dependent thermal properties and phase change reactions of some common building materials. This subroutine can be expanded as desired when new materials are encountered. When called from the main program this subroutine supplies the thermal properties for the ith layer of solid currently being calculated.

The function subroutines are self-explanatory. The comment statement at the beginning of each function subroutine properly identifies it with the corresponding equation and boundary conditions in section 3.

5. SAMPLE CASES CALCULATED

5.1. Description of Panels

Case 1: Four solid layers (gypsum, wood, wood, gypsum), three air gaps, heat from one side as shown,

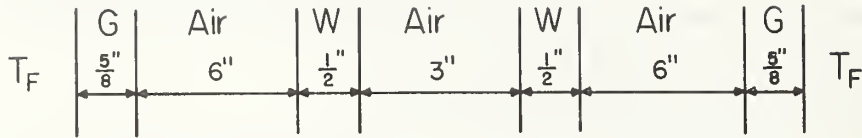


where

G: Gypsum board

W: Plywood

Case 2: Four solid layers (gypsum, wood, wood, gypsum), three air gaps, heating from both sides as shown,



where

G: Gypsum board

W: Plywood

Case 3: Bulkhead 2B², four solid layers (marinite, mineral wool, aluminum, marinite), two air gaps, heat from one side as shown,



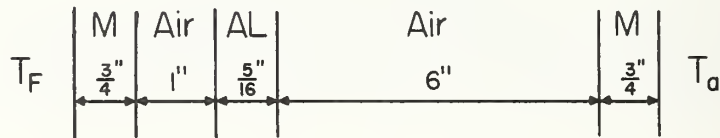
where

M : Marinite

MW: Mineral Wool

AL: Aluminum

Case 4: Bulkhead 3, three solid layers (marinite, aluminum, marinite), two air gaps, heat from one side as shown,



where

M : Marinite

AL: Aluminum

²Assembly descriptions and details of the actual ASTM E 119 fire endurance tests of this and following bulkheads are presented in reference [11].

Case 5: Bulkhead 3C, four solid layers (marinite, aluminum, mineral wool, marinite), two air gaps, heat from one side as shown,



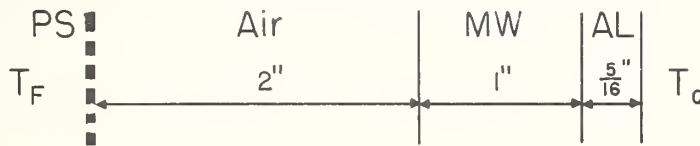
where

- M : Marinite
- AL: Aluminum
- MW: Mineral Wool

Case 6: Bulkhead 3F, four solid layers (marinite, mineral wool, aluminum, marinite), two air gaps, heat from one side as shown,



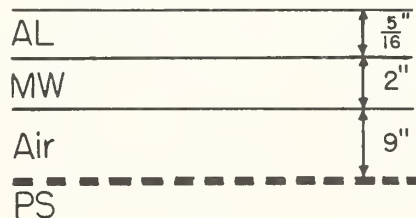
Case 7: Bulkhead 4, three solid layers (perforated steel, mineral wool, aluminum), one air gap, heat from one side as shown,



where

- PS: Perforated steel sheet (#16 USCG, 3/16 inch diameter holes, 3/8 inch diameter holes, 3/8 inch center, 23% open area)
- MW: Mineral wool
- AL: Aluminum

Case 8: Deck 5B1, three solid layers (perforated steel, mineral wool, aluminum), heat from bottom as shown,



5.2. Thermal Properties

The following thermal properties are taken from Ref. [1] and Ref. [10].
NBS property measurements are programmed into subroutine PROPT,

Gypsum Board

$$\begin{aligned}\rho &= 60 \text{ lb/ft}^3 \\ c &= .26 \text{ Btu/lb } ^\circ\text{F} \\ k &= .125 \text{ Btu/hr ft } ^\circ\text{F} && 0 \leq T \leq 200 \text{ } ^\circ\text{F} \\ &= .075 \text{ Btu/hr ft } ^\circ\text{F} && 200 \text{ } ^\circ\text{F} \leq T \leq 400 \text{ } ^\circ\text{F} \\ &= (.05 + \frac{T}{16,000}) \text{ Btu/hr ft } ^\circ\text{F} && 400 \text{ } ^\circ\text{F} \leq T \leq 2000 \text{ } ^\circ\text{F} \\ \epsilon &= .9\end{aligned}$$

Heat of moisture desorption and calcination: 20,740 Btu/ft

Brick

$$\begin{aligned}\rho &= 110 \text{ lb/ft}^3 \\ c &= .216 \text{ Btu/lb } ^\circ\text{F} \\ \epsilon &= .9 \\ k &= 1.0 \text{ Btu/hr ft } ^\circ\text{F} && 0 \leq T \leq 200 \text{ } ^\circ\text{F} \\ &= (.46 + 2T/10,000) \text{ Btu/hr ft } ^\circ\text{F} && 200 \text{ } ^\circ\text{F} \leq T \leq 2000 \text{ } ^\circ\text{F}\end{aligned}$$

Heat of moisture desorption 5000 Btu/ft³

Plywood

$$\begin{aligned}\rho &= 31 \text{ lb/ft}^3 \\ c &= .67 \text{ Btu/lb } ^\circ\text{F} \\ \epsilon &= .9 \\ k &= .065 \text{ Btu/hr ft } ^\circ\text{F}\end{aligned}$$

Heat of moisture desorption 1500 Btu/ft³

Mineral Wool

$$\begin{aligned}\rho &= 6.04 \text{ lb/ft}^3 \\ c &= .2 \text{ Btu/lb } ^\circ\text{F} \\ \epsilon &= .9 \\ k &= .02 \text{ Btu/hr ft } ^\circ\text{F} && 0 \leq T \leq 50 \text{ } ^\circ\text{F} \\ &= .02167 \text{ Btu/hr ft } ^\circ\text{F} && 50 \text{ } ^\circ\text{F} \leq T \leq 75 \text{ } ^\circ\text{F} \\ &= .0229 + 0.517(T-100)/10,000 && 75 \text{ } ^\circ\text{F} \leq T \leq 2000 \text{ } ^\circ\text{F}\end{aligned}$$

Aluminum

$$\begin{aligned}\alpha &= 3.33 \text{ ft}^2/\text{hr} \\ \rho &= 169 \text{ lb}/\text{ft}^3 \\ c &= .208 \text{ Btu}/\text{lb } ^\circ\text{F} \\ \epsilon &= .09 \\ k &= .167 + 1.63 T/10,000 && 0 \leq T \leq 200 \text{ } ^\circ\text{F} \\ &= 117 + .13 (T-32) && 200 \leq T \leq 2000 \text{ } ^\circ\text{F}\end{aligned}$$

Marinite

$$\begin{aligned}\rho &= 36 \text{ lb}/\text{ft}^3 \\ c &= .25 \text{ Btu}/\text{lb } ^\circ\text{F} && 0 \leq T \leq 200 \text{ } ^\circ\text{F} \\ &= .25 + 3(T-200)/10,000 && 200 \text{ } ^\circ\text{F} \leq T \leq 2000 \text{ } ^\circ\text{F} \\ \epsilon &= .9 \\ k &= .063 \text{ Btu}/\text{hr ft } ^\circ\text{F} && 0 \leq T \leq 200 \text{ } ^\circ\text{F} \\ &= (.76 + 1.1(T-100)/10,000)/12 && 200 \text{ } ^\circ\text{F} \leq T \leq 2000 \text{ } ^\circ\text{F}\end{aligned}$$

5.3. Input Data

The following are the complete input data for the sample cases calculated.

Case 1: Four solid layers, 3 air gaps, furnace on one side (gypsum-air-wood-air-wood-air-gypsum)

4531	68.	.0	5380.0	1500.0	1.0
1010101					
1331					
.052	.0417	.0417	.052		
.25	0.	.25	0.	.25	0.

Case 2: Four solid layers, 3 air gaps, furnace on both sides (gypsum-air-wood-air-wood-air-gypsum)

4532	68.0	.0	5380.0	1500.0	1.0
1010101					
1331					
.052	.0417	.0417	.052		
.5	0.	.25	0.	0.	

Case 3: Bulkhead 2B, four solid layers, 2 air gaps, furnace on one side
(marinite-air-mineral wool-aluminum-air-marinite)

4321	68.0	.0	.0	.0	1.0
101101					
6456					
.063	.083	0.052	.083		
.5	.00	.083	.00		

Case 4: Bulkhead 3, three solid layers, 2 air gaps, furnace on one side
(marinite-air-aluminum-air-marinite)

3321	68.0	.0	.0	.0	1.0
10101					
656					
.063	.052	.063			
.083	.0	.5	.0		

Case 5: Bulkhead 3C, four solid layers, two air gaps furnace on one side
(marinite-air-aluminum-mineral wool-air-marinite)

4331	68	.00	.00	.00	1.0
101101					
6546					
.063	.05	.083	.042		
.083	.00	.5	.00		

Case 6: Bulkhead 3F, four solid layers, two air gaps, furnace on one side
(marinite-air-mineral wool-aluminum-air-marinite)

4321	68.0	.00	.00	.00	1.0
101101					
6456					
.063	.083	.052	.063		
.083	.00	.5	.00		

6. DISCUSSION OF RESULTS AND CONCLUSIONS

Comparison plots of calculated and measured temperatures from standard fire endurance tests represented by the above sample cases are presented in figures 8-15. Tests were conducted at the NBS large scale fire test center, Washington, D.C. Complete specification of the bulkheads and decks and descriptions of the tests are presented in a separate NBS report [11]. The good agreement between calculations and actual fire endurance test measurements as shown in the comparison plots reflect the success of the mathematical modeling.

In the comparison plots, temperature-time histories were recorded for each individual panel in a given wall construction for comparison with computer calculations. The plots can be examined for details of the heat transfer processes. For the purpose of fire endurance rating generally only the temperature history of the unexposed surface is needed. Table 1 shows a comparison of the fire endurance times by experiment and calculation. The criterion used in this table is the 250 °F average temperature rise condition at the unexposed surface. The agreement of experimental results and theoretical predictions of fire endurance times is good. Based on those calculations one would recommend using the present computer program for the purposes of fire endurance evaluation and design studies. Such applications would result in considerable savings in both money and time. This program could also be used to evaluate the performance of new materials.

Finally a word of caution in the use of a thermal analyzer program with air gap heat balances such as the present program. Due to the low heat capacity of air, one must exercise caution in selecting the incremental $\Delta\theta$. The iteration time, $\Delta\theta$, used in the previous sample calculations are 1/720 or 1/1440 hour for cases which do not involve metal layers and 1/14400 hour for cases involving metals.

7. ACKNOWLEDGMENT

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The author also wishes to thank Mr. J. Newton Breese for his part in preparing the graphs and the flow chart for reproduction.

Table 1. Comparison of Fire Endurance Times by Experiment and Calculations

Case No.	Description	Endurance Time	
		Experiment	Calculation
1	4 Layers, Gypsum, Wood, Wood, Gypsum, 3 Air Gaps	Passed 1 hr	Passed 1 hr
2	4 Layers, Gypsum, Wood, Wood, Gypsum, 3 Air Gaps, fire on both sides	Failed at 35 min	Failed at 37 min
3	4 Layers, Marinite, Mineral Wool Aluminum, Marinite, 2 Air Gaps	Passed 1 hr	Passed 1 hr
4	3 Layers, Marinite, Aluminum, Marinite, 2 Air Gaps	Passed 1 hr	Passed 1 hr
5	4 Layers, Marinite, Aluminum, Mineral Wool, marinite, 2 Air Gaps	Passed 1 hr	Passed 1 hr
6	4 Layers, Marinite, Mineral Wool, Aluminum, Marinite, 2 Air Gaps	Passed 1 hr	Passed 1 hr
7	3 Layers, Perforated Steel, Mineral Wool, Aluminum 1 Air Gap	Failed at 38 min	Failed at 36 min
8	3 Layers, Perforated Steel, Mineral Wool, Aluminum, 1 Air Gap	Failed at 30 min	Failed at 34 min

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- [11] Parker, W. J., Fire Endurance Tests of Aluminum Bulkhead and Deck Assemblies, NBS Report 10813, Nat. Bur. Stand. (U.S.), Washington, D.C., 3 (1972).

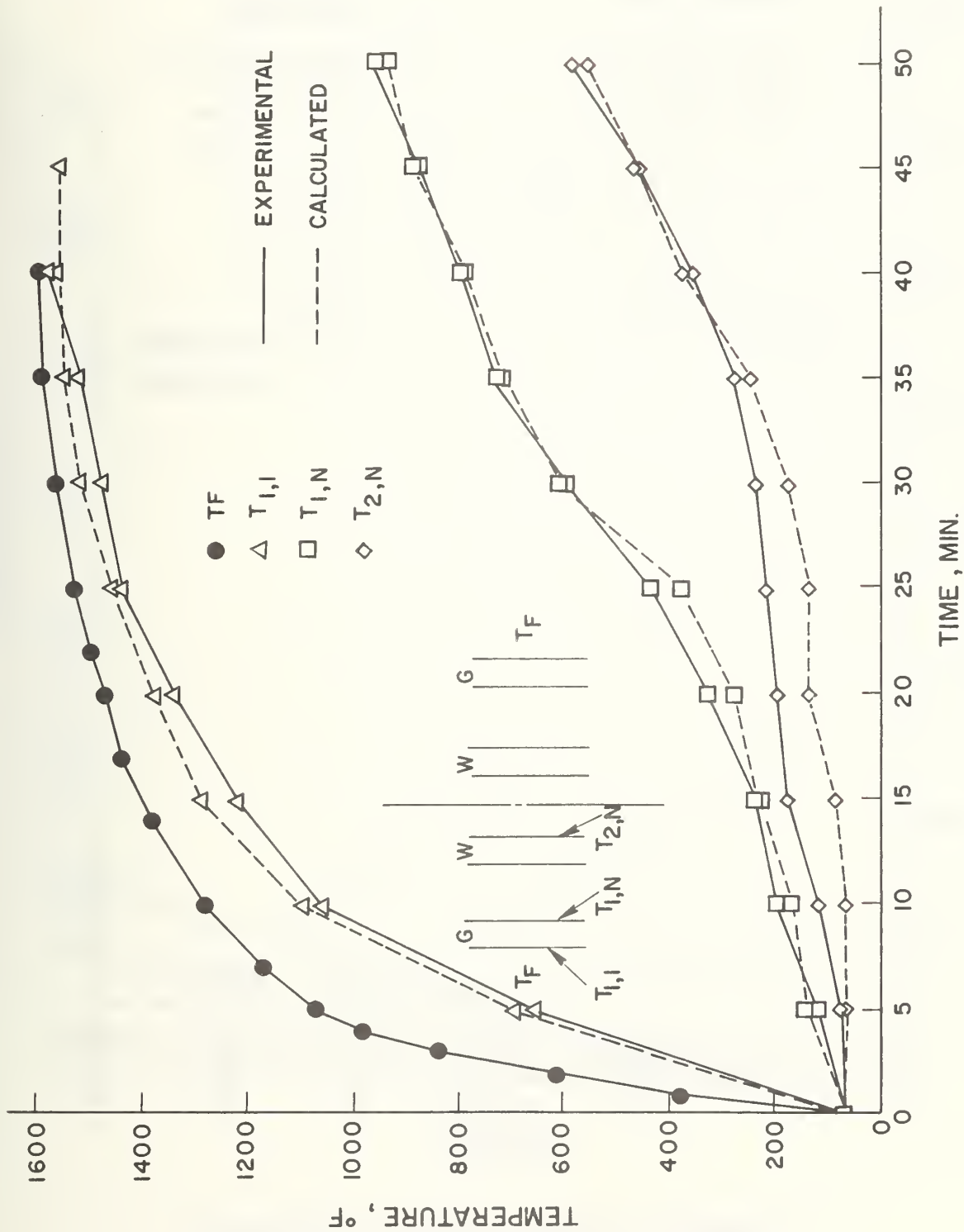


Figure 9. Thermal Response of Gypsum Wood Wall, Case 2.

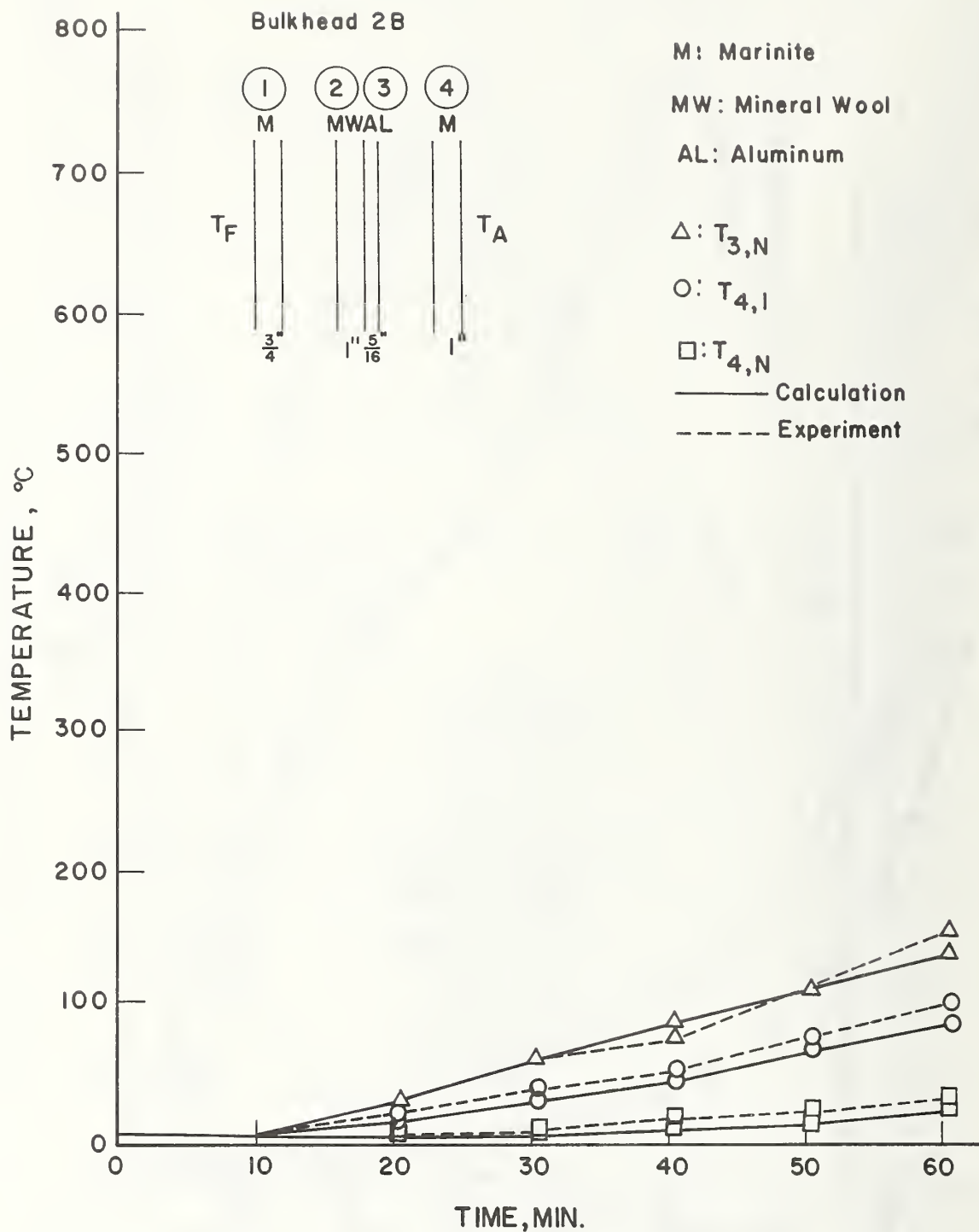


Figure 10. Thermal Response of Bulkhead 2B

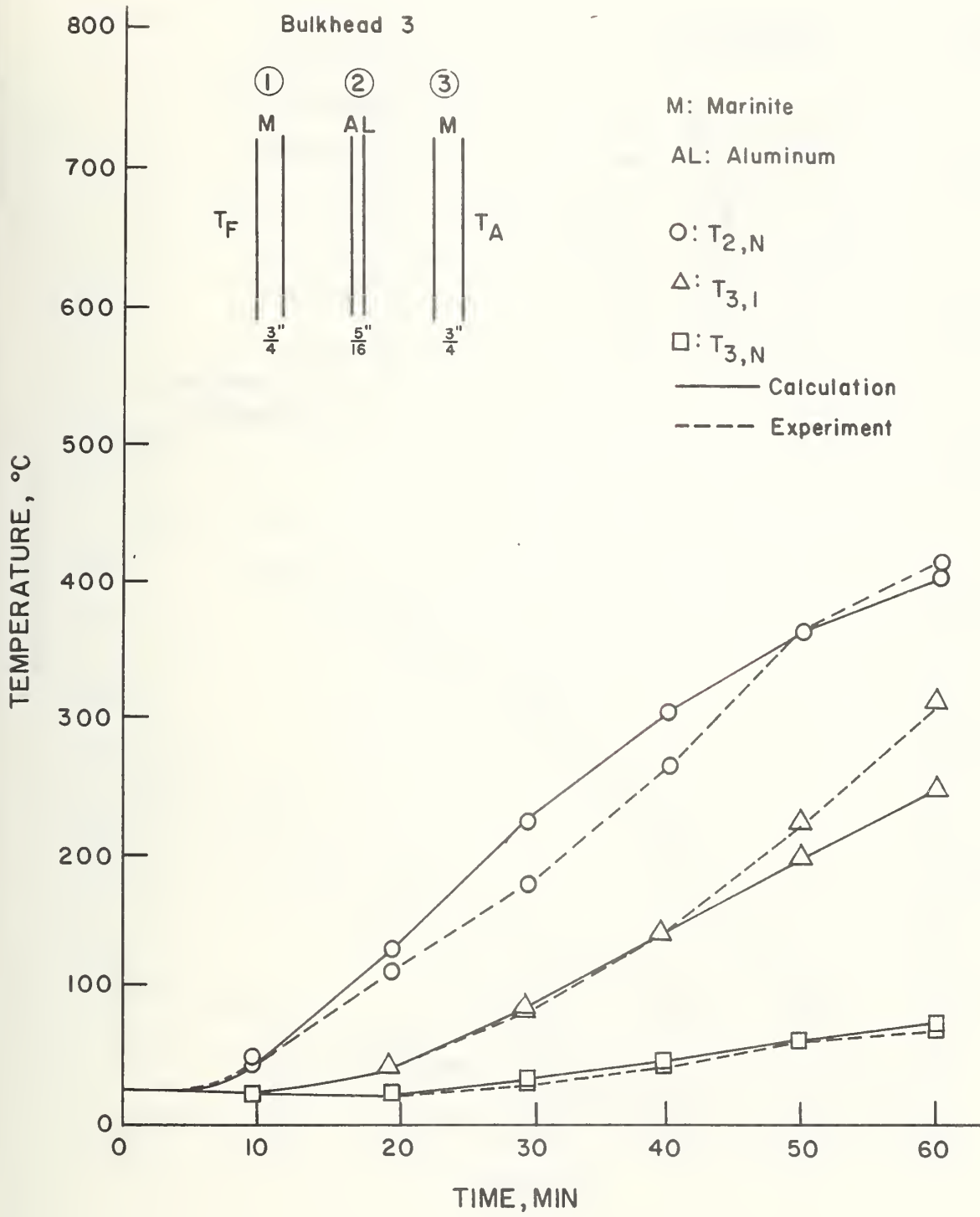


Figure 11. Thermal Response of Bulkhead 3.

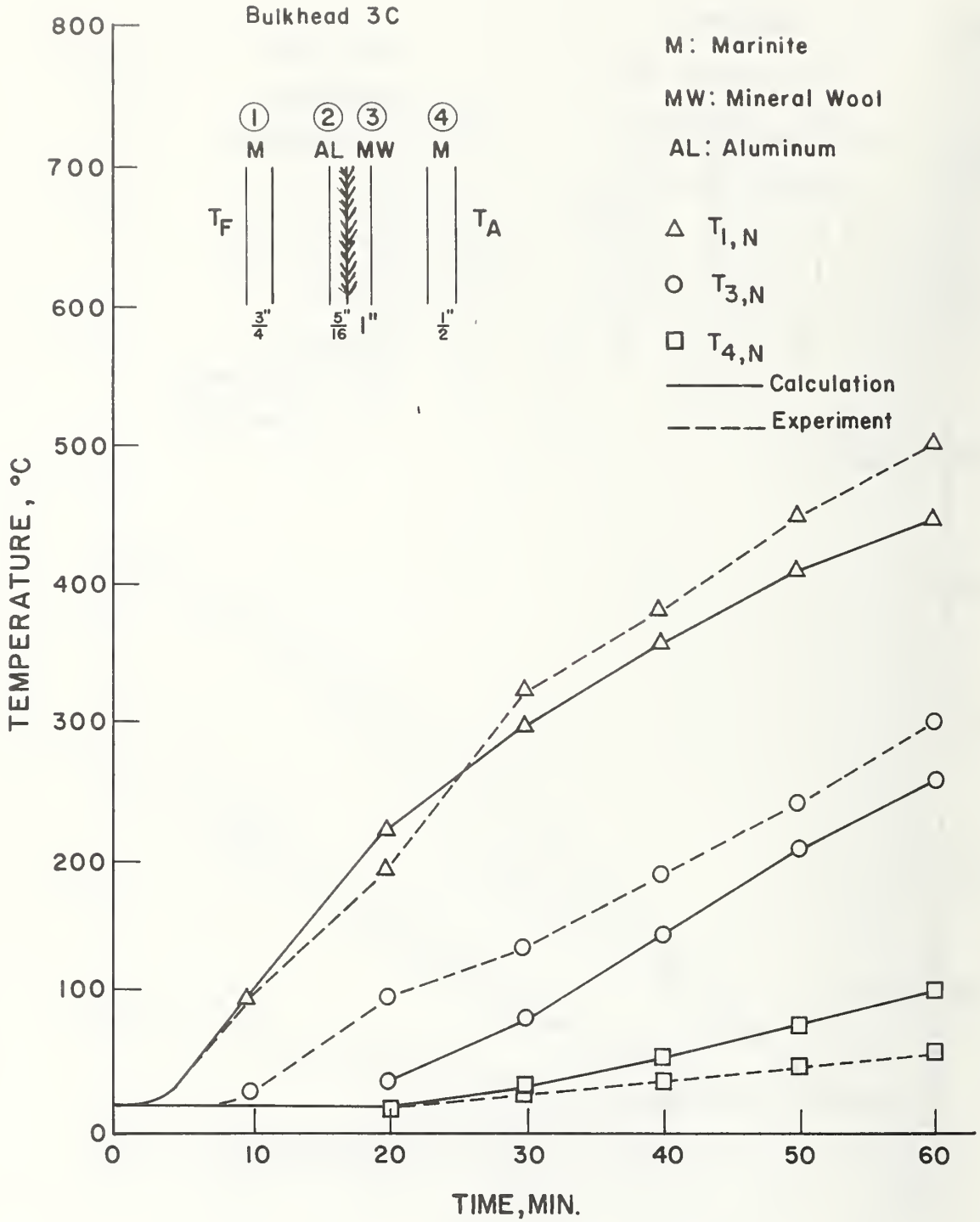


Figure 12. Thermal Response of Bulkhead 3C.

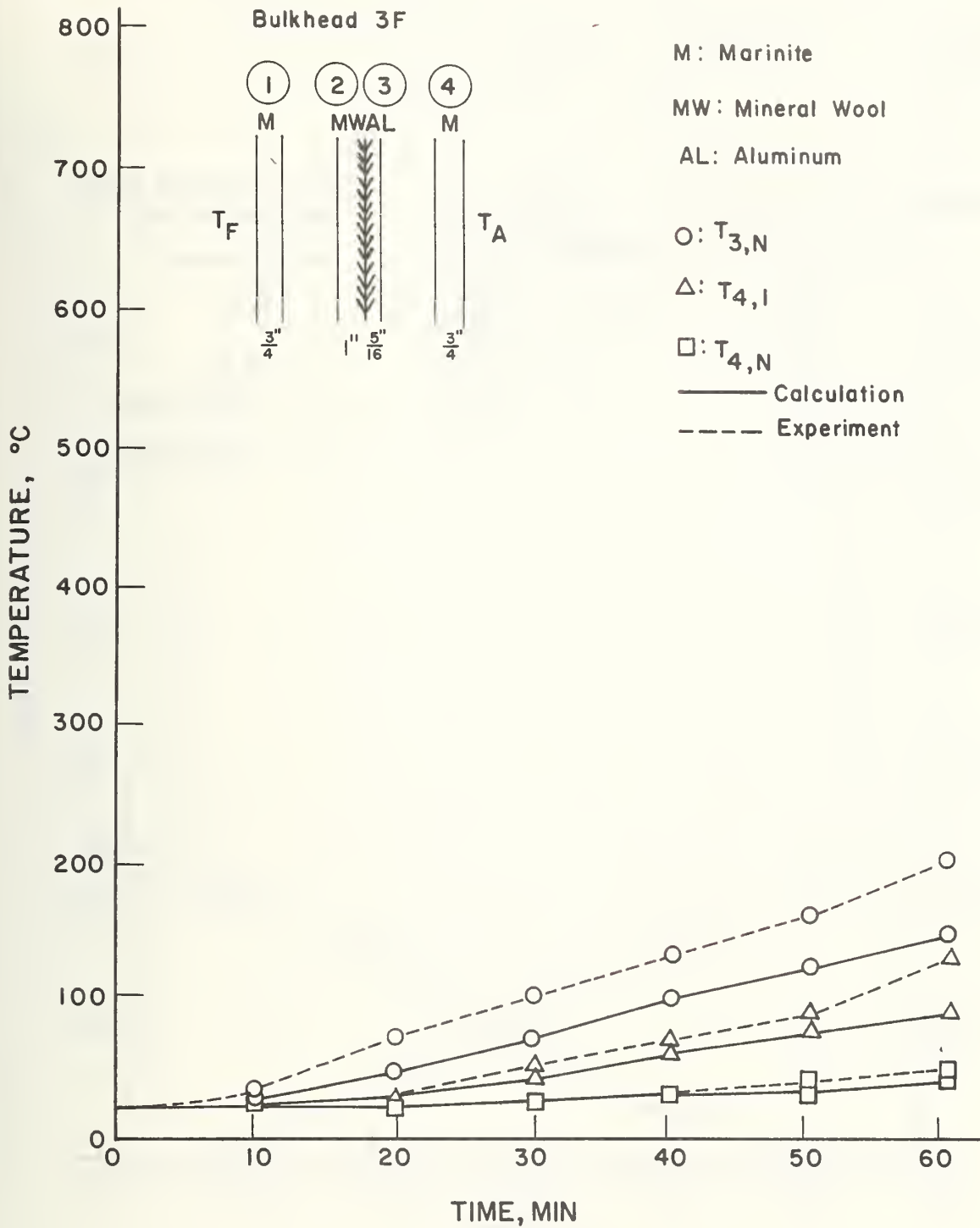


Figure 13. Thermal Response of Bulkhead 3F.

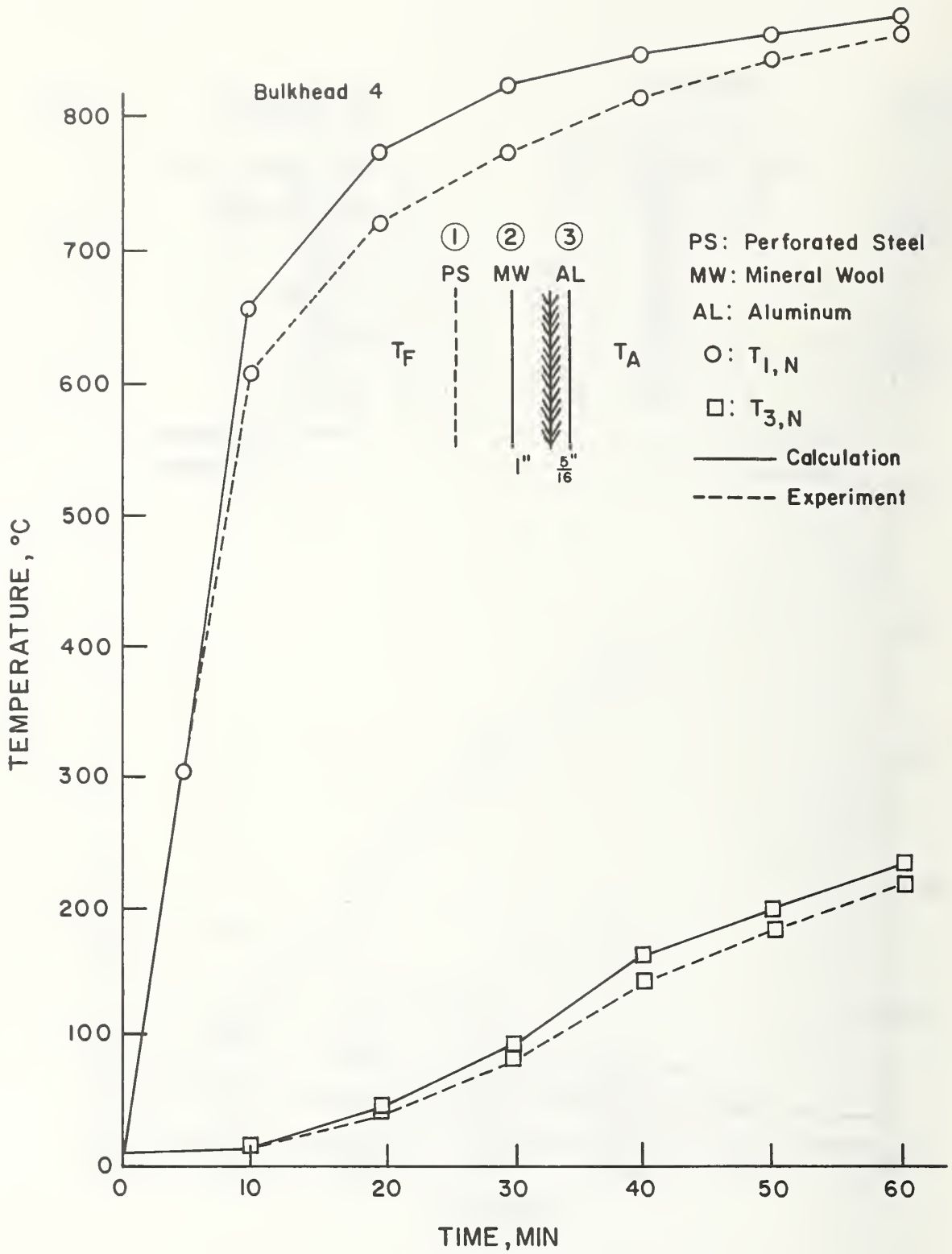


Figure 14. Thermal Response of Bulkhead 4.

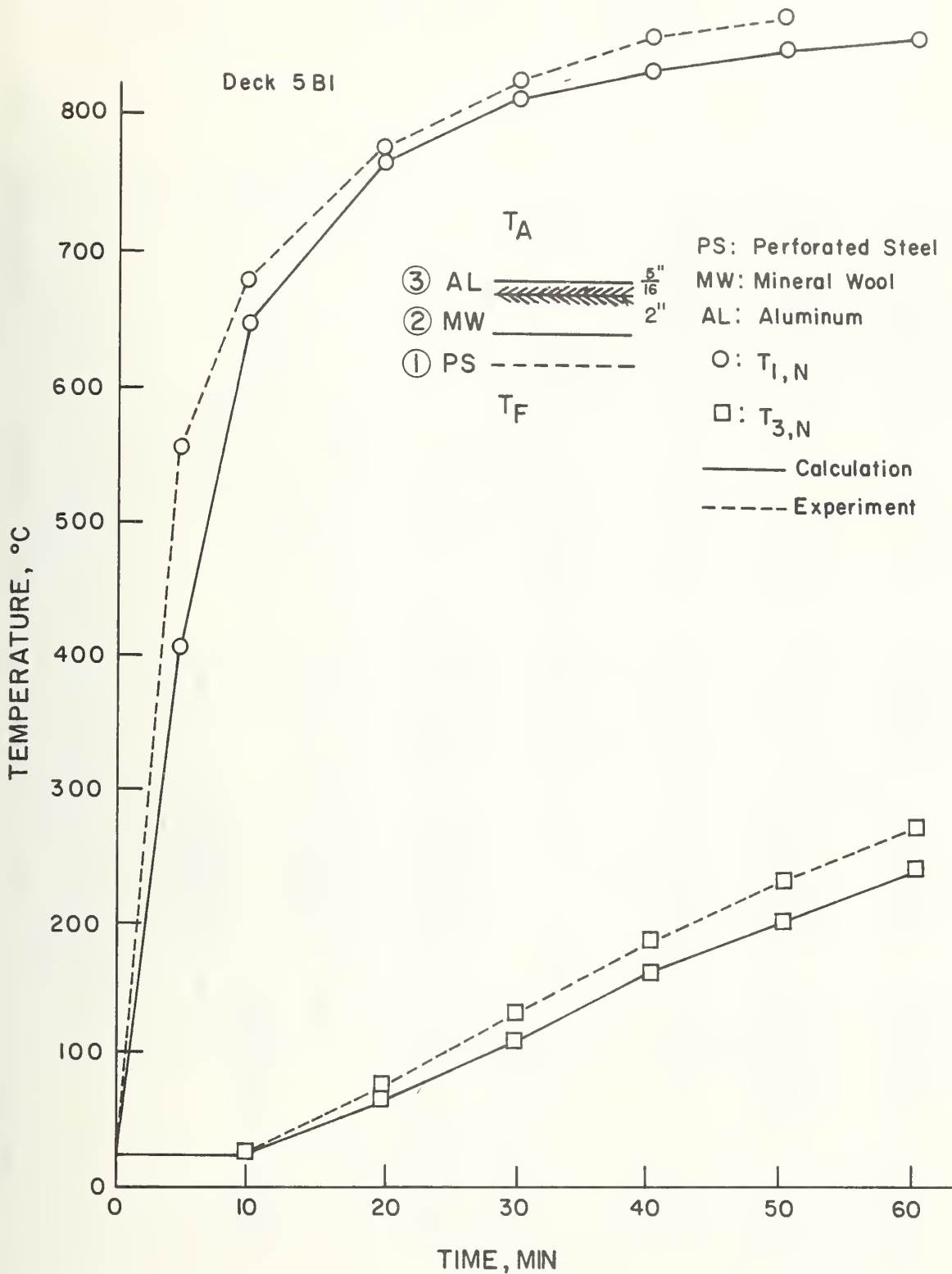


Figure 15. Thermal Response of Bulkhead 5B1.

APPENDIX - PROGRAM LISTING


```

00100 1* C ELEMENT HEAT MAIN PROGRAM 000000
00100 2* C INPUTS 000000
00100 3* C NRE NUMBER OF SOLIDS 000000
00100 4* C NIE NUMBER OF NODES IN SOLID 000000
00100 5* C NIE NUMBER OF AIR SPACES 000000
00100 6* C ITST = AN INTEGER THAT INDICATES WHETHER FORMULA 6 OR FORMULA 8 000000
00100 7* C WILL BE USED IN COMPUTATIONS; 1 INDICATES FORMULA 6 ANY OTHER 000000
00100 8* C NUMBER INDICATES FORMULA 8 000000
00100 9* C T0 = INITIAL TEMPERATURE NOW 6R 000000
00100 10* C GM1 = HEAT RELEASE PER UNIT VOLUME DUE TO MOISTURE VAPORIZATION FOR 000000
00100 11* C GYPSUM 000000
00100 12* C GM2 = HEAT RELEASE PER UNIT VOLUME DUE TO MOISTURE VAPORIZATION FOR 000000
00100 13* C BRICK 000000
00100 14* C GM3 = HEAT RELEASE PER UNIT VOLUME DUE TO MOISTURE VAPORIZATION FOR 000000
00100 15* C WOOD 000000
00100 16* C ID AIR ARRAY OF INTEGERS THAT INDICATES THE SOLID-AIR CONFIGURATION 000000
00100 17* C THATS BEING TESTED 9E AN AIR GAP NONE=ZERO = SOLID 000000
00100 18* C A DATA CARD WITH 1010101 WOULD INDICATE 4 SOLIDS AND THREE AIR GAPS 000000
00100 19* C IND AN ARRAY OF INTEGERS THAT INDICATE THE TYPE OF SOLIDS 1= GYPSUM 000000
00100 20* C 2= BRICK 3= WOOD 4= SOLIDS GYPSUM,WOOD,BRICK 000000
00100 21* C AND GYPSUM THEN DATA CARD WOULD BE PUNCHED AS 1321 000000
00100 22* C AL = SOLID THICKNESS IN FEET 000000
00100 23* C ALPHA = HEAT DIFFUSION COEFFICIENT 000000
00100 24* C RHO = DENSITY OF SOLID IN CURT FEET 000000
00100 25* C C-SPECIFIC HEAT CAPACITY OF SOLID 000000
00100 26* C AI = AIR GAP DISTANCE IN FEET 000000
00100 27* C GA = HEAT RELEASE PER UNIT VOLUME IN AIR GAP 000000
00100 28* C OUTPUTS 000000
00100 29* C T(I,J) PRIME = TEMPERATURE AT TIME(THETA+DTHETA) OF JTH NODE IN 000000
00100 30* C ITH SOLID LAYER 000000
00100 31* C TAC(I) = TEMPERATURE OF MID-POINT OF AIR SPACING BETWEEN ITH AND 000000
00100 32* C I+1 LAYER OF SOLID THETA = TIME 000000
00100 33* C IMPLICIT DOUBLE PRECISION(A-H,O-Z) 000000
00100 34* C REAL T0, AL, AI+GA, X,Y,GM1,GM2,GM3,TMAX 000001
00100 35* C DIMENSION I(30,30),AL(30),AI(30),TA(30),DELTA(30),AM(30),H(30), 000001
00100 36* C 1 BH(30),AK(30,30),G(30,30) 000001
00100 37* C 2 P(30),R(30),O(30),D(P0),GA(30) 000001
00100 38* C DIMENSION X(500,5),Y(500,5),NRMAX(5) 000001
00100 39* C 1 RHOA(30),D(30,30),YDD(30),THETA1(30,30),THETA2(30,30), 000001
00100 40* C DTHETA = TIME INCREMENT 000001
00100 41* C DTHETA1=D3/720.00 000001
00100 42* C H=CHARACTERISTIC HEAT TRANSFER COEFFICIENT 000003
00100 43* C HHE=2700 000003
00100 44* C CPAE = SPECIFIC HEAT CAPACITY FOR AIR 000005
00100 45* C CPAE=0.2500 000005
00100 46* C AMO= VOLUME AIR FLOW THROUGH THE LAYERS, CURIC FEET PER HOUR 000007
00100 47* C AMO= 0.00 000007
00100 48* C ROAI= DENSITY OF AIR IN LB PER CUBIC FOOT 000011
00100 49* C ROAI=0.500 000011
00100 50* C SIGMA = BOLTZMAN STEFAN CONSTANT 000013
00100 51* C SIGMA=0.17140E-8 000013
00100 52* C AK = HEAT CONDUCTION COEFFICIENT 000016
00100 53* C READ IN DATA THAT DESCRIBE PANELS AND READ IN OTHER DATA 000035
00100 54* C READ 99,NN,NN,N,ITEST,T0, G1,GM2,GM3,TMAX 000040
00100 55* C KKEIN=11 000054
00100 56* C READ 91,(ID(I),I=1,KN) 000054
00100 57* C READ 91,(ID(I),I=1,NN)

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00144 5A* READ 99,(AL(I),I=1,NN)
00152 59* IF(.EQ.0)GO TO 307
00154 60* READ 99,(AI(I),GA(I),I=1,M)
00154 61* C THETA = TIME IN HOURS
00163 62* 307 THETA=0.000
00164 63* XMAX=TM*MAX
00165 64* NA=0
00166 65* DO 301 J=1,N
00171 66* DO 301 I=1,NN
00174 67* T(I,J)=T0
00177 68* IF(.EQ.0) GO TO 308
00201 69* DO 302 I=1,M
00204 70* TA(I)=T0
00206 71* 308 DO 305 I=1,NN
00211 72* 305 H(I)=HH
00213 73* DO 104 T=1,NN
00216 74* 104 DELTA(I)=AL(I)/FLOAT(N-1)
00220 75* 309 PRINT 100,NN,N,HH,IFST,T0,
00232 76* PRINT 101,(ID(I),I=1,KK)
00240 77* PRINT 101,(I00(I),I=1,NN)
00246 78* IF(.EQ.0)GO TO 310
00250 79* PRINT 102,(AI(I),GA(I),I=1,M)
00257 80* 310 PRINT 102,(AL(I)
00265 81* G1=GM1
00266 82* G2=GM2
00267 83* G3=GM3
00270 84* TS=T0
00271 85* TF=T0
00271 85* C PLOT VALUES
00271 86* X(1,1)=THETA*60.00
00272 87* X(1,2)=THETA*60.00
00273 88* X(1,3)=THETA*60.00
00274 89* X(1,4)=THETA*60.00
00276 91* X(1,5)=THETA*60.00
00277 92* Y( 1,1)=(T(2,1)-32.00)/1.800
00300 93* Y( 1,2)=(T(3,N)-32.00)/1.800
00301 94* Y( 1,3)=(TA(2)-32.00)/1.800
00302 95* Y( 1,4)=(T(4,1)-32.00)/1.800
00303 96* Y( 1,5)=(T(4,N)-32.00)/1.800
00304 97* I=2
00305 98* PRINT 97
00307 99* PRINT 98
00311 100* PRINT 99,T(1,1),T(1,N),T(2,1),T(2,N),T(3,1),T(3,N),T(4,1),T(4,N),
00311 101* 1 THETA
00324 102* MMEN=1
00325 103* I=1
00326 104* IA=1
00327 105* DO 106 JJ=1,N
00332 106* DO 105 LL=1,NN
00335 107* G(LL,JJ)=0.000
00340 108* K=0
00340 109* C COMPUTE TF FORMULA 7
00341 110* IF(THETA.GE.1.00)GO TO 415
00343 111* TF=T0+101520.00*THETA/(60.00*THETA+4.00)
00344 112* GO TO 417
00345 113* 415 IF(THETA.GE.1.900)GO TO 416
00347 114* TF=(926.00+42.00*THETA-0.013100* (120.00-60.00*THETA)**2)*1.800
00347 115* 1 +32.00

```

```

000065
000076
000100
000100
000115
000116
000120
000140
000140
000140
000145
000150
000155
000160
000176
000204
000204
000207
000223
000234
000245
000247
000264
000307
000311
000313
000315
000317
000317
000320
000322
000324
000325
000326
000333
000341
000346
000353
000359
000362
000366
000372
000372
000407
000413
000414
000432
000432
000432
000440
000440
000441
000445
000456
000460
000463
000463

```

```

G=1,GM2,GM3

```

```

,I=1,NN)

```

```

00350 116* GO TO 417
00351 117* TF=(C26*NO+42*DC*THETA)*1.0D0+32.0D0
00352 118* C COMPUTE T(I,J) AND TPRIME
00353 119* IJ=I00(I)
00354 120* C TEST PROPERTIES FOR CURRENT SOLID
00355 121* CALL PROP(T(I,J),AK(I,J),THETA1(I,J),THETA2(I,J),THETA,
00356 122* I,DTHTA,G(I,J),G1,G2,G3,ALPHA,RHO,C,EPS LON,IJ)
00357 123* AM(I)=DELTA(I)*2/(ALPHA *DTHTA)
00358 124* BH(I)=(2.*H(I)*DTHTA)/(RHO *C *DELTA(I))
00359 125* R1(I)=(2.*DTHTA*SIGMA*FPSLON
00360 126* AKK=AK(I,J) )/(DELTA(I)*RHO *C )
00361 127* IF(AM(I).LE.2.0D0)GO TO 76
00362 128* TPRIME=T(I,J)+R1(I)*(TF-T(I,J))*(TF+T(I,J)+920.0D0)*(TF+460.0D0)
00363 129* 1 **2*(T(I,J)+460.0D0)**2+BH(I)*ABS(TF-T(I,J))*0.25*(TF-T(I,J))
00364 130* 2 * (G(I,J)+DELTA(I)**2)/(AKK*A**(I,J))-2.0D0/AM(I)*(T(I,J)-T(I,J))
00365 131* T(I,J)=TPRIME
00366 132* C COMPUTE TPRIME(I,J) FORMULA 1
00367 133* IJ=I00(I)
00368 134* DO 10 IJ=I00(I)
00369 135* C TEST PROPERTIES FOR CURRENT SOLID
00370 136* CALL PROP(T(I,J),AK(I,J),THETA1(I,J),THETA2(I,J),THETA,
00371 137* I,DTHTA,G(I,J),G1,G2,G3,ALPHA,RHO,C,EPS LON,IJ)
00372 138* AM(I)=DELTA(I)*2/(ALPHA *DTHTA)
00373 139* BH(I)=(2.*H(I)*DTHTA)/(RHO *C *DELTA(I))
00374 140* R1(I)=(2.*DTHTA*SIGMA*FPSLON
00375 141* AKK=AK(I,J) )/(DELTA(I)*RHO *C )
00376 142* IF(AM(I).LE.2.0D0)GO TO 77
00377 143* T(I,J)=T(I,J)+R1(I)*(TF-T(I,J))*(TF+T(I,J)+920.0D0)*(TF+460.0D0)
00378 144* 1 DELTA(I)
00379 145* C CONTINUE
00380 146* IF(I.EQ.M)GO TO 45
00381 147* IF(D(I)+I.EQ.0)GO TO 12
00382 148* C SOLID TO SOLID COMPUTATION
00383 149* IJ=I00(I)
00384 150* C TEST PROPERTIES FOR CURRENT SOLID
00385 151* CALL PROP(T(I,J),AK(I,J),THETA1(I,J),THETA2(I,J),THETA,
00386 152* I,DTHTA,G(I,J),G1,G2,G3,ALPHA,RHO,C,EPS LON,IJ)
00387 153* A(I)=(C40+C*DELTA(I))/2.0D0
00388 154* B(I)=(C40+C*DELTA(I))/2.0D0
00389 155* D(I)=AK(I,J)*DTHTA/DELTA(I)
00390 156* IJ=I00(I+1)
00391 157* CALL PROP(T(I+1,J),AK(I+1,J),THETA1(I+1,J),THETA2(I+1,J),THETA,
00392 158* I,A(I+1)=(PHO+C*DELTA(I+1))/2.0D0)
00393 159* B(I+1)=(DELTA(I+1)*DTHTA)/2.0D0
00394 160* D(I+1)=(AK(I+1,J)*DTHTA)/DELTA(I+1)
00395 161* AKK=AK(I,N)
00396 162* T(I,N)=T55(A(I),T(I,N),A(I+1),T(I+1,J),R(I),G(I,N),B(I+1),
00397 163* I,G(I+1,J),D(I,N),T(I,N-1),D(I+1,J),T(I+1,J))
00398 164* T(I+1,J)=T(I,N)
00399 165* I=I+1
00400 166* GO TO 5
00401 167* C COMPUTE TPRIME FORMULA 2 AIR SPACE COMPUTATION
00402 168* K=K+1
00403 169* IJ=I00(I)
00404 170* C TEST PROPERTIES FOR CURRENT SOLID
00405 171*
00406 172*
00407 173*

```

```

00431 174* CALL PROP(T(I,N),AK(I,J),THETA(I,N),THETA2(I,N),THETA,
00431 175* DTHETA,G(I,N),G1,G2,G3,ALPHA,RHO,C,EPS, LON,IJ)
00432 176* AM(I)=DELTA(I)**2/(ALPHA *DTHETA)
00433 177* BH(I)=(C*H(I)+DTHETA)/(RHO *C *DELTA(T))
00434 178* R1(I)=(C*THETA+SIGMA*EPSLON
00435 179* )/(DELTA(I)*RHO *C )
00436 180* 611
00436 180* IF(AM(I).LE.2.00)GO TO 75
00440 181* T(I,N)=T2(AM(I),T(I,N),T(I,N-1),R1(I),T(I+1),BH(I),TA(K),
00440 182* G(I),H),AKK,DELTA(I))
00440 183* C COMPUTE TAPPIE FORMULA 3
00441 184* RHOA(N)=39.674D0/(TA(K)+460.00)
00442 185* P(K)=(H(K)*DTHETA)/(AI(K)*CPA*PHOA(K))
00443 186* GA(K)=0.0D0
00444 187* S(K)=(AM0*DTHETA)/(AI(K))
00445 188* Q(K)=(H(K+1)*DTHETA)/(AI(K)*CPA*RHOA(K))
00446 189* GAA=GAK(K)
00447 190* TA(I)=T33(TA(K),P(K),T(I,H),G(K),T(I+1),S(K),GAA )
00447 191* C COMPUTE TAPPIE(T+1,1) FORMULA 4
00450 192* IJ=I+(I+1)
00450 193* C TEST PROPERTIES FOR CURRENT SOLID
00451 194* CALL PROP(T(I+1),AK(I+1),THETA(I+1),THETA2(I+1),
00451 195* THETA,DTHETA,G(I+1),G1,G2,G3,ALPHA,RHO,
00451 196* C,EPSLON,IJ)
00452 197* AM(I+1)=DELTA(I+1)**2/(ALPHA*DTHETA)
00453 198* BH(I+1)=(C*H(I+1)+DTHETA)/(RHO*C*DELTA(I+1))
00454 199* R1(I+1)=(C*THETA+SIGMA*EPSLON)/(DELTA(I+1)*RHO*C)
00455 200* AKK=AK(I+1)
00456 201* 412
00456 201* IF(AM(I+1).LE.2.00)GO TO 80
00460 202* T(I+1)=T44(T(I+1),P(I),Q(I),T(I),AM(I+1),BH(I+1),TA(K),T(I+1,2),
00460 203* )
00461 204* 1 G(I+1),AKK,DELTA(I+1))
00463 205* IF(K*CO*W)K=0
00465 206* 39 IF(I*CO*NN)GO TO 45
00466 207* I=I+1
00467 208* IA=IA+1
00467 209* GO TO 5
00467 209* C DECIDE BETWEEN FORMULAS 5 AND 8
00470 210* C COMPUTE T(N+1) FORMULA 6
00470 211* 45 IF(ITE*NE.1)GO TO 37
00472 212* T1=I0
00473 213* IJ=I0(NH)
00473 214* C TEST PROPERTIES FOR CURRENT SOLID
00474 215* CALL PROP(T(I,N),AK(NH),THETA1(NH,N),THETA2(NH,N),THETA,
00475 216* DTHETA,G(I,H),H),G1,G2,G3,ALPHA,RHO,C,EPSLON,IJ)
00475 217* AM(NH)=DELTA(NH)**2/(ALPHA*DTHETA)
00475 218* BH(NH)=(C*H(NH)+DTHETA)/(RHO*C*DELTA(NH))
00477 219* R1(NH)=(C*THETA+SIGMA*EPSLON)/(DELTA(NH)*RHO*C)
00500 220* AKK=AK(NH)
00501 221* 431 IF(AM(NH).LE.2.00)GO TO 78
00503 222* T(NH,N)=T65(T(NH),D),AM(NH),T(NH-1),P1(NH),T1,BH(NH),
00504 223* G(I,H),AKK,DELTA(NH))
00504 224* GO TO 200
00504 225* C COMPUTE T(NH,N) FORMULA 8
00505 226* IJ=I0(NH)
00505 227* C TEST PROPERTIES FOR CURRENT SOLID
00506 228* CALL PROP(T(NH,N),AK(NH,N),THETA1(NH,N),THETA2(NH,N),THETA,
00506 229* DTHETA,G(NH,N),G1,G2,G3,ALPHA,RHO,C,EPSLON,IJ)
00507 230* AM(NH)=DELTA(NH)**2/(ALPHA*DTHETA)
00510 231* BH(NH)=(C*THETA+SIGMA*DELTA(NH))

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00511 232* R1( N,I)=(2.00*DTHETA*SIGMA*EPSI(N))/(DELTA( N))*RH0*C)
00512 233* AKK=AK(N)*I
00513 234* IF(AM(N).LT.2.00)GO TO 79
00515 235* T(RI,N)=TRR(T(N),N) ,T(N,N-1),TS,AM(N),RH(N),
00516 237* G(N),N),AKK,DELTA(N),RI(N))
00517 238* PS=0.1500*DTHETA/(0.500*CPA*ROA1)
00520 239* TS=TS+PS*ADAPS(T(N),N)-TS)**.25*(T(N),N)-TS)
00522 240* IF(PS*(N),I,0),HE,0)GO TO 57
00522 241* PRINT 80,T(1,1),T(1,N),T(2,1),T(2,N),T(3,1),T(3,N),T(4,1),T(4,N),
1 THETA
00522 242* C PLOT VALUFS
00532 243* X(I,1)=THETA*60.00
00535 244* X(I,2)=THETA*60.00
00536 245* X(I,3)=THETA*60.00
00537 246* X(I,4)=THETA*60.00
00540 247* X(I,5)=THETA*60.00
00542 248* Y( I,1)=(T(2,1)-32.00)/1.800
00543 249* Y( I,2)=(T(3,N)-32.00)/1.800
00544 250* Y( I,3)=(T(2)-32.00)/1.800
00545 251* Y( I,4)=(T(4,1)-32.00)/1.800
00546 252* Y( I,5)=(T(4,N)-32.00)/1.800
00547 253* I=I+1
00550 254* IF( THETA.GT.XMAX)GO TO 200
00552 255* NAME=I
00552 256* C INCREMENT TIME
00553 257* THETA=THETA+DTHETA
00554 258* GO TO 1
00555 259* I=I-1
00556 260* PRINT 87
00560 261* NRO=500
00561 262* NRMX(1)=I
00562 263* NRMX(2)=I
00563 264* NRMX(3)=I
00564 265* NRMX(4)=I
00565 266* NRMX(5)=I
00566 267* NAME5=5
00567 268* PPRINT 87
00571 269* CALL PLOTS(NARGS,X,Y,NRMX,NROW)
00572 270* GO TO 377
00573 271* PRINT 93 ,AM(1)
00576 272* STOP
00577 273* PRINT 81,AM(N)
00602 274* STOP
00603 275* PRINT 82,AM(N)
00606 276* STOP
00607 277* PRINT 83,AM(I)
00612 278* STOP
00613 279* PRINT 84, AM(I+1)
00616 280* STOP
00617 281* PRINT 85, A*(I)
00622 282* STOP
00623 283* FORMAT(IX,*,M NOT GREATER THAN 2 FORMULA 6 ME,E14.8)
00624 284* FORMAT(IX,*,M NOT GREATER THAN 2 FORMULA 8 ME,E14.6)
00625 285* FORMAT(IX,*,M NOT GREATER THAN 2 FORMULA 4 ME,E14.8)
00626 286* FORMAT(IX,*,M NOT GREATER THAN 2 FORMULA 4 ME,E14.8)
00627 287* FORMAT(IX,*,M NOT GREATER THAN 2 FORMULA 2 ME,E14.8)
00630 288* FORMAT(IX,*,M NOT GREATER THAN 2 T(1,1)-ME,E14.8)
00631 289* FORMAT( T(1,1) T(1,1) T(1,1) T(1,1) T(1,1) T(1,1) T(2,1) T(2,1) T(2,1) T(2,1) T(2,1) T(2,1) T(2,N) T(2,N) T(2,N) T(2,N)

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ADDRESS	OPERATOR	OPERAND	OPERATION	OPERAND	OPERATION	OPERAND	OPERATION	OPERAND
00631	290*	1	T(3,1)	T(3,1)	T(4,1)	T(4,N)	THETA*	002414
00632	291*	101	FOR**AT(20I3)					002414
00633	292*	100	FOR**AT(1X,4I6,5F11.3)					002414
00634	293*	98	FOR**AT(10F5.0)					002414
00635	294*	92	FOR**AT(F6.0)					002414
00636	295*	97	FOR**AT(2F6.0)					002414
00637	296*	91	FOR**AT(20I1)					002414
00640	297*	216	FOR**AT(1X,1Y,2I3,3F14.2)					002414
00641	298*	90	FOR**AT(4I2,5F6.0)					002414
00642	299*	89	FOR**AT(1X,F12.3,1X,F12.3,1X,F12.3,1X,F12.3)					002414
00643	300*	87	F12.3,1X,F12.3,7X,F6.3)					002414
00644	301*	102	FOR**AT(1H1)					002414
00645	303*	312	FOR**AT(1X,4D26.16)					002414
00646	304*	311	FOR**AT(1X,F14.8,4D26.16)					002414
00647	305*	86	FOR**AT(1X,F12.3,1X,F12.3,1X,F12.3,1X,F12.3)					002414
00650	306*	317	FOR**AT(1X,3F12.3,D26.16,3F12.3)					002414
00651	307*		END					002414

END OF COMPILATION: NO DIAGNOSTICS.

FOR,IS S1
FOR 50E3-01/25/77-23:19:05 (,0)

FUNCTION T11 ENTRY POINT 000027

STORAGE USED: CODE(1) 000031; DATA(0) 000015; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

0003 IJPR3*

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0000 000002 2F 0000 000011 INUP\$ 0000 D 000000 T11

ADDRESS	OPERATOR	OPERAND	OPERATION	OPERAND	OPERATION	OPERAND	OPERATION	OPERAND
00100	1*	C	ELEMENT TRANSI					000000
00101	2*		DOUBLE PRECISION FUNCTION T11(AM,T1,T2,T3,AK,DELTA)					000000
00103	3*		IMPLICIT DOUBLE PRECISION(A-H,O-W)					000000
00104	4*	C	FORMULA 1					000000
00105	5*		T11=(T1+T2)/AM+(1.00-2.00/AM)*T3+(6*DELTA**2)/(AK*AM)					000000
00106	7*	2	FOR**AT(FORMULA 1)					000017
00107	8*		RETURN					000017
			END					000030

END OF COMPILATION: NO DIAGNOSTICS.

FOR,IS S2
FOR 50E3-01/25/77-23:19:06 (,0)

FUNCTION T2 ENTRY POINT 000065

STORAGE USED: CODE(1) 000102; DATA(0) 000047; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

0003 XPRR
0004 FERR3\$

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0000 000002 1F 0000 000007 2F 0000 000021 INJP\$ 0000 D 000000 T22

00100	1*	C	ELEMENT TRANS	000000
00100	2*	C	FORMULA 2	000000
00101	3*		DOUBLE PRECISION FUNCTION T2(A,T1,T2,P1,T3,H,T4,G,AK,DELTA)	000000
00103	4*		IMPLICIT DOUBLE PRECISION(A-H,O-W)	000000
00104	5*		T22=T1+P.O0/AV*(T2-T1)-P1*(T1-T3)*(T1+T3+920.00)*((T1+460.00)**2+	000000
00104	6*		1*(T3+460.00)**2)-H*OARS*(T1-TA)**.25*(T1-TA)+(6*DELTA**2)/(AK*AM)	000000
00105	7*	1	FORMAT(1X,3F12.3,D26.16,3F12.3)	000053
00106	8*	2	FORMAT(' FORMULA 2')	000053
00107	9*		RETURN	000053
00110	10*		END	000101

END OF COMPILATION: NO DIAGNOSTICS.

FOR IS 53
FOR S0E3-01/25/77-23:19:08 (,0)

FUNCTION T3 ENTRY POINT 000047

STORAGE USED: CODE(1) 000067; DATA(0) 000036; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

0003 XPRR
0004 FERR3\$

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0000 000002 2F 0000 000006 INJP\$ 0000 D 000000 T33

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00100 1* C ELEMENT TRANS3 000000
00100 2* C FORMULA 3 000000
00101 3* DOUBLE PRECISION FUNCTION T33(T1,P,T1,Q,T2,S,G,A) 000000
00103 4* IMPLICIT DOUBLE PRECISION(A-H,O-W) 000000
00104 5* T33=TA +P*ABS(T1-TA)**.25*(T1-TA)-Q*DARS(TA-T2)**.25*(TA-T2)+ 000000
00104 6* 1 S*(T1-T2)+6A 000036
00105 7* 2 FORMAT(' FORMULA 3') 000036
00106 8* RETURN 000066
00107 9* END 000066

```

END OF COMPILATION: NO DIAGNOSTICS.

FOR IS S4
FOR S0E3-01/25/77-23:19:09 (*0)

FUNCTION T44 ENTRY POINT 000065

STORAGE USED: CODE(1) 000102; DATA(0) 000042; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

0003 XPCR
0004 NERR35

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0000 000002 2F 0000 000014 INJPS 0000 000000 T44

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00100 1* C ELEMENT TRANS4 000000
00100 2* C FORMULA 4 000000
00101 3* DOUBLE PRECISION FUNCTION T44(T1,P1,T2,AM,H,TA,T3,G,AK,DELTA) 000000
00103 4* IMPLICIT DOUBLE PRECISION(A-H,O-W) 000000
00104 5* T44=T1 +R1*(T2-T1)*(T2+T1+Q20.00)*((T2+460.00)**2+(T1+460.00)**2) 000000
00104 6* 1 -2.00/AM*(T1-T3)+H*DARS(TA-T1)**.25*(TA-T1)+(G*DELTA**2)/(AK*AM) 000000
00105 7* 2 FORMAT(' FORMULA 4') 000053
00106 8* RETURN 000053
00107 9* END 000101

```

END OF COMPILATION: NO DIAGNOSTICS.

FOR IS S5
FOR S0E3-01/25/77-23:19:11 (*0)

FUNCTION T66 ENTRY POINT 000062

STORAGE USED: CODE(1) 000076; DATA(0) 000040; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

0003 XPDR
0004 NEPR3\$

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0000 000002 2F 0000 000014 INJPS 0000 D 000000 T66

00100	1*	C	ELEMENT TRANS5	000000
00100	2*	C	FORMULA 6	000000
00101	3*		DOUBLE PRECISION FUNCTION T66(T1,AM,T2,R1,T0,H,G,AV,DELTA)	000000
00103	4*		IMPLICIT DOUBLE PRECISION(A-H,O-W)	000000
00104	5*		T66=T1+2.00/AM*(T2-T1)-R1*(T1-T0)*(T1+T0+920.00)*((T1+460.00)**2	000000
00104	6*	1	+(T0+460.00)**2)-H*DABS(T1-T0)**.25*(T1-T0)+(G*DELTA**2)/(AK*AM)	000000
00105	7*	2	FORMAT(' FORMULA 6')	000051
00106	8*		RETURN	000051
00107	9*		END	000075

END OF COMPILATION: NO DIAGNOSTICS.

FOR IS S6
FOR 50L3-01/25/77-23:19:13 (*0)

FUNCTION TR8 ENTRY POINT 000046

STORAGE USED: CODE(1) 000053; DATA(0) 000030; BLANK COMP(0)(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

0003 XPDR
0004 NEPR3\$

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0000 000002 2F 0000 000010 INJPS 0000 D 000000 TRR

00100	1*	C	ELEMENT TRANS6	000000
00100	2*	C	FORMULA A	000000
00101	3*		DOUBLE PRECISION FUNCTION TRR(T1,T2,TS,AM,H,G,AK,DELTA,R1)	000000
00103	4*		IMPLICIT DOUBLE PRECISION(A-H,O-W)	000000
00104	5*		TRR=T1+2.00/AM*(T2-T1)-H*DABS(T1-TS)**.25*(T1-TS)+(G*DELTA**2)/	000000
00104	6*	1	(AK*AM)	000000
00105	7*	2	FORMAT(' FORMULA A')	000034
00106	8*		RETURN	000034
00107	9*		END	000052

END OF COMPILATION: NO DIAGNOSTICS.

FOR IS S7
FOR S0E3-01/25/77-23:19:14 (.0)

FUNCTION T55 ENTRY POINT 000037

STORAGE USED: CODE(1) 000041; DATA(0) 000006; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

0003 TIEPR35

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0000 000002 INUPs 0000 P 000000 T55

00100	1*	C	ELEMENT TRANS7	0000000
00100	2*	C	FORMULA	0000000
00101	3*		DOUBLE PRECISION FUNCTION T55(A1,T1,A2,T2,R1,G1,R2,G2,R01,T3,D2,	0000000
00101	4*		1 T4)	0000000
00103	5*		IMPLICIT DOUBLE PRECISION (A-1,0-W)	0000000
00104	6*		T55=(A1*T1+A2*T2+R1*G1+R2*G2+T1*(T3-T1)-D2*(T2-T4))/(A1+A2)	0000000
00105	7*		RETURN	000027
00105	8*		END	000040

END OF COMPILATION: NO DIAGNOSTICS.

FOR IS S8
FOR S0E3-01/25/77-23:19:16 (.0)

SUBROUTINE PROP ENTRY POINT 001033

STORAGE USED: CODE(1) 001217; DATA(0) 000174; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

0003 TIEPR25
0004 TIEPR35

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0001	000013	501L	0001	000172	502L	0001	000325	503L	0001	000417	504L	0001	000600	505L
0001	000656	506L	0001	001022	522L	0000	000150	INUPs						


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00210 50* 1T) 000551
00212 GO TO 522 000576
00212 C MATERIAL NO. 5 IS ALUMINIUM 000576
00213 505 ALPHA=3.33D0 000600
00214 RHO=169.D0 000601
00215 C=20000 000603
00216 64* IF (T1.GE.0.D0.AND.T1.LE.200.D0) EPSLON=.0900 000605
00220 65* IF (T1.GE.200.D0.AND.T1.LE.2000.D0) PSLON=.16700+1.63D-4 *T1 000625
00222 66* AK=117.D0+1.1300*(T1-32.D0) 000647
00223 67* GO TO 522 000654
00223 C MATERIAL NO. 6 IS MARINITE 000654
00224 506 RHO=36.D0 000656
00225 70* C=.2500+3.D-4*(T1-200.D0) 000657
00226 71* IF (T1.GE.0.D00.AND.T1.LE.200.D0) C=.25D0 000664
00230 72* EPS LON=.900 000704
00231 73* AK=(.7600+1.1D-4*(T1-100.D0))/12.D0 000706
00232 74* IF (T1.GE.0.D0.AND.T1.LE.100.D0) AK=.063D0 000714
00234 ALPHA=AK/(RHO*C) 000734
00235 76* IF (T1.GE.210.D0.AND.T1.LE.220.D0) THETA1=THETA 000741
00237 77* IF (T1.GE.210.D0) THETA2=THETA-THETA1 000761
00241 78* IF (THETA2.LT.DDTHET) GO TO 522 000770
00243 79* IF (THETA2.GE.0.D0.AND.THETA2.LE.1000.D0) DDTHET)G=-GM2/(1000.D0* 000774
00243 1DDTHET) 001022
00245 81* RETURN 001216
00246 82* END

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END OF COMPILATION: NO DIAGNOSTICS.

FOR IS S9
FOR 50E3-01/25/77-23:19:19 (*0)

SUBROUTINE PLOTS ENTRY POINT 000472

STORAGE USED: CODE(1) 000521; DATA(0) 000313; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

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0003 FWDUS
0004 NI02$
0005 NFR2$
0006 NI03$
0007 NERR3$

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STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

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0001 00023 136G 0001 000037 1426 0001 000066 156G 0001 000102 162G 0001 000153 201G
0001 000163 205G 0001 000166 210G 0001 000174 215G 0001 000213 222G 0001 000243 235G
0001 000262 240L 0001 000275 244L 0001 000306 253G 0001 000315 260L 0001 000426 335G
0001 000341 240L 0000 000217 290F 0001 000363 300L 0001 000223 310F 0001 000426 335G
0001 000373 350L 0001 000377 400L 0001 000227 420F 0000 000232 620F 0000 000171 PLANK
0000 I 000000H 000L 0000 P 000172 COLX 0000 I 000176 J 0000 000160 IDGT 0000 000251 INJPS
0000 I 000173 IPRINT 0000 I 000174 IX 0000 I 000177 J 0000 I 000206 K 0000 I 000213 KA
0000 I 000207 KK 0000 I 000214 KKK 0000 I 000175 K2 0000 I 000200 K4 0000 I 000210 K5

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0000 I 000205 L
 0000 R 000237 XMIN
 0000 R 000240 X1
 0000 R 000215 YP

0000 I 000005 PRINT
 0000 R 000152 XP
 0000 R 000201 YDELTA
 0000 R 000204 YT

0000 R 000202 XDELTA
 0000 R 000216 XR
 0000 R 000203 YL
 0000 R 000241 Y0

0000 R 000211 XL
 0000 R 000212 XT
 0000 R 000242 YMAX
 0000 R 000241 YMIN
 0000 R 000240 XMAX
 0000 R 000237 X0
 0000 R 000241 YMIN

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00100 1* C ELEMENT PLOTS 000012
00101 2* C SUBROUTINE PLOTS (NARGS,X,Y, NPMX,NROW) 000012
00101 3* C PLOTS UP TO 5 PAIRS OF COLUMNS. THE NOTATION IS AS FOLLOWS. 000012
00101 4* C 000012
00101 5* C X = A MATRIX HAVING UP TO 5 COLUMNS AND NROW ROWS 000012
00101 6* C 000012
00101 7* C Y = A MATRIX HAVING UP TO 5 COLUMNS AND NROW ROWS 000012
00101 8* C 000012
00101 9* C THE FIRST COLUMN OF Y IS PLOTTED VERSUS THE FIRST COLUMN OF X 000012
00101 10* C SECOND X 000012
00101 11* C ETC 000012
00101 12* C 000012
00101 13* C NROW = THE NUMBER OF ROWS IN X AND Y IN THEIR DIMENSION STATEMENTS 000012
00101 14* C IN THE MAIN PROGRAM. E.G. IF X AND Y ARE DIMENSIONED 000012
00101 15* C AS X(130,4) , Y(130,4) IN THE MAIN PROGRAM THEN SET NROW=130 000012
00101 16* C 000012
00101 17* C NARGS = THE NUMBER OF PAIRS OF COLUMNS TO BE PLOTTED. 000012
00101 18* C 000012
00101 19* C NRMX = A VECTOR CONTAINING THE LENGTHS OF THE DATA TO BE 000012
00101 20* C PLOTTED IN THE SEVERAL COLUMN PAIRS. THAT IS, 000012
00101 21* C NPMX(1) IS NUMBER OF POINTS TO BE PLOTTED IN FIRST COLUMN PAIR 000012
00101 22* C SECOND 000012
00101 23* C THIRD 000012
00101 24* C ETC. 000012
00101 25* C 000012
00101 26* C THE SYMBOLS USED ARE FIRST SECOND THIRD FOURTH FIFTH COLUMN PAIR 000012
00101 27* C + 000012
00101 28* C * 000012
00101 29* C IF MORE THAN ONE POINT FALLS ON THE SAME POSITION A TALLEY IS KEPT AND 000012
00101 30* C THE NUMBER IS PRINTED. 000012
00101 31* C 000012
00101 32* C LIMITS FOR THE PLOT ARE FIGURED OUT AUTOMATICALLY BASED ON THE SMALLEST 000012
00101 33* C AND LARGEST DATA POINTS. 000012
00101 34* C **** 000012
00101 35* C **** DOES NOT CALL A NEW PAGE. 000012
00101 36* C 000012
00101 37* C **** WRITTEN BY S. PEAVY 5/1/67 0004
00101 38* C COMMENTS BY R.L. JOINER 6/4/69 000012
00101 39* C 000012
00101 40* C 000012
00103 41* C DIMENSION NPMX(5),X(NPMX,5),Y(NROW,5) 200
00104 42* C DIMENSION PRINT(101),XP(16),ROOL(5),IDGT(9) 220
00105 43* C INTEGER PRINT,BLANK PRINT(101),XP(16),ROOL(5),IDGT(9) 240
00106 44* C EQUIVALENCE (XO,XMIN),(X1,XMAX),(YO,YMIN),(Y1,YMAX) 240
00107 45* C INTEGER POOL 240
00110 46* C DATA ROOL(1),ROOL(2),ROOL(3),ROOL(4),ROOL(5)/1H,1H,1H,1H,1H-/ 320
00110 47* C DATA IDGT(1),IDGT(2),IDGT(3),IDGT(4),IDGT(5),IDGT(6),IDGT(7), 320
00120 48* C IDGT(8),IDGT(9)/1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,1HX / 000012
00132 49* C IPRINT=6 860
00132 50* C 000012

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00133 51* X1=Y(I+1) 870 000014
00134 52* X0=X1 880 000016
00135 53* DO 130 I=1,NARGS 894 000023
00140 54* K2=IRMX(IY) 898 000031
00141 55* DO 130 I=1,K2 890 000033
00144 56* IF(X1-LT.X(I,IX)) X1=Y(I,IX) 000037
00146 57* IF(X0-GT.X(I,IX)) X0=X(I,IX) 000044
00150 58* 130 CONTINUE 910 000057
00153 59* Y1=Y(I+1) 910 000057
00154 60* Y0=Y1 945 000061
00155 61* 135 DO 150 I=1,NARGS 950 000066
00160 62* K4=IRMX(J) 970 000074
00161 63* DO 150 I=1,K4 1095 000076
00164 64* IF(Y1-LT.Y(I,J)) Y1=Y(I,J) 000102
00166 65* IF(Y0-GT.Y(I,J)) Y0=Y(I,J) 000107
00172 67* C**** DETERMINE X AND Y INCREMENTS FOR PLOT 1110 000122
00174 68* YDELTA=(YMAX-YMIN)/50. 1120 000127
00175 69* XDELTA=(XMAX-XMIN)/100. 1150 000133
00176 70* YL=YMAX-YDELTA/2. 1190 000137
00177 71* YI=YMAX 1200 000143
00177 72* C**** THE I LOOP CONTROLS THE 5 DIVISIONS OF THE Y ORDINATE 1300 000143
00200 73* DO 350 I=1,6 1400 000153
00203 74* L=1 1420 000156
00203 75* C**** THE J LOOP IS FOR EACH LINE OF PRINT WITHIN THE DIVISIONS 1430 000156
00204 76* DO 350 J=1,10 1440 000166
00204 77* C**** BLANK OUT PRINT BUFFER LINE. 1450 000166
00207 78* DO 200 K=1,101 1460 000166
00212 79* 200 PRINT(K)ERLANK 1490 000166
00212 80* C**** THE KK INDEX IS FOR EACH CURVE. KK LESS THAN 6. 1490 000166
00214 81* DO 270 K=1,NARGS 1500 000174
00217 82* YG=IRMX(KK) 1500 000202
00220 83* K5=1 1560 000204
00220 84* C**** THIS DETERMINES IF Y(K) VALUE IS ON THE PRESENT PRINT LINE 1570 000204
00221 85* DO 260 K=1,K4 1580 000213
00224 86* IF(Y(K,KK)-YT) 205,205,250 000222
00227 87* 205 IF(Y(K,KK)-YL) 250,250,210 000226
00227 88* C**** YES, Y(K) BELONGS ON THIS PRINT LINE 1625 000226
00227 89* C**** THEREFORE DETERMINE WHERE ALL THE X(K5) FALL ON THE X-AXIS 1630 000226
00232 90* 210 XL=X(I) 1640 000232
00233 91* YI=X(I)+YDELTA/2. 1640 000234
00234 92* DO 255 K=1,101 1680 000243
00237 93* IF(X(K5,KK)-XL) 250,215,215 000247
00242 94* 215 IF(X(K5,KK)-YT) 220,250,250 000253
00245 95* 220 IF(PRIIT(KA)-RLANK) 240,230,240 1740 000253
00250 96* 230 PRINT(KA)=B00L(KK) 1750 000256
00251 97* GO TO 260 1762 000260
00251 98* C**** IF MORE THEN ONE POINT FALLS ON THE PRINT POSITION, TALLY THE NO. 1754 000260
00251 99* C**** OF POINTS. 1765 000260
00252 100* 240 DO 242 KKK=1,9 1766 000264
00255 101* IF(PRIIT(KA)-IDGT(KKK)) 242,244,242 1768 000264
00260 102* 242 CONTINUE 1770 000271
00262 103* PRINT(KA)=IDGT(1) 1772 000271
00263 104* GO TO 260 1774 000273
00264 105* 244 IF(PRIIT(KA).NE.IDGT(9)) PRINT(KA)=IDGT(KKK+1) 1776 000275
00266 106* GO TO 260 1778 000304
00267 107* 250 XL=XT 1780 000306
00270 108* 255 XI=XT+XDELTA 1800 000307

```

```

00272 100* 260 K5EK5+1 1820 000315
00274 110* 270 CONTINUE 1830 000325
00276 111* YL=YL 1840 000327
00277 112* YL=YDELTA 1850 000331
00300 113* GO TO (280,300),L 1900 000341
00301 114* 280 IF(I-5) 285,285,400 1920 000343
00304 115* 285 L=2 1925 000343
00304 116* C**** THIS PATH IS EXECUTED ONCE IN EVERY DIVISION OF THE Y-AXIS. EVERY 1930 000343
00304 117* C**** TENTH LINE, STARTING WITH ZERO LINE 1940 000345
00305 118* YP=YDELTA/2. 1940 000350
00306 119* WRITE(PRINT,290) YP,PRINT 1940 000361
00312 120* 290 FORMAT(1X,E12.5,1H+,101A1,1H+) 2000 000361
00313 121* GO TO 350 2020 000363
00314 122* 300 WRITE(PRINT,310) PRINT 2030 000363
00314 123* C**** PRINTS LINE 2040 000377
00317 124* 310 FORMAT(13X,1H-,101A1,1H-) 2060 000377
00320 125* 350 CONTINUE 2090 000377
00323 126* 400 WRITE(PRINT,290) YMIN,PRINT 2090 000377
00323 127* C**** LAST LINE OF PRINT OUT PLUS X VALUES ALONG X-AXIS. 2100 000407
00327 128* WRITE(PRINT,620) 2100 000414
00331 129* XP(1)=YMIN 2140 000414
00332 130* XP(5)=YMAX 2140 000414
00333 131* XR=20.*YDELTA 2160 000420
00334 132* DO 410 I=2,5 2190 000426
00337 133* 410 XP(I)=XP(I-1)+XR 2200 000426
00341 134* WRITE(PRINT,420) XP 2210 000431
00344 135* 420 FORMAT(6(7X,E13.5)) 2240 000441
00345 136* RETURN 2260 000441
00346 137* 620 FORMAT(14X,1H+,10(10H-----+)) 2390 000520
00347 138* END 000520

```

END OF COMPILATION: NO DIAGNOSTICS.

GFOR*IS S=0
FOR S0E3-01/25/77-23:19:22 (r0)

SUBROUTINE PLOTL ENTRY POINT 000412

STORAGE USED: CODE(1) 000440; DATA(0) 000515; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

```

0003 NWFUS
0004 HIG2$
0005 HERR2$
0006 HIG3$
0007 HERR3$

```

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

```

0000 000412 100F 0001 000045 120L 0001 00036 125G 0001 000053 140L 0001 000116 160G
0001 000062 160L 0001 000126 164G 0001 000131 167G 0001 000144 176G 0001 000070 180L
0001 000163 211G 0001 000205 240L 0001 000236 245G 0001 000213 250L 0001 000221 260L

```

```

0001 000250 272L 0001 000253 275L 0001 000255 27PL 0001 000264 290L 0000 000435 290F
0001 000306 300L 0000 000441 310F 0001 000351 317G 0001 000316 350L 0001 000322 400L
0000 000445 420F 0000 I 000363 BLANK 0000 I 000364 I 0000 I 000401 IFLAG 0000 000456 INJPS
0000 I 000365 IO 0000 I 000405 ITA 0000 I 000216 ITOTAL 0000 I 000377 J 0000 I 000400 K
0000 I 000404 KA 0000 I 000407 KK 0000 I 000376 L 0000 I 000406 LA 0000 I 000205 NIIRB
0000 I 000000 PRINT 0000 I 000153 SYM 0000 R 000373 XDELTA 0000 R 000402 XL 0000 R 000371 XMAX
0000 R 000370 XMIN 0000 R 000145 XP 0000 R 000411 XR 0000 R 000403 XT 0000 P 000372 YDELTA
0000 R 000374 YL 0000 R 000367 YMAX 0000 R 000366 YMIN 0000 R 000410 YP 0000 R 000375 YT

```

```

00100 C ELEMENT PLOTT
00101 2* SUBROUTINE PLOTT(N,X,Y,IT)
00101 3* PLOTT FIGURES OUT LIMITS FOR THE PLOT BASED ON THE DATA. 010
00101 4* DOES NOT CALL A NEW PAGE.
00101 5* C****
00101 6* C****
00101 7* C THPEF VECTORS ARE REQUIRED X,Y,IT EACH HAVING N VALUES.
00101 R* C
00101 R* C PLOTS Y(I) VERSUS X(I) FOR I=1,2,...,N
00101 0* C
00101 10* C THE SYMBOL PLOTTED FOR THE I,TH POINT IS THE LETTER OF THE ALPHABET
00101 11* C CORRESPONDING TO IT(I).
00101 12* C
00101 13* C VALUE OF IT(I) 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
00101 14* C SYMBOL PLOTTED A B C D E F G H I J K L M N O P Q R S T U V W X
00101 15* C
00101 16* C VALUE (CONTD) 25 26
00101 17* C SYMBOL (CONTD) Y Z
00101 18* C
00101 19* C ORIGINAL DATA IS PRESERVED (THIS ROUTINE SEARCHES
00101 20* C INSTEAD OF SORTING)
00101 21* C
00101 22* C S. PEAVY PLOT L 10/13/66
00101 23* C LAST UPDATED 3/23/69
00101 24* C COMMENTS BY B.L. JOHNER 6/ 5/69
00101 25* C
00103 26* C DIMENSION X(1),Y(1),IT(1),POINT(101),XP(6),SYM(26)
00104 27* C DIMENSION NPMR(9),ITOTAL(101)
00105 28* C INTEGER PRINT,BLANK,SYM
00105 29* C DATA STATEMENTS ARE DIFFERENT FOR DIFFERENT MACHINES
00105 30* C THIS IS IBM 7094 AND UNIVAC 1108 VERSION
00106 31* C DATA BLANK/1H /
00110 32* C DATA (SYM(I),I=1,26)/1HA,1HC,1HD,1HE,1HF,1HG,1HH,1HI,1HJ,1HK
00112 33* C 1,1L,1HM,1HN,1HO,1HP,1HQ,1HR,1HS,1HT,1HU,1HV,1HW,1HX,1HY,1HZ/
00112 34* C DATA (NPMR(I),I=1,9)/1HI,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9/
00112 35* C
00112 36* C IO = NUMBER OF PRINT TAPE
00114 37* C IO = 6
00114 38* C
00115 39* C WRITE(IO,100)
00117 40* C 100 FORMAT(14X,101H+-----+-----+-----+-----+
00117 41* C 1-----+-----+-----+-----+-----+-----+-----+-----+
00117 42* C SEARCH FOR MIN AND MAX OF Y AND X
00120 43* C YMIN=Y(1)
00121 44* C YMAX=Y(I)
00122 45* C XMIN=X(1)
00123 46* C XMAX=X(I)

```



```

C0276      105*      300 WRITE (IO,310) PRINT
C0301      106*      310 FORMAT (13X,1H-,10I1,1H-)
C0302      107*      350 CONTINUE
C0305      108*      400 WRITE (IO,290) YMIN,PRINT
C0311      109*      XP(1)=XMIN
C0313      110*      XP(5)=XMAX
C0314      111*      XR=20.*XDELTA
C0315      112*      DO 410 I=2,5
C0316      113*      410 XP(I)=XP(I-1)+XR
C0321      114*      420 FORMAT(6(7X,E13.5))
C0323      115*      RETURN
C0326      116*      END
C0327      117*
C0330      118*      END

```

END OF COMPILATION: NO DIAGNOSTICS.

```

@FOR*IS S11
FOR S0F3-01/25/77-23:19:25 (.0)

```

SUBROUTINE PLOTLA ENTRY POINT 000426

STOPAGE USED: CODE(1) 000462; DATA(0) 000515; BLANK COMPON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

```

0003 F*ADUS
0004 F*IC2*
0005 REFERR*
0006 F*IC3*
0007 REFERR*

```

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

```

0000 000412 100F 0001 000045 120L 0001 000036 126G 0001 000053 140L 0001 000062 160L
0001 000132 172G 0001 000142 172G 0001 000177 223G 0001 000101 191L 0001 000107 19AL
0001 000252 257G 0001 000145 201G 0001 000264 272L 0001 000221 240L 0001 000227 250L
0001 000300 280L 0001 000252 257G 0001 000322 300L 0001 000267 275L 0001 000271 270L
0001 000332 356L 0001 000336 400L 0001 000445 420F 0001 000441 310F 0001 000365 332G
0001 000401 1FLAG 0001 000456 1*UP* 0001 000363 310F 0001 000364 I
0001 000377 J 0001 000400 K 0001 000405 ITA 0001 000205 ITOTAL
0001 000406 LA 0001 000352 NUMR 0001 000407 KK 0001 000376 L 0001 000373 XDELTA
0001 000402 XL 0001 000371 XMAX 0001 000370 XMJN 0001 000145 XP 0001 000411 XP
0001 000403 XT 0001 000372 XDELTA 0001 000367 YMAX 0001 000366 YMIN
0001 000410 YP 0001 000375 YI

```

```

00100 1* C ELEMENT PLOTA 000015
C0101 2* SUBROUTINE PLOTLA(N,X,Y,I,T,YMIS,YMAXS) 000015
00101 3* C**** PLOTLA FIGURES OUT LIMITS FOR THE X-AXIS (ABSCISSA) FROM THE DATA, 000015

```



```

00324 120* WRITE (IO,100)
00326 121* XP(1)=X*IH
00327 122* XP(6)=Y*HAY
00330 123* XR=20.*YDELTA
00331 124* DO 410 I=2,5
00334 125* 410 XP(I)=XP(I-1)+XR
00336 126* WRITE (IO,420) XP
00341 127* 420 FORMAT(6(7X,E13.5))
00342 128* RETURN
00343 129* END

```

END OF COMPILATION: NO DIAGNOSTICS.

```

@FOR,IS S12
FOR 50E3-01/25/77-23:19:28 (*0)

```

SUBROUTINE PLOTFL ENTRY POINT 000410

STORAGE USED: CODE(1) 000446; DATA(0) 000536; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

```

0003 TIMEUR
0004 HLO2F
0005 HERR2K
0006 HIO3F
0007 HPR3F

```

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

```

0000 000411 100F 0001 000373 100L 0001 000076 110L 0001 000053 130G 0001 000103 150G
0001 000113 150G 0001 000116 163G 0001 000131 172G 0001 000150 205G 0001 000172 240L
0001 000223 241G 0001 000206 260L 0001 000235 272L 0001 000240 274L 0001 000240 274L
0001 000242 278L 0001 000251 280L 0001 000430 290F 0001 000273 300L 0000 000440 310F
0001 000336 314G 0001 000303 350L 0001 000430 290F 0000 000444 420F 0000 000447 550F
0001 000363 600L 0001 000363 BLANK 0001 000364 I 0000 I 000401 15LAG 0000 000473 1M1P$
0000 I 000365 10 0000 I 000375 101T 0000 I 000400 ITA 0000 I 000205 ITOTAL 0000 I 000377 J
0000 I 000400 K 0000 I 000403 KK 0000 I 000406 KK 0000 I 000376 L 0000 I 000405 LA
0000 I 000352 HUBR 0000 I 000000 PRINT 0000 I 000153 SYM 0000 R 000374 YDELTA 0000 R 000374 YDELTA
0000 R 000373 XL 0000 R 000145 XP 0000 R 000410 XP 0000 R 000402 XT 0000 R 000366 YDELTA
0000 R 000370 YL 0000 R 000372 YLOW 0000 R 000407 YP 0000 R 000371 YT

```

```

00100 1* C ELEMENT PLOTFL
00101 2* SUBROUTINE PLOTFL (N,X,Y,IT,XMI,XMAX,YMTN,YMAX)
00101 3* C*** PLOTFL OMMITS ANY POINTS OUTSIDE THE USER SPECIFIED LIMITS XMTN,XMAX,ETC.
00101 4* C*** A CALL OF THE NUMBER OBTAINED IS GIVEN.
00101 5* C*** DOES NOT CALL A NEW PAGE.
00101 6* C THREE VECTORS ARE REQUIRED Y,Y,IT EACH HAVING N VALUES.
00101 7* C
00101 8* C PLOTS Y(I) VERSUS X(I) FOR I=1,2,...,N

```


00203	67*	XT=X*Y+YDELTA/2.	210	000143
00204	68*	DO 255 KA=1,101	220	000150
00207	69*	IF (X(K)-XL) 250,215,215		000150
00212	70*	215 IF (X(K)-XT) 220,250,250		000154
00215	71*	220 IF (PRINT(KA)-RLAUK) 240,230,240		000160
00220	72*	230 ITA=IT(K)	245	000163
00221	73*	PRINT(KA)=SYM(ITA)	250	000166
00222	74*	GO TO 260	260	000170
00223	75*	240 ITOTAL(KA)=ITOTAL(KA)+1		000172
00224	76*	IFLAG=1		000174
00225	77*	GO TO 260	290	000176
00226	78*	250 XL=XT	290	000200
00227	79*	255 XT=XT+YDELTA	300	000201
00231	80*	260 CONTINUE	305	000212
00233	81*	YT=YL	310	000212
00234	82*	YL=YL-YDELTA	320	000214
00235	83*	IF (IFLAG) 265,276,265		000216
00240	84*	265 DO 275 LA=1,101		000223
00243	85*	IF (ITOTAL(LA)-1) 268,275,268		000223
00246	86*	268 KK=ITOTAL(LA)		000225
00247	87*	IF (KK=0) 272,272,270		000227
00252	88*	270 KK=0	330	000232
00253	89*	272 PRINT (LA)=NIMB(KK)		000235
00254	90*	275 CONTINUE		000242
00256	91*	278 CONTINUE		000242
00257	92*	GO TO (290,300),L		000242
00260	93*	280 IF (I=5) 285,285,400		000251
00263	94*	285 L=2	350	000253
00264	95*	YP=YI+YDELTA/2.	360	000255
00265	96*	WRITE (I0,200) YP,PRINT	370	000260
00271	97*	290 FORMAT(1X,E12.4,1.4,101A1,1H)	390	000271
00272	98*	GO TO 350	390	000271
00273	99*	300 WRITE (I0,310) PRINT	400	000273
00276	100*	310 FORMAT (13X,1H--,101A1,1H--)	410	000307
00277	101*	350 CONTINUE	420	000307
00302	102*	400 WRITE (I0,200) YMIN,PRINT	430	000307
00306	103*	WRITE (I0,100)	440	000317
00310	104*	XP(I)=X*YH	450	000324
00311	105*	XP(6)=YAY	460	000326
00312	106*	XR=20.*YDELTA		000330
00313	107*	DO 410 I=2,5	490	000336
00316	108*	410 XP(I)=XP(I-1)+XR	500	000336
00320	109*	WRITE (I0,420) XP	510	000341
00323	110*	420 FORMAT(5(7X,F13.5))	510	000351
00324	111*	IF (I00) 600,600,500		000351
00327	112*	500 WRITE (I0,550) IOUT		000354
00332	113*	550 FORMAT (20X,9H**IOUTF. I4,60H POINTS FELL OUTSIDE THE SPECIFIED L		000363
00332	114*	IMITS AND WERE OMITTF.)		000363
00333	115*	600 CONTINUE		000363
00334	116*	RETURN	520	000363
00335	117*	END	530	000445

END OF COMPILATION: NO DIAGNOSTICS.

FOR IS S13
FOR SOL3-01/25777-23:19:31 (10)


```

C0123 30* IF(YMIN-Y(I)) 120,120,110 000036
C0126 31* 110 YMIN=Y(I) 000041
C0127 32* GO TO 140 000043
C0130 33* 120 IF(YMAX-Y(I)) 130,140,140 000045
C0133 34* 130 YMAX=Y(I) 000050
C0134 35* 140 IF(XMIN-Y(I)) 160,160,150 000053
C0137 36* 150 XMIN=X(I) 000056
C0140 37* GO TO 140 000060
C0141 38* 160 IF(XMAX-X(I)) 170,180,180 000062
C0144 39* 170 XMAX=X(I) 000065
C0145 40* 180 CONTINUE 000072
C0147 41* YDELTA=(YMAX-YMIN)/50. 100 000072
C0150 42* XDELTA=(XMAX-XMIN)/100. 110 000076
C0151 43* YL=YMAX-YDELTA/2. 120 000102
C0152 44* YL=YMAX 130 000106
C0153 45* DO 350 I=1,6 140 000116
C0156 46* L=0 000121
C0157 47* DO 350 J=1,10 160 000130
C0162 48* DO 200 K=1,101 170 000130
C0165 49* 200 IPRINT(K)=ISYAK 000130
C0167 50* DO 260 K=1,1 180 000137
C0172 51* IF(Y(K)-YI) 205,205,260 000137
C0175 52* IF(Y(K)-YL) 260,260,210 000143
C0200 53* 210 XL=X(I) 000147
C0201 54* XI=X(I)+XDELTA/2. 000151
C0202 55* DO 255 KA=1,101 220 000156
C0205 56* IF(X(K)-XL) 250,215,215 000156
C0210 57* 215 IF(X(K)-XI) 220,250,250 000162
C0213 58* 220 IPRINT(KA)=ISYAK 000166
C0214 59* GO TO 260 000170
C0215 60* 250 XI=XI 200 000172
C0216 61* 255 XI=XI+XDELTA 300 000173
C0220 62* 260 CONTINUE 305 000203
C0222 63* YI=YI 310 000203
C0223 64* YL=YI-YDELTA 320 000205
C0224 65* IF(L) 240,240,300 000207
C0227 66* 240 IF(I-5) 285,285,400 000212
C0232 67* 285 L=L 000215
C0233 68* YP=YI+YDELTA/2. 360 000217
C0234 69* WRITE (IOUT,290) YP,IPRINT 000222
C0240 70* 290 FORMAT(1X,E12.4,1H+,101A1,1H+) 000233
C0241 71* GO TO 350 390 000233
C0242 72* 300 WRITE (IOUT,310) IPRINT 000235
C0245 73* 310 FORMAT(13X,1H-,101A1,1H-) 410 000251
C0246 74* 350 CONTINUE 420 000251
C0251 75* 400 WRITE (IOUT,290) YMIN,IPRINT 000251
C0255 76* WRITE (IOUT,100) 000261
C0257 77* XP(1)=YAP 450 000266
C0260 78* XP(6)=YMAX 460 000270
C0261 79* XR=20.*XDELTA 000272
C0262 80* DO 410 I=2,5 400 000300
C0265 81* 410 XP(I)=XP(I-1)+XR 490 000300
C0267 82* WRITE (IOUT,420) XP 000303
C0272 83* 420 FORMAT(6(7X,E13.5)) 510 000313
C0273 84* RETURN 520 000313
C0274 85* END 530 000360

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<p>16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)</p> <p>A general one-dimensional transient heat and mass transfer numerical program has been developed for composite building constructions. Since typical building constructions consist of a series of composite layers and intermediate air layers transient heat transfer is modeled by conduction through solids and by radiation and convection through air spaces. In addition the program has built-in features for ease of application to building constructions where various combinations of solid-to-solid and solid-to-air interfaces are encountered. The complete Fortran language program as used on the NBS Univac 1108 computer is given. A discussion of the program and instruction for its use are facilitated by the aid of examples. Numerical solutions using the present program compare favorably with experimental data in standard fire endurance tests.</p>			
<p>17. KEY WORDS (six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons) Composite building constructions; convection; experimental data; fire endurance; heat generation or absorption; numerical solutions; radiation; one-dimensional; thermal conduction; transient heat transfer.</p>			
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