NUREG/CR-3239
UCLA-ENG-8257
RG

COMPBRN- A Computer Code for Modeling Compartment Fires

Manuscript Completed: August 1982
Date Published: May 1983

Prepared by
N. O. Siu

School of Engineering and Applied Science
University of California
Los Angeles, CA 90024

**Prepared for
Division of Risk Analysis
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN B0493**

ABSTRACT

The computer code COMPBRN deterministically models the behavior of fire in a compartment. This manual presents information necessary to run COMPBRN, including descriptions of required input and resulting output. Also included are a sample problem and a listing of the code (written in FORTRAN for an IBM 3033 computer). This manual is to be used in conjunction with NUREG/CR-2269, "Probabilistic Models for the Behavior of Compartment Fires," August 1981, which describes the fire models employed by COMPBRN.

CONTENTS

ABSTRACT iii

ACKNOWLEDGMENTS vii

Chapter page

1. INTRODUCTION 1

2. METHODOLOGY 3

    Theory 3
    Additional Modeling During Application 5

3. EXPLANATION - PROGRAM FLOW 8

4. OUTPUTS 11

5. INPUTS 13

    Overall Job Parameters (&STRT) 13
    Title Card 14
    Individual Job Parameters (&SIZE) 14
    Fuel Bed Definition (&FUELB) 15
    Pilot Fuel Parameters (&PILOT) 16
    Physical Fuel Parameters (&FUELT) 18
    Miscellaneous Data (&MISC) 19
    Communication Data (&SEE) 19
    Non-communication Data (&NSEE) 20
    Room Data (&ROOM) 21
    Initialization Data (&GINIT) 22
    Model Variation Factors (&MODVAR) 23
    Output Definition (&OUTF) 24

6. A SAMPLE PROBLEM 26

7. REFERENCES 51

Appendix *page*

A. SOME DETAILS ON THE MODELS FOR WALLS AND THERMAL BARRIERS 52

Thermal Barrier Model 52
Wall Model 54

B. CODE LISTING 56

LIST OF TABLES

Table *page*

1. COMPBRN Sample Problem Input 31
2. COMPBRN Sample Problem Output 33

LIST OF FIGURES

Figure *page*

1. Flow Chart for Computational Model 4
2. COMPBRN Subroutine Flow 9
3. Wood Crib 27
4. Compartment Housing Crib 28
5. Model of Wood Crib 29
6. Crib Mass Burning Rate 48
7. Heat Flux from Wall to Detector 49
8. Hot Gas Layer Temperature 50

ACKNOWLEDGMENTS

The author gratefully acknowledges the aid and guidance provided by Professor G. Apostolakis in this work. Also acknowledged are Dr. M. Kazarians for his support, Pickard, Lowe, and Garrick, Inc. for providing the opportunity to apply the COMPBRN program in nuclear power plant risk analyses, and Ms. S. Rao and Mr. E. Avidor for their helpful discussions, comments, and criticisms.

Chapter 1

INTRODUCTION

COMPBRN is a deterministic fire hazards computer program designed to be used in a probabilistic analysis of fire growth in a particular room. As described in References (1) through (3), this probabilistic analysis is required when assessing the risk associated with fires in nuclear power plants. Possible outputs of the program include the total heat release rate of the fire, the temperature and thickness of the hot gas layer near the compartment ceiling, the mass burning rate for individual fuel elements, and the thermal heat flux at user-specified locations.

The various sub-models used to construct COMPBRN are obtained from the fire research literature. Efforts are made to keep the model complexity to a low level, due to the large uncertainties inherent in the modeling of accidental fires.

Model simplicity is also desirable from an economic point of view, since computing costs can be greatly magnified in a probabilistic analysis. However, simplifications in modeling naturally lead to some loss of accuracy for certain types of scenarios. The assumptions made in COMPBRN are geared towards the modeling of relatively small fires in large rooms. Thus, the code's predictions are expected to be most reasonable for fire scenarios involving small fuel loads and for the early portions of fire scenarios involving larger fuel loads.

Verification of the code's predictions for conditions typical of nuclear power plant fires is currently in progress.

This manual documents an updated edition of COMPBRN; the earlier program was documented in a draft version of UCLA-ENG-8113. The primary changes are in the computation of the average temperature and extent of the hot gas layer lying underneath the compartment ceiling. In the earlier form, these quantities were derived using a Newton-Raphson iteration scheme. Numerical convergence problems were subsequently experienced in a number of cases; a slower but more stable scheme is employed in this version.

The current version of COMPBRN employed at UCLA is compiled with the FORTRAN H Extended compiler, using 650K bytes of storage space on an IBM 3033 machine. The load module obtained after link-editting requires approximately 200K bytes of storage, depending upon the amount of array space called for by the MAIN subroutine. Running times are relatively short (on the order of seconds) for most problems; they are directly related to the number of time steps and the total number of fuel cells used in the scenario of interest.

Chapter 2

METHODOLOGY

2.1 THEORY

The overall model underlying COMPBRN is described in Reference (1); descriptions of the model for a particular fire scenario and of the probabilistic risk analysis in which the model was used are given in References (4) and (5). Briefly, the burning rate of a fuel element is used to determine the heat output rate of that element. The burning rate depends on the physical properties of the fuel, and on the compartment ventilation rate. Using standard shape factor analysis and idealizing the flame as a cylinder, the heat transferred to other fuel elements, the walls, and ceiling via radiation is computed. Correlations are used to determine the convective heat transfer in the buoyant plume of hot gases above the flames. Provisions are also made to simply model the effect of the walls and ceiling, thermal barriers within the room, and the layer of hot gases accumulating near the ceiling as thermal sources. The times required for ignition of the fuel elements are then computed and an element is considered ignited if its ignition time is less than the time that the element has been exposed to the heat source. Time is incremented, and the process starts over, with newly ignited fuel elements adding their contributions to the total rate of heat release. A flow chart for this process is given in Figure 1.

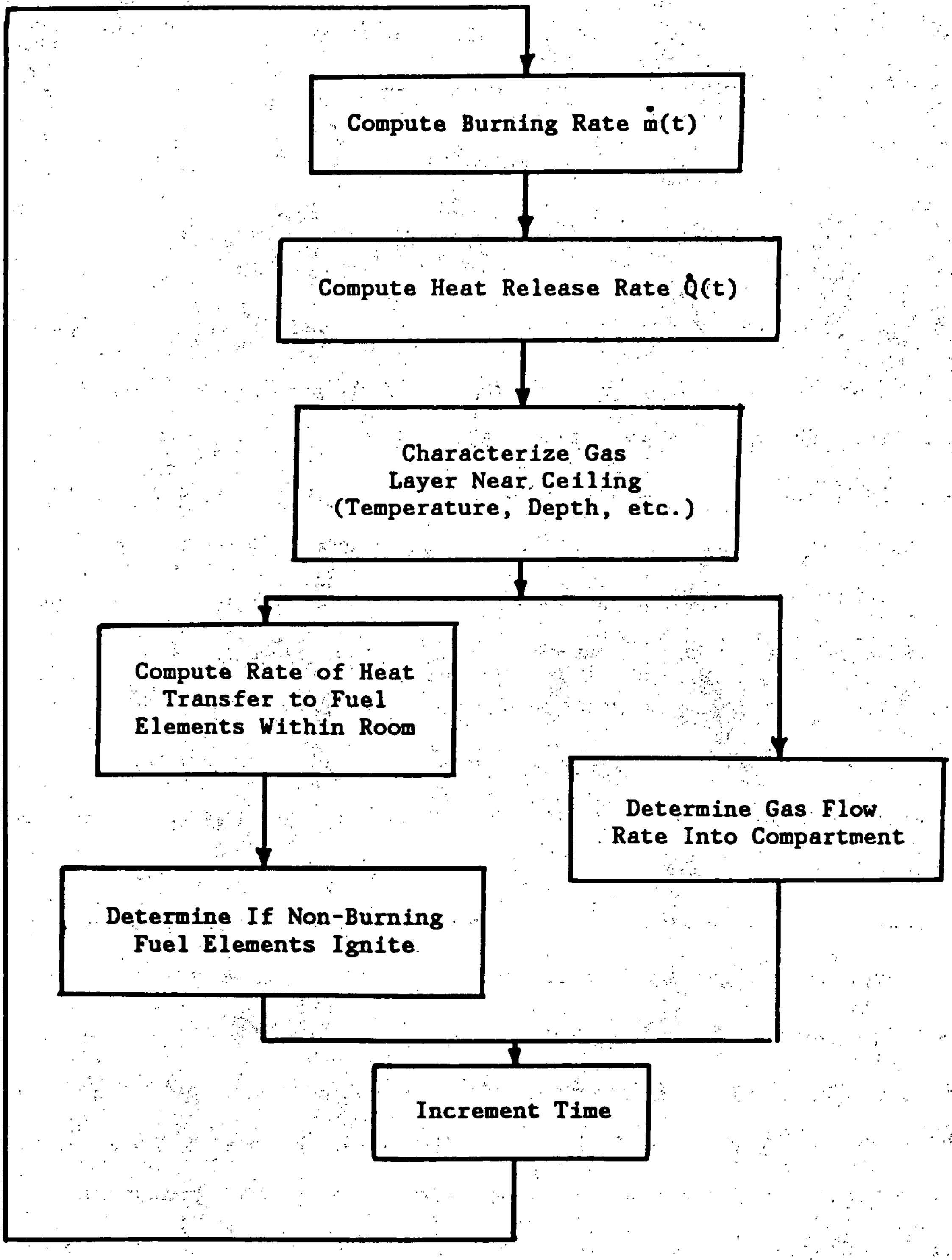


Figure 1: Flow Chart for Computational Model

The models used to describe these individual phenomena which comprise the overall model are, with the exception of the ceiling gas layer model, algebraically quite simple. The main role of the computer in COMPBRN is to keep track of the heat input and output of each of the many fuel elements used to model a complex fuel bed.

2.2 ADDITIONAL MODELING DURING APPLICATION

Because there are a number of assumptions implicit in COMPBRN's various models, further modeling of the compartment is required before an actual fire can be analyzed.

In general, a compartment fire will involve a fuel bed of arbitrary geometry, location, and orientation. Furthermore, the fuel bed may be composed of a number of different fuel types, the relative amounts of which may vary with location.

In preparing the input data for COMPBRN, the analyst must proceed as follows:

1. A Cartesian coordinate system is defined with respect to some arbitrary location in the compartment. The z-axis always represents the vertical direction. The compartment walls and ceiling are assumed to be rectangular in shape and parallel to the planes defined by the coordinate axes.
2. The fuel bed is modeled with a series of homogeneous, two-dimensional rectangular slabs, called "super modules." The long axis of each slab defines its "direction," and must be parallel to one of the coordinate

axes. The direction normal to the slab's face defines its "orientation," and also must be parallel to one of the coordinate axes. The imposition of a regular geometry on the fuel bed is not always a severe modeling restriction, since a physical fuel element can be modeled as a number of contiguous super modules. However, COMPBRN is presently incapable of modeling fires progressing along an inclined surface.

3. The super modules are then further discretized (along the direction of their long axes) into contiguous fuel packets, called "fuel cells." These fuel cells should be almost square in dimension when modeling horizontal fuel beds, since COMPBRN's flame models for this configuration are based on results from flames over square or round pools of fuel.

4. The fuel bed is further modeled using the "porosity factor" and the "communication matrix." The porosity factor is required since a "rough" fuel element (e.g. cables in a cable tray section) will have more surface area available for burning than provided by the representing flat super module of the same nominal dimensions. This factor is defined as the actual area available for burning per unit base (super module) area.

   The communication matrix is constructed by the analyst. It allows him to specify which super modules or fuel cells are contiguous, and which ones cannot transmit heat to others (due to intervention by other fuel elements, barriers, etc.). If instructions to the contrary are not provided, all fuel elements are assumed to be able to "communicate with," i.e. transmit heat to, all other fuel elements.

The porosity factor and the communication matrix allow some fine-tuning of COMPBRN's simple modeling. It must be realized however that the memory space requirement for the communication matrix expands as the square of the number of fuel cells, and this is a practical limiting factor in the ability of COMPBRN to handle complex problems in detail.

Chapter 3

EXPLANATION - PROGRAM FLOW

COMPBRN is a FORTRAN computer code which is divided into a main program, a group of primary subroutines, and a number of auxiliary subroutines and function subprograms. The modular nature of the code is not necessary for execution efficiency, but is intended to allow the analyst to incorporate improved models as they become available. All of the subroutines incorporate variably-dimensioned arrays; if the fuel bed configuration requires a large number of fuel cells, only the main program need be modified and recompiled.

As can be seen in Figure 2, COMPBRN execution begins with the MAIN program. Fuel bed geometry, initial fire characteristics, fuel type characteristics, communication matrix data, compartment parameters, model variation factors, and output format data are read using NAMELIST directed input. MAIN calls subroutine INCHK, in which various portions of the input data can be printed for verification, and then the two initialization subroutines, INIT and TINIT.

After problem definition and initialization is complete, subroutine SOURCE is used to compute the fuel burning rate, the resulting rate of heat output, and the flame height, for each burning fuel cell. The models vary according to the degree of compartment ventilation and whether the fuel element is horizontal or vertical. The strength of each element as a source of heat flux is then calculated. The auxiliary su-

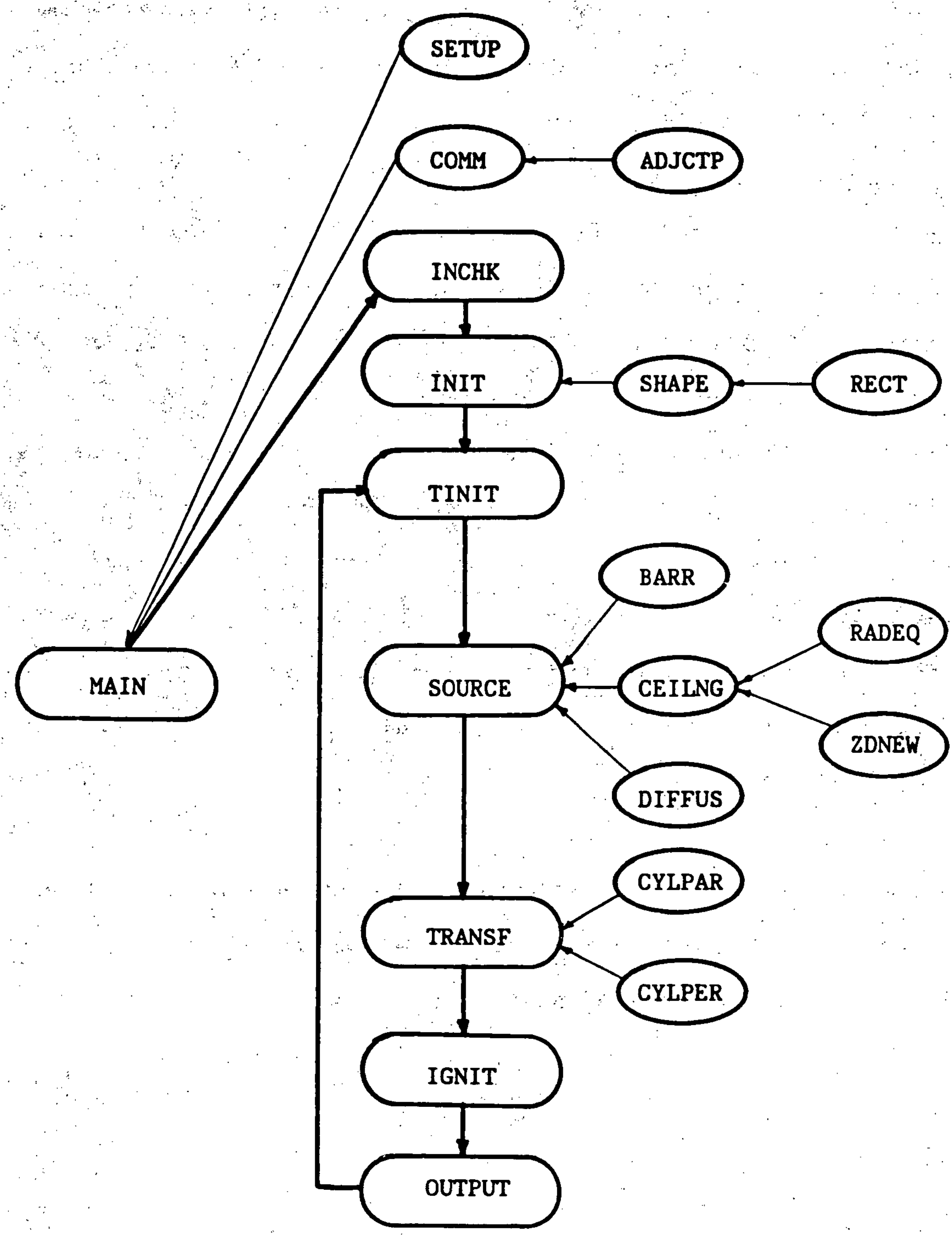


Figure 2: COMPBRN Subroutine Flow

broutines BARR, DIFFUS, or CEILNG are called by SOURCE to determine the heat fluxes from a thermal barrier, a wall, or the ceiling, respectively. Subroutine CEILNG, if called, requires the use of function subroutine RADEQ, which solves a special version of the quartic equation to obtain an improved value for the hot gas layer temperature, and subroutine ZDNEW, which updates the height of the neutral density plane within the compartment given an updated hot gas layer temperature.

Subroutine TRANSF follows SOURCE, and transfers the heat fluxes from the various sources to the target elements via convective and/or radiative pathways. The shape factors used in the flame radiation transfer calculations are computed using the function subroutines CYLPAR and CYLPER. The shape factors for transfer from rectangular sources (e.g. the ceiling) were computed earlier using SHAPE and RECT, and are stored in the communication matrix. Special models are used to account for the feedback radiation of a flame over a vertical slab back to the slab, and for the conduction of heat to contiguous (and non-burning) fuel elements.

Subroutine IGNIT is used to determine if non-burning fuel elements have absorbed enough heat to ignite, and subroutine OUTPUT prints data desired by the analyst for each time step.

Chapter 4

OUTPUTS

COMPBRN prints two sections of output data. The first is used to verify the problem input data, while the second lists user-specified variables during computations.

The input data check is regulated using the indicator variable INCHCK. If INCHCK equals 0, only heading material and the model variation parameters stored in the array FCTR are output. These variation parameters can be used to multiply the computed results of a particular correlation, if individual model uncertainties are to be propagated through the code. A list of the models which can be modified with FCTR is given in Section 5.12. If INCHCK equals 1, the physical parameters characterizing the fuel are also output. If INCHCK is not equal to 0 or 1, all input data, with one exception, are printed. In the case of the super module coordinates, the super module midpoints input (SMX, SMY, and SMZ in Section 5.4) are not printed when INCHCK is not equal to 0 or 1. Instead, the code outputs the coordinates of the first fuel cell in each super module, where the cells are numbered as described in Section 5.4.

The output data listed each time step is specified with the indicator variables IOUTPT and NSMOUT, and the arrays MOUTPT and MSMOUT. IOUTPT determines the number of output variables to be printed, and the elements of MOUTPT specify which variables are to be printed (see Section

5.13). Similarly, NSMOUT determines the number of super modules for which output data is to be printed, and the elements of MSMOUT specify which particular super modules are included in this number. If IOUTPT and NSMOUT equal 0, only the elapsed time since initiation and the total mass burning rate in the compartment are printed. If IOUTPT equals 0 and NSMOUT is not equal to 0, the elapsed time, the burning rate, and an indicator variable array, $BURN, which specifies which fuel cells (if any) in the specified super module are burning, are printed.

Chapter 5

INPUTS

COMPBRN requires a large amount of input data to specify each particular problem. This data is read using NAMELIST format, and the NAMELISTs must be input in the order presented.

5.1 OVERALL JOB PARAMETERS (&STRT)

This data block defines parameters which are in effect for all of the jobs to be performed. All subsequent data blocks apply only for the particular job being executed.

Data Set Members

NJOB = The number of jobs to be run. In general, the entire input data block must be repeated for each job.

NTIME = The maximum number of time steps for each job. Jobs may end earlier if certain iterative calculations do not converge sufficiently quickly or if all fuel which can be ignited has been exhausted.

NREAD = The logical unit number off which remaining data is to be read (default = 5).

NWRITE = The logical unit number on which output is to be written (default = 6).

DELT = The time step increment in seconds.

5.2 TITLE CARD

The first 80 characters on this card will be reproduced as the job title in the code output.

5.3 INDIVIDUAL JOB PARAMETERS (&SIZE)

The limits given in this data block are for the COMPBRN version listed in Appendix B.

Data Set Members

NSM = The number of super modules. (NSM ≤ 12)

NFUEL = The maximum number of fuel types. (NFUEL ≤ 5)

NCOM = The number of entries for the construction of the adjacency portion of the communication matrix ICOMM. See Section 5.8 (NCOM ≤ 30)

NNCOM = The number of non-communicating entries for the construction of ICOMM. See Section 5.9. (NNCOM ≤ 200)

NPILOT = The number of fuel cells initially on fire. (NPILOT ≤ 10)

IROOM = The indicator variable which determines if compartment data is to be included or not. This latter option is useful when the fire is sufficiently small with respect to the room such that enclosure effects can be neglected.

IROOM=1 => compartment data is input
IROOM≠1 => no compartment data input

INITG = The indicator variable which shows if the hot gas layer has some initial characteristics and/or if the initial external heat fluxes are non-zero. Input only if

IROOM = 1.

INITG=1 => Initial values for gas layer and/or heat fluxes are input

INITG≠1 => TG (Gas Layer Temperature) = 298°K
DG (Gas Layer Thickness) = 0.0 m
QEXT (External Heat Fluxes For All Fuel Elements) = 0.0 W/m^2

5.4 FUEL BED DEFINITION (&FUELB)

This data block must be entered once for each super module, i.e. NSM times. The first entry corresponds to super module number 1, the second to module 2, etc.

Data Set Members

SMX = x-coordinate midpoint of super module (m).
SMY = y-coordinate midpoint of super module (m).
SMZ = z-coordinate midpoint of super module (m).
SLNG = Super module length (m).
SWID = Super module width (m).
SDEP = Super module depth (m).
SMASS = Super module mass (kg).
SPOR = Super module porosity factor f_p (Dimensionless).
SLOSS = Undefined variable.
NFCL = Number of fuel cells in super module.
IORNT = Orientation of super module.

IORNT=1 => Normal axis is in the x-direction.

IORNT=2 => Normal axis is in the y-direction.

IORNT=3 => Normal axis is in the z-direction.

IDIREC = Direction of super module.

IDIREC=1 => Long axis is in the x-direction.

IDIREC=2 => Long axis is in the y-direction.

IDIREC=3 => Long axis is in the z-direction.

IFTYP = Super module fuel name/identification number.

IFTYP = Super module fuel type location identifier. This parameter identifies the particular location in the array IFUEL of NAMELIST block FUELT (Section 5.6) which corresponds to the fuel for the super module described.

Example: "IFTYP=3" means that the super module fuel is type 3, where fuel type 3 is defined by position 3 of array IFUEL. Note that IFTYP ≤ NFUEL.

COMPBRN will automatically compute the locations of the fuel cells in each super module. It will also number the fuel cells, the numbers increasing with distance in the direction of the long axis. Thus, if the super module is directed along the x-axis, a fuel cell at x=1 will have a lower number than a fuel cell at x=2.

5.5 PILOT FUEL PARAMETERS (&PILOT)

COMPBRN assumes that a compartment fire starts on top of a small number of selected fuel cells in the fuel bed. These initial fires, called pilot fires, may involve materials not comprising the main fuel bed. For example, a segment of cable tray may be overlaid by an amount of external fuel which is used to initiate the compartment fire. The location of this pilot fire is, however, treated as being identical with the location of the underlying fuel cell.

Each item in this data block is an array, with the first entry corresponding to the first pilot fuel cell, the second with the second cell, and so forth. NPILOT entries should be made for each array.

Data Set Members

IPIL = Array listing the super modules of the pilot fuels.

JPIL = Array listing the particular fuel cells (within the given super module) which are assigned pilot fires.

Example: If NPILOT=2, IPIL=(3,2), and JPIL=(4,5), this means that there are two pilot fires, the first being located on the top of the 4th fuel cell of the 3rd super module, and the second being on top of the 5th fuel cell of the 2nd super module.

IPFUEL = Pilot fuel type array. This entry corresponds to IFTYP defined in Section 5.4. Fuel types are numbered consecutively. Thus, if the 3rd entry of IPFUEL is '5', this means that the 3rd pilot fire involves fuel type 5.

PMASS = Pilot fuel mass array (kg).

5.6 PHYSICAL FUEL PARAMETERS (&FUELT)

Each of the items in this data block represents an array of dimension NFUEL. The first entry in each array corresponds to fuel type 1, the second entry corresponds to fuel type 2, and so forth.

Data Set Members

IFUEL = Array of idendification numbers (names) assigned to each fuel type.

$0 < IFUEL(I) < 10$ => Super module is combustible fuel.

$10 \le IFUEL(I) < 20$ => Super module is a detector (useful for measuring heat fluxes).

$20 \le IFUEL(I) < 30$ => Super module is a wall.

$30 \le IFUEL(I) < 40$ => Super module is a thermal barrier.

$40 \le IFUEL(I) < 50$ => Super module is the room ceiling.

Note that the room ceiling can only be modeled with one super module, and that those super modules modeling the ceiling and the walls may only have one fuel cell each.

In the following list, entries must be provided for all fuel types, but realistic entries are optional for the ranges of IFUEL noted below (where for notational simplicity, we let K = IFUEL(I)).

DENS = Density (kg/m^3). ($10 \le K < 20$ and $30 \le K < 40$)

SPHT = Specific heat ($J/kg^\circ K$). ($10 \le K < 20$ and $30 \le K < 40$)

THK = Thermal conductivity ($W/m^\circ K$). ($10 \le K < 20$)

HEAT = Heating value (J/kg). ($10 \le K < 50$)

FIGTP = Piloted ignition temperature ($^\circ K$). ($10 \le K < 50$)

FIGTS = Spontaneous ignition temperature ($^\circ K$). ($10 \le K < 50$)

BRATV = Ventilation controlled burning rate constant C_V (Dimensionless). $(10 \le K < 50)$

BRATS0 = Surface controlled burning rate constant $\dot{m}''_0$ $(\mathrm{kg/m^2 s})$. $(10 \le K < 50)$

BRATS1 = Surface controlled burning rate constant C_S $(\mathrm{kg/m^2 s})$. $(10 \le K < 50)$

GAMMA = Fraction of flame heat released as radiation (Dimensionless). $(10 \le K < 50)$

FABSRP = Absorption coefficient for flame gases $(\mathrm{m^{-1}})$. $(10 \le K < 50)$

REFL = Reflectivity (Dimensionless). $(0 \le K < 20)$

5.7 MISCELLANEOUS DATA (&MISC)

Data Set Members

RTEMP = Room temperature (°K). (Default = 298.)

FLCF = Heat transfer coefficient for heat transfer in a flame $(\mathrm{W/m^2 {}^\circ K})$.

5.8 COMMUNICATION DATA (&SEE)

This data block is used to input information defining if a given fuel cell touches another fuel cell. This affects the heat transfer models used, transfer between contiguous cells being greater than transfer between disconnected cells.

COMPBRN automatically establishes adjacency for consecutive fuel cells in each super module. Furthermore, by default, all fuel cells can transmit heat to all other fuel cells (i.e. they "communicate"). The purpose of this data block is to define some exceptions to these general rules (non-communication is handled in Section 5.9). NCOM entries must be made, one for each exception.

Data Set Members

IV = 4 element array containing adjacency data. If fuel cell j of super module i is adjacent to fuel cell l of super module k, IV would be (i,j,k,l). If super modules i and k are parallel, have the same number of fuel cells, are of the same length, and are adjacent, IV would be (i,999,k,0). The '999' tells COMPBRN that the jth cell of super module i is adjacent to the jth cell of super module k, i ≤ j ≤ NFCL. Note that the adjacency relationship is symmetrical. Two separate entries, (i,j,k,l) and (k,l,i,j) are not required; only enter one of the two.

5.9 NON-COMMUNICATION DATA (&NSEE)

This data block defines which fuel cells cannot transmit heat to certain other fuel cells. It is treated similarly to the preceding data block, NNCOM entries being required.

Data Set Members

NV = 4 element array containing non-communication data. If fuel cell j of super module i cannot transmit heat to fuel cell l of super module k, NV would be (i,j,k,l). If all of the fuel cells in super module i cannot transmit heat to all of the fuel cells in super module k, NV would be (i,999,k,0). If all of the fuel cells in super module i cannot transmit heat to all of the fuel cells in super modules j through j', NV would be (i,888,j,j'). Note that the non-communication relationship is asymmetrical.

5.10 ROOM DATA (&ROOM)

This data block should be entered only if IROOM = 1. Default values are assigned for some of the parameters.

Data Set Members

DCF = Coefficient of discharge for doorway (Dimensionless). (Default = 1.0)

DHGT = Height of doorway (m).

DWID = Width of doorway (m).

FC = Fraction of forced ventilation inflow which enters the gas layer (Dimensionless).

FH = Fraction of forced ventilation outflow which leaves the gas layer (Dimensionless).

GABSRP = Absorption coefficient for ceiling gas layer (m^{-1}). (Default = 1.4)

HCEIL = Heat transfer coefficient for ceiling ($W/m^2\,^\circ K$).

PLCF1 = Buoyant plume entrainment coefficient, flame tip is above neutral plane (Dimensionless).
(Default = 1.0)

PLCF2 = Buoyant plume entrainment coefficient, flame tip is below neutral plane (Dimensionless).
(Default = 0.5)

THETA = Convergence acceleration parameter used in calculation of neutral plane height ZD.
(Default = 0.5)

VFV = Forced ventilation volumetric airflow (m^3/s).

5.11 INITIALIZATION DATA (&GINIT)

This data block should be entered only if IROOM = 1 and INITG = 1.

Data Set Members

TG = Initial gas layer temperature (°K).

DG = Initial gas layer thickness (m).

QEXT = Two dimensional array containing initial external heat fluxes impinging on each fuel cell, the (i,j) entry corresponding to fuel cell j of super module i.

5.12 MODEL VARIATION FACTORS (&MODVAR)

This data block allows the user to multiply the results of various models by a specified factor. Unless otherwise specified, all factors are set to 1.0.

Data Set Members

FCTR = 15 element array containing the modification factors for 15 models:

1) Modifies room-averaged value for C_V (ventilation controlled burning rate constant).
2) Modifies surface controlled burning rate of fuel.
3) Modifies flame height over horizontal fuel slabs.
4) Modifies flame height over vertical fuel slabs.
5) Modifies radiative heat flux received by target element.
6) Modifies buoyant plume temperature above flame.
7) Modifies heat transfer coefficient for vertical surfaces in the flame.
8) Modifies heat transfer coefficient for horizontal surfaces in the flame.
9) Modifies convective heat flux received by each element.
10) Modifies heat transfer from flame over vertical fuel bed back to fuel bed.
11) Modifies conductive heat flux received.
12) Undefined.
13) Undefined.
14) Modifies critical time for spontaneous ignition.
15) Modifies critical time for piloted ignition.

5.13 OUTPUT DEFINITION (&OUTF)

This data block allows the user to specify the printed output desired (see Section 4).

Data Set Members

INCHCK = Indicator variable controlling the amount of input data printed.

INCHCK=0 => Only heading material and FCTR.

INCHCK=1 => Above, plus fuel parameters (Section 5.6).

INCHCK=2 => All input data.

IOUTPT = Number of output variables to be printed (IOUTPT ≤ 11).

MOUTPT = Array whose ith element is the identification number of the output variable desired. IOUTPT elements should be input.

I.D. Numbers:

1) Total mass burning rate TMDOT (kg/s).
2) Total heat release rate TQDOT (W).
3) Gas layer temperature TG (°K).
4) Gas layer thickness DG (m).
5) Fuel cell indicator variable for burning $BURN; $BURN(i,j)=.TRUE. => fuel cell j of super module i is burning.
6) Fuel cell source heat flux QDOT2P (W/m^2).
7) Fuel cell external heat flux QEXT (W/m^2).
8) Fuel cell mass FMASS (kg).
9) Flame height over fuel cell FLHT (m).
10) Fuel cell flame temperature FLTEMP (°K).

11) Fuel cell surface temperature TEMP (°K) (useful only for walls, barriers, and ceiling).

NSMOUT = Number of super modules for which variables (I.D. numbers 5 through 11) are to be printed.

MSMOUT = Array whose ith element is the identification number of the super module to be documented.

For example, if the input card is:

```
&OUTPT  IOUTPT=3, MOUTPT=1,6,7, NSMOUT=2, MSMOUT=1,2, &END
```

COMPBRN will print the total mass burning rate for the compartment, and the source and external heat fluxes for each fuel cell in super modules 1 and 2.

Notes:
1) IOUTPT=0 and NSMOUT=0 => Only TMDOT, the total mass burning rate, is printed.
2) IOUTPT=0 and NSMOUT≠0 => TMDOT and $BURN, an array which shows which fuel cells are burning, are printed.

Chapter 6

A SAMPLE PROBLEM

In this section, we use COMPBRN to predict the behavior *of a* wood crib fire in a compartment. The wood crib consists of three layers of three sticks, as shown in Figure 3, and is located on the floor in the middle of the room. The room itself is shown in Figure 4. The room walls and ceiling are concrete, and have no openings other than the 2.4 m high by 1.0 m wide doorway in one wall. There is no forced ventilation airflow into the room. The fire is initiated on the central stick of the bottom layer in the crib.

We model the crib with 9 super modules, as seen in Figure 5. Each super module consists of 5 fuel cells. To improve our analysis of the fire, we make 3 additional modeling assumptions:

1. The porosity factor of each fuel super module is set equal to 3.0. This accounts for the surface area of the wood stick sides which are available for burning.
2. The feedback coefficient, BRATS1 (C_S in Reference (1)), is set equal to 0 for the bottom two layers. Our modeling thus prohibits enhanced burning within the crib, since the crib latticework restricts the amount of fresh air which can reach the fire.
3. The bottom super modules (numbers 1, 2, and 3) cannot transmit large amounts of heat directly to the uppermost

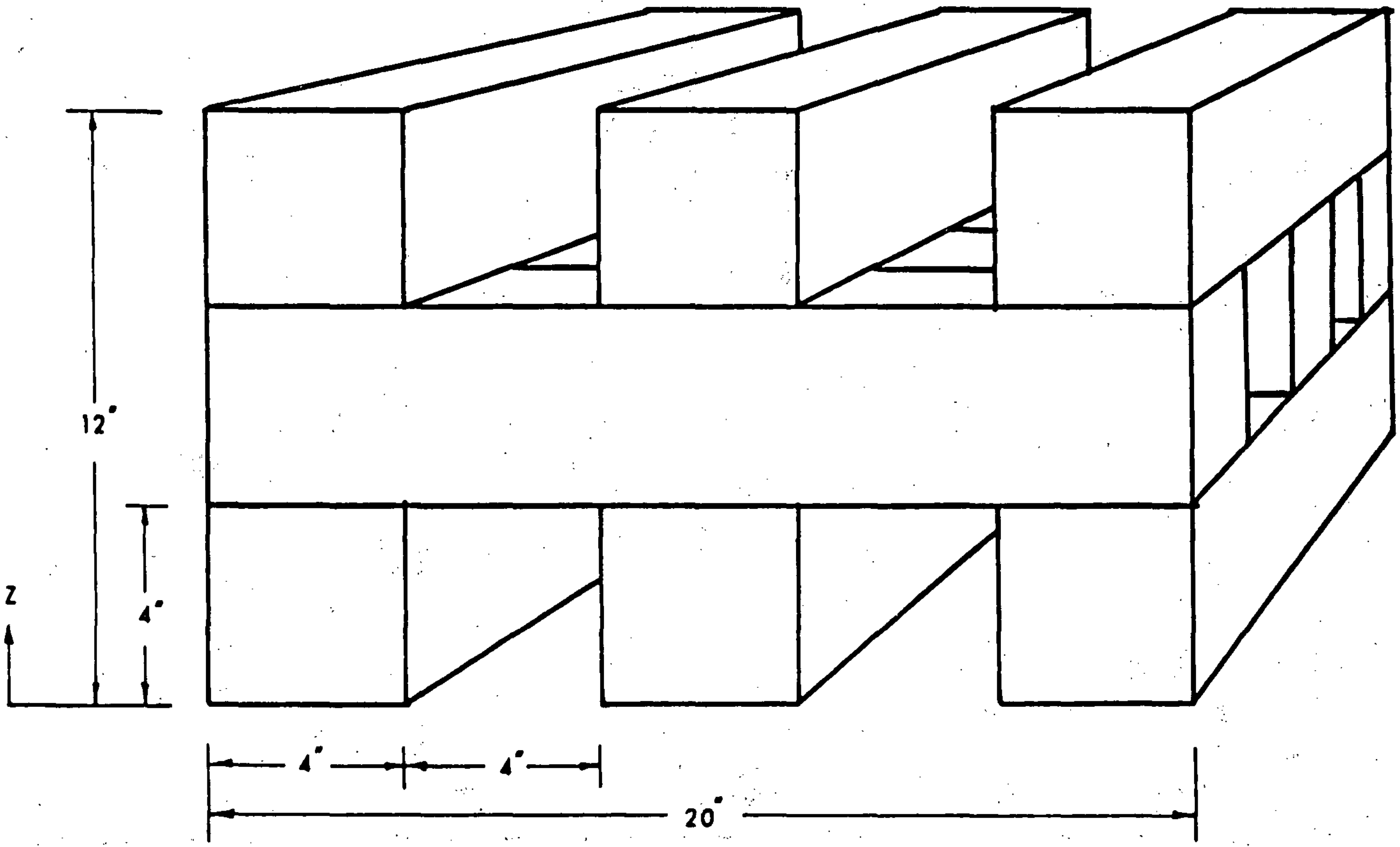
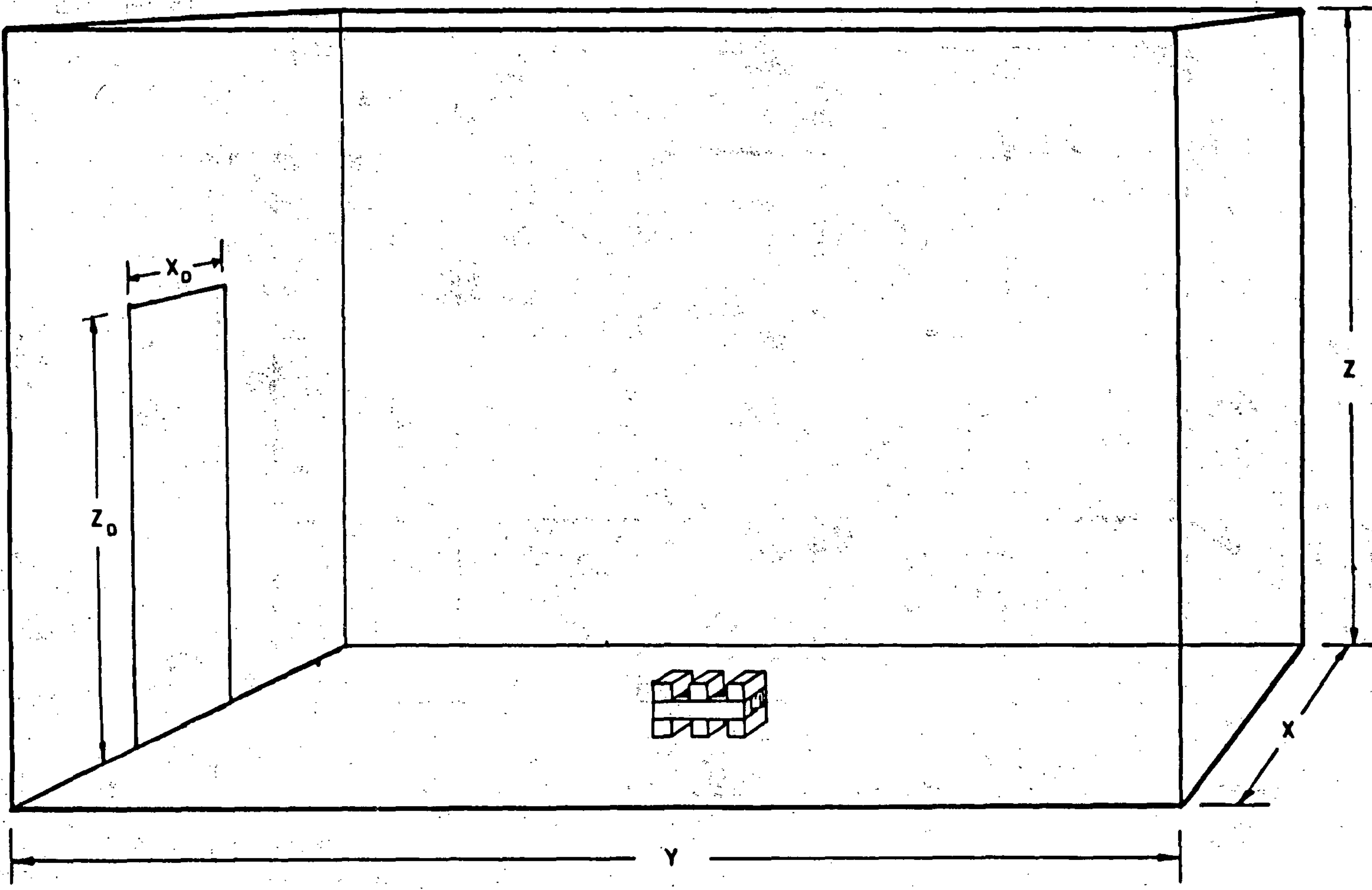


Figure 3: Wood Crib



X = 13.1 ft
Y = 19.7 ft
Z = 13.1 ft
X_D = 3.30 ft
Z_D = 7.90 ft

Figure 4: Compartment Housing Crib

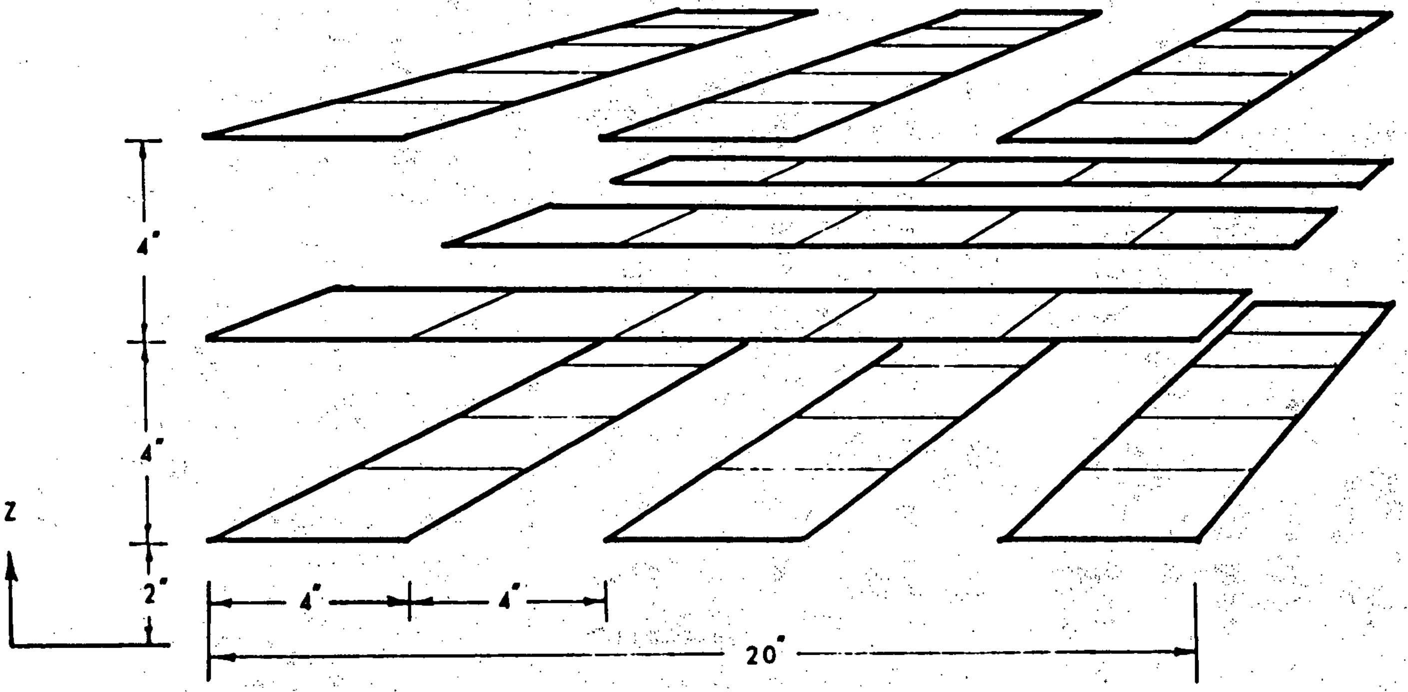


Figure 5: Model of Wood Crib

super modules (numbers 7, 8, and 9) because the intermediate wood sticks intervene. Furthermore, each layer of sticks cannot transmit significant amounts of heat to any underlying layers.

These assumptions have proven useful in the earlier wood crib fire simulations described in Reference (1). More importantly, they illustrate how the porosity factor SPOR, the communication matrix ICOMM, and the artificial definition of various fuel types can be used to improve our modeling.

The enclosure is modeled with two super modules: one represents the ceiling and the other represents one of the walls. To measure the heat flux contribution from the wall (to see if more walls should be added to the model), we also place a heat flux detector near the wall, and use the communication matrix to prevent the detector from seeing any heat sources other than the wall.

The problem input and output are respectively given in Table 1 and Table 2. A graph of the crib's total mass burning rate is presented in Figure 6, and the heat flux from the wall to the detector is plotted in Figure 7. Finally, the average hot gas layer temperature is plotted in Figure 8.

TABLE 1

COMPBRN Sample Problem Input

```
&STRT NJOB=1, NTIME=30, NREAD=5, NWRITE=6, DELT=60., &END
&SIZE NSM=12, NFUEL=5, NPILOT=1, NCOM=0, NNCOM=29, IROOM=1,
      INITG=0, &END
********** TEST CASE:  WOOD CRIB IN ENCLOSURE **************************
&FUELB SMX=2.0, SMY=2.7968, SMZ=0.0508, SLNG=0.508,
       SWID=.1016, SDEP=0.1016, SMASS=4.20, SPOR=3.0,
       SLOSS=1., NFCL=5, IORNT=3, IDIREC=1, IFTYP=1, &END
&FUELB SMY=3.0, &END
&FUELB SMY=3.2032, &END
&FUELB SMX=1.7968, SMY=3.0, SMZ=0.1524, IDIREC=2,  &END
&FUELB SMX=2.0, &END
&FUELB SMX=2.2032, &END
&FUELB SMX=2.0, SMY=2.7968, SMZ=0.2540, IFTYP=2, IDIREC=1,  &END
&FUELB SMY=3.0, &END
&FUELB SMY=3.2032, &END
&FUELB SMX=2.0, SMY=0.0, SMZ=2.0, SLNG=4.0, SWID=4.0,
       SDEP=0.1, SMASS=1.0, SPOR=1.0, SLOSS=1.0,
       NFCL=1, IORNT=2, IDIREC=1, IFTYP=3,  &END
&FUELB SMY=3.0, SMZ=4.0, SLNG=6.0,
       IORNT=3, IDIREC=2, IFTYP=4, &END
&FUELB SMY=0.1, SMZ=2.0, SLNG=0.1, SWID=0.1,
       SLOSS=1.0, IORNT=2, IDIREC=1, IFTYP=5,  &END
&PILOT IPIL=2, JPIL=2, IPFUEL=1, PMASS=0.1, &END
&FUELT IFUEL=1,2,20,40,10, DENS=2*800.,3*1000., SPHT=2*1045.,3*2000.,
       THK=2*0.092,3*1., BRATV=3*0., FABSRP=2*1.4,3*0., REFL=5*.1,
       BRATS1=0.,5.53E-7,3*0., GAMMA=2*.4,3*0.,
       BRATS0=2*.0062,3*0.,
       HEAT=2*1.86E7,3*0.,
       FIGTP=2*480.,3*0.,
       FIGTS=2*530.,3*0., &END
&MISC RTEMP=298., FLCF=22., &END
&NSEE NV=1,999,3,0, &END
&NSEE NV=1,999,9,0, &END
&NSEE NV=1,888,11,12, &END
&NSEE NV=2,888,10,12, &END
&NSEE NV=3,999,1,0, &END
&NSEE NV=3,999,7,0, &END
&NSEE NV=3,888,10,12, &END
&NSEE NV=4,888,1,3, &END
&NSEE NV=4,999,10,0, &END
&NSEE NV=4,999,12,0, &END
&NSEE NV=5,888,1,3, &END
&NSEE NV=5,999,10,0, &END
&NSEE NV=5,999,12,0, &END
&NSEE NV=6,888,1,3, &END
&NSEE NV=6,999,10,0, &END
&NSEE NV=6,999,12,0, &END
&NSEE NV=7,888,1,6, &END
&NSEE NV=7,999,12,0, &END
```

```
&NSEE NV=8,888,1,6, &END
&NSEE NV=8,999,10,0, &END
&NSEE NV=8,999,12,0, &END
&NSEE NV=9,888,1,6, &END
&NSEE NV=9,999,10,0, &END
&NSEE NV=9,999,12,0, &END
&NSEE NV=10,888,2,6, &END
&NSEE NV=10,888,8,9, &END
&NSEE NV=11,888,1,6, &END
&NSEE NV=11,999,12,0, &END
&NSEE NV=12,888,1,11, &END
&ROOM DCF=1.0, DHGT=2.4, DWID=1.0, FC=0.0, FH=0.0, GABSRP=1.4,
      HCEIL=3.0, PLCF1=1.0, PLCF2=1.5, THETA=0.5, VFV=0.0,  &END
&MODVAR FCTR=15*1., &END
&OUTF INCHCK=2, IOUTPT=7, MOUTPT=1,2,3,4,5,6,7,
      NSMOUT=12, MSMOUT=1,2,3,4,5,6,7,8,9,10,11,12, &END
```

TABLE 2

COMPBRN Sample Problem Output

```
PROGRAM COMPBRN - A DETERMINISTIC CODE TO COMPUTE THE PROGRESS OF FIRE
                  OVER A GIVEN FUEL ARRAY WITHIN ENCLOSING
                  BOUNDARIES.  ALL UNITS ARE IN THE MKS SYSTEM.

*********** TEST CASE:  WOOD CRIB IN ENCLOSURE *************************

INPUT DATA:

JOB  1 OF  1 JOBS
```

VARIABILITY FACTORS FOR FIRE MODELS:

VENTILATION CONTROLLED BURNING RATE	1.0000
FUEL-SURFACE CONTROLLED BURNING RATE	1.0000
FLAME HEIGHT FOR HORIZONTAL FUEL	1.0000
FLAME HEIGHT FOR VERTICAL FUEL	1.0000
RADIATIVE HEAT FLUX INTERCHANGE	1.0000
BUOYANT PLUME TEMPERATURE	1.0000
CONVECTIVE HEAT TRANSFER COEFFICIENT FOR FLAME	1.0000
CONVECTIVE HEAT TRANSFER COEFFICIENT FOR PLUME	1.0000
CONVECTIVE HEAT FLUX	1.0000
HEAT TRANSFER TO SELF FOR VERTICAL FUEL	1.0000
HEAT TRANSFER TO ADJACENT FUEL	1.0000
HEAT FLUX FROM CEILING HOT GAS LAYER	1.0000
HEAT FLUX FROM REFLECTIONS OFF WALLS	1.0000
CRITICAL TIME TO SPONTANEOUS IGNITION	1.0000
CRITICAL TIME TO PILOTED IGNITION	1.0000

```
NUMBER OF FUEL TYPES:    5

DATA FOR FUEL TYPE  1:

     FUEL TYPE:     1

     DENSITY (KG/M**3):                                                         800.
     SPECIFIC HEAT (J/KG-K):                                                   1045.
     THERMAL CONDUCTIVITY (W/M-K):                                             0.092
     HEAT OF COMBUSTION (J/KG):                                           .1860E+08
     PILOTED IGNITION TEMPERATURE (DEG. K):                                     480.
     SPONTANEOUS IGNITION TEMPERATURE (DEG. K):                                 530.
     VENTILATION CONTROLLED BURNING RATE FACTOR (KG/M**2.5-S):            .0
     SURFACE CONTROLLED SPECIFIC BURNING RATE (KG/M**2-S):                .6200E-02
     SPECIFIC BURNING RATE RADIATION AUGMENTATION (KG/J-M**2):            .0
     FRACTION OF HEAT RELEASED AS RADIATION:                                   0.400
     SMOKE ATTENUATION FACTOR (M**-1):                                         1.400
     REFLECTIVITY:                                                             0.100

DATA FOR FUEL TYPE  2:

     FUEL TYPE:     2

     DENSITY (KG/M**3):                                                         800.
     SPECIFIC HEAT (J/KG-K):                                                   1045.
     THERMAL CONDUCTIVITY (W/M-K):                                             0.092
     HEAT OF COMBUSTION (J/KG):                                           .1860E+08
     PILOTED IGNITION TEMPERATURE (DEG. K):                                     480.
     SPONTANEOUS IGNITION TEMPERATURE (DEG. K):                                 530.
     VENTILATION CONTROLLED BURNING RATE FACTOR (KG/M**2.5-S):            .0
     SURFACE CONTROLLED SPECIFIC BURNING RATE (KG/M**2-S):                .6200E-02
     SPECIFIC BURNING RATE RADIATION AUGMENTATION (KG/J-M**2):            .5530E-06
     FRACTION OF HEAT RELEASED AS RADIATION:                                   0.400
     SMOKE ATTENUATION FACTOR (M**-1):                                         1.400
     REFLECTIVITY:                                                             0.100

DATA FOR FUEL TYPE  3:
     FUEL TYPE (WALL):  20
     THERMAL CONDUCTIVITY (W/M-K):                                             1.000
     THERMAL DIFFUSIVITY (M**2/S):                                        .5000E-06
     REFLECTIVITY:                                                             0.100

DATA FOR FUEL TYPE  4:
     FUEL TYPE (CEILING):  40
     THERMAL CONDUCTIVITY (W/M-K):                                             1.000
     THERMAL DIFFUSIVITY (M**2/S):                                        .5000E-06
     REFLECTIVITY:                                                             0.100

DATA FOR FUEL TYPE  5:
     FUEL TYPE (DETECTOR):  10
```

```
ROOM PARAMETERS:

     CEILING LENGTH, WIDTH, HEIGHT (M):                                  6.00   4.00   4.00
     DOOR HEIGHT, WIDTH (M), ORIFICE COEFFICIENT:                        2.40   1.00   1.00
     FORCED VENTILATION (M**3/S):                                                      0.0
     FORCED VENTILATION CONSTANTS (FH AND FC):                                  0.0    0.0
     PLUME ENTRAINMENT CONSTANTS (PLCF1 AND PLCF2):                             1.00   1.50
     HOT GAS ABSORPTION COEFFICIENT (M**-1):                                         1.4000
     NUMERICAL ACCELERATION PARAMETER (THETA):                                         0.50

     CEILING HEAT TRANSFER COEFFICIENT (W/M**2 DEG.K):                                3.000
```

```
PILOT FIRE DATA:
     NUMBER OF PILOT FIRES:     1

     DATA FOR PILOT FIRE  1:

          LOCATION OF PILOT FIRE (FUEL ARRAY,FUEL CELL):                                     2,  2
          FUEL TYPE:                                                                             1
          MASS (KG):                                                                         0.100
```

```
NUMBER OF FUEL ARRAYS:    12

DATA FOR FUEL ARRAY  1:

      INITIAL FUEL CELL COORDINATES (X,Y,Z) (M):                      1.80      2.80      0.05
      DIMENSIONS (LENGTH,WIDTH,DEPTH) (M):                            0.51      0.10      0.10
      NUMBER OF FUEL CELLS:                                                                  5
      DIRECTION OF AXIS, ORIENTATION:                                              X         Z
      MASS (KG):                                                                        0.8400
      POROSITY FACTOR (DIMENSIONLESS):                                                  3.0000
      HEAT LOSS FACTOR (UNDEFINED):                                                      1.000
      FUEL TYPE:                                                                             1

DATA FOR FUEL ARRAY  2:

      INITIAL FUEL CELL COORDINATES (X,Y,Z) (M):                      1.80      3.00      0.05
      DIMENSIONS (LENGTH,WIDTH,DEPTH) (M):                            0.51      0.10      0.10
      NUMBER OF FUEL CELLS:                                                                  5
      DIRECTION OF AXIS, ORIENTATION:                                              X         Z
      MASS (KG):                                                                        0.8400
      POROSITY FACTOR (DIMENSIONLESS):                                                  3.0000
      HEAT LOSS FACTOR (UNDEFINED):                                                      1.000
      FUEL TYPE:                                                                             1

DATA FOR FUEL ARRAY  3:

      INITIAL FUEL CELL COORDINATES (X,Y,Z) (M):                      1.80      3.20      0.05
      DIMENSIONS (LENGTH,WIDTH,DEPTH) (M):                            0.51      0.10      0.10
      NUMBER OF FUEL CELLS:                                                                  5
      DIRECTION OF AXIS, ORIENTATION:                                              X         Z
      MASS (KG):                                                                        0.8400
      POROSITY FACTOR (DIMENSIONLESS):                                                  3.0000
      HEAT LOSS FACTOR (UNDEFINED):                                                      1.000
      FUEL TYPE:                                                                             1

DATA FOR FUEL ARRAY  4:

      INITIAL FUEL CELL COORDINATES (X,Y,Z) (M):                      1.80      2.80      0.15
      DIMENSIONS (LENGTH,WIDTH,DEPTH) (M):                            0.51      0.10      0.10
      NUMBER OF FUEL CELLS:                                                                  5
      DIRECTION OF AXIS, ORIENTATION:                                              Y         Z
      MASS (KG):                                                                        0.8400
      POROSITY FACTOR (DIMENSIONLESS):                                                  3.0000
      HEAT LOSS FACTOR (UNDEFINED):                                                      1.000
      FUEL TYPE:                                                                             1

DATA FOR FUEL ARRAY  5:

      INITIAL FUEL CELL COORDINATES (X,Y,Z) (M):                      2.00      2.80      0.15
      DIMENSIONS (LENGTH,WIDTH,DEPTH) (M):                            0.51      0.10      0.10
      NUMBER OF FUEL CELLS:                                                                  5
      DIRECTION OF AXIS, ORIENTATION:                                              Y         Z
      MASS (KG):                                                                        0.8400
      POROSITY FACTOR (DIMENSIONLESS):                                                  3.0000
      HEAT LOSS FACTOR (UNDEFINED):                                                      1.000
      FUEL TYPE:                                                                             1

DATA FOR FUEL ARRAY  6:

      INITIAL FUEL CELL COORDINATES (X,Y,Z) (M):                      2.20      2.80      0.15
      DIMENSIONS (LENGTH,WIDTH,DEPTH) (M):                            0.51      0.10      0.10
      NUMBER OF FUEL CELLS:                                                                  5
      DIRECTION OF AXIS, ORIENTATION:                                              Y         Z
      MASS (KG):                                                                        0.8400
      POROSITY FACTOR (DIMENSIONLESS):                                                  3.0000
      HEAT LOSS FACTOR (UNDEFINED):                                                      1.000
```

```
          FUEL TYPE:                                                          1

      DATA FOR FUEL ARRAY  7:

          INITIAL FUEL CELL COORDINATES (X,Y,Z) (M):     1.80     2.80     0.25
          DIMENSIONS (LENGTH,WIDTH,DEPTH) (M):           0.51     0.10     0.10
          NUMBER OF FUEL CELLS:                                               5
          DIRECTION OF AXIS, ORIENTATION:                            X        Z
          MASS (KG):                                                     0.8400
          POROSITY FACTOR (DIMENSIONLESS):                               3.0000
          HEAT LOSS FACTOR (UNDEFINED):                                   1.000
          FUEL TYPE:                                                          2

      DATA FOR FUEL ARRAY  8:

          INITIAL FUEL CELL COORDINATES (X,Y,Z) (M):     1.80     3.00     0.25
          DIMENSIONS (LENGTH,WIDTH,DEPTH) (M):           0.51     0.10     0.10
          NUMBER OF FUEL CELLS:                                               5
          DIRECTION OF AXIS, ORIENTATION:                            X        Z
          MASS (KG):                                                     0.8400
          POROSITY FACTOR (DIMENSIONLESS):                               3.0000
          HEAT LOSS FACTOR (UNDEFINED):                                   1.000
          FUEL TYPE:                                                          2

      DATA FOR FUEL ARRAY  9:

          INITIAL FUEL CELL COORDINATES (X,Y,Z) (M):     1.80     3.20     0.25
          DIMENSIONS (LENGTH,WIDTH,DEPTH) (M):           0.51     0.10     0.10
          NUMBER OF FUEL CELLS:                                               5
          DIRECTION OF AXIS, ORIENTATION:                            X        Z
          MASS (KG):                                                     0.8400
          POROSITY FACTOR (DIMENSIONLESS):                               3.0000
          HEAT LOSS FACTOR (UNDEFINED)                                    1.000
          FUEL TYPE:                                                          2

      DATA FOR FUEL ARRAY 10:

          INITIAL FUEL CELL COORDINATES (X,Y,Z) (M):     2.00     0.0      2.00
          DIMENSIONS (LENGTH,WIDTH,DEPTH) (M):           4.00     4.00     0.10
          NUMBER OF FUEL CELLS:                                               1
          DIRECTION OF AXIS, ORIENTATION:                            X        Y
          MASS (KG):                                                     1.0000
          POROSITY FACTOR (DIMENSIONLESS):                               1.0000
          HEAT LOSS FACTOR (UNDEFINED):                                   1.000
          FUEL TYPE:                                                          3

      DATA FOR FUEL ARRAY 11:

          INITIAL FUEL CELL COORDINATES (X,Y,Z) (M):     2.00     3.00     4.00
          DIMENSIONS (LENGTH,WIDTH,DEPTH) (M):           6.00     4.00     0.10
          NUMBER OF FUEL CELLS:                                               1
          DIRECTION OF AXIS, ORIENTATION:                            Y        Z
          MASS (KG):                                                     1.0000
          POROSITY FACTOR (DIMENSIONLESS):                               1.0000
          HEAT LOSS FACTOR (UNDEFINED):                                   1.000
          FUEL TYPE:                                                          4

      DATA FOR FUEL ARRAY 12:

          INITIAL FUEL CELL COORDINATES (X,Y,Z) (M):     2.00     0.10     2.00
          DIMENSIONS (LENGTH,WIDTH,DEPTH) (M):           0.10     0.10     0.10
          NUMBER OF FUEL CELLS:                                               1
          DIRECTION OF AXIS, ORIENTATION:                            X        Y
          MASS (KG):                                                     1.0000
          POROSITY FACTOR (DIMENSIONLESS):                               1.0000
          HEAT LOSS FACTOR (UNDEFINED):                                   1.000
```

FUEL TYPE: 5

```
COMMUNICATION DATA:


NON-COMMUNICATION DATA:
     NUMBER OF NON-COMMUNICATING FUEL CELLS:   29

        FUEL CELL PAIR   (FUEL ARRAY,FUEL CELL) , (FUEL ARRAY,FUEL CELL)

                1             1        999            3          0
                2             1        999            9          0
                3             1        888           11         12
                4             2        888           10         12
                5             3        999            1          0
                6             3        999            7          0
                7             3        888           10         12
                8             4        888            1          3
                9             4        999           10          0
               10             4        999           12          0
               11             5        888            1          3
               12             5        999           10          0
               13             5        999           12          0
               14             6        888            1          3
               15             6        999           10          0
               16             6        999           12          0
               17             7        888            1          6
               18             7        999           12          0
               19             8        888            1          6
               20             8        999           10          0
               21             8        999           12          0
               22             9        888            1          6
               23             9        999           10          0
               24             9        999           12          0
               25            10        888            2          6
               26            10        888            8          9
               27            11        888            1          6
               28            11        999           12          0
               29            12        888            1         11
```

```
MISCELLANEOUS:
    ROOM TEMPERATURE (DEG. K):                                                              298.
    CONVECTIVE HEAT TRANSFER COEFFICIENT FOR FLAME (W/M**2-K):                             22.00
    TIME INCREMENT (S):                                                                    60.00
    NUMBER OF TIME STEPS FOR JOB:                                                             30
```

```
*********** TEST CASE:  WOOD CRIB IN ENCLOSURE *************************
TIME (SEC):    0.


TOTAL MASS BURNING RATE (KG/S):    .1920E-03
TOTAL HEAT RELEASE RATE (W)   :    3571.
HOT GAS LAYER TEMPERATURE (K) :    298.1
HOT GAS LAYER THICKNESS (M)   :    1.600


MODULE:   1   BURNING ?           F          F          F          F          F
MODULE:   2   BURNING ?           F          T          F          F          F
MODULE:   3   BURNING ?           F          F          F          F          F
MODULE:   4   BURNING ?           F          F          F          F          F
MODULE:   5   BURNING ?           F          F          F          F          F
MODULE:   6   BURNING ?           F          F          F          F          F
MODULE:   7   BURNING ?           F          F          F          F          F
MODULE:   8   BURNING ?           F          F          F          F          F
MODULE:   9   BURNING ?           F          F          F          F          F
MODULE:  10   BURNING ?           F
MODULE:  11   BURNING ?           F
MODULE:  12   BURNING ?           F


MODULE:   1   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   2   SRCE FLUX   .0         .306E+05   .0         .0         .0
MODULE:   3   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   4   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   5   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   6   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   7   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   8   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   9   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:  10   SRCE FLUX   403.
MODULE:  11   SRCE FLUX   448.
MODULE:  12   SRCE FLUX   .0


MODULE:   1   EXT FLUX    .135E+04   .153E+04   .135E+04   .103E+04   757.
MODULE:   2   EXT FLUX    .126E+05   .0         .126E+05   .148E+04   907.
MODULE:   3   EXT FLUX    .130E+04   .148E+04   .130E+04   978.       707.
MODULE:   4   EXT FLUX    .109E+04   .201E+04   .300E+04   .201E+04   .109E+04
MODULE:   5   EXT FLUX    .109E+04   .201E+04   .300E+04   .201E+04   .109E+04
MODULE:   6   EXT FLUX    516.       642.       699.       642.       516.
MODULE:   7   EXT FLUX    .128E+04   .148E+04   .128E+04   947.       691.
MODULE:   8   EXT FLUX    .317E+04   .308E+05   .317E+04   .143E+04   828.
MODULE:   9   EXT FLUX    .124E+04   .143E+04   .124E+04   898.       642.
MODULE:  10   EXT FLUX    98.1
MODULE:  11   EXT FLUX    46.2
MODULE:  12   EXT FLUX    402.
```

```
*********** TEST CASE:  WOOD CRIB IN ENCLOSURE *************************
TIME (SEC):   60.

TOTAL MASS BURNING RATE (KG/S):   .1920E-03
TOTAL HEAT RELEASE RATE (W)    :   3571.
HOT GAS LAYER TEMPERATURE (K)  :   298.1
HOT GAS LAYER THICKNESS (M)    :   1.600

MODULE:   1   BURNING ?         F         F         F         F         F
MODULE:   2   BURNING ?         T         T         T         F         F
MODULE:   3   BURNING ?         F         F         F         F         F
MODULE:   4   BURNING ?         F         F         F         F         F
MODULE:   5   BURNING ?         F         F         F         F         F
MODULE:   6   BURNING ?         F         F         F         F         F
MODULE:   7   BURNING ?         F         F         F         F         F
MODULE:   8   BURNING ?         F         T         F         F         F
MODULE:   9   BURNING ?         F         F         F         F         F
MODULE:  10   BURNING ?         F
MODULE:  11   BURNING ?         F
MODULE:  12   BURNING ?         F

MODULE:   1   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   2   SRCE FLUX   .0         .306E+05   .0         .0         .0
MODULE:   3   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   4   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   5   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   6   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   7   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   8   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   9   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:  10   SRCE FLUX   414.
MODULE:  11   SRCE FLUX   448.
MODULE:  12   SRCE FLUX   .0

MODULE:   1   EXT FLUX    .135E+04   .153E+04   .135E+04   .103E+04   759.
MODULE:   2   EXT FLUX    .126E+05   .0         .126E+05   .148E+04   907.
MODULE:   3   EXT FLUX    .130E+04   .148E+04   .130E+04   978.       707.
MODULE:   4   EXT FLUX    .109E+04   .201E+04   .300E+04   .201E+04   .109E+04
MODULE:   5   EXT FLUX    .109E+04   .201E+04   .300E+04   .201E+04   .109E+04
MODULE:   6   EXT FLUX    516.       642.       699.       642.       516.
MODULE:   7   EXT FLUX    .129E+04   .148E+04   .129E+04   948.       692.
MODULE:   8   EXT FLUX    .317E+04   .308E+05   .317E+04   .143E+04   828.
MODULE:   9   EXT FLUX    .124E+04   .143E+04   .124E+04   898.       642.
MODULE:  10   EXT FLUX    98.1
MODULE:  11   EXT FLUX    47.1
MODULE:  12   EXT FLUX    413.
```

```
*********** TEST CASE:  WOOD CRIB IN ENCLOSURE *************************
TIME (SEC):  120.


TOTAL MASS BURNING RATE (KG/S):   .1295E-02
TOTAL HEAT RELEASE RATE (W)   :   .2409E+05
HOT GAS LAYER TEMPERATURE (K) :   299.0
HOT GAS LAYER THICKNESS (M)   :   1.600


MODULE:   1   BURNING ?         F          F          F          F          F
MODULE:   2   BURNING ?         T          T          T          T          F
MODULE:   3   BURNING ?         F          F          F          F          F
MODULE:   4   BURNING ?         F          F          T          F          F
MODULE:   5   BURNING ?         F          F          T          F          F
MODULE:   6   BURNING ?         F          F          F          F          F
MODULE:   7   BURNING ?         F          F          F          F          F
MODULE:   8   BURNING ?         T          T          T          T          F
MODULE:   9   BURNING ?         F          F          F          F          F
MODULE:  10   BURNING ?         F
MODULE:  11   BURNING ?         F
MODULE:  12   BURNING ?         F


MODULE:   1   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   2   SRCE FLUX   .306E+05   .306E+05   .306E+05   .0         .0
MODULE:   3   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   4   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   5   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   6   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   7   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   8   SRCE FLUX   .0         .533E+05   .0         .0         .0
MODULE:   9   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:  10   SRCE FLUX   415.
MODULE:  11   SRCE FLUX   453.
MODULE:  12   SRCE FLUX   .0


MODULE:   1   EXT FLUX    .381E+04   .413E+04   .381E+04   .304E+04   .225E+04
MODULE:   2   EXT FLUX    .148E+04   .0         .148E+04   .150E+05   .299E+04
MODULE:   3   EXT FLUX    .376E+04   .408E+04   .376E+04   .299E+04   .220E+04
MODULE:   4   EXT FLUX    .314E+04   .610E+04   .349E+05   .610E+04   .314E+04
MODULE:   5   EXT FLUX    .314E+04   .610E+04   .349E+05   .610E+04   .314E+04
MODULE:   6   EXT FLUX    .164E+04   .214E+04   .241E+04   .214E+04   .164E+04
MODULE:   7   EXT FLUX    .568E+04   .630E+04   .568E+04   .438E+04   .321E+04
MODULE:   8   EXT FLUX    .569E+05   .184E+05   .569E+05   .778E+04   .426E+04
MODULE:   9   EXT FLUX    .563E+04   .625E+04   .563E+04   .433E+04   .316E+04
MODULE:  10   EXT FLUX    99.2
MODULE:  11   EXT FLUX    .538E+04
MODULE:  12   EXT FLUX    413.
```

```
*********** TEST CASE:  WOOD CRIB IN ENCLOSURE **************************
TIME (SEC):  180.

TOTAL MASS BURNING RATE (KG/S):    .4317E-02
TOTAL HEAT RELEASE RATE (W)   :    .8029E+05
HOT GAS LAYER TEMPERATURE (K) :    302.4
HOT GAS LAYER THICKNESS (M)   :    2.292

MODULE:   1   BURNING ?          F          F          F          F          F
MODULE:   2   BURNING ?          T          T          T          T          T
MODULE:   3   BURNING ?          F          F          F          F          F
MODULE:   4   BURNING ?          F          T          T          T          F
MODULE:   5   BURNING ?          T          T          T          T          T
MODULE:   6   BURNING ?          F          F          T          F          F
MODULE:   7   BURNING ?          T          T          T          T          T
MODULE:   8   BURNING ?          T          T          T          T          T
MODULE:   9   BURNING ?          T          T          T          T          T
MODULE:  10   BURNING ?          F
MODULE:  11   BURNING ?          F
MODULE:  12   BURNING ?          F

MODULE:   1   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   2   SRCE FLUX   .306E+05   .306E+05   .306E+05   .306E+05   .0
MODULE:   3   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   4   SRCE FLUX   .0         .0         .306E+05   .0         .0
MODULE:   5   SRCE FLUX   .0         .0         .306E+05   .0         .0
MODULE:   6   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   7   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:   8   SRCE FLUX   .649E+05   .462E+05   .649E+05   .384E+05   .0
MODULE:   9   SRCE FLUX   .0         .0         .0         .0         .0
MODULE:  10   SRCE FLUX   416.
MODULE:  11   SRCE FLUX   474.
MODULE:  12   SRCE FLUX   .0

MODULE:   1   EXT FLUX    .452E+04   .511E+04   .511E+04   .452E+04   .355E+04
MODULE:   2   EXT FLUX    .238E+04   .148E+04   .148E+04   .238E+04   .156E+05
MODULE:   3   EXT FLUX    .446E+04   .506E+04   .506E+04   .446E+04   .350E+04
MODULE:   4   EXT FLUX    .611E+04   .206E+05   .187E+05   .206E+05   .611E+04
MODULE:   5   EXT FLUX    .669E+04   .220E+05   .210E+05   .220E+05   .669E+04
MODULE:   6   EXT FLUX    .422E+04   .604E+04   .750E+04   .604E+04   .422E+04
MODULE:   7   EXT FLUX    .144E+05   .160E+05   .157E+05   .136E+05   .106E+05
MODULE:   8   EXT FLUX    .354E+05   .276E+05   .365E+05   .255E+05   .293E+05
MODULE:   9   EXT FLUX    .143E+05   .159E+05   .156E+05   .135E+05   .105E+05
MODULE:  10   EXT FLUX    115.
MODULE:  11   EXT FLUX    .134E+05
MODULE:  12   EXT FLUX    428.
```

```
************ TEST CASE:  WOOD CRIB IN ENCLOSURE **************************
TIME (SEC):  240.

TOTAL MASS BURNING RATE (KG/S):   .1061E-01
TOTAL HEAT RELEASE RATE (W)   :   .1974E+06
HOT GAS LAYER TEMPERATURE (K) :   544.6
HOT GAS LAYER THICKNESS (M)   :   4.000

MODULE:   1  BURNING ?          T          T          T          T          F
MODULE:   2  BURNING ?          T          T          T          T          T
MODULE:   3  BURNING ?          T          T          T          T          F
MODULE:   4  BURNING ?          T          T          T          T          T
MODULE:   5  BURNING ?          T          T          T          T          T
MODULE:   6  BURNING ?          T          T          T          T          T
MODULE:   7  BURNING ?          T          T          T          T          T
MODULE:   8  BURNING ?          T          T          T          T          T
MODULE:   9  BURNING ?          T          T          T          T          T
MODULE:  10  BURNING ?          F
MODULE:  11  BURNING ?          F
MODULE:  12  BURNING ?          F

MODULE:   1  SRCE FLUX  .0         .0         .0         .0         .0
MODULE:   2  SRCE FLUX  .306E+05   .306E+05   .306E+05   .306E+05   .306E+05
MODULE:   3  SRCE FLUX  .0         .0         .0         .0         .0
MODULE:   4  SRCE FLUX  .0         .306E+05   .306E+05   .306E+05   .0
MODULE:   5  SRCE FLUX  .306E+05   .306E+05   .306E+05   .306E+05   .306E+05
MODULE:   6  SRCE FLUX  .0         .0         .306E+05   .0         .0
MODULE:   7  SRCE FLUX  .435E+05   .446E+05   .444E+05   .429E+05   .406E+05
MODULE:   8  SRCE FLUX  .556E+05   .516E+05   .562E+05   .505E+05   .525E+05
MODULE:   9  SRCE FLUX  .434E+05   .445E+05   .443E+05   .429E+05   .406E+05
MODULE:  10  SRCE FLUX  419.
MODULE:  11  SRCE FLUX  .499E+04
MODULE:  12  SRCE FLUX  .0

MODULE:   1  EXT FLUX   .577E+04   .656E+04   .683E+04   .656E+04   .577E+04
MODULE:   2  EXT FLUX   .299E+04   .238E+04   .295E+04   .238E+04   .299E+04
MODULE:   3  EXT FLUX   .498E+04   .576E+04   .604E+04   .576E+04   .498E+04
MODULE:   4  EXT FLUX   .245E+05   .150E+05   .243E+05   .150E+05   .245E+05
MODULE:   5  EXT FLUX   .120E+05   .166E+05   .293E+05   .166E+05   .120E+05
MODULE:   6  EXT FLUX   .120E+05   .272E+05   .255E+05   .272E+05   .120E+05
MODULE:   7  EXT FLUX   .347E+05   .380E+05   .489E+05   .365E+05   .317E+05
MODULE:   8  EXT FLUX   .646E+05   .610E+05   .721E+05   .583E+05   .593E+05
MODULE:   9  EXT FLUX   .339E+05   .372E+05   .481E+05   .357E+05   .309E+05
MODULE:  10  EXT FLUX   .260E+04
MODULE:  11  EXT FLUX   .495E+05
MODULE:  12  EXT FLUX   .116E+04
```

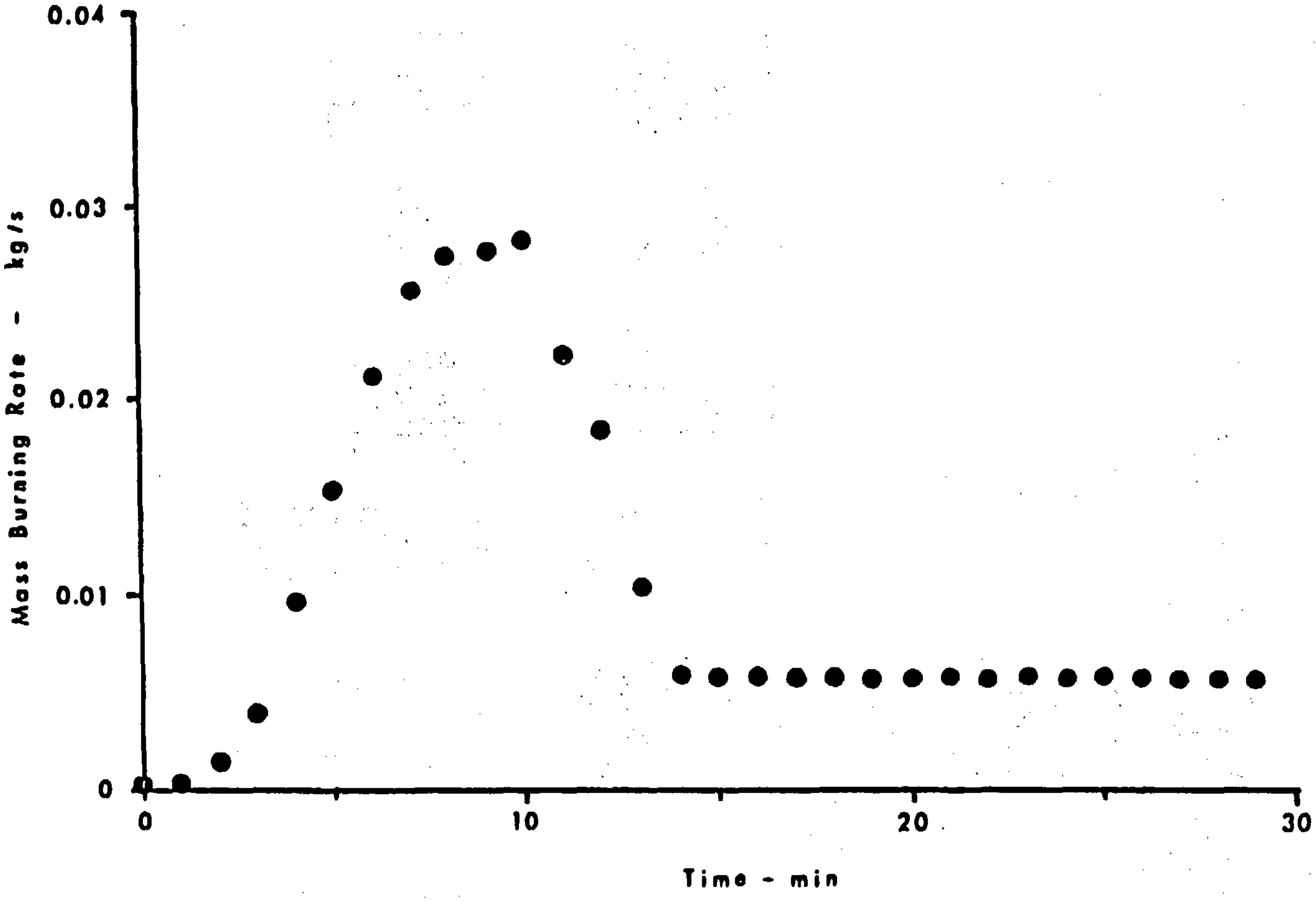


Figure 6: Crib Mass Burning Rate

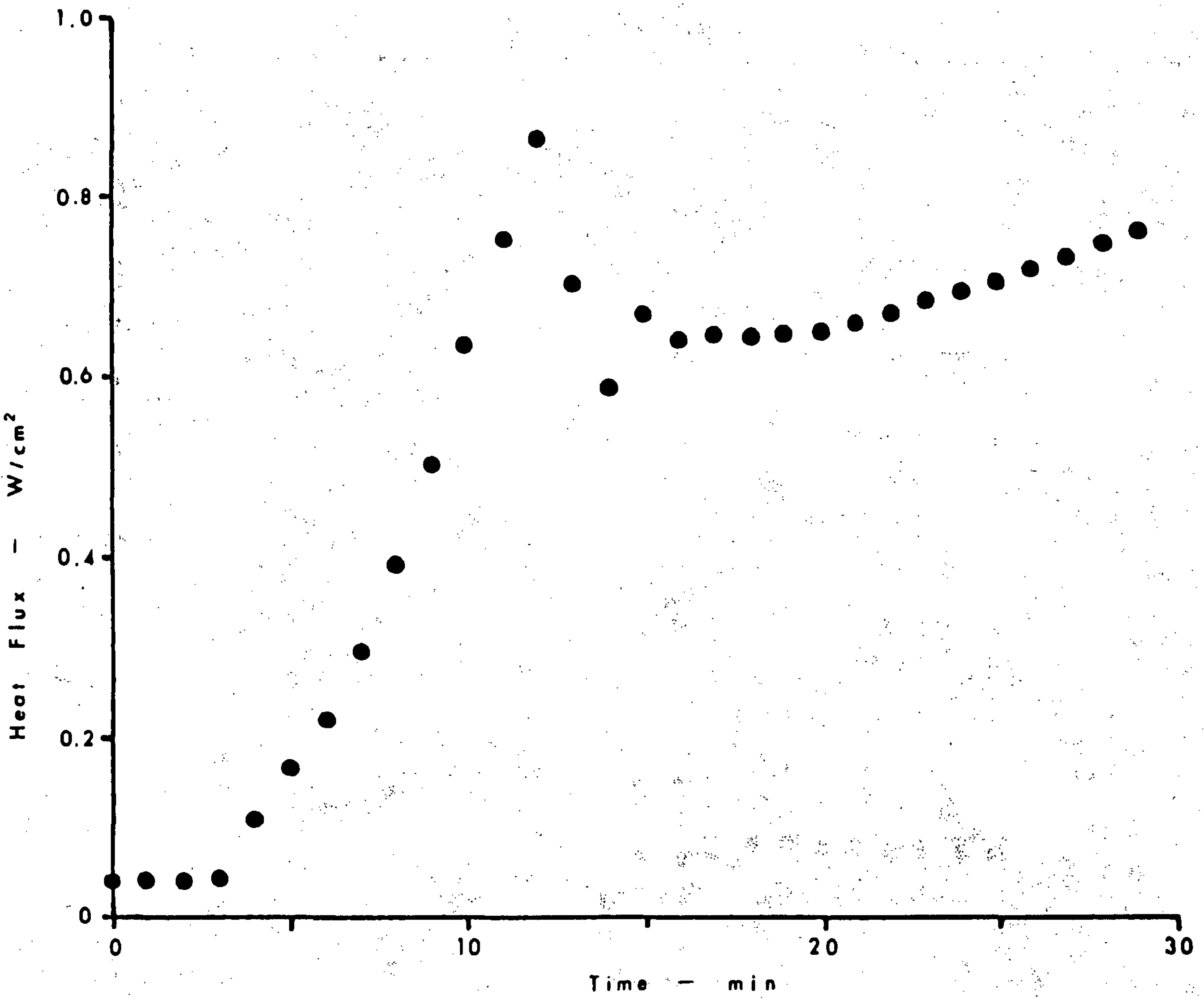


Figure 7: Heat Flux from Wall to Detector

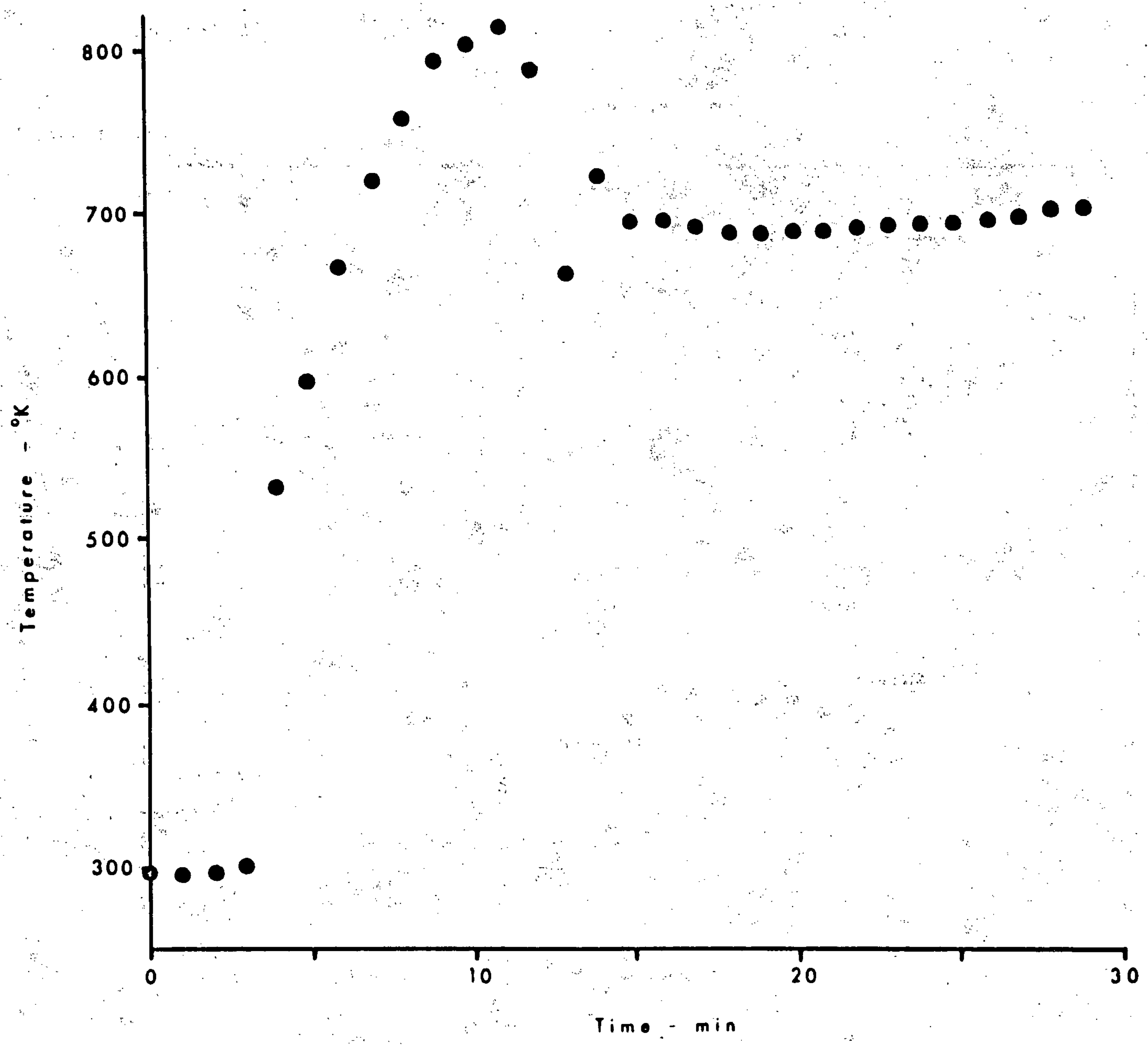


Figure 8: Average Hot Gas Layer Temperature

Chapter 7

REFERENCES

1. N. O. Siu, "Probabilistic Models for the Behavior of Compartment Fires," NUREG/CR-2269,UCLA-ENG-8090, University of California at Los Angeles, August 1981.

2. G. Apostolakis, M. Kazarians, and D. C. Bley, "Methodology for Assessing the Risk from Cable Fires," *Nuclear Safety*, 23(4): 391-407(July-August 1982)

3. M. Kazarians and G. Apostolakis, "Fire Risk Analysis for Nuclear Power Plants," NUREG/CR-2258,UCLA-ENG-8102, University of California at Los Angeles, September 1981.

4. N. O. Siu, "Physical Models for Compartment Fires," *Reliability Engineering*, 3: 229-252(1982)

5. N. O. Siu and G. Apostolakis, "Probabilistic Models for Cable Tray Fires," *Reliability Engineering*, 3: 213-227(1982)

6. B. Carnahan, H. Luther, and J. Wilkes, *Applied Numerical Methods*, John Wiley and Sons, Inc., New York, 1969.

Appendix A

SOME DETAILS ON THE MODELS FOR WALLS AND THERMAL BARRIERS

In our analysis of compartment fires, we are often interested in the behavior of slabs of non-combustible materials as they absorb heat from the flames. We are particularly interested in their strength as heat flux sources, since the heat from these slabs may enhance the growth rate of a fire. If we are interested in the heat flux radiating from the back (unexposed) side of the slab, we treat the slab as a "barrier." If the heat flux re-radiated and reflected from the front face of the slab is of interest, we treat the slab as a "wall."

A.1 THERMAL BARRIER MODEL

Consider a slab of width L, with an isotropic heat flux of strength $\dot{q}_0''$ impinging on the left face (x=0). The time-dependent diffusion equation, with appropriate boundary conditions, then governs the temperature profile within the barrier:

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2} \qquad (A.1)$$

$t = 0$: $T(x,0) = T_0$

$$x = 0: \quad \varepsilon \dot{q}_0'' = h_0[T(0,t)-T_A] + \sigma\varepsilon[T^4(0,t)-T_A^4] - k \left.\frac{\partial T}{\partial x}\right|_0 \qquad (A.2)$$

$$x = L: \quad -k \left.\frac{\partial T}{\partial x}\right|_L = h_L[T(L,t)-T_A] + \sigma\varepsilon[T^4(L,t)-T_A^4] \qquad (A.3)$$

where α = barrier thermal diffusivity (m^2/s)

ε = barrier emissivity

σ = Stefan-Boltzmann constant (5.6697×10^{-8} W/m²°K⁴)

h = barrier surface heat transfer coefficient (W/m²°K)

k = barrier thermal conductivity (W/m°K)

T_A = ambient temperature (°K)

If we assume that steady-state conditions exist, the solution of Equation (A.1) is a linear temperature profile, i.e.

$$T(x) = T(0) + [T(L) - T(0)](x/L) \tag{A.4}$$

and the boundary conditions become (assuming a constant h):

$$\varepsilon \dot{q}''_0 = h[T(0)-T_A] + \sigma\varepsilon[T^4(0)-T_A^4] - [T(L)-T(0)](k/L) \tag{A.5}$$

$$-\frac{k}{L}[T(L)-T(0)] = h[T(L)-T_A] + \sigma\varepsilon[T^4(L)-T_A^4] \tag{A.6}$$

Equations (A.5) and (A.6) can be solved numerically for T(0) and T(L). The radiative heat flux emerging form the back side of the barrier is then

$$\dot{q}''_L = \sigma\varepsilon T^4(L) \tag{A.7}$$

The convective component is relatively small for high values of T(L), and will not impact on distant objects.

To compute the net heat flux impinging on an object maintained at ambient temperature, we use

$$\dot{q}'' = \sigma\varepsilon[T^4(L) - T_A^4] \tag{A.8}$$

The values of $\dot{q}''$ computed from Equations (A.7) and (A.8) vary only slightly for significant levels of thermal radiation.

We note that the steady-state assumption is conservative, since a thermal wave takes a finite amount of time to penetrate the slab. The time scale for this penetration is of the order

$$\tau \sim L^2/\alpha$$

and may be very long for dense, poorly conducting materials. For example, the time constant for two inches of concrete is about 1.5 hours (by which time, the fire may be extinguished).

A.2 WALL MODEL

The governing equations for the wall temperature are also Equations (A.1), (A.2), and (A.3). However, since the walls tend to be thick and are often composed of concrete, we cannot ignore their transient behavior under thermal loads. We must therefore solve the governing equations numerically.

In COMPBRN, we choose to model the wall with a very coarse spatial grid consisting only of 10 mesh points. These mesh points are lumped near the wall's exposed surface, since the penetration of the thermal wave is very slow. In fact, the time scale of many fires is sufficiently short that the actual wall thickness has little impact on the calculations; we can easily fix T(L,t) at ambient levels, and ignore Equation (A.3) without significantly changing our results. The actual numerical solution is obtained using a Crank-Nicolson scheme described in Reference (6).

Once the temperature profile within the wall is found for any particular time step, the radiative heat flux source strength of the wall's exposed face is given by

$$\dot{q}''_S = \sigma\varepsilon T^4(0,t) + \rho\dot{q}''_0 \qquad (A.9)$$

where

ρ = wall reflectivity

As in the barrier model, the target object's re-radiation can be accounted for by subtracting a term proportional to T_A^4. We also neglect the convective heat flux from the wall in COMPBRN, although suitable models can be incorporated easily by the user, if desired.

Appendix B

CODE LISTING

```
C***********************************************************************
C                                                                      *
C   COMPBRN - A COMPUTER PROGRAM FOR MODELING THE BEHAVIOR             *
C             OF COMPARTMENT FIRES                                     *
C                                                                      *
C   AUTHOR  - NATHAN O. SIU                                            *
C                                                                      *
C   VERSION - IBM 3033 (7/82)                                          *
C                                                                      *
C***********************************************************************
C
C
C***********************************************************************
C                                                                      *
C   MAIN PROGRAM (READS INPUT DATA, CALLS SUBROUTINES)                 *
C                                                                      *
C***********************************************************************
      IMPLICIT LOGICAL ($)
C
C   FUEL CELL ARRAYS
C
      DIMENSION BRAT(12,5), FLHT(12,5), FLTEMP(12,5), FMASS(12,5),
     1          FX(12,5), FY(12,5), FZ(12,5), GAMN(12,5), QDOT2P(12,5),
     2          Q(12,5), QDOTC(12,5), QEXT(12,5), QEXT0(12,5),
     3          SUMQSQ(12,5), TEMP(12,5,10), ICOUNT(12,5),
     4          $BURN(12,5), $FMASS(12,5), $PIGN(12,5), $STRT0(12,5),
     5          $TOP(12,5)
C
C   SUPER-MODULE VECTORS
C
      DIMENSION AREA(12), DELS(12), DEP(12), FLNG(12), FLOSS(12),
     1          FMASS0(12), RAD(12), POR(12), WID(12),
     2          IDIR(12), IORT(12), ITYP(12), MSMOUT(12), NFC(12),
     3          $B(12), $C(12), $D(12), $W(12)
C
C   FUEL TYPE VECTORS
C
      DIMENSION BRATS0(5), BRATS1(5), BRATV(5), DENS(5), DIFF(5),
     1          FABSRP(5), FIGTP(5), FIGTS(5), GAMMA(5), HEAT(5),
     2          SPHT(5), REFL(5), THK(5),
     3          IFUEL(5),
     4          $BF(5), $CF(5), $DF(5), $WF(5)
C
C   PILOT FIRE VECTORS
C
      DIMENSION PBRATV(10), PBRTS0(10), PBRTS1(10), PHEAT(10),
     1          PMASS(10), PMDOTS(10),
     2          IPIL(10), IPFUEL(10), JPIL(10),
     3          $PMASS(10)
C
C   COMMUNICATION ARRAYS AND VECTORS
C
      DIMENSION IV(4), NV(4), ICOMM(60,60), IAD(30,4), NAD(200,4)
C
```

```
C     COMMON STATEMENTS
C
      COMMON /ALL/ ACEIL, AWALL, DELT, FCTR(15), FLCF, RTEMP, TIME,
     1             TITLE(20),
     2             ICEIL, IJOB, INCHCK, INITG, IOUTPT, MOUTPT(11),
     3             $DOOR, $END, $ROOM
      COMMON /GAS/ A4, CDOOR, CF, CFV, DCF, DEN, DG, DHGT, DWID,
     1             FC, FH, GABSRP, HCEIL, PLCF1, PLCF2,
     2             TG, TG0, THETA, VFV, WFL, WFVC, WFVH, ZD, ZN
      DATA IDIM1/12/, IDIM2/5/, IDIM3/60/, IDIM4/30/, IDIM5/200/,
     1     NREAD/5/, NWRITE/6/
      NAMELIST /STRT/ NJOB, NTIME, NREAD, NWRITE, DELT
      NAMELIST /SIZE/ NSM, NCOM, NFUEL, NNCOM, NPILOT, IROOM, INITG
      NAMELIST /FUELB/ SMX, SMY, SMZ, SLNG, SWID, SDEP, SMASS, SPOR,
     1         SLOSS, NFCL, IORNT, IDIREC, IFTYP
      NAMELIST /PILOT/ IPIL, JPIL, IPFUEL, PMASS
      NAMELIST /FUELT/ IFUEL, DENS, SPHT, THK, HEAT, FIGTP,
     1         FIGTS, BRATV, BRATS0, BRATS1, GAMMA, FABSRP, REFL
      NAMELIST /MISC/ RTEMP, FLCF
      NAMELIST /SEE/ IV
      NAMELIST /NSEE/ NV
      NAMELIST /ROOM/ DWID, DHGT, DCF, FC, FH, GABSRP, HCEIL, PLCF1,
     1                PLCF2, THETA, VFV
      NAMELIST /GINIT/ TG, DG, QEXT
      NAMELIST /MODVAR/ FCTR
      NAMELIST /OUTF/ INCHCK, IOUTPT, MOUTPT, NSMOUT, MSMOUT
      READ (NREAD,STRT)
      IF (NJOB.EQ.0) NJOB = 1
      DO 8000 IJOB=1,NJOB
C
C     INPUT PROBLEM DATA
C
      READ (NREAD,SIZE)
      READ (NREAD,9100) TITLE
C
C     READ FUEL BED CHARACTERISTICS
C
      DO 1000 I=1,NSM
      READ (NREAD,FUELB)
      XNFCL = FLOAT(NFCL)
      DELS(I) = SLNG/XNFCL
      AREA(I) = DELS(I)*SWID
      RAD(I) = SQRT(AREA(I)/3.14159)
      IF (IORNT.EQ.3) RAD(I) = SWID/2.
      FMASS0(I) = SMASS/XNFCL
      WID(I) = SWID
      POR(I) = SPOR
      FLOSS(I) = SLOSS
      FLNG(I) = SLNG
      DEP(I) = SDEP
      IDIR(I) = IDIREC
      IORT(I) = IORNT
      ITYP(I) = IFTYP
      NFC(I) = NFCL
```

```
      $D(I) = .FALSE.
      $W(I) = .FALSE.
      $B(I) = .FALSE.
      $C(I) = .FALSE.
      CALL SETUP(I,IDIREC,IDIM1,IDIM2,NFCL,SMX,SMY,SMZ,SLNG,DELS(I),
     1           FX,FY,FZ)
      DO 500 J=1,NFCL
      FMASS(I,J) = FMASS0(I)
  500 CONTINUE
 1000 CONTINUE
C
C   READ PILOT FIRE CHARACTERISTICS
C
      READ (NREAD,PILOT)
C
C   READ FUEL TYPE CHARACTERISTICS
C
      READ (NREAD,FUELT)
      DO 2900 I=1,NFUEL
      DIFF(I) = THK(I)/(DENS(I)*SPHT(I))
      $DF(I) = .FALSE.
      $WF(I) = .FALSE.
      $BF(I) = .FALSE.
      $CF(I) = .FALSE.
      ITYPE = IFUEL(I)
      IF (ITYPE.LT.10) GO TO 2900
      IF ((ITYPE.GE.10).AND.(ITYPE.LT.20)) $DF(I) = .TRUE.
      IF ((ITYPE.GE.20).AND.(ITYPE.LT.30)) $WF(I) = .TRUE.
      IF ((ITYPE.GE.30).AND.(ITYPE.LT.40)) $BF(I) = .TRUE.
      IF ((ITYPE.GE.40).AND.(ITYPE.LT.50)) $CF(I) = .TRUE.
      DO 2500 J=1,NSM
      IF (ITYP(J).NE.I) GO TO 2500
      IF ($DF(I)) $D(J) = .TRUE.
      IF ($WF(I)) $W(J) = .TRUE.
      IF ($BF(I)) $B(J) = .TRUE.
      IF (.NOT.$CF(I)) GO TO 2500
      $C(J) = .TRUE.
      ICEIL = J
 2500 CONTINUE
 2900 CONTINUE
      READ (NREAD,MISC)
      DO 3100 I=1,IDIM3
      DO 3000 J=1,IDIM3
      ICOMM(I,J) = 1
 3000 CONTINUE
 3100 CONTINUE
      IF (NCOM.EQ.0) GO TO 3500
      DO 3300 I=1,NCOM
      READ (NREAD,SEE)
      DO 3200 J=1,4
      IAD(I,J) = IV(J)
 3200 CONTINUE
 3300 CONTINUE
 3500 IF (NNCOM.EQ.0) GO TO 3900
```

```
      DO 3800 I=1,NNCOM
      READ (NREAD,NSEE)
      DO 3700 J=1,4
      NAD(I,J) = NV(J)
 3700 CONTINUE
 3800 CONTINUE
 3900 CALL COMM(NCOM,NNCOM,NSM,IDIM1,IDIM3,IDIM4,IDIM5,NFC,IAD,NAD,
     1          ICOMM)
      $ROOM = (IROOM.EQ.1)
      IF (.NOT.$ROOM) GO TO 5000
C
C   READ ROOM CHARACTERISTICS
C
      READ (NREAD,ROOM)
      ADOOR = DWID*DHGT
      $DOOR = (ADOOR.LE.1.E-2)
      CDOOR = 3.56*DCF*ADOOR*SQRT(DHGT)
      CFV = 352.6*VFV
      CF = 1000.*CFV
      IF (INITG.EQ.1) READ (NREAD,GINIT)
      IF (DCF.EQ.0.) DCF = 1.
      IF (GABSRP.EQ.0.) GABSRP = 1.4
      IF (PLCF1.EQ.0.) PLCF1 = 1.
      IF (PLCF2.EQ.0.) PLCF2 = .5
      IF (RTEMP.EQ.0.) RTEMP = 298.
      IF (THETA.EQ.0.) THETA = .5
      WFVC = CFV/RTEMP
 5000 READ (NREAD,MODVAR)
      DO 6000 I=1,15
      IF (FCTR(I).LE.0.0) FCTR(I) = 1.0
 6000 CONTINUE
      READ (NREAD,OUTF)
C
C   ECHO CHECK FOR INPUT DATA
C
      CALL INCHK (FX,FY,FZ,QEXT,DEP,FLNG,FLOSS,FMASS0,POR,WID,BRATS0,
     1 BRATS1,BRATV,DENS,DIFF,FABSRP,FIGTP,FIGTS,GAMMA,HEAT,REFL,SPHT,
     2 THK,PMASS,IDIR,IORT,ITYP,NFC,IFUEL,IPIL,IPFUEL,JPIL,IAD,NAD,
     3 $BF,$CF,$DF,$WF,IDIM1,IDIM2,IDIM4,IDIM5,NCOM,NFUEL,NJOB,
     4 NNCOM,NPILOT,NSM,NTIME,NWRITE)
C
C   INITIALIZE JOB VARIABLES
C
      CALL INIT(QEXT,SUMQSQ,FX,FY,FZ,TEMP,$BURN,$FMASS,AREA,DELS,POR,
     1 WID,BRATS0,BRATS1,BRATV,HEAT,PBRATV,PBRTS0,PBRTS1,PHEAT,PMASS,
     2 IDIR,IORT,NFC,IPIL,IPFUEL,JPIL,$PMASS,ICOMM,$B,$C,$W,IDIM1,
     3 IDIM2,IDIM3,NFUEL,NPILOT,NSM)
      TIME = 0.0
      DO 7000 ITIME=1,NTIME
C
C   TIME-STEP INITIALIZATIONS
C
      CALL TINIT(FLHT,FLTEMP,Q,QDOT2P,QEXT,QEXT0,$PIGN,$STRT0,NFC,
     1 IDIM1,IDIM2,NSM)
```

```
C
C   COMPUTE SOURCE HEAT FLUXES
C
      CALL SOURCE(BRAT,FLHT,FLTEMP,FMASS,FZ,GAMN,Q,QDOTC,QDOT2P,QEXT,
     1 QEXTO,TEMP,AREA,DELS,DEP,FMASSO,POR,RAD,WID,PBRATV,PBRTSO,PBRTS1,
     2 PHEAT,PMASS,PMDOTS,BRATSO,BRATS1,BRATV,DIFF,GAMMA,HEAT,REFL,THK,
     3 ICOUNT,IORT,ITYP,NFC,IPIL,IPFUEL,JPIL,$BURN,$FMASS,$STRTO,$TOP,
     4 $B,$C,$D,$W,$PMASS,IDIM1,IDIM2,NFUEL,NPILOT,NSM,NWRITE)
      IF ($END) GO TO 8000
C
C   COMPUTE HEAT FLUX TRANSFER TO RECEIVERS
C
      CALL TRANSF(FLHT,FLTEMP,FX,FY,FZ,QDOTC,QDOT2P,QEXT,TEMP,AREA,
     1 DELS,RAD,WID,FABSRP,GAMMA,ICOUNT,IORT,ITYP,NFC,ICOMM,$BURN,
     2 $PIGN,$B,$C,$D,$W,IDIM1,IDIM2,IDIM3,NFUEL,NSM,NWRITE)
      IF ($END) GO TO 8000
C
C   DETERMINE IF OTHER FUEL CELLS IGNITE
C
      CALL IGNIT(QEXT,SUMQSQ,TEMP,DIFF,FIGTP,FIGTS,THK,ITYP,NFC,
     1 $BURN,$FMASS,$PIGN,$B,$C,$D,$W,IDIM1,IDIM2,NFUEL,NSM)
C
C   OUTPUT FOR EACH TIME STEP
C
      CALL OUTPUT(FLHT,FLTEMP,FMASS,QDOT2P,QEXT,TEMP,$BURN,NFC,MSMOUT,
     1 IDIM1,IDIM2,NSM,NSMOUT,NWRITE)
      TIME = TIME + DELT
 7000 CONTINUE
 8000 CONTINUE
 9100 FORMAT (20A4)
 9000 STOP
      END
```

```
C*************************************************************************
C                                                                        *
C   SUBROUTINE INCHK (READ CHECK FOR INPUT DATA)                         *
C                                                                        *
C*************************************************************************
      SUBROUTINE INCHK (FX,FY,FZ,QEXT,DEP,FLNG,FLOSS,FMASS0,POR,WID,
     1 BRATS0,BRATS1,BRATV,DENS,DIFF,FABSRP,FIGTP,FIGTS,GAMMA,HEAT,REFL,
     2 SPHT,THK,PMASS,IDIR,IORT,ITYP,NFC,IFUEL,IPIL,IPFUEL,JPIL,IAD,
     3 NAD,$BF,$CF,$DF,$WF,IDIM1,IDIM2,IDIM4,IDIM5,NCOM,NFUEL,NJOB,
     4 NNCOM,NPILOT,NSM,NTIME,NWRITE)
      IMPLICIT LOGICAL ($)
      DIMENSION QEXT(IDIM1,IDIM2), FX(IDIM1,IDIM2), FY(IDIM1,IDIM2),
     1          FZ(IDIM1,IDIM2)
      DIMENSION DEP(NSM), FLNG(NSM), FLOSS(NSM), FMASS0(NSM), POR(NSM),
     1          WID(NSM), IDIR(NSM), IORT(NSM), ITYP(NSM), NFC(NSM)
      DIMENSION BRATS0(NFUEL), BRATS1(NFUEL), BRATV(NFUEL), DENS(NFUEL),
     1          DIFF(NFUEL), FABSRP(NFUEL), FIGTP(NFUEL), FIGTS(NFUEL),
     2          GAMMA(NFUEL), HEAT(NFUEL), REFL(NFUEL), SPHT(NFUEL),
     3          THK(NFUEL), IFUEL(NFUEL),
     4          $BF(NFUEL), $CF(NFUEL), $DF(NFUEL), $WF(NFUEL)
      DIMENSION PMASS(NPILOT),
     1          IPIL(NPILOT), IPFUEL(NPILOT), JPIL(NPILOT)
      DIMENSION IAD(IDIM4,4), NAD(IDIM5,4)
      COMMON /ALL/ ACEIL, AWALL, DELT, FCTR(15), FLCF, RTEMP, TIME,
     1             TITLE(20),
     2             ICEIL, IJOB, INCHCK, INITG, IOUTPT, MOUTPT(11),
     3             $DOOR, $END, $ROOM
      COMMON /GAS/ A4, CDOOR, CF, CFV, DCF, DEN, DG, DHGT, DWID,
     1             FC, FH, GABSRP, HCEIL, PLCF1, PLCF2,
     2             TG, TG0, THETA, VFV, WFL, WFVC, WFVH, ZD, ZN
      DATA X/1HX/, Y/1HY/, Z/1HZ/
      WRITE (NWRITE,9000) TITLE, IJOB, NJOB
      WRITE (NWRITE,9100)
      WRITE (NWRITE,9101) FCTR(1)
      WRITE (NWRITE,9102) FCTR(2)
      WRITE (NWRITE,9103) FCTR(3)
      WRITE (NWRITE,9104) FCTR(4)
      WRITE (NWRITE,9105) FCTR(5)
      WRITE (NWRITE,9106) FCTR(6)
      WRITE (NWRITE,9107) FCTR(7)
      WRITE (NWRITE,9108) FCTR(8)
      WRITE (NWRITE,9109) FCTR(9)
      WRITE (NWRITE,9110) FCTR(10)
      WRITE (NWRITE,9111) FCTR(11)
      WRITE (NWRITE,9112) FCTR(12)
      WRITE (NWRITE,9113) FCTR(13)
      WRITE (NWRITE,9114) FCTR(14)
      WRITE (NWRITE,9115) FCTR(15)
      IF (INCHCK.EQ.0) RETURN
      WRITE (NWRITE,9200) NFUEL
      DO 6000 I=1,NFUEL
      WRITE (6,9210) I
      IF ($DF(I)) GO TO 1000
      IF ($WF(I)) GO TO 2000
```

```
      IF ($BF(I)) GO TO 3000
      IF ($CF(I)) GO TO 4000
      WRITE (NWRITE,9220) IFUEL(I)
      WRITE (NWRITE,9230) DENS(I)
      WRITE (NWRITE,9240) SPHT(I)
      WRITE (NWRITE,9250) THK(I)
      WRITE (NWRITE,9255) HEAT(I)
      WRITE (NWRITE,9260) FIGTP(I)
      WRITE (NWRITE,9270) FIGTS(I)
      WRITE (NWRITE,9280) BRATV(I)
      WRITE (NWRITE,9290) BRATS0(I)
      WRITE (NWRITE,9300) BRATS1(I)
      WRITE (NWRITE,9310) GAMMA(I)
      WRITE (NWRITE,9320) FABSRP(I)
      WRITE (NWRITE,9330) REFL(I)
      GO TO 6000
 1000 WRITE (NWRITE,9340) IFUEL(I)
      GO TO 6000
 2000 WRITE (NWRITE,9350) IFUEL(I)
      GO TO 5000
 3000 WRITE (NWRITE,9360) IFUEL(I)
      GO TO 5000
 4000 WRITE (NWRITE,9370) IFUEL(I)
 5000 WRITE (NWRITE,9250) THK(I)
      WRITE (NWRITE,9400) DIFF(I)
      WRITE (NWRITE,9330) REFL(I)
 6000 CONTINUE
      IF (INCHCK.EQ.1) RETURN
      IF (.NOT.$ROOM) GO TO 7000
      WRITE (NWRITE,9500)
      WRITE (NWRITE,9501) FLNG(ICEIL), WID(ICEIL), FZ(ICEIL,1)
      WRITE (NWRITE,9510) DHGT, DWID, DCF
      WRITE (NWRITE,9520) VFV
      WRITE (NWRITE,9525) FH, FC
      WRITE (NWRITE,9530) PLCF1, PLCF2
      WRITE (NWRITE,9540) GABSRP
      WRITE (NWRITE,9550) THETA
      WRITE (NWRITE,9570) HCEIL
      IF (INITG.EQ.0) GO TO 7000
      WRITE (NWRITE,9580) TG, DG
      WRITE (NWRITE,9585)
      DO 6900 I=1,NSM
      NFCI = NFC(I)
      WRITE (NWRITE,9590) (QEXT(I,J),J=1,NFCI)
 6900 CONTINUE
 7000 WRITE (NWRITE,9600) NPILOT
      DO 7500 I=1,NPILOT
      WRITE (NWRITE,9605) I
      WRITE (NWRITE,9610) IPIL(I), JPIL(I)
      WRITE (NWRITE,9620) IPFUEL(I)
      WRITE (NWRITE,9630) PMASS(I)
 7500 CONTINUE
      WRITE (NWRITE,9700) NSM
      DO 8000 I=1,NSM
```

```
     WRITE (NWRITE,9705) I
     WRITE (NWRITE,9710) FX(I,1), FY(I,1), FZ(I,1)
     WRITE (NWRITE,9720) FLNG(I), WID(I), DEP(I)
     WRITE (NWRITE,9730) NFC(I)
     IF (IDIR(I).EQ.1) DIREC = X
     IF (IDIR(I).EQ.2) DIREC = Y
     IF (IDIR(I).EQ.3) DIREC = Z
     IF (IORT(I).EQ.1) ORNT = X
     IF (IORT(I).EQ.2) ORNT = Y
     IF (IORT(I).EQ.3) ORNT = Z
     WRITE (NWRITE,9740) DIREC, ORNT
     WRITE (NWRITE,9750) FMASS0(I)
     WRITE (NWRITE,9760) POR(I)
     WRITE (NWRITE,9770) FLOSS(I)
     WRITE (NWRITE,9780) ITYP(I)
8000 CONTINUE
     IF ((NCOM.NE.0).OR.(NNCOM.NE.0)) WRITE (NWRITE,9790)
     IF (NCOM.EQ.0) GO TO 8500
     WRITE (NWRITE,9800) NCOM
     DO 8200 I=1,NCOM
     WRITE (NWRITE,9810) I, (IAD(I,J),J=1,4)
8200 CONTINUE
8500 IF (NNCOM.EQ.0) GO TO 8900
     WRITE (NWRITE,9820) NNCOM
     DO 8800 I=1,NNCOM
     WRITE (NWRITE,9810) I, (NAD(I,J),J=1,4)
8800 CONTINUE
8900 WRITE (NWRITE,9900)
     WRITE (NWRITE,9910) RTEMP
     WRITE (NWRITE,9920) FLCF
     WRITE (NWRITE,9930) DELT
     WRITE (NWRITE,9940) NTIME
9000 FORMAT (1H1,'PROGRAM COMPBRN - A DETERMINISTIC CODE TO COMPUTE',
    1   ' THE PROGRESS OF FIRE',/,19X,'OVER A GIVEN FUEL ARRAY WITHIN',
    2   ' ENCLOSING',/,19X,'BOUNDARIES.  ALL UNITS ARE IN THE ',
    3  'MKS SYSTEM.',///,1X,20A4,
    4  //,' INPUT DATA:',///,' JOB',I3,' OF',I3,' JOBS')
9100 FORMAT (1H1,'VARIABILITY FACTORS FOR FIRE MODELS:')
9101 FORMAT (1H0,5X,'VENTILATION CONTROLLED BURNING RATE',T89,F7.4)
9102 FORMAT (1H0,5X,'FUEL-SURFACE CONTROLLED BURNING RATE',T89,F7.4)
9103 FORMAT (1H0,5X,'FLAME HEIGHT FOR HORIZONTAL FUEL',T89,F7.4)
9104 FORMAT (1H0,5X,'FLAME HEIGHT FOR VERTICAL FUEL',T89,F7.4)
9105 FORMAT (1H0,5X,'RADIATIVE HEAT FLUX INTERCHANGE',T89,F7.4)
9106 FORMAT (1H0,5X,'BUOYANT PLUME TEMPERATURE',T89,F7.4)
9107 FORMAT (1H0,5X,'CONVECTIVE HEAT TRANSFER COEFFICIENT FOR ',
    1               'FLAME',T89,F7.4)
9108 FORMAT (1H0,5X,'CONVECTIVE HEAT TRANSFER COEFFICIENT FOR ',
    1               'PLUME',T89,F7.4)
9109 FORMAT (1H0,5X,'CONVECTIVE HEAT FLUX',T89,F7.4)
9110 FORMAT (1H0,5X,'HEAT TRANSFER TO SELF FOR VERTICAL FUEL',T89,F7.4)
9111 FORMAT (1H0,5X,'HEAT TRANSFER TO ADJACENT FUEL',T89,F7.4)
9112 FORMAT (1H0,5X,'HEAT FLUX FROM CEILING HOT GAS LAYER',T89,F7.4)
9113 FORMAT (1H0,5X,'HEAT FLUX FROM REFLECTIONS OFF WALLS',T89,F7.4)
9114 FORMAT (1H0,5X,'CRITICAL TIME TO SPONTANEOUS IGNITION',T89,F7.4)
```

```
9115 FORMAT (1H0,5X,'CRITICAL TIME TO PILOTED IGNITION',T89,F7.4)
9200 FORMAT (1H1,5X,'NUMBER OF FUEL TYPES:',I5)
9210 FORMAT (1H0,5X,'DATA FOR FUEL TYPE',I3,':')
9220 FORMAT (1H0,10X,'FUEL TYPE:',3X,I3)
9230 FORMAT (1H0,10X,'DENSITY (KG/M**3):',T90,F6.0)
9240 FORMAT (1H ,10X,'SPECIFIC HEAT (J/KG-K):',T90,F6.0)
9250 FORMAT (1H ,10X,'THERMAL CONDUCTIVITY (W/M-K):',T90,F6.3)
9255 FORMAT (1H ,10X,'HEAT OF COMBUSTION (J/KG):',T84,G12.4)
9260 FORMAT (1H ,10X,'PILOTED IGNITION TEMPERATURE (DEG. K):',T90,
     1                F6.0)
9270 FORMAT (1H ,10X,'SPONTANEOUS IGNITION TEMPERATURE (DEG. K):',
     1                T90,F6.0)
9280 FORMAT (1H ,10X,'VENTILATION CONTROLLED BURNING RATE FACTOR',
     1                ' (KG/M**2.5-S):',T84,G12.4)
9290 FORMAT (1H ,10X,'SURFACE CONTROLLED SPECIFIC BURNING RATE ',
     1                '(KG/M**2-S):',T84,G12.4)
9300 FORMAT (1H ,10X,'SPECIFIC BURNING RATE RADIATION AUGMENTATION',
     1                ' (KG/J-M**2):',T84,G12.4)
9310 FORMAT (1H ,10X,'FRACTION OF HEAT RELEASED AS RADIATION:',
     1                T90,F6.3)
9320 FORMAT (1H ,10X,'SMOKE ATTENUATION FACTOR (M**-1):',T90,F6.3)
9330 FORMAT (1H ,10X,'REFLECTIVITY:',T90,F6.3)
9340 FORMAT (1H ,10X,'FUEL TYPE (DETECTOR):',I4)
9350 FORMAT (1H ,10X,'FUEL TYPE (WALL):',I4)
9360 FORMAT (1H ,10X,'FUEL TYPE (BARRIER):',I4)
9370 FORMAT (1H ,10X,'FUEL TYPE (CEILING):',I4)
9400 FORMAT (1H ,10X,'THERMAL DIFFUSIVITY (M**2/S):',T84,
     1                G12.4)
9500 FORMAT (1H1,5X,'ROOM PARAMETERS:')
9501 FORMAT (1H0,10X,'CEILING LENGTH, WIDTH, HEIGHT (M):',T78,3F6.2)
9510 FORMAT (1H ,10X,'DOOR HEIGHT, WIDTH (M), ORIFICE ',
     1                'COEFFICIENT:',T78,3F6.2)
9520 FORMAT (1H ,10X,'FORCED VENTILATION (M**3/S):',T89,F7.2)
9525 FORMAT (1H ,10X,'FORCED VENTILATION CONSTANTS (FH AND FC):',
     1                T84,2F6.2)
9530 FORMAT (1H ,10X,'PLUME ENTRAINMENT CONSTANTS (PLCF1 AND',
     1                ' PLCF2):',T84,2F6.2)
9540 FORMAT (1H ,10X,'HOT GAS ABSORPTION COEFFICIENT (M**-1):',
     1                T90,F6.4)
9550 FORMAT (1H ,10X,'NUMERICAL ACCELERATION PARAMETER (THETA):',
     1                T89,F7.2)
9570 FORMAT (1H0,10X,'CEILING HEAT TRANSFER COEFFICIENT ',
     1                '(W/M**2 DEG.K):',T90,F6.3)
9580 FORMAT (1H0,//,6X,'INITIAL CEILING GAS LAYER PARAMETERS:',//,
     1              11X,'AVERAGE GAS TEMPERATURE:',T89,F7.2,/,
     2              11X,'GAS LAYER DEPTH:',T89,F7.3)
9585 FORMAT (1H1,'INITIAL HEAT FLUXES TO FUEL BED:',//)
9590 FORMAT (1H ,'MODULE:',I3,/,10D12.4)
9600 FORMAT (1H1,'PILOT FIRE DATA:',/,6X,'NUMBER OF PILOT FIRES:',I5)
9605 FORMAT (1H0,5X,'DATA FOR PILOT FIRE',I3,':')
9610 FORMAT (1H0,10X,'LOCATION OF PILOT FIRE (FUEL ARRAY,FUEL CELL)',
     1                ':',T89,I3,',',I3)
9620 FORMAT (1H ,10X,'FUEL TYPE:',T91,I5)
9630 FORMAT (1H ,10X,'MASS (KG):',T90,F6.3)
```

```
9700 FORMAT (1H1,5X,'NUMBER OF FUEL ARRAYS:',I5)
9705 FORMAT (1H0,5X,'DATA FOR FUEL ARRAY',I3,':')
9710 FORMAT (1H0,10X,'INITIAL FUEL CELL COORDINATES (X,Y,Z) (M):',T70,
    1                 F8.2,1X,F8.2,1X,F8.2)
9720 FORMAT (1H ,10X,'DIMENSIONS (LENGTH,WIDTH,DEPTH) (M):',T70,
    1                 F8.2,1X,F8.2,1X,F8.2)
9730 FORMAT (1H ,10X,'NUMBER OF FUEL CELLS:',T91,I5)
9740 FORMAT (1H ,10X,'DIRECTION OF AXIS, ORIENTATION:',T86,A1,8X,A1)
9770 FORMAT (1H ,10X,'HEAT LOSS FACTOR (UNDEFINED):',T90,F6.3)
9750 FORMAT (1H ,10X,'MASS (KG):',T88,F8.4)
9760 FORMAT (1H ,10X,'POROSITY FACTOR (DIMENSIONLESS):',T89,F7.4)
9780 FORMAT (1H ,10X,'FUEL TYPE:',T91,I5)
9790 FORMAT (1H1,5X,'COMMUNICATION DATA:',/)
9800 FORMAT (1H0,5X,'NUMBER OF ADJACENT FUEL CELLS NOT IN SAME FUEL',
    2               ' ARRAY:',I5,//,14X,'FUEL CELL PAIR',3X,
    3               '(FUEL ARRAY,FUEL CELL) , (FUEL ARRAY,FUEL CELL',/)
9810 FORMAT (1H ,19X,I3,12X,I3,8X,I3,11X,I3,8X,I3)
9820 FORMAT (1H0,//,6X,'NON-COMMUNICATION DATA:',/,11X,'NUMBER OF ',
    1                  'NON-COMMUNICATING FUEL CELLS:',I5,//,
    2              14X,'FUEL CELL PAIR',3X,'(FUEL ARRAY,FUEL CELL)',
    3                  '  , (FUEL ARRAY,FUEL CELL)',/)
9900 FORMAT (1H1,6X,'MISCELLANEOUS:')
9910 FORMAT (1H ,10X,'ROOM TEMPERATURE (DEG. K):',T90,F6.0)
9920 FORMAT (1H ,10X,'CONVECTIVE HEAT TRANSFER COEFFICIENT FOR FLAME',
    1                ' (W/M**2-K):',T90,F6.2)
9930 FORMAT (1H ,10X,'TIME INCREMENT (S):',T90,F6.2)
9940 FORMAT (1H ,10X,'NUMBER OF TIME STEPS FOR JOB:',T91,I5)
     RETURN
     END
```

```
C***********************************************************************
C                                                                      *
C   SUBROUTINE INIT (INITIALIZATION OF PROBLEM PARAMETERS)             *
C                                                                      *
C***********************************************************************
      SUBROUTINE INIT(QEXT,SUMQSQ,FX,FY,FZ,TEMP,$BURN,$FMASS,AREA,DELS,
     1 POR,WID,BRATS0,BRATS1,BRATV,HEAT,PBRATV,PBRTS0,PBRTS1,PHEAT,
     2 PMASS,IDIR,IORT,NFC,IPIL,IPFUEL,JPIL,$PMASS,ICOMM,$B,$C,$W,
     3 IDIM1,IDIM2,IDIM3,NFUEL,NPILOT,NSM)
      IMPLICIT LOGICAL ($)
      DIMENSION QEXT(IDIM1,IDIM2), SUMQSQ(IDIM1,IDIM2), FX(IDIM1,IDIM2),
     1          FY(IDIM1,IDIM2), FZ(IDIM1,IDIM2), TEMP(IDIM1,IDIM2,10),
     2          $BURN(IDIM1,IDIM2), $FMASS(IDIM1,IDIM2)
      DIMENSION AREA(NSM), DELS(NSM), POR(NSM), WID(NSM),
     1          IDIR(NSM), IORT(NSM), NFC(NSM),
     2          $B(NSM), $C(NSM), $W(NSM)
      DIMENSION BRATS0(NFUEL), BRATS1(NFUEL), BRATV(NFUEL), HEAT(NFUEL)
      DIMENSION PBRATV(NPILOT), PBRTS0(NPILOT), PBRTS1(NPILOT),
     1          PHEAT(NPILOT), PMASS(NPILOT),
     2          IPIL(NPILOT), IPFUEL(NPILOT), JPIL(NPILOT),
     3          $PMASS(NPILOT)
      DIMENSION ICOMM(IDIM3,IDIM3)
      COMMON /ALL/ ACEIL, AWALL, DELT, FCTR(15), FLCF, RTEMP, TIME,
     1             TITLE(20),
     2             ICEIL, IJOB, INCHCK, INITG, IOUTPT, MOUTPT(11),
     3             $DOOR, $END, $ROOM
      COMMON /GAS/ A4, CDOOR, CF, CFV, DCF, DEN, DG, DHGT, DWID,
     1             FC, FH, GABSRP, HCEIL, PLCF1, PLCF2,
     2             TG, TG0, THETA, VFV, WFL, WFVC, WFVH, ZD, ZN
      COMMON /VENTC/ AFUEL, AFUEL0, CVA, CVA0, FHTA, FRADA, FUELA, QMAX,
     1               QTOT, QTOT0, QTOT1, QTOT2, TMDOT, TMDOT0,
     2               TMDOTS, TQDOT, TQDOTC, WIN, Z0A,
     3               NBURN, NBURN0,
     4               $DECAY, $FLUX1, $FLUX2, $VENT, $VCONT
C
C   COMPUTE SHAPE FACTORS FROM WALLS, BARRIERS, AND CEILING TO OBJECTS
C
      IJ = 0
      DO 1900 I=1,NSM
      NFCI = NFC(I)
      IF ($W(I).OR.$B(I).OR.$C(I)) GO TO 1100
      IJ = IJ + NFCI
      GO TO 1900
 1100 DO 1700 J=1,NFCI
      IJ = IJ + 1
      KL = 0
      DO 1500 K=1,NSM
      NFCK = NFC(K)
      DO 1300 L=1,NFCK
      KL = KL + 1
      IF (I.EQ.K) ICOMM(IJ,KL) = 0
      IF (ICOMM(IJ,KL).EQ.0) GO TO 1300
      F12 = SHAPE(IORT(I),IORT(K),IDIR(I),FX(I,J),FY(I,J),
     1            FZ(I,J),FX(K,L),FY(K,L),FZ(K,L),DELS(I),WID(I))
```

```
      ICOMM(IJ,KL) = IFIX(F12*1000.)
 1300 CONTINUE
 1500 CONTINUE
 1700 CONTINUE
 1900 CONTINUE
      IF (.NOT.$ROOM) GO TO 3000
      IF ((INITG.EQ.1).AND.(ZD.GT.0.)) GO TO 2500
      TG = 300.
      ZD = 0.2*DHGT
      ZN = 2.*ZD
 2500 IF (TG.EQ.0.) TG = 300.
      CVA = 0.
      TG0 = TG
      QTOT = 0.
      QTOT0 = 0.
      QTOT1 = 0.
      QTOT2 = 0.
      AWALL = 2.*FZ(ICEIL,1)*(DELS(ICEIL) + WID(ICEIL))
      ACEIL = AREA(ICEIL)
      QMAX = 4.21E6*FZ(ICEIL,1)*ACEIL
      $VENT = .FALSE.
      $VCONT = .FALSE.
      $DECAY = .FALSE.
      $FLUX1 = .FALSE.
 3000 TMDOT = 0.
      TMDOTS = 0.
      DO 3700 I=1,NSM
      NFCI = NFC(I)
      DO 3500 J=1,NFCI
      $BURN(I,J) = .FALSE.
      $FMASS(I,J) = .FALSE.
      IF ($ROOM.AND.(INITG.EQ.1)) GO TO 3100
      SUMQSQ(I,J) = 0.
      QEXT(I,J) = 0.
      GO TO 3200
 3100 SUMQSQ(I,J) = QEXT(I,J)**2
 3200 DO 3300 K=1,10
      TEMP(I,J,K) = RTEMP
 3300 CONTINUE
 3500 CONTINUE
 3700 CONTINUE
      $END = .FALSE.
      AFUEL = 0.
      NBURN = 0
C
C   INITIALIZE PILOT FIRES
C
      DO 4000 I=1,NPILOT
      NBURN = NBURN + 1
      AFUEL = AFUEL + POR(IPIL(I))*AREA(IPIL(I))
      $BURN(IPIL(I),JPIL(I)) = .TRUE.
      IPTYP = IPFUEL(I)
      PBRATV(I) = BRATV(IPTYP)
      PBRTS0(I) = BRATS0(IPTYP)
```

```
      PBRTS1(I) = BRATS1(IPTYP)
      PHEAT(I) = HEAT(IPTYP)
      $PMASS(I) = .TRUE.
 4000 CONTINUE
      RETURN
      END
```

```
C*****************************************************************************
C                                                                            *
C   SUBROUTINE TINIT (PERFORMS TIME STEP INITIALIZATIONS)                    *
C                                                                            *
C*****************************************************************************
      SUBROUTINE TINIT(FLHT,FLTEMP,Q,QDOT2P,QEXT,QEXTO,$PIGN,$STRTO,
     1 NFC,IDIM1,IDIM2,NSM)
      IMPLICIT LOGICAL ($)
      DIMENSION FLHT(IDIM1,IDIM2), FLTEMP(IDIM1,IDIM2), Q(IDIM1,IDIM2),
     1    QDOT2P(IDIM1,IDIM2), QEXT(IDIM1,IDIM2), QEXTO(IDIM1,IDIM2),
     2    NFC(NSM), $PIGN(IDIM1,IDIM2), $STRTO(IDIM1,IDIM2)
      COMMON /ALL/ ACEIL, AWALL, DELT, FCTR(15), FLCF, RTEMP, TIME,
     1             TITLE(20),
     2             ICEIL, IJOB, INCHCK, INITG, IOUTPT, MOUTPT(11),
     3             $DOOR, $END, $ROOM
      COMMON /GAS/ A4, CDOOR, CF, CFV, DCF, DEN, DG, DHGT, DWID,
     1             FC, FH, GABSRP, HCEIL, PLCF1, PLCF2,
     2             TG, TGO, THETA, VFV, WFL, WFVC, WFVH, ZD, ZN
      COMMON /VENTC/ AFUEL, AFUELO, CVA, CVAO, FHTA, FRADA, FUELA, QMAX,
     1               QTOT, QTOTO, QTOT1, QTOT2, TMDOT, TMDOTO,
     2               TMDOTS, TQDOT, TQDOTC, WIN, ZOA,
     3               NBURN, NBURNO,
     4               $DECAY, $FLUX1, $FLUX2, $VENT, $VCONT
      IF (.NOT.$ROOM) GO TO 1000
      CVAO = CVA*FCTR(1)
      CVA = 0.
      FHTA = 0.
      FUELA = 0.
      TGO = TG
      ZOA = 0.
      $FLUX2 = $FLUX1
      $FLUX1 = .FALSE.
 1000 AFUELO = AFUEL
      AFUEL = 0.
      TMDOTO = TMDOT
      TMDOT = 0.
      TMDOTS = 0.
      TQDOT = 0.
      TQDOTC = 0.
      NBURNO = NBURN
      NBURN = 0
      DO 2500 I=1,NSM
      NFCI = NFC(I)
      DO 2000 J=1,NFCI
      QEXTO(I,J) = QEXT(I,J)
      QEXT(I,J) = 0.
      $PIGN(I,J) = .FALSE.
      $STRTO(I,J) = .FALSE.
      FLTEMP(I,J) = 0.
      FLHT(I,J) = 0.
      QDOT2P(I,J) = 0.
      Q(I,J) = 0.
 2000 CONTINUE
 2500 CONTINUE
```

```
      RETURN
      END
```

```
C*************************************************************************
C                                                                        *
C   SUBROUTINE SOURCE (COMPUTES HEAT FLUX SOURCE STRENGTH OF FUEL        *
C                       ELEMENTS, WALLS, BARRIERS, AND CEILING)          *
C                                                                        *
C*************************************************************************
      SUBROUTINE SOURCE(BRAT,FLHT,FLTEMP,FMASS,FZ,GAMN,Q,QDOTC,QDOT2P,
     1 QEXT,QEXT0,TEMP,AREA,DELS,DEP,FMASS0,POR,RAD,WID,PBRATV,PBRTS0,
     2 PBRTS1,PHEAT,PMASS,PMDOTS,BRATS0,BRATS1,BRATV,DIFF,GAMMA,HEAT,
     3 REFL,THK,ICOUNT,IORT,ITYP,NFC,IPIL,IPFUEL,JPIL,
     4 $BURN,$FMASS,$STRTO,$TOP,$B,$C,$D,$W,$PMASS,
     5 IDIM1,IDIM2,NFUEL,NPILOT,NSM,NWRITE)
      IMPLICIT LOGICAL ($)
      DIMENSION BRAT(IDIM1,IDIM2), FLHT(IDIM1,IDIM2),
     1    FLTEMP(IDIM1,IDIM2), FMASS(IDIM1,IDIM2), FZ(IDIM1,IDIM2),
     2    GAMN(IDIM1,IDIM2), Q(IDIM1,IDIM2), QDOTC(IDIM1,IDIM2),
     3    QDOT2P(IDIM1,IDIM2), QEXT(IDIM1,IDIM2), QEXT0(IDIM1,IDIM2),
     4    TEMP(IDIM1,IDIM2,10),
     5    ICOUNT(IDIM1,IDIM2), $BURN(IDIM1,IDIM2),
     6    $FMASS(IDIM1,IDIM2), $STRTO(IDIM1,IDIM2), $TOP(IDIM1,IDIM2)
      DIMENSION AREA(NSM), DELS(NSM), DEP(NSM), FMASS0(NSM), POR(NSM),
     1          RAD(NSM), WID(NSM),
     2          IORT(NSM), ITYP(NSM), NFC(NSM),
     3          $B(NSM), $C(NSM), $D(NSM), $W(NSM)
      DIMENSION PBRATV(NPILOT), PBRTS0(NPILOT), PBRTS1(NPILOT),
     1          PHEAT(NPILOT), PMASS(NPILOT), PMDOTS(NPILOT),
     2          IPIL(NPILOT), IPFUEL(NPILOT), JPIL(NPILOT),
     3          $PMASS(NPILOT)
      DIMENSION BRATS0(NFUEL), BRATS1(NFUEL), BRATV(NFUEL), DIFF(NFUEL),
     1          GAMMA(NFUEL), HEAT(NFUEL), REFL(NFUEL), THK(NFUEL)
      COMMON /ALL/ ACEIL, AWALL, DELT, FCTR(15), FLCF, RTEMP, TIME,
     1             TITLE(20),
     2             ICEIL, IJOB, INCHCK, INITG, IOUTPT, MOUTPT(11),
     3             $DOOR, $END, $ROOM
      COMMON /VENTC/ AFUEL, AFUEL0, CVA, CVA0, FHTA, FRADA, FUELA, QMAX,
     1               QTOT, QTOT0, QTOT1, QTOT2, TMDOT, TMDOT0,
     2               TMDOTS, TQDOT, TQDOTC, WIN, Z0A,
     3               NBURN, NBURN0,
     4               $DECAY, $FLUX1, $FLUX2, $VENT, $VCONT
C
C   PILOT FIRE BURNING RATE
C
      DO 1900 I=1,NPILOT
      IF (.NOT.$PMASS(I)) GO TO 1900
      IPILOT = IPIL(I)
      JPILOT = JPIL(I)
      PAREA = AREA(IPILOT)
      IF (PMASS(I).GT.0.0) GO TO 1500
      PAREA = 0.0
      PMASS(I) = 0.0
      $PMASS(I) = .FALSE.
 1500 PMDOTS(I) = (PBRTS0(I) + PBRTS1(I)*QEXT0(IPILOT,JPILOT))*
     1            PAREA*POR(IPILOT)*FCTR(2)
      $STRT0(IPILOT,JPILOT) = ($PMASS(I))
```

```
 1900 CONTINUE
      DO 8000 I=1,NSM
      IF ($D(I).OR.$W(I).OR.$B(I).OR.$C(I)) GO TO 8000
      FRMASS = .3*FMASS0(I)
      ITYPE = ITYP(I)
      NFCI = NFC(I)
      $ORNT = (IORT(I).NE.3)
      DO 4000 J=1,NFCI
      IF (.NOT.$BURN(I,J)) GO TO 4000
      NBURN = NBURN + 1
      $STRT = $STRT0(I,J)
      IF (.NOT.$STRT) GO TO 2500
      DO 2000 II=1,NPILOT
      IF ((I.NE.IPIL(II)).OR.(J.NE.JPIL(II))) GO TO 2000
      INDEX = II
      GO TO 2500
 2000 CONTINUE
C
C   BURNING RATES (VENTILATION AND FUEL SURFACE CONTROLLED)
C
 2500 AFUEL = AFUEL + AREA(I)*POR(I)
      FMDOTS = (BRATS0(ITYPE) + BRATS1(ITYPE)*QEXT0(I,J))*
     1         AREA(I)*POR(I)
      IF ($STRT) FMDOTS = PMDOTS(INDEX)
      IF (FMDOTS.GT.0.) GO TO 2700
      BRAT(I,J) = 0.
      $BURN(I,J) = .FALSE.
      GO TO 4000
 2700 FMDOT = FMDOTS
      IF (.NOT.$ROOM) GO TO 2900
      FBV = BRATV(ITYPE)
      IF ($STRT) FBV = PBRATV(INDEX)
      CVA = CVA + FBV*AREA(I)*POR(I)
      IF ($VENT) FMDOT = WIN*AREA(I)*POR(I)*CVA0/AFUEL0**2
 2900 TMDOT = TMDOT + FMDOT
      TMDOTS = TMDOTS + FMDOTS
      BRAT(I,J) = FMDOT
C
C   HEAT PRODUCTION RATE
C
      QCOMB = HEAT(ITYPE)
      IF ($STRT) QCOMB = PHEAT(INDEX)
      Q(I,J) = FMDOT*QCOMB
      TQDOT = TQDOT + Q(I,J)
      GAMN(I,J) = 1. - GAMMA(ITYPE)
      IF ($STRT) GAMN(I,J) = 1. - GAMMA(IPFUEL(INDEX))
C
C   DECREMENT FUEL MASS
C
      IF ($STRT) GO TO 3000
      XMASS = FMASS(I,J) - FMDOT*DELT
      IF (XMASS.GT.FRMASS) GO TO 3500
      $BURN(I,J) = .FALSE.
      $FMASS(I,J) = .TRUE.
```

```
      FMASS(I,J) = FRMASS
      GO TO 4000
C
C   DECREMENT PILOT MASS
C
 3000 PMASS(INDEX) = PMASS(INDEX) - FMDOT*DELT
      GO TO 4000
 3500 FMASS(I,J) = XMASS
 4000 CONTINUE
C
C   FLAME HEIGHTS
C
      VMDOT = 0.0
      KCOUNT = 0
      DO 5900 J=1,NFCI
      IF (.NOT.$BURN(I,J)) GO TO 5900
      FMDOT = BRAT(I,J)
      IF ($ORNT) GO TO 5100
C
C   FLAMES OVER HORIZONTAL FUEL SLABS
C
      FHT = (30.64*RAD(I)*(BRAT(I,J)/(AREA(I)*SQRT(RAD(I))))**.61)
     1      *FCTR(3)
      IF ($ROOM) ZOA = ZOA + FZ(I,J)*TMDOT
      GO TO 5700
C
C   FLAMES OVER VERTICAL FUEL SLABS
C
 5100 VMDOT = VMDOT + FMDOT
      KCOUNT = KCOUNT + 1
      IF ((J.LT.NFCI).AND.$BURN(I,J+1)) GO TO 5500
      FHT = (29.7*(VMDOT/WID(I))**.6667)*FCTR(4) + DELS(I)
      IF ($ROOM) ZOA = ZOA + FZ(I,J-KCOUNT+1)*VMDOT
      VMDOT = 0.0
      KCOUNT = 0
      $TOP(I,J) = .TRUE.
      GO TO 5700
 5500 FHT = DELS(I)
      $TOP(I,J) = .FALSE.
 5700 FLHT(I,J) = FHT
      IF (.NOT.$ROOM) GO TO 5900
      FUELA = FUELA + AREA(I)
      FHTA = FHTA + FHT*FMDOT
 5900 CONTINUE
C
C   SOURCE STRENGTH OF FLAMES
C
      IF ($ORNT) GO TO 7000
C
C   HORIZONTAL FUEL SLABS
C
      DO 6000 J=1,NFCI
      IF (.NOT.$BURN(I,J)) GO TO 6000
      HTFLUX = Q(I,J)/(3.14159*RAD(I)*(RAD(I) + 2.*FLHT(I,J)))
```

```
      QDOT2P(I,J) = HTFLUX
      FLTEMP(I,J) = SQRT(SQRT(HTFLUX/5.6697E-8))
      QDOTC(I,J) = GAMN(I,J)*Q(I,J)
      TQDOTC = TQDOTC + QDOTC(I,J)
 6000 CONTINUE
      GO TO 8000
C
C   VERTICAL FUEL SLABS
C
 7000 IBOTP = 1
 7100 JCOUNT = 0
      $BOT = .FALSE.
      IBOT = IBOTP
      DO 7300 J=IBOT,NFCI
      IF (.NOT.$BURN(I,J)) GO TO 7300
      IF (.NOT.$BOT) IBOTP = J
      $BOT = .TRUE.
      JCOUNT = JCOUNT + 1
      ICOUNT(I,J) = JCOUNT
      IF ($TOP(I,J)) GO TO 7500
 7300 CONTINUE
      GO TO 8000
 7500 ITOP = IBOTP + JCOUNT - 1
      TFLHT = 0.0
      VQDOT = 0.0
      DO 7700 J=IBOTP,ITOP
      TFLHT = TFLHT + FLHT(I,J)
      VQDOT = VQDOT + Q(I,J)
 7700 CONTINUE
      QDOTC(I,ITOP) = VQDOT*GAMN(I,ITOP)
      HTFLUX = VQDOT/(2.*TFLHT*WID(I))
      FLAMT = SQRT(SQRT(HTFLUX/5.6697E-8))
      DO 7900 J=IBOTP,ITOP
      QDOT2P(I,J) = HTFLUX
      FLTEMP(I,J) = FLAMT
 7900 CONTINUE
      IBOTP = ITOP + 1
      IF (IBOTP.LE.NFCI) GO TO 7100
 8000 CONTINUE
      IF (NBURNO.EQ.0) GO TO 9500
      IF (.NOT.$ROOM) GO TO 8200
      FRADA = SQRT(FUELA/3.14159)
      FHTA = FHTA/TMDOT
      ZOA = ZOA/TMDOT
 8200 DO 8900 I=1,NSM
      ITYPE = ITYP(I)
      NFCI = NFC(I)
      EPS = 1. - REFL(ITYPE)
      TK = THK(ITYPE)
      TDIFF = DIFF(ITYPE)
      DELX = DEP(I)/10.
      IF ($W(I).OR.$C(I)) GO TO 8500
      IF ($B(I)) CALL BARR(IDIM1,IDIM2,I,NFCI,NWRITE,TK,EPS,
     1                    DEP(I),FZ,QDOT2P,QEXTO,TEMP)
```

```
      IF ($END) GO TO 9000
      GO TO 8900
 8500 IF ($C(I)) CALL CEILNG(EPS,REFL(ITYPE),QDOT2P(ICEIL,1),
     1            QEXT0(ICEIL,1),TEMP(ICEIL,1,1),FZ(ICEIL,1),NWRITE)
      IF ($END) GO TO 9000
      DO 8700 J=1,NFCI
      HL = HCEIL
      CALL DIFFUS(IDIM1,IDIM2,I,J,NWRITE,DELX,EPS,FZ(I,J),HL,
     1            QEXT(I,J),QEXT0(I,J),TDIFF,TK,TEMP)
      IF ($W(I)) QDOT2P(I,J) = 5.6697E-8*EPS*TEMP(I,J,1)**4  +
     1                         REFL(ITYPE)*QEXT0(I,J)
      IF ($END) GO TO 9000
 8700 CONTINUE
 8900 CONTINUE
 9000 RETURN
 9500 WRITE (NWRITE,9600)
 9600 FORMAT (1H0,'END OF JOB: NO FLAMES OVER FUEL BED')
      $END = .TRUE.
      RETURN
      END
```

```
C***********************************************************************
C                                                                      *
C   SUBROUTINE TRANSF (COMPUTES HEAT FLUX TRANSMITTED TO FUEL          *
C                      ELEMENTS, WALLS, BARRIERS, AND CEILING)         *
C                                                                      *
C***********************************************************************
      SUBROUTINE TRANSF(FLHT,FLTEMP,FX,FY,FZ,QDOTC,QDOT2P,QEXT,TEMP,
     1 AREA,DELS,RAD,WID,FABSRP,GAMMA,ICOUNT,IORT,ITYP,NFC,ICOMM,
     2 $BURN,$PIGN,$B,$C,$D,$W,IDIM1,IDIM2,IDIM3,NFUEL,NSM,NWRITE)
      IMPLICIT LOGICAL ($)
      DIMENSION FLHT(IDIM1,IDIM2), FLTEMP(IDIM1,IDIM2), FX(IDIM1,IDIM2),
     1          FY(IDIM1,IDIM2), FZ(IDIM1,IDIM2), QDOTC(IDIM1,IDIM2),
     2          QDOT2P(IDIM1,IDIM2), QEXT(IDIM1,IDIM2),
     3          TEMP(IDIM1,IDIM2,10), ICOUNT(IDIM1,IDIM2),
     4          $BURN(IDIM1,IDIM2), $PIGN(IDIM1,IDIM2)
      DIMENSION AREA(NSM), DELS(NSM), RAD(NSM), WID(NSM),
     1          IORT(NSM), ITYP(NSM), NFC(NSM),
     2          $B(NSM), $C(NSM), $D(NSM), $W(NSM)
      DIMENSION FABSRP(NFUEL), GAMMA(NFUEL)
      DIMENSION  ICOMM(IDIM3,IDIM3)
      COMMON /ALL/ ACEIL, AWALL, DELT, FCTR(15), FLCF, RTEMP, TIME,
     1             TITLE(20),
     2             ICEIL, IJOB, INCHCK, INITG, IOUTPT, MOUTPT(11),
     3             $DOOR, $END, $ROOM
      COMMON /GAS/ A4, CDOOR, CF, CFV, DCF, DEN, DG, DHGT, DWID,
     1             FC, FH, GABSRP, HCEIL, PLCF1, PLCF2,
     2             TG, TG0, THETA, VFV, WFL, WFVC, WFVH, ZD, ZN
      COMMON /VENTC/ AFUEL, AFUEL0, CVA, CVA0, FHTA, FRADA, FUELA, QMAX,
     1               QTOT, QTOT0, QTOT1, QTOT2, TMDOT, TMDOT0,
     2               TMDOTS, TQDOT, TQDOTC, WIN, Z0A,
     3               NBURN, NBURN0,
     4               $DECAY, $FLUX1, $FLUX2, $VENT, $VCONT
      IJ = 0
C
C   HEAT FLUX SOURCE LOOP
C
      DO 5900 I=1,NSM
      NFCI = NFC(I)
      IF (.NOT.$D(I)) GO TO 1000
      IJ = IJ + NFCI
      GO TO 5900
 1000 FRAD = RAD(I)
      ITYPE = ITYP(I)
      $WALBR = ($W(I).OR.$B(I).OR.$C(I))
      $ORNT = (IORT(I).NE.3)
      DO 5800 J=1,NFCI
      IJ = IJ + 1
      IF ($WALBR) GO TO 2000
      IF (.NOT.$BURN(I,J)) GO TO 5800
C
C   FLAME LOCATION
C
      FLX = FX(I,J)
      FLY = FY(I,J)
```

```
      FLZ1 = FZ(I,J)
      IF ($ORNT) FLZ1 = FLZ1 - DELS(I)/2.
      FLZ2 = FLZ1 + FLHT(I,J)
      HTFLUX = GAMMA(ITYPE)*QDOT2P(I,J)
 2000 KL = 0
C
C   HEAT FLUX RECEIVER LOOP
C
      DO 5500 K=1,NSM
      NFCK = NFC(K)
      $IK = (I.EQ.K)
 3000 IF ($WALBR) GO TO 3500
      $ORNT2 = (IORT(K).NE.3)
      $ORNT3 = ($ORNT.AND.$ORNT2)
 3500 DO 5000 L=1,NFCK
      KL = KL + 1
      IF (ICOMM(IJ,KL).EQ.0) GO TO 5000
      IF ($WALBR) GO TO 4700
      IF (ICOMM(IJ,KL).EQ.2) GO TO 5000
C
C   RECEIVER LOCATION (FLAME LOOP)
C
      FZKL = FZ(K,L)
      FR = SQRT((FX(K,L) - FLX)**2 + (FY(K,L) - FLY)**2)
      DELZ1 = ABS(FZKL - FLZ1)
      DELZ2 = ABS(FZKL - FLZ2)
      IF (FR.LE.RAD(I)) GO TO 4300
C
C
C   RADIATIVE HEAT FLUXES (WHEN FR.GT.FRAD)
C
C
      IF ($ORNT2) GO TO 4000
      Q1 = CYLPAR(DELZ1,FR,FRAD)
      Q2 = CYLPAR(DELZ2,FR,FRAD)
      GO TO 4100
 4000 Q1 = CYLPER(DELZ1,FR,FRAD)
      Q2 = CYLPER(DELZ2,FR,FRAD)
 4100 IF (FZKL.GT.FLZ2) Q2 = -Q2
      IF (FZKL.LT.FLZ1) Q1 = -Q1
      DELTQ = ((DELZ1*Q1 + DELZ2*Q2)/FLHT(I,J))*HTFLUX*FCTR(5)
      GO TO 4800
C
C
C   CONVECTIVE AND RADIATIVE HEAT FLUXES (WHEN FR.LE.FRAD)
C
C
 4300 IF ((QDOTC(I,J).LT.100.).OR.(FZKL.LT.FLZ1).OR.
     1             ((I.EQ.K).AND.$BURN(K,L))) GO TO 5000
      IF (FZKL.GE.FLZ2) GO TO 4400
      $PIGN(K,L) = .TRUE.
      DELTQ = GAMMA(ITYPE)*QDOT2P(I,J)
      IF (.NOT.($BURN(K,L).OR.$ORNT2)) DELTQ = QDOT2P(I,J)
      GO TO 4800
```

```
C
C   PLUME TEMPERATURE USING ALPERT'S CORRELATION
C
 4400 PLTEMP = .169*(QDOTC(I,J)**.6667)/(DELZ1**1.6667) + RTEMP
      PLTEMP = AMIN1(PLTEMP,FLTEMP(I,J))*FCTR(6)
      IF (.NOT.$ORNT2) GO TO 4500
C
C   FOR VERTICAL OBJECTS, HEAT TRANSFER COEFFICIENT = FLAME COEFFICIENT
C
      PLCOEF = FLCF*FCTR(7)
      GO TO 4600
C
C   HEAT TRANSFER COEFFICIENT FOR HORIZONTAL OBJECTS
C
 4500 RKL = SQRT(DELS(K)*WID(K)/3.14159)/DELZ1
      PLCOEF = .64
      IF (RKL.LT.0.18) PLCOEF = 2.06
      PLCOEF = (PLCOEF*(QDOTC(I,J)/DELZ1)**.3333)*FCTR(8)
C
C   CONVECTIVE HEAT FLUX
C
 4600 DELTQ = PLCOEF*(PLTEMP - TEMP(I,J,1))*FCTR(9)
      GO TO 4800
C
C   WALL, BARRIER, AND CEILING SOURCES
C
 4700 DELTQ = ICOMM(IJ,KL)*QDOT2P(I,J)/1000.
      IF ((FZ(K,L).GT.ZD).AND.$ROOM)
     1          DELTQ = DELTQ + HCEIL*(TG - TEMP(K,L,1))
 4800 QEXT(K,L) = QEXT(K,L) + DELTQ
      $FLUX1 = .TRUE.
 5000 CONTINUE
 5500 CONTINUE
C
C   HEAT TRANSFER TO SELF FOR VERTICAL FUEL CELLS
C   (USING A BEST-FIT FOR THE SHAPE FACTOR FROM FLAME TO FUEL)
C
      IF ((.NOT.$ORNT).OR.$VCONT.OR.$WALBR) GO TO 5800
      XCOUNT = ICOUNT(I,J)
      VSHAPE = -.197 + .24*WID(I) + .02*FLHT(I,J) + .0538*DELS(I)
     1         * (XCOUNT - .5) + .0256*DELS(I)*(XCOUNT-.5)/FLHT(I,J)
     2         + .0724*FABSRP(I)
      VSHAPE = AMIN1(1.,AMAX1(0.,VSHAPE))
      DELTQ = GAMMA(ITYPE)*QDOT2P(I,J)*VSHAPE*FCTR(10)
      QEXT(I,J) = QEXT(I,J) + DELTQ
 5800 CONTINUE
 5900 CONTINUE
      IF (.NOT.$ROOM) GO TO 6000
C
C   DETERMINE IF VENTILATION CONTROLLED (USING SIMPSON'S RULE
C   EXTRAPOLATION FOR HEAT SUPPORT BY AIR INITIALLY IN ROOM
C
      DQTOT = DELT*(-QTOT0 + 8.*QTOT1 + 5.*TQDOT)/12.
      QTOT = QTOT + DQTOT
```

```
      QTOT0 = QTOT1
      QTOT1 = QTOT2
      QTOT2 = TQDOT
      $FLUX = ($FLUX1.AND.$FLUX2)
      IF ((.NOT.$VENT).OR.($VENT.AND.$DECAY.AND.$FLUX)) TMDTS0 = TMDOTS
      TMDOTV = CVA0*WIN/AFUEL0
      $VENT = ((TMDOTV.LT.TMDTS0).AND.(QTOT.GE.QMAX))
      $DECAY = ($DECAY.OR.(NBURN.LT.NBURN0))
      $VCONT = ($VENT.AND..NOT.$DECAY)
C
C   HEAT TRANSFER TO ADJACENT (NON-BURNING) FUEL CELLS FROM
C   CONTINUOUS PROPAGATION OF FLAMES
C
 6000 IJ = 0
      DO 6900 I=1,NSM
      NFCI = NFC(I)
      IF (.NOT.($D(I).OR.$W(I).OR.$B(I).OR.$C(I))) GO TO 6050
      IJ = IJ + NFCI
      GO TO 6900
 6050 ITYPE = ITYP(I)
      $ORNT = (IORT(I).NE.3)
      DO 6600 J=1,NFCI
      IJ = IJ + 1
      IF (.NOT.$BURN(I,J)) GO TO 6600
      FLZ = FZ(I,J)
C
C   CONDUCTIVE HEAT TERM
C
      QCOND = (.01157+5.6697D-5*FLTEMP(I,J))*(FLTEMP(I,J)-TEMP(I,J,1))*
     1        WID(I)
      KL = 0
      DO 6400 K=1,NSM
      AREAK = WID(K)*DELS(K)
      NFCK = NFC(K)
      $ORNT2 = ($ORNT.AND.(IORT(K).NE.3))
      DO 6300 L=1,NFCK
      KL = KL + 1
      IF ((ICOMM(IJ,KL).NE.2).OR.$BURN(K,L)) GO TO 6300
      IF ($ORNT2) GO TO 6100
      QRAD = GAMMA(ITYPE)*QDOT2P(I,J)*AREA(I)
      DELTQ = (QRAD + QCOND)/AREAK
      GO TO 6200
 6100 DELTQ = QCOND/AREAK
      IF ((I.EQ.K).AND.(L.GT.J)) DELTQ = QDOT2P(I,J)
 6200 QEXT(K,L) = QEXT(K,L) + DELTQ*FCTR(11)
      $PIGN(K,L) = .TRUE.
 6300 CONTINUE
 6400 CONTINUE
 6600 CONTINUE
 6900 CONTINUE
      RETURN
      END
```

```
C***********************************************************************
C                                                                      *
C   SUBROUTINE IGNIT (DETERMINES IF EXPOSED FUEL ELEMENTS IGNITE)      *
C                                                                      *
C***********************************************************************
      SUBROUTINE IGNIT(QEXT,SUMQSQ,TEMP,DIFF,FIGTP,FIGTS,THK,ITYP,NFC,
     1 $BURN,$FMASS,$PIGN,$B,$C,$D,$W,IDIM1,IDIM2,NFUEL,NSM)
      IMPLICIT LOGICAL ($)
      DIMENSION QEXT(IDIM1,IDIM2), SUMQSQ(IDIM1,IDIM2),
     1  TEMP(IDIM1,IDIM2,10), $BURN(IDIM1,IDIM2), $FMASS(IDIM1,IDIM2),
     2  $PIGN(IDIM1,IDIM2)
      DIMENSION DIFF(NFUEL), FIGTP(NFUEL), FIGTS(NFUEL), THK(NFUEL),
     1          ITYP(NSM), NFC(NSM), $B(NSM), $C(NSM), $D(NSM), $W(NSM)
      COMMON /ALL/ ACEIL, AWALL, DELT, FCTR(15), FLCF, RTEMP, TIME,
     1             TITLE(20),
     2             ICEIL, IJOB, INCHCK, INITG, IOUTPT, MOUTPT(11),
     3             $DOOR, $END, $ROOM
      DO 8000 I=1,NSM
      IF ($D(I).OR.$W(I).OR.$B(I).OR.$C(I)) GO TO 8000
      ITYPE = ITYP(I)
      NFCI = NFC(I)
      DO 7000 J=1,NFCI
      IF ($BURN(I,J).OR.$FMASS(I,J)) GO TO 7000
      TIG = FIGTS(ITYPE)
      IF ($PIGN(I,J)) TIG = FIGTP(ITYPE)
      SUMQSQ(I,J) = SUMQSQ(I,J) + QEXT(I,J)**2*DELT
      IF (SUMQSQ(I,J).NE.0.) GO TO 6000
      TCRIT = 1.E30
      GO TO 6100
 6000 IF (TIME.NE.0.) AVGHT = SUMQSQ(I,J)/TIME
      IF (TIME.EQ.0.) AVGHT = QEXT(I,J)**2
      TIMIG = .7854*(THK(ITYPE)*(TIG - TEMP(I,J,1)))**2/
     1        (DIFF(ITYPE)*AVGHT)
      TCRIT = TIMIG*FCTR(14)
      IF ($PIGN(I,J)) TCRIT = TIMIG*FCTR(15)
 6100 IF ((TIME.LT.TCRIT).OR.(TIME.EQ.0.)) GO TO 7000
      $BURN(I,J) = .TRUE.
      $PIGN(I,J) = .TRUE.
 7000 CONTINUE
 8000 CONTINUE
      RETURN
      END
```

```
C***********************************************************************
C                                                                      *
C   SUBROUTINE OUTPUT (PRINTS PROGRAM OUTPUT)                          *
C                                                                      *
C***********************************************************************
      SUBROUTINE OUTPUT(FLHT,FLTEMP,FMASS,QDOT2P,QEXT,TEMP,$BURN,NFC,
     1 MSMOUT,IDIM1,IDIM2,NSM,NSMOUT,NWRITE)
      IMPLICIT LOGICAL ($)
      DIMENSION FLHT(IDIM1,IDIM2), FLTEMP(IDIM1,IDIM2),
     1          FMASS(IDIM1,IDIM2), QDOT2P(IDIM1,IDIM2),
     2          QEXT(IDIM1,IDIM2), TEMP(IDIM1,IDIM2,10),
     3          $BURN(IDIM1,IDIM2), MSMOUT(NSMOUT), NFC(NSM)
      COMMON /ALL/ ACEIL, AWALL, DELT, FCTR(15), FLCF, RTEMP, TIME,
     1             TITLE(20),
     2             ICEIL, IJOB, INCHCK, INITG, IOUTPT, MOUTPT(11),
     3             $DOOR, $END, $ROOM
      COMMON /GAS/ A4, CDOOR, CF, CFV, DCF, DEN, DG, DHGT, DWID,
     1             FC, FH, GABSRP, HCEIL, PLCF1, PLCF2,
     2             TG, TGO, THETA, VFV, WFL, WFVC, WFVH, ZD, ZN
      COMMON /VENTC/ AFUEL, AFUELO, CVA, CVAO, FHTA, FRADA, FUELA, QMAX,
     1               QTOT, QTOTO, QTOT1, QTOT2, TMDOT, TMDOTO,
     2               TMDOTS, TQDOT, TQDOTC, WIN, ZOA,
     3               NBURN, NBURNO,
     4               $DECAY, $FLUX1, $FLUX2, $VENT, $VCONT
      WRITE (NWRITE,9000) TITLE, TIME
      $OUT = (NSMOUT.EQ.0)
      IF (IOUTPT.NE.0) GO TO 2000
      WRITE (NWRITE,9100) TMDOT
      IF ($OUT) RETURN
      DO 1000 I=1,NSMOUT
      K = MSMOUT(I)
      NFCK = NFC(K)
      WRITE (NWRITE,9500) K, ($BURN(K,J),J=1,NFCK)
 1000 CONTINUE
      RETURN
 2000 DO 5000 II=1,IOUTPT
      INDEX = MOUTPT(II)
      GO TO (2100,2300,2500,2700,2900,2900,2900,2900,2900,2900,2900),
     1   INDEX
 2100 WRITE (NWRITE,9100) TMDOT
      GO TO 5000
 2300 WRITE (NWRITE,9200) TQDOT
      GO TO 5000
 2500 WRITE (NWRITE,9300) TG
      GO TO 5000
 2700 WRITE (NWRITE,9400) DG
      GO TO 5000
 2900 IF ($OUT) GO TO 5000
      WRITE (NWRITE,9450)
      DO 4000 I=1,NSMOUT
      K = MSMOUT(I)
      NFCK = NFC(K)
      GO TO (4000,4000,4000,4000,3000,3100,3200,3300,3400,3500,3600),
     1     INDEX
```

```
3000 WRITE (NWRITE,9500) K, ($BURN(K,J),J=1,NFCK)
     GO TO 4000
3100 WRITE (NWRITE,9600) K, (QDOT2P(K,J),J=1,NFCK)
     GO TO 4000
3200 WRITE (NWRITE,9700) K, (QEXT(K,J),J=1,NFCK)
     GO TO 4000
3300 WRITE (NWRITE,9800) K, (FMASS(K,J),J=1,NFCK)
     GO TO 4000
3400 WRITE (NWRITE,9900) K, (FLHT(K,J),J=1,NFCK)
     GO TO 4000
3500 WRITE (NWRITE,9930) K, (FLTEMP(K,J),J=1,NFCK)
     GO TO 4000
3600 WRITE (NWRITE,9950) K, (TEMP(K,J,1),J=1,NFCK)
4000 CONTINUE
5000 CONTINUE
9000 FORMAT (1H1,20A4,/,' TIME (SEC):',F6.0,//)
9100 FORMAT (1H ,'TOTAL MASS BURNING RATE (KG/S):',G12.4)
9200 FORMAT (1H ,'TOTAL HEAT RELEASE RATE (W)   :',G12.4)
9300 FORMAT (1H ,'HOT GAS LAYER TEMPERATURE (K) :',G12.4)
9400 FORMAT (1H ,'HOT GAS LAYER THICKNESS (M)   :',G12.4)
9450 FORMAT (1H0)
9500 FORMAT (1H ,'MODULE:',I4,3X,'BURNING ?',10G11.3)
9600 FORMAT (1H ,'MODULE:',I4,3X,'SRCE FLUX',10G11.3)
9700 FORMAT (1H ,'MODULE:',I4,3X,'EXT FLUX ',10G11.3)
9800 FORMAT (1H ,'MODULE:',I4,3X,'FUEL MASS',10G11.3)
9900 FORMAT (1H ,'MODULE:',I4,3X,'FLAME HGT',10G11.3)
9930 FORMAT (1H ,'MODULE:',I4,3X,'FLAME TMP',10G11.3)
9950 FORMAT (1H ,'MODULE:',I4,3X,'FUEL TEMP',10G11.3)
     RETURN
     END
```

```
C------------------------------------------------------------------------
C                                                                       -
C   SUBROUTINE ADJCTP FILLS IN BLOCKS OF THE ADJACENCY MATRIX.          -
C   IF NADJ(IND,2) EQUALS '999', MODULE NADJ(IND,1) DOES NOT            -
C   COMMUNICATE WITH MODULE NADJ(3).  IF NADJ(2) EQUALS '888',          -
C   MODULE NADJ(IND,1) DOES NOT COMMUNICATE WITH MODULES NADJ(IND,3)    -
C   THRU NADJ(IND,4)                                                    -
C                                                                       -
C------------------------------------------------------------------------
      SUBROUTINE ADJCTP(IJ,KL,NFCL,NSTOP,IDIM3,ICOMM)
      IMPLICIT LOGICAL ($)
      DIMENSION ICOMM(IDIM3,IDIM3)
      IIJ = IJ
      DO 2000 LI=1,NFCL
      KKL = KL
      DO 1000 LL=1,NSTOP
      KKL = KKL + 1
      ICOMM(IIJ,KKL) = 0
 1000 CONTINUE
      IIJ = IIJ + 1
 2000 CONTINUE
      RETURN
      END
```

```
C-----------------------------------------------------------------------
C                                                                      -
C   SUBROUTINE BARR COMPUTES THE HEAT FLUX FROM A THERMAL BARRIER,     -
C   ASSUMING THAT THE THERMAL WAVE PENETRATES THE BARRIER INSTANTLY    -
C                                                                      -
C-----------------------------------------------------------------------
      SUBROUTINE BARR(IDIM1,IDIM2,I,NFCL,NWRITE,TK,EPS,FDEP,
     1                FZ,QDOT2P,QEXTO,TEMP)
      IMPLICIT LOGICAL ($)
      DIMENSION FZ(IDIM1,IDIM2), QDOT2P(IDIM1,IDIM2),
     1          QEXTO(IDIM1,IDIM2), TEMP(IDIM1,IDIM2,10)
      COMMON /ALL/ ACEIL, AWALL, DELT, FCTR(15), FLCF, RTEMP, TIME,
     1             TITLE(20),
     2             ICEIL, IJOB, INCHCK, INITG, IOUTPT, MOUTPT(11),
     3             $DOOR, $END, $ROOM
      COMMON /GAS/ A4, CDOOR, CF, CFV, DCF, DEN, DG, DHGT, DWID,
     1             FC, FH, GABSRP, HCEIL, PLCF1, PLCF2,
     2             TG, TGO, THETA, VFV, WFL, WFVC, WFVH, ZD, ZN
      DO 1000 J=1,NFCL
      J1 = J
      TE = RTEMP
      IF ($ROOM.AND.(FZ(I,J).GT.ZD)) TE = TG
      BOLD = TEMP(I,J,1)
      AOLD = (TEMP(I,J,10) - BOLD)/FDEP
      JCOUNT = 0
  500 TB1 = BOLD
      TB2 = AOLD*FDEP + BOLD
      F = -TK*AOLD - HCEIL*(TE - TB1) - 5.6697E-8*EPS*(TE**4 - TB1**4)
     1     - EPS*QEXTO(I,J)
      G = -TK*AOLD - HCEIL*(TB2 - TE) - 5.6697E-8*EPS*(TB2**4 - TE**4)
      FA = -TK
      FB = HCEIL + 2.268E-7*EPS*TB1**3
      GA = -(TK + HCEIL*FDEP + 2.268E-7*EPS*FDEP*TB2**3)
      GB = -(HCEIL + 2.268E-7*EPS*TB2**3)
      D = FA*GB - GA*FB
      ANEW = AOLD - (F*GB - G*FB)/D
      BNEW = BOLD - (G*FA - F*GA)/D
      TB1P = BNEW
      TB2P = ANEW*FDEP + BNEW
      ERR1 = ABS(TB1P - TB1)
      ERR2 = ABS(TB2P - TB2)
      IF ((ERR1.LE.1.).AND.(ERR2.LE.1.)) GO TO 700
      IF (JCOUNT.GT.30) GO TO 8000
      AOLD = ANEW
      BOLD = BNEW
      JCOUNT = JCOUNT + 1
      GO TO 500
  700 TEMP(I,J,1) = TB1P
      TEMP(I,J,10) = TB2P
      QDOT2P(I,J) = 5.6697E-8*EPS*(TB2P**4 - TE**4)
 1000 CONTINUE
      GO TO 9000
 8000 WRITE (NWRITE,8100) I, J1, JCOUNT, TB1P, ERR1, TB2P, ERR2
 8100 FORMAT (1H0,'ITERATION MAX EXCEEDED IN SUBROUTINE BARR:',/,
```

```
     1 ' MODULE:',I4,3X,'FUEL CELL:',I4,/,' NO. OF ITERATIONS:',I4,
     2 /,' HOT WALL TEMPERATURE :',G12.4,5X,'ERROR:',G12.4,/,
     3 ' COLD WALL TEMPERATURE:',G12.4,5X,'ERROR:',G12.4)
      $END = .TRUE.
 9000 RETURN
      END
```

```
C-----------------------------------------------------------------------
C                                                                      -
C   SUBROUTINE CEILNG CALCULATES THE CEILING HOT GAS LAYER BEHAVIOR    -
C   USING AN IMPLICIT DIFFERENCE SCHEME TO SOLVE THE HEAT CONDUCTION   -
C   PROBLEM FOR THE CEILING, AND A STEPWISE ITERATION SCHEME FOR TG    -
C                                                                      -
C-----------------------------------------------------------------------
      SUBROUTINE CEILNG(EPS,WREFL,QCEIL,QEXTC,TCEIL,ZCEIL,NWRITE)
      IMPLICIT LOGICAL ($)
      DIMENSION Z(2,2)
      COMMON /ALL/ ACEIL, AWALL, DELT, FCTR(15), FLCF, RTEMP, TIME,
     1             TITLE(20),
     2             ICEIL, IJOB, INCHCK, INITG, IOUTPT, MOUTPT(11),
     3             $DOOR, $END, $ROOM
      COMMON /GAS/ A4, CDOOR, CF, CFV, DCF, DEN, DG, DHGT, DWID,
     1             FC, FH, GABSRP, HCEIL, PLCF1, PLCF2,
     2             TG, TGO, THETA, VFV, WFL, WFVC, WFVH, ZD, ZN
      COMMON /VENTC/ AFUEL, AFUELO, CVA, CVAO, FHTA, FRADA, FUELA, QMAX,
     1               QTOT, QTOTO, QTOT1, QTOT2, TMDOT, TMDOTO,
     2               TMDOTS, TQDOT, TQDOTC, WIN, ZOA,
     3               NBURN, NBURNO,
     4               $DECAY, $FLUX1, $FLUX2, $VENT, $VCONT
C
C   CHARACTERIZE HOT GAS LAYER
C
      WFL = TMDOT*(PLCF1*FHTA/FRADA + 1.)**2.5
      FSIG = EPS*5.6697E-8
      IF (VFV.LE.1.E-3) GO TO 1000
      DF = FH - FC
      DFMX = (TQDOTC + ACEIL*(HCEIL*(TCEIL - RTEMP) + FSIG*(TCEIL**4 -
     1       RTEMP**4)))/CF
      A3 = HCEIL/FSIG
      A4 = -(HCEIL*TCEIL/FSIG + TCEIL**4 + (TQDOTC - CF*DF)/(FSIG*
     1      ACEIL))
      $DFLO = (DF.LE.0.)
      $DFHI = (DF.GE.DFMX)
      $DFLH = ($DFLO.OR.$DFHI)
      IF ($DOOR.AND.$DFLH) GO TO 7000
      IF ($DFLH) GO TO 1000
C
C   SOLUTION WHEN ZN > DHGT
C
      TG = RADEQ (A3,A4)
      DFR = FH/TG - FC/RTEMP
      IF (DFR.LT.0.) GO TO 1000
      WFVH = CFV/TG
      WPL = CFV*DFR
      ZD = (FRADA/PLCF1)*((WPL/TMDOT)**.4 - 1.) + Z0A
      IF (ZD.GT.FHTA) ZD = (FRADA/PLCF2)*((WPL/WFL)**.6 - 1.)
     1                      + FHTA
      IF (ZD.LT.DHGT) GO TO 500
      ZN = DHGT
      GO TO 7999
  500 WDC = WPL - DF*WFVC
```

```
      IF (WDC.LE.0.) GO TO 1000
      ZD2 = 0.5*ZD/DHGT
      Q = -ZD2**2
      R = ZD2**3 + 0.5*(WDC/(C*SQRT(1. - RTEMP/TG)))
      D = R**2 + Q**3
      ZN = DHGT*((R + SQRT(D))**(1./3.) + (R - SQRT(D))**(1./3.))
      IF (ZN.GT.DHGT) GO TO 7999
C
C   SOLUTION WHEN ZN < DHGT
C
 1000 A4 = -(HCEIL*TCEIL/FSIG + TCEIL**4 + (TQDOTC + CF*FC)/(FSIG*
     1          ACEIL))
      WPLMX = (TQDOTC + ACEIL*(HCEIL*(TCEIL - RTEMP) + FSIG*(TCEIL**4
     1          - RTEMP**4)))/(1000.*RTEMP)
      IF (WFL.GE.WPLMX) ZDMX = (FRADA/PLCF1)*((WPLMX/TMDOT)**.4 - 1.)
     1                          + Z0A
      IF (WFL.LT.WPLMX) ZDMX = (FRADA/PLCF2)*((WPLMX/WFL)**.6 - 1.)
     1                          + FHTA
      IF (ZD.GE.ZDMX) ZD = 0.8*ZDMX
      ZD0 = 0.
      ZD01 = ZD0
      ZD02 = ZD0
      ZD03 = ZD0
      ZD1 = 0.
      CALL ZDNEW (ZD1,ZDP1,FSIG,1)
      TGP = TG
      IF (ZDP1.LE.0.) GO TO 7800
      ZD2 = AMIN1(DHGT,.995*ZDMX)
      CALL ZDNEW (ZD2,ZDP2,FSIG,1)
      ASLOPE = (ZDP2 - ZDP1)/(ZD2 - ZD1)
      IF ((ASLOPE.GE.0.).AND.(ZDP1.GT.ZD1).AND.(ZDP2.GT.ZD2)) GO TO 7800
      IF ((ASLOPE.LE.0.).AND.(ZDP2.GT.ZD2)) GO TO 7900
      DO 1500 J=1,2
      CALL ZDNEW (ZD,ZDP,FSIG,0)
      Z(J,1) = ZD
      Z(J,2) = ZDP
      IF (ABS(ZDP-ZD).LE.0.001) GO TO 7999
      IF (ZDP.GE.ZD) ZD = ZD + THETA*(AMIN1(ZDP,ZDMX) - ZD)
      IF (ZDP.LT.ZD) ZD = ZD + THETA*(AMAX1(ZDP,0.) - ZD)
 1500 CONTINUE
      DO 6000 ITR=1,20
      Z12 = Z(1,2)
      Z22 = Z(2,2)
      IF (Z12.GT.Z22) GO TO 1750
      Z11 = Z(1,1)
      Z21 = Z(2,1)
      Z(1,1) = Z21
      Z(1,2) = Z22
      Z(2,1) = Z11
      Z(2,2) = Z12
 1750 SLOPE = (Z(2,2) - Z(1,2))/(Z(2,1) - Z(1,1))
      ZD = (Z(1,2) - SLOPE*Z(1,1))/(1. - SLOPE)
      IF (ZD.GE.ZDMX) ZD = Z(2,1) + THETA*(ZDMX - Z(2,1))
      IF (ZD.LE.0.) ZD = (1. - THETA)*Z(1,1)
```

```
      IF ((SLOPE.GE.0.).AND.(ASLOPE.LE.0.).AND.(ZDP2.LE.ZD2).AND.
     1    (ABS(ZD-Z(2,1)).LE.1.E-3)) ZD = ZD + THETA*(ZDMX-ZD)
      CALL ZDNEW (ZD,ZDP,FSIG,0)
      DZ = ZDP - ZD
      IF (ABS(DZ).LE.0.001) GO TO 7999
      IF (Z(2,2).LT.ZD) GO TO 2000
      Z21 = Z(2,1)
      Z22 = Z(2,2)
      Z(2,1) = ZD
      Z(2,2) = ZDP
      Z(1,1) = Z21
      Z(1,2) = Z22
      GO TO 5000
 2000 IF (Z(2,1).GT.ZD) GO TO 2100
      Z11 = Z(1,1)
      Z12 = Z(1,2)
      Z(1,1) = ZD
      Z(1,2) = ZDP
      Z(2,1) = Z11
      Z(2,2) = Z12
      GO TO 5000
 2100 IF (DZ.LT.0.) GO TO 2200
      Z(1,1) = ZD
      Z(1,2) = ZDP
      GO TO 5000
 2200 Z(2,1) = ZD
      Z(2,2) = ZDP
 5000 ZD01 = ZD02
      ZD02 = ZD03
      ZD03 = ZD
      IF (ITR.LE.3) GO TO 6000
      ZD0A = (ZD01 + ZD02 + ZD03)/3.
      ERRMSQ = ((ZD01-ZD0A)**2 + (ZD02-ZD0A)**2 + (ZD03-ZD0A)**2)/3.
      ERRMSQ = SQRT(ERRMSQ)
      IF (ERRMSQ.LE.1.E-4) GO TO 7999
      IF (ITR.EQ.20) GO TO 8000
 6000 CONTINUE
      GO TO 7999
 7000 IF ($DFHI) GO TO 7500
      TG = RADEQ (A3,A4)
      ZD = 0.
      ZN = 0.
      GO TO 7999
 7500 TG = RTEMP
      ZD = 0.
      ZN = 0.
      GO TO 7999
 7800 TG = TGP
      ZD = 0.
      ZN = 0.
      GO TO 7999
 7900 ZD = DHGT
      ZN = DHGT
 7999 WDC = CDOOR*SQRT(RTEMP/TG)*SQRT(1. - RTEMP/TG)*(1. - ZN/DHGT)**1.5
```

```
      WIN = WDC + WFVC
      DG = ZCEIL - ZD
C
C   DETERMINE HEAT FLUX FROM GAS LAYER
C
      EX1 = EXP(-1.5*GABSRP*DG)
      QCEIL = 5.6697E-8*(EPS*EX1*TCEIL**4
     1 (1. - EX1)*(1. + WREFL*EX1)*TG**4) + WREFL*QEXTC*EX1**2
      GO TO 9000
8000  WRITE (NWRITE,8100) ZN, ZD, TG
8100  FORMAT (1H0,'INNER ITERATION MAX EXCEEDED IN SUBROUTINE CEILNG:',
     1          /,' NEUTRAL PLANE HEIGHT:',G12.4,/,
     2            ' PLANE HEIGHT AT DOOR:',G12.4,/,
     2            ' GAS TEMPERATURE     :',G12.4)
      $END = .TRUE.
9000  RETURN
      END
```

```
C-----------------------------------------------------------------------
C                                                                      -
C   SUBROUTINE COMM CONSTRUCTS THE ADJACENCY (COMMUNICATION) MATRIX    -
C   FOR THE INDIVIDUAL FUEL CELLS - 0 = NO COMMUNICATION,              -
C   1 = COMMUNICATION, 2 = ADJACENCY                                   -
C                                                                      -
C-----------------------------------------------------------------------
      SUBROUTINE COMM(NCOM,NNCOM,NSM,IDIM1,IDIM3,IDIM4,IDIM5,NFC,IAD,
     1                NAD,ICOMM)
      IMPLICIT LOGICAL ($)
      DIMENSION IAD(IDIM4,4), NAD(IDIM5,4), ICOMM(IDIM3,IDIM3),
     1          NFC(IDIM1)
      IF (NCOM.EQ.0) GO TO 1000
      DO 900 IND=1,NCOM
      IJ = 0
      DO 800 I=1,NSM
      NFCI = NFC(I)
      IF (IAD(IND,1).EQ.I) GO TO 100
      IJ = IJ + NFCI
      GO TO 800
  100 DO 700 J=1,NFCI
      IJ = IJ + 1
      $IADJ = (IAD(IND,2).EQ.999)
      $ID = ($IADJ.OR.(IAD(IND,2).EQ.J))
      IF (.NOT.$ID) GO TO 700
      KL = 0
      DO 600 K=1,NSM
      NFCK = NFC(K)
      IF (IAD(IND,3).EQ.K) GO TO 200
      KL = KL + NFCK
      GO TO 600
  200 IF ($IADJ) GO TO 400
      DO 300 L=1,NFCK
      KL = KL + 1
      IF (IAD(IND,4).NE.L) GO TO 300
      ICOMM(IJ,KL) = 2
      ICOMM(KL,IJ) = 2
      GO TO 900
  300 CONTINUE
  400 DO 500 L=1,NFCK
      KL = KL + 1
      ICOMM(IJ,KL) = 2
      ICOMM(KL,IJ) = 2
      IJ = IJ + 1
  500 CONTINUE
      GO TO 900
  600 CONTINUE
  700 CONTINUE
  800 CONTINUE
  900 CONTINUE
 1000 IF (NNCOM.EQ.0) GO TO 2000
      DO 1900 IND=1,NNCOM
      IJ = 0
      DO 1800 I=1,NSM
```

```
      NFCI = NFC(I)
      IF (NAD(IND,1).EQ.I) GO TO 1100
      IJ = IJ + NFCI
      GO TO 1800
 1100 DO 1700 J=1,NFCI
      IJ = IJ + 1
      $NADJP = (NAD(IND,2).EQ.888)
      $NADJ = (NAD(IND,2).EQ.999)
      $ND = ($NADJ.OR.$NADJP.OR.(NAD(IND,2).EQ.J))
      IF (.NOT.$ND) GO TO 1700
      KL = 0
      DO 1600 K=1,NSM
      NFCK = NFC(K)
      IF (NAD(IND,3).EQ.K) GO TO 1200
      KL = KL + NFCK
      GO TO 1600
 1200 IF ($NADJP) GO TO 1330
      IF ($NADJ) GO TO 1380
      IF (NAD(IND,4).EQ.999) GO TO 1400
      DO 1300 L=1,NFCK
      KL = KL + 1
      IF (NAD(IND,4).NE.L) GO TO 1300
      ICOMM(IJ,KL) = 0
      GO TO 1900
 1300 CONTINUE
 1330 NSTOP = 0
      KL1 = NAD(IND,3)
      KL2 = NAD(IND,4)
      DO 1350 KLDUM=KL1,KL2
      NSTOP = NSTOP + NFC(KLDUM)
 1350 CONTINUE
      CALL ADJCTP(IJ,KL,NFCI,NSTOP,IDIM3,ICOMM)
      GO TO 1900
 1380 NSTOP = NFCK
      CALL ADJCTP(IJ,KL,NFCI,NSTOP,IDIM3,ICOMM)
      GO TO 1900
 1400 DO 1500 L=1,NFCK
      KL = KL + 1
      ICOMM(IJ,KL) = 0
 1500 CONTINUE
      GO TO 1900
 1600 CONTINUE
 1700 CONTINUE
 1800 CONTINUE
 1900 CONTINUE
 2000 IJ = 0
      DO 3000 I=1,NSM
      NFCI = NFC(I)
      DO 2500 J=1,NFCI
      IJ = IJ + 1
      ICOMM(IJ,IJ) = 0
      KL = IJ + 1
      IF (J.EQ.NFCI) GO TO 3000
      ICOMM(IJ,KL) = 2
```

```
      ICOMM(KL,IJ) = 2
 2500 CONTINUE
 3000 CONTINUE
      RETURN
      END
```

```
C-----------------------------------------------------------------------
C                                                                      -
C   FUNCTION CYLPAR FINDS THE HEAT FLUX FROM A CYLINDRICAL FLAME TO    -
C   AN INFINITESIMAL SURFACE PARALLEL TO THE GROUND                    -
C                                                                      -
C-----------------------------------------------------------------------
      FUNCTION CYLPAR(Z,FR,FRAD)
      IMPLICIT LOGICAL ($)
      IF (Z.GT.0.0) GO TO 100
      CYLPAR = 0.0
      RETURN
  100 X = Z/FRAD
      Y = FR/FRAD
      YPLS = Y + 1.
      YMIN = Y - 1.
      A = YPLS**2 + X**2
      B = YMIN**2 + X**2
      CYLPAR = ATAN(X/SQRT(Y**2 - 1.))
     1         + X*((A - 2.*Y)*ATAN(SQRT(A*YMIN/(B*YPLS)))/SQRT(A*B)
     2         - ATAN(SQRT(YMIN/YPLS)))
      CYLPAR = CYLPAR/(3.14159*Y)
      RETURN
      END
```

```
C-----------------------------------------------------------------------
C                                                                      -
C   FUNCTION CYLPER FINDS THE HEAT FLUX FROM A CYLINDRICAL FLAME TO    -
C   AN INFINITESIMAL SURFACE PERPENDICULAR TO THE GROUND               -
C                                                                      -
C-----------------------------------------------------------------------
      FUNCTION CYLPER(Z,FR,FRAD)
      IMPLICIT LOGICAL ($)
      PI = 3.14159
      IF (Z.NE.0.0) GO TO 100
      CYLPER = 0.0
      RETURN
  100 X = Z/FRAD
      Y = FR/FRAD
      A = (1.+Y)**2 + X**2
      B = (1.-Y)**2 + X**2
      YMIN = Y - 1.
      YPLS = Y + 1.
      CYLPER = (1./(PI*Y))*ATAN(X/SQRT(Y**2-1.)) + (X/PI)*
     1   ((A-2.*Y)*ATAN(SQRT(A*YMIN/(B*YPLS)))/(Y*SQRT(A*B))
     2   - (1./Y)*ATAN(SQRT(YMIN/YPLS)))
      RETURN
      END
```

```
C-----------------------------------------------------------------------
C                                                                      -
C   SUBROUTINE DIFFUS SOLVES THE TIME-DEPENDENT HEAT CONDUCTION        -
C   EQUATION FOR GEOMETRY USING A CRANK-NICOLSON SCHEME                -
C                                                                      -
C-----------------------------------------------------------------------
      SUBROUTINE DIFFUS(IDIM1,IDIM2,I1,J1,NWRITE,DELX,EPS,FZIJ,HL,
     1                  QXT,QXTO,TDIFF,TK,TEMP)
      IMPLICIT LOGICAL ($)
      DIMENSION BETA(10), GAMMA(10), D(10), V(10), TEMP(IDIM1,IDIM2,10)
      COMMON /ALL/ ACEIL, AWALL, DELT, FCTR(15), FLCF, RTEMP, TIME,
     1             TITLE(20),
     2             ICEIL, IJOB, INCHCK, INITG, IOUTPT, MOUTPT(11),
     3             $DOOR, $END, $ROOM
      COMMON /GAS/ A4, CDOOR, CF, CFV, DCF, DEN, DG, DHGT, DWID,
     1             FC, FH, GABSRP, HCEIL, PLCF1, PLCF2,
     2             TG, TG0, THETA, VFV, WFL, WFVC, WFVH, ZD, ZN
C
C   INITIALIZATIONS
C
      FSIG = EPS*5.6697E-8
      TLAM = .5*TDIFF*DELT/DELX**2
      BJ = 1. + 2.*TLAM
      B1 = -4.*TLAM
      C1 = .5*TLAM
      CB = -3.*DELX
      DO 3500 J=2,10
      D(J) = TEMP(I1,J1,J) + TLAM*(TEMP(I1,J1,J-1) - 2.*TEMP(I1,J1,J)
     1                            + TEMP(I1,J1,J+1))
 3500 CONTINUE
      V1OLD = TEMP(I1,J1,1)
C
C   BEGIN ITERATIONS
C
      DO 8000 ITR=1,20
C   LHS BOUNDARY
      A1 = 1. + 3.5*TLAM - TLAM*CB*(HL + FSIG*V1OLD**3)/TK
      D1 = TEMP(I1,J1,1) + TLAM*(-3.5*TEMP(I1,J1,1) + 4.*TEMP(I1,J1,2)
     1        - .5*TEMP(I1,J1,3))
     2        + CB*HL*(-TLAM*TG + TLAM*(TEMP(I1,J1,1) - TG0))/TK
     3        + CB*(TLAM*(FSIG*(TEMP(I1,J1,1)**4 - TG0**4) - EPS*QXT0)
     4              - TLAM*(FSIG*TG**4 + EPS*QXT))/TK
      C2 = -TLAM*(1. - C1/A1)
C
C   TRANSFORMED COEFFICIENTS (BETA AND GAMMA)
C
      BETA(2) = BJ + TLAM*B1/A1
      GAMMA(2) = (D(2) + TLAM*D1/A1)/BETA(2)
      DO 6000 I=3,9
      BETA(I) = BJ - TLAM*TLAM/BETA(I-1)
      GAMMA(I) = (D(I) + TLAM*GAMMA(I-1))/BETA(I)
 6000 CONTINUE
      BETA(10) = BJ - TLAM*TLAM/BETA(9)
      GAMMA(10) = (D(10) + TLAM*(RTEMP + GAMMA(9)))/BETA(10)
```

```
C
C   SOLVE FOR TEMPERATURES
C
      V(10) = GAMMA(10)
      DO 7000 I=2,8
      K = 11 - I
      V(K) = GAMMA(K) + TLAM*V(K+1)/BETA(K)
 7000 CONTINUE
      V(2) = GAMMA(2) - C2*V(3)/BETA(2)
      V(1) = (D1 - B1*V(2) - C1*V(3))/A1
C
C   CONVERGENCE BASED ON BOUNDARY TEMPERATURE ERROR
C
      ERRL = ABS(V(1) - V1OLD)
      IF (ERRL.LT.1.) GO TO 8900
      V1OLD = V(1)
 8000 CONTINUE
C
C   TEMPERATURE DUMP IF ITERATION MAXIMUM EXCEEDED
C
      WRITE (NWRITE,8100) I1, J1, V(1), ERRL
 8100 FORMAT (1H0,'ITERATION MAX EXCEEDED IN SUBROUTINE DIFFUS:',/,
     1         ' MODULE:',I4,3X,'FUEL CELL:',I4,/,' ITERATION NO. 20',
     2        /,' SURFACE TEMPERATURE:',E15.7,3X,'ERROR:',E15.7)
      $END = .TRUE.
      GO TO 9000
 8900 DO 8950 I=1,10
      TEMP(I1,J1,I) = V(I)
 8950 CONTINUE
 9000 RETURN
      END
```

```
C-----------------------------------------------------------------------
C                                                                      -
C   FUNCTION RADEQ SOLVES THE QUARTIC EQUATION: X**4 + A3*X + A4 = 0   -
C                                                                      -
C-----------------------------------------------------------------------
      FUNCTION RADEQ (A3,A4)
      IMPLICIT LOGICAL ($)
      R = 0.5*A3**2
      Q = -4.*A4/3.
      D = R**2 + Q**3
      Y1 = (R + SQRT(D))**(1./3.) - (SQRT(D) - R)**(1./3.)
      RADEQ = .5*(SQRT(2.*SQRT(Y1**2 - 4.*A4) - Y1) - SQRT(Y1))
      RETURN
      END
```

```
C-----------------------------------------------------------------------
C                                                                      -
C   FUNCTION RECT(A,B,C,$P) FINDS THE SHAPE FACTOR FROM A DIFFERENTIAL -
C   ELEMENT TO A RECTANGLE OF DIMENSIONS A X B, AND SPACED C AWAY      -
C   FROM THE ELEMENT.  $P=.TRUE. => ELEMENT IS PARALLEL TO RECTANGLE,  -
C   $P=.FALSE. => ELEMENT IS PERPENDICULAR                             -
C                                                                      -
C-----------------------------------------------------------------------
      FUNCTION RECT(ZDEP,XLEN,YWID,$PARL)
      IMPLICIT LOGICAL ($)
      IF ((ZDEP.EQ.0.D0).OR.(XLEN.EQ.0.D0).OR.(YWID.EQ.0.D0))
     1                                                      GO TO 200
      PI = 3.14159
      IF (.NOT.$PARL) GO TO 100
      X = XLEN/ZDEP
      Y = YWID/ZDEP
      A = SQRT(1. + X**2)
      B = SQRT(1. + Y**2)
      RECT = .5*(X*ATAN(Y/A)/A + Y*ATAN(X/B)/B)/PI
      RETURN
  100 X = XLEN/YWID
      Y = ZDEP/YWID
      A = SQRT(XLEN**2 + ZDEP**2)
      RECT = .5*(ATAN(YWID/ZDEP) - ZDEP*ATAN(YWID/A)/A)/PI
      RETURN
  200 IF ($PARL.AND.(ZDEP.EQ.0.D0)) RECT = .5
      IF (.NOT.$PARL.AND.(ZDEP.EQ.0.D0)) RECT = .25
      IF ((XLEN.EQ.0.D0).OR.(YWID.EQ.0.D0)) RECT = 0.
      RETURN
      END
```

```
C------------------------------------------------------------------------
C                                                                       -
C   SUBROUTINE SETUP COMPUTES THE FUEL CELL LOCATIONS FROM THE INPUT    -
C   SUPER-MODULE DATA                                                   -
C                                                                       -
C------------------------------------------------------------------------
      SUBROUTINE SETUP(I,IDIREC,IDIM1,IDIM2,NFCL,SMX,SMY,SMZ,SLNG,
     1                 DS,FX,FY,FZ)
      IMPLICIT LOGICAL ($)
      DIMENSION FX(IDIM1,IDIM2), FY(IDIM1,IDIM2), FZ(IDIM1,IDIM2)
      IF (IDIREC.EQ.3) GO TO 400
      IF (IDIREC.EQ.2) GO TO 200
      FX0 = SMX - (SLNG + DS)/2.
      DO 100 J=1,NFCL
      FX(I,J) = FX0 + J*DS
      FY(I,J) = SMY
      FZ(I,J) = SMZ
  100 CONTINUE
      GO TO 600
  200 FY0 = SMY - (SLNG + DS)/2.
      DO 300 J=1,NFCL
      FY(I,J) = FY0 + J*DS
      FX(I,J) = SMX
      FZ(I,J) = SMZ
  300 CONTINUE
      GO TO 600
  400 FZ0 = SMZ - (SLNG + DS)/2.
      DO 500 J=1,NFCL
      FZ(I,J) = FZ0 + J*DS
      FX(I,J) = SMX
      FY(I,J) = SMY
  500 CONTINUE
  600 CONTINUE
      RETURN
      END
```

```
C-----------------------------------------------------------------------
C                                                                      -
C   FUNCTION SHAPE FINDS THE SHAPE FACTOR FROM A DIFFERENTIAL FUEL     -
C   ELEMENT TO AN ARBITRARILY LOCATED RECTANGLE, USING FUNCTION RECT   -
C                                                                      -
C-----------------------------------------------------------------------
      FUNCTION SHAPE(IOR,KOR,IDIRC,X1,Y1,Z1,X2,Y2,Z2,D1,D2)
      IMPLICIT LOGICAL ($)
      DU = ABS(X1 - X2)
      IF (IOR.EQ.2) DU = ABS(Y1 - Y2)
      IF (IOR.EQ.3) DU = ABS(Z1 - Z2)
      GO TO (100,200,300), IDIRC
  100 W0 = X2
      W1 = X1 - D1/2.
      V0 = Y2
      V1 = Y1 - D2/2.
      IF (IOR.NE.2) GO TO 400
      V0 = Z2
      V1 = Z1 - D2/2.
      GO TO 400
  200 W0 = Y2
      W1 = Y1 - D1/2.
      V0 = X2
      V1 = X1 - D2/2.
      IF (IOR.NE.1) GO TO 400
      V0 = Z2
      V1 = Z1 - D2/2.
      GO TO 400
  300 W0 = Z2
      W1 = Z1 - D1/2.
      V0 = X2
      V1 = X1 - D2/2.
      IF (IOR.NE.1) GO TO 400
      V0 = Y2
      V1 = Y1 - D2/2.
  400 W2 = W1 + D1
      V2 = V1 + D2
      WSIGN = 1.
      VSIGN = 1.
      IF ((W0.GT.W2).OR.(W0.LT.W1)) WSIGN = -1.
      IF ((V0.GT.V2).OR.(V0.LT.V1)) VSIGN = -1.
      DW2 = ABS(W2 - W0)
      DW1 = ABS(W1 - W0)
      DV2 = ABS(V2 - V0)
      DV1 = ABS(V1 - V0)
      DWA = AMAX1(DW2,DW1)
      DWB = AMIN1(DW2,DW1)
      DVA = AMAX1(DV2,DV1)
      DVB = AMIN1(DV2,DV1)
      $PR = (KOR.EQ.IOR)
      IF (.NOT.$PR.AND.(KOR.NE.IDIRC)) GO TO 500
      SHAPE = RECT(DU,DWA,DVA,$PR) + VSIGN*RECT(DU,DWA,DVB,$PR)
     1  WSIGN*RECT(DU,DWB,DVA,$PR) + VSIGN*WSIGN*RECT(DU,DWB,DVB,$PR)
      RETURN
```

```
500 SHAPE = RECT(DU,DVA,DWA,$PR) + VSIGN*RECT(DU,DVB,DWA,$PR)
   1  WSIGN*RECT(DU,DVA,DWB,$PR) + VSIGN*WSIGN*RECT(DU,DVB,DWB,$PR)
    RETURN
    END
```

```
C-----------------------------------------------------------------------
C                                                                      -
C   SUBROUTINE ZDNEW FINDS A NEW VALUE FOR ZD GIVEN AN OLD VALUE       -
C                                                                      -
C-----------------------------------------------------------------------
      SUBROUTINE ZDNEW (ZIN,ZOUT,FSIG,IBRNCH)
      IMPLICIT LOGICAL ($)
      COMMON /ALL/ ACEIL, AWALL, DELT, FCTR(15), FLCF, RTEMP, TIME,
     1             TITLE(20),
     2             ICEIL, IJOB, INCHCK, INITG, IOUTPT, MOUTPT(11),
     3             $DOOR, $END, $ROOM
      COMMON /GAS/ A4, CDOOR, CF, CFV, DCF, DEN, DG, DHGT, DWID,
     1             FC, FH, GABSRP, HCEIL, PLCF1, PLCF2,
     2             TG, TG0, THETA, VFV, WFL, WFVC, WFVH, ZD, ZN
      COMMON /VENTC/ AFUEL, AFUEL0, CVA, CVA0, FHTA, FRADA, FUELA, QMAX,
     1               QTOT, QTOT0, QTOT1, QTOT2, TMDOT, TMDOT0,
     2               TMDOTS, TQDOT, TQDOTC, WIN, Z0A,
     3               NBURN, NBURN0,
     4               $DECAY, $FLUX1, $FLUX2, $VENT, $VCONT
      ZFLA = FHTA + Z0A
      DO 1000 K=1,50
      IF (ZIN.LT.Z0A) WPL = TMDOT
      IF ((ZIN.GE.Z0A).AND.(ZIN.LE.ZFLA))
     1        WPL = TMDOT*(PLCF1*(ZIN - Z0A)/FRADA + 1.)**2.5
      IF (ZIN.GT.ZFLA)
     1        WPL = WFL*(PLCF2*(ZIN - ZFLA)/FRADA + 1.)**(5./3.)
      A3TH = (HCEIL*ACEIL + (WPL + FC*WFVC)*1000.)/(FSIG*ACEIL)
      TG = RADEQ (A3TH,A4)
      C1 = CDOOR*SQRT(1. - RTEMP/TG)
      C2 = C1*SQRT(RTEMP/TG)
      WFVH = CFV/TG
      RN = 1. - (((WPL - FH*WFVH + FC*WFVC)/C2)**2)**(1./3.)
      ZN = RN*DHGT
      A1ZD = 3.*RN
      A3ZD = 4.*((WPL + (FC - FH)*WFVC)/C1 - RN**3)
      IF (IBRNCH.EQ.1) GO TO 2000
      IF (A3ZD.GE.0.) GO TO 500
      ZD0 = ZIN
      GO TO 2000
  500 ZIN = ZD0 + THETA*(ZIN - ZD0)
 1000 CONTINUE
      ZD0 = 0.
 2000 R = -.5*A3ZD - (A1ZD**3)/27.
      Q = -(A1ZD/3.)**2
      D = R**2 + Q**3
      IF (D.LT.0.) RD = RN*(2.*COS(ARCOS(R/SQRT(-Q**3))/3.) - 1.)
      IF (D.GE.0.) RD = (ABS(R) + SQRT(D))**(1./3.)
     1                + (ABS(R) - SQRT(D))**(1./3.)
      IF ((R.LT.0.).AND.(D.GE.0.)) RD = -RD
      ZOUT = RD*DHGT
      RETURN
      END
```

NRC FORM 335
(11-81)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER *(Assigned by DDC)*
NUREG/CR-3239
UCLA-ENG-8257

2. *(Leave blank)*

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE *(Add Volume No., if appropriate)*
COMPBRN - A COMPUTER CODE FOR MODELING COMPARTMENT FIRES

5. DATE REPORT COMPLETED

MONTH	YEAR
August	1982

DATE REPORT ISSUED

MONTH	YEAR
May	1983

6. *(Leave blank)*

7. AUTHOR(S)
Nathan O. Siu

8. *(Leave blank)*

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
School of Engineering and Applied Science
University of California
Los Angeles, CA 90024

10. PROJECT/TASK/WORK UNIT NO.

11. FIN NO.
NRC FIN B0493

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
Division of Risk Analysis
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

13. TYPE OF REPORT
COMPBRN Manual

PERIOD COVERED *(Inclusive dates)*
August 1982

14. *(Leave blank)*

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(200 words or less)*

The computer code COMPBRN deterministically models the behavior of fire in a compartment. This manual presents information necessary to run COMPBRN, including descriptions of required input and resulting output. Also included are a sample problem and a listing of the code (written in FORTRAN for an IBM 3033 computer). This manual is to be used in conjunction with NUREG/CR-2269, "Probabilistic Models for the Behavior of Compartment Fires," August 1981, which describes the fire models employed by COMPBRN.

17. KEY WORDS AND DOCUMENT ANALYSIS
Fire, fire growth,
computer fires,
deterministic fire growth.

17a. DESCRIPTORS

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
Unlimited

19. SECURITY CLASS *(This report)*
Unclassified

20. SECURITY CLASS *(This page)*
Unclassified

21. NO. OF PAGES
103

22. PRICE
S