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User's Manual for FIRIN

A Computer Code to Estimate Accidental Fire and Radioactive Airborne Releases in Nuclear Fuel Cycle Facilities

Prepared by M.K. Chan, M.Y. Ballinger, P.C. Owczarski

Pacific Northwest Laboratory
Operated by
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A Computer Code to Estimate Accidental Fire and Radioactive Airborne Releases in Nuclear Fuel Cycle Facilities

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Prepared by
M.K. Chan, M.Y. Ballinger, P.C. Owczarski

Pacific Northwest Laboratory
Richland, WA 99352

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SUMMARY

This manual describes the technical bases and use of the computer code FIRIN. This code was developed to estimate the source term release of smoke and radioactive particles from potential fires in nuclear fuel cycle facilities. FIRIN is a product of a broader study, Fuel Cycle Accident Analysis, which Pacific Northwest Laboratory conducted for the U.S. Nuclear Regulatory Commission.

The technical bases of FIRIN consist of a nonradioactive fire source term model, compartment effects modeling, and radioactive source term models. These three elements interact with each other in the code affecting the course of the fire.

This report also serves as a complete FIRIN user's manual. Included are the FIRIN code description with methods/algorithms of calculation and subroutines, code operating instructions with input requirements, and output descriptions.

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1.0 INTRODUCTION

Source terms generated by potential accidental fires in nuclear fuel cycle facilities can be estimated using the computer code FIRIN developed by Pacific Northwest Laboratory (PNL). The primary thrust of the work is to estimate the mass generation rate and size distribution of radioactive particles that become airborne in a fire accident. These releases can be calculated using FIRIN. Other information calculated by FIRIN includes (but is not limited to) fire source mass loss rates, energy generation rates, and transient conditions such as temperature and pressure in the fire compartment. Los Alamos National Laboratory has developed the computer code FIRAC to analyze fire-induced flow and thermal and material transport in the building ventilation system.

FIRIN is designed to provide mass and energy input to FIRAC. Using both codes, a user can analyze radioactive source terms up to the facility atmosphere interface. Used alone, FIRIN predicts this release within the fire compartment.

Radioactive release factors incorporated in the code are primarily those developed in experimental work at PNL. Combustion product data were developed from a literature review (Chan and Mishima 1982) for combustibles that are commonly found in nuclear fuel cycle facilities and from experimental work performed at Factory Mutual Research (Steciak, Tewarson, and Newman 1983).

This manual is designed to instruct the FIRIN user, who is assumed to be a knowledgeable engineer/scientist required to make a safety assessment of a specific facility. The user is assumed to be familiar with basic programming, heat transfers, and the facility for which the fire accident is simulated.

Chapter 2.0 is a description of the technical basis of the models in the code. Background information, such as program and data structure, numerical algorithms, subroutine functions, input requirements, and output interpretation, are included in Chapter 3.0. Operational instructions are given using illustrative sample problems in Chapter 4.0.

2.0 MODEL DESCRIPTION

This chapter describes the models used in the FIRIN computer code. The major assumptions and features used in developing the models are discussed. This is followed by sections describing fire source term models, compartment effects, and radioactive source term models.

2.1 ASSUMPTIONS AND FEATURES

Certain assumptions were made about the fire during FIRIN development:

- Fire growth is approximated by using the concepts of burning order and ignition energy in FIRIN. Applying these concepts allows the user to examine the effects of fire severity ranging from a small fire involving only one combustible to a large fire that involves all combustibles found in the compartment.
- The burning order concept requires that the user estimates the consumption order of combustible materials in the fire scenario of interest. This concept permits the user to set bounds for the severity of compartment fires.
- The ignition energy concept (an option) features autoignition of combustibles at risk, if the heat flux levels generated by the initial burning combustibles are sufficient. Ignition energy data for the combustibles (Tewarson 1982) are stored in FIRIN. The user selects the initial ignition point and other combustibles at risk other than the initial buring material inside the fire compartment.
- Each burning element is assumed to burn at a constant rate when exposed to a constant oxygen and heat flux environment. These rates are found in the Factory Mutual Data Base (Tewarson 1982) and are experimentally determined.
- Flaming combustion is the principal burning mode in FIRIN. Limited smoldering combustion data are available and are used in other burn modes. Ample oxygen is available during the initial burning; as less oxygen is available during later stages of the fire, the burning mode is reduced in an approximate manner.
- Burning rates (or mass loss rates) are a function of the oxygen provided by room ventilation flow, type of combustible, and exposed surface area of combustible.
- FIRIN provides output suitable for input to FIRAC (e.g., mass and size distribution of smoke and radioactive particles attacking the filters as a function of time).

- Wall and equipment heat absorption models are incorporated into FIRIN. This feature provides a more realistic estimate of the net energy input required for FIRAC. Additionally, these models can be used to predict equipment heating and overpressurizing, and subsequent rupturing.

- The potential for water vapor formation is high because concrete loses water at 90° to 900°C. When heated to 600°C, the water in a 1/4-in. concrete wall surrounding a 10-ft x 10-ft x 10-ft room (less ceiling) produces about seven room volumes of water vapor. This phenomena, not found in other fire models, is included in FIRIN. Reactor containment modelers have produced the information needed to couple this water and carbon dioxide source to the wall heat transfer model. This water vapor could either raise the room pressure or substantially increase ventilation flow. It could also be a substantial source of condensate in cooler regions of the ventilation system.

- Flame radiation is estimated in laboratory-scale experiments for each type of combustible material by increasing the oxygen concentration in air (Tewarson 1982). When burning a combustible mixture, the component material with the greatest flame radiation is used for calculating burn rates of individual components in FIRIN.

- The following particle depletion mechanisms are included: gravity settling, Brownian diffusion, diffusiophoresis, and thermophoresis.

2.2 FIRE SOURCE TERM MODELS

Source terms required to characterize a fire include mass loss rates, heat release rates, and combustion product generation rates. Using the steady-state heat balance on the surface of a burning element, Tewarson et al. (1976, 1980) derived rate equations for these fire source terms. The rate equations are developed as a function of material properties and fire conditions. The following sections discuss these source term rate equations. The model equations used in FIRIN are identified, and required input parameters are given for computing fire source terms. In addition, a simple model is developed to approximate changes in pyrolysis/combustion properties caused by ventilation conditions. FIRIN calculates the fire source terms to correspond to the available oxygen.

2.2.1 Mass Loss Rate ($\dot{M}''$)

The mass loss rate of various combustible materials depends on the available net heat flux received by the material in a fire and the heat required to generate a unit mass of combustible vapors. This loss rate is calculated as follows (Tewarson 1980a):

$$\dot{M}'' = \dot{q}''_n/L \tag{2-1}$$

where $\dot{M}''$ is the mass loss rate of the material, $\dot{q}''_n$ is the net heat flux received by the fuel material per unit fuel surface area, and L is the heat required to generate a unit mass of fuel vapors. In the rotation used, a dot above the parameter indicates per unit of time, and quotation marks on the upper right side of the parameter indicated per unit of area. Thus $\dot{M}''$ has units of grams/(s m^2) and is a rate of mass flux. Similarly $\dot{q}''$ is a rate of energy flux.

Mass loss rate for the two phenomena, pyrolysis and combustion, is used in FIRIN and defined as follows (Tewarson 1980b):

- mass loss rate in pyrolysis ($\dot{M}''_p$)

$$\dot{M}''_p = (\dot{q}''_e - \dot{q}''_{rr})/L \tag{2-2}$$

where $(\dot{q}''_e - \dot{q}''_{rr})$ is the net heat flux, $\dot{q}''_e$ is the external heat flux, and $\dot{q}''_{rr}$ is the surface radiation heat loss

- mass loss rate in combustion ($\dot{M}''_b$)

$$\dot{M}''_b = (\dot{q}''_e + \dot{q}''_{fs} - \dot{q}''_{rr})/L \tag{2-3}$$

where $(\dot{q}''_e + \dot{q}''_{fs} - \dot{q}''_{rr})$ is the net heat flux, and the total flame heat flux $\dot{q}''_{fs}$ is included in the net heat transfer because of flaming combustion. The total flame heat flux is the summation of flame convective heat flux $\dot{q}''_{fc}$ and radiative heat flux $\dot{q}''_{fr}$.

Physical/chemical and pyrolysis/combustion properties (right-hand side of both equations) are stored in the FIRIN data base, except $\dot{q}''_e$, which is calculated in the compartment effect models. The data base contains properties of fuels of interest (i.e., combustible materials commonly found in nuclear fuel cycle facilities). The fuel pyrolysis/combustion properties were developed from combustion experiments conducted by Factory Mutual Research Corporation (Tewarson 1980b; Steciak, Tewarson, and Newman 1983). Appendix B tabulates the valves used in FIRIN.

Mass loss rate in a fire is a function of fuel type and surface area; therefore, this information is required input to FIRIN. Fuel mass is the input required to estimate the length of time a particular fuel burns. Oxygen concentration also influences mass loss rate and is calculated within FIRIN for each time step.

2.2.4 Heat Release Rate ($\dot{Q}''_a$)

Heat release rates must be considered to describe the rate of fire growth and the size of the fire. Heat release rates in fires can be expressed as follows (Tewarson 1980a):

$$\dot{Q}''_i = H_i \dot{M}''_b \tag{2-4}$$

where $\dot{Q}''_i$ is the heat release rate, H_i is the heat of combustion, and $\dot{M}''_b$ is the mass loss rate in combustion.

When all the fuel vapors burn completely, H_i of Equation (2-4) is defined as heat of complete combustion of the fuel H_t. In an actual fire, where both material pyrolysis and combustion often coexist and oxygen is not always available, fuel vapors generated from pyrolysis do not often burn completely. Therefore, H_i is defined as the actual heat of combustion of fuel H_a, and $\dot{Q}''_a$ is the actual heat release rate; thus, Equation (2-4) can be rewritten as

$$\dot{Q}''_a = H_a \dot{M}''_b \tag{2-5}$$

Furthermore, the ratio of actual-to-complete heat of combustion (H_a/H_t) is defined as combustion efficiency of the fuel X_a. Therefore,

$$\dot{Q}''_a = X_a H_t \dot{M}''_b \tag{2-6}$$

or, from Equations (2-3) and (2-6), the heat release rate is written as

$$\dot{Q}''_a = X_a \, (H_t/L)(\dot{q}''_e + \dot{q}''_{fs} - \dot{q}''_{rr}) \qquad (2\text{-}7)$$

Equation (2-7) is the final expression that is used in FIRIN to calculate energy release rates. The combustion efficiency X_a and the heat of complete combustion H_t for the combustibles of interest are also stored in the data base in FIRIN.

Heat release rates (Tewarson 1980b) involve all of the following parameters: a) combustion efficiency of combustible materials, b) ratio of complete combustion heat to the heat required to generate a unit mass of vapors, and c) net heat flux absorbed by the surface. Tewarson studied the dependence of heat release rates on thermal and over- or underventilated fire environments for various materials. He found that the combustion efficiency for an overventilated fire environment becomes approximately constant for each generic type of material tested. According to Tewarson, combustion efficiency can decrease if

- the ratio of carbon relative to hydrogen, oxygen, or other fuel constituents in the vapors is decreased
- the gas-phase reactions are quenched or retarded by lack of available oxygen, chemical retardants in the materials, or a decrease in temperature
- soot-forming reactions are preferred in the gas phase [i.e., polystyrene (PS)].

Table 2.1 lists combustion efficiencies for some materials (Chan and Mishima 1982).

TABLE 2.1. Combustion Efficiency, X_a

Nonaromatic Polymers[(a)]	High ($0.81 < X_a < 0.97$)
Polymethyl methacrylate	
Polypropylene	
Aromatic Compounds[(b)]	Medium ($0.51 < X_a < 0.7$)
Red Oak	
Polystyrene	
Chlorinated Compound	Low ($X_a \sim 0.35$)
Polyvinyl chloride	

(a) Noncharring materials.
(b) Charring materials.

Since the heat release rate is a function of mass loss rate, both fuel type and surface area are required input.

2.2.3 Combustion Product Generation Rate ($\dot{G}''_j$)

According to Tewarson (1980b), the combustion product (i.e., carbon dioxide, carbon monoxide, water, smoke, and low volatile hydrocarbon) generation rate is equal to the fractional yield of the product times the mass loss rate. This is expressed as

$$\dot{G}''_j = Y_j \dot{M}'' \tag{2-8}$$

where

$\dot{G}''_j$ = mass generation rate of product j per unit surface area of the combustible

j = subscript denoting conbustion product

Y_j = the yield of product j, which can be expressed as a multiple of the yield of product j expected from stoichiometry k_j and the product generation efficiency f_j [Equation (2-9)]

$\dot{M}''$ = the mass loss rate from pyrolysis or combustion

$$Y_j = f_j k_j \tag{2-9}$$

Thus, the product generation rate of certain species for pyrolysis can be written as

$$\dot{G}''_{pj} = f_j(k_j/L)(\dot{q}''_e - \dot{q}''_{rr}) \tag{2-10}$$

Using Equation (2-3), the product generation rate for combustion is

$$\dot{G}''_{bj} = f_j(k_j/L)(\dot{q}''_e + \dot{q}''_{fs} - \dot{q}''_{rr}) \tag{2-11}$$

$\dot{G}''_j$, like $\dot{Q}''_a$, depends on both material properties and fire conditions. Equations (2-10) and (2-11) are the final expressions used in FIRIN for the calculation of product generation rates. The values of Y_j or $(f_j k_j)$ for the combustibles of interest are stored in the data base in FIRIN. Similar to other combustion properties, only overventilated data are currently available. Underventilated data are estimated. Since the product generation rate is also a function of mass loss rate, the input requirement is the same as for the other two rates discussed in the previous subsections.

2.2.4 Burning Modes

Flaming and smoldering combustion are the two burning modes considered in FIRIN. In an overventilated fire with an oxygen level greater than 15%, fuels are assumed to burn in a flaming mode. In an underventilated fire with an oxygen level less than 11%, fuels are assumed to burn in a smoldering mode. In a semiventilated fire with an oxygen level between 11% and 15%, fuels are assumed to burn in a mixed flaming and smoldering mode.

The pyrolysis/combustion properties are assumed to have a linear relationship with oxygen levels. The model used is

$$P_{sv} = P_{ov} - S(P_{ov} - P_{uv}) \tag{2-12}$$

where P_{sv} = pyrolysis/combustion properties, semiventilated fire

P_{ov} = pyrolysis/combustion properties, overventilated fire

S = linear scaling factor, $S = \frac{15\% - O_2}{15\% - 11\%}$

P_{uv} = pyrolysis/combustion properties, underventilated

O_2 = oxygen level in fire, and $15\% \leq O_2 \leq 11\%$.

Some of the P_{uv} values in the data base are estimated. Available P_{ov} values were multiplied by an assumed fraction 0.2 to 0.8 (depending on the pyrolysis and combustion properties) to estimate needed values. The assumed fractions were estimated using limited fuel data from both over- and underventilated experimental fire tests (Tewarson 1980a,b). The oxygen transient is calculated from the fire compartment mass balance.

2.2.5 Fire Particulate Material Characteristics

Fire (smoke) particle characteristics of interest are the particle size, size distribution, and number density as a function of time in a compartment fire. In fire research, a few studies have been successful in predicting particle size and number density by applying the Mie Scattering Theory (Chan and Mishima 1982). Model equations for predicting these characteristics are available in a diffusion flame study by Pagni and Bard (1978).(a) Currently, too few data are available for FIRIN to fully use the existing models. Smoke characteristic studies of this type are under way at the Factory Mutual Research Corporation (Newman 1982).

Users can (at this level of approximation) also refer to Table 2.2 for various steady-state smoke particle sizes (Chan and Mishima 1982). Ranges of particulate mass median diameter (MMD) and standard deviation (σ_g) for cellulose and various polymers are tabulated in this table for both normal and high ventilation air temperatures. These data were obtained from B. T. Zinn and his colleagues at Georgia Institute of Technology (Bankston et al. 1978; Zinn et al. 1978, 1980). Notice that in flaming combustion in both normal and highly ventilated conditions, MMD and particle-size distribution data are unavailable for the polymers [except polymethyl methacrylate (PMMA)]. Large, sooty particles produced during flaming combustion tend to rapidly clog up the

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(a) Pagni, P. J., and J. Bard. 1978. "Particulate Volume Fractions in Diffusion Flames," p. 1017. Paper presented at the Seventeenth Symposium (International) on Combustion, August 20-25, 1978, Leeds, England.

TABLE 2.2. Particle Size and Particle-Size Distribution of Fuel Materials

Fuel Material	Mass Median Diameter (μm)	Standard Deviation (σ)	Volume Surface Mean Particle Dia. at Maximum Optical Density Drs (μm)	F or NF(a)	Heat Flux (W/cm^2)	Air Flow Rate (ℓ/min)	Environmental Conditions
Douglas fir	0.5-0.9	1.8-2.0	0.75-0.8	NF	3.2-6.2	142-425	Normal temp. (25°C) and composition
	0.4	2.4	0.5-0.45	F	2.5-5	283-425	Normal temp. (25°C)
	1.0	2.0	0.9	NF	6.2	---	Normal temp.; composition of 80% N_2, 5 to 10% O_2, 10% CO_2, 5% CO
	--	--	0.75-0.55	NF	5	425	Air temp. of 25° to 200°C, normal composition
	--	--	0.5-0.55	F	5	425-283	Air temp. of 25° to 200°C, normal composition
Polymethyl-methacrylate	0.7	1.9	0.6	NF	5	425	Normal temp. (25°C) and composition
	--	--	1.2	F	5	425	Normal temp. (25°C) and composition
	--	--	1.2-1.3	F	5	425	Air temp. of 25° to 200°C; normal composition
Polystyrene	2.6	1.9	1.4	NF	5	425	Normal temp. (25°C)
	--	--	1.3	F	5	425	Normal temp. (25°C)
	--	--	1.3-1.25	F	5	425	Air temp. of 25° to 200°C; normal composition
Polyethylene	1.5	1.75	1.1	NF	5	425	Normal temp. (25°C)
	--	--	1.3	F	5	425	Normal temp. (25°C)
	--	--	1.3-1.35	F	5	425	Air temp. of 25° to 200°C; normal composition
Polypropylene	2.05	1.8	1.6	NF	5	425	Normal temp. (25°C) and composition
	--	--	1.2	F	5	425	Normal temp. (25°C) and composition
	--	--	--	F	5	425	Air temp. of 25° to 200°C; normal composition
Polyvinyl chloride	1.4	1.45	1.0	NF	5	425	Normal temp. (25°C) and composition
	--	--	1.2	F	5	425	Normal temp. (25°C) and composition
	--	--	1.1-1.5	F	5	425	Air temp. of 25° to 200°C; normal composition
Hydraulic fluid	--	--	1.23	NF	5	425	Normal temp. (25°C) and composition
	--	--	1.33-1.31	F	5	425	Air temp. of 25° to 200°C; normal composition

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(a) F = Flaming combustion
NF = Nonflaming combustion

cascade impactor plates used in taking samples. For PMMA the quantities of smoke particles collected were too small for reliable size-distribution measurements. Mean particle diameter is measured in these conditions by in situ optical techniques.

Smoke particle-size distributions were also measured in combustion experiments at PNL. Paper, PMMA, and polychloroprene (PC) were burned and the aerodynamic equivalent diameter (AED) of smoke particles were measured with a cascade impactor. Table 2.3 lists the MMD and standard deviation (σ) of these smoke particles.

TABLE 2.3 Smoke Particle-Size Characteristics

Material	Mass Median Diameter (μm)	Standard Deviation (σ)
Polymethyl methacrylate	0.80 to 1.68	2.6 to 3.2
Polychloroprene	0.40	2.7
Paper	0.47	3.1

At the point measured (several feet from the flame in both the PNL and Georgia Tech experiments), smoke particle size does not seem to be a function of material burned. An average MMD of approximately one micron and an average σ_g of 2 is used in FIRIN to estimate smoke particle sizes from all burning materials.

2.3 COMPARTMENT EFFECTS

The severity of a fire inside an enclosure can be affected by the constraint of the compartment barriers. For nuclear fuel cycle facility fires, the quantity of radioactive releases from mechanisms such as burning and heating of radioactive-contaminated materials, and heating of vessels and equipment containing radioactive materials depends on the fire severity inside the compartment and ventilation conditions. The compartment barriers not only contain most of the mass and gases generated from the fire, they also trap a portion of the thermal energy released during the combustion processes. Because of the inlet ventilation located near the ceiling (commonly found in nuclear facilities), air contaminated with fire gases and smoke accumulating in the hot ceiling layer is pushed rapidly to the fire site, causing the early starvation of oxygen supply to the fire. On the other hand, the trapped energy is available to enhance the pyrolysis rate of the combustible materials at risk.

If the compartment barriers are made of concrete, the decomposition of water vapor and carbon dioxide from the heated concrete could significantly contribute to the overall mass releases from the fire. The possibility of these additional releases will be significant in a long-lasting fire inside a small compartment. The overall airborne mass can challenge the filter and ventilation system of the building, which can lead to release of radioactive particles to the atmosphere.

To provide realistic estimates of both the radioactive and fire source terms inside the fire compartment, the above characteristics of barrier effects and their interaction with the fire strength are modeled. The models developed and selected are for heat transfer, heat and mass balances, concrete decomposition, fluid flow, and particle depletion inside the compartment. The following sections describe these models and their relationships in FIRIN. The required input parameters for the model calculations are also identified.

2.3.1 Heat Transfer in the Fire Compartment

Three major types of heat transfer phenomena considered for fire inside a compartment are as follows:

1. direct radiative heat transfer
2. convective heat transfer
3. conductive heat transfer.

Mathematical models for all of these phenomena are given below, including heat transfer to and within equipment[a] at risk inside the fire compartment. Some equipment might contain radioactive materials in various physical forms that

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[a] Equipment refers to machinery, gloveboxes, vessels, and other apparatus in the fire compartment that could affect the source term by adding to source term release and/or absorbing heat from the fire.

can be released into the fire environment as a consequence of heating processes. In modeling heat transfer within the compartment, we assume the fire is anchored at or above the floor level and is located at the center of the enclosure in order to acquire geometric simplicity.

2.3.1.1 Direct Radiative Heat Transfer

At the initial stage of a fire inside a given compartment, the dominant radiative heat transfer is from the flame itself. This flame radiative heat loss is absorbed by the hot layer, walls, and equipment. Radiative heat transfer is also occurring between the smoke layer and the ceiling in contact with it.

As the hot layer descends, it becomes a major radiation heat source for the combustible materials, compartment walls, floor, and equipment. For a nuclear fuel cycle facility fire, the growth rate of a hot layer from the ceiling level is naturally greater than other fire compartments that have ventilation inlet near the floor level. The ceiling ventilation inlet of a nuclear fuel cycle facility tends to mix and lower the hot layer fairly quickly to the floor. This ceiling inlet and floor outlet ventilation system reduces the duration of direct radiative heat transfer from the flames to the walls and equipment. Because of the rapidly descending smoke layer, the quantity of direct radiative heat transfer from the flames to the floor is neglected. This also avoids the complication of handling radiation shape factors.

From Fire to Hot Layer. From radiation heat balance, the radiative heat transfer to hot layer, $\dot{Q}_{rhl}$(kW), from the flame can be written as

$$\dot{Q}_{rhl} = \dot{Q}_{r} - \dot{Q}_{rcl} \tag{2-13}$$

where $\dot{Q}_r$ is the overall radiative heat loss from the flame, and $\dot{Q}_{rcl}$ is the heat gain by the cooler materials in the cold layer. In modeling the fire inside a compartment, we assumed a two-layer regime: a black gas (smokey) layer on top, produced from the rising of the hot fire products and 2) a cooler layer below the smokey layer that contains no contaminant gas, only air.

$\dot{Q}_r$ is calculated by

$$\dot{Q}_r = X_r\, H_z\, \dot{M}_b'' \tag{2-14}$$

where X_r is the radiative fraction of overall heat release, H_z is the heat of combustion, and M_b'' is the mass burn rate, g/s.

$\dot{Q}_{rcl}$ is approximated using the following expression in the code:

$$\dot{Q}_{rcl} = \dot{Q}_r \left(\frac{Z_{cl}}{Z_{rm}}\right) \tag{2-15}$$

where Z_{cl} is the thickness of the cold layer and Z_{rm} is the height of the fire compartment. In using the ratio of Z_{cl} and Z_{rm} to obtain $\dot{Q}_{rcl}$, we assumed that the radiative heat release from the flame is uniformly distributed to both the hot and cold layers. Combining Equations (2-13) and (2-15) gives

$$\dot{Q}_{rhl} = \dot{Q}_r \left[1 - \left(\frac{Z_{cl}}{Z_{rm}}\right)\right] \tag{2-16}$$

Since the thickness of cold layer Z_{cl} approaches zero at some points during the fire, $\dot{Q}_{rhl}$ becomes $\dot{Q}_r$ as Z_{cl} approaches zero. Z_{cl} is determined from calculating the hot layer accumulation during the progress of the fire and by assuming that the hot layer behaves like an ideal gas.

In FIRIN, the radiation from fire to hot layer is calculated in every time step to demonstrate transient behavior. For each time step, Equation (2-17) is used:

$$Q_{rhl} = \dot{Q}_{rhl}\,\Delta t = \dot{Q}_r \left[1 - \left(\frac{Z_{cl}}{Z_{rm}}\right)\Delta t\right] \tag{2-17}$$

where Δt is the size of the time step to be specified by the user. Q_{rhl} and Δt are expressed in units of kJ and seconds, respectively. Besides fuel type and surface area, as mentioned in Section 2.2, size of time step and height of the compartment are also required as input to FIRIN for calculating Q_{rhl}.

From Fire to Walls and Equipment. Before the smoke layer reaches the floor level of the fire compartment, direct flame radiative heat transfer to the nearby walls and equipment in the odd layer will occur. This assumption is based on the earlier supposition that the fire is anchored at or above the floor level in the center of the enclosure. To estimate the fraction of radiation that will be intercepted by the equipment and the remaining fraction that will be received by the walls, the following assumptions are made:

- At the fire vicinity, all the equipment at risk is located at the periphery of the compartment, surrounding the fire; therefore, the overall effective surface area for heat transfer is the summation of the projected areas of all equipment from the incident rays of the flame.
- The shape of all equipment is generalized into a cylindrical geometry, and the effective area can be approximated by simply multiplying the diameter by the height of the equipment. The shape of all compartment types is also cylindrical.
- The radiative energy received by both the walls and equipment is uniformly distributed. The intensity of the radiation does not change significantly with the distance.

For large fires, the smoke layer descends quickly and the radiative heat transfer described here occurs over a short length of time, thus reducing error associated with these assumptions.

The fraction of the overall radiative heat transfer to the equipment in the fire vicinity is estimated using the following equation:

$$\dot{Q}_{re} = \dot{Q}_{rcl} \times \frac{A_{ee}}{A_{ew}} \tag{2-18}$$

where $\dot{Q}_{re}$ is the flame radiation absorbed by equipment at risk; A_{ee} and A_{ew} are the effective heat transfer areas of the equipment and walls, respectively; and the ratio of A_{ee}/A_{ew} represents the fraction of the overall area intercepted by the equipment. A_{ee} is approximated by summing the individual projected area of the equipment and

$$A_{ee} = \sum_{i=1}^{j} D_{e_i} H_{e_i} \text{ , for } i = 1, 2, \ldots, j \tag{2-19}$$

where j is the total number of pieces of equipment modeled (FIRIN considers up to 40 pieces of equipment). D_{e_i} and H_{e_i} are the diameter and height of the i^{th}-equipment, respectively. A_{ew} is calculated as follows:

$$A_{ew} = \pi D_r Z_{cl} \tag{2-20}$$

where the diameter of the room D_r is approximated by

$$D_r = \sqrt{\frac{4(W_c \times L_c)}{\pi}} \tag{2-21}$$

where W_c and L_c are the width and length of the fire compartment if it is rectangular in shape. Combining Equations (2-18) through (2-21) gives the final equation for $\dot{Q}_{re}$:

$$\dot{Q}_{re} = \frac{\dot{Q}_{rcl} \sum_{i=1}^{j} D_{e_i} H_{e_i}}{Z_{cl}\sqrt{4 \pi (W_c \times L_c)}} \tag{2-22}$$

Again, Z_{cl} is the thickness of the cold layer. For each time step,

$$Q_{re} = \dot{Q}_{re} (\Delta t) \tag{2-23}$$

where Q_{re} is in units of kJ. The remaining fraction of radiative heat absorbed by the walls is obtained by using the following expression:

$$Q_{rw} = Q_{rcl} - Q_{re} \tag{2-24}$$

where Q_{rc1} is obtained using Equation (2-15). The required inputs to FIRIN for the above radiative heat transfer calculations are as follows: equipment diameter and height, and the length and width of the fire compartment.

From Hot Layer to Floor, Walls, Ceiling, and Equipment. Since rapid descending of the smoke layer is the characteristic of nuclear facility fires, this hot layer becomes one of the major radiation heat sources other than the flame itself. When the hot layer (medium-1) is in contact with another object (medium-2), such as a piece of equipment or the compartment barrier, the radiative heat flow between the two mediums can be expressed as follows (Holman 1976):

$$\dot{Q}_{r1,2} = \frac{\sigma A \left(T_1^4 - T_2^4\right)}{1/\varepsilon_1 + 1/\varepsilon_2 - 1} \tag{2-25}$$

where σ = Stefan-Boltzmann constant = 5.669×10^{-8} W/m$^2 \cdot$°K^4

A = contacting area of mediums 1 and 2 (m^2)

T_1, T_2 = temperature of mediums 1 and 2 (°K)

ε_1, ε_2 = thermal emissivity of mediums 1 and 2.

Assuming a smoky fire, which is typical in burning of combustible materials commonly found in nuclear fuel cycle facilities (e.g., cellulosic materials, plastic, and rubber materials), the smoke layer may behave like a black body with $\varepsilon_1 \sim 0.9$ (Berry 1980). The emissivity for medium-2 is mostly material dependent. The FIRIN data base contains values of emissivity for various types of construction materials.

Radiative heat transfer between the hot layer and its contacting surfaces is also determined for every time step [after substituting $\varepsilon_1 = 0.9$ in Equation (2-25)]:

$$Q_{r1,2} = \dot{Q}_{r1,2} (\Delta t)$$

$$= \frac{\sigma A \left(T_1^4 - T_2^4\right) \Delta t}{1/\varepsilon_2 + 0.111} \qquad (2\text{-}26)$$

The contacting area, A, is internally calculated in FIRIN from input information on compartment and equipment dimensions as identified earlier. The temperature of hot layer, T_1, determined from mass and energy balance inside the compartment and the model equation, is also calculated in FIRIN (see Section 2.3.3). The equipment and barrier temperatures, T_2, are calculated internally by the code. The only input requirements for calculating $Q_{r1,2}$ are the initial temperatures of the equipment and the compartment before the fire.

2.3.1.2 Convective Heat Transfer

In a fire, a fraction of the overall energy release from combustion is in the form of convective heat, while the remaining fraction is radiative heat. The convective heat is carried by the fire gases into the ceiling hot layer. Whenever a solid body is exposed to this moving hot layer having a temperature different from that of the body, heat is transferred between the fluid and the solids.

The overall heat release from a fire, $\dot{Q}_a''$, is as follows:

$$\dot{Q}_a'' = X_a H_t \dot{M}_b'' \qquad (2\text{-}27)$$

while the convective fraction per unit area of combustible materials is

$$\dot{Q}_c = X_c A_f \dot{Q}_a'' \qquad (2\text{-}28)$$

where X_c is the convective fraction of overall heat release, and A_f is the effective burning surface areas of fuel materials, (m^2).

For each time step, convective heat release can be expressed as

$$Q_c = X_c A_f \dot{Q}_a''(\Delta t) \qquad (2\text{-}29)$$

where Q_c is in units of kJ. This convective heat is deposited into the hot layer via the hot gases produced during combustion.

The values of X_c for various combustible materials of interest are stored in the data base within the FIRIN code. They were obtained experimentally as a function of fire conditions by Tewarson et al. (1980) at the Factory Mutual Research Corporation. Fuel surface area and type of fuel are the only required inputs for calculating convective heat release.

Besides radiation, the fluid motions in the hot layer promote convective heat transfer to and from the objects that are immersed. The amount of energy transferred is governed by Newton's law of cooling/heating (Holman 1976):

$$\dot{Q}_{c1,2} = hA\ (T_1 - T_2) \tag{2-30}$$

where h is the convective heat-transfer coefficient, A is the heat-transfer area, T_1 is the temperature of hot layer, and T_2 is the temperature of the contacting object.

The heat-transfer coefficient is sometimes called the film conductance because of its relation to the conduction process in the thin, stationary layer (boundary layer) of fluid adjacent to the immersed body. The primary resistance to convective heat transfer is normally controlled within the thin layer where temperature effects are important. For complex systems, heat-transfer coefficients are usually obtained experimentally. In the case of fire gases, the following empirical relationship for h is suggested (Berry 1980):

$$h = 0.005\ (T_1 - T_2)^{1/3} \tag{2-31}$$

h is in units of kW/m^2-°K. A minimum h of 0.005 is used if T_1-T_2 < 1°K. Combining Equations (2-30) and (2-31) gives

$$\dot{Q}_{c1,2} = 0.005\ A\ (T_1 - T_2)^{4/3} \quad \text{and} \tag{2-32}$$

$$Q_{c1,2} = 0.005A\,(T_1 - T_2)^{4/3}\,(\Delta t) \qquad (2\text{-}33)$$

The input requirement for $Q_{c1,2}$ calculation is similar to $Q_{r1,2}$ calculation described in Section 2.3.1.1.

2.3.1.3 Conductive Heat Transfer

Compartment barriers are temporary heat sinks for energy generated from burning materials in an enclosure fire. The resultant heat gained by the barriers will eventually dissipate to the ambient air. The mechanism that transfers energy through a medium (i.e., the barrier's construction materials) is called heat conduction. A simple heat-transfer rate relationship within the medium, using the Fourier law, is expressed as a function of local temperature gradient, thermal properties of material, and heat-transfer area normal to the gradient direction. The following subsections show the usage of the Fourier law and other heat-transfer relations to develop conduction models for the fire compartment and for the equipment within the compartment. A transient numerical method is employed for approximation.

Within the Floor and Ceiling. In modeling heat conduction in the barriers, a one-dimensional time-varying form of the Fourier equation with convective boundary conditions is applied. The one-dimensional Fourier equation with internal energy conversion (Holman 1976) is given as

$$\frac{\partial^2 T}{\partial x^2} + \frac{q_i''}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \qquad (2\text{-}34)$$

assuming that thermal conductivity, k, can be taken as constant. The internal energy term q_i'' has a unit of heat rate per unit volume, and it is used here for endothermic decomposition of concrete barriers. Thermal diffusivity, α, is the ratio of the thermal conductivity to the thermal capacity of the material,

$$\alpha = \frac{k}{\rho C p} \qquad (2\text{-}35)$$

where ρ and Cp are material density and heat capacity, respectively. The units of α are in ft^2/h or m^2/s. In the application of transient numerical technique, the following finite-difference approximations are employed:

$$\frac{\partial^2 T}{\partial x^2} \approx \frac{1}{(\Delta x)^2} \left(T_{n+1}^t - 2T_n^t + T_{n-1}^t\right)$$

$$\frac{\partial T}{\partial t} \approx \frac{1}{\Delta t} \left(T_n^{t+1} - T_n^t\right) , \qquad (2\text{-}36)$$

where Δx is the finite distance between two nodal points, n denotes a nodal point, and T_{n+1}^t is the temperature at node n+1 at time t. Definitions for other terms are similar. Inserting Equation (2-36) into Equation (2-34) and solving for T_n^{t+1}, which has the unit of °K, results in a one-dimensional explicit nodal equation expressed as

$$T_n^{t+1} = T_n^t + \frac{\alpha \Delta t}{(\Delta x)^2} \left(T_{n+1}^t - 2T_n^t + T_{n-1}^t\right) + \frac{\Delta t}{\rho Cp} q_i'' \qquad (2\text{-}37)$$

The above equation is used in FIRIN. Note that T_n^{t+1} is determined in a time marching technique. The temperature of a node at a future time increment is expressed in terms of the adjacent (in the x-direction) nodal temperatures at the beginning of the time increment. As a stability requirement for numerical solution, the inverse of $\alpha\Delta t/(\Delta x)^2$, shown in Equation (2-37), must be greater than or equal to two; therefore, small time steps, Δt, are recommended. Details on q_i'' are given in Section 2.3.4 on thermal decomposition of concrete.

Equation (2-37) is appropriate for interior nodes of a body. For exterior nodal points subjected to convection, the following two boundary conditions in a one-dimensional case are required (by simple energy balance):

- Fire compartment side

$$-k \left.\frac{\partial T}{\partial x}\right|_{bi} = h_i \left(T_{hl} - T_{bi}\right) + \dot{Q}_{ri}'' \qquad (2\text{-}38)$$

- Cool side of the fire compartment (assuming $\dot{Q}''_{re} \approx 0$)

$$-k \left.\frac{\partial T}{\partial x}\right|_{be} = h_e\,(T_{be} - T_\infty) + \dot{Q}''_{re} \qquad (2\text{-}39)$$

where $-k \left.\frac{\partial T}{\partial x}\right|_{bi}$ = heat flux (kW/m^2) into the compartment barriers at the interior surface; it can be approximated as $-k\,(T_{bi+1} - T_{bi})/(\Delta x)$, where T_{bi+1} is the temperature at node bi+1

$-k \left.\frac{\partial T}{\partial x}\right|_{be}$ = heat flux (kW/m^2) out of the compartment barriers at the exterior surface; it can be approximated as $-k\,(T_{be-1} - T_{be})/(\Delta x)$

h_i, h_e = convective heat-transfer coefficients near the interior and exterior surfaces of the fire compartment (kW/m^2 - °K)

Thl = hot layer temperature (°K)

T_{bi}, T_{be} = temperatures of the interior surface and exterior surface of the compartment barriers (°K)

T_∞ = ambient temperature at the outside of the compartment (°K)

$\dot{Q}''_{ri}$, $\dot{Q}''_{re}$ = net radiative flux to the interior surface from fire, and from the exterior surface of the compartment to the ambient, respectively, (kW/m^2).

By rearranging Equations (2-38) and (2-39) for T_{bi} and T_{be}, respectively, we have

$$T_{bi} = \frac{h_i T_{hl} + kT_{bi+1}/\Delta x + \dot{Q}''_{ri}}{k/\Delta x + h_i} \qquad (2\text{-}40)$$

$$T_{be} = \frac{h_e T_\infty + kT_{be-1}/\Delta x}{k/\Delta x + h_e} \qquad (2\text{-}41)$$

The above two equations are used in FIRIN to determine temperatures of the convective boundary nodes for the ceiling and floor. The overall conductive heat rate through the barriers, by energy balance, is the net convective and radiative heat rates from hot layer and flames to the surfaces of the barriers. The sum of Equations (2-25) and (2-30) will give such net heat rate.

All thermal properties of materials, except the convective heat-transfer coefficient, that are required for heat calculations are available in the data base of FIRIN. The data are limited to the materials listed in Section 3.2.1 and are assumed to have linear temperature dependence. Convective heat-transfer coefficients are determined using the empirical temperature relationship given in Equation (2-31). The type of construction material as well as thickness of the barriers are the input variables to FIRIN for calculating T_n^{t+1}, T_{bi}, and T_{be}.

Within Compartment Walls. The descending of a smoke layer inside the fire compartment affects the net quantity of heat flux entering the various sections of the wall. The section exposed to the cold layer will receive direct flame radiation if the fire site is also in the cold layer, while the section immersed in the hot layer will receive both radiative heat flux and convective heat transfer from hot gases.

The numerical heat conduction model for interior nodes of the wall is identical to the model developed for the floor and ceiling in the above section. The major difference appears in the energy balance for the convective boundary nodes at the fire compartment side. Performing heat balance for these nodes gives

$$-k \left.\frac{\partial T}{\partial x}\right|_{bi} = \dot{Q}''_{net} \qquad (2\text{-}42)$$

where $\dot{Q}''_{net}$ is the net heat flux (kW/m^2) to the wall surface via various heat transfer mechanisms caused by the descending hot layer. Assuming the two-layer regime is applicable, $\dot{Q}''_{net}$ (for the wall section that is exposed to the cold layer) can be expressed as

$$\dot{Q}''_{net} = Q_{rw}/A_{cw}\Delta t \qquad (2\text{-}43)$$

where Q_{rw} is the direct radiative heat (kJ) to the wall given in Equation (2-24), and A_{cw} is the total surface area of the wall (m^2) section that is exposed to the cold layer. Because the hot gases transfer convective heat to the wall section immersed in the smoke layer, $\dot{Q}''_{net}$ for this wall section is as follows:

$$\dot{Q}''_{net} = (\dot{Q}_{r12} + \dot{Q}_{c12} / A_{hw}) \qquad (2\text{-}44)$$

where $\dot{Q}_{r12}$, $\dot{Q}_{c12}$ are the radiative and convective heat rates, respectively, from hot gases, denoted by subscript 1, to immersed object, denoted by subscript 2 (kW). A_{hW} is the total surface area of the wall section that is immersed in the hot gases (m^2). The input requirements to FIRIN are material type and thickness of the wall. The hot/cold layer interface will be determined within the program to signal the appropriate heat-transfer calculations for the two vertical wall sections.

Within Equipment Walls. In nuclear facilities, highly corrosion resistant stainless steel or a similar material is commonly used as construction material for equipment and vessels. This material has negligible thermal resistance through a fairly thin wall; therefore, we assumed that the temperature throughout the equipment wall is constant.

Instead of using the conduction model given for the compartment barriers, heat balance for the equipment walls can be performed in the following manner:

$$\dot{Q}_{ne} = mCp \; (T_e^{t+1} - T_e^{t}) / \Delta t \qquad (2\text{-}45)$$

where $\dot{Q}_{ne}$ = net heat rate to equipment (kW/m^2)

m = mass of equipment wall (kg)

C_p = heat capacity of wall material (kJ/kg - °K)

T_e^{t+1} = equipment wall temperature at time t+1 (°K)

T_e^{t} = equipment wall temperature at time t (°K)

Δt = time step increment(s)

Depending on the elevation of the hot/cold layer interface, the value of $\dot{Q}_{ne}$ is also affected by the two-layer regime. $\dot{Q}_{ne}$ can be obtained by summing the direct flame radiative heat rate and gases convective and radiative heat rates, respectively. By rearranging Equation (2-45), T_e^{t+1} is expressed in terms of T_e^t as follows:

$$T_e^{t+1} = T_e^t + \dot{Q}_{ne}\Delta t/mCp \tag{2-46}$$

The user inputs to FIRIN for the above calculations are equipment type, material of construction, elevation (with respects to the floor level), size, and the weight of wall material.

2.3.2 Mass Balance in the Fire Compartment

Models for species inventories of both hot and cold layers are developed for nuclear fuel cycle facility fires. Assumptions are made in the mass balance calculations that no mixing takes place between layers, and only air is found in the cold layer. It is further assumed that mixing within each layer is uniform. The ideal gas law is employed to obtain total mass and molar information for gas dynamic and heat-transfer calculations. The oxygen concentration calculated from compartment mass balance equations provides information for the adjustment of burning mode approximations discussed in Section 2.2.4.

2.3.2.1 Cold Layer

Since the cold layer is assumed to contain uncontaminated air, only oxygen and nitrogen balances are necessary. A list of the components in the continuity equation for both the oxygen and nitrogen balances in the cold layer follows:

Rate of change of moles of oxygen and nitrogen inside the cold layer depends on

- flow of oxygen and nitrogen into the cold layer from inlet ventilation
- flow of oxygen and nitrogen from the cold layer to outlet ventilation

- consumption of oxygen in the fire
- entrainment of oxygen and nitrogen by fire plume away from cold layer
- flow of oxygen and nitrogen from the cold layer to new flow paths.

The flows of oxygen and nitrogen through the ventilations can be obtained by multiplying molar density of air by ventilation rate during each time step. The results are corrected to temperature and pressure of the cold layer. The number of moles of oxygen consumed in the fire is back calculated using gaseous generation rates in combustion, which are approximated using the fuel material data and burning mode concepts (Section 2.2.4). Plume and new flow path entrainment is discussed in Section 2.3.5.

2.3.2.2 Hot Layer

Component balances in the hot layer include carbon dioxide, carbon monoxide, water, HCl, nitrogen, oxygen, and methane. The general continuity equation contains the following components:

Rate of change of moles of component inside the hot layer depends on

- flow of the component into the hot layer from inlet ventilation
- flow of the component from the hot layer to outlet ventilation
- decomposition of the component from concrete boundaries into the hot layer
- generation/consumption of the component in the fire
- entrainment of component by the fire plume into the hot layer
- flow of the component from the hot layer to new flow paths.

Methane shows up in the inventory to represent unburned pyrolysate from fuel decomposition. Carbon dioxide and water can be generated from combustion and from thermal decomposition of concrete. Hydrochloric acid vapor may be found in fuel cycle facility fires generated by the burning of wrapping materials made of polyvinyl chloride (PVC).

Material balance in the hot layer also includes both radioactive and combustion-generated particles. Various radioactive source term models are given and discussed in Section 2.4. The generation rates of soot particles from burning combustible materials commonly found in fuel cycle facility are described in Section 2.2.3.

2.3.3 Heat Balance in the Fire Compartment

In order to calculate hot layer temperature, an overall heat balance in the fire compartment must be performed. Using the principle of conservation of energy, and assuming that potential- and kinetic-energy terms are negligible, a simplified form of the internal energy and enthalpy equation can be formulated as follows:

Rate of change of internal energy of hot layer depends on

- flow of enthalpy (direct flame radiation) into the hot layer boundary
- flow of enthalpy into/out of the hot layer boundary
- energy (heat) added to the hot layer by combustion
- heat lost to equipment at risk inside the fire compartment
- enthalpy in the hot layer.

Rate of change of internal energy of hot layer after differentiation

$$= C_p \, (\rho_1 V_1 \, THl_1 - \rho_2 V_2 THl_2)/\Delta t \quad [=] \text{ kW} \tag{2-47}$$

where C_p = specific heat capacity of the hot layer at constant pressure (kJ/kg-°K)

ρ_1,ρ_2 = mass density of the hot layer, at new and old time step (kg/m^3), respectively. (They are obtained from mass balance)

V_1,V_2 = volume of fire compartment occupied by the hot layer at present and previous time step (m^3), respectively

THl_1,THl_2 = hot layer temperature at present and previous time step (m^3), respectively (°K)

Δt = time step increment (s)

The flow of enthalpy into the hot layer boundary after differentiation is equal to the flame radiation to the hot layer ($Q_{rh\ell/\Delta t}$), which is given in Equation (2-16).

The flow of enthalpy into/out of the hot layer boundary after differentiation equals heat gained/lost by convection and radiation from/to the ceiling, floor, and wall of the fire compartment + heat gained/lost by ventilation to/from the hot layer. The equation is

$$= (Q_{r1c} + Q_{r1w} + Q_{r1f} + Q_{c1c} + Q_{c1w} + Q_{c1f}) \;/\; \Delta t \; +$$

$$m \, C_p \, (THl_2 - T_i) \;/\; \Delta t \qquad (2\text{-}48)$$

where $Q_{r1c}, Q_{r1w}, Q_{r1f}$ = radiative heat transfer between hot layer and ceiling, wall, and floor, respectively, (kJ) [see Eq. (2-25)]

$Q_{c1c}, Q_{c1w}, Q_{c1f}$ = convective heat transfer between hot layer and ceiling, wall, and floor respectively, (kJ) [see Equation (2-30)]

m = mass of hot gases in smoke layer (kg) obtained from mass balance

THl_2 = hot layer temperature at previous time step (°K)

T_i = initial temperature of the compartment before fire (°K).

The energy (heat) added to the hot layer by combustion after differentiation

= convective heat from burning

$$= Q_c/\Delta t \qquad (2\text{-}49)$$

which is calculated as shown in Equation (2-29). The heat lost to equipment at risk inside the fire compartment after differentiation equals the heat lost by hot layer convection and radiation to equipment

$$= (Q_{r1e} + Q_{c1e})/\Delta t \qquad (2\text{-}50)$$

where Q_{r1e} is the hot layer radiation to equipment (kJ) [see Equation (2-25)], and Q_{c1e} is the hot layer convection to equipment (kJ) [see Equation (2-30)]. The enthalpy in hot layer after differentiation

$$= \rho_2 V_2 C_p \ (TH1_2 - T_i) \qquad (2\text{-}51)$$

Combining all the above equations and solving for $Th1_1$, we get

$$TH1_1 = \left(\frac{P_2\ V_2}{P_1\ V_1}\right) TH1_2 + \frac{1}{\rho_1 V_1 C_p} [Q_{rh\ell} + Q_{r1c} + Q_{r1w} + Q_{r1f} + Q_{c1c} + Q_{c1w} + Q_{c1f}$$

$$+ mC_p \ (TH1_2 - T_i) + Q_c - Q_{r1e} - Q_{c1e} + \rho_2 V_2 C_p \ (TH1_2 - T_i)]$$

This equation is used in FIRIN to predict 'new' hot layer temperature as a function of 'old' hot layer temperature, convective and radioactive heat transfer, and enthalpy associated with ventilation flow. The major input parameters, other than those given earlier for heat transfer calculations, are initial compartment temperature and pressure, elevation of inlet and outlet ventilation ducts, initial ventilation rate, and vertical elevation of the fire.

2.3.4 Thermal Decomposition of Concrete

Concrete is commonly used as the building material for nuclear fuel cycle facilities. Typical concrete barriers found in this facility have thicknesses ranging from 6 in. to several feet. During a fire, the gas released by thermal decomposition of concrete has the potential of sufficiently increasing pressures to endanger the integrity of a facility ventilation and filteration system. Depending on the nature of the concrete, up to 30 wt% of the material may be volatilized at elevated temperature (Powers 1977).

Thermogravimetric analyses of small calcareous concrete samples at Sandia National Laboratories reveal the following three major weight-loss events over the 20° to 1200°C temperature range (Powers 1977):

- loss of evaporable water ($\leq$5 wt% of concrete mass at 20° to 200°C)
- loss of chemically constituted water ($\leq$5 wt% of concrete mass at 200° to 600°C)
- loss of carbon dioxide (~22 wt% of concrete mass at $\geq$ 650°C).

The kinetic equations describing the above weight-loss events may be empirically fitted using first-order rate laws. Powers (1977) formulated these Arrhenius rate equations in the following manner:

$$\frac{dY_1}{dt} = (1-Y_1) \exp [(14.07 - 5557)/T] \tag{2-52}$$

$$\frac{dY_2}{dt} = (1-Y_2) \exp [(28.31 - 20560)/T] \tag{2-53}$$

$$\frac{dY_3}{dt} = (1-Y_3) \exp [(16.8 - 19362)/T] \tag{2-54}$$

where Y_i denotes the fraction of gas released and the subscripts 1,2,3 refer to evaporable water (water), chemically bound water (water vapor), and carbon dioxide, respectively. As before, T is the concrete temperature in degrees kelvin. In the application of a finite difference technique on modeling mass transfer in concrete, Beck and Knight (1980) approximated the above equations with

$$Y_1^{t+1} = 1 - (1 - Y_1^t) \exp [-\Delta t (\exp ((14.07 - 5557)/T))] \tag{2-55}$$

$$Y_2^{t+1} = 1 - (1 - Y_2^t) \exp [-\Delta t (\exp ((28.31 - 20560)/T))] \tag{2-56}$$

$$Y_3^{t+1} = 1 - (1 - Y_3^t) \exp [-\Delta t (\exp ((16.8 - 19362)/T))] \tag{2-57}$$

where Y_1^{t+1} is the fraction of evaporable water released at time t + 1. Definitions for other Y terms are similar.

These equations are used in FIRIN to predict the material released from heated concrete during a fire. The temperatures used in these equations are the nodal temperatures of the barriers (see Section 2.3.1.3). The required inputs for these calculations are thickness and dimensions of the barrier. With concrete density available in the data base as the function of temperature, both mass and molar evolution rates of water, water vapor, and carbon dioxide are calculated for mass and energy balance, and gas dynamic consideration.

Furthermore, the internal energy term for barrier conduction can be expressed as the summation of energy-absorption rates for the three decomposing species:

$$q_i'' = \Delta H_1 \rho_1 \frac{dY_1}{dt} + \Delta H_2 \rho_2 \frac{dY_2}{dt} + \Delta H_3 \rho_3 \frac{dY_3}{dt} \qquad (2\text{-}58)$$

where ΔH_i is the heat of degradation to form i (kJ/kg), and ρi is the mass density of i (kg/m^3).

The above equation assumes flow resistance of vaporized water and carbon dioxide equal to zero within concrete. Again, q_i'' has units of kW/m^3. Currently, the ρi values listed in FIRIN are 101, 101, and 975 kg/m^3, for water, water vapor, and carbon dioxide, respectively, while the ΔH_i values are 2.79×10^3, 5.81×10^3, and 4.18×10^3 kJ/kg, respectively.

2.3.5 Fluid Flows

Three major mechanisms of fluid motion can be identified in a typical fuel cycle facility fire that would enable the transport of radioactive aerosols. They are fluid flows caused by

- fire plume entrainment
- ventilation
- additional flow paths.

The characteristics of each mechanism are discussed in the following sections. Model equations are derived and given for characteristics that govern the release of radioactive particles in fires.

2.3.5.1 Fire Plume Entrainment

A fire plume can be pictured as a continuous rising mass of hot gases, vapors, and particulate materials generated in the flame beneath it. Because of oxygen demand for combustion, the flame acts as a natural pump, which draws in air from its vicinity. Some of the drawn air will be consumed in the flame, while the rest is entrained into the plume to mix and cool the hot gases. In an enclosure fire, the hot layer or smoke layer is the resultant mass from the rising plume.

Frequently, fluid motion near a burning object has turbulent behavior caused by the entrainment process. If the burning object or its vicinity is contaminated with radioactive particles, they can be entrained into the hot layer; therefore, characterizing this turbulent fluid motion is important in order to predict radioactive source terms in fuel cycle facility fires. At PNL, parameters such as rate of entrainment and temperature have been correlated with radioactive releases from burning objects contaminated with a known quantity of radioactive materials.

FIRIN uses the equations derived by Zukoski, Kubota, and Cetegen (1980) to calculate entrainment of gases by the fire plume. According to Zukoski's theory, the plume mass flow rate, M_{pt}, can be calculated by

$$\dot{M}_{pt} = 0.21\,\rho\sqrt{qz}\,z^2\,Q^{*1/3} \tag{2-59}$$

where $\dot{M}pt$ = plume mass flow rate, g moles/s

ρ = gas density, g mole/m^3

q = gravitational constant, m/s^2

z = flame height, m

Q^* = dimensionless heat addition parameter

Using the ideal gas law, the gas density can be calculated by

$$\rho = \frac{n}{V} = \frac{P}{RT} \tag{2-60}$$

where n = number of moles of gas, g moles

V = volume, m^3

P = pressure, atm

R = gas constant, (atm m^3)/(g mole °K)

T = temperature, °K

Equation (2-59) can be rewritten as

$$\dot{M}_{pt} = 0.21 \frac{P}{RT} \sqrt{g}\, z^{2.5}\, Q^{*1/3} \qquad (2\text{-}61)$$

The dimensionless heat parameter, Q*, is used in several empirical relationships developed by Zukoski. Q* is defined as

$$Q^* = \dot{Q}/(\rho\, Cp\, T\, \sqrt{gz}\, z^2) \qquad (2\text{-}62)$$

where $\dot{Q}$ = heat release rate, kW

Substituting (P/RT) for ρ, this equation becomes

$$Q^* = \dot{Q}/[(P\, Cp/R)\, \sqrt{g}\, z^{2.5}] \qquad (2\text{-}63)$$

Zukoski noted that for a wide range of natural gas fire sites the flame height, z, followed the relationship

$$z = 0.23\, \dot{Q}^{0.4} \qquad (2\text{-}64)$$

This equation has been used in FIRIN as the best available means of calculating flame height for all final types in the FIRIN data base.

During each time step of the fire, FIRIN calculates the heat release rate based on burn parameters described in Section 2.2. Pressure and temperature of the fire compartment are also internally calculated. Equation 2-64, 2-63, and 2-61 are then used to determine the flow rate of gases in the plume.

2.3.5.2 Ventilation

Most nuclear fuel cycle facilities use forced air ventilation. Outlet ventilation is commonly found near the floor level, while inlet ventilation is often located near the ceiling. In a fire, flow in this type of orientation tends to draw the smoke layer down to the floor level quite rapidly. Major nuclear fuel cycle facility fires may be underventilated because of oxygen deficiency in the hot layer, which reaches the flame zone early in the fire. The ventilation flows may carry radioactive aerosols with combustion aerosols to the building exterior through the facility ventilation system.

High-efficiency particulate air (HEPA) filters are commonly used in the facilities to prevent the outside environment from being exposed to airborne radioactive particles. In a fire, exposure of a HEPA filter to heat and smoke significantly changes the filter's operating characteristics. Investigators at New Mexico State University (NMSU) and LANL have investigated the characteristics of HEPA filters plugging with combustion aerosols (Fenton et al. 1983). Two fuels, polystyrene and polymethyl methacrylate, commonly found in nuclear fuel cycle facilities as bagging materials and glove box viewing windows, were selected for their experiments to produce combustion aerosols. An empirical model for ventilation flow through the HEPA filter was formulated by applying the preliminary experimental results from burning polystyrene.

Pressure drop across a filter can be related to flow rate as follows:

$$\Delta P = \dot{Q}R \qquad (2\text{-}65)$$

where ΔP is the change in pressure (or pressure drop), atm, $\dot{Q}$ is the fluid flow rate (or ventilation rate), m^3/s, and R is the filter resistance.

The magnitude of this filter resistance depends on aerosol type, aerosol size distribution and concentration, water content, fluid temperature, and other factors, such as flow conditions in the fluid stream. Filter resistance can be written as a monotonically increasing function of the total mass of particles accumulated on the filter (Fenton et al. 1983):

$$R = (1 + \beta M_s + \alpha M_s^2)\, R_o \tag{2-66}$$

where β and α are the filter resistance parameters determined by experimentation, M_s is the total mass of particles on the filter, and R_o is the value of R for a clean filter. The preliminary results from burning polystyrene at various burning rates give the average β value of 9.79 and α value of 0.01395 (Fenton et al. 1983). Rearranging the pressure drop equation for $\dot{Q}$ and replacing R with the above equation gives

$$\dot{Q} = \Delta P/(1 + 9.79\, M_s + 0.01395\, M_s^2)\, R_o \tag{2-67}$$

Using this equation and the appropriate pressure drop, inlet and outlet ventilation rates ($\dot{Q}_{in}$ and $\dot{Q}_{out}$) can be expressed as

$$\dot{Q}_{in} = (P_1 - P_2)/(1 + 9.79\, M_s + 0.01395\, M_s^2)\, R_o \tag{2-68}$$

$$\dot{Q}_{out} = (P_2 - P_3)/(1 + 9.79\, M_s + 0.01395\, M_s^2)\, R_o \tag{2-69}$$

where P_1 = pressure at inlet ventilation, atm

P_2 = transient compartment pressure, atm

P_3 = pressure at outlet ventilation, atm

$R_o = (P_1 - P_{2i})/\dot{Q}_i$

P_{2i} = initial compartment pressure, atm

$\dot{Q}_i$ = initial ventilation rate, m^3/s.

The transient compartment pressure is calculated using the ideal gas law. M_s is obtained from the material balance of the hot layer and from accumulative mass inventory on filter media assuming all particulate materials will be captured by the filter. The required inputs to FIRIN are $\dot{Q}_i$, P_1, P_{2i}, and P_3.

2.3.5.3 Additional Flow Paths

Openings other than ventilation ducts to a fire compartment are considered to be additional flow paths where radioactive materials escape to the outside. Gloveboxes are examples of compartments where gloveports may be additional flow paths if the gloves burn in a fire.

Characterizing flows through the paths is an available option as part of FIRIN's capabilities. Because a large quantity of mass can escape through the paths in the absence of filtering media, being able to quantify the amount of airborne radioactive materials released is important. The required inputs are number of additional flow paths, their failure times, size of openings, elevations of the paths, and the pressures at the exits of all specified paths. Currently, FIRIN allows up to 20 flow paths.

When FIRIN is used to simulate nuclear facility fires, both radioactive and fire-generated particles (i.e., soot) can be monitored for mass release rates (in g/s) through the additional flow paths. The model equations are as follows:

- Soot release rate, $\dot{V}_{sr}$ (through additional flow paths)

$$\dot{V}_{sr} = \left(\frac{M_{shl}}{V_{hl}}\right)\left(\frac{RT_{hl}}{P_2}\right)\dot{N}_{fp} \tag{2-70}$$

- Radioactive release rate, $\dot{V}_{rr}$ (through additional flow paths)

$$\dot{V}_{rr} = \left(\frac{M_{rhl}}{V_{hl}}\right)\left(\frac{RT_{hl}}{P_2}\right)\dot{N}_{fp} \tag{2-71}$$

where M_{shl}, M_{rhl} = mass of soot and airborne radioactive materials in the hot layer, (g)

V_{hl} = volume of hot layer, (m^3)

R = universal gas constant = $8.206 \times 10^{-5} \frac{m^3 atm}{g\ mole\ °K}$

T_{hl} = hot layer temperature, °K

P_2 = transient compartment pressure, atm

$\dot{N}_{fp}$ = molar rate of gases through a flow path, g mole/s.

FIRIN determines $M_{sh\ell}$ and $M_{rh\ell}$ by material balance, while $T_{h\ell}$ is calculated by performing heat balance in the fire compartment. $V_{h\ell}$ is estimated in FIRIN using the ideal gas law, and $\dot{N}_{fp}$ is calculated based on the concept of flow through an orifice corrected to temperature and pressure.

2.3.6 Particle Depletion

Mechanisms that were identified as being potentially important to the depletion of aerosol particles are the following:

- sedimentation
- Brownian diffusion
- diffusiophoresis
- thermophoresis.

Each mechanism was evaluated, and preliminary predictive equations were derived to quantify the particle deposition caused by each mechanism. A simple two-layer model was used to describe particle transport and deposition in the fire compartment. Each layer was considered well-mixed. Particles can enter the lower (cold) layer by gravity settling. Flow entrained in the fire plume can carry the lower compartment particles to the upper (hot) layer. Deposition mechanisms modeled in the hot layer are gravity settling, thermophoresis, diffusiophoresis and Brownian diffusion. Because only the 'heavier' particles are in the cold layer, deposition was restricted there to gravity settling. A Laplace Transform solution was obtained for the unsteady-state particle behavior over a time step Δt.

Sedimentation

The removal rate constant for gravity settling is simply the product of settling velocity and surface area:

$$K_s = V_s A_s \tag{2-72}$$

where V_s = particle settling velocity, m/s

A_s = horizontal upward facing area, m^2.

Particle settling velocity, V_s, can be related to particle size and gas properties by means of Stokes' law:

$$V_s = \frac{\rho_p d_p^2 g C_m}{18\mu} \tag{2-73}$$

where ρ_p = effective particle density, kg/m^3

d_p = effective particle diameter, m

g = acceleration due to gravity, m/s^2

C_m = Cunningham correction factor, dimensionless

μ = gas viscosity, kg/m•s

Combining the previous two equations leads to

$$K_s = \frac{\rho_p d_p^2 g C_m A_s}{18\mu} \tag{2-74}$$

The settling area, A_s, is the floor of the compartment.

Stokes' law is valid for Reynolds numbers up to ~1 (Knudsen and Katz 1958), which corresponds to an aerodynamic particle diameter of ~70 μm. If larger particles are present, their settling velocities are computed using a modified equation that would account for the change in drag coefficient caused by the change in Reynolds number.

Brownian Diffusion

Particles exhibit a diffusivity as a result of momentum exchanges with surrounding gas molecules. For the case where the gas is isothermal and has no molecular weight gradients, the particle mobility arises from Brownian diffusion. Particles would experience a net flux toward surfaces because of concentration gradients; particle capture by the surface is assumed to reduce the gas-phase concentration of particles to zero.

The efficiency of deposition depends both on the diffusivity and the fluid flow pattern past a surface. For naturally convected flows, a mass transfer coefficient can be predicted using a heat transfer/mass transfer analogy (Knudsen and Hilliard 1969; Bird et al. 1966):

$$\frac{k_D \ell}{D} = 0.13\ (\mathrm{Gr}\ \mathrm{Sc})^{1/3} \tag{2-75}$$

where k_D = mass transfer coefficient, m/s

ℓ = length of surface in direction of flow, m

Gr = Grashof number

Sc = Schmidt number = $\mu/\rho D$.

The Grashof number characterizes the flow of naturally convected boundary layers. It may be expressed as

$$\mathrm{Gr} = \frac{\ell^3 g}{\nu^2}\,\frac{\Delta\rho}{\rho} \tag{2-76}$$

where ℓ = length of surface in direction of flow, m

g = acceleration due to gravity, m/s^2

ν = kinematic viscosity of gas, m^2/s

$\Delta\rho$ = density difference in fluid-bulk compared to fluid at the surface, kg/m^3

ρ = bulk density, kg/m^3.

The density difference, $\Delta\rho$, is the total value that would result from both temperature differences and differences in molecular weight.

Since the layers are assumed to be well-mixed, the density difference in fluid bulk compared to fluid at the surface is proportional to the difference in temperature between the bulk fluid and surface fluid. Therefore,

$$\frac{\Delta\rho}{\rho} = \frac{T_{surface} - T_{avg}}{T_{avg}} \qquad (2\text{-}77)$$

Diffusiophoresis

The condensation of steam onto surfaces causes particle drift by two mechanisms: 1) a net flow of gas occurs toward the cool surface, often termed Stephan flow, which convects particles toward the surface; and 2) the gradient in steam concentration results in a molecular weight gradient that causes particles to experience a force in the direction of the gradient. For steam air mixtures, these two mechanisms are opposing; however, the Stephan flow dominates and the particles are convected to the surface and scrubbed by the condensing steam.

The removal rate constant, K_D, may be expressed as

$$K_D = V_D A_D \qquad (2\text{-}78)$$

where V_D = particle deposition velocity, m/s

A_D = surface area for diffusiophoretic deposition, m^2.

The net deposition velocity caused by both Stephan flow and the molecular weight gradient may be related to particle and gas parameters by means of a formula presented by Waldmann and Schmitt (1966):

$$V_D = - 1 + \sigma_{12} X_2 \frac{D}{X_2} \frac{dX}{dy}\bigg|_w \qquad (2\text{-}79)$$

where V_D = drift velocity of a particule caused by condensation of steam or ice, m/s

σ_{12} = a parameter whose value is dependent on the molecular weights of the two gases present, dimensionless

X_2 = mole fraction of non-condensible gas

D = diffusivity of steam/air mixture, m^2/s

X = mole fraction of water vapor

y = distance measured from the surface onto which condensation occurs, m

w = a subscript referring to properties at the wall (surface) onto which steam condenses.

The value of σ_{12} depends on particle and gas parameters. For large particles (diameter large compared to the mean freepath of the gas) Waldmann and Schmidt (1966) present an empirical formula:

$$\sigma_{12} = 0.95 \frac{m_1 - m_2}{m_1 + m_2} - \frac{d_1 - d_2}{d_1 + d_2} \tag{2-80}$$

where m = molecular weight of the gases

d = atomic diameter of the gases

1,2 = subscripts referring to condensible and noncondensible gas, respectively.

$\left.\frac{D}{X_2}\frac{dX}{dy}\right|_w$ is the velocity of steam to the wall and may be calculated by

$$V_s = \frac{Hc}{\lambda} \frac{(T_{Hl} - T_W)}{\rho_g} \tag{2-81}$$

where V_s = velocity of steam to the wall, m/s

H_c = condensing heat transfer coefficient, $J/m^2s°K$

λ = heat of condensation, J/g

T_{Hl} = hot layer temperature, °K

T_W = wall temperature, °K

ρ_g = gas density, g/m^3.

Thermophoresis

Particles experience a radiometric force when they are suspended in a gas in which a temperature gradient exists. In general, the drift velocity is directly proportional to the magnitude of the temperature gradient (Waldmann and Schmitt 1966; Goldsmith and May 1966; Gieseke 1972):

$$V_T = -C_1 \frac{dT}{dy} \qquad (2\text{-}82)$$

where V_T = thermophoretic drift velocity, m/s

C_1 = a constant whose value depends on particle and gas properties, m^2/s•°K

$\frac{dT}{dy}$ = temperature gradient, °K/m.

The removal rate constant, K_T, resulting from thermophoresis is the average of the products of deposition velocity and surface area:

$$K_T = V_T A_T \qquad (2\text{-}83)$$

where A_T = surface area for thermophoresis, m^2.

The temperature gradient that causes particle drift also causes the transport of sensible heat from the gas phase. The rate of sensible heat loss may be related to the temperature gradient in the gas adjacent to the surface:

$$\text{heat loss rate} = -kA_T \left.\frac{dT}{dy}\right|_w \qquad (2\text{-}84)$$

where k = thermal conductivity of gas, W/m•K.

The heat loss rate is calculated in FIRIN. Therefore,

$$\left.\frac{dT}{dy}\right|_{w} = \frac{\text{heat loss rate}}{-k\ A_T} \qquad (2\text{-}85)$$

and

$$V_T = C_1\ \frac{\text{heat loss rate}}{k\ A_T} \qquad (2\text{-}86)$$

The numerical value of C_1 depends on particle and gas properties; predictive equations that account for important parameters are listed in Waldmann and Schmitt 1966; Goldsmith and May 1966; and Gieseke 1972. Rough estimates of C_1/α indicate that this quantity has a numerical value of $\sim 10^{-3}/°C$.

The thermal diffusivity α is equal to $k/\rho Cp$. Therefore,

$$V_T = 10^{-3}\ \frac{HLR}{\rho\ Cp\ A_T} \qquad (2\text{-}87)$$

where HLR = heat loss rate, kW

Cp = specific heat of air, J/kg•°K

ρ = density of gas, kg/m^3

A_T = surface area, m^2.

2.4 RADIOACTIVE SOURCE TERM MODELS

Several major mechanisms are identified as causing radioactive material releases from fires in a nuclear fuel cycle facility. These mechanisms are modeled using information generated in experiments at PNL as well as from current literature. Models are built into the FIRIN code in the form of subroutines enabling estimation of the mass rate and size distribution of radioactive particles becoming airborne in a fire. The models and event-controlling parameters involved are discussed in the following sections.

Radioactive releases mechanisms from fires include the following:

- burning of contaminated combustibles
- heating of noncombustible contaminated surfaces
- heating of unpressurized radioactive liquids
- pressurized releases of radioactive materials
- burning radioactive pyrophoric metals.

2.4.1 Burning of Contaminated Combustibles

Radioactive particles may become airborne in nuclear fuel cycle materials from burning contaminated combustibles. Waste materials such as rags, gloves, plastic bags, and combustible portions of gloveboxes can contribute to the fuel loading as combustible solids. Liquids such as solvent extraction fluids and cleaning fluids may also be involved in a fire.

2.4.1.1 Solids

A series of 25 experiments were performed to provide data for the radioactive aerosol source term subroutine of the FIRIN fuel cycle facility compartment fire code (Halverson and Ballinger 1984). The experiments involved burning various combustible materials with radioactive contamination of several forms. The data collected in the experiments included cumulative radioactive aerosol release, cumulative smoke release, and mass loss rate of the combustible material.

Table 2.4 lists the combustible materials, contaminant materials, and the various parameters that were varied during the experiments.

The radioactive source term (RST) release was correlated with the parameters that were varied in the experiments. Experimental data can be found in Appendix A. The correlations were carried out using the MINITAB statistical package. Linear regressions were run on the data, and the regression that fit the data best was chosen as the FIRIN model. The goodness of fit was determined by comparing the R^2 values obtained in the regression analysis. The

TABLE 2.4. Experimental Parameters

Combustible Materials

Cellulose
Polychloroprene
Polystyrene
Polymethyl methacrylate

Contaminant Materials

Depleted uranium dioxide (DUO) powder
Uranyl nitrate hexhydrate (UNH) solution
Uranyl nitrate hexahydrate salt

Other Parameters

External heat flux
Oxygen concentration
Airflow
Contaminant concentration
Ignition system

higher the R^2, the better the fit. Standard t-tests were used to determine the significance of the regression constants. Those constants that are statistically no different from zero are set at zero to simplify the regression equation.

A separate equation (in some cases, more than one equation) is used to describe RST release from each type of combustible material. These equations are shown in Table 2.5. The cellulose and PC release predictions are given an upper limit of 0.01 and 0.05, respectively. Polystyrene and PMMA are assumed to be spike releases occurring in the time step in which the combustible starts to burn.

Other combustible solids in the FIRIN data base are PVC and wood. Polyvinyl chloride releases are assumed similar to PC, since both materials are charring polymers. The cellulose equations are used for wood. If combustible

TABLE 2.5. Radioactive Source Term Equations for Burning Contaminant Combustible Solids

Combustible Material	Contaminant Form	Equation
Cellulose	Air-dried UNH	$\dot{M}_r = 7.40E\text{-}7 \times W_r \times \dot{M}b \times QT$
	UNH liquid	$\dot{M}_r = 6.08E\text{-}8 \times W_r \times \dot{M}b \times QT$
	DUO powder-flaming combustion	$\dot{M}_r = 1.18E\text{-}9 \times W_r \times Mb \times V \times UC \times QT$
	DUO powder-smoldering combustion	$M_r = 5.64E\text{-}6 \times M_b \times W_r$
Polychloroprene	UNH liquid	$\dot{M}_r = 0.104 \times W_r \times \dot{S}_r$
	DUO powder, air-dried UNH	$\dot{M}_r = 0.0227 \times W_r \times \dot{S}_r$
Polystyrene	UNH liquid	$\dot{M}_r = 0.02 \times W_r$
Polymethyl methacrylate	Air-dried UNH	$\dot{M}_r = 0.007 \times W_r$
	UNH liquid	$\dot{M}_r = 0.02 \times W_r$
	DUO powder	$\dot{M}_r = 0.05 \times W_r$

$\dot{M}_r$ = mass release rate of radioactive particles, g/s

M_r = mass release of radioactive particles, g

$\dot{M}_b$ = mass loss rate of fuel, g/s

QT = external heat flux to the combustible, kW

$\dot{S}_r$ = smoke release rate, g/s

UC = uranium concentration, gU/g combustible

V = air velocity, cm/s

W_r = mass of radioactive material, g

materials other than those in the FIRIN data base are input to the code, a radioactive source term release of 1% is used, and the rate of release assumed to be proportional to the mass burn rate.

The size distribution of radioactive particles made airborne was also measured for some of the experiments. This information is used in FIRIN to characterize the size of accident aerosols from burning contaminated solids. If combustible materials other than those in the FIRIN data base are input to the code, FIRIN assumes the radioactive aerosol produced is similar in size to that of ball-milled uranium given in Mishima and Schwendiman (1973a).

2.4.1.2 Liquids

Fires involving solvent extraction fluids or combustible liquids used to clean or maintain process equipment in a nuclear fuel cycle facility may cause radioactive materials in contact with or in solution with the burning fuel to be released. Experiments at PNL, Savannah River, Germany, and France have examined the release of radioactive materials from pool fires.

Halverson et al. (1987) report small-scale experiments at PNL in which a solvent/acid combination was burned. Either the organic, the acid, or both were contaminated with uranium before burning. The radioactive release was larger in the burns that gave off more smoke, suggesting that uranium is carried up with the smoke or that the smoke producing mechanisms (i.e., a higher more violent burn rate involving the TBP in solution) also produce uranium aerosols. Another explanation is that the UNH is chemically tied to the TBP as a coordination complex. When this complex burns, UNH is directly involved in the combustion process. A maximum of 5% smoke was given off in these tests with up to 7% uranium release.

Experiments reported by Jordan and Lindner (1983, 1985) indicate uranium release is a function of uranium concentration which in turn is a function of burn rate. Therefore, in these experiments, burn rate influences uranium release. A lower uranium concentration used in the burn tests may be the reason the Jordan and Lindner experiments obtained a maximum of 1.5% uranium release compared to up to 7% uranium released in the PNL experiments. About 14% smoke was given off when 70/30 kerosene-TBP was burned, and TBP was identified as the major smoke producer.

Malet et al. (1983) describe pool fire tests carried out at the Cadarache Nuclear Research Center in France. Less than 1% of the contaminants (cerium and thorium) reached the filters in the small-scale fire tests and less than 0.1% in the large-scale tests. Although a very small amount of the contaminant is reported to be left in the organic residue after the burn, the complexity of analysis techniques and uncertainties in mass balance preclude the use of these data in estimating the amount airborne.

Earlier experiments at PNL (Mishima and Schwendiman 1973b; Sutter, Mishima, and Schwendiman 1974) burned contaminated solvent. Small-scale experiments resulted in a 0-1% or less release of all contaminants except for iodine of which 85% was made airborne. The large-scale test resulted in a release of 0.2% strontium. Harper and Jolly (1964) also reported 1% or less release from contaminated pool fires.

As much as 11% uranium was made airborne when gasoline was spilled over contaminats and burned outdoors (Mishima and Schwendiman 1973a). In the tests, surface type and airflow rate greatly influenced releases. These experiments simulated outdoor transportation accidents and are not as applicable to contaminated combustible liquid fires inside nuclear fuel cycle facilities as the other data cited.

The only data on release of volatiles from burning contaminated, combustible liquids are 64-84% release of iodine in the small-scale experiments reported by Mishima and Schwendiman (1973b). If the maximum release (84%) is assumed to occur uniformly throughout the burn, the following equation may be used to predict release from volatiles:

$$\text{mass rate (g/s)} = 0.84\ Wr/t \tag{2-88}$$

where Wr is the grams of radioactive volatiles in the solvent and

$$t = \frac{\text{mass of fuel (g)}}{\text{mass loss rate (g/s)}} \tag{2-89}$$

For all other contaminants, Halverson et al. (1987) provide the most complete and conservative data.

These data show that uranium release is greatly influenced by smoke release. At the start of a fire involving kerosene/TBP mixtures, the more volatile component, kerosene, burns first and TBP concentrates as the burn progresses. However, toward the end of the fire or if the fire burns more rapidly causing turbulence in the solvent, TBP burns, producing most of the smoke. Radioactive contaminants appear to be carried up with the smoke during this smoke production process. At high burn rates radioactive particles may be spewed up by the boiling or frothing of contaminated acid under the burning solvent. A linear regression on the data provides the relationship:

$$\text{Fraction Uranium} = 1.38 \text{ Fraction Smoke} - 0.0033 \tag{2-90}$$

Taking the derivative with respect to time, the constant drops out (making the equation slightly more conservative), and the source term equation becomes:

$$\frac{dFU}{dt} = 1.38 \frac{dFS}{dt} \tag{2-91}$$

For each time step, FIRIN calculates the mass rate of uranium released based on the release rate of smoke by

$$\text{U release rate (g/s)} = 1.38 \frac{\text{smoke release rate (g/s)}}{\text{g combustible liquid}} \times \text{g uranium in liquid} \tag{2-92}$$

The mass of combustible liquid and mass of uranium at risk, either in solution or in contact with the combustible liquid, are input to the code. FIRIN calculates smoke release rate and, using the above equation, uranium release rate.

The size distribution of radioactive aerosols was measured in one of the PNL experiments reported by Halverson et al. (1987). An airborne mass median diameter of 0.6 and geometric standard deviation of 3.1 resulted. Table 2.6 lists the data used in FIRIN for sizes of radioactive airborne particles from burning contaminated combustible liquids.

TABLE 2.6. Radioactive Particle Size Distribution from Burning Contaminated Combustible Liquids (Halverson et al. 1987)

Particle Size (μ)	% of Particles
<0.1	5
0.1 - 0.3	21
0.3 - 0.5	15
0.5 - 0.7	20
0.7 - 0.9	11
0.9 - 1.1	6
1.1 - 2	8
2 - 6	10.8
6 - 10	2.9
10 - 20	0.3
>20	0.0

2.4.2 Heating of Noncombustible Contaminated Surfaces

Fires heating contaminated surfaces cause radioactive particles to be released because of induced air currents caused by the fire, changes in the contaminant moisture content, and changes in radioactive particle adhesion to surfaces and other particles.

Experiments in which powders were heated to varying temperatures at different airflow rates (Mishima, Schwendiman, and Radasch 1968a) show that the quantity of radioactive material released varies with the temperature of the surface, velocity of air entraining particles, and characteristics of the powder (e.g., size distribution and agglomeration tendencies).

A plutonium nitrate solution was dried and the residual solids heated in other experiments (Mishima, Schwendiman and Radasch 1968b). The release rate of radioactive particles from this set of experiments varied with temperature of the surface and velocity of air-entraining particles but was much less for all conditions than the powder giving the greatest releases in the powder experiments.

Because the effect of powder characteristics such as bulk density, particle density, moisture content, size distribution, and agglomeration tendencies on the release rate is difficult to determine from the data at hand

and may be difficult to estimate as input by the user of the code, the model draws on the data from the powder giving the greatest releases at the various temperatures and flow rates (partially oxidized oxalate). Table 2.7 shows that the maximum release from different powders differs by one and one half orders of magnitude and that all releases are less than 1% of the total mass of material at risk.

Table 2.8 lists the data from which the model for this mechanism is derived. The best fit of the data shows the mass rate as a function of the square of the air temperature as shown in the equation below:

$$\text{mass rate (g/s)} = (9.85 \times 10^{-8})T^2\ W_r \tag{2-93}$$

where T is the temperature of the surface on which contaminant rests, °C, and W_r is the total mass of radioactive material, g. T is determined by FIRIN calculations. FIRIN requires W_r as input.

Particles entrained have a size distribution generally 26% to 68% of that of their precursor (Mishima, Schwendiman, and Radasch 1968a). The size varies with the airflow rate and the powder behavior at high temperatures. Particle size of original powders is expected to range from 15 to 50 µm MMD; therefore, airborne particles may range from 3.9 to 34 µm MMD with a range of 8 to 36 µm.

TABLE 2.7. Characteristics and Range of Releases from Radioactive Powders Studied

Material	Original Particle Size	Range of Releases (%/h)
Pu oxalate	50 µm MMD	0.38 - 0.90
Pu F_4	26 µm MMD, 38 µm MMD agglomerates	0.007 - 0.05
PuO_2	15-44 µm	6.1×10^{-6} - 0.025
Pu partially oxidized oxidate	32 µm MMD	0.051 - 0.82
PuO_2	15-150 µm AED	5.3×10^{-6} - 0.024
$Pu(NO_3(4)$ air dried		2×10^{-8} - 0.12
UO_2		0.32

TABLE 2.8. Radioactive Releases from Heating Partially Oxidized Plutonium Oxalate

Release Fraction (%/s)	Temperature (°C)	Velocity (cm/s)
1.42E-5	25	10
1.58E-5	400	100
2.04E-4	700	100
6.94E-5	1000	10
1.72E-4	1000	50
2.28E-4	1000	100

The particle-size distribution shown in Mishima, Schwendiman, and Radasch (1968a) is used in the code as the probable size for particles entrained from a noncombustible contaminated surface in a fire.

2.4.3 Heating of Unpressurized Radioactive Liquids

Radioactive liquids in an open container release a small percentage of radioactive particles along with vapors when the liquid is heated. This situation may occur in a nuclear fuel cycle facility fire. Experiments designed to study this release mechanism (Mishima, Schwendiman, and Radasch 1968b) show that three stages can occur during a fire, each contributing to the radioactive source term. These three stages, preboiling, boiling, and heating of residue, are discussed below.

2.4.3.1 Preboiling

In the preboiling phase, releases are low; less than 4 x 10^{-5} wt% is made airborne over a 1-h period for the greatest release measured (100 cm/s and 90°C). A general increase in source term generation rate with temperature can be seen as well as a slight increase with velocity. The equation for the preboiling phase of heating a liquid is derived from the data in Table 2.9. The best fit is a polynomial equation showing the release rate as a function of temperature of the liquid squared:

$$\text{Preboiling mass rate (g/s)} = 9.57 \times 10^{-15}\, T_l^2\, W_r \qquad (2\text{-}94)$$

TABLE 2.9. Releases from Heating of Unpressurized Radioactive Liquid

Release Rate (%/s)	Liquid Temperature (°C)	Velocity of Air (cm/s)
1E-11	25	10
1E-11	25	10
2.9E-12	25	50
7.4E-9	90	50
2.3E-13	25	100
1.8E-9	75	100
1.06E-8	90	100

where T_l is the temperature of the liquid, °C, and W_r is the the total mass of radioactive material in the liquid, g. Liquids are assumed to be in the preboiling phase until they reach a boiling rate of 0.4 mℓ/min.

2.4.3.2 Boiling

At temperatures greater than 95° to 100°C, nitrate solutions boil. The amount of contaminant made airborne during the boiling phase depends on the intensity of the boil, which may be estimated by the boil-off rate. Simmering liquids with a boil-off rate of 0.4 mℓ/min give off fewer radioactive particles than liquids under a vigorous boil. The equation used to model release rates from nitrate solutions draws on data measured by Mishima, Schwendiman, and Radasch (1968b) on releases of plutonium nitrate solutions. A linear regression on the data shown in Table 2.10 provides the relationship between mass rate and boil-off rate. This equation is given below:

$$\text{mass rate (g/s)} = (5.74 \times 10^{-9}\, R_B - 3.42 \times 10^{-9}\, W_r) \qquad (2\text{-}95)$$

where R_B is the boil-off rate, mℓ/min, and W_r is the total mass of radioactive material in the liquid, g.

This equation gives a negative release for R_B less than 0.6 mℓ/min. To correct this, the fraction airborne is assumed to be 5×10^{-10}/s at boiling rates of 0.4 to 0.6 mℓ/min. This value was the measured value at 0.6 mℓ/min in

TABLE 2.10. Fraction of Radioactive Material Released from Boiling Liquids (Mishima 1968b)

Boil-off rate (mℓ/min)	wt% Made Airborne	Time (min)	Fraction Released (/s)
0.5	1.3×10^{-4}	150	1.44×10^{-10}
0.6	4.5×10^{-4}	151	4.97×10^{-10}
0.66	5.8×10^{-3}	121	7.99×10^{-9}
0.73	2.4×10^{-2}	124	3.23×10^{-8}
0.9	8.4×10^{-2}	80	1.75×10^{-7}
1.4(a)	1.8×10^{-1}	63	4.76×10^{-7}

(a) Three releases were measured at this boiling rate; the greatest release fraction is assumed to apply.

the above mentioned experiments. The equation given above is used for boiling rates greater than 0.6 mℓ/min. R_B is calculated internally in the FIRIN code. W_r is required as input.

2.4.3.3 Heating of Residue

Continued heating of residual material after the liquid has boiled off will release additional radioactive particles to the air. Mishima, Schwendiman and Radasch (1968b) measured the quantity airborne from this residue at various temperatures and velocities. A general increase was found in airborne release with temperature of the surface on which the residue rested, as well as a slight increase with velocity of airflow. The data are shown in Table 2.11. The following equation is the best fit of the data and is used in the model:

$$\text{mass rate (g/s)} = (7.37 \times 10^{-12} T + 7.51 \times 10^{-11} V)\, W_r \tag{2-90}$$

where T is the air temperature, °C, V is the air velocity, cm/s, and W_r is the mass of radioactive materials, g.

A separate calculation is performed to estimate the radioactive release from each stage of heating unpressurized liquids. The user must input the W_r value, which is the original mass of radioactive material in the liquid. Although the W_r will change slightly as the material boils, this loss is so minor that it is ignored in following stages. Heat transfer equations within FIRIN provide the input to decide which source term calculation should be

TABLE 2.11. Releases from Heating Residue Following Boiling of Radioactive Liquids

Release Fraction (%/s)	T (°C)	V (cm/s)
1.67E-6	1000	100
1.28E-6	700	100
9.44E-7	400	100
1.67E-5	1000	50
1.04E-6	700	50
8.89E-7	400	50
9.86E-7	1000	10

applied as well as providing T_L for preboiling, the boil-off rate R_B for the boiling stage, and T and V for residue releases. Releases are assumed to continue for 2 h after the material has boiled off completely.

2.4.4 Pressurized Releases

Radioactive materials are usually kept in closed vessels in nuclear fuel cycle facilities. Vessels in the vicinity of a fire may become pressurized because of the buildup of vapors under temperature increases. When the difference between the internal pressure of the vessel and pressure of the room exceeds the vessel integrity, the container will fail, releasing radioactive materials to the room.

FIRIN requires failure pressure of the vessel, quantity of radioactive material, and certain characteristics of the material to be specified as input for this mechanism. The time of failure will be determined by heat transfer equations within FIRIN determining the pressure buildup inside the vessel.

Models have been developed to estimate the release of radioactive materials from pressurized releses (Ayer et al. 1988). A separate computer code has been created for determining the source term from pressurized releases involving radioactive powders. For simplicity, however, the following regression algorithm is used instead of integrating the PREL code with FIRIN to obtain a pressurized powder release source term estimate.

$$F = 1 \times 10^4 (V_o)^{1.4} \qquad (2\text{-}96)$$

where F = fraction of radioactive powder airborne

V_0 = initial velocity of powder jetting out of the vessel, m/s

Velocity can be calculated by

$$V_o = \left(\frac{2\ P\ V_t}{m}\right)^{1/2} \qquad (2\text{-}97)$$

where P = failure pressure, Pa

V_t = void space in the vessel (vessel volume minus mass of powder/theoretical powder density), m^3

m = powder mass, kg

The user inputs failure pressure, vessel volume, powder mass, and theoretical powder density. FIRIN calculates time of failure and quantity of release. Airborne particles are assumed to have on AMMD of 11.2 μm and a σg of 6.

Models for estimating the source term from pressurized releases of radioactive liquids are also given in Ayer et al. (1988). The mole fraction of pressurizing gas is the determining factor in these equations and can be calculated by the methods shown in Appendix B of Ballinger, Sutter, and Hodgson (1987). These methods involve using temperature and pressure dependent properties of the pressurizing gas to compute the amount of gas dissolved. In the experiments reported, the highest quantity released was 8.9% from a flashing spray of uranine solution. For simplicity, FIRIN assumes 10% of radioactive liquid is made airborne from pressurized release. The AMMD and σg of the airborne material are assumed to be 7.3 μm and 3.9, respectively. Failure pressure and mass of radioactive material involved are the only inputs required for this subroutine.

2.4.5 Burning Radioactive Pyrophoric Metals

Although radioactive materials in nuclear fuel cycle facilities are primarily in the form of oxides and nitrates, some pyrophoric metals may be handled. These metals are usually kept in an inert atmosphere and handled with special engineered safety features; however, potential fires involving pyrophoric metals can be taken into consideration with the following model.

Burning plutonium metal rods in airflows of 50 cm/s and temperatures up to 900°C gave releases of 2.8×10^{-6} to 5.3×10^{-5} wt% airborne (Schwendiman, Mishima, and Radasch 1968). Larger pieces of plutonium metal gave off 3.9×10^{-4} to 0.049 wt% maximum when heated up to 1000°C at flow rates of 525 cm/s (Mishima 1966). Release fractions among the two sets of experiments may be caused by the difference in size of the burning metal pieces, the difference in flow rates, a combination of these, or other experimental differences.

Table 2.12 lists the data from which the model is derived. The mass rate is a function of the site of the metal piece squared as shown below.

$$\text{mass rate (g/s)} = (1.66 \times 10^{-14}\ W^2)W_r \qquad (2\text{-}98)$$

where W_r is the total mass of radioactive material, g, and W is the size of the radioactive metal pieces, g.

FIRIN requires W_r and W as input and assumes the metal burns in 1 h.

Although the burning of pyrophoric metals is a two-step process initially controlled by temperature and, once ignited, controlled by diffusion of oxygen from the fuel, for simplicity, the above equation assumes uniform release and complete oxidation of the fuel.

TABLE 2.12. Releases from Burning Radioactive Pyrophoric Metals

Releases Fraction (%/s)	Metal Size (g)
5.28E-6	1770
1.25E-6	1000
8.06E-8	4.60
3.00E-10	9.9 to 11.3
6.97E-9	9.9 to 11.3
1.18E-8	9.9 to 11.3
4.67E-10	9.9 to 11.3
2.83E-9	9.9 to 11.3
4.42E-10	9.9 to 11.3

3.0 THE FIRIN COMPUTER PROGRAM

A user of FIRIN can estimate the radioactive mass generation rate and size distribution of radioactive particles becoming airborne in a fire. This radioactive source term computation is the major project thrust; however, other fire source terms are also calculated. These terms include mass loss and energy generation rates, and compartment transient conditions. To perform these estimations, the user has certain information requirements and options available. This chapter provides background information to enable the user to understand and use the code.

Descriptions include the following:

- program and data structure of the FIRIN code
- numerical algorithms used in the program
- subroutine functions
- input requirements to run FIRIN
- interpretation of output information
- code limitations.

3.1 PROGRAM STRUCTURE

FIRIN is structured into operational modules shown in Figure 3.1. These major modules, or blocks, are computations of the following:

- fire source terms
- heat and mass transfer
- radioactive source terms.

Fire source terms and heat and mass transfer are discussed in this section; radioactive source terms are composed of seven routines, which are explained in Section 3.4.

The block identified as Increment Time Step updates the time. Before this block (See Figure 3.1), the program checks if the updated time exceeded a specified end time selected by the user for terminating the run.

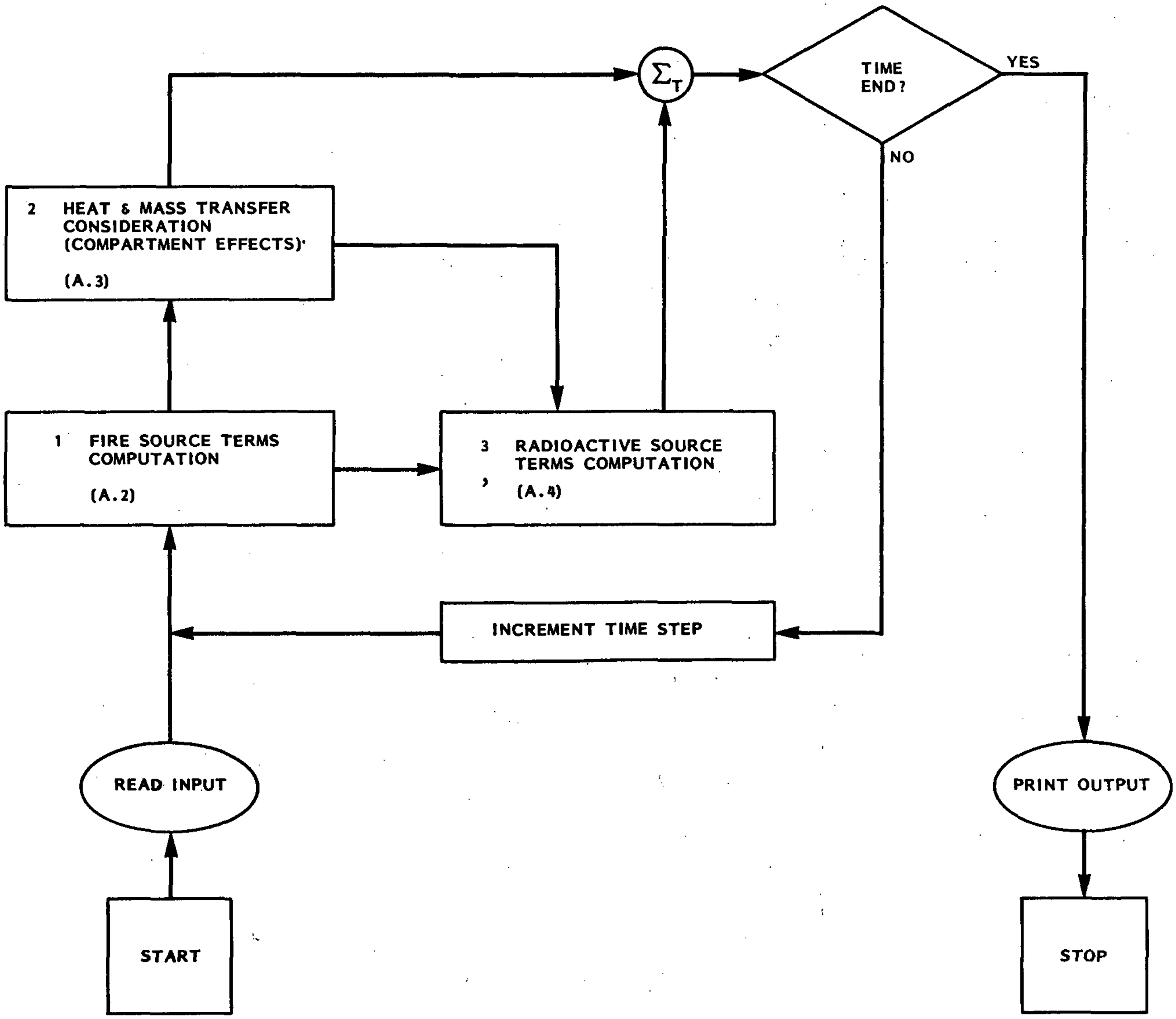

FIGURE 3.1. FIRIN--Overview Flow Chart

Block 1, fire source term computations, is expanded in Figure 3.2. The blocks in this figure illustrate determination of the maximum fire duration, and computation of mass, heat, gas, and smoke generation rates. They provide input for subsequent blocks. Block 1.1 computes the mass burning rate and maximum fire duration. This enables computation of heat, gas, and smoke generation rates in the fire compartment. These factors are summed at the top of Figure 3.2 and lead to Block 2.

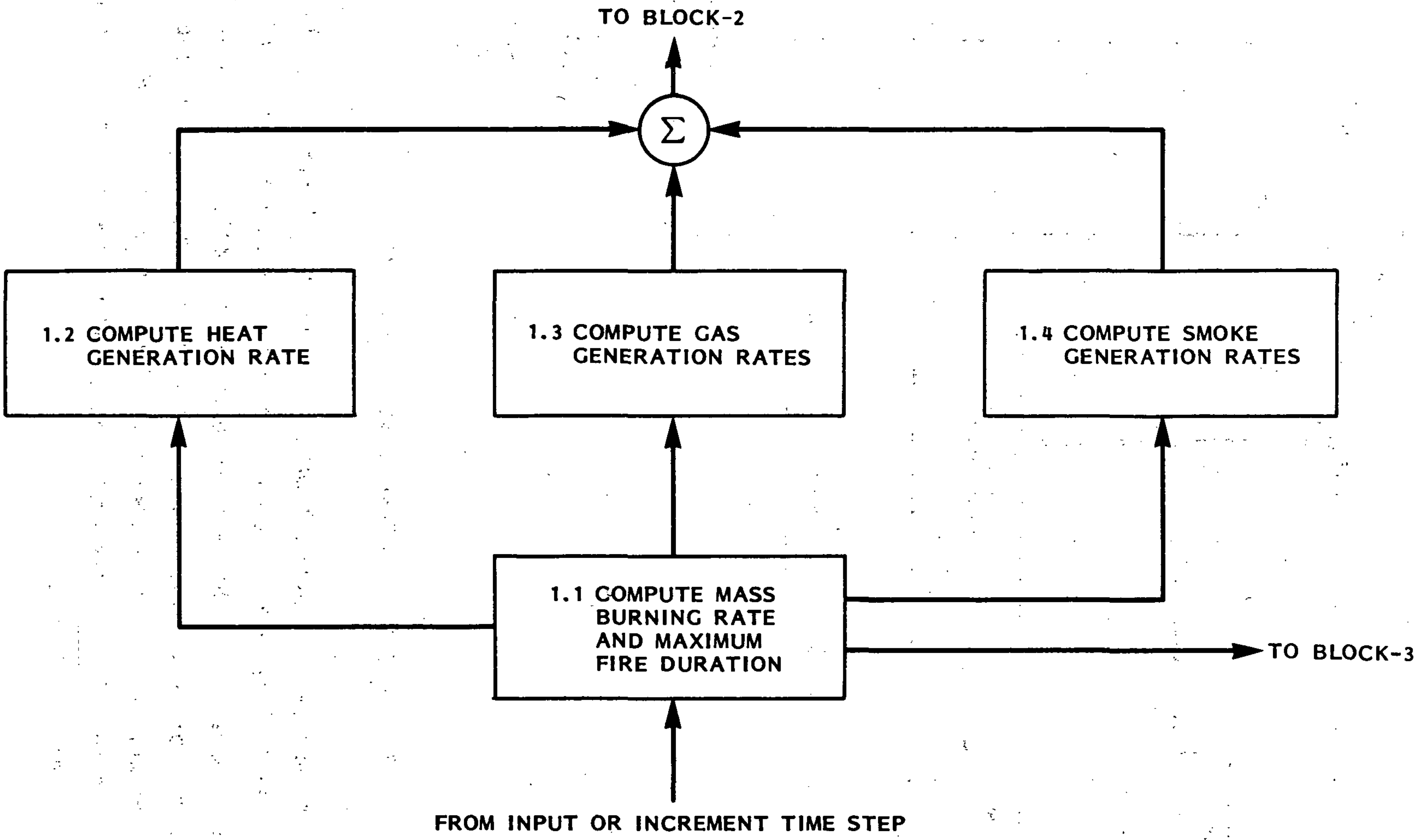

FIGURE 3.2. BLOCK 1--Fire Source Terms Computation

Block 2, shown in expanded form in Figure 3.3, structures heat and mass transfer considerations in the compartment. This summation, with input from Block 1, permits computation of the fire-generated radioactive releases in Block 3, Figure 3.4. The radioactive source term development is included in Section 3.4 after the data structure and numerical algorithms are defined; thus, FIRIN is structured in a sequential form to approximate the history of the mass, both radioactive and nonradioactive, and energy of a fire confined in a compartment.

3.2 DATA STRUCTURE

Types of combustible (e.g., paper wipes, solvents) and noncombustible materials (e.g., stainless steel, concrete) found in the fire compartment will affect the fire behavior. Data on physical/chemical and pyrolysis/combustion properties of fuels (combustibles) and physical properties of noncombustibles are stored in data statements at the beginning of the main program. The materials data format is described in the following section; fire ventilation conditions are included, since they determine the burning mode. Fuel properties are listed in Appendix B.

3.2.1 Fuel Material Data

Fuel materials are combustible items normally found in nuclear fuel cycle facilities. Although they are not the direct cause of the fire, they are available to sustain the fire once it is initiated; therefore, properties of these fuel materials must be used to compute the fire source terms. Fuel materials commonly found in nuclear fuel cycle facilities are listed in Table 3.1. Ventilation options are also listed. They have been assigned array element designations. The array element I is the identifier for 1 through 9, which represent the combustible materials; element J is the identifier for 1 through 3, which represent ventilation conditions. Two additional fuels can be included if the user desires. Combustion data (listed in Table 3.2) must be read in for these additional fuels.

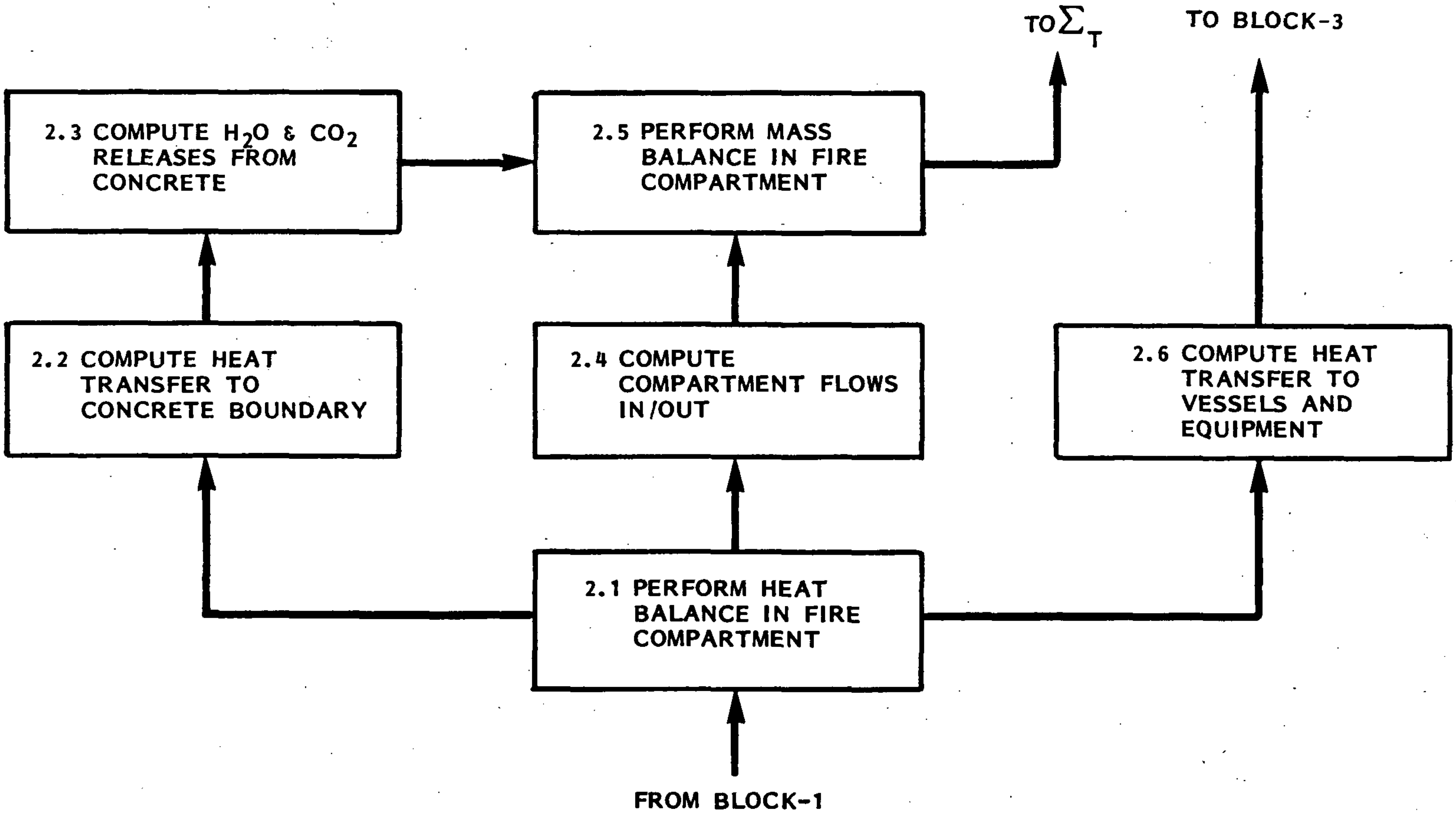

FIGURE 3.3. BLOCK 2--Heat and Mass Transfer Considerations (Compartment Effects)

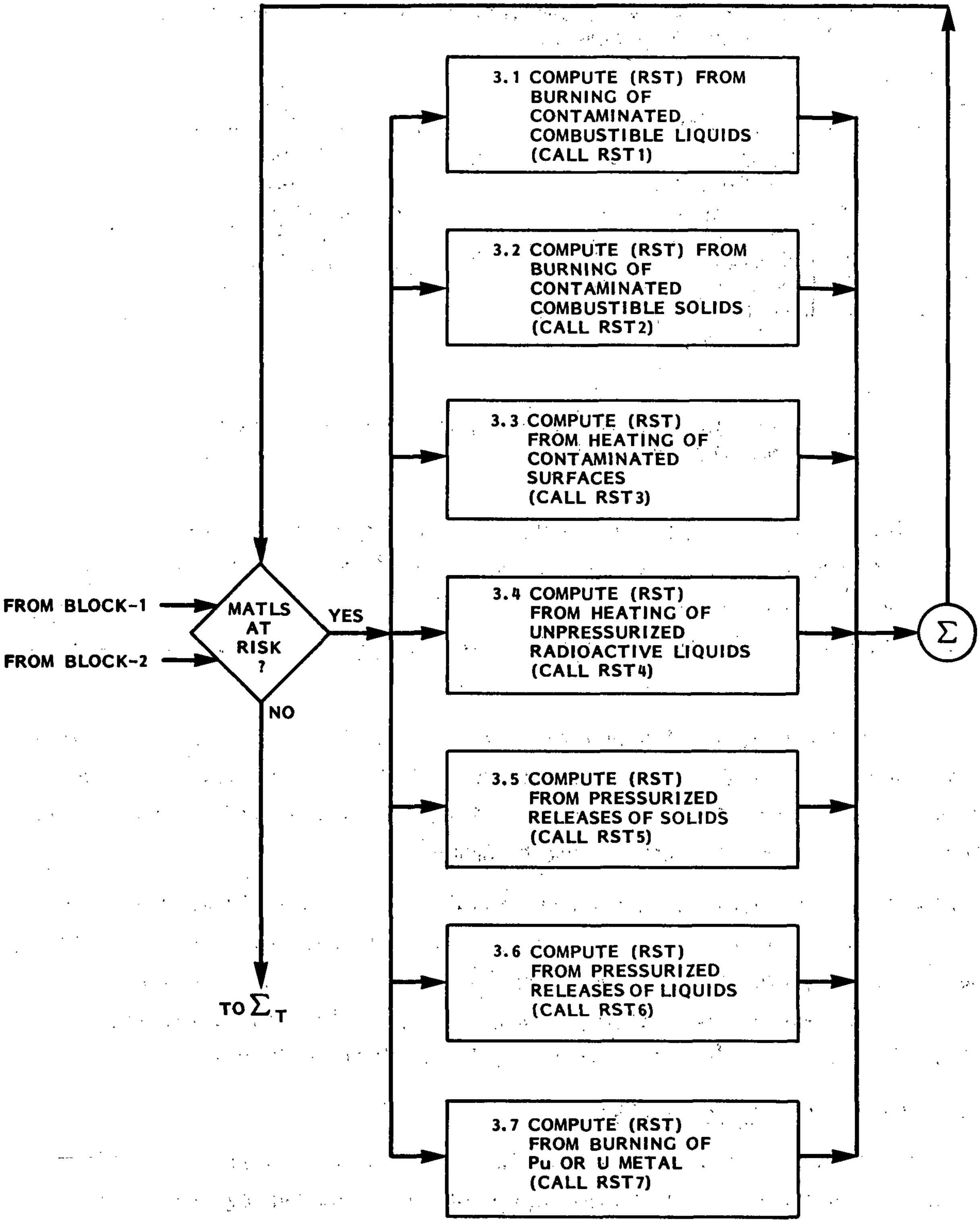

FIGURE 3.4. BLOCK 3--Radioactive Source Terms (RST) Computation

TABLE 3.1. Fuel Material and Ventilation Conditions for the Fire Compartments

	Fuel Materials (I)		Ventilation Conditions (J)
1	Polymethyl methacrylate	1	Overventilated ($[O_2] > 15\%$)
2	Polystyrene	2	Semiventilated ($11\% < [O_2] \leq 15\%$)
3	Polyvinyl chloride	3	Underventilated ($[O_2] < 11\%$)
4	Polychloroprene		
5	Cellulose (oak)(a)		
6	Cellulosic material		
7	Kerosene		
8	User's option		
9	User's option		

(a) Oak was selected to represent wood products based on the information available.

Physical/chemical and pyrolysis/combustion properties of the listed fuel materials are stored in data statements at the beginning of the main program. Most of the information was developed in small- and large-scale combustion apparatus at Factory Mutual Research Company (Tewarson et al. 1980; Steciak et al. 1983).

Variable array names assigned for the physical/chemical and pyrolysis/combustion properties of fuel materials are listed in Table 3.2. The identification of corresponding properties are included. The actual values for these variables used in the code are listed in Appendix B.

Heat flux, for example, can be represented using the information in these tables. QFC (I,J) with I = 2, J = 1 represents the convective heat flux from a flame to fuel surface during polystyrene burning under an overventilated fire. This particular combustion property (if specified) is called within FIRIN by internal logic whenever the Fire Source Terms Module is in operation.

3.2.2 Construction Material Data

Construction materials in the fire compartment have an effect on the heat transfer calculations. Construction materials are used for equipment, vessels, walls, ceilings, and floors in nuclear fuel cycle facilities. As shown in

TABLE 3.2. Data Base for Physical/Chemical and Pyroloysis/Combustion Properties of Fuel Materials

Variable Array Name in FIRIN	Property
A. Physical/Chemical Properties	
QRR(I); I = 1 to 9	Fuel material surface reradiation, kW/m^2
QCHEAT(I)	Energy required to generate combustible vapor air mixture, kJ/m^2
HEATV(I)	Heat required to generate a unit mass of vapor, kJ/g
HEATC(I)	Net heat of complete combustion, kJ/g
WFC(I)	Weight fraction of carbon in fuel
WFH(I)	Weight fraction of hydrogen in fuel
WFH(I)	Weight fraction of oxygen in fuel
WFCL(I)	Weight fraction of chlorine in fuel
B. Pyrolysis/Combustion Properties	
QFC(I,J); I = 1 TO 9, J = 1 to 3	Convective heat flux from flame to fuel surface, kW/m^2
QFRR(I,J)	Radiative heat flux from flame to fuel surface, kW/m^2
XA(I,J)	Combustion efficiency
XC(I,J)	Convective fraction of combustion efficiency
XR(I,J)	Radiative fraction of combustion efficiency
YFCO2(I,J)	Fractional yield of carbon dioxide
YFCO1(I,J)	Fractional yield of carbon monoxide
YFH2O(I,J)	Fractional yield of water vapor
YFHCL(I,J)	Fractional yield of hydrochloric acid
YSMOK(I,J)	Fractional yield of smoke
SOFRA(I)	Soot fraction in smoke
YFCH4(I,J)	Fractional yield of methane

Table 3.3, the array element MATER is the identifier from 1 to 15 and represents a variety of noncombustible materials.

Array names for physical properties such as material conductivity, emissivity, density, and heat capacity of noncombustible solids are listed in Table 3.4. Material thermal conductivity of concrete, for example, is represented by COND (MATER=1).

The user must specify MATER in the input data. The array elements 8 to 15 are the user's option to be used to fill in material properties for materials other than those listed above. If this option is implemented, physical

TABLE 3.3. Noncombustible Material Options for the Fire Compartment

MATER	Noncombustible Materials
1	Concrete
2	Fire brick
3	Stainless steel
4	Steel
5	Aluminum
6	Copper
7	Brass
8 to 15	User's option

TABLE 3.4. Data Base for Physical Properties of Noncombustible Solid Materials

Variable Array Name in FIRIN	Physical Property
COND (MATER), MATER = 1 TO 15	Material thermal conductivity, kJ/m-s-°K
CONDM (MATER)	Linear extrapolation factor(a) of thermal conductivity
EMIS(MATER)	Material emissivity
RHOO (MATER)	Material density, kg/m^3
CPCA (MATER)	Material heat capacity, kJ/kg-°K
CPCAM(MATER)	Linear extrapolation factor(a) of material heat capacity

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(a) A slope factor interpolated by assuming the physical properties are linearly proportional to the change in temperature (ΔT) in compartment heat balance (i.e., COND = COND ± CONDM x (ΔT) where CONDM is a linear extrapolation factor of material thermal conductivity).

properties (listed in Table 3.4) of the material must be input. Appendix B lists the physical property data used in the code.

3.2.3 Other Data

In addition to the data bases discussed above, there are a total of 12 other unit files where input and output data for FIRIN are stored. These unit files are located after the FIRIN data statements, before the input from the user is read in. Discussion on these unit files is presented in Section 3.5.

Other data (e.g., the ideal gas constant, gravitational constant, Stefan-Boltzmann constant) are required for the calculations. They are initialized at the section labeled initialization and parameterization after the input data has been read in.

3.3 NUMERICAL ALGORITHMS

This section addresses the three major algorithms used in FIRIN in the heat and mass balances. Specific details of the models and equations are found in Chapter 2.0.

The first algorithm deals with five variables: compartment pressure, hot-layer moles and temperature, and cold-layer moles and temperatures. These variables are coupled and dependent on the flows into and out of the compartment. Three other first-order differential equations for the hot-layer moles, hot-layer temperature, and cold-layer moles are solved in simple finite difference form at each time step. An exact equation for compartment pressure is then used, which is a form of the equation of state. This method works well for suitably small time steps. Larger time steps can cause computational instabilities. A time step of 0.01 to 1.0 s is suggested. The cold-layer temperature is fixed at the initial value. Since this layer is usually short-lived in forced ventilated fires of the type likely to occur in nuclear fuel cycle facilities (with cold air entering at the top and exiting through air vents at the bottom), the error in the energy balance is small.

The second type of algorithm is the unsteady-state heat transfer to the walls, floor, and ceiling. The usual second-order conduction equation is solved using finite differences and a standard explicit method. The explicit method was preferred over implicit methods for programming simplicity. This decision is consistent with the sufficiently small time step needed in the first algorithm.

The third algorithm is the iterative method used to obtain the equilibrium pressure inside heated vessels containing solutions. This algorithm assumes a new temperature inside the vessel with each time step. Then, it calculates water evaporation and adjusts the heat input between phases or at equilibrium. The assumption that equilibrium exists is not completely accurate. Some delay in readily reaching equilibrium will occur; therefore, the condition calculated in the vessel does not reflect this short time delay.

3.4 SUBROUTINE FUNCTIONS

The seven subroutines listed in Table 3.5 are used to calculate the quantity and characteristics of radioactive particles given off during the fire. They compose the Radioactive Source Terms (RST) Computation Module within FIRIN. Each subroutine predicts the radioactive releases based on one of these release mechanisms listed in the table. K is the numeric identifier for subroutines RSTI through RST7 called in the main program.

Figure 3.4 is the breakdown block diagram of the RST Computation Module, showing its interdependency with the other two major modules described in Section 3.1 (Program Structure). Blocks 3.1 to 3.7 in this module call on subroutines RST1 to RST7 for the prediction of mass rate and particle characteristics from the mechanism listed in each block.

3.5 INPUT AND OUTPUT DATA

Twelve unit files store the data input to and output from FIRIN. Table 3.6 lists these file names and corresponding types of input and output.

INPUTFILE is a dummy variable for the input file name. The user must read in the appropriate name immediately after invoking FIRIN. Once the program reaches completion, the data in all the output unit files are ready to be printed on the user's request. The user should refer to the output file names shown in the table to call for a printout.

TABLE 3.5. Subroutines for Estimating Radioactive Releases

Subroutine Name	(K)	Release Mechanism
RSTI	1	Burning of contaminated combustible solids
RST2	2	Burning of contaminated combustible liquids
RST3	3	Heating of contaminated surface
RST4	4	Heating of unpressurized radioactive liquids
RST5	5	Pressurized releases of radioactive powders
RST6	6	Pressurized releases of radioactive liquids
RST7	7	Burning of radioactive pyrophonic metals

TABLE 3.6. Unit Files (in FIRIN) for Input and Output Data

Unit File Names	Types of Information Stored
	Input data for
INPUTFILE[(a)]	-fire source terms computation -compartment effects computation -radioactive source terms computation
	Output data from
RSTHL.DAT	Change in mass of radioactive particles in hot layer at each time step. Shows losses by particle depletion mechanism
RSTCL.DAT	Same as RSTHL, but for cold layer
SMKHL.DAT	Same as RSTHL, but for smoke particles
SMKCL.DAT	Same as SMKHL but for cold layer
RSZHL.DAT	Size distribution of radioactive particles in hot layer at each time step
RSZCL.DAT	Same as RSZHL, but for cold layer
SSZHL.DAT	Same as RSZHL, but for smoke particles
SSZCL.DAT	Same as SSZHL, but for cold layer
PRINT.DAT	Fire source term and compartment effects by time step
ARAD.DAT	Buildup of radioactive particles on floor, walls, ceiling, and vents at each time step
ASMK.DAT	Same as ARAD.DAT, but for smoke particles

The following two sections describe the input format and output information to/from FIRIN. Chapter 4.0 gives examples of these by illustrating sample problem input and output.

3.5.1 Input Format

Various input parameters are required depending on the initial compartment conditions, amount and types of combustibles, and mechanisms releasing radioactive particles. The input information required to produce a compartment fire history is listed in Table 3.7. Explanations of the data for each type are included in the table.

TABLE 3.7. Input Data

Card Type	Variable Name	Description
1	PLUTANS	PLOT ANSWER--User specifies 'Y' for FIRIN to store variables plotting packages. Two new units named PLOTTING_DATA_1.DAT and PLOTTING_DATA_2.DAT are then opened and written to during program execution.
1	TSPEC	COMPUTING TIME--User can specify the duration (in seconds) desired to observe the fire. The execution of the program will be terminated at time = TSPEC.
1	DELT	TIME STEP--User must specify the size of time step (in seconds) desired for the computation uses in FIRIN. For stable numerical solution results, small time steps are suggested (i.e., $1.0 \geq \mathrm{DELT} \geq 0.01$).
1	MIBO	BURNING ORDER--One way to approximate fire growth in FIRIN; users estimate the orders of fuel consumption (burning order) in the fire if more than one combustible material in the compartment is assumed to burn. The maximum number of burning orders is MIBO, and it governs the numbers of physical card requirement for Card Types 2 and 3.
1	IGNITE	IGNITION ENERGY--Another less conservative way to approximate fire growth in FIRIN is to use the ignition energy concept. This approximation allows autoignition of combustibles at risk if the heat-flux levels generated by the initial burning combustibles in the compartment are above a specified level. The ignition energy levels required for autoignition of the combustibles depend on material properties, and are stored in the program. To use this concept for approximation, IGNITE = 1 must be inputted. Otherwise IGNITE = 0 must be specified. When this concept is applied, MIBO = 2 must be specified. The first burning order (IBO = 1) refers to initial burning materials and (IBO = 2) combustibles at risk because of possible autoignition are specified.
1	IPRINT	PRINT--User specifies the number of time steps between printout into the output unit files. For example, when DELT = 0.1 is selected and the user wishes to obtain computed data every 10 s in real time of the fire, IPRINT = 100 should be specified.

TABLE 3.7. (contd)

Line Type	Variable Name	Description
1	MJE(IE)	EQUIPMENT AT RISK--User can specify up to a total of 10 pieces of equipment and vessels of each of the following four types: 1) simple heat sink, 2) closed containers of powder, 3) closed containers of liquid, and 4) open liquid containers. MJE is the number of each container type. If no equipment or vessel of each type is to be modeled, use 0,0,0;0.

Input data to Fire Source Terms Computation Module

2	FUEL(I,IBO) I=1,9 IBO=1,MIBO	Mass of combustible material (g) involved in the fire. I denotes type of fuel as listed: I = 1) PMMA 2) PS 3) PVC 4) PC 5) Cellulose - wood 6) Cellulosic materials - paper, cardboard 7) Kerosene 8) User's option 9) User's option IBO is the burn order and denotes the sequence in which the fuels burn. The maximum burn order is 5. MIBO physical lines are required, one for each burn order. 0.0 must be input for each combustible material type not involved in the fire.
3	AREC(I,IBO) I=1.9 IBO = 1, MIBO	Burning surface area (m^2) of each fuel involved in the fire. Similar to FUEL (I,IBO).

If the User's Option is implemented for FUEL(I,IBO) [FUEL(8 or 9, IBO) greater than 0.0], combustion properties of the material must be input as shown in line types 3a - 3e. One set of lines is required for each new fuel material.

3a	QCHEAT(I)	Energy required to generate combustible vapor-air mixture (kJ/m^2).
3a	QRR(I)	Fuel material surfaces reradiation (kW/m^2).
3a	HEATV(I)	Heat required to generate a unit mass of vapor (kJ/g).
3a	HEATC(I)	Net heat of complete combustion (kJ/g).
3a	WFC(I)	Weight fraction of carbon in fuel.

TABLE 3.7. (contd)

Card Type	Variable Name	Description
3a	WFH(I)	Weight fraction of hydrogen in fuel.
3a	WFO(I)	Weight fraction of oxygen in fuel.
3a	WFCL(I)	Weight fraction of chlorine in fuel.
3b	QFC(I,J) J=1,3	Convective heat flux from flame to fuel surfaces (kW/m^2).
3b	QFRR(I,J) J=1,3	Radiative heat flux from flame to fuel surface (kW/m^2).
3b	XA(I,J) J=1,3	Combustion efficiency.
3c	XC(I,J) J=1,3	Convective fraction of combustion efficiency.
3c	XR(I,J) J=1,3	Radiative fraction of combustion efficiency.
3c	$YFCO_2(I,J)$ J=1,3	Fractional yield of carbon dioxide.
3d	$YFH_2O(I,J)$ J=1,3	Fractional yield of water vapor.
3d	YFHCL(I,J) J=1,3	Fractional yield of hydrochloric acid.
3d	YSMOK(I,J) J=1,3	Fractional yield of smoke.
3e	$YFCO_1(I,J)$ J=1,3	Fractional yield of carbon monoxide.
3e	YFCH4(I,J) J=1,3	Fractional yield of methane.
Input data to Compartment Effects Module		
4	LR	Length of the fire compartment (m).
4	WR	Width of the fire compartment (m).
4	ZR	Height of the fire compartment (m).

TABLE 3.7. (contd)

Card Type	Variable Name	Description
4	XCEIL	Thickness of the compartment ceiling (m).
4	XWALL	Thickness of the compartment wall (m).
4	XFLOOR	Thickness of the compartment floor (m). If the compartment is on the floor level with no other compartment below it, a large value of XFLOOR is suggested for heat transfer consideration.
4	MATERC	Ceiling construction material. Use the numeric identifier (MATER = 1,2,...15) for noncombustible solid materials. MATERC = 1 (see Table 3.3) denotes concrete as ceiling material.
4	MATERW	Wall construction material. Use the numeric identifier as above. MATERW = 2 denotes fire break as wall material.
4	MATERF	Floor construction material. Use the numeric identified as for MATERC and MATERW. MATERF = 1 denotes concrete as floor material.

If a material of construction other than the seven for which FIRIN has data is input by setting MATERC, MATERW, and/or MATERF = 8 to 15, card type 4a must be read in for each new material introduced. Material properties should not be read in twice; i.e., if MATERC and MATERF = 8 and MATERW = 9, two cards should be read in, the first one for material type 8 and the second for material type 9.

Card Type	Variable Name	Description
4a	COND(MATER)	Material thermal conductivity (kJ/m•s•°K).
4a	CONDM(MATER)	Liner extrapolation factor of thermal conductivity (see Table 3.4).
4a	EMIS(MATER)	Material emissivity.
4a	EMISM(MATER)	Linear extrapolation factor of material emissivity (see Table 3.4).
4a	RHOO(MATER)	Material density (kg/m^3).
4a	RHOOM(MATER)	Linear extrapolation factor of material density (see Table 3.4).
4a	CPCA(MATER)	Material heat capacity (kJ/kg°K).

TABLE 3.7. (contd)

Line Type	Variable Name	Description
4a	CPCAM(MATER)	Linear extrapolation factor of material heat capacity (see Table 3.4).
5	NFP	Number of additional flow paths to/from the fire compartment. A glove box is an example of a compartment that has glove ports as its additional flow paths where the gloves attached to it have burned off. As many as 20 paths can be designated in FIRIN. The value selected for NFP governs the number of physical line requirements for Line Types 28 through 31. If NFP = 0, no data input is required for these line types.
5	P1	Initial pressure (atm) at the outside of the inlet ventilation. Usually P1 = 1.0.
5	P2	Initial pressure (atm) at the outside of the outlet ventilation.
5	TINIT	Initial temperature (°K) of the fire compartment.
5	PINIT	Initial pressure (atm) inside the fire compartment.
5	ZIF	Height of elevation of the center plane of inlet ventilator from the floor level in the compartment.
5	ZOF	Height of elevation of the center plane of outlet ventilator from the floor level in the compartment.
5	ZFIRE	Normalized height of the flame base above floor level (m). For example when a glove box is in a fire, ZFIRE is the elevation of the glove box floor.
5	VIF	Initial volumetric inlet flow rate to fire compartment (m^3/s).
5	EQUIP	Numeric identifier for equipment and for vessels at risk in the fire compartment. EQUIP = 1.0 (equipment and/or vessels) EQUIP = 0.0 (no equipment or vessels) If EQUIP = 0.0 is specified, no input data are required for Line Types 8 through 28.
5	EFFIC	Initial efficiency of inlet and outlet filters, fraction.

TABLE 3.7. (contd)

Line Type	Variable Name	Description
6	TFO	Initial floor temperature, °K.
6	TCO	Initial ceiling temperature, °K.
6	TWO	Initial wall temperature, °K.
6	N2X2IF	Size of inlet filter in terms of multiples of 2' x 2'.
6	N2X2OF	Size of outlet filter in terms of multiples of 2' x 2'.
7	NBO(I)	Numeric identifier for the nine combustibles at risk. This line type is required only when ignition energy concept is applied (or IGNITE = 1). Input NBO(I) = 0 for material that burns initially in the fire. NBO(I) = 1 for combustibles that are at risk and that can contribute to the fire via ignition energy concept NBO(I) = 2 for any of the nine combustible types that will not contribute to the fire at all NBO(I) = 3 for material types that burn at the start of the fire and are also at risk because of ignition energy concept.

Input to Equipment Type 1: simple heat sink.
Lines 8-13 are not required if there are no Type 1 vessels or equipment (MJE(1)=0).

Line Type	Variable Name	Description
8	WD(JE,1) JE=1,MJE(1)	Width of equipment and/or vessels (m). JE denotes number of each vessel or area of equipment up to 10.
9	HEQ(JE,1) JE=1,MJE(1)	Length of equipment or vessels (m). Height of cylinders, length of boxes or square vessels. This parameter used with WD to find area exposed to fire for heat transfer.
10	HTF(JE,1) JE=1,(MJE(1)	Height of the base of equipment or vessels (m).
11	MATERE(JE,1) JE=1,MJE(1)	Material of construction of equipment or vessel. FIRIN contains data for seven types as listed in Table 3.3. If the User's Option is implemented by setting MATERE=8 to 15, physical properties of the material must be input as shown by line type 4a.

TABLE 3.7. (contd)

Line Type	Variable Name	Description
One line type, 4a, is required here for each new material introduced by MATERE(JE,1) > 7. Material properties should not be repeated. For example, if MATERC=8, then properties for type 8 material has been read and should not be input again.		
12	WMASS(JE,1) JE=1,MJE(1)	Weight (kg) of equipment or vessel when empty.
13	TE1(JE) JE=1, MJE(1)	Initial surface temperatures (°K) of equipment or vessels.
Input to Equipment Type 2: closed containers of powder. Lines 14 - 24 are not required if there are no type 2 vessels (MJE(2)=0).		
14	WD(JE,2) JE=1,MJE(2)	Same as line 8.
15	HEQ(JE,2) JE=1, MJE(2)	Same as line 9.
16	HTF(JE,2) JE=1, MJE(2)	Same as line 10.
17	MATERE(JE,2) JE=1, MJE(2)	Same as line 11.
18	WMASS(JE,2) JE-1, MJE(2)	Same as line 12.
19	VGAS2(JE) JE=1, MJE(2)	Gas volume (m^3) inside vessel.
20	VPWD(JE) JE=1, MJE(2)	Volume of powder (m^3) inside vessel.
21	WH2O2(JE) JE=1, MJE(2)	Mass of water (g) inside vessel. This value can be obtained using the moisture content of the powder.
22	TE2(JE) JE-1,MJE(2)	Initial surface temperature (°K) of vessel.
23	TI2(JE) JE=1, MJE(2)	Initial inside temperature (°K) of vessel.
24	PF2(JE) JE=1, MJE(2)	Failure or rupture pressure (atm) of vessel.

TABLE 3.7. (contd)

Line Type	Variable Name	Description
Input to Equipment Type 3: closed containers of liquid. Lines 25 - 34 are not required if there are no type 3 vessels (MJE(3)=0).		
25	WD(JE,3) JE=1, MJE(3)	Same as line 7.
26	HEQ(JE,3) JE=1, MJE(3)	Same as line 8.
27	HTF(JE,3) JE=1, MJE(3)	Same as line 9.
28	MATERE(JE,3) JE=1, MJE(3)	Same as line 10.
29	WMASS(JE,3) JE=1, MJE(3)	Same as line 11.
30	VGAS3(JE) JE=1, MJE(3)	Volume of gas (m^3) inside vessel.
31	WH2O3(JE) JE=1, MJE(3)	Mass of liquid (g) inside vessel.
32	TE3(JE) JE=1,MJE(3)	Initial surface temperature (°K) of vessel.
33	TI3(JE) JE=1, MJE(3)	Initial inside temperature (°K) of vessel.
34	PF3(JE) JE=1, MJE(3)	Failure or rupture pressure of vessel.
Input to Equipment Type 4: open containers of liquid. Lines 35 - 42 are not required if there are no type 4 vessels (MJE(4)=0).		
35	WD(JE,4) JE=1, MJE(4)	Same as line 7.
36	HEQ(JE,4) JE=1, MJE(4)	Same as line 8.
37	HTF(JE,4) JE=1, MJE(4)	Same as line 9.

TABLE 3.7. (contd)

Line Type	Variable Name	Description
38	MATERE(JE,4) JE=1, MJE(4)	Same as line 10.
39	WMASS(JE,4) JE=1, MJE(4)	Same as line 11.
40	VOL(JE) JE=1, MJE(4)	Liquid volume (m^3) inside vessel.
41	TE4(JE) JE=1, MJE(4)	Initial surface temperature (°K) of vessel.
42	TL(JE) JE=1, MJE(4)	Initial liquid temperature (°K) of vessel.
Input for alternate flow paths. Lines 43 - 46 are not required if NFP = 0.		
43	TFP(IFP) IFP=1,NFP	Failure times (in seconds) of the additional flow paths to the fire compartment during the course of the fire. The total of NFP = 20 additional flow paths are currently allowed input to FIRIN.
44	HFP(IFP) IFP=1,NFP	Height of the additional flow paths (m).
45	PFP(IFP) IFP=1,NFP	Pressure (atm) at the outlets of the additional flow paths to the compartment.
46	DFP(IFP) IFP=1,NFP	Equivalent diameters (m) of the additional flow paths to the compartment.
Input data to RST Computation Module		
47	NRAD(K) K=1,7	Number of radioactive source terms that will be generated under the Kth type of release mechanism. K is the numeric identifier for the total of seven types of radioactive release mechanisms described in Section 3.4. Provide a total of seven values including zeros if the mechanism is not involved. Thus, NRAD(1) = 2 denotes that there are 2 radioactive source terms resulting from burning two types of contaminated combustible solids. The values specified for NRAD(J) are the numbers of physical lines required for Line Types 48 through 56.

TABLE 3.7. (contd)

Line Type	Variable Name	Description
48	IFORM	Line Types 48 and 49 are used for radioactive releases from the burning of contaminated combustible solids. The number of physical lines required for input depends on the NRAD(1) value specified in Line Type 47. If NRAD(1) = 0, no input data is required of Line Type 48. IFORM here denotes the physical form of radioactive contaminant found on the combustible solid: IFORM = 1 (powder) IFORM = 2 (air-dried liquid) IFORM = 3 (liquid)
48	I	I is the numeric identified for the types of combustible materials the radioactive material is associated with, where I = 1, 9. See Section 3.2 for the combustible materials and their corresponding numeric identifier.
48	JACT	JACT can be any integer, ranging from 1 to 10, assigned to a source term for identification among other possible source terms in a single fire scenario. Up to 20 radioactive species can be tracked.
48	IBO	IBO is the burning order of the contaminated combustible solids. See descriptions for Line Types 2 and 3.
49	QRAD1	QRAD1 is the estimated total mass of radioactive material. NOTE: If NRAD(1) is greater than 1, Lines 48 and 49 must be repeated in alternating fashion NRAD(1) times.
50	IFORM	Line Type 50 and 51 are used for radioactive releases from burning of contaminated combustible liquids. The number of physical lines required for input depends on the NRAD(2) value specified in Line Type 47. If NRAD(2)=0, no input data is required of Line Type 50. IFORM here denotes the forms of radioactive contaminant in combustible liquids: IFORM = 1 (uranium or plutonium powder) IFORM = 2 (uranium or plutonium liquid) IFORM = 3 [nonvolatile radioisotopes other than uranium or plutonium (e.g., zirconium, cerium)] IFORM = 4 [semivolatile radioisotopes (e.g., cesium)] IFORM = 5 [volatile radioisotopes, e.g., iodine)].
50	I	Same description as I above in Line Type 48.

TABLE 3.7. (contd)

Variable Name	Description
JACT	Same description as JACT above in Line Type 48.
IBO	Same description as IBO above in Line Type 48.
QRAD2	QRAD2 is the estimated total mass (g) of radioactive material. If NRAD(2) is greater than 1, lines 50 and 57 must be repeated in alternating fashion NRAD(2) times.
JACT	Line Type 52 is used for radioactive releases from heating of contaminated surfaces. The number of physical lines required depends on the NRAD(3) value specified in Line Type 47. If NRAD(3)=0, no input data is required of Line Type 52.
QRAD3	Mass (g) of radioactive material on the surface heated by the fire.
IVES	Line Type 53 is used for radioactive releases from heating of unpressurized radioactive liquids. NRAD(4) physical lines must be input. IVES is a number from 1 to 10 identifying up to 10 vessels of radioactive liquid. IVES is the same as JE for equipment type 4 (see lines 35 - 42).
JACT	Same description as JACT above in Line Type 48.
QRAD4	Mass (g) of radioactive material in the liquid. Similar input requirement as for QRAD3.
IVES	Line Type 54 is used for radioactive releases from pressurized releases of solids. NRAD(5) physical lines must be input. Same description as IVES above in Line Type 53 but with powder. IVES is the same as JE for Equipment Type 2 (see Lines 14 - 24).
JACT	Same description as JACT above in Line Type 48.
QRAD5	Mass (g) of radioactive powder in the vessel. Similar input requirement as for QRAD3.
VOLP	Volume of powder container, m^3.
POEN	Theoretic density of radioactive powder, g/m^3.

TABLE 3.7. (contd)

Line Type	Variable Name	Description
55	IVES	Line Type 55 is used for radioactive releases from pressurized releases of liquids. NRAD(6) physical lines must be input. Same description as IVES above in Line Type 53. IVES is the same as JE for Equipment Type 3 (see Lines 25 - 34).
55	JACT	Same description as JACT above in Line Type 48.
55	QRAD6	Mass (g) of radioactive liquid in the vessel. Similar input requirement as for QRAD3.
56	JACT	Line Type 56 is used for radioactive releases from burning pyrophoric metals. NRAD(7) physical lines must be input. Same description as JACT above in Line Type 48.
56	IBO	Same description as IBO above in Line Type 47.
56	QRAD7	Mass (g) of metal burned. Similar input requirement as for QRAD3.
56	SQ	Size of radioactive metal (g) that are burned.

Line Type 1 - 3. These lines provide input data to the Fire Source Terms Computation Module. A minimum of one physical line of each type is required to run FIRIN. More than one of each can be used as input when appropriate.

Line Types 4 - 42. These lines provide input data to the Compartment Effects Module. One physical line of Line Types 4, 5, and 6 is required. Line Type 7 is required if an ignition energy concept is chosen to approximate fire growth. Line Types 8 through 42 are required if equipment is modeled in the fire compartment.

Line Types 43 - 46. These lines are not required as an input unless there are additional flow paths besides normal ventilation. One or more physical lines of each of these types are used when required.

Line Types 47 - 56. These lines input data to the RST Computation Model. One physical line of Line Type 47 is required; additional lines can be used as input when appropriate.

Before using FIRIN, the user should review the input data requirements in Table 3.7. For a simple fire (i.e., a compartment with a few combustibles and limited quantities of radioactive materials at risk), less than 20 physical lines are required to run FIRIN. The simplest case with radioactive material requires only 8 lines. With the addition of equipment, vessels, and flow paths to the fire compartment, the analysis sophistication increases and more lines are required.

3.5.2 Output Information

FIRIN can be used independently as a source term code; however, it has been designed to fill the input requirements of FIRAC. With the use of both codes, a user can analyze the radioactive source terms up to the facility-atmosphere interface.

Several unit files store the time history output from FIRIN. Output information includes transient data on the 1) fire source term, 2) fire compartment, 3) accumulation on filters, and 4) radioactive source term. Frequency of data output printing is specified by the user in input for IPRINT. For example, in a fire lasting 500 s (based on quantity of combustible materials and fire compartment conditions) with IPRINT=10 and DELT = 1, 50 outputs (1 every 10 s) would be printed.

Output is terminated at the end of a specified time noted by the following remark at the bottom of the output table:

```
TIME EXCEEDS USER SPECIFIED TIME AT ... SEC
```

Other messages can be found in the output files. The following message occurs when combustibles have auto ignited:

```
COMBUSTIBLE TYPE X HAS IGNITED AT TIME: ...SEC
```

If the fire becomes oxygen depleted before all the combustibles have finished burning, the following message will be printed:

```
ALL BURNING HAS STOPPED AT TIME:  ...SEC WITH X% OF ALL
COMBUSTIBLES CONSUMED IN THIS FIRE
```

The message

```
ALL COMBUSTIBLE MATERIALS WERE CONSUMED BY ...SEC
```

appears after the time step in the last combustible is burned up. The program will keep running after this until it reaches the user specified time. In this way the transport of particles to surfaces and the vents as well as depletion of particles can be followed after the fire goes out.

Information given in the various output files are summarized in Table 3.8.

TABLE 3.8. Parameters in Output Files

File	Parameters	
RSTHL and SMKHL	Time, s	
	Airborne at T0, g + Generated by Fire, g + Entrashed w Plume, g - Total Losses, g = Airborne at T	hot layer mass balance over time step
	Fraction of Losses Due to:	
	Settling Browman Diffusion Thermophoresis Diffusiophoresis Out Vent	breaks down contribution of losses from each particle depletion mechanism
RSTCH and SMKCL	Time, s	
	Airborne at T0, g + Hot Layer Settling - Total Losses, g = Airborne at T	cold layer mass balance over time step

TABLE 3.8. (contd)

File	Parameters		
	Fraction of Losses Due to:		
	Settling		
	Out Vent		
	Plume Gas		
RSZHL, RSZCL, SSZHL, SSZCL	Particle Diameter (microns) for Bins		
	>0.1	0.1	bin size and geometric average of sizes
	0.1-0.3	0.173	
	0.3-0.5	0.387	
	0.5-0.7	0.592	
	0.7-0.9	0.794	
	0.9-1.1	0.995	
	1.1-2	1.480	
	2-6	3.460	
	6-10	7.750	
	10-20	14.140	
	>20	20.00	
PRINT	Time, s		
	Compartment Pressure, atm		
	Oxygen Concentration, volume fraction		
	Hot Layer Thickness, m		
	Volumetric Inlet, m^3/s		
	Volumetric Outlet, m^3/s		
	Hot Layer Temperature, °F		
	Mass Burn Rate, g/s		
	Heat Generated by Fire, kW		
	Heat Loss to Walls, kW		
	Heat to Fire Gas, kW		
ARAD, ASMK	Time, s		
	Accumulated Mass (g) on:		
	Floor		
	Wall		
	Ceiling		
	Vents		
	Environment		

3.6 PROGRAM LIMITATIONS

FIRIN was not programmed to mechanistically calculate fire growth. An approximation of fire growth can be made using the concept of burning order. The user decides in what order combustibles burn or whether they burn simultaneously and inputs the burn order in the FUEL and AREC arrays (see Table 3.7).

Because the calculations for many of the compartment effects were approximations, instabilities may occur in the output if too large a time step is chosen. For smaller fires, time steps of 1 or 2 s may be adequate. Larger fires require time steps of less than 1 s to avoid instabilities.

To determine the optimum time step (largest time step that will not result in instabilities), the user can run several small test cases varying the time step and analyzing compartment pressure over short time intervals. First the user should try to determine where maximum burning that occurs in the postulated fire, then assign the identified fuels a burn order of one. The first 100 s of the fire can be run with time steps ranging from 0.01 to 5. From PRINT.DAT a person can obtain data on compartment pressure and plot this parameter against time. The optimum time step will be the largest one resulting in minimal pressure fluctuations.

Radioactive source term equations are based on empirical correlations of the current available data. Little attempt has been made to produce equations based on first principal theories because of the lack of data on radioactive aerosols produced in a fire. However, the most recent experiments at PNL have explored the mechanistic effects of various parameters on radioactive source terms, and equations based on these latest experiments have been included.

3.6.1 Cautions

The FIRIN code was developed without the benefit of complete structured programming techniques. Other than providing subroutines for the radioactive source term mechanisms of release and for particle depletion mechanisms, very little compartmentalization was used. The user must be extremely careful in making code changes. Since temperature, pressure, and fluid flow parameters are all interrelated, a change in one area of the code may affect many other areas.

At the time of this publication, FIRIN has not undergone any formal verification. Informal comparisons have been made comparing FIRIN output against other codes in simulating compartment fire experiments. The radioactive source term part of FIRIN has not even been informally verified against experiments independent of those from which it was developed.

4.0 SAMPLE PROBLEMS

Sample problems are presented in this chapter to illustrate the use of FIRIN. Input files and selected output are shown for a basic problem (problem one) and for variations of the basic scenario (problems two - five). A listing of the FIRIN code is given in Appendix C. This version of the code was used to run all the sample problems described in this chapter. Appendix D is a listing of the parameters used in the main FIRIN code, their definition, and units.

4.1 BASIC SCENARIO

A glove box made of PMMA containing PVC bagging material, paper wipes, solvent, and rubber gloves is located in a concrete room. Room dimensions are 21 m x 9 m x 4 m; the ceiling and walls are 0.25 m thick; and the floor is 0.15 m thick. Each of the combustibles is assumed to be contaminated with plutonium dioxide powder. The glove box is elevated 0.61 m above the floor. Airflows through the room at the rate of 1.5 m^3/s or seven air changes per hour and in a downward direction from the ceiling to the floor. An inlet vent is located at ceiling level and outlet vent at floor level. Each vent is a 2-in. x 2-in. filter with efficiency of 99.95%. The change in pressure across inlet and outlet filters is 0.005 atm. Initial temperatures of the air and surface are 298 °K. Initial pressure in the room is 0.995 atm.

4.2 PROBLEM ONE

In the first sample problem, the PVC, paper, and solvent are assumed to burn first. The fire spreads to include PMMA and rubber gloves. (PVC, paper, and solvent are given a burn order of one; PMMA and rubber gloves are given a burn order of two). Table 4.1 lists the combustibles, the quantity involved in the fire, their burning surface area, and level of contamination.

In addition to the contaminated combustibles, the floor of the glove box is contaminated with 15-g PuO_2, thus involving another radioactive source term: heating of contaminated surfaces. Table 4.2a shows the input parameters

Table 4.1. Combustibles for Sample Problems

Type	Quantity (g)	Surface Area (m^2)	Contaminants (g PuO_2)
PMMA	40,860	3.6	27
PVC	454	0.09	1
PC	4,540	2.0	75
Paper	227	0.09	1
Solvent	910	0.3	2

and values required to run this sample problem. JACT was used in this problem to identify the source term from each burning material. In other problems the user may wish to identify contaminants with different decay levels or physical forms. In problem four JACT is used to identify the source term from radioactive powder as opposed to that from radioactive liquid.

FIRIN echoes the input to a CRT screen if the user is running the problem interactively, or to the log file if the user is running the program in batch mode. The echoing output aids the user to see if the input values were read in correctly. Output files produced in running FIRIN are described in Table 3.6. Appendix D contains all output files from this sample problem except the plotting data bases. Plotting data bases contain the same data as are in some of the other files but in a form that is more easily read by plotting programs.

The output file PRINT.DAT contains data on burn rates, energy generation rates, and conditions in the first compartment. Table 4.2b shows PRINT.DAT for the first sample problem. The increase in mass burn rate at 300 s pinpoints the start of the second burn order. The large amount of combustion gases produced in this time step overpressurize the compartment, and air is blown out the inlet vent until the flow becomes positive again at 420 s. The hot layer completely descends at 340 s. About the same time, oxygen concentration decreases rapidly but stays slightly above 11%, which is considered the limit below which a fire is smothered.

TABLE 4.2a. Input for Problem One

```
PLOTANS,  TSPEC, DELT, MIBO, IGNITE, IPRINT, MJE(1), MJE(2), MJE(3), MJE(4)
   'Y', 1000.0,  2.0,    2,     0,     10,      0,      0,      0,      0
FUEL(1,1), FUEL(2,1), FUEL(3,1), FUEL(4,1)...
      0.0,       0.0,     454.0,       0.0, 0.0, 227.0, 910.0, 0.0, 0.0
FUEL(1,2), FUEL(2,2), FUEL(3,2), FUEL(4,2)...
  40860.0,       0.0,       0.0,    4540.0, 0.0, 0.0, 0.0, 0.0, 0.0
AREC(1,1), AREC(2,1), AREC(3,1), AREC(4,1)...
      0.0,       0.0,      0.09,       0.0, 0.0, 0.09, 0.30, 0.0, 0.0
AREC(1,2), AREC(2,2), AREC(3,2), AREC(4,2)...
      3.6,       0.0,       0.0,       2.0, 0.0, 0.0, 0.0, 0.0, 0.0
  LR,  WR,  ZR, XCEIL, XWALL, XFLOOR, MATERC, MATERW, MATERF
21.0, 9.0, 4.0,  0.25,  0.25,   0.15,      1,      1,      1
NFP,  P1,    P2, TINIT, PINIT, ZIF, ZOF, ZFIRE, VIF, EQUIP, EFFIC
  0, 1.0, 0.990  298.0, 0.995  4.0, 0.0,  0.61, 1.5,   0.0, 0.9995
  TFO,   TCO,   TWO, N2X2IF, N2X2OF
298.0, 298.0, 298.0,      1,      1
NRAD(1), NRAD(2), NRAD(3), NRAD(4), NRAD(5), NRAD(6), NRAD(7)
      4,       1,       1,       0,       0,       0,       0
IFORM, I, JACT, IBO
    1, 3,    3,   1
QRAD1
 1.0
IFORM, I, JACT, IBO
    1, 6,    6,   1
QRAD1
 1.0
IFORM, I, JACT, IBO
    1, 1,    1,   2
QRAD1
 27.0
IFORM, I, JACT, IBO
    1, 4,    4,   2
QRAD1
 75.0
IFORM, I, JACT, IBO
    1, 7,    7,   1
QRAD2
  2.0
JACT, QRAD3
   8,  15.0
```

TABLE 4.2b. PRINT.DAT from Problem One

```
                                          OUTPUT FOR COMPARTMENT EFFECTS

         COMPARTMENT    OXYGEN     HOT LAYER     VOLUMETRIC FLOW RATE     HOT LAYER     MASS BURN    HEAT GEN.   HEAT LOSS    HEAT TO
  TIME    PRESSURE      CONC.      THICKNESS      INLET       OUTLET     TEMPERATURE      RATE        BY FIRE    TO WALLS    FIRE GAS
 ( SEC )   ( ATM )   (VOL FRACT)     ( M )    ( M**3/S )  ( M**3/S )      ( F )       ( G/S )       ( KW )      ( KW )      ( KW )
-------------------------------------------------------------------------------------------------------------------------------------

    0.00     0.9950     0.2100      0.0000      1.5000     -1.5000      76.4000       0.0000       0.0000      0.0000      0.0000
   20.00     0.9954     0.2100      0.4032      1.3815     -1.6185     115.3005      10.5429     359.7645   -344.5267     15.2378
   40.00     0.9953     0.2100      0.7918      1.3966     -1.6034     112.2768      10.5414     359.7131   -334.4408     25.2722
   60.00     0.9953     0.2100      1.1342      1.4002     -1.5998     111.9967      10.5402     359.6726   -326.0364     33.6362
   80.00     0.9953     0.2100      1.4399      1.4003     -1.5997     112.5872      10.5392     359.6376   -319.4371     40.2005
  100.00     0.9954     0.2100      1.7348      1.3921     -1.6079     113.5621      10.5382     359.6062   -313.7714     45.8348
  120.00     0.9956     0.2100      2.0068      1.3317     -1.6683     112.1149       2.4308      21.3886    -36.0367    -14.6481
  140.00     0.9949     0.2100      2.1883      1.5156     -1.4844     108.0533       2.4313      21.3928    -35.8402    -14.4474
  160.00     0.9949     0.2100      2.3644      1.5158     -1.4842     104.7199       2.4314      21.3944    -34.5921    -13.1978
  180.00     0.9949     0.2100      2.5359      1.5150     -1.4850     101.9597       2.4315      21.3953    -33.1885    -11.7932
  200.00     0.9950     0.2100      2.7035      1.5139     -1.4861      99.6523       2.4316      21.3959    -31.8250    -10.4291
  220.00     0.9950     0.2100      2.8690      1.5120     -1.4880      97.7054       2.4317      21.3964    -30.5638     -9.1674
  240.00     0.9950     0.2100      3.0347      1.5104     -1.4896      96.0493       2.4317      21.3968    -29.4319     -8.0351
  260.00     0.9949     0.2100      3.1986      1.5249     -1.4751      94.4550       1.5307       8.7864    -23.3760    -14.5896
  280.00     0.9949     0.2100      3.3578      1.5187     -1.4813      92.8679       1.5307       8.7865    -21.9379    -13.1514
  300.00     1.0089     0.2046      3.5204     -2.6842     -5.6842     106.1561     162.9438    3011.3425  -1803.8683   1207.4742
  320.00     1.0012     0.1983      3.8534     -0.3350     -3.3513     160.8075     163.5692    3023.8186  -1887.4059   1136.4127
  340.00     1.0084     0.1917      4.0000     -1.9335     -3.5355     244.6716     156.0263    2873.3374   -894.4583   1978.8792
  360.00     1.0102     0.1843      4.0000     -1.5290     -2.1880     333.2971     162.2772    2998.0435  -1702.0354   1296.0081
  380.00     1.0010     0.1767      4.0000     -0.1186     -0.8657     376.4951     102.0798    2418.0659  -2131.2954    286.7705
  400.00     1.0001     0.1693      4.0000     -0.0064     -0.6889     391.8969     102.6818    2432.3267  -2222.4307    209.8960
  420.00     0.9996     0.1618      4.0000      0.0409     -0.5935     403.3500     103.0873    2441.9312  -2279.1914    162.7397
  440.00     0.9995     0.1544      4.0000      0.0613     -0.5324     412.2040     103.3489    2448.1277  -2312.1697    135.9580
  460.00     0.9984     0.1470      4.0000      0.1823     -0.4379     417.3847     100.1799    2304.3577  -2318.2805    -13.9229
  480.00     0.9948     0.1416      4.0000      0.5976     -0.2393     402.8062      91.1003    1943.5426  -2105.7485   -162.2059
  500.00     0.9945     0.1377      4.0000      0.6326     -0.2166     383.6743      83.9528    1690.6640  -1853.5145   -162.9105
  520.00     0.9948     0.1344      4.0000      0.6009     -0.2215     366.3522      78.0900    1496.5461  -1642.6213   -146.0752
  540.00     0.9951     0.1317      4.0000      0.5637     -0.2272     351.2458      73.1433    1341.2505  -1470.7566   -129.5061
  560.00     0.9954     0.1293      4.0000      0.5293     -0.2305     338.0438      68.8902    1213.8297  -1329.1017   -115.2720
  580.00     0.9957     0.1272      4.0000      0.4982     -0.2313     326.4149      65.1799    1107.2998  -1210.6145   -103.3147
  600.00     0.9959     0.1253      4.0000      0.4703     -0.2302     316.0846      61.9039    1016.8616  -1110.1416    -93.2800
  620.00     0.9962     0.1236      4.0000      0.4450     -0.2274     306.8351      58.9819     939.0893  -1023.9113    -84.8220
  640.00     0.9964     0.1221      4.0000      0.4220     -0.2235     298.4929      56.3526     871.4600   -949.1132    -77.6532
  660.00     0.9965     0.1207      4.0000      0.4011     -0.2187     290.9198      53.9684     812.0829   -883.6204    -71.5375
  680.00     0.9967     0.1194      4.0000      0.3818     -0.2133     284.0035      51.7922     759.5112   -825.7933    -66.2821
  700.00     0.9969     0.1182      4.0000      0.3641     -0.2075     277.6532      49.7940     712.6201   -774.3571    -61.7370
  720.00     0.9970     0.1171      4.0000      0.3477     -0.2015     271.7943      47.9497     670.5220   -728.3005    -57.7785
  740.00     0.9971     0.1161      4.0000      0.3326     -0.1955     266.3646      46.2397     632.5088   -686.8120    -54.3032
  760.00     0.9972     0.1151      4.0000      0.3185     -0.1894     261.3131      44.6478     598.0068   -649.2415    -51.2346
  780.00     0.9974     0.1142      4.0000      0.3054     -0.1834     256.5963      43.1603     566.5473   -615.0513    -48.5040
  800.00     0.9975     0.1134      4.0000      0.2932     -0.1775     252.1777      41.7659     537.7449   -583.8048    -46.0599
  820.00     0.9976     0.1126      4.0000      0.2818     -0.1718     248.0261      40.4550     511.2757   -555.1332    -43.8575
  840.00     0.9977     0.1119      4.0000      0.2711     -0.1662     244.1151      39.2194     486.8686   -528.7316    -41.8630
  860.00     0.9977     0.1111      4.0000      0.2611     -0.1609     240.4213      38.0519     464.2953   -504.3385    -40.0432
  880.00     0.9978     0.1105      4.0000      0.2517     -0.1557     236.9252      36.9464     443.3596   -481.7365    -38.3769
ALL COMBUSTIBLE MATERIALS WERE CONSUMED BY:  890.0000 SEC

  900.00     0.9909     0.1114      4.0000      1.0510     -0.0177     222.0959       0.0000       0.0000   -392.3703   -392.3703
  920.00     0.9924     0.1146      4.0000      0.8778     -0.0462     201.6803       0.0000       0.0000   -258.5367   -258.5367
  940.00     0.9943     0.1169      4.0000      0.6600     -0.0807     188.1795       0.0000       0.0000   -183.4765   -183.4765
  960.00     0.9954     0.1186      4.0000      0.5269     -0.0999     178.5825       0.0000       0.0000   -137.2334   -137.2334
  980.00     0.9962     0.1199      4.0000      0.4391     -0.1107     171.3725       0.0000       0.0000   -106.6377   -106.6377
 1000.00     0.9967     0.1211      4.0000      0.3776     -0.1168     165.7341       0.0000       0.0000    -85.3472    -85.3472
```

4.3 PROBLEM TWO - ONE BURN ORDER

The second sample problem is similar to the first except that all combustible materials, the PVC, paper, solvent, PMMA, and rubber gloves, are assumed to start burning at the same time. Each combustible is given a burn order of one. Table 4.3a shows the input parameters and values required for this sample problem. The time step was reduced to 1 s to avoid instability problems in airflow.

TABLE 4.3a. Input for Problem Two

```
PLOTANS, TSPEC, DELT, MIBO, IGNITE, IPRINT, MJE(1), MJE(2), MJE(3), MJE(4)
   'Y', 1000.0,  1.0,    1,      0,      20,      0,      0,      0,      0
FUEL(1,1), FUEL(2,1), FUEL(3,1), FUEL(4,1)...
  40860.0,      0.0,      454.0,     4540.0, 0.0, 227.0, 910.0, 0.0, 0.0
AREC(1,1), AREC(2,1), AREC(3,1), AREC(4,1)...
     3.6,       0.0,        0.09,        2.0, 0.0, 0.09, 0.30, 0.0, 0.0
  LR,  WR,  ZR, XCEIL, XWALL, XFLOOR, MATERC, MATERW, MATERF
21.0, 9.0, 4.0,  0.25,  0.25,   0.15,      1,      1,      1
NFP,  P1,    P2, TINIT, PINIT, ZIF, ZOF, ZFIRE, VIF, EQUIP, EFFIC
  0, 1.0, 0.990  298.0, 0.995  4.0, 0.0,  0.61, 1.5,   0.0, 0.9995
  TFO,   TCO,   TWO, N2X2IF, N2X2OF
298.0, 298.0, 298.0,      1,      1
NRAD(1), NRAD(2), NRAD(3), NRAD(4), NRAD(5), NRAD(6), NRAD(7)
     4,       1,       1,       0,       0,       0,       0
IFORM, I, JACT, IBO
    1, 3,    3,   1
QRAD1
 1.0
IFORM, I, JACT, IBO
    1, 6,    6,   1
QRAD1
 1.0
IFORM, I, JACT, IBO
    1, 1,    1,   1
QRAD1
 27.0
IFORM, I, JACT, IBO
    1, 4,    4,   1
QRAD1
 75.0
IFORM, I, JACT, IBO
    1, 7,    7,   1
QRAD2
  2.0
JACT, QRAD3
   8,  15.0
```

Results from this sample problem are shown in Table 4.3b. This PRINT.DAT file can be compared to the PRINT.DAT file from the first problem (Table 4.2b). With all material burning at once, the fire starts out at its maximum burn rate. The hot layer descends sooner (at 260 s compared to 340 s) than in problem one, and all combustibles are burned up in slightly over 10 min. Reverse flow through the inlet filter is experienced at the start of the fire for problem two.

4.4 PROBLEM THREE - AUTOIGNITION ENERGY OPTION

Use of the autoignition energy option is illustrated in the third sample problem. The PMMA and rubber gloves are assumed to burn first. Paper, solvent, and PVC are present in the fire compartment but do not start burning unless heat flux from the fire reaches a sufficient, material dependent level to cause flashover of these materials. PMMA and rubber gloves are given a burn order of two, but are identified with the NBO parameter as being at risk via ignition energy option. The parameters and values required for input are shown in Table 4.4a. The PRINT.DAT file is shown in Table 4.4b.

As shown by the PRINT.DAT output file, heat flux in the room reaches sufficient levels to start the solvent burning but not the paper or PVC. The solvent starts burning at 26 s raising the mass burn rate at this time to its maximum value during the fire. The oxygen concentration drops below 11% at a little over 10 min into the fire, extinguishing any remaining flames. Most of the combustibles (98.7%) that started burning (PMMA, rubber gloves, and solvent) have been consumed by this time.

4.5 PROBLEM FOUR - EQUIPMENT AT RISK

In this sample problem, pieces of equipment are added to the scenario in problem one. Four containers of radioactive material on the floor of the glove box and an adjacent steel glove box located next to the burning glove box are modeled. Two of the four containers of radioactive material hold plutonium

TABLE 4.3b. PRINT.DAT from Problem Two

```
                                       OUTPUT FOR COMPARTMENT EFFECTS

         COMPARTMENT    OXYGEN    HOT LAYER   VOLUMETRIC FLOW RATE     HOT LAYER    MASS BURN  HEAT GEN.   HEAT LOSS    HEAT TO
  TIME     PRESSURE      CONC.    THICKNESS    INLET       OUTLET     TEMPERATURE     RATE     BY FIRE     TO WALLS    FIRE GAS
 ( SEC )   ( ATM )   (VOL FRACT)    ( M )   ( M**3/S )  ( M**3/S )     ( F )        ( G/S )    ( KW )      ( KW )      ( KW )
--------------------------------------------------------------------------------------------------------------------------------

    0.00    0.9950      0.2100     0.0000     1.5000     -1.5000      76.4000       0.0000     0.0000      0.0000      0.0000
   20.00    1.0080      0.2100     1.1681    -1.4060     -5.3953     694.8214     178.4136  3497.3787  -3662.5647   -165.1860
   40.00    1.0050      0.2100     2.3219    -0.6703     -4.4868     629.3456     178.0537  3489.7983  -3934.7261   -444.9277
   60.00    1.0033      0.1732     3.4058    -0.3970     -4.0020     575.3207     177.7712  3483.8472  -3956.8259   -472.9788
   80.00    0.9915      0.1630     3.4440     1.0113     -0.4353     519.7217     110.8035  2751.2288  -3000.4688   -249.2400
  100.00    0.9927      0.1550     3.4929     0.8651     -0.8060     486.7648      99.9377  2325.6021  -2488.1008   -162.4988
  120.00    0.9938      0.1485     3.5538     0.7296     -1.1497     463.5696      98.0361  2248.5427  -2300.6143    -52.0715
  140.00    0.9934      0.1433     3.6204     0.7823     -1.0159     443.2081      89.0443  1905.2052  -1989.3739    -84.1687
  160.00    0.9933      0.1394     3.6842     0.7894     -0.9979     423.2783      82.3957  1668.0485  -1750.6318    -82.5834
  180.00    0.9934      0.1363     3.7494     0.7810     -1.0193     405.4338      77.2722  1495.1665  -1561.8726    -66.7061
  200.00    0.9935      0.1339     3.8172     0.7729     -1.0397     389.8403      73.2063  1364.1675  -1418.4805    -54.3130
  220.00    0.9935      0.1319     3.8877     0.7649     -1.0601     376.2856      69.9156  1262.1958  -1304.9890    -42.7932
  240.00    0.9936      0.1303     3.9606     0.7625     -1.0661     364.3439      66.5186  1174.1160  -1207.6857    -33.5697
  260.00    0.9920      0.1291     4.0000     0.9451     -0.5170     346.5760      71.4058  1234.8180  -1377.0164   -142.1984
  280.00    0.9934      0.1279     4.0000     0.7775     -0.6123     332.3489      68.5254  1161.7498  -1217.8215    -56.0718
  300.00    0.9944      0.1265     4.0000     0.6597     -0.5763     322.9827      65.8257  1089.7850  -1121.6067    -31.8217
  320.00    0.9950      0.1251     4.0000     0.5863     -0.5105     315.3943      62.1946  1016.1987  -1047.8049    -31.6062
  340.00    0.9955      0.1237     4.0000     0.5301     -0.4554     308.5564      59.7467   951.4331   -983.9459    -32.5128
  360.00    0.9959      0.1224     4.0000     0.4890     -0.4079     302.1992      57.4202   891.4023   -926.7134    -35.3111
  380.00    0.9961      0.1211     4.0000     0.4565     -0.3688     296.1595      55.2276   836.3746   -874.1184    -37.7438
  400.00    0.9964      0.1199     4.0000     0.4291     -0.3365     290.3957      53.1689   786.1346   -825.4814    -39.3468
  420.00    0.9966      0.1187     4.0000     0.4051     -0.3095     284.8984      51.2375   740.2823   -780.4684    -40.1861
  440.00    0.9968      0.1177     4.0000     0.3837     -0.2867     279.6641      49.4245   698.3725   -738.8329    -40.4604
  460.00    0.9969      0.1167     4.0000     0.3643     -0.2671     274.6849      47.7205   659.9849   -700.3160    -40.3311
  480.00    0.9971      0.1157     4.0000     0.3467     -0.2500     269.9506      46.1164   624.7430   -664.6655    -39.9225
  500.00    0.9972      0.1148     4.0000     0.3306     -0.2350     265.4491      44.6041   592.3109   -631.6358    -39.3250
  520.00    0.9973      0.1139     4.0000     0.3157     -0.2216     261.1674      43.1759   562.3925   -600.9960    -38.6035
  540.00    0.9974      0.1131     4.0000     0.3020     -0.2097     257.0924      41.8249   534.7305   -572.5334    -37.8030
  560.00    0.9976      0.1124     4.0000     0.2894     -0.1989     253.2111      40.5451   509.0998   -546.0520    -36.9522
  580.00    0.9977      0.1116     4.0000     0.2776     -0.1892     249.5112      39.3310   485.3026   -521.3764    -36.0738
  600.00    0.9977      0.1109     4.0000     0.2667     -0.1803     245.9810      38.1775   463.1630   -498.3442    -35.1812
  620.00    0.9978      0.1103     4.0000     0.2565     -0.1722     242.6098      37.0802   442.5274   -476.8174    -34.2900
ALL COMBUSTIBLE MATERIALS WERE CONSUMED BY:  621.0000 SEC

  640.00    0.9913      0.1131     4.0000     1.0284     -0.0281     218.4489       0.0000     0.0000   -318.6615   -318.6615
  660.00    0.9935      0.1159     4.0000     0.7674     -0.0745     201.2742       0.0000     0.0000   -217.8627   -217.8627
  680.00    0.9949      0.1180     4.0000     0.5987     -0.1018     189.5225       0.0000     0.0000   -158.8688   -158.8688
  700.00    0.9958      0.1195     4.0000     0.4913     -0.1166     180.9238       0.0000     0.0000   -121.2564   -121.2564
  720.00    0.9965      0.1208     4.0000     0.4178     -0.1243     174.3214       0.0000     0.0000    -95.7889    -95.7889
  740.00    0.9969      0.1219     4.0000     0.3648     -0.1281     169.0668       0.0000     0.0000    -77.7596    -77.7596
  760.00    0.9973      0.1228     4.0000     0.3250     -0.1295     164.7656       0.0000     0.0000    -64.5469    -64.5469
  780.00    0.9975      0.1236     4.0000     0.2940     -0.1294     161.1638       0.0000     0.0000    -54.5851    -54.5851
  800.00    0.9977      0.1244     4.0000     0.2693     -0.1283     158.0906       0.0000     0.0000    -46.8971    -46.8971
  820.00    0.9979      0.1250     4.0000     0.2492     -0.1268     155.4272       0.0000     0.0000    -40.8433    -40.8433
  840.00    0.9980      0.1256     4.0000     0.2325     -0.1248     153.0879       0.0000     0.0000    -35.9927    -35.9926
  860.00    0.9982      0.1262     4.0000     0.2184     -0.1227     151.0095       0.0000     0.0000    -32.0449    -32.0449
  880.00    0.9983      0.1267     4.0000     0.2063     -0.1205     149.1446       0.0000     0.0000    -28.7884    -28.7884
  900.00    0.9983      0.1272     4.0000     0.1958     -0.1183     147.4568       0.0000     0.0000    -26.0679    -26.0679
  920.00    0.9984      0.1277     4.0000     0.1866     -0.1160     145.9181       0.0000     0.0000    -23.7717    -23.7717
  940.00    0.9985      0.1282     4.0000     0.1785     -0.1138     144.5057       0.0000     0.0000    -21.8126    -21.8126
  960.00    0.9986      0.1286     4.0000     0.1713     -0.1117     143.2018       0.0000     0.0000    -20.1258    -20.1258
  980.00    0.9986      0.1290     4.0000     0.1648     -0.1096     141.9919       0.0000     0.0000    -18.6615    -18.6615
 1000.00    0.9987      0.1294     4.0000     0.1589     -0.1075     140.8641       0.0000     0.0000    -17.3810    -17.3810
```

TABLE 4.4a. Input Problem Three

```
PLOTANS, TSPEC, DELT, MIBO, IGNITE, IPRINT, MJE(1), MJE(2), MJE(3), MJE(4)
   'Y', 1000.0, 2.0,    2,     1,     10,      0,      0,      0,      0
FUEL(1,2), FUEL(2,2), FUEL(3,2), FUEL(4,2)...
  40860.0,       0.0,       0.0,      4540.0, 0.0, 0.0, 0.0, 0.0, 0.0
FUEL(1,1), FUEL(2,1), FUEL(3,1), FUEL(4,1)...
      0.0,       0.0,     454.0,         0.0, 0.0, 227.0, 910.0, 0.0, 0.0
AREC(1,2), AREC(2,2), AREC(3,2), AREC(4,2)...
      3.6,       0.0,       0.0,         2.0, 0.0, 0.0, 0.0, 0.0, 0.0
AREC(1,1), AREC(2,1), AREC(3,1), AREC(4,1)...
      0.0,       0.0,      0.09,         0.0, 0.0, 0.09, 0.30, 0.0, 0.0
  LR,  WR,  ZR, XCEIL, XWALL, XFLOOR, MATERC, MATERW, MATERF
21.0, 9.0, 4.0,  0.25,  0.25,   0.15,      1,      1,      1
NFP,  P1,    P2, TINIT, PINIT, ZIF, ZOF, ZFIRE, VIF, EQUIP, EFFIC
  0, 1.0, 0.990  298.0, 0.995  4.0, 0.0,  0.61, 1.5,   0.0, 0.9995
  TFO,   TCO,   TWO, N2X2IF, N2X2OF
298.0, 298.0, 298.0,      1,      1
NBO(1), NBO(2), NBO(3), NBO(4), NBO(5), NBO(6), NBO(7), NBO(8), NBO(9)
     0,      2,      1,      0,      2,      1,      1,      2,      2
NRAD(1), NRAD(2), NRAD(3), NRAD(4), NRAD(5), NRAD(6), NRAD(7)
      4,       1,       1,       0,       0,       0,       0
IFORM, I, JACT, IBO
    1, 3,    3,   2
QRAD1
 1.0
IFORM, I, JACT, IBO
    1, 6,    6,   2
QRAD1
 1.0
IFORM, I, JACT, IBO
    1, 1,    1,   1
QRAD1
 27.0
IFORM, I, JACT, IBO
    1, 4,    4,   1
QRAD1
 75.0
IFORM, I, JACT, IBO
    1, 7,    7,   2
QRAD2
  2.0
JACT, QRAD3
   8, 15.0
```

TABLE 4.4b. PRINT.DAT from Problem Three

```
                                        OUTPUT FOR COMPARTMENT EFFECTS

           COMPARTMENT    OXYGEN     HOT LAYER    VOLUMETRIC FLOW RATE    HOT LAYER    MASS BURN   HEAT GEN.   HEAT LOSS    HEAT TO
   TIME     PRESSURE      CONC.      THICKNESS     INLET       OUTLET    TEMPERATURE     RATE       BY FIRE     TO WALLS    FIRE GAS
 ( SEC )    ( ATM )    (VOL FRACT)     ( M )    ( M**3/S )  ( M**3/S )     ( F )        ( G/S )     ( KW )      ( KW )      ( KW )
_____________________________________________________________________________________________________________________________________

    0.00     0.9950      0.2100       0.0000      1.5000     -1.5000      76.4000       0.0000      0.0000      0.0000      0.0000
    2.00     0.9950      0.2100       0.0000      1.5000     -1.5000     411.1837     150.1266   2755.6375  -1799.8984    955.7390
    4.00     1.0069      0.2100       0.1218     -2.0796     -5.0796     495.4149     162.9638   3011.7368  -2738.8726    272.8643
    6.00     1.0026      0.2100       0.2201     -0.7042     -3.7695     541.0549     163.9454   3031.3247  -2730.0889    301.2358
    8.00     1.0068      0.2100       0.3367     -1.8236     -5.0494     570.1249     163.9579   3031.5737  -2758.5608    273.0129
   20.00     1.0060      0.2100       1.0097     -1.1836     -4.8062     615.8334     163.7008   3026.4446  -3033.0967     -6.6521
COMBUSTIBLE TYPE  7 HAS IGNITED AT TIME:    26.0000 SEC

   40.00     1.0050      0.2100       2.1375     -0.7282     -4.4851     590.2865     175.0944   3463.3540  -3714.3215   -250.9675
   60.00     1.0035      0.2100       3.2245     -0.4415     -4.6495     552.5978     174.7944   3456.9646  -3804.1992   -347.2348
   80.00     0.9915      0.1669       3.4765      1.0357     -0.4568     504.5337     107.8879   2724.4441  -2966.9832   -242.5391
  100.00     0.9940      0.1587       3.5294      0.7348     -1.1956     476.7923     107.8411   2723.2637  -2746.7053    -23.4417
  120.00     0.9950      0.1507       3.6123      0.6168     -1.4854     465.6208     107.7664   2721.3811  -2651.4841     69.8970
  140.00     0.9934      0.1451       3.6838      0.8070     -1.0183     444.6542      89.8105   2009.2694  -2109.6714   -100.4020
  160.00     0.9934      0.1410       3.7474      0.8095     -1.0121     423.9310      83.0005   1754.1699  -1840.2595    -86.0896
  180.00     0.9934      0.1378       3.8132      0.8014     -1.0320     405.6675      77.7416   1568.0516  -1640.3732    -72.3215
  200.00     0.9935      0.1353       3.8819      0.7917     -1.0560     389.8694      73.5676   1427.1570  -1485.6582    -58.5012
  220.00     0.9936      0.1332       3.9536      0.7828     -1.0778     376.2143      70.1880   1317.5464  -1359.5187    -41.9723
  240.00     0.9920      0.1315       4.0000      0.9740     -0.5429     357.1132      74.7061   1364.4645  -1505.9420   -141.4775
  260.00     0.9934      0.1300       4.0000      0.8044     -0.6418     342.2518      71.2052   1269.1863  -1326.4757    -57.2894
  280.00     0.9944      0.1284       4.0000      0.6899     -0.6012     332.1121      68.1090   1181.5399  -1216.8308    -35.2909
  300.00     0.9950      0.1268       4.0000      0.6127     -0.5371     323.8179      65.1931   1099.5997  -1132.5330    -32.9332
  320.00     0.9954      0.1252       4.0000      0.5584     -0.4778     316.3352      62.4485   1024.2654  -1059.9221    -35.6567
  340.00     0.9958      0.1238       4.0000      0.5169     -0.4282     309.3243      59.8813    955.8013   -994.4923    -38.6910
  360.00     0.9960      0.1224       4.0000      0.4827     -0.3877     302.6870      57.4879    893.8534   -934.7045    -40.8511
  380.00     0.9963      0.1211       4.0000      0.4534     -0.3542     296.3956      55.2579    837.8126   -879.8895    -42.0769
  400.00     0.9965      0.1199       4.0000      0.4274     -0.3262     290.4372      53.1780    787.0168   -829.5939    -42.5771
  420.00     0.9967      0.1187       4.0000      0.4042     -0.3023     284.7979      51.2346    740.8508   -783.4124    -42.5615
  440.00     0.9969      0.1177       4.0000      0.3832     -0.2816     279.4617      49.4152    698.7665   -740.9636    -42.1971
  460.00     0.9970      0.1166       4.0000      0.3641     -0.2635     274.4106      47.7061    660.2870   -701.8883    -41.6013
  480.00     0.9972      0.1157       4.0000      0.3467     -0.2475     269.6259      46.1032    625.0013   -665.8539    -40.8525
  500.00     0.9973      0.1148       4.0000      0.3307     -0.2333     265.0897      44.5914    592.5560   -632.5627    -40.0067
  520.00     0.9974      0.1139       4.0000      0.3160     -0.2206     260.7845      43.1646    562.6437   -601.7451    -39.1014
  540.00     0.9975      0.1131       4.0000      0.3024     -0.2091     256.6943      41.8157    534.9999   -573.1622    -38.1623
  560.00     0.9976      0.1124       4.0000      0.2898     -0.1987     252.8035      40.5382    509.3944   -546.6004    -37.2060
  580.00     0.9977      0.1116       4.0000      0.2781     -0.1892     249.0986      39.3266    485.6252   -521.8715    -36.2462
  600.00     0.9978      0.1109       4.0000      0.2672     -0.1806     245.5668      38.1758    463.5143   -498.8096    -35.2953
ALL BURNING HAS STOPPED AT TIME:   608.0000 SEC WITH  98.7 PERCENT OF ALL COMBUSTIBLES CONSUMED IN THIS FIRE

  620.00     0.9907      0.1124       4.0000      1.1385     -0.0151     227.5817       0.0000      0.0000   -387.0560   -387.0560
  640.00     0.9928      0.1157       4.0000      0.8750     -0.0624     207.0284       0.0000      0.0000   -254.1741   -254.1741
  660.00     0.9946      0.1179       4.0000      0.6638     -0.0979     193.4685       0.0000      0.0000   -180.4563   -180.4563
  680.00     0.9956      0.1196       4.0000      0.5349     -0.1167     183.7958       0.0000      0.0000   -135.1602   -135.1602
  700.00     0.9963      0.1210       4.0000      0.4493     -0.1266     176.5008       0.0000      0.0000   -105.2580   -105.2580
  720.00     0.9968      0.1222       4.0000      0.3888     -0.1315     170.7720       0.0000      0.0000    -84.4850    -84.4850
  740.00     0.9972      0.1231       4.0000      0.3440     -0.1335     166.1314       0.0000      0.0000    -69.4829    -69.4829
  760.00     0.9975      0.1240       4.0000      0.3096     -0.1337     162.2784       0.0000      0.0000    -58.3076    -58.3076
  780.00     0.9977      0.1248       4.0000      0.2824     -0.1329     159.0137       0.0000      0.0000    -49.7674    -49.7673
  800.00     0.9979      0.1255       4.0000      0.2605     -0.1313     156.2006       0.0000      0.0000    -43.0994    -43.0994
  820.00     0.9980      0.1261       4.0000      0.2424     -0.1294     153.7419       0.0000      0.0000    -37.7949    -37.7949
  840.00     0.9981      0.1267       4.0000      0.2272     -0.1272     151.5667       0.0000      0.0000    -33.5060    -33.5060
  860.00     0.9982      0.1273       4.0000      0.2142     -0.1249     149.6221       0.0000      0.0000    -29.9881    -29.9881
  880.00     0.9983      0.1278       4.0000      0.2030     -0.1226     147.8678       0.0000      0.0000    -27.0651    -27.0651
```

TABLE 4.4b. (contd)

```
   900.00      0.9984     0.1283     4.0000     0.1933    -0.1202    146.2726     0.0000     0.0000   -24.6082   -24.6082
   920.00      0.9985     0.1287     4.0000     0.1847    -0.1179    144.8120     0.0000     0.0000   -22.5209   -22.5209
   940.00      0.9986     0.1292     4.0000     0.1770    -0.1157    143.4664     0.0000     0.0000   -20.7314   -20.7314
   960.00      0.9986     0.1296     4.0000     0.1702    -0.1135    142.2203     0.0000     0.0000   -19.1833   -19.1832
   980.00      0.9987     0.1300     4.0000     0.1640    -0.1113    141.0605     0.0000     0.0000   -17.8328   -17.8328
  1000.00      0.9987     0.1303     4.0000     0.1584    -0.1093    139.9767     0.0000     0.0000   -16.6470   -16.6470

 TIME EXCEEDS USER SPECIFIED TIME AT: 1000.0000 SEC
```

dioxide. The other two contain plutonium nitrate solution. All four containers are stainless steel with a diameter of 0.15 m and a height of 0.23 m. The weight of each of the containers alone is estimated at 0.45 kg.

Of the two powder containers, one is full of powder. The other is partially full containing about half powder and half air. Applicable powder properties are moisture content 1%, bulk density 1.5 g/cm^3, theoretic density 10 g/cm^3. All four are sealed and may overpressurize and rupture during the fire. The failure pressures of the containers are 3.4 atm and 1.3 atm for the full and partially full cans, respectively.

One of the liquid containers is assumed to be full containing about 90% liquid and 10% air by volume. The other liquid container is half full of liquid. The nitrate solution has a density of 1.5 g/cm^3. Failure pressures of the cans are similar to those for the powder containers.

The steel glove box acts as a heat sink during the fire. Dimensions are 0.61 m x 0.91 m. The glove box sits at floor level and weighs about 9 kg. All initial temperatures are 298 °K.

For this sample problem, JACT was set to 1 for all plutonium dioxide powder source terms, and 2 for the nitrate contaminant. The required parameters and input file for this problem are shown in Table 4.5a. The PRINT.DAT file is shown in Table 4.5b.

The results in PRINT.DAT from this problem are very similar to those in problem one. The heat absorbed by the steel glove box is part of the heat loss to walls so cannot be seen separately. The radioactive source term, however, is much greater for this problem than for problem one because the two partially full containers of radioactive material became overpressurized during the fire and contribute to the radioactive release. Over 28 g of contaminant remain airborne in the compartment at 1000 s in this problem compared to a little over 1 g in problem one.

4.6 PROBLEM FIVE - ALTERNATE FLOW PATH

Another variation of problem one is shown here. An alternate flow path is assumed to open up in the room 400 s after the fire starts. The flow path, due

TABLE 4.5a. Input for Problem Four

```
PLOTANS,  TSPEC, DELT, MIBO, IGNITE, IPRINT, MJE(1), MJE(2), MJE(3), MJE(4)
   'Y', 1000.0,  2.0,    2,      0,     10,      1,      2,      2,      0
FUEL(1,1), FUEL(2,1), FUEL(3,1), FUEL(4,1)...
      0.0,       0.0,     454.0,        0.0, 0.0, 227.0, 910.0, 0.0, 0.0
FUEL(1,2), FUEL(2,2), FUEL(3,2), FUEL(4,2)...
  40860.0,       0.0,       0.0,     4540.0, 0.0, 0.0, 0.0, 0.0, 0.0
AREC(1,1), AREC(2,1), AREC(3,1), AREC(4,1)...
      0.0,       0.0,      0.09,        0.0, 0.0, 0.09, 0.30, 0.0, 0.0
AREC(1,2), AREC(2,2), AREC(3,2), AREC(4,2)...
      3.6,       0.0,       0.0,        2.0, 0.0, 0.0, 0.0, 0.0, 0.0

  LR,  WR,  ZR, XCEIL, XWALL, XFLOOR, MATERC, MATERW, MATERF
 21.0, 9.0, 4.0,  0.25,  0.25,   0.15,      1,      1,      1
 NFP,  P1,    P2, TINIT, PINIT, ZIF, ZOF, ZFIRE, VIF, EQUIP, EFFIC
   0, 1.0, 0.990  298.0, 0.995  4.0, 0.0,  0.61, 1.5,   0.0, 0.9995
   TFO,    TCO,    TWO, N2X2IF, N2X2OF
 298.0, 298.0, 298.0,      1,      1
 WD(1,1)
  0.61
 HEQ(1,1)
  0.91
 HTF(1,1)
  0.0
 MATERE(1,1)
   4
 WMASS(1,1)
  9.0
 TE1(1)
 298.0
 WD(1,2), WD(2,2)
    0.15,   0.15
HEQ(1,2), HEQ(2,2)
   0.23,   0.23
HTF(1,2), HTF(2,2)
   0.61,   0.61
MATERE(1,2), MATERE(2,2)
      3,          3
WMASS(1,2), WMASS(2,2)
     0.45,     0.45
VGAS2(1), VGAS2(2)
  3.7E-4,  2.0E-3
VPWD(1), VPWD(2)
 4.1E-3, 2.0E-3
WH2O2(1), WH2O2(2)
   60.0,     30.0
TE2(1), TE2(2)
 298.0, 298.0
TI2(1), TI2(2)
 298.0, 298.0
PF2(1), PF2(2)
   3.4,  1.3
```

TABLE 4.5a. (contd)

```
WD(1,3), WD(2,3)
  0.15,   0.15
HEQ(1,3), HEQ(2,3)
  0.23,   0.23
HTF(1,3), HTF(2,3)
  0.61,   0.61
MATERE(1,3), MATERE(2,3)
    3,           3
WMASS(1,3), WMASS(2,3)
    0.45,       0.45

VGAS3(1), VGAS3(2)
 4.0E-4,   2.0E-3
WH203(1), WH203(2)
  5800.0,  3200.0
TE3(1), TE3(2)
298.0,  298.0

TI3(1), TI3(2)
298.0,  298.0
PF3(1), PF3(2)
 3.4,    1.3
NRAD(1), NRAD(2), NRAD(3), NRAD(4), NRAD(5), NRAD(6), NRAD(7)
      4,       1,       1,       0,       2,       2,       0
IFORM, I, JACT, IBO
    1, 3,    1,   1
QRAD1
 1.0
IFORM, I, JACT, IBO
    1, 6,    1,   1
QRAD1
 1.0
IFORM, I, JACT, IBO
    1, 1,    1,   2
QRAD1
 27.0
IFORM, I, JACT, IBO
    1, 4,    1,   2
QRAD1
 75.0
IFORM, I, JACT, IBO
    1, 7,    1,   1
QRAD2
  2.0
JACT, QRAD3
   1,  15.0
IVES, JACT,  QRAD5,    VOLP, PDEN
   1,     1, 6000.0, 0.0041, 1.0E+7
IVES, JACT,  QRAD5,    VOLP, PDEN
   2,     1, 3000.0, 0.0041, 1.0E+7
IVES, JACT, QRAD6
   1,     2, 5800.0
IVES, JACT, QRAD6
   2,     2, 3200.0
```

TABLE 4.5b. PRINT.DAT from Problem Four

```
                                       OUTPUT FOR COMPARTMENT EFFECTS

           COMPARTMENT    OXYGEN    HOT LAYER    VOLUMETRIC FLOW RATE    HOT LAYER    MASS BURN   HEAT GEN.   HEAT LOSS    HEAT TO
   TIME     PRESSURE      CONC.     THICKNESS     INLET       OUTLET    TEMPERATURE     RATE       BY FIRE    TO WALLS    FIRE GAS
 ( SEC )    ( ATM )    (VOL FRACT)    ( M )    ( M**3/S )  ( M**3/S )     ( F )       ( G/S )     ( KW )      ( KW )      ( KW )
------------------------------------------------------------------------------------------------------------------------------------

     0.00     0.9950     0.2100      0.0000      1.5000     -1.5000     76.4000      0.0000      0.0000      0.0000      0.0000
    20.00     0.9954     0.2100      0.4031      1.3825     -1.6175    115.0380     10.5423    359.7440   -344.3492     15.3949
    40.00     0.9953     0.2100      0.7916      1.3974     -1.6026    111.9976     10.5407    359.6905   -334.1955     25.4950
    60.00     0.9953     0.2100      1.1339      1.4010     -1.5990    111.7143     10.5395    359.6475   -325.8058     33.8416
    80.00     0.9953     0.2100      1.4396      1.4010     -1.5990    112.2966     10.5383    359.6097   -319.1855     40.4242
   100.00     0.9954     0.2100      1.7344      1.3922     -1.6078    113.2972     10.5373    359.5750   -313.0818     46.4931
   120.00     0.9956     0.2100      2.0064      1.3319     -1.6681    111.9209      2.4308     21.3886    -35.2429    -13.8543
   140.00     0.9949     0.2100      2.1881      1.5150     -1.4850    107.9225      2.4313     21.3927    -35.3839    -13.9912
   160.00     0.9949     0.2100      2.3642      1.5156     -1.4844    104.6202      2.4314     21.3943    -34.4102    -13.0160
   180.00     0.9949     0.2100      2.5358      1.5152     -1.4848    101.8679      2.4315     21.3952    -33.3026    -11.9074
   200.00     0.9950     0.2100      2.7033      1.5147     -1.4853     99.5404      2.4316     21.3958    -32.4964    -11.1007
   220.00     0.9950     0.2100      2.8687      1.5128     -1.4872     97.5629      2.4316     21.3962    -31.0753     -9.6790
   240.00     0.9950     0.2100      3.0344      1.5109     -1.4891     95.8902      2.4317     21.3965    -29.7781     -8.3816
   260.00     0.9949     0.2100      3.1982      1.5253     -1.4747     94.2878      1.5307      8.7863    -23.6651    -14.8788
   280.00     0.9949     0.2100      3.3573      1.5190     -1.4810     92.6968      1.5307      8.7864    -22.1217    -13.3353
   300.00     1.0091     0.2046      3.5202     -2.7220     -5.7220    106.2448    162.5802   3004.0889  -1756.1403   1247.9486
   320.00     1.0018     0.1983      3.8619     -0.5014     -3.5442    164.6337    162.3574   2999.6438  -1727.9757   1271.6681
   340.00     1.0086     0.1916      4.0000     -1.7905     -3.3621    258.7447    157.1004   2894.7654  -1034.4063   1860.3591
   360.00     1.0102     0.1840      4.0000     -1.4065     -2.0622    342.7002    163.1130   3014.7183  -1810.5853   1204.1329
   380.00     1.0005     0.1763      4.0000     -0.0536     -0.7864    381.8283    102.4477   2426.7822  -2195.0435    231.7388
   400.00     0.9997     0.1689      4.0000      0.0322     -0.6407    394.6332    102.8702   2436.7891  -2253.8533    182.9358
   420.00     0.9995     0.1615      4.0000      0.0526     -0.5668    404.6769    103.1739   2443.9839  -2292.9507    151.0332
   440.00     0.9994     0.1540      4.0000      0.0616     -0.5145    412.9556    103.3946   2449.2107  -2318.9290    130.2817
   460.00     0.9981     0.1467      4.0000      0.2059     -0.4099    417.2576     99.6872   2282.7485  -2315.9187    -33.1702
   480.00     0.9946     0.1413      4.0000      0.5945     -0.2205    401.9769     90.6694   1927.2357  -2094.1279   -166.8922
   500.00     0.9943     0.1374      4.0000      0.6240     -0.2008    382.7915     83.5645   1676.9672  -1841.9349   -164.9678
   520.00     0.9946     0.1342      4.0000      0.5919     -0.2072    365.5075     77.7295   1484.5676  -1632.1653   -147.5977
   540.00     0.9949     0.1315      4.0000      0.5552     -0.2141    350.4468     72.8023   1330.4546  -1461.2849   -130.8303
   560.00     0.9952     0.1291      4.0000      0.5214     -0.2184    337.2825     68.5639   1203.9478  -1320.4728   -116.5250
   580.00     0.9955     0.1270      4.0000      0.4912     -0.2202    325.6776     64.8659   1098.1782  -1202.7114   -104.5332
   600.00     0.9958     0.1251      4.0000      0.4639     -0.2200    315.3630     61.6010   1008.4008  -1102.8079    -94.4071
   620.00     0.9960     0.1234      4.0000      0.4392     -0.2181    306.1252     58.6890    931.2053  -1017.0567    -85.8514
   640.00     0.9962     0.1219      4.0000      0.4167     -0.2150    297.7924     56.0691    864.0933   -942.6744    -78.5811
   660.00     0.9964     0.1205      4.0000      0.3962     -0.2110    290.2272     53.6941    805.1851   -877.5499    -72.3648
   680.00     0.9966     0.1192      4.0000      0.3774     -0.2063    283.3187     51.5267    753.0409   -820.0587    -67.0178
   700.00     0.9967     0.1181      4.0000      0.3600     -0.2012    276.9761     49.5370    706.5425   -768.9283    -62.3859
   720.00     0.9969     0.1170      4.0000      0.3440     -0.1958    271.1261     47.7011    664.8070   -723.1531    -58.3461
   740.00     0.9970     0.1159      4.0000      0.3291     -0.1902    265.7040     45.9993    627.1306   -681.9297    -54.7991
   760.00     0.9971     0.1150      4.0000      0.3153     -0.1846    260.6614     44.4152    592.9405   -644.6049    -51.6644
   780.00     0.9972     0.1141      4.0000      0.3024     -0.1790    255.9539     42.9355    561.7719   -610.6483    -48.8764
   800.00     0.9974     0.1133      4.0000      0.2904     -0.1735    251.5450     41.5487    533.2394   -579.6187    -46.3792
   820.00     0.9975     0.1125      4.0000      0.2792     -0.1681    247.4034     40.2450    507.0211   -551.1529    -44.1318
   840.00     0.9975     0.1117      4.0000      0.2687     -0.1629    243.5026     39.0164    482.8490   -524.9450    -42.0960
   860.00     0.9976     0.1110      4.0000      0.2589     -0.1578    239.8195     37.8557    460.4939   -500.7359    -40.2420
   880.00     0.9977     0.1103      4.0000      0.2496     -0.1529    236.3339     36.7569    439.7636   -478.3063    -38.5427
ALL COMBUSTIBLE MATERIALS WERE CONSUMED BY:  892.0000 SEC

   900.00     0.9914     0.1108      4.0000      0.9457     -0.0262    223.9146      0.0000      0.0000   -406.1432   -406.1432
   920.00     0.9918     0.1141      4.0000      0.8952     -0.0348    202.8881      0.0000      0.0000   -266.1525   -266.1525
   940.00     0.9939     0.1164      4.0000      0.6699     -0.0728    189.0065      0.0000      0.0000   -187.7884   -187.7884
   960.00     0.9951     0.1181      4.0000      0.5320     -0.0942    179.1957      0.0000      0.0000   -139.9482   -139.9482
   980.00     0.9960     0.1195      4.0000      0.4420     -0.1064    171.8522      0.0000      0.0000   -108.4947   -108.4947
  1000.00     0.9965     0.1206      4.0000      0.3792     -0.1133    166.1230      0.0000      0.0000    -86.7011    -86.7011
```

to a filter failure or other opening in the room, is 0.7 m in diameter and 4.3 m above the floor. (The size of the opening approximates the size of a filter and is a large opening, which may adversely affect fluid flow calculations.) The time step was lowered to 0.5 s to avoid instabilities in flow calculations. Also note that NFP was changed to 1 so that alternate flow path parameters could be read in. Table 4.6a shows the change in parameters required for this problem. The PRINT.DAT file from this problem is shown in Table 4.6b.

The results show the opening of the alternate flow path at 400 s. Prior to this, the fire is similar to problem one, with reverse flow occurring at the maximum burn rate. After the flow path opens, however, outlet flow is quickly diverted to this opening, stabilizing flow in the compartment. Radioactive material is allowed to escape unfiltered through this path. Figure 4.1 shows the accumulated mass of radioactive particles that escape the fire compartment for problems one and five after 400 s. Prior to 400 s, results from the two problems are approximately equal. After 400 s, however, radioactive particles are ventilated out the unfiltered alternate flow path in problem five resulting in a higher radioactive release to the environs.

TABLE 4.6a. Input for Problem Five

```
PLOTANS,  TSPEC, DELT, MIBO, IGNITE, IPRINT, MJE(1), MJE(2), MJE(3), MJE(4)
    'Y', 1000.0,  0.5,    2,      0,     10,      0,      0,      0,      0
FUEL(1,1), FUEL(2,1), FUEL(3,1), FUEL(4,1)...
      0.0,       0.0,     454.0,       0.0, 0.0, 227.0, 910.0, 0.0, 0.0
FUEL(1,2), FUEL(2,2), FUEL(3,2), FUEL(4,2)...
  40860.0,       0.0,       0.0,    4540.0, 0.0, 0.0, 0.0, 0.0, 0.0
AREC(1,1), AREC(2,1), AREC(3,1), AREC(4,1)...
      0.0,       0.0,      0.09,       0.0, 0.0, 0.09, 0.30, 0.0, 0.0
AREC(1,2), AREC(2,2), AREC(3,2), AREC(4,2)...
      3.6,       0.0,       0.0,       2.0, 0.0, 0.0, 0.0, 0.0, 0.0
   LR,  WR,  ZR, XCEIL, XWALL, XFLOOR, MATERC, MATERW, MATERF
21.0, 9.0, 4.0,  0.25,  0.25,   0.15,      1,      1,      1
NFP,  P1,    P2, TINIT, PINIT, ZIF, ZOF, ZFIRE, VIF, EQUIP, EFFIC
  1, 1.0, 0.990  298.0, 0.995  4.0, 0.0,  0.61, 1.5,   0.0, 0.9995
  TFO,    TCO,    TWO, N2X2IF, N2X2OF
298.0, 298.0, 298.0,      1,      1
TFP(1)
400.0
HFP(1)
 4.3
PFP(1)
0.99
DFP(1)
 0.7
NRAD(1), NRAD(2), NRAD(3), NRAD(4), NRAD(5), NRAD(6), NRAD(7)
      4,       1,       1,       0,       0,       0,       0
IFORM, I, JACT, IBO
    1, 3,    3,   1
QRAD1
 1.0
IFORM, I, JACT, IBO
    1, 6,    6,   1
QRAD1
 1.0
IFORM, I, JACT, IBO
    1, 1,    1,   2
QRAD1
 27.0
IFORM, I, JACT, IBO
    1, 4,    4,   2
QRAD1
 75.0
IFORM, I, JACT, IBO
    1, 7,    7,   1
QRAD2
  2.0
JACT, QRAD3
   8,  15.0
```

TABLE 4.6b. PRINT.DAT from Problem Five

```
                                          OUTPUT FOR COMPARTMENT EFFECTS

            COMPARTMENT     OXYGEN     HOT LAYER    VOLUMETRIC FLOW RATE     HOT LAYER    MASS BURN   HEAT GEN.   HEAT LOSS    HEAT TO
   TIME      PRESSURE       CONC.      THICKNESS     INLET        OUTLET    TEMPERATURE     RATE       BY FIRE    TO WALLS    FIRE GAS
 ( SEC ) -- ( ATM )      (VOL FRACT)     ( M )    ( M**3/S )  ( M**3/S )     ( F )       ( G/S )     ( KW )      ( KW )      ( KW )
 ----------------------------------------------------------------------------------------------------------------------------------------

     0.00      0.9950       0.2100      0.0000      1.5000     -1.5000      76.4000      0.0000      0.0000      0.0000      0.0000
    20.00      0.9953       0.2100      0.4288      1.4035     -1.5965     106.1667     10.5425    359.7523   -342.2163     17.5359
    40.00      0.9953       0.2100      0.8114      1.4046     -1.5954     105.7407     10.5411    359.7041   -331.3324     28.3717
    60.00      0.9953       0.2100      1.1497      1.4031     -1.5969     106.8655     10.5400    359.6649   -322.7629     36.9021
    80.00      0.9953       0.2100      1.4531      1.4002     -1.5998     108.4113     10.5390    359.6309   -315.9845     43.6464
   100.00      0.9954       0.2100      1.7480      1.3915     -1.6085     110.0921     10.5381    359.6002   -310.3917     49.2084
   120.00      0.9950       0.2100      2.0075      1.5123     -1.4877     109.5328      2.4310     21.3906    -34.0268    -12.6362
   140.00      0.9950       0.2100      2.1891      1.5135     -1.4865     105.8558      2.4313     21.3934    -33.6964    -12.3031
   160.00      0.9950       0.2100      2.3653      1.5133     -1.4867     102.8275      2.4315     21.3947    -32.6169    -11.2222
   180.00      0.9950       0.2100      2.5369      1.5126     -1.4874     100.3155      2.4316     21.3955    -31.4110    -10.0154
   200.00      0.9950       0.2100      2.7045      1.5116     -1.4884      98.2120      2.4316     21.3961    -30.2305     -8.8344
   220.00      0.9950       0.2100      2.8703      1.5100     -1.4900      96.4345      2.4317     21.3965    -29.1353     -7.7387
   240.00      0.9950       0.2100      3.0362      1.5085     -1.4915      94.9203      2.4317     21.3969    -28.1444     -6.7475
   260.00      0.9949       0.2100      3.1993      1.5191     -1.4809      93.4244      1.5307      8.7864    -22.1406    -13.3544
   280.00      0.9949       0.2100      3.3587      1.5171     -1.4829      91.9423      1.5308      8.7865    -20.8263    -12.0398
   300.00      1.0008       0.2044      3.5437     -0.2249     -3.2251     104.2160    163.8712   3029.8442  -1869.2704   1160.5739
   320.00      1.0012       0.1981      3.8622     -0.3420     -3.3566     159.1001    163.4975   3022.3875  -1886.8055   1135.5819
   340.00      1.0087       0.1918      4.0000     -1.9523     -3.4721     241.7253    156.7619   2888.0122   -924.2510   1963.7612
   360.00      1.0106       0.1846      4.0000     -1.5367     -2.1673     330.5834    162.8054   3008.5806  -1713.6301   1294.9504
   380.00      1.0017       0.1772      4.0000     -0.1944     -0.9115     372.0951    101.8714   2413.1304  -2083.0913    330.0391
   400.00      1.0005       0.1698      4.0000     -0.0557     -0.7125     389.5906    102.5850   2430.0334  -2197.6245    232.4089
   420.00      0.9907       0.1643      4.0000      1.0632     -0.0441     392.1656    102.4514   2426.8687  -2156.1956    270.6731
   440.00      0.9907       0.1589      4.0000      1.0594     -0.0460     396.1879    102.4222   2426.1760  -2139.2488    286.9272
   460.00      0.9907       0.1538      4.0000      1.0577     -0.0467     400.7271    102.4529   2426.9048  -2134.2439    292.6609
   480.00      0.9906       0.1489      4.0000      1.0675     -0.0407     404.8737    101.1330   2367.3760  -2129.6936    237.6824
   500.00      0.9904       0.1448      4.0000      1.0971     -0.0235     399.1869     94.6789   2100.6829  -2020.0581     80.6248
   520.00      0.9903       0.1416      4.0000      1.1049     -0.0190     387.8179     89.1719   1892.6975  -1858.1411     34.5564
   540.00      0.9903       0.1390      4.0000      1.1062     -0.0182     375.7424     84.6448   1731.9897  -1701.7128     30.2770
   560.00      0.9903       0.1370      4.0000      1.1054     -0.0186     364.6524     80.9624   1607.1536  -1566.3903     40.7633
   580.00      0.9903       0.1353      4.0000      1.1038     -0.0194     355.0038     77.9674   1509.1958  -1453.6635     55.5323
   600.00      0.9903       0.1340      4.0000      1.1022     -0.0203     346.8041     75.5220   1431.4832  -1360.9066     70.5765
   620.00      0.9903       0.1329      4.0000      1.1005     -0.0211     339.9146     73.5157   1369.1982  -1284.7498     84.4485
   640.00      0.9903       0.1320      4.0000      1.0991     -0.0218     334.1616     71.8615   1318.8228  -1222.0964     96.7263
   660.00      0.9904       0.1312      4.0000      1.0978     -0.0225     329.3765     70.4912   1277.7567  -1170.3555    107.4012
   680.00      0.9904       0.1306      4.0000      1.0966     -0.0230     325.4102     69.3516   1244.0591  -1127.4384    116.6207
   700.00      0.9904       0.1300      4.0000      1.0956     -0.0234     322.1354     68.4006   1216.2501  -1091.6914    124.5587
   720.00      0.9904       0.1296      4.0000      1.0948     -0.0238     319.4450     67.6046   1193.1902  -1061.7919    131.3983
   740.00      0.9904       0.1292      4.0000      1.0940     -0.0240     317.2493     66.9366   1173.9886  -1036.6943    137.2943
   760.00      0.9904       0.1289      4.0000      1.0933     -0.0243     315.4725     66.3749   1157.9468  -1015.5513    142.3955
ALL COMBUSTIBLE MATERIALS WERE CONSUMED BY:  772.0000 SEC

   780.00      0.9887       0.1320      4.0000      1.2878      0.0810     285.1660      0.0000      0.0000   -760.2640   -760.2640
   800.00      0.9892       0.1390      4.0000      1.2299      0.0494     237.8274      0.0000      0.0000   -401.3062   -401.3062
   820.00      0.9895       0.1442      4.0000      1.1963      0.0311     210.5921      0.0000      0.0000   -236.8908   -236.8908
   840.00      0.9896       0.1484      4.0000      1.1789      0.0216     192.8766      0.0000      0.0000   -148.3610   -148.3610
   860.00      0.9897       0.1520      4.0000      1.1692      0.0163     180.3921      0.0000      0.0000    -95.6102    -95.6102
   880.00      0.9898       0.1552      4.0000      1.1634      0.0132     171.0848      0.0000      0.0000    -61.9292    -61.9292
   900.00      0.9898       0.1581      4.0000      1.1597      0.0112     163.8486      0.0000      0.0000    -39.3096    -39.3096
   920.00      0.9898       0.1607      4.0000      1.1574      0.0099     158.0359      0.0000      0.0000    -23.5196    -23.5196
   940.00      0.9898       0.1631      4.0000      1.1558      0.0090     153.2430      0.0000      0.0000    -12.1551    -12.1551
   960.00      0.9899       0.1653      4.0000      1.1547      0.0084     149.2059      0.0000      0.0000     -3.7702     -3.7702
   980.00      0.9899       0.1674      4.0000      1.1540      0.0080     145.7444      0.0000      0.0000      2.5431      2.5432
  1000.00      0.9899       0.1694      4.0000      1.1534      0.0077     142.7320      0.0000      0.0000      7.3779      7.3779
```

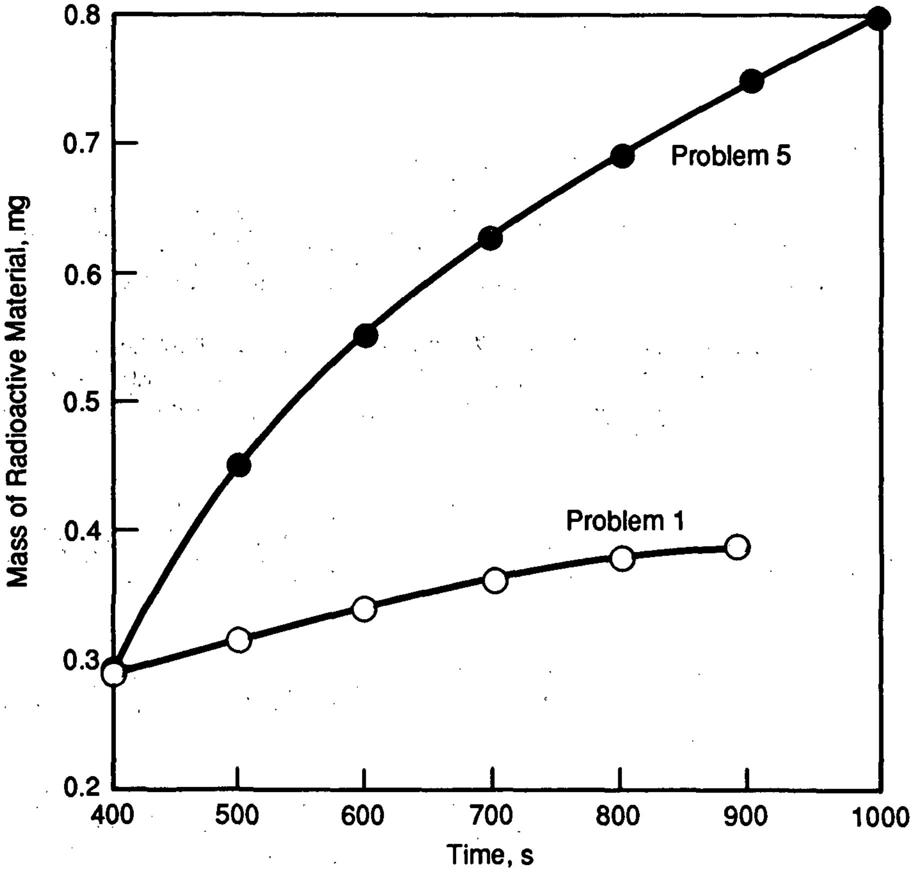

FIGURE 4.1. Accumulated Mass of Radioactive Material to Environs from Problems 1 and 5

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APPENDIX A

EXPERIMENTAL DATA FOR BURNING CONTAMINATED COMBUSTIBLE SOLIDS

APPENDIX A

EXPERIMENTAL DATA FOR BURNING CONTAMINATED COMBUSTIBLE SOLIDS

TABLE A.1. Burning Cellulose Contaminated with DUO Powder

Run Number	Time, min	Cumulative Fractional Release of U x 10^5	Cumulative Mass Loss, g	Notes[(a)]
4	0	0	0	HF = 23 kW/m^2
	3.00	1.38	2.57	A = 8 ℓ/m
	7.50	8.38	19.97	UC = 0.10 g/g
	11.00	16.13	29.95	Smoldering
	14.00	18.78	31.00	
12	0	0	0	
	7.42	3.28	14.68	HF = 23 kW/m^2
	8.50	8.62	21.87	A = 8 ℓ/m
	12.17	15.40	31.10	UC = 0.03 g/g
	17.00	23.90	31.12	
15	0	0	0	
	21.33	12.67	5.43	HF = 13 kW/m^2
	22.32	14.40	9.20	A = 8 ℓ/m
	29.25	27.82	26.77	UC = 0.09 g/g
	33.50	30.27	27.84	
23	0	0	0	
	3.20	12.30	5.66	HF = 23 kW/m^2
	3.97	32.80	11.32	A = 8 ℓ/m
	7.68	47.50	24.43	UC = 0.09 g/g
	10.97	47.80	23.86	
26	0	0	0	
	3.28	25.40	5.33	HF = 23 kW/m^2
	5.00	43.00	15.88	A = 8 ℓ/m
	7.28	51.50	21.56	UC = 0.08 g/g
	10.42	54.60	22.49	
27	0	0	0	
	4.10	20.40	10.88	HF = 23 kW/m^2
	5.88	38.10	20.38	A = 8 ℓ/m
	7.73	43.10	22.96	UC = 0.09 g/g
	12.72	47.80	21.77	

TABLE A.1. (contd)

Run Number	Time, min	Cumulative Fractional Release of U x 10^5	Cumulative Mass Loss, g	Notes[a]
28	0	0	0	
	3.68	56.60	4.53	HF = 23 kW/m^2
	6.05	76.10	20.65	A = 17.5 ℓ/m
	6.80	86.00	22.33	UC = 0.095 g/g
	11.38	90.30	23.15	

(a) HF = external heat flux
A = airflow
UC = uranium concentration (gu/g combustible)

TABLE A.2. Burning Cellulose Contaminated with Air-Dried UNH

Run Number	Time, min	Cumulative Fractional Release of U x 10^5	Cumulative Mass Loss, g	Notes[a]
20	0	0	0	
	1.12	10.5	5.27	HF = 23 kW/m^2
	2.57	18.9	11.65	
	4.48	20.5	13.16	
	9.78	28.9	14.53	
22	0	0	0	
	1.00	7.91	8.22	HF = 13 kW/m^2
	2.25	8.58	12.00	
	8.25	9.62	14.57	

(a) HF = external heat flux

TABLE A.3. Burning Cellulose Contaminated with Liquid UNH

Run Number	Time, min	Cumulative Fractional Release of U x 10^5	Cumulative Mass Loss, g	Notes[(a)]
3	0	0	0	
	7.00	2.63	25.81	HF = 23 kW/m^2
	12.00	9.10	62.47	
	17.00	13.18	93.75	
	20.50	14.47	101.69	
5	0	0	0	
	20.00	0.28	29.91	
	32.00	0.50	64.07	
	39.00	4.33	84.91	HF= 7 kW/m^2
	44.50	7.52	108.79	
18	0	0	0	
	4.87	1.51	5.97	
	5.95	2.33	13.17	HF = 23 kW/m^2
	8.30	4.17	24.34	
	15.30	7.04	38.04	

(a) HF = external heat flux

TABLE A.4. Burning Contaminated Polychloroprene

Run Number	Time, min	Cumulative Fractional Release of U x 10^3	Cumulative Fractional Smoke Release	Notes
DUO Powder Contaminant:				
7	0	0	0	
	1.00	4.79	0.0435	
	1.50	9.72	0.1149	
	2.83	10.05	0.1294	
	7.50	10.26	0.1393	
9	0	0	0	
	1.16	6.44	0.0862	
	2.33	7.61	0.1312	
	4.00	7.76	0.1418	
	10.00	8.00	0.1484	
11	0	0	0	
	8.25	2.39	0.0154	
	13.58	3.12	0.0498	
	15.08	3.54	0.0670	
	15.67	3.71	0.0703	
Air-Dried UNH Contaminant:				
24	0	0	0	
	1.00	1.19	0.115	
	2.00	3.86	0.0685	
	4.40	4.16	0.0955	
	7.50	4.22	0.1002	
Liquid UNH Contaminant				
8	0	0	0	
	0.66	1.1	0.0152	
	1.25	22.7	0.0576	
	2.25	32.3	0.0748	
	9.00	34.7	0.1028	

TABLE A.5. Burning Contaminant Polymethyl Methacrylate

Run Number	Time, min	Cumulative Fractional Release of U x 100	Notes
DUO powder contaminant:			
6	0	0	
	14.50	2.92	
	18.00	3.15	
	24.50	3.16	
	31.50	3.18	
13	0	0	
	9.00	2.26	
	19.00	2.84	
	27.27	2.92	
	34.57	2.98	
Liquid UNH contaminant:			
10	0	0	
	13.78	1.86	
	15.41	1.87	
	20.25	1.87	
	26.00	1.88	
21	0	0	
	4.12	1.08	
	7.50	1.62	
	13.33	1.78	
	16.65	2.01	
Air-dried UNH contaminant:			
14	0	0	
	7.25	0.261	
	10.53	0.606	
	13.33	0.634	
	16.60	0.645	

TABLE A.6. Burning Polystyrene Contaminated with Liquid UNH

Run Number	Time, min	Cumulative Fractional Release of U x 10^3	Notes
17	0	0	
	9.00	1.48	
	10.00	1.52	
	13.50	1.55	
	18.53	1.57	
25	0	0	
	6.65	1.74	
	7.75	1.78	
	9.25	1.80	
	12.75	1.82	

APPENDIX B

FUEL AND CONSTRUCTION MATERIAL PROPERTIES IN FIRIN DATA BASE

TABLE B.1. Fuel Material Properties in FIRIN Data Base

Property	Polymethyl methacrylate	Polystyrene	Polyvinyl chloride	Polychloroprene	Cellulose (wood)	Cellulosic Materials (paper)	Kerosene
QCHEAT, kJ/m^2	2600.00	1950.00	2300.00	2440.00	420.00	2000.00	100.00
QRR, kW/m^2	11.00	14.00	21.00	8.00	16.00	12.00	8.00
HEATV, kJ/g	1.63	1.70	2.47	2.35	3.60	3.20	1.50
HEATC, kJ/g	25.20	39.20	16.40	25.00	17.70	14.00	46.00
WFC, fraction	0.60	0.92	0.38	0.54	0.48	0.45	0.87
WFH, fraction	0.08	0.08	0.05	0.06	0.06	0.06	0.13
WFO, fraction	0.32	0.00	0.00	0.00	0.46	0.49	0.00
WFCL, fraction	0.00	0.00	0.57	0.40	0.00	0.00	0.00
QFC, kW/m^2							
OV	12.00	13.00	26.00	38.00	18.00	7.00	10.80
SV	6.00	6.50	13.00	19.00	9.00	3.50	5.40
UV	0.00	0.00	0.00	0.00	0.00	0.00	0.00
QFRR, kW/m^2							
OV	40.00	66.00	37.00	34.00	40.00	6.00	13.70
SV	20.00	33.00	18.50	17.00	20.00	3.00	6.85
UV	0.00	0.00	0.00	0.00	0.00	0.00	0.00
XA, fraction							
OV	0.94	0.68	0.35	0.41	0.70	1.00	0.91
SV	0.47	0.34	0.17	0.21	0.35	0.50	0.45
UV	0.00	0.00	0.00	0.00	0.00	0.00	0.00
XC, fraction							
OV	0.64	0.40	0.19	0.24	0.44	0.80	0.57
SV	0.32	0.20	0.09	0.07	0.22	0.40	0.28
UV	0.00	0.00	0.00	0.00	0.00	0.00	0.00
XR, fraction							
OV	0.30	0.28	0.16	0.16	0.26	0.20	0.33
SV	0.15	0.14	0.08	0.05	0.13	0.10	0.17
UV	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE B.1. (contd)

Property	Polymethyl methacrylate	Polystyrene	Polyvinyl chloride	Polychloroprene	Cellulose (wood)	Cellulosic Materials (paper)	Kerosene
$YFCO_2$, fraction							
OV	2.10	2.20	0.46	0.50	1.30	1.60	2.80
SV	1.47	1.54	0.38	0.25	1.04	1.12	1.96
UV	0.00	0.00	0.00	0.00	0.00	0.00	0.00
YFH_2O, fraction							
OV	0.69	0.45	0.09	0.10	0.43	0.54	1.04
SV	0.49	0.32	0.08	0.05	0.34	0.38	0.73
UV	0.00	0.00	0.00	0.00	0.00	0.00	0.00
YFHCL, fraction							
OV	0.00	0.00	0.19	0.19	0.00	0.00	0.00
SV	0.00	0.00	0.16	0.16	0.00	0.00	0.00
UV	0.00	0.00	0.00	0.00	0.00	0.00	0.00
YSMOK, fraction							
OV	0.210	0.15	0.086	0.38	0.015	0.001	0.087
SV	0.254	0.85	0.277	0.43	0.075	0.002	0.200
UV	0.000	0.00	0.000	0.00	0.000	0.000	0.000
YFCO1, fraction							
OV	0.011	0.021	0.039	0.035	0.004	0.003	0.030
SV	0.005	0.035	0.019	0.003	0.002	0.001	0.015
UV	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$YFCH_4$, fraction							
OV	0.001	0.02	0.02	0.02	0.001	0.002	0.005
SV	0.005	0.10	0.10	0.10	0.005	0.010	0.002
UV	0.000	0.00	0.00	0.00	0.000	0.000	0.000

TABLE B.1. (contd)

Parameter	Definition
QCHEAT	Energy required to generate combustible vapor air mixture
QRR	Fuel material surface reradiation
HEATV	Heat required to generate a unit mass of vapor
HEATC	Net heat of complete combustion
WFC	Weight fraction of carbon in fuel
WFH	Weight fraction of hydrogen in fuel
WFO	Weight fraction of oxygen in fuel
WFCL	Weight fraction of chlorine in fuel
QFC	Convective heat flux from flame to fuel
OV	Over-ventilated ($O_2 > 15\%$)
SV	Semi-ventilated ($15\% > O_2 > 11\%$)
UV	Under-ventilated ($O_2 < 11\%$)
QFRR	Radioactive heat flux from flame to fuel
XA	Combustion efficiency
XC	Convective fraction of combustion efficiency
XR	Radiative fraction of combustion efficiency
$YFCO_2$	Fractional yield of carbon dioxide
YFH_2O	Fractional yield of water
YFHCL	Fractional yield of hydrochloric acid
YSMOK	Fractional yield of smoke
$YFCO_1$	Fractional yield of carbon monoxide
$YFCH_4$	Fractional yield of methane

TABLE B.2. Construction Material Properties in FIRIN Data Base

	Thermal Conductivity, kJ/m·s·°K		Emissivity(b)	Density, kg/m^3	Heat Capacity,(c) kJ/kg °K	
	COND	CONDM(a)	EMIS	RHOO	CPCA	CPCAM(a)
Concrete	1.878E-3	1.0575E-6	0.94	2240.0	0.879	0.0
Firebrick	1.075E-3	0.0	0.75	2000.0	0.837	0.0
Stainless steel	13.84E-3	-1.52E-5	0.24	7820.0	0.465	4.075E-4
Steel	45.83E-3	1.56E-5	0.16	7850.0	0.465	4.075E-4
Aluminum	202.36E-3	-1.35E-4	0.06	2707.0	0.879	4.10E-4
Copper	387.43E-3	5.88E-5	0.07	8940.0	0.379	1.2E-4
Brass	106.37E-3	-1.35E-4	0.09	8520.0	0.377	2.5E-4

(a) Extrapolation factor with change in temperature
(b) Siegal and Howell 1981
(c) Raznjevic 1976.

REFERENCES

Raznjevic, K. 1976. Handbook of Thermodynamic Tables and Charts. McGraw-Hill, Inc., New York.

Siegal, R., and J. R. Howell. 1981. Thermal Radiation Heat Transfer. 2nd ed. McGraw-Hill, Inc., New York.

APPENDIX C

FIRIN CODE LISTING

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C
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$C
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$C
C                                                                              C
C                             FIRIN COMPUTER CODE                             C
C                                                                              C
C         FIRIN is developed to estimate both the radioactive and non-       C
C     radioactive source terms for fire accident scenarios in nuclear fuel     C
C     cycle facilities.  The major FIRIN calculations include:               C
C         1. Generation rate of:                                               C
C              smoke and soot mass                                             C
C              net energy deposition in gases                                  C
C         2. Mass loss rate of combustion from fire                            C
C         3. Mass generation rate of radioactive particles                     C
C         4. Source particle characteristics                                   C
C              smoke                                                           C
C              radioactive                                                     C
C     FIRIN can be used independently to estimate fire generated releases,   C
C     the releases at the atmospheric boundary can be estimated in conjunct-   C
C     ion with the computer code FIRAC, which is developed at Los Alamos       C
C     National laboratory.                                                     C
C                                                                              C
C******************************************************************************C
C                                                                              C
C                               Dimension Block                                C
C                                                                              C

      PARAMETER NUM = 51
      PARAMETER IIBO= 5
C
      CHARACTER INPUTFILE*30
      CHARACTER*1 PLOTANS
      REAL MASS(9,3),LR,N2X2IF,N2X2OF
C
C  N2X2IF = NO. OF 2FT X 2FT FILTERS ON INLET FILTER BANK
C  N2X2OF = NO. OF 2FT X 2FT FILTERS ON OUTLET FILTER BANK
C
      COMMON/PARA1/RHOO(15),CPCA(15),CPCAM(15)
      COMMON/PARA2/COND(15),CONDM(15)
      COMMON/PARA3/EMIS(15),TINIT,UMIN,WRADF
      COMMON/PARA5/IFORM,I,TSTEP,QMR(11,10),JACT,J
      COMMON/PARA6/FMH2O,FMHO2,FMHN2,FMCO1,FMCO2,LR,WR,ZR,
     @ZM,TAVWH,TAVWC,TCAV,TFAV,PCOMP,FHL,FCL,DPART(11),
     @HLR,FRAC(8,12),DX,GRPART(2,12),A(2,12),B(2,12),
     @A0(2,12),B0(2,12),ALOSS(2,12),BLOSS(2,12),FRACF(11),
     @FRACW(11),FRACC(11),FLAG
      COMMON/PARA7/FE,DELT,THL,TCL
C
      DIMENSION OUTVEN(2),VEMASS(2),FMASS(2),WAMASS(2),CMASS(2)
C
      DIMENSION TC(NUM,2),YEC(NUM),YHC(NUM),YCC(NUM),
     1TDIFC(NUM),TW(NUM,NUM,2),QWA(NUM),TDIFW(NUM,NUM),
     2YEW(NUM,NUM),YHW(NUM,NUM),YCW(NUM,NUM),SMSZ(11),
     3ZCL(10,4),TBCL(10,4),EQ(4),AFLOSS(8,2,12)
     5,TF(NUM,2),YEF(NUM),YHF(NUM),YCF(NUM)
     6,TDIFF(NUM),ARER(10,4),WD(10,4),HEQ(10,4),ARHT(10,4)
     7,WMASS(10,4),MATERE(10,4),HTF(10,4)
     8,MJE(4),TE1(10),QE1(10),TE2(10),QE2(10),FAIL2(10),TI2(10)
     9,VGAS2(10),VPWD(10),WH2O2(10),QI2(10),PF2(10),VOL(10)
C
      DIMENSION OKFP(20),TFP(20),OKFHL(20),HFP(20),OKPFO(20),PFP(20),
```

```
     10KPFI(20),FPIHL(20),FPICL(20),FPOHL(20),FPOCL(20),DFP(20)
     2,ARBL(10),TE4(10),QE4(10),TL(10),TE3(10),TI3(10),FAIL3(10),
     3VGAS3(10),WH2O3(10),PF3(10),PI21(10),PI2(10),QE3(10),QI3(10),
     4PI3(10)
C
      DIMENSION QFC(9,3),QFRR(9,3),QRR(9),HEATV(9),HEATC(9),QCHEAT(9),
     1XA(9,3),XC(9,3),XR(9,3),YFCO2(9,3),YFH2O(9,3),YSMOK(9,3)
     2,YFCO1(9,3),YFCH4(9,3),WFC(9),WFH(9),WFO(9),WFCL(9),YFHCL(9,3)
C
      DIMENSION TBURN(9,IIBO),BRATE(9,3),FUEL(9,IIBO),AREC(9,IIBO),
     1NBO(9),QACT(9,3),QCON(9,3),QRAD(9,3),
     2GCO2(9,3),GCO1(9,3),GH2O(9,3),SMOK(9,3),GHCL(9,3),GCH4(9,3)
C
      DIMENSION QRAD1(29,10,IIBO),QRAD2(6,10,IIBO),NRAD(7),QRAD3(10),
     1SQ(10,IIBO),QRAD4(10,10),QRAD7(10,IIBO),OFUEL(9,IIBO),
     1TEND(9,IIBO),TSTART(9,IIBO),XMAX3(29,10),VOLP(10),PDEN(10,10),
     2RBOIL(10),QRAD5(10,10),QRAD6(10,10),XMAX1(29,10),XMAX2(29,10)
C
C******************************************************************************C
C                                                                              C
C                               Data Block                                     C
C                                                                              C
C         This block contains data on physical/chemical and pyrolysis/         C
C     combustion properties of fuels and physical properties of non-           C
C     combustibles.                                                            C
C                                                                              C
C         The mean values of QCHEAT are used here for ignition concept         C
C
      DATA QCHEAT/2600.,1950.,2300.,2440.,420.,2000.,100.,0.,0./
      DATA QRR/11.,14.,21.,8.,16.,12.0,8.,0.,0./
      DATA HEATV/1.63,1.7,2.47,2.35,3.6,3.2,1.5,1.,1./
      DATA HEATC/25.2,39.2,16.4,25.,17.7,14.0,46.0,0.,0./
      DATA QFC/12.,13.,26.,38.,18.,7.,10.8,0.,0.,
     +6.,6.5,13.,19.,9.,3.5,5.4,11*0.0/
      DATA QFRR/40.,66.,37.,34.,40.,6.,13.7,0.,0.,
     +20.,33.,18.5,17.,20.,3.,6.85,11*0.0/
      DATA XA/.94,.68,.35,0.41,.7,1.,0.91,0.,0.,
     +.47,.34,.17,0.12,.35,0.5,0.45,11*0.0/
      DATA XC/.64,.40,.19,0.24,.44,.80,0.57,0.,0.,
     +.32,.20,.09,0.07,.22,.4,0.28,11*0.0/
      DATA XR/.3,.28,.16,0.16,.26,.2,0.33,0.,0.,
     +.15,.14,.08,0.05,.13,.1,0.17,11*0.0/
      DATA YFCO2/2.1,2.2,.46,0.5,1.3,1.6,2.8,0.,0.,
     +1.47,1.54,.38,0.25,1.04,1.12,1.96,11*0.0/
      DATA YFH2O/.69,.45,.09,0.1,.43,.54,1.04,0.,0.,
     +.49,.32,.08,0.05,.34,.38,0.73,11*0.0/
      DATA YFHCL/2*0.,.19,.19,7*0.,.16,.16,14*0./
      DATA YSMOK/.021,.15,.086,0.38,.015,.001,0.087,0.,0.,
     +.254,.85,0.277,0.43,.075,.002,0.2,11*0.0/
      DATA YFCO1/.011,.071,.039,0.035,.004,.003,0.03,0.,0.,
     +.005,.035,.019,0.003,.002,.001,0.015,11*0.0/
      DATA YFCH4/.001,.02,.02,.02,.001,.002,.005,0.,0.,
     +.005,.1,.1,.1,.005,.01,.002,11*0.0/
      DATA WFC/.6,.92,.38,.54,.48,.45,.87,0.,0./
      DATA WFH/.08,.08,.05,.06,.06,.06,.13,0.,0./
      DATA WFO/.32,0.,0.,0.,.46,.49,0.,0.,0./
      DATA WFCL/2*0.,.57,.40,5*0./
      DATA COND/1.878E-3,1.075E-3,13.84E-3,45.83E-3,202.36E-3,
     @387.43E-3,106.37E-3,8*0./
      DATA CONDM/1.0575E-6,0.0,-1.52E-5,1.56E-5,-1.35E-4,5.88E-5,
     @-1.35E-4,8*0./
```

```
      DATA EMIS/.94,.75,.24,.16,.06,.07,.09,8*0./
      DATA RHOO/2240.,2000.,7820.,7850.,2707.,8940.,8520.,8*0./
      DATA CPCA/.879,.837,.465,.465,.879,.379,.379,8*0./
      DATA CPCAM/2*0.,2*4.075E-4,4.1E-4,1.2E-4,2.5E-4,8*0.0/
      DATA DPART/0.1,0.173,0.387,0.592,0.794,0.995,1.48,3.46,7.75,
     014.14,20./
      DATA SMSZ/0.,0.045,0.115,0.14,0.14,0.11,0.28,0.17,3*0./
C
C       READ IN NAME OF INPUTFILE
C
      TYPE *,' ENTER NAME OF INPUT FILE: '
      READ(*,'(A)') INPUTFILE
C
C****************************************************************************C
C                                                                            C
C                    Open unit files for output data                         C
C                                                                            C
      OPEN(UNIT=2,NAME=INPUTFILE,TYPE='OLD',READONLY)
      OPEN(UNIT=3,NAME='RSTHL.DAT',TYPE='NEW',FORM='FORMATTED')
      OPEN(UNIT=4,NAME='RSTCL.DAT',TYPE='NEW',FORM='FORMATTED')
      OPEN(UNIT=5,NAME='SMKHL.DAT',TYPE='NEW',FORM='FORMATTED')
      OPEN(UNIT=7,NAME='SMKCL.DAT',TYPE='NEW',FORM='FORMATTED')
      OPEN(UNIT=8,NAME='RSZHL.DAT',TYPE='NEW',FORM='FORMATTED')
      OPEN(UNIT=9,NAME='RSZCL.DAT',TYPE='NEW',FORM='FORMATTED')
      OPEN(UNIT=11,NAME='SSZHL.DAT',TYPE='NEW',FORM='FORMATTED')
      OPEN(UNIT=13,NAME='SSZCL.DAT',TYPE='NEW',FORM='FORMATTED')
      OPEN(UNIT=10,NAME='PRINT.DAT',TYPE='NEW',FORM='FORMATTED')
      OPEN(UNIT=12,NAME='ARAD.DAT',TYPE='NEW',FORM='FORMATTED')
      OPEN(UNIT=14,NAME='ASMK.DAT',TYPE='NEW',FORM='FORMATTED')

C
C****************************************************************************C
C
C                 Read and write input data for program execution            C
C                                                                            C
      READ(2,*) PLOTANS,TSPEC,DELT, MIBO,IGNITE,IPRINT,(MJE(I),I=1,4)
      PRINT * , 'TSPEC=',TSPEC,' DELT=',DELT,' MIBO=',MIBO,' IGNITE=',
     +IGNITE,' IPRINT=',IPRINT,' (MJE(I),I=1,4)',(MJE(I),I=1,4),
     +' PLOTANS = ',PLOTANS


C
C..... OPEN PLOTTING FILES IF USER DESIRES
C

      IF((PLOTANS .EQ. 'Y') .OR. (PLOTANS .EQ. 'y')) THEN
          OPEN(UNIT=15,NAME='PLOTTING_DATA_1.DAT',TYPE='NEW',
     .         FORM='FORMATTED',RECL=150)
          OPEN(UNIT=16,NAME='PLOTTING_DATA_2.DAT',TYPE='NEW',
     .         FORM='FORMATTED',RECL=160)
      ENDIF

C Input IGNITE=0 for using Burning Order concept
C Input IGNITE=1 for using Ignition Energy concept

      READ(2,*)  ((FUEL(I,IBO),I=1,9),IBO=1,MIBO)
      PRINT * ,  '((FUEL(I,IBO),I=1,9),IBO=1,MIBO)'
      PRINT * ,  ((FUEL(I,IBO),I=1,9),IBO=1,MIBO)
      READ(2,*)  ((AREC(I,IBO),I=1,9),IBO=1,MIBO)
      PRINT * ,  '((AREC(I,IBO),I=1,9),IBO=1,MIBO)'
      PRINT * ,  ((AREC(I,IBO),I=1,9),IBO=1,MIBO)
```

```
      DO 990 IBO=1,MIBO

C Input fuel characteristics for fuels other than those in data base

      DO 990 J=8,9
      IF (FUEL(J,IBO).GT.0.)THEN
        IF (QCHEAT(J).GT.0.)GO TO 990
        READ(2,*)QCHEAT(J),QRR(J),HEATV(J),HEATC(J),WFC(J),
     +  WFH(J),WFO(J),WFCL(J)
        READ(2,*)(QFC(J,K),K=1,3),(QFRR(J,K),K=1,3),(XA(J,K),K=1,3)
        READ(2,*)(XC(J,K),K=1,3),(XR(J,K),K=1,3),(YFC02(J,K),K=1,3)
        READ(2,*)(YFH20(J,K),K=1,3),(YFHCL(J,K),K=1,3),(YSMOK(J,K),
     +K=1,3)
        READ(2,*)(YFC01(J,K),K=1,3),(YFCH4(J,K),K=1,3)
        PRINT * , 'QCHEAT(J)=',QCHEAT(J),' QRR(J)=',QRR(J)
        PRINT * , ' HEATV(J)=',HEATV(J),' HEATC(J)=',HEATC(J)
        PRINT * , ' WFC(J)=',WFC(J)
        PRINT * , ' WFH(J)=',WFH(J),' WFO(J)=',WFO(J)
        PRINT * , ' WFCL(J)=',WFCL(J)
        PRINT * , '(QFC(J,K),K=1,3)',(QFC(J,K),K=1,3)
        PRINT * , '  (QFRR(J,K),K=1,3)',(QFRR(J,K),K=1,3)
        PRINT * , '  (XA(J,K),K=1,3)',(XA(J,K),K=1,3)
        PRINT * , '(XC(J,K),K=1,3)',(XC(J,K),K=1,3)
        PRINT * , '(XR(J,K),K=1,3)',(XR(J,K),K=1,3)
        PRINT * , '(YFC02(J,K),K=1,3)',(YFC02(J,K),K=1,3)
        PRINT * , '(YFH20(J,K),K=1,3)',(YFH20(J,K),K=1,3)
        PRINT * , '(YFHCL(J,K),K=1,3)',(YFHCL(J,K),K=1,3)
        PRINT * , '(YSMOK(J,K),K=1,3)',(YSMOK(J,K),K=1,3)
        PRINT * , '(YFC01(J,K),K=1,3)',(YFC01(J,K),K=1,3)
        PRINT * , '(YFCH4(J,K),K=1,3)',(YFCH4(J,K),K=1,3)
      END IF
  990 CONTINUE
      READ(2,*) LR, WR,ZR,XCEIL,XWALL,XFLOOR,MATERC,MATERW,MATERF
      PRINT * , 'LR=',LR,' WR=',WR,' ZR=',ZR
      PRINT * , 'XCEIL=',XCEIL,' XWALL=',XWALL,' XFLOOR=',XFLOOR
      PRINT * , 'MATERC=',MATERC,' MATERW=',MATERW,' MATERF=',MATERF
      IF(MATERC.LT.8)GO TO 900

C Input building material characteristics if other than those in data base

      M=MATERC
      READ(2,*)COND(M),CONDM(M),EMIS(M),RHOO(M),CPCA(M),CPCAM(M)
      PRINT * , 'COND(MATERC)=',COND(M),' CONDM(MATERC)=',CONDM(M)
      PRINT * , 'EMIS(MATERC)=',EMIS(M),' RHOO(MATERC)=',RHOO(M)
      PRINT * , 'CPCA(MATERC)=',CPCA(M),' CPCAM(MATERC)=',CPCAM(M)
  900 IF(MATERW.LT.8)GO TO 901
      IF(COND(MATERW).NE.0.)GO TO 901
      M=MATERW
      READ(2,*)COND(M),CONDM(M),EMIS(M),RHOO(M),CPCA(M),CPCAM(M)
      PRINT * , 'COND(MATERW)=',COND(M),' CONDM(MATERW)=',CONDM(M)
      PRINT * , 'EMIS(MATERW)=',EMIS(M),' RHOO(MATERW)=',RHOO(M)
      PRINT * , 'CPCA(MATERW)=',CPCA(M),' CPCAM(MATERW)=',CPCAM(M)
  901 IF(MATERF.LT.8)GO TO 902
      IF(COND(MATERF).NE.0.)GO TO 902
      M=MATERF
      READ(2,*)COND(M),CONDM(M),EMIS(M),RHOO(M),CPCA(M),CPCAM(M)
      PRINT * , 'COND(MATERF)=',COND(M),' CONDM(MATERF)=',CONDM(M)
      PRINT * , 'EMIS(MATERF)=',EMIS(M),' RHOO(MATERF)=',RHOO(M)
      PRINT * , 'CPCA(MATERF)=',CPCA(M),' CPCAM(MATERF)=',CPCAM(M)
  902 CONTINUE
```

```
C Input initial T, P, and flow of compartment

      READ(2,*) NFP,P1,P2,TINIT,PINIT,ZIF,ZOF,ZFIRE,VIF,EQUIP,EFFIC
      PRINT * , 'NFP=',NFP,' P1=',P1,' P2=',P2,' TINIT=',TINIT
      PRINT * , 'PINIT=',PINIT,' ZIF=',ZIF,' ZOF=',ZOF
      PRINT * , 'ZFIRE=',ZFIRE,' VIF=',VIF,' EQUIP=',EQUIP,' EFFIC=',
     @EFFIC
      READ(2,*)TF0,TC0,TW0,N2X2IF,N2X2OF
      PRINT * , 'INITIAL T OF FLOOR=',TF0,' CEILING=',TC0,' WALL=',
     @TW0
        PRINT * , 'NO. OF 2FT X 2FT INLET FILTERS =',N2X2IF
        PRINT * , 'NO. OF 2FT X 2FT OUTLET FILTERS = ',N2X2OF
      IF(IGNITE.EQ.0) GO TO 1000
      READ(2,*) (NBO(I),I=1,9)
      PRINT * , '(NBO(I),I=1,9)=',(NBO(I),I=1,9)

C Input NBO(I)=0 for material burns at the start of the fire
C Input NBO(I)=1 for combustibles that are at risk and they can
C                    contribute to the fire via Ignition Energy concept
C Input NBO(I)=2 for any of the nine combustible types that will not
C                    contribute to the fire at all
C Input NBO(I)=3 for material types that burn at the start of the fire
C                    and also at risk due Ignition Energy concept

 1000  IF(EQUIP.EQ.0.0) GO TO 1005
      DO 1004 IE=1,4
      IF(MJE(IE).EQ.0.)GO TO 1004
      K=MJE(IE)
      READ(2,*)(WD(JE,IE),JE=1,K)
      PRINT * ,  '(WD(JE,IE),JE=1,K)',(WD(JE,IE),JE=1,K)
      READ(2,*)(HEQ(JE,IE),JE=1,K)
      PRINT * ,  '(HEQ(JE,IE),JE=1,K)',(HEQ(JE,IE),JE=1,K)
      READ(2,*)(HTF(JE,IE),JE=1,K)
      PRINT * ,  '(HTF(JE,IE),JE=1,K)',(HTF(JE,IE),JE=1,K)
      READ(2,*)(MATERE(JE,IE),JE=1,K)
      PRINT * ,  '(MATERE(JE,IE),JE=1,K)',(MATERE(JE,IE),JE=1,K)
      DO 999 JE=1,K
      IF(MATERE(JE,IE).LT.7)GO TO 999

C Input construction material characteristics if other than those in data base

      M=MATERE(JE,IE)
      IF(COND(M).NE.0.)GO TO 999
      READ(2,*)COND(M),CONDM(M),EMIS(M),RHOO(M),CPCA(M),CPCAM(M)
      PRINT * , 'COND(MATER)=',COND(M),' CONDM(MATER)=',CONDM(M)
      PRINT * , 'EMIS(MATER)=',EMIS(M),' RHOO(MATER)=',RHOO(M)
      PRINT * , 'CPCA(MATER)=',CPCA(M),' CPCAM(MATER)=',CPCAM(M)
  999 CONTINUE
      READ(2,*)(WMASS(JE,IE),JE=1,K)
      PRINT * ,  '(WMASS(JE,IE),JE=1,K)',(WMASS(JE,IE),JE=1,K)
      IF(IE.GT.1)GO TO 1001
      READ(2,*)(TE1(JE),JE=1,K)
      PRINT * ,  '(TE1(JE),JE=1,K)',(TE1(JE),JE=1,K)
      GO TO 1004
 1001 IF(IE.GT.2)GO TO 1002
      READ(2,*)(VGAS2(JE),JE=1,K)
      PRINT * ,  '(VGAS2(JE),JE=1,K)',(VGAS2(JE),JE=1,K)
      READ(2,*)(VPWD(JE),JE=1,K)
      PRINT * ,  '(VPWD(JE),JE=1,K)',(VPWD(JE),JE=1,K)
      READ(2,*)(WH2O2(JE),JE=1,K)
      PRINT * ,  '(WH2O2(JE),JE=1,K)',(WH2O2(JE),JE=1,K)
```

```
      READ(2,*)(TE2(JE),JE=1,K)
      PRINT * , '(TE2(JE),JE=1,K)',(TE2(JE),JE=1,K)
      READ(2,*)(TI2(JE),JE=1,K)
      PRINT * , '(TI2(JE),JE=1,K)',(TI2(JE),JE=1,K)
      READ(2,*)(PF2(JE),JE=1,K)
      PRINT * , '(PF2(JE),JE=1,K)',(PF2(JE),JE=1,K)
      GO TO 1004
 1002 IF(IE.EQ.4)GO TO 1003
      READ(2,*)(VGAS3(JE),JE=1,K)
      PRINT * , '(VGAS3(JE),JE=1,K)',(VGAS3(JE),JE=1,K)
      READ(2,*)(WH2O3(JE),JE=1,K)
      PRINT * , '(WH2O3(JE),JE=1,K)',(WH2O3(JE),JE=1,K)
      READ(2,*)(TE3(JE),JE=1,K)
      PRINT * , '(TE3(JE),JE=1,K)',(TE3(JE),JE=1,K)
      READ(2,*)(TI3(JE),JE=1,K)
      PRINT * , '(TI3(JE),JE=1,K)',(TI3(JE),JE=1,K)
      READ(2,*)(PF3(JE),JE=1,K)
      PRINT * , '(PF3(JE),JE=1,K)',(PF3(JE),JE=1,K)
      GO TO 1004
 1003 READ(2,*)(VOL(JE),JE=1,K)
      PRINT * , '(VOL(JE),JE=1,K)',(VOL(JE),JE=1,K)
      READ(2,*)(TE4(JE),JE=1,K)
      PRINT * , '(TE4(JE),JE=1,K)',(TE4(JE),JE=1,K)
      READ(2,*)(TL(JE),JE=1,K)
      PRINT * , '(TL(JE),JE=1,K)',(TL(JE),JE=1,K)
 1004 CONTINUE
 1005 IF(NFP.EQ.0) GO TO 1010

C Input alternate flow path parameters

      READ(2,*)  (TFP(IFP),IFP=1,NFP)
      PRINT * , '(TFP(IFP),IFP=1,NFP)',(TFP(IFP),IFP=1,NFP)
      READ(2,*)  (HFP(IFP),IFP=1,NFP)
      PRINT * , '(HFP(IFP),IFP=1,NFP)',(HFP(IFP),IFP=1,NFP)
      READ(2,*)  (PFP(IFP),IFP=1,NFP)
      PRINT * , '(PFP(IFP),IFP=1,NFP)',(PFP(IFP),IFP=1,NFP)
      READ(2,*)  (DFP(IFP),IFP=1,NFP)
      PRINT * , '(DFP(IFP),IFP=1,NFP)',(DFP(IFP),IFP=1,NFP)

C Input radioactive source term parameters

 1010 READ(2,*)(NRAD(J),J=1,7)
      PRINT * , '(NRAD(J),J=1,7)',(NRAD(J),J=1,7)
C
C INITIALIZE QRAD ARRAYS
C
      DO 1013 J1=1,IIBO
      DO 1013 J2=1,10
      DO 1011 J3=1,29
 1011 QRAD1(J3,J2,J1)=0.0
      DO 1012 J3=1,6
 1012 QRAD2(J3,J2,J1)=0.0
 1013 QRAD7(J2,J1)=0.0
      DO 1016 J1=1,10
      DO 1014 J2=1,10
      QRAD4(J2,J1)=0.0
      QRAD5(J2,J1)=0.0
 1014 CONTINUE
 1016 QRAD3(J1)=0.0
C
      DO 1020 J=1,7
```

```
      IF(NRAD(J).EQ.0)GO TO 1020
      DO 1020 K=1,NRAD(J)
      IF(J.GT.2)GO TO 1015
      IF(J.GT.1)GO TO 1017
      READ(2,*) IFORM,I,JACT,IBO
      PRINT * , 'IFORM=',IFORM,' I=',I,' JACT=',JACT,' IBO=',IBO
      NJ=((IFORM*10)-10)+I
      READ(2,*)QRAD1(NJ,JACT,IBO)
      PRINT * , 'QRAD1=',QRAD1(NJ,JACT,IBO)
      GO TO 1020
 1017 READ (2,*)IFORM,I,JACT,IBO
      PRINT *, 'IFORM=',IFORM,' I=',I,' JACT=',JACT,' IBO=',IBO
      NJ=(I-6)+(IFORM-1)*3
      READ(2,*)QRAD2(NJ,JACT,IBO)
      PRINT * , 'QRAD2=',QRAD2(NJ,JACT,IBO)
      GO TO 1020
 1015 IF(J.EQ.3)READ(2,*)JACT,QRAD3(JACT)
      IF(J.EQ.3)PRINT * , 'JACT=',JACT,' QRAD3=',QRAD3(JACT)
      IF(J.EQ.4)READ(2,*)IVES,JACT,QRAD4(IVES,JACT)
      IF(J.EQ.4)PRINT * , 'IVES=',IVES,' JACT=',JACT,
     +' QRAD4=',QRAD4(IVES,JACT)
      IF(J.EQ.5)READ(2,*)IVES,JACT,QRAD5(IVES,JACT),VOLP(IVES),
     +PDEN(IVES,JACT)
      IF(J.EQ.5)PRINT * , 'IVES=',IVES,' JACT=',JACT,
     +' QRAD5=',QRAD5(IVES,JACT),' VOLUME= ',VOLP(JE),
     +' POWDER DENSITY = ',PDEN(IVES,JACT)
      IF(J.EQ.6)READ(2,*)IVES,JACT,QRAD6(IVES,JACT)
      IF(J.EQ.6)PRINT * , 'IVES=',IVES,' JACT=',JACT,
     +' QRAD6 =',QRAD6(IVES,JACT)
      IF(J.EQ.7)READ(2,*)JACT,IBO,QRAD7(JACT,IBO),SQ(JACT,IBO)
      IF(J.EQ.7)PRINT * , 'JACT=',JACT,' IBO=',IBO,
     +'QRAD7=',QRAD7(JACT,IBO),' SQ=',SQ(JACT,IBO)
 1020 CONTINUE
      CLOSE(UNIT=2)
C
C*****************************************************************************C
C                                                                             C
C                             Format Block                                    C
C
  200 FORMAT(1H1,49X,'OUTPUT FOR RADIOACTIVE SOURCE TERM',/)
  205 FORMAT(1H ,3X,'TIME  ACCUMULATED MASS (G) ON:',/,4X,'(S)',
     +5X,'FLOOR',5X,'WALL',5X,'CEILING',4X,'VENTS   ENVIRON')
  210 FORMAT(131('_'),/)
  245 FORMAT(1H ,F8.2,12(1X,E9.3) )
  250 FORMAT(1H1,49X,'OUTPUT FOR COMPARTMENT EFFECTS ',//)
  255 FORMAT(1H ,11X,'COMPARTMENT    OXYGEN    HOT LAYER    VOLUMETRIC'
     +,' FLOW RATE',4X,'HOT LAYER',4X,'MASS BURN   HEAT GEN.   HEAT ',
     +'LOSS   HEAT TO',/,5X,'TIME',4X,'PRESSURE',6X,'CONC.',5X,
     +'THICKNESS',5X,'INLET',7X,'OUTLET',4X,'TEMPERATURE',5X,'RATE',
     +7X,'BY FIRE',5X,'TO WALLS   FIRE GAS',/,4X,'( SEC )   ( ATM )'
     +3X,'(VOL FRACT)',4X,'( M )',5X,'( M**3/S )  ( M**3/S )',4X,'( F )'
     +8X,'( G/S )',5X,'( KW )',2(6X,'( KW )'))
  270 FORMAT(1X,F9.2,10(1X,F11.4))
  275 FORMAT(1H1,49X,'OUTPUT FOR FIRE SOURCE TERMS',//)
  305 FORMAT(' COMBUSTIBLE TYPE ',I2,' HAS IGNITED AT TIME: ',
     1         F10.4,' SEC',/)
  312 FORMAT(1X,F9.2,8(2X,E9.3))
  315 FORMAT(' ALL BURNING HAS STOPPED AT TIME: ',F10.4,' SEC WITH ',
     1F5.1,' PERCENT OF ALL COMBUSTIBLES CONSUMED IN THIS FIRE ',/)
  320 FORMAT(' ALL COMBUSTIBLE MATERIALS WERE CONSUMED BY:',
     1         F10.4,' SEC',/)
```

```
  326 FORMAT(1H0,'TIME EXCEEDS USER SPECIFIED TIME AT:',F10.4,' SEC' )
  370 FORMAT(1H ,57X,'PARTICLE DIAMETER (MICRONS)',/,4X,'TIME',
     @11(1X,F9.3),4X,'TOTAL')
  390 FORMAT(1H1,49X,'OUTPUT FOR SMOKE SOURCE TERM',/)
  395 FORMAT(1H ,'MASS IN HOT LAYER, G')
  400 FORMAT(1H ,'MASS IN COLD LAYER, G')
  405 FORMAT(1H ,13X,'AIRBORNE',3X,'GENERATED   ENTRAINED',5X,
     @'TOTAL',5X,'AIRBORNE   FRACTION OF LOSSES DUE TO:',/,4X,'TIME,S',
     @5X,'AT T0 (+) BY FIRE (+) W PLUME (-) LOSSES  (=) AT T',7X,
     @'SETTLING  B. DIFFUS THERMOPH. DIFFUSIO. OUT VENT')
  410 FORMAT(1H ,F9.2,5(3X,E9.2),5(1X,F9.4))
  415 FORMAT(1H ,12X, 'AIRBORNE    HOT LAYER     TOTAL',5X,'AIRBORNE',
     @3X,'FRACTION OF LOSSES DUE TO:',/,4X,'TIME,S',6X,'AT TO   (+)',
     @' SETTLING(-) LOSSES  (=) AT T',4X,'SETTLING  OUT VENT',2X,
     @'PLUME GAS')
  420 FORMAT(1H ,F9.2,4(3X,E9.2),3(1X,F9.4))
C
C******************************************************************************C
C                                                                              C
C                 Initialization and Parameterization Block                    C
C                                                                              C
      NFLAGC=1
      NFLAGW=0
      NFLAGF=0
      FLAG=0.
      QE=0.0
      QFA=0.0
      EIGN=0.0
      UMIN = 5.0E-03    !Minimum convective heat transfer coefficient,kW/K
      A1=1000./99.
      R=8.206E-5        !Gas constant,atm*M3/gmole*K
      CPL=4.184E-03     !Specific heat of water,kJ/cm s K
      CPAIR=2.88E-02    !Specific heat of air,kJ/gmole*K
      ELV=2.26
      CP=33.5E-3
      GR=9.8            !Acceleration due to gravity,M/s2
      SIG=5.669E-11     !Stefan-Boltzmann constant,kW/M2*K4
      TSTEP=DELT
      JACTO=0
      TSTEPO=0.0
      ITSTEP=1
      QLOSSR=0.0
      TQNETR=0.0
      TQACTR=0.0
      TMASSN=0.0
      TMASSR=0.0
      TGRAD=0.0
      GTMASS=0.
      PI=3.1415927
      DO 1035 ISIZE=1,11
 1035 DPART(ISIZE)=DPART(ISIZE)*1.E-4  !CONVERT DPART TO CM
      DO 1036 JT=1,2
      DO 1036 ISZ=1,12
      A0(JT,ISZ)=0.
      B0(JT,ISZ)=0.
 1036 CONTINUE
      VOLRM=LR*WR*ZR
      AMCL=(PINIT*VOLRM)/(R*TINIT)
      AMHL=0.
      FMO2=.21
      THL=TINIT
```

```
      TCL=TINIT
      PCOMP=PINIT
      TA=TINIT
      CHO2=0.
      CHN2=0.
      CHCO1=0.
      CHCO2=0.
      CHCH4=0.
      CHH2O=0.
      CHHCL=0.
      CCN2=0.79*AMCL
      CCO2=0.21*AMCL
      WSMIF=0.
      WSMOF=0.
      WRADIF=0.
      WRADOF=0.
      AW1=LR*ZR
      AW2=WR*ZR
      AFLOOR=LR*WR
      DX=ZR*100./(NUM-1)   !DX IN CM
        DXC=XCEIL/(NUM-1)
        DXW=XWALL/(NUM-1)
        DXF=XFLOOR/(NUM-1)
        VC=AFLOOR*XCEIL*A1
        VF=AFLOOR*XFLOOR*A1
        CKDC=COND(MATERC)/DXC
        CKDW=COND(MATERW)/DXW
        CKDF=COND(MATERF)/DXF
      DO 1040 JC=1,NUM
      TC(JC,1)=TC0
      TF(JC,1)=TF0
      YEC(JC)=0.0
      YHC(JC)=0.0
      YCC(JC)=0.0
      YEF(JC)=0.0
      YHF(JC)=0.0
      YCF(JC)=0.0
      DO 1040 IW=1,NUM
      TW(IW,JC,1)=TW0
      YEW(IW,JC)=0.0
      YHW(IW,JC)=0.0
      YCW(IW,JC)=0.0
1040  CONTINUE
      TECL=0.
      DO 1045 IE=1,4
      DO 1045 JE=1,10
      TBCL(JE,IE)=0.
1045  CONTINUE
      DO 1050 JE=1,10
      FAIL2(JE)=0.0
      FAIL3(JE)=0.0
1050  CONTINUE
      DO 1055 JT=1,2
      FMASS(JT)=0.
      WAMASS(JT)=0.
      CMASS(JT)=0.
      OUTVEN(JT)=0.
      VEMASS(JT)=0.
1055  CONTINUE
      VOF=-VIF
      RESISTI=(P1-PINIT)/VIF
```

```
        RESISTO = -(PINIT-P2)/VOF
      THLUC=1.8*TINIT-460.0
C
C*******************************************************************************C
C                                                                               C
C              Write output for time=0
C
      WRITE(3,200)
      WRITE(3,395)
      WRITE(3,405)
      WRITE(3,410)TSTEP0,A0(1,12),GRPART(1,12)*DELT,AFLOSS(8,1,12),
     @ALOSS(1,12),A(1,12),(AFLOSS(M,1,12),M=1,5)
      WRITE(4,200)
      WRITE(4,400)
      WRITE(4,415)
      WRITE(4,420)TSTEP0,B0(1,12),AFLOSS(1,1,12),BLOSS(1,12),B(1,12),
     @(AFLOSS(M,1,12),M=6,8)
      WRITE(5,390)
      WRITE(5,395)
      WRITE(5,405)
      WRITE(5,410)TSTEP0,A0(2,12),GRPART(2,12)*DELT,AFLOSS(8,2,12),
     @ALOSS(2,12),A(2,12),(AFLOSS(M,2,12),M=1,5)
      WRITE(7,390)
      WRITE(7,400)
      WRITE(7,415)
      WRITE(7,420)TSTEP0,B0(2,12),AFLOSS(1,2,12),BLOSS(2,12),B(2,12),
     @(AFLOSS(M,2,12),M=6,8)
      WRITE(8,200)
      WRITE(8,395)
      WRITE(8,370),(DPART(I)*1.E4,I=1,11)
      WRITE(8,245)TSTEP0,(A0(1,M),M=1,12)
      WRITE(9,200)
      WRITE(9,400)
      WRITE(9,370),(DPART(I)*1.E4,I=1,11)
      WRITE(9,245)TSTEP0,(B0(1,M),M=1,12)
      WRITE(11,390)
      WRITE(11,395)
      WRITE(11,370),(DPART(I)*1.E4,I=1,11)
      WRITE(11,245)TSTEP0,(A0(2,M),M=1,12)
      WRITE(13,390)
      WRITE(13,400)
      WRITE(13,370),(DPART(I)*1.E4,I=1,11)
      WRITE(13,245)TSTEP0,(B0(2,M),M=1,12)
      WRITE(10,250)
      WRITE(10,255)
      WRITE(10,210)
      WRITE(10,270) TSTEPO,PINIT,FMO2,ZHL,VIF,VOF,THLUC,TMASSR,TQACTR,
     +QLOSSR,TQNETR
      WRITE(12,200)
      WRITE(12,205)
      WRITE(12,245)TSTEP0,FMASS(1),WAMASS(1),CMASS(1),VEMASS(1),
     @OUTVEN(1)
      WRITE(14,390)
      WRITE(14,205)
      WRITE(14,245)TSTEP0,FMASS(2),WAMASS(2),CMASS(2),VEMASS(2),
     @OUTVEN(2)
C
C*******************************************************************************C*
C                                                                               C
C                Parameters for heat transfer to equipment                      C
C                                                                               C
```

```
      IF(EQUIP.EQ.0.0) GO TO 1065
      ARAD=0.0
      DO 1060 IE=1,4
      DO 1060 JE=1,10
      ARER(JE,IE)=WD(JE,IE)*HEQ(JE,IE)
      ARAD=ARAD+ARER(JE,IE)
      ARHT(JE,IE)=PI*WD(JE,IE)*HEQ(JE,IE)+PI*(WD(JE,IE)**2/2.0)
C
C     ARHT(JE,IE)=HEAT TRANSFER AREA (OUTSIDE SURFACE AREA)
C
      ZCL(JE,IE)=HTF(JE,IE)+0.5*HEQ(JE,IE)
 1060 CONTINUE
C
C******************************************************************************C
C                                                                              C
C                    Fire source term calculation                              C
C                                                                              C

 1065 CONTINUE
        J=1
      TFUEL=0.0
      DO 1070 IBO=1,MIBO
        DO 1070 I=1,9
        TFUEL=TFUEL+FUEL(I,IBO) !Calculate total risking fuel
 1070 CONTINUE
      DO 1080 IBO=1,MIBO
      DO 1080 I=1,9
      OFUEL(I,IBO)=FUEL(I,IBO)
      BRATE(I,J)=(QE+QFC(I,J)+QFRR(I,J)-QRR(I))*AREC(I,IBO)
     1/HEATV(I)
      IF(BRATE(I,J).GT.0.0)GO TO 1075
      TBURN(I,IBO)=0.
      GO TO 1080
 1075 TBURN(I,IBO)=FUEL(I,IBO)/BRATE(I,J)
 1080 CONTINUE
C
C           ****  DO LOOP FOR BURNING ORDERS  ****
C

      IF(IGNITE.EQ.1) MIBO=1
 1085 DO 1515 IBO=1,MIBO
      DO 1090 K=1,9
      TSTART(K,IBO)=TSTEP
 1090 CONTINUE
 1100 BTMAX=0.
      DO 1105 I=1,9
      IF (TBURN(I,IBO).LT.BTMAX) GO TO 1105
      BTMAX=TBURN(I,IBO)
 1105 CONTINUE
C
C Calculate thermal diffusivities for heat transfer equations.
C
      DO 1095 JW=1,NUM-1
      CALL THERMD(TC(JW,1),TDIFC(JW),MATERC)
      CALL THERMD(TF(JW,1),TDIFF(JW),MATERF)
      DO 1092 IW=1,NUM-2
      CALL THERMD(TW(IW,JW,1),TDIFW(IW,JW),MATERW)
 1092 CONTINUE
 1095 CONTINUE
C
```

```
      EIG=-QFA*DELT
      EIGN=EIGN+EIG !Calculate total ignition energy available
      TAREC=0.0
      DO 1120 I=1,9

C Identify ignition of combustibles at risk due to room fluxes

         IF (NBO(I).EQ.1 .AND. EIGN.GE.QCHEAT(I)
     1      .OR. NBO(I).EQ.3 .AND.  EIGN.GE.QCHEAT(I) ) THEN
           FUEL(I,1)=FUEL(I,2)+FUEL(I,1)
           OFUEL(I,1)=FUEL(I,1)
           AREC(I,1)=AREC(I,2)+AREC(I,1)
           FUEL(I,2)=0.
           NBO(I)=0
           WRITE(3,305) I,TSTEP
           WRITE(4,305) I,TSTEP
           WRITE(5,305) I,TSTEP
           WRITE(7,305) I,TSTEP
           WRITE(8,305) I,TSTEP
           WRITE(9,305) I,TSTEP
           WRITE(11,305) I,TSTEP
           WRITE(13,305) I,TSTEP
           WRITE(10,305) I,TSTEP

C Identify contaminated combustibles for radioactive release calculation

          IF (NRAD(1).EQ.0 .AND. NRAD(2).EQ.0)GO TO 1115
           DO 1110 JACT=1,10
            DO 1111 IFORM=1,3
             NJ=((IFORM*10)-10)+I
             QRAD1(NJ,JACT,1)=QRAD1(NJ,JACT,2)+QRAD1(NJ,JACT,1)
 1111 CONTINUE
            DO 1110 JFORM=1,2
             NJ=(I-6)+(JFORM-1)*3
             QRAD2(NJ,JACT,1)=QRAD2(NJ,JACT,2)+QRAD2(NJ,JACT,1)
 1110      CONTINUE
 1115    ENDIF
      TAREC=TAREC+AREC(I,IBO)
 1120 CONTINUE
      IF(TAREC.GE.AFLOOR) TAREC=AFLOOR
      IF (BTMAX.EQ.0.)GO TO 1515
      IF (TSTEP.GT.TSPEC)GO TO 1530
      J=1
      QE=-QFA      !QE HAS UNIT OF KW/M2
      DO 1135 I=1,9
        IF( FMO2 .GE. 0.15 ) GOTO 1125  !Interpalation of values
        SCALE = 25.0 * ( 0.15 - FMO2 )
        QFC(I,3) = QFC(I,1) - ( QFC(I,1) - QFC(I,2) ) * SCALE
        QFRR(I,3) = QFRR(I,1) - ( QFRR(I,1) - QFRR(I,2) ) * SCALE
        XA(I,3) = XA(I,1) - ( XA(I,1) - XA(I,2) ) * SCALE
        XC(I,3) = XC(I,1) - ( XC(I,1) - XC(I,2) ) * SCALE
        XR(I,3) = XR(I,1) - ( XR(I,1) - XR(I,2) ) * SCALE
        YFCO2(I,3) = YFCO2(I,1) - ( YFCO2(I,1) - YFCO2(I,2) ) * SCALE
        YFCO1(I,3) = YFCO1(I,1) - ( YFCO1(I,1) - YFCO1(I,2) ) * SCALE
        YFHCL(I,3) = YFHCL(I,1) - ( YFHCL(I,1) - YFHCL(I,2) ) * SCALE
        YSMOK(I,3) = YSMOK(I,1) - ( YSMOK(I,1) - YSMOK(I,2) ) * SCALE
        YFH2O(I,3) = YFH2O(I,1) - ( YFH2O(I,1) - YFH2O(I,2) ) * SCALE
        YFCH4(I,3) = YFCH4(I,1) - ( YFCH4(I,1) - YFCH4(I,2) ) * SCALE
        J=3
        IF( FMO2 .GT. 0.11 ) GO TO 1125
        IF( FLAG .NE. 1.) GO TO 1516
```

```
1125    CONTINUE
      QFRMAX=0.0
      DO 1130 K=1,9
        IF(AREC(K,IBO).EQ.0.0 .OR. QFRR(K,J).LE.QFRMAX) GOTO 1130
        QFRMAX=QFRR(K,J)
1130  CONTINUE
      BRATE(I,J)=(QE+QFC(I,J)+QFRMAX-QRR(I))*AREC(I,IBO)
     1/HEATV(I)
      MASS(I,J)=BRATE(I,J)*DELT
      QACT(I,J)=XA(I,J)*HEATC(I)*MASS(I,J)
      QCON(I,J)=XC(I,J)*HEATC(I)*MASS(I,J)
      QRAD(I,J)=XR(I,J)*HEATC(I)*MASS(I,J)
      GCO2(I,J)=YFCO2(I,J)*MASS(I,J)
      GCO1(I,J)=YFCO1(I,J)*MASS(I,J)
      GCH4(I,J)=YFCH4(I,J)*MASS(I,J)
      GH2O(I,J)=YFH2O(I,J)*MASS(I,J)
      GHCL(I,J)=YFHCL(I,J)*MASS(I,J)
      SMOK(I,J)=YSMOK(I,J)*MASS(I,J)
 1135 CONTINUE
      GRPART(1,12)=0.
      GRPART(2,12)=0.
      TQACT=0.
      TQCON=0.
      TQRAD=0.
      TGCO2=0.
      TGCO1=0.
      TGH2O=0.
      TGCH4=0.
      TGHCL=0.
      TSMOK=0.
      TMASS=0.
      TMO=0.
      TMC=0.
      TMH=0.
      TMCL=0.
      DO 1140 I=1,9
      TQACT=TQACT+QACT(I,J)
      TQCON=TQCON+QCON(I,J)
      TQRAD=TQRAD+QRAD(I,J)
      TGCO2=TGCO2+GCO2(I,J)
      TGCO1=TGCO1+GCO1(I,J)
      TGH2O=TGH2O+GH2O(I,J)
      TGCH4=TGCH4+GCH4(I,J)
      TGHCL=TGHCL+GHCL(I,J)
      TSMOK=TSMOK+SMOK(I,J)
      TMASS=TMASS+MASS(I,J)
      TMO=TMO+WFO(I)*MASS(I,J)
      TMC=TMC+WFC(I)*MASS(I,J)
      TMH=TMH+WFH(I)*MASS(I,J)
      TMCL=TMCL+WFCL(I)*MASS(I,J)
 1140 CONTINUE
      DO 1139 ISZ=1,11
      GRPART(1,ISZ)=0.
      GRPART(2,ISZ)=SMSZ(ISZ)*TSMOK/DELT
      GRPART(2,12)=GRPART(2,12)+GRPART(2,ISZ)
 1139 CONTINUE
      TQACTR=TQACT/DELT
      TQACTN =TQACTR*.003412
      GTMASS=GTMASS+TMASS
      DO 1145 I=1,9
      FUEL(I,IBO)=FUEL(I,IBO)-MASS(I,J)
```

```
      IF(FUEL(I,IBO).LE.0..AND.AREC(I,IBO).GT.0.) TEND(I,IBO)=TSTEP
      IF (FUEL(I,IBO).LE.0.) AREC(I,IBO)=0.
 1145 CONTINUE
      DO 1155 I=1,9
      IF(BRATE(I,J).GT.0.0)GO TO 1150
      TBURN(I,IBO)=0.0
      GO TO 1155
 1150 TBURN(I,IBO)=FUEL(I,IBO)/BRATE(I,J)
 1155 CONTINUE
C
C******************************************************************************C*
C                                                                              C
C            Additionl flow paths to/from compartment                          C
C                                                                              C
      P1COM=PCOMP
      PCOMP=(R/VOLRM)*(AMCL*TCL+AMHL*THL)
      ZM=(AMCL*R*TCL)/(AFLOOR*PCOMP)
      FPIHLT=0.0
      FPICLT=0.0
      FPOCLT=0.0
      FPOHLT=0.0
      IF(NFP.EQ.0) GO TO 1170
      DO 1165 IFP=1,NFP
      OKFP(IFP)=0.0
      IF(TSTEP.GE.TFP(IFP))OKFP(IFP)=1.
      OKFHL(IFP)=0.0
      IF(HFP(IFP).GE.ZM)OKFHL(IFP)=1.
      OKPFO(IFP)=0.0
      IF(PCOMP.GE.PFP(IFP))OKPFO(IFP)=1.
      OKPFI(IFP)=0.0
      IF(PCOMP.LT.PFP(IFP))OKPFI(IFP)=1.
      DELP=ABS(PCOMP-PFP(IFP))*1.01325   !1.01325 is conversion from atm to bar
      PLP=1.01325*PCOMP
C
C     FPIHL(IFP) = FLOW INTO HL, M**3/S
C     FPICL(IFP) = FLOW INTO CL, M**3/S
C     FPOHL(IFP) = FLOW OUT HL, M**3/S
C     FPOCL(IFP) = FLOW OUT CL, M**3/S
C
      IF(OKFP(IFP).EQ.0.)GO TO 1160
      FPIHL(IFP)=OKFP(IFP)*OKFHL(IFP)*OKPFI(IFP)*(DFP(IFP)**2)
     1*3217.8*(DELP*PLP/TINIT)**.5
      FPICL(IFP)=OKFP(IFP)*(1.-OKFHL(IFP))*OKPFI(IFP)*(DFP(IFP)**2)
     1*3217.8*(DELP*PLP/TINIT)**.5
      FPOHL(IFP)=OKFP(IFP)*OKFHL(IFP)*OKPFO(IFP)*(DFP(IFP)**2)
     1*3217.8*(DELP*PLP/THL)**.5
      FPOCL(IFP)=OKFP(IFP)*(1.-OKFHL(IFP))*OKPFO(IFP)*(DFP(IFP)**2)
     1*3217.8*(DELP*PLP/TCL)**.5
 1160 CONTINUE
      FPIHLT=FPIHLT+FPIHL(IFP)*PCOMP/(R*TINIT)
      FPOHLT=FPOHLT+FPOHL(IFP)*PCOMP/(R*THL)
      FPICLT=FPICLT+FPICL(IFP)*PCOMP/(R*TINIT)
      FPOCLT=FPOCLT+FPOCL(IFP)*PCOMP/(R*TCL)
 1165 CONTINUE
      FPOHLV=FPOHLT*(R*THL)/PCOMP
      FPOCLV=FPOCLT*(R*TCL)/PCOMP
C
C******************************************************************************C
C                                                                              C
C                 HEAT TRANSFER TO CEILING,WALLS,AND FLOOR                     C
C                  ADDITIONAL MASS RELEASES FROM CONCRETE                      C
```

```
C                                                                              C
C
C               ****  1.CEILING  ****
C
 1170 CONTINUE
      TCH2O=0.
      TCCO2=0.
      DO 1185 JC=2,NUM-1
      CALL TEMP(MATERC,DELT,TC(JC,1),TC(JC,2),YEC(JC),YHC(JC),YCC(JC),
     +TDIFC(JC),TC(JC-1,1),TC(JC+1,1),DXC,TCH2O,TCCO2,VC,NFLAGC)
 1185 CONTINUE
      CALL ENDPT(TC(1,1),TC(1,2),TC(2,1),TC(2,2),TC(NUM,1),
     +TC(NUM-1,1),TC(NUM,2),TC(NUM-1,2),MATERC,DXC,QCA,CKDC,THL,
     +NFLAGC)
      QC=AFLOOR*QCA
      DO 1195 J2=1,NUM
      TC(J2,1)=TC(J2,2)
 1195 CONTINUE
C
C  *  AVAILABLE RADIANT HEAT TO WALL,EQUIPMENT AND HOTLAYER *
C
      ZHL=ZR-ZM
      WRAD=TQRAD*ZM/ZR
      HLRAD=TQRAD-WRAD
      DR=SQRT(4.*AFLOOR/PI)
      IF(ZM.LE.0.)GO TO 1205
      ERAD=WRAD*ARAD/(PI*DR*ZM)
      IF(ERAD.GT.WRAD)ERAD=WRAD
      WRAD=WRAD-ERAD
      GO TO 1210
 1205 WRAD=0.
      ERAD=0.
C
C               ****  2.WALL  ****
C
 1210 TWH2O=0.
      TWCO2=0.
      AE=ZM*4.*SQRT(AFLOOR)
      IF( AE .LE. 0.0 ) THEN
        WRADF = 0.0
      ELSE
        WRADF=WRAD/(AE*DELT)
      END IF
      ZW=ZR/(NUM-1)
      NW=INT(ZHL/ZW)
      IF(NW.LT.1) NW=1
      IF(NW.GT.NUM-2)NW=NUM-2
      AHL=2.0*ZHL*(LR+WR)
      VW=AHL*XWALL*A1
      DO 1235 IW=1,NUM-2
      IF(IW.GT.NW)NFLAGW=1
      DO 1230 JW=2,NUM-1
      CALL TEMP(MATERW,DELT,TW(IW,JW,1),TW(IW,JW,2),YEW(IW,JW),
     +YHW(IW,JW),YCW(IW,JW),TDIFW(IW,JW),TW(IW,JW-1,1),TW(IW,JW+1,1),
     +DXW,TWH2O,TWCO2,VW,NFLAGW)
 1230 CONTINUE
      THLC=THL
      IF(IW.GT.NW)THLC=TCL
      CALL ENDPT(TW(IW,1,1),TW(IW,1,2),TW(IW,2,1),TW(IW,2,2),
     +TW(IW,NUM,1),TW(IW,NUM-1,1),TW(IW,NUM,2),TW(IW,NUM-1,2),MATERW,
```

```
     +DXW,QWA(IW),CKDW,THLC,NFLAGW)
      NFLAGW=0
 1235 CONTINUE
      TAVWH=0.
      TAVWC=0.
      DO 1240 IW=1,NW
 1240 TAVWH=TAVWH+TW(IW,1,1)
      TAVWH=TAVWH/NW
      DO 1245 IW=NW,NUM-2
 1245 TAVWC=TAVWC+TW(IW,1,1)
      IF(NW.EQ.NUM-2)GO TO 1250
      TAVWC=TAVWC/(NUM-2-NW)
 1250 CONTINUE
      QWB=0.
      DO 1255 NT=1,NW
      QWB=QWB+QWA(NT)
 1255 CONTINUE
      PNW=FLOAT(NW)
      QWH=(QWB/PNW)*(AW1*2.+AW2*2.)*ZHL/ZR
      QWD=0.
      IF(NW.GE.NUM-2) GO TO 1270
      NC=NW+1
      DO 1265 NT=NC,NUM-2
      QWD=QWD+QWA(NT)
 1265 CONTINUE
      PNC=FLOAT( (NUM-2) - NW )
 1270 QWC=(QWD/PNC)*(AW1*2.+AW2*2.)*ZM/ZR
      DO 1275 JW=1,NUM
      DO 1275 IW=1,NUM
      TW(IW,JW,1)=TW(IW,JW,2)
 1275 CONTINUE
      QW=QWC+QWH
C
C  *  COMPUTE TIMES OF HOT LAYER PAST CERTAIN POINTS *
C

      DO 1285 IE=1,4
      DO 1285 JE=1,10
      IF(ZM.LT.ZCL(JE,IE).AND.TBCL(JE,IE).EQ.0.)TBCL(JE,IE)=TSTEP
 1285 CONTINUE
      ZTEST5=ZM-ZFIRE
      ZTEST6=ZM-ZOF
      IF(ZTEST5.LT.0..AND.ZTEST6.LT.0..AND.TECL.EQ.0.)TECL=TSTEP
C
C              ****  3.FLOOR  ****
C
      TFH2O=0.
      TFCO2=0.
      IF  (ZHL.LT.ZR)NFLAGF=1
      DO 1300 JF=2,NUM-1
      CALL TEMP(MATERF,DELT,TF(JF,1),TF(JF,2),YEF(JF),YHF(JF),
     +YCF(JF),TDIFF(JF),TF(JF-1,1),TF(JF+1,1),DXF,TFH2O,TFCO2,VF,
     +NFLAGF)
 1300 CONTINUE
      THLC=TCL
      IF(TECL.GT.0.)THLC=THL
      CALL ENDPT(TF(1,1),TF(1,2),TF(2,1),TF(2,2),TF(NUM,1),
     +TF(NUM-1,1),TF(NUM,2),TF(NUM-1,2),MATERF,DXF,QFA,CKDF,THLC,
     +NFLAGF)
      NFLAGF=0
      QF=AFLOOR*QFA
```

```
      DO 1305 JF=1,NUM
      TF(JF,1)=TF(JF,2)
 1305 CONTINUE
C
C******************************************************************************C*
C                                                                              C
C                       Mass balance in fire compartment                       C
C                                                                              C

      WTOT1=WSMIF+WRADIF
        WTOT1=WTOT1/N2X2IF
      DENOM1=RESISTI*(1.0+9.79E-3*(WTOT1)+13.95E-6*(WTOT1**2.0))
      WTOT2=WSMOF+WRADOF
        WTOT2=WTOT2/N2X2OF
      DENOM2=RESISTO*(1.0+9.79E-3*(WTOT2)+13.95E-6*(WTOT2**2.0))
      VIF=(P1-PCOMP)/DENOM1
      VOF=(P2-PCOMP)/DENOM2
      ZTEST1=P1-PCOMP
      ZTEST2=ZIF-ZM
      ZTEST3=ZM-ZOF
      OKHL=0.0
      OKHL1=0.0
      OKHL2=0.0
      OKCL=0.0
      OKCL1=0.0
      OKCL2=0.0
      IF(ZTEST1.GT.0.0.AND.ZTEST2.GE.0.0)OKHL=1.
      IF(ZTEST1.GT.0.0.AND.ZTEST2.GE.0.0)TA=TINIT
      IF(ZTEST1.LT.0.0.AND.ZTEST2.GE.0.0)OKHL1=1.
      IF(ZTEST1.LT.0.0.AND.ZTEST2.GE.0.0)TA=THL
      IF(ZTEST3.GT.0.0)OKCL2=1.0
      IF(ZTEST1.LT.0.0.AND.ZTEST2.LT.0.0)OKCL=1.0
      IF(ZTEST1.LT.0.0.AND.ZTEST2.LT.0.0)TA=TCL
      IF(ZTEST1.GT.0.0.AND.ZTEST2.LT.0.0)OKCL1=1.0
      IF(ZTEST3.LE.0.0)OKHL2=1.0
      ZTEST4=ZFIRE-ZM
      TIF=THL
      IF(ZTEST4.LT.0.0)TIF=TCL
        IF( TQCON .LE. 0.0 ) TQCON = 1.0E-10
      ZFLAME=0.23*(TQCON/DELT)**0.4
        IF( TMASS .LE. 0.0 ) ZFLAME = 1.0E-6
      ZZ = ZR - ( ZFIRE + ZFLAME )
      IF( ZZ .LE. 0.0 ) ZFLAME = ZR - ZFIRE
      QZ=(TQCON/DELT)/((PCOMP*CP/R)*(GR**0.5)*(ZFLAME**2.5))
      VEL=(FMIF*(TCL/PCOMP)*8.2E-5)/TAREC
      FMOF=.21*(PCOMP/(R*TCL))*(GR**.5)*(ZFLAME**2.5)
     1*(QZ**.333)
      TOF=TCL+TCL*(QZ**.667)/.21
      FUN=FMOF-(TGCH4/16.+TGCO1/28.+TGCO2/44.+TGH2O/18.
     1+TGHCL/36.5)/DELT
      FMO2B=(TGCO1/56.+TGCO2/44.+TGH2O/36.)/DELT
      FMIF=FUN+FMO2B
      ZPL=ZR-ZFIRE
      IF( ZZ .LE. 0.0 ) ZPL = ZFLAME
      IF(TSTEP.GT.DELT)ZPL=ZM-ZFIRE
      IF( ZPL .LT. ZFLAME ) ZPL = ZFLAME
      QZM=QZ*(ZFLAME/ZPL)**2.5
      FM=FMOF*((ZPL/ZFLAME)**2.5)*((QZM/QZ)**.333)
      TM=TCL+TCL*(QZM**.667)/.21
      FE=FM*R*TM/PCOMP
      OKCLF=0.0
```

```
      OKHLF=0.
      IF(ZTEST4.LT.0.0)OKCLF=1.0
      IF(ZTEST4.GE.0.)OKHLF=1.
      FIF=VIF*PCOMP/(R*TA)
      FOF=VOF*PCOMP/(R*TIF)
      AMHL=AMHL+(OKHL*FIF+OKHL1*FIF+OKHL2*FOF+FM*OKCLF+FPIHLT-FPOHLT+
     1(FMOF-FMIF)*OKHLF)*DELT+(TCCO2+TWCO2+TFCO2)/44.+(TCH2O+TWH2O+
     2TFH2O)/18.
      AMCL=AMCL+(OKCL*FIF+OKCL1*FIF+OKCL2*FOF-FMIF*OKCLF-(FM-FMOF)
     1+FPICLT-FPOCLT)*DELT
      IF(ZTEST5.LT.0.0.AND.ZTEST6.LT.0.0)GO TO 1310
      GO TO 1315
 1310 AMHL=AMHL+AMCL
      CHN2=CHN2+CCN2
      CHO2=CHO2+CCO2
      THL=(THL*AMHL+TCL*AMCL)/(AMHL+AMCL)
      AMCL=0.0
      CCN2=0.0
      CCO2=0.0
 1315 FN2IF=FMIF*0.79*OKCLF
      FO2IF=FMIF*0.21*OKCLF
      OKPF=0.0
      IF(ZPL.GT.0.0)OKPF=1.0
      FIP=(FM-FMOF)*OKPF
      FN2IP=FIP*0.79
      FO2IP=FIP*0.21
C
C****** OXYGEN BALANCE
C
      IF(AMHL.LE.0.0)GO TO 1320
      FMHO2=CHO2/AMHL
      GO TO 1325
 1320 FMHO2=0.0
 1325 IF(ZTEST4.GE.0.0)FO2IF=0.0
      CHO2=CHO2+(OKHL*0.21*FIF+OKHL1*FMHO2*FIF+OKHL2*FMHO2*FOF+(FO2IF-
     1FMO2B)+FO2IP+0.21*FPIHLT-FMHO2*FPOHLT)*DELT
      CCO2=CCO2+(OKCL*0.21*FIF+OKCL1*0.21*FIF+OKCL2*0.21*FOF-FO2IF-
     1FO2IP+0.21*(FPICLT-FPOCLT))*DELT
      IF(ZTEST5.LT.0.0.AND.ZTEST6.LT.0.0)CCO2=0.0
C
C****** NITROGEN BALANCE
C
      IF(AMHL.LE.0.)GO TO 1330
      FMHN2=CHN2/AMHL
      GO TO 1335
 1330 FMHN2=0.0
 1335 CHN2=CHN2+(OKHL*0.79*FIF+OKHL1*FMHN2*FIF+OKHL2*FMHN2*FOF+FN2IF
     1+FN2IP+.79*FPIHLT-FMHN2*FPOHLT)*DELT
      CCN2=CCN2+(OKCL*0.79*FIF+OKCL1*0.79*FIF+OKCL2*0.79*FOF-FN2IF-
     1FN2IP+.79*(FPICLT-FPOCLT))*DELT
      IF(ZTEST5.LT.0.0.AND.ZTEST6.LT.0.0)CCN2=0.0
C
C****** CO2 BALANCE
C
      IF(AMHL.LE.0.0)GO TO 1340
      FMCO2=CHCO2/AMHL
      GO TO 1345
 1340 FMCO2=0.0
 1345 CHCO2=CHCO2+(OKHL1*FMCO2*FIF+OKHL2*FMCO2*FOF-FMCO2*FPOHLT)*DELT
     1+(TGCO2+TWCO2+TCCO2+TFCO2)/44.0
C
```

```
C****** CO BALANCE
C
      IF(AMHL.LE.0.0)GO TO 1350
      FMCO1=CHCO1/AMHL
      GO TO 1355
 1350 FMCO1=0.0
 1355 CHCO1=CHCO1+(OKHL1*FMCO1*FIF+OKHL2*FMCO1*FOF-FMCO1*FPOHLT)
     1*DELT+TGCO1/28.0
C
C****** H2O BALANCE
C
      IF(AMHL.LE.0.0)GO TO 1360
      FMH2O=CHH2O/AMHL
      GO TO 1365
 1360 FMH2O=0.0
 1365 CHH2O=CHH2O+(OKHL1*FMH2O*FIF+OKHL2*FMH2O*FOF-FMH2O*FPOHLT)*DELT+
     1 (TGH2O+TWH2O+TCH2O+TFH2O)/18.0
C
C****** HCL BALANCE
C
      IF(AMHL.LE.0.0)GO TO 1370
      FMHCL=CHHCL/AMHL
      GO TO 1375
 1370 FMHCL=0.0
 1375 CHHCL=CHHCL+(OKHL1*FMHCL*FIF+OKHL2*FMHCL*FOF-FMHCL*FPOHLT)
     1*DELT+TGHCL/36.5
      FMHO2=CHO2/AMHL
      IF(AMCL.LE.0.0)  GO TO 1380
      FMO2=CCO2/AMCL
 1380 IF(ZTEST4.GE.0.0)FMO2=FMHO2
C
C****** CH4 BALANCE
C
      IF(AMHL.LE.0.0)GO TO 1385
      FMCH4=CHCH4/AMHL
      GO TO 1390
 1385 FMCH4=0.0
 1390 CHCH4=CHCH4+(OKHL1*FMCH4*FIF+OKHL2*FMCH4*FOF-FMCH4*FPOHLT)*DELT+
     1TGCH4/16.0
C
C****** SMOKE BALANCE
C
      VOLHL=AFLOOR*(ZR-ZM)
      IF(VOLHL.LE.0.)VOLHL=1.E+20
      V1HL=VOLHL

C     * FPSMOK=RATE OF SMOKE OUT OF ADDITIONAL FLOW PATHS (G/S)
      FPSMOK=(A(2,12)/VOLHL)*(-FPOHLT*R*THL/PCOMP)

      WSMI=DELT*A(2,12)*OKHL1*VIF/VOLHL
      WSMO=DELT*A(2,12)*OKHL2*VOF/VOLHL
      IF(VOLCL.LE.0.)GO TO 1392
      WSMI=WSMI+DELT*B(2,12)*OKCL*VIF/VOLCL
      WSMO=WSMO+DELT*B(2,12)*OKCL2*VOF/VOLCL
 1392 CONTINUE
      IF(VIF.GT.0.0)WSMI=0.0
      IF(VOF.GT.0.0)WSMO=0.0
      WSMIF=WSMIF-WSMI
      WSMOF=WSMOF-WSMO
C
C******************************************************************************
```

```
C
C                          HEAT TRANSFER TO EQUIPMENT
C
C     TYPES OF EQUIPMENT (IE):
C
C     IE     TYPE
C
C      1     SIMPLE HEAT SINKS - NO INTERIOR RADIOACTIVITY
C      2     PRESSURIZED - WITH POWDER ONLY (RADIOACTIVE)
C      3     PRESSURIZED LIQUID CONTAINERS (RADIOACTIVE LIQUID)
C      4     OPEN LIQUID CONTAINERS (RADIOACTIVE AQUEOUS)
C
C      JE = NO OF EACH TYPE OF EQUIPMENT
C
C      SPECIFY CONTAINER HEIGHT, WIDTH, MATERIAL TYPE, HEIGHT OF
C      BOTTOM OFF OF FLOOR, AND MASS OF CONTAINER
C
C      HEQ(JE,IE)=HEIGHT OF CONTAINER (M)
C      WD(JE,IE)=WIDTH OF CONTAINER (M)
C      MATERE(JE,IE)=1,2,.......9 ACCORDING TO DATA BASE
C      WMASS(JE,IE)=MASS OF CONTAINER (KG)
C      HTF(JE,IE)=HEIGHT OF BASE OFF OF FLOOR (M)
C      MJE(IE)=NO. OF JE FOR EACH IE
C      PF2(JE)=FAILURE PRESSURE (ATM)
C      PF3(JE)=FAILURE PRESSURE (ATM)
C      PI2(JE)=INTERNAL PRESSURE OF EQUIPMENT TYPE 2
C      PI3(JE)=INTERNAL PRESSURE OF EQUIPMENT TYPE 3
C
C***********************************************************************
C
C       ***** FIRST TYPE OF CONTAINER-SIMPLE HEAT SINK *****
C
C      IE=1 IS FOR INACTIVE EQUIPMENT (NO RADIOACTIVE SOURCES OR FAILURES
C      EXPECTED
C
      TGRAD=0.0 ! TO ZERO TOTAL RADIOATIVE RELEASES EACH TIME STEP
      DO 1395 IE=1,4
      EQ(IE) = 0.0
 1395 CONTINUE
      IF(EQUIP.EQ.0.0) GO TO 1475
      IF(MJE(1).EQ.0) GO TO 1405
      DO 1400 JE=1,MJE(1)
      OKE1=1.
      IF(TBCL(JE,1).EQ.0.)OKE1=0.
      U0=0.005*(ABS(THL*OKE1+TCL*(1.-OKE1)-TE1(JE)))**.3333
      IF(U0.LT.UMIN)U0=UMIN
      QE1(JE)=-(ERAD/(ARAD*DELT))*(1.-OKE1)*HEQ(JE,1)/(PI*
     1(WD(JE,1)/2.+HEQ(JE,1)))-SIG*OKE1*(THL**4-TE1(JE)**4)
     2/(1./EMIS(MATERE(JE,1))+.1111)-U0*(THL*OKE1+TCL*(1.-OKE1)
     3-TE1(JE))
      TE1(JE)=TE1(JE)-DELT*QE1(JE)*ARHT(JE,1)/(WMASS(JE,1)*
     1*CPCA(MATERE(JE,1)))
      EQ(1)=EQ(1)+QE1(JE)*ARHT(JE,1)*DELT
 1400 CONTINUE
C
C       ***** SECOND TYPE OF EQUIPMENT-PRESSURIZED POWDER *****
C
 1405 IF(MJE(2).EQ.0) GO TO 1430
      DO 1425 JE=1,MJE(2)
      OKE2=1.
      IF(TBCL(JE,2).EQ.0.)OKE2=0.
```

```
      UO=.005*(ABS(TM-TE2(JE)))**.3333
      IF(UO.LT.UMIN)UO=UMIN
      QE2(JE)=-(ERAD/(ARAD*DELT))*(1.-OKE2)*HEQ(JE,2)/(PI*
     1(WD(JE,2)/2.+HEQ(JE,2)))-SIG*(TM**4-TE2(JE)**4)
     2/(1./EMIS(MATERE(JE,2))+.1111)-UO*(TM-TE2(JE))
C
C     FLUX TO INSIDE QI2(JE),  INSIDE TEMP = TI2(JE)
C
      IF(FAIL2(JE).EQ.1.) GO TO 1415
      PR=0.7
      TB=0.5*(TE2(JE)+TI2(JE))
      TS=TE2(JE)
      EL=HEQ(JE,2)*(VGAS2(JE)/(VGAS2(JE)+VPWD(JE)))
      DFT=ABS(TE2(JE)-TI2(JE))
      WDT=WD(JE,2)
      UIN=UINS(EL,TS,DFT,TINIT,WDT,TB)
      GMOL=VGAS2(JE)*273./(2.24E-02*TINIT)+WH2O2(JE)/18.
      QI2(JE)=UIN*(TE2(JE)-TI2(JE))
      TE2(JE)=TE2(JE)-(QE2(JE)+QI2(JE))*DELT*ARHT(JE,2)/
     1(WMASS(JE,2)*CPCA(MATERE(JE,2)))
      TI2(JE)=TI2(JE)+QI2(JE)*DELT*ARHT(JE,2)/(CPAIR*GMOL)
      PI21(JE)=1.0
      PI2(JE)=PI21(JE)*TI2(JE)/TINIT
      PTEST=PI2(JE)-PF2(JE)
      IF(PTEST.GE.0.0) FAIL2(JE)=1.0
C
C  *  PRESSURIZED POWER RELEASES OF VESSELS AT RISK
C
      IF(FAIL2(JE).GT.0.5) THEN
      AMHL=AMHL+GMOL
      AD52=VGAS2(JE)*273./(2.24E-02*TINIT)
      CHO2=CHO2+FAIL2(JE)*AD52*.21
      CHN2=CHN2+FAIL2(JE)*AD52*.79
      CHH2O=CHH2O+FAIL2(JE)*WH2O2(JE)/18.
      NRST=5
      DO 1410 JACT=1,10
      IF(QRAD5(JE,JACT).EQ.0.0)GO TO 1410
      CALL RST5(QRAD5(JE,JACT),PF2(JE),VOLP(JE),PDEN(JE,JACT),
     +GRAD,QMR,JACT)
      GO TO 1501
 1410 CONTINUE
      ENDIF
C
C                    *******************
C
      GO TO 1420
 1415 CONTINUE
      QE2(JE)=2.*QE2(JE)  ! Failed vessel has 2 times heat transfer area
      TE2(JE)=TE2(JE)-QE2(JE)*DELT*ARHT(JE,2)/(WMASS(JE,2)*
     1CPCA(MATERE(JE,2)))
 1420 CONTINUE
      EQ(2)=EQ(2)+QE2(JE)*ARHT(JE,2)*DELT
 1425 CONTINUE
C
C       ***** THIRD TYPE OF EQUIPMENT-PRESSURIZED LIQUID VESSELS *****
C
 1430 IF(MJE(3).EQ.0) GO TO 1460
      DO 1455 JE=1,MJE(3)
      OKE3=1.
      IF(TBCL(JE,3).EQ.0.)OKE3=0.
      UO=.005*(ABS(TM-TE3(JE)))**.3333
```

```
      IF(UO.LT.UMIN)UO=UMIN
      QE3(JE)=-(ERAD/(ARAD*DELT))*(1.-OKE3)*HEQ(JE,3)/(
     1PI*(WD(JE,3)/2.+HEQ(JE,3)))-SIG*(TM**4-TE3(JE)**4)/
     2(1./EMIS(MATERE(JE,3))+.1111)-UO*(TM-TE3(JE))
C
C       FLUX TO INSIDE = QI3(JE) , INSIDE TEM = TI3(JE)
C
      IF(FAIL3(JE).EQ.1.) GO TO 1445
      TB=0.5*(TE3(JE)+TI3(JE))
      TS=TE3(JE)
      EL=HEQ(JE,3)
      DFT=ABS(TE3(JE)-TI3(JE))
      WDT=WD(JE,3)
      UIN=UINS(EL,TS,DFT,TINIT,WDT,TB)
      AI=ARHT(JE,3)
      Q3=UIN*AI*(TE3(JE)-TI3(JE))
      ANAIR=VGAS3(JE)*273./(2.24E-02*TINIT)
      TIN=TI3(JE)+1.
      DO 1435 K3=1,5
      TRED=TIN/647.3
      PG2=10.**(-3.1423/TRED+8.3610-EXP(-20.*(TRED-.163)**2))
      PG2=PG2/753.18
      TR1=TI3(JE)/647.3
      PG1=10.**(-3.1423/TR1+8.361-EXP(-20.*(TR1-.163)**2))/753.18
      EML=WH2O3(JE)-18.*VGAS3(JE)*PG1/(R*TI3(JE))
      EML2=WH2O3(JE)-18.*VGAS3(JE)*PG2/(R*TIN)
      EMV=-EML2+EML
      TVH2O=VGAS3(JE)*PG2/(R*TIN)
      TIN=TI3(JE)+(Q3-ELV*EMV)/(CPL*EML2+CPAIR*(ANAIR+TVH2O))
 1435 CONTINUE
      QI3(JE)=UIN*(TE3(JE)-TI3(JE))
      TI3(JE)=TIN
      TE3(JE)=TE3(JE)-(QE3(JE)+QI3(JE))*DELT*ARHT(JE,3)
     1/WMASS(JE,3)*CPCA(MATERE(JE,3))
      PI3(JE)=(ANAIR+TVH2O)*R*TI3(JE)/VGAS3(JE)
      PTEST=PI3(JE)-PF3(JE)
      IF(PTEST.GE.0.)FAIL3(JE)=1.
C
C  *  PRESSURIZED LIQUID RELEASES OF VESSELS AT RISK
C
      IF(FAIL3(JE).GT.0.5) THEN
      AMHL=AMHL+(ANAIR+WH2O3(JE)/18.)
      CHO2=0.21*ANAIR+CHO2
      CHN2=CHN2+0.79*ANAIR
      CHH2O=CHH2O+WH2O3(JE)/18.
      NRST=6
      DO 1440 JACT=1,10
      IF(QRAD6(JACT,JE).EQ.0.)GO TO 1440
      CALL RST6(QRAD6(JACT,JE),GRAD,QMR,JACT)
      GO TO 1501
 1440 CONTINUE
      ENDIF
C
C                       ************************
C
      GO TO 1450
 1445 CONTINUE
      QE3(JE)=2.*QE3(JE)
      TE3(JE)=TE3(JE)-QE3(JE)*DELT*ARHT(JE,3)/WMASS(JE,3)
     1*CPCA(MATERE(JE,3))
 1450 CONTINUE
```

```
      EQ(3)=EQ(3)+QE3(JE)*ARHT(JE,3)*DELT
 1455 CONTINUE
C
C    ***** FOURTH TYPE-UNPRESSURIZED LIQUID CONTAINERS(RADIOACTIVE LIQUID) *****
C
 1460 IF(MJE(4).EQ.0) GO TO 1475
      DO 1465 JE=1,MJE(4)
      OKE4=1.
      IF(TBCL(JE,4).EQ.0.)OKE4=0.
      TR5=TL(JE)/647.3
      PVAP=10.**(-3.1423/TR5+8.361-EXP(-20*(TR5-.163)**2))
     1/753.18
      RHOV=PVAP/(R*TL(JE))
      TBG=OKE4*THL+(1.0-OKE4)*TCL
      TFILM=(TL(JE)+TBG)*0.9-460.0
      RHOGM=29.0/(R*TBG)
      RHOVM=18.0*RHOV+29.0*(1.0-PVAP)/(R*TL(JE))
      DRHODX=11.0/(R*TL(JE))
      ZETA=DRHODX/RHOVM
      AK=AKSH(WD(JE,4),RHOVM,RHOGM,ZETA,PVAP,TL(JE),TBG)
C    AK is Sherwood number mass transfer coefficient for
C       non-boiling surface, M/sec.
      WDW=WD(JE,4)*3.28
      UT4=(2.2117E-3+3.662E-5*(TFILM)**0.5)/WDW**0.25
      IF(TL(JE).LT.373.2)UI4=0.559*(ABS(TE4(JE)-TL(JE)))**0.41301
      IF(TL(JE).GE.373.2)UI4=7.8464E-4*(ABS(TE4(JE)-TL(JE)))**3.55684
      IF(VOL(JE).LE.0.) GO TO 1465
      ARHT(JE,4)=PI*(WD(JE,4)**2/4.)+4*VOL(JE)/WD(JE,4)
      ARBL(JE)=PI*(WD(JE,4)**2/4.)
      U0=.005*ABS(THL*OKE4+TCL*(1.-OKE4)-TE4(JE))**.333
      IF(U0.LT.UMIN)U0=UMIN
      QE4(JE)=-U0*(THL*OKE4+TCL*(1.-OKE4)-TE4(JE))
     1-(ERAD/(ARAD*DELT))*(1.-OKE4)*HEQ(JE,4)/(PI*(WD(JE,4)/2.+
     2HEQ(JE,4)))-SIG*OKE4*(THL**4.-TE4(JE)**4)/
     3(1./EMIS(MATERE(JE,4))+.1111)
      REVAP=RHOV*ARBL(JE)*AK*18.
      IF(TL(JE).GE.373.2)REVAP=18.0*QIL/2.26
      QIL=UI4*(TE4(JE)-TL(JE))*ARHT(JE,4)+
     1UT4*(THL*OKE4+TCL*(1.-OKE4)-TL(JE))*ARBL(JE)
     2-REVAP*0.13+ARBL(JE)*SIG*OKE4*(THL**4.-TL(JE)**4.)
      RBOIL(JE)=REVAP*60.
      V10=VOL(JE)*1.E+06
      TLTEST=QIL*DELT/(V10*CPL)
      IF(TL(JE).GE.373.2)TLTEST=0.0
      TL(JE)=TL(JE)+TLTEST
      TE4(JE)=TE4(JE)+(-QE4(JE)*ARHT(JE,4)*DELT-UI4*
     1(TE4(JE)-TL(JE))*ARHT(JE,4)*DELT)/(WMASS(JE,4)
     2*CPCA(MATERE(JE,4)))
      VOL(JE)=VOL(JE)-DELT*REVAP*1.E-06
      CHH2O=CHH2O+REVAP*DELT/18.
      EQ(4)=EQ(4)+QE4(JE)*ARHT(JE,4)*DELT
 1465 CONTINUE
 1475 CONTINUE
      EQT=EQ(1)+EQ(2)+EQ(3)+EQ(4)
C
C*****************************************************************************C*
C                                                                             C
C                          NET MASS AND ENERGY CALCULATION                    C
C                                                                             C

      T1HL=THL
```

```
      GHL=V1HL*P1COM/(R*T1HL)
      QHL=(THL-TINIT)*CPAIR*GHL
      QCOMB=TQCON+HLRAD
      QLOST=(QC+QWH+QF)*DELT+EQT
      AIRIN=(OKHL*ABS(FIF)+FPIHLT)*DELT
      AIROUT=(OKHL2*-1.*FOF+FPOHLT+OKHL1*ABS(FIF))*DELT
      THL=TINIT+(QHL+QCOMB+QLOST-AIROUT*CPAIR*(THL-TINIT))/(CPAIR*
     +(GHL+AIRIN-AIROUT))
      TZL=(FIF*OKHL*TINIT+FM*TM)/(FIF*OKHL+FM)
      IF(TSTEP.EQ.DELT)  THL=TZL
      QLOSSR=EQT/DELT+QC+QW+QF
      QLOSSN=QLOSSR*.003412
      TQNETR=TQACTR+QLOSSR
      TQNET=TQNETR*.003412
      TMASSR=(TMASS+TWCO2+TWH2O+TCCO2+TCH2O+TFCO2+TFH2O)/DELT
      TMASSN=TMASSR*7.93
      TMOLEN=((TGH2O+TCH2O+TFH2O+TWH2O)/18.0+(TGCO2+TCCO2+
     1TFCO2+TWCO2)/44.0+TGCO1/28.+TGHCL/36.5+TGCH4/16.0)/DELT
      HLR=QWH+QC
      IF(ZM.LE.0.)HLR=HLR+QF
      OKDP=0.
      IF(P2.LT.PCOMP)OKDP=1.
      FHL=OKHL2*OKDP*ABS(VOF)+FPOHLV+OKHL1*ABS(VIF)
      FCL=OKCL2*OKDP*ABS(VOF)+FPOCLV+OKCL*ABS(VIF)
      TCAV=TC(1,1)
      TFAV=TF(1,1)
C
C*******************************************************************************
C
C         CALCULATION OF RADIOACTIVE SOURCE TERMS
C
      DO 1510 JACT=1,10
      IF(NRAD(1).LT.1)GO TO 1480
      NRST=1
      DO 1480 I=1,9
      DO 1480 IFORM=1,3
      NJ=((IFORM*10)-10)+I
      IF(QRAD1(NJ,JACT,IBO).LE.0.)GO TO 1480
      QT=QE+QFC(I,J)+QFRMAX-QRR(I)
      RSMOK=YSMOK(I,J)*BRATE(I,J)
      CALL RST1(QRAD1(NJ,JACT,IBO),TEND(I,IBO),GRAD,OFUEL(I,IBO),
     +BRATE(I,J),RSMOK,QT,VEL,XMAX1(NJ,JACT),XMAX2(NJ,JACT),
     +XMAX3(NJ,JACT))
      GO TO 1501
 1480 CONTINUE
      DO 1485 I=7,9
      IF(NRAD(2).LT.1)GO TO 1485
      NRST=2
      DO 1485 IFORM=1,2
      NJ=(I-6)+(IFORM-1)*3
      IF(QRAD2(NJ,JACT,IBO).LE.0.)GO TO 1485
      IF(TEND(I,IBO).EQ.TSTEP.AND.TEND(I,IBO).NE.0.)
     1QRAD2(NJ,JACT,IBO)=0.0
      SMOKFR=SMOK(I,J)/OFUEL(I,IBO)/DELT
      CALL RST2(QRAD2(NJ,JACT,IBO),IFORM,GRAD,QMR,JACT,SMOKFR,
     @OFUEL(I,IBO),BRATE(I,J))
      GO TO 1501
 1485 CONTINUE
      IF(NRAD(3).LT.1)GO TO 1490
      NRST=3
      IF(QRAD3(JACT).LE.0.) GO TO 1490
```

```
      T=THL-273.0
      IF(T.LE.30.)GO TO 1490
      CALL RST3(QRAD3(JACT),GRAD,DELT,QMR,JACT,T)
      GO TO 1501
 1490 CONTINUE
      IF(NRAD(4).LT.1)GO TO 1500
      NRST=4
      DO 1500 IVES=1,10
      T=TE4(IVES)-273.0
      IF(QRAD4(IVES,JACT).LE.0.) GO TO 1495
      CALL RST4(QRAD4(IVES,JACT),VOL(IVES),IVES,TSTEP,T,VEL,
     1TL(IVES),DELT,RBOIL(IVES),GRAD,QMR,JACT)
      GO TO 1501
 1495 CONTINUE
 1500 CONTINUE
      IF(NRAD(7).LT.1)GO TO 1505
      NRST=7
      IF(QRAD7(JACT,IBO).LE.0.) GO TO 1505
      CALL RST7(QRAD7(JACT,IBO),SQ(JACT,IBO),GRAD,TSTEP,IBO,QMR,JACT)
 1501 CONTINUE
      TGRAD=TGRAD+GRAD
      DO 1502 ISIZE=1,11
 1502 GRPART(1,ISIZE)=GRPART(1,ISIZE)+QMR(ISIZE,JACT)
      GRPART(1,12)=GRPART(1,12)+GRAD
      WRADI=DELT*A(1,12)*OKHL1*VIF/VOLHL
      WRADO=DELT*A(1,12)*OKHL2*VOF/VOLHL
      IF(VOLCL.LE.0.)GO TO 1503
      WRADI=WRADI+DELT*B(1,12)*OKCL*VIF/VOLCL
      WRADO=WRADO+DELT*B(1,12)*OKCL2*VOF/VOLCL
 1503 CONTINUE
      IF(VIF.GT.0.0)WRADI=0.0
      IF(VOF.GT.0.0)WRADO=0.0
      WRADIF=WRADIF-WRADI
      WRADOF=WRADOF-WRADO
      GO TO (1480,1485,1490,1495,1410,1440,1505)NRST
 1505 CONTINUE
 1510 CONTINUE

C       * FPRAD=RATE OF RADIOACTIVITY OUT OF ADDITIONAL FLOW PATHS
C                (G/S)
      FPRAD=(A(1,12)/VOLHL)*(-FPOHLT*R*THL/PCOMP)
C
      CSMOKE=A(2,12)/VOLHL
      CGRAD=A(1,12)/VOLHL
C
C***************************************************************************
C
C                     PARTICLE DEPLETION CALCULATIONS
C
      if(tstep.eq.delt)zm=(amcl*r*tcl)/(afloor*pcomp)
      CALL PDMECH
      DO 1550 K=1,2
      A(K,12)=0.
      B(K,12)=0.
      DO 1550 M=1,8
      AFLOSS(M,K,12)=0.
 1550 CONTINUE
      DO 1555 ISZ=1,11
      DO 1555 JT=1,2
      DO 1560 M=1,5
      AFLOSS(M,JT,ISZ)=FRAC(M,ISZ)*ALOSS(JT,ISZ)
```

```
      AFLOSS(M,JT,12)=AFLOSS(M,JT,12)+AFLOSS(M,JT,ISZ)
 1560 CONTINUE
      DO 1565 M=6,8
      AFLOSS(M,JT,ISZ)=FRAC(M,ISZ)*BLOSS(JT,ISZ)
      AFLOSS(M,JT,12)=AFLOSS(M,JT,12)+AFLOSS(M,JT,ISZ)
 1565 CONTINUE
      A(JT,12)=A(JT,12)+A(JT,ISZ)
      B(JT,12)=B(JT,12)+B(JT,ISZ)
 1555 CONTINUE
      DO 1568 JT=1,2
      ALOSS(JT,12)=0.
      BLOSS(JT,12)=0.
      DO 1567 M=1,5
 1567 ALOSS(JT,12)=ALOSS(JT,12)+AFLOSS(M,JT,12)
      DO 1568 M=6,8
 1568 BLOSS(JT,12)=BLOSS(JT,12)+AFLOSS(M,JT,12)
      DO 1569 ISZ=1,11
      DO 1569 JT=1,2
      ABLOSS=BLOSS(JT,ISZ)
      IF(ZM.LE.0.)ABLOSS=ALOSS(JT,ISZ)
      FMASS(JT)=FMASS(JT)+FRACF(ISZ)*ABLOSS
        if(fmass(jt).lt.0.0)fmass(jt)=0.0
      WAMASS(JT)=WAMASS(JT)+FRACW(ISZ)*ALOSS(JT,ISZ)
      CMASS(JT)=CMASS(JT)+FRACC(ISZ)*ALOSS(JT,ISZ)
 1569 CONTINUE
      DO 1570 JT=1,2
      VENT=AFLOSS(5,JT,12)+AFLOSS(7,JT,12)
      VEMASS(JT)=VEMASS(JT)+EFFIC*VENT
      OUTVEN(JT)=OUTVEN(JT)+(1-EFFIC)*VENT
 1570 CONTINUE
C
C*****************************************************************************
C
C                   PRINT OUTPUT FOR TIMESTEP
C
        THLUC = 1.8 * THL - 460.0
      IF(MOD(ITSTEP,IPRINT).EQ.0.0) THEN
      WRITE(10,270) TSTEP,PCOMP,FMO2,ZHL,VIF,VOF,THLUC,TMASSR,TQACTR,
     +QLOSSR,TQNETR
      WRITE(8,245)TSTEP,(A(1,M),M=1,12)
      WRITE(11,245)TSTEP,(A(2,M),M=1,12)
      IF(ALOSS(1,12).GT.0.)THEN
      WRITE(3,410)TSTEP,A0(1,12),GRPART(1,12)*DELT,AFLOSS(8,1,12),
     @ALOSS(1,12),A(1,12),((AFLOSS(M,1,12)/ALOSS(1,12)),M=1,5)
      ELSE
      WRITE(3,410)TSTEP,A0(1,12),GRPART(1,12)*DELT,AFLOSS(8,1,12),
     @ALOSS(1,12),A(1,12)
      END IF
      IF(ALOSS(2,12).GT.0.)THEN
      WRITE(5,410)TSTEP,A0(2,12),GRPART(2,12)*DELT,AFLOSS(8,2,12),
     @ALOSS(2,12),A(2,12),((AFLOSS(M,2,12)/ALOSS(2,12)),M=1,5)
      ELSE
      WRITE(5,410)TSTEP,A0(2,12),GRPART(2,12)*DELT,AFLOSS(8,2,12),
     @ALOSS(2,12),A(2,12)
      END IF
      IF(ZM.LE.0.)GO TO 1571
      WRITE(9,245)TSTEP,(B(1,M),M=1,12)
      WRITE(13,245)TSTEP,(B(2,M),M=1,12)
      IF(BLOSS(1,12).GT.0.)THEN
      WRITE(4,420)TSTEP,B0(1,12),AFLOSS(1,1,12),BLOSS(1,12),B(1,12),
     @((AFLOSS(M,1,12)/BLOSS(1,12)),M=6,8)
```

```
      ELSE
      WRITE(4,420)TSTEP,B0(1,12),AFLOSS(1,1,12),BLOSS(1,12),B(1,12)
      END IF
      IF(BLOSS(2,12).GT.0.)THEN
      WRITE(7,420)TSTEP,B0(2,12),AFLOSS(1,2,12),BLOSS(2,12),B(2,12),
     @((AFLOSS(M,2,12)/BLOSS(2,12)),M=6,8)
      ELSE
      WRITE(7,420)TSTEP,B0(2,12),AFLOSS(1,2,12),BLOSS(2,12),B(2,12)
      END IF
 1571 CONTINUE
      WRITE(12,245)TSTEP,FMASS(1),WAMASS(1),CMASS(1),VEMASS(1),
     @OUTVEN(1)
      TOTAL_RAD_MASS = FMASS(1) + WAMASS(1) + CMASS(1) +
     .                 VEMASS(1) + OUTVEN(1) + a(1,12)
      WRITE(14,245)TSTEP,FMASS(2),WAMASS(2),CMASS(2),VEMASS(2),
     @OUTVEN(2)
      TOTAL_SMK_MASS = FMASS(2) + WAMASS(2) + CMASS(2) +
     .                 VEMASS(2) + OUTVEN(2) + a(2,12)
      IF((PLOTANS .EQ. 'Y') .OR. (PLOTANS .EQ. 'y')) THEN
          WRITE(15,10) TSTEP,ZHL,VIF,VOF,TQACTR,QLOSSR,TQNETR,TMASSR,
     .                 THLUC,FMASS(1),WAMASS(1),CMASS(1)
          WRITE(16,20) VEMASS(1),OUTVEN(1),A(1,12),FMASS(2),WAMASS(2),
     .                 CMASS(2),VEMASS(2),OUTVEN(2),A(2,12),
     .                 TOTAL_RAD_MASS,TOTAL_SMK_MASS,TSPEC,ZR
      ENDIF
10    FORMAT(12(1X,G11.5))
20    FORMAT(14(1X,G11.5))
      END IF
      DO 1575 ISZ=1,12
      DO 1575 JT=1,2
      A0(JT,ISZ)=A(JT,ISZ)
      B0(JT,ISZ)=B(JT,ISZ)
 1575 CONTINUE
        IF(TSTEP.GT.10000.)DELT=100.0
      TSTEP=TSTEP+DELT
      ITSTEP=ITSTEP+1
      GO TO 1100
 1515 CONTINUE
C
C*************************************************************************
C
C                   PRINT OUTPUT FOR END OF FUEL AND/OR RUN
C
 1516 TSTEP=TSTEP-DELT
      CONSUM=(GTMASS/TFUEL)*100.0
      IF(TFUEL.GT.GTMASS) THEN
        WRITE(3,315) TSTEP,CONSUM
        WRITE(4,315) TSTEP,CONSUM
        WRITE(5,315) TSTEP,CONSUM
        WRITE(7,315) TSTEP,CONSUM
        WRITE(8,315) TSTEP,CONSUM
        WRITE(9,315) TSTEP,CONSUM
        WRITE(11,315) TSTEP,CONSUM
        WRITE(13,315) TSTEP,CONSUM
        WRITE(10,315) TSTEP,CONSUM
      ENDIF
      IF(TFUEL.GT.GTMASS) GO TO 1520
      WRITE(3,320)TSTEP
      WRITE(4,320)TSTEP
      WRITE(5,320)TSTEP
      WRITE(7,320)TSTEP
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      WRITE(8,320)TSTEP
      WRITE(9,320)TSTEP
      WRITE(11,320)TSTEP
      WRITE(13,320)TSTEP
      WRITE(10,320)TSTEP
 1520 IF(TSPEC .GT. TSTEP) THEN
         NBO(1)=0
         FUEL(1,1)=500000.0
         AREC(1,1)=0.00000001
         TBURN(1,1)=500000.0
         YSMOK(1,1)=0.
         YSMOK(1,2)=0.
         YSMOK(1,3)=0.
         DO 1525 I=2,9
         NBO(I)=0
         FUEL(I,1)=0.0
         AREC(I,1)=0.0
         TBURN(I,1)=0.0
 1525    CONTINUE
         FLAG=1.
         TSTEP=TSTEP+DELT
         GO TO 1085
      END IF
      GO TO 1535
 1530 TSTEP=TSTEP-DELT
      WRITE(3,325)TSTEP
      WRITE(4,325)TSTEP
      WRITE(5,325)TSTEP
      WRITE(7,325)TSTEP
      WRITE(8,325)TSTEP
      WRITE(9,325)TSTEP
      WRITE(11,325)TSTEP
      WRITE(13,325)TSTEP
      WRITE(10,325)TSTEP
1535  CONTINUE
      CLOSE(UNIT=3)
      CLOSE(UNIT=4)
      CLOSE(UNIT=5)
      CLOSE(UNIT=7)
      CLOSE(UNIT=8)
      CLOSE(UNIT=9)
      CLOSE(UNIT=11)
      CLOSE(UNIT=13)
      CLOSE(UNIT=10)
      CLOSE(UNIT=12)
      CLOSE(UNIT=14)
      STOP
C
C***********************************************************************
C***********************************************************************
C
C                   END OF MAIN PROGRAM
C
C***********************************************************************
C***********************************************************************
      END
      SUBROUTINE THERMD(T,DIF,MATER)
      COMMON/PARA1/RHOO(15),CPCA(15),CPCAM(15)
      COMMON/PARA2/COND(15),CONDM(15)
      DT=T-273.
      DIF=(COND(MATER)-DT*CONDM(MATER))/(RHOO(MATER)*(CPCA(MATER)
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     ++DT*CPCAM(MATER)))
      RETURN
      END
      SUBROUTINE TEMP(M,DELT,T1,T2,YE1,YH1,YC1,TDIF,TP,TN,DX,TH2O,
     +TCO2,V,NFLAG)
      COMMON/PARA1/RHOO(15),CPCA(15),CPCAM(15)
      DOUBLE PRECISION AH
      IF(M.NE.1.OR.NFLAG.EQ.1)GO TO 5
      AE=DELT*EXP((14.07-5557.)/T1)/60.
      YE2=1.+(YE1-1.)*EXP(-AE)
      IF(T2.LT.363.)YE2=YE1
      AH=DELT*EXP((28.31-20560.)/T1)/60.
      YH2=1.+(YH1-1.)*DEXP(-AH)
      IF(T1.LT.473.)YH2=YH1
      AC=DELT*EXP((16.8-19362.)/T1)/60.
      YC2=1.+(YC1-1.)*EXP(-AC)
      IF(T1.LT.923.)YC2=YC1
      QCON=-2.82E+5*(YE2-YE1)/DELT-5.87E+5*(YH2-YH1)/DELT-4.08E+6*
     +(YC2-YC1)/DELT
      TH20=TH20+101.*(YE2-YE1)*V+101.*(YH2-YH1)*V
      TCO2=TCO2+975.*(YC2-YC1)*V
      YE1=YE2
      YH1=YH2
      YC1=YC2
      GO TO 10
    5 QCON=0.0
   10 CONTINUE
      A=RHOO(M)*(CPCA(M)+(T1-273.)*CPCAM(M))
      T2=T1+((TDIF*DELT/DX**2)*(TN-2.*T1+TP)+QCON*DELT/A)
      RETURN
      END
      SUBROUTINE ENDPT(T11,T12,T21,T22,TN1,TPN1,TN2,TPN2,M,DX,
     +QA,CKD,THLC,NFLAG)
      COMMON/PARA2/COND(15),CONDM(15)
      COMMON/PARA3/EMIS(15),TINIT,UMIN,WRADF
      COMMON/PARA7/FE,DELT,THL,TCL
      UO=0.005*(ABS(TN1-TINIT))**.3333
      IF(UO.LT.UMIN)UO=UMIN
      U=0.005*(ABS(THLC-T11))**.3333
      IF(U.LT.UMIN)U=UMIN
      IF(NFLAG.EQ.1)THEN
        CON=COND(M)
        QR=-WRADF
        QA=QR-U*(TCL-T11)
        GO TO 5
      END IF
      TA=(T11+T12)/2.
      CON=COND(M)-(TA-273.)*CONDM(M)
      QR=-5.669E-11*(THL**4-T11**4)/(1.0/EMIS(M)+0.1111)
      QA=-U*(THLC-T11)+QR
    5 T12=(U*THLC+T22*CON/DX-QR)/(CON/DX+U)
      TN2=(CKD*TPN2+UO*TINIT)/(CKD+UO)
      RETURN
      END
      SUBROUTINE RST1(Q,TEND,GR,OFUEL,BR,SMOK,QT,VEL,XMAX1,XMAX2,
     +XMAX3)
C
C     THIS SUBROUTINE CALCULATES THE MASS RATE AND SIZE DISTRIBUTION OF
C     RADIOACTIVE PARTICLES GIVEN OFF FROM BURNING CONTAMINATED
C     COMBUSTIBLE SOLIDS. THE INPUT PARAMETERS ARE DEFINED BELOW.
C
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C          Q = GRAMS OF RADIOACIVE CONTAMINANT OF THE COMBUSTIBLE
C          IFORM = 1 IF CONTAMINANT IS A POWDER
C                  2 IF CONTAMINANT IS AN AIR DRIED NITRATE SOLUTION
C                  3 IF A LIQUID NITRATE SOLUTION
C          I = COMBUSTIBLE MATERIAL TYPE
C          TEND = THE TIME WHEN THE COMBUSTIBLE IS BURNED UP (SEC)
C          TSTEP = THE CURRENT TIME STEP AT WHICH THE SUBROUTINE IS CALLED (SEC)
C          DELT = TIME STEP INCREMENT
C          JACT = RADIOACTIVITY IDENTIFIER (NUMERIC)
C          OFUEL = ORIGINAL MASS OF COMBUSTIBLE (G)
C          BR = BURN RATE OF COMBUSTIBLE (G/S)
C          SMOK = RATE OF SMOKE GIVEN OFF IN THE TIMESTEP (G/S)
C          QT = TOTAL HEAT FLUX (KW/M2)
C          VEL = AIR VELOCITY (M/S)
C          J = BURN MODE
C
C      OUTPUT PARAMETERS ARE:
C
C          GR = TOTAL MASS RATE OF RADIOACTIVE PARTICLES GIVEN OFF (G/SEC)
C          QMR = MASS RATE OF RADIOACTIVE PARTICLES GIVEN OF FOR EACH
C                BIN (G/SEC)
C
C
      COMMON/PARA5/IFORM,I,TSTEP,QMR(11,10),JACT,J
      COMMON/PARA7/FE,DELT,THL,TCL
      DIMENSION SFRAC(11,6)
C SFRAC IS THE FRACTION OF RADIOACTIVE PARTICLES IN EACH SIZE BIN FROM
C BURNING 1)PMMA-PWDR CONT., 2)PMMA-NONPWDR CONT., 3)PS, 4)PVC OR PC,
C 5)WOOD OR PAPER, AND 6)OTHER
      DATA SFRAC/2*0.0,0.042,0.043,2*0.05,0.215,0.415,0.11,0.075,0.0,
     +3*0.0,2*0.015,0.022,0.128,0.47,0.19,0.125,0.035,
     +0.0,0.085,0.082,0.078,0.065,0.66,0.14,0.337,0.078,0.05,0.025,
     +4*0.0,0.02,0.008,0.037,0.15,0.11,0.175,0.5,
     +0.9,0.023,0.01,0.007,2*0.003,0.009,0.13,0.005,0.006,0.021,
     +0.05,0.1,0.075,0.055,0.05,0.04,0.125,0.225,0.08,0.09,0.11/
      GR=0.
      IF(I.GT.1)GO TO 10
      IF(IFORM.GT.1)GO TO 5
      GR=0.05*Q/DELT
      LF=1
      GO TO 16
    5 IF(IFORM.EQ.2)GR=0.007*Q/DELT
      IF (IFORM.EQ.3)GR=0.02*Q/DELT
      LF=2
      GO TO 16
   10 IF(I.GT.2)GO TO 20
      GR=0.02*Q/DELT
      LF=3
   16 Q=0.0
      GO TO 90
   20 CONTINUE
      IF(I.GT.4)GO TO 30
      SRATE=SMOK/OFUEL
      IF(IFORM.LT.3)GR=0.0227*Q*SRATE
      IF(IFORM.EQ.3)GR=0.104*Q*SRATE
      PMAX=XMAX1
      XMAX1=XMAX1+GR*DELT
      TMAX=0.05*Q
      IF(XMAX1.GT.TMAX)THEN
      GR=(TMAX-PMAX)/DELT
      Q=0.0
```

```
      END IF
      LF=4
      GO TO 90
   30 IF( BR .EQ. 0.0 ) GOTO 45
      IF (I.GT.6)GO TO 40
      IF(IFORM.GT.1)GO TO 35
      IF(J.NE.1)GR=5.64E-6*BR*Q
      IF(J.EQ.1)GR=6.76E-4*Q*BR*(Q/OFUEL)*QT*VEL
      IF(XMAX2.EQ.0.0)GR=GR+1.0E-4*Q/DELT
      PMAX=XMAX2
      XMAX2=XMAX2+GR*DELT
      TMAX=0.01*Q
      IF(XMAX2.GT.TMAX)THEN
      GR=(TMAX-PMAX)/DELT
      Q=0.0
      END IF
      LF=5
      GO TO 90
   35 IF(IFORM.EQ.2)GR=7.40E-7*Q*BR*QT
      IF(IFORM.EQ.3)GR=6.08E-8*Q*BR*QT
      PMAX=XMAX3
      XMAX3=XMAX3+GR*DELT
      TMAX=0.01*Q
      IF(XMAX3.GT.TMAX)THEN
      GR=(TMAX-PMAX)/DELT
      Q=0.0
      END IF
      LF=5
      GO TO 90
   40 TM = OFUEL / BR
   45 GR=0.01*Q/TM
      LF=6
   90 DO 95 L=1,11
      QMR(L,JACT)=SFRAC(L,LF)*GR
   95 CONTINUE
      IF(TEND.NE.0..AND.TSTEP.EQ.TEND)Q=0.
  100 RETURN
      END
      SUBROUTINE RST2(Q,IFORM,GR,QMR,JACT,SMOKFR,FUEL,BR)
C
C     THIS SUBROUTINE CALCULATES THE MASS RATE AND SIZE DISTRIBUTION OF
C     RADIOACTIVE PARTICLES GIVEN OFF FROM BURNING CONTAMINATED
C     COMBUSTIBLE LIQUIDS. THE INPUT PARAMETERS ARE DEFINED BELOW:
C
C         Q = GRAMS OF RADIOACTIVE CONTAMINANT IN THE LIQUID
C         IFORM = 1 IF CONTAMINANT IS NON OR SEMIVOLATILE
C                 2 IF CONTAMINANT IS VOLATILE
C         TM = THE TIME IT WOULD TAKE TO BURN ALL OF THE COMBUSTIBLE LIQUID
C              AT THE CURRENT BURN RATE (SEC)
C         SMOKFR = SMOKE RATE / TOTAL GRAMS LIQUID FUEL (FRAC/S)
C         JACT = RADIOACTIVITY IDENTIFIER (NUMERIC)
C         FUEL = MASS OF COMBUSTIBLE (G)
C         BR = BURN RATE OF COMBUSTIBLE (G/S)
C
C     OUTPUT PARAMETERS ARE:
C
C         GR = MASS RATE OF RADIOACTIVE PARTICLES GIVEN OFF DURING BURNING
C              (G/SEC)
C         QMR = MASS RATE OF RADIOACTIVE PARTICLES GIVEN OF FOR EACH
C                BIN (G/SEC)
C
```

```
      DIMENSION QMR(11,JACT),SFRAC(11)
      DATA SFRAC/.05,.21,.15,.20,.11,.06,.08,.108,.029,.003,0.0/
      GR=0.
      IF(IFORM.GT.1)GO TO 10
      GR=1.38*SMOKFR*Q
      GO TO 20
   10 TM=FUEL/BR
      GR=.84*Q/TM
   20 DO 30 L=1,11
      QMR(L,JACT)=SFRAC(L)*GR
   30 CONTINUE
      RETURN
      END
      SUBROUTINE RST3(Q,GR,DELT,QMR,JACT,T)
C
C     THIS SUBTOUTINE CALCULATES THE MASS RATE AND SIZE DISTRIBUTION OF
C     RADIOACTIVE PARTICLES GIVEN OFF FROM HEATING CONTAMINATED SURFACES.
C     INPUT PARAMETERS ARE:
C
C         Q = GRAMS OF CONTAMINANT ON AFFECTED HEATED SURFACE
C         T = TEMPERATURE OF THE SURFACE
C         JACT = RADIOACTIVITY IDENTIFIER (NUMERIC)
C
C     OUTPUT PARAMETERS ARE:
C
C         GR = TOTAL MASS RATE OF RADIOACIVE PARTICLES GIVEN OFF (G/SEC)
C         QMR = MASS RATE OF RADIOACTIVE PARTICLES GIVEN OF FOR EACH
C                BIN (G/SEC)
C
      DIMENSION QMR(11,JACT)
    5 GR=1.379E-12*(T**2)*Q
      Q=Q-GR*DELT
      IF(Q.LE.0.0) GO TO 10
    7 QMR(9,JACT)=.0002*GR
      QMR(10,JACT)=.1408*GR
      QMR(11,JACT)=.85*GR
   10 RETURN
      END
      SUBROUTINE RST4(Q,VOL,IVES,TSTEP,T,VEL,TL,
     1DELT,RBOIL,GR,QMR,JACT)
C
C     THIS SUBROUTINE CALCULATES THE MASS RATE AND SIZE DISTRIBUTION OF
C     OF RADIOACTIVE PARTICLES GIVEN OFF DURING THE HEATING AND BOILING
C     OF UNPRESSURIZED RADIOACTIVE LIQUIDS.
C     INPUT PARAMETERS ARE:
C
C         Q = GRAMS OF RADIOACTIVE MATERIAL IN THE LIQUID
C         VOL = MILILITERS OF RADIOACTIVE LIQUID IN THE CONTAINER AT THE
C               CURRENT TIME STEP - CORRECTIONS MADE WITHIN THE SUBROUTINE
C               TO REDUCE THE VOLUME AS THE LIQUID BOILS
C         IVES = NUMBER OF THE VESSEL FROM WHICH SOURCE TERM IS GENERATED
C                - UP TO 10 VESSELS CAN BE SPECIFIED.
C         TSTEP = CURRENT TIME STEP (SEC)
C         DELT = WIDTH OF THE TIME STEP INCREMENT
C         TL = TEMPERATURE OF PREBOILING LIQUID
C         VEL = VELOCITY OF AIR FLOW OVER RESIDUE AFTER BURNING
C         RBOIL= BOILING RATE OF LIQUID
C         JACT = RADIOACTIVITY IDENTIFIER (NUMERIC)
C
C     OUTPUT PARAMETERS ARE:
C
```

```
C          GR = MASS RATE OF RADIOACTIVE PARTICLES GIVEN OFF DURING THE
C               PREBOILING, BOILING, OR ENTRAINMENT OF RESIDUE (G/SEC)
C          QMR = MASS RATE OF RADIOACTIVE PARTICLES GIVEN OF FOR EACH
C                BIN (G/SEC)
C
C      UNPRESSURIZED LIQUIDS ARE CONSIDERED PREBOILING IF THE BOILING RATE IS
C      LESS THAN .4 ML/MIN, AND BOILING IF OVER THAT RATE. RELEASES FROM
C      HEATING OF RESIDUE START WHEN THE VOLUME OF LIQUID IS DOWN TO ZERO
C      AND THE LIQUID HAS BOILED AWAY. THESE RELEASES CONTINUE FOR TWO HOURS.
C      IFLAG(IVES) EQUALS 2 WHEN THE LIQUID HAS BOILED AWAY SO THAT THE
C      HEATING OF RESIDUE RELEASES ARE ONLY CALCULATED ONCE.
C
      DIMENSION VOL(10),RBOIL(10),IFLAG(10),QMR(11,JACT)
      GR=0.
      IF(VOL(IVES).LE.0.) GO TO 30
      IF(RBOIL(IVES).GE.0.4)GO TO 10
      GR=9.57E-15*(TL**2)*Q
      GO TO 20
   10 IF(RBOIL(IVES).GT.0.6)GO TO 40
      GR=5.0E-10*Q
      GO TO 20
   40 GR=(5.74E-7*RBOIL(IVES)-3.42E-7)*Q
      GO TO 20
   30 IF(IFLAG(IVES).EQ.2) GO TO 50
      T2=TSTEP+7200.
      IFLAG(IVES)=2
   50 IF(TSTEP.LE.T2) GO TO 60
      Q=0.0
      DO 55 L=1,11
      QMR(L,JACT)=0.0
   55 CONTINUE
      GO TO 90
   60 GR=(7.37E-12*T+7.51E-11*VEL)*Q
   20 CONTINUE
      QMR(9,JACT)=.03*GR
      QMR(10,JACT)=.42*GR
      QMR(11,JACT)=.55*GR
   90 RETURN
      END
C
C*********************************************************************
C
      SUBROUTINE RST5(Q,PF2,VOL,PDEN,GR,QMR,JACT)
C     INTERIM SUBROUTINE FOR PRESSURIZED POWDER RELEASES.
C     RELEASE= F(PF2,Q) WHERE PF2 IS THE FAILURE PRESSURE
C     OF THE CONTAINER AND Q IS THE SOURCE QUANTITY.
      DIMENSION QMR(11,JACT)
      PF2=PF2*1.013E+5  !Convert atm to Pa
        XM=Q*1000.0       !Convert g to kg
        VOID = VOL - (Q/PDEN)
        VEL = ((2 * PF2 * VOID)/XM)**0.5
      GR=(1E+4 * (VEL**1.4))
      QMR(1,JACT)=.0*GR
      QMR(2,JACT)=.02*GR
      QMR(3,JACT)=.02*GR
      QMR(4,JACT)=.015*GR
      QMR(5,JACT)=.02*GR
      QMR(6,JACT)=.015*GR
      QMR(7,JACT)=.07*GR
      QMR(8,JACT)=.20*GR
      QMR(9,JACT)=.11*GR
```

```
      QMR(10,JACT)=.15*GR
      QMR(11,JACT)=.38*GR
      RETURN
      END
C
C*****************************************************************************
C
      SUBROUTINE RST6(Q,GR,QMR,JACT)
C     SUBROUTINE FOR PRESSURIZED LIQUID RELEASES.
      DIMENSION QMR(11,JACT)
      GR=0.1 * Q
      QMR(1,JACT)=.0*GR
      QMR(2,JACT)=.01*GR
      QMR(3,JACT)=.015*GR
      QMR(4,JACT)=.02*GR
      QMR(5,JACT)=.015*GR
      QMR(6,JACT)=.02*GR
      QMR(7,JACT)=.09*GR
      QMR(8,JACT)=.27*GR
      QMR(9,JACT)=.15*GR
      QMR(10,JACT)=.18*GR
      QMR(11,JACT)=.23*GR
      RETURN
      END
      SUBROUTINE RST7(Q,SQ,GR,TSTEP,IBO,QMR,JACT)
C
C*****************************************************************************
C
C
C     THIS SUBROUTINE CALCULATES THE MASS RATE AND SIZE DISTRIBUTION OF
C     PARTICLES GIVEN OFF FROM BURNING RADIOACTIVE PYROPHONIC METALS.
C     INPUT PARAMETERS ARE:
C
C         Q = GRAMS OF RADIOACTIVE MATERIAL BEING BURNED
C         IBO = BURN ORDER OF RADIOACTIVE MATERIAL - DETERMINS WHEN THE
C               STARTS BURNING
C         SQ = SIZE OF METAL PIECES (G)
C         TSTEP = TIME STEP
C         JACT = RADIOACTIVITY IDENTIFIER (NUMERIC)
C
C     OUTPUT PARAMETERS ARE:
C
C         GR = TOTAL MASS RATE OF RADIOACTIVE PARTICLES GIVEN OFF (G/SEC)
C         QMR = MASS RATE OF RADIOACTIVE PARTICLES GIVEN OF FOR EACH
C                BIN (G/SEC)
C
C     SINCE THE SOURCE TERM IS CONSTANT OVER TIME IT ONLY NEEDS TO
C     BE CALCULATED ONCE. HENCE IFLAG=1 WHEN THE SOURCE TERM HAS BEEN
C     CALCULATED SO IT WILL NOT BE ADDED TO THE TOTAL AT ANOTHER TIME.
C     IT IS ASSUMED THE RELEASE TAKES PLACE OVER 30 MINUTES.
C
      DIMENSION IFLAG(100),QMR(11,JACT)
      GR=0.
      IF(IFLAG(IBO).EQ.1)GO TO 10
      T2=TSTEP+3600.
      IFLAG(IBO)=1
   10 IF(TSTEP.LE.T2)GO TO 30
      Q=0.0
      DO 40 L=1,11
      QMR(L,JACT)=0.0
   40 CONTINUE
```

```
      GO TO 20
   30 GR=1.66E-14*(SQ**2)*Q
      QMR(6,JACT)=.005*GR
      QMR(7,JACT)=.035*GR
      QMR(8,JACT)=.96*GR
   20 RETURN
      END
      FUNCTION UINS(X1,X2,X3,X4,X5,X6)
      DIMENSION CC(15),C1(16),C2(16),C3(16),BB(5),B1(6),B2(6),B3(6)
      DATA CC/0.,32.,100.,200.,300.,400.,500.,600.,700.,800.,900.
     +,1000.,1500.,2000.,3000./
      DATA C1/2*4.2E+06,3.16E+06,1.76E+06,8.5E+05,4.44E+05,2.58E+05,
     +1.59E+05,1.06E+05,7.04E+04,4.98E+04,3.6E+04,2.65E+04,7.45E+03,
     +2.84E+03,815./
      DATA C2/0.,3.25E+04,2.059E+04,9.1E+03,4.06E+03,1.86E+03,990.,
     +530.,356.,206.,138.,95.,38.1,9.22,2.025,0./
      DATA C3/2*0.,32.,100.,200.,300.,400.,500.,600.,700.,800.,900.,
     +1000.,1500.,2000.,0./
      DATA BB/0.,500.,1000.,2000.,3000./
      DATA B1/2*.0133,.0231,.0319,.0471,.054/
      DATA B2/0.,1.96E-05,1.76E-05,1.52E-05,6.9E-06,0./
      DATA B3/2*0.,500.,1000.,2000.,0./
      XF=X2*1.8-460.
      XL=X1*3.28084
      XD=X3*1.8
      DO 10 I=1,15
      I1=I
      IF(XF.LE.CC(I))GO TO 11
   10 CONTINUE
      I1=16
   11 GP=C1(I1)-C2(I1)*(XF-C3(I1))
      GP=GP*X2/X6
      GRPR=GP*XD*(XL**3.)*0.7*(X2/X4)**2
C
C         GRPR = PRODUCT OF GRASHOFF NO. AND PRANDTL NO. (.7) FOR AIR
C
C         COND OF AIR = AIRCON
C
      DO 15 I=1,5
      I2=I
      IF(XF.LE.BB(I))GO TO 16
   15 CONTINUE
      I2=6
   16 AIRCON=B1(I2)+B2(I2)*(XF-B3(I2))
C
C         CHANGE UNITS TO (KW/M-K)
C
      AIRCON=AIRCON*1.7296E-03
      WR=X5*3.28084/4.
      IF(XL.NE.0.0)GO TO 17
      GPTEST=0.0
      GO TO 18
   17 GPTEST=GRPR*WR/XL
   18 BNUSS=0.065*GPTEST
      IF(GPTEST.GE.20.)BNUSS=0.42*(GPTEST)**.25
      UINS=BNUSS*AIRCON/WR
      RETURN
      END
      FUNCTION AKSH(B1,B2,B3,B4,B5,B6,B7)
C    AKSH calculates the evaporative mass transfer coeff. for
C     vessel type four-open liquid surface
```

```
C     Product of Grashof and Schmidt number, GrSc, first assume
C      film properties as average between surface and bulk gas
       TFILM2=(B6+B7)/2.0
       RHOFLM=(B2+B3)/2.0
       ZETA2=(B4+11.0/(8.206E-5*B7*B3))/2.0
       XVAP=B5/2.0
C     Viscosity of steam air mixtures from CORRAL code
C      ( WASH-1400, App.VII, Page VII-243 )
       TR=1.8*TFILM2
       TRIP5=TR*SQRT(TR)
       VST=0.003339*TRIP5/(TR+1224.2)
       VAIR=0.0414*(TR/492.0)**0.768
       PAS=(1.0+SQRT((VAIR/VST)*SQRT(18./29.)))**2./4.5704
       PSA=(1.0+SQRT((VST/VAIR)*SQRT(29./18.)))**2./3.6008
       RMOL=XVAP/(1.0-XVAP)
       VMIX=VAIR/(1.0+RMOL*PAS)+VST/(1.0+PSA*RMOL)
       VMIX=4.134E-04*VMIX
C     VMIX has unit of KG/MS
C     Diffusivity of steam/air mixtures from program BUBBLE
       RM=0.300064
       A1=0.00214-0.000492*RM
       SIG=3.129
       EPS=280.1
       OMEGA=0.7075+0.7341*EPS/TFILM2
       DIFF=A1*(TFILM2**1.5)*RM/(OMEGA*SIG**2.0)
       DIFF=1.0E-04*DIFF
C     DIFF has unit of M*M/S
       GRSC=(B1**3.0)*RHOFLM*9.8*ZETA2*XVAP/(VMIX*DIFF)
       IF(RHOFLM.LT.B3 .AND. GRSC.GT.1.0E+07)
      1SH=0.14*(GRSC)**(1./3.)
       IF(RHOFLM.LT.B3 .AND. GRSC.LE.1.0E+07)
      1SH=0.54*(GRSC)**(0.25)
C     Correlations 8.35C, P.263, Natural Convection Heat and
C      Mass Transfer, Y.J Aluria, Pergamon, Oxford,1980.
       IF(RHOFLM.GE.B3)SH=0.58*(GRSC)**0.2
C     Correlation 8.34B above
       AKSH=SH*DIFF/B1
C     AKSH has unit of M/S
       RETURN
       END
       SUBROUTINE PDMECH
       DOUBLE PRECISION XN,XM,RLOSS1,RLOSS2
       REAL LR
       COMMON/PARA6/FMH2O,FMHO2,FMHN2,FMCO1,FMCO2,LR,WR,ZR,
      @ZM,TAVWH,TAVWC,TCAV,TFAV,PCOMP,FHL,FCL,DPART(11),
      @HLR,FRAC(8,12),DX,GRPART(2,12),A(2,12),B(2,12),
      @A0(2,12),B0(2,12),ALOSS(2,12),BLOSS(2,12),FRACF(11),
      @FRACW(11),FRACC(11),FLAG
       COMMON/DEPL/VCL,RLOSS2,VSET1,AFLOOR,VHL,XM,XN,RLOSS1
       COMMON/PARA7/FE,DELT,THL,TCL
       AFLOOR=LR*WR
       THAVW=(THL+TAVWH)/2.
       TCAVW=(TCL+TAVWC)/2.
       TAVC=(THL+TCAV)/2.
       TAVF=(THL+TFAV)/2.
       AHL=2.*(ZR-ZM)*(LR+WR)
       ACL=2.*ZM*(LR+WR)
       VHL=(ZR-ZM)*AFLOOR
       VCL=ZM*AFLOOR
       XMID=(4*AFLOOR*FE)/VHL
       XNC=FMHO2+FMHN2+FMCO1+FMCO2
```

```
      CALL VISC(THL,FMH2O,FMHO2,FMHN2,FMCO1,FMCO2,AMWH,VISMIX,AKG)
      CALL VISC(TCL,0.0,0.21,0.79,0.0,0.0,AMWC,VISAIR,AKG2)
      RHOGASH=AMWH*PCOMP/(.08206*THL)    !RHO IN KG/M**3
      VT=1.E-6*-HLR/((AFLOOR+AHL)*RHOGASH)   !VT IN M/S
      RHOGASH=RHOGASH/1000.    !RHO IN G/CM**3
      CALL VDIFFU(FMH2O,XNC,PCOMP,AMWH,THAVW,RHOGASH,VDW)
      CALL VDIFFU(FMH2O,XNC,PCOMP,AMWH,TAVC,RHOGASH,VDC)
      CALL VDIFFU(FMH2O,XNC,PCOMP,AMWH,TAVF,RHOGASH,VDF)
      DO 5 ISZ=1,11
      CALL DIFFU(DPART(ISZ),VISMIX,THL,AMWH,PCOMP,DIFUS,CM,ELAM)
      CALL VSETL(CM,DPART(ISZ),VISMIX,AMWH,PCOMP,THL,RHOGASH,VSET1)
      CALL VBROWN(THL,THAVW,VISMIX,RHOGASH,DX,DIFUS,VBDW)
      CALL VBROWN(THL,TAVC,VISMIX,RHOGASH,DX,DIFUS,VBDC)
      IF(VCL.LE.0.)THEN
        CALL VBROWN(THL,TAVF,VISMIX,RHOGASH,DX,DIFUS,VBDF)
        TVSET=VSET1*AFLOOR
        TVBD=(VBDC+VBDF)*AFLOOR+VBDW*AHL
        TVTH=VT*(AHL+2.*AFLOOR)
        TVD=(VDC+VDF)*AFLOOR+VDW*AHL
        FLOOR=(VSET1+VBDF+VT+VDF)*AFLOOR
        WALL=(VBDW+VT+VDW)*AHL
        CEIL=(VBDC+VT+VDC)*AFLOOR
        TVHL=TVSET+TVBD+TVTH+TVD+FHL
        RLOSS1=TVHL/VHL
        FRAC(6,ISZ)=0.
        FRAC(7,ISZ)=0.
        FRAC(8,ISZ)=0.
        FRACF(ISZ)=FLOOR/TVHL
        EX1=EXP(-RLOSS1*DELT)
        DO 3 JT=1,2
        A(JT,ISZ)=A0(JT,ISZ)*EX1+(GRPART(JT,ISZ)/RLOSS1)*(1.-EX1)
        ALOSS(JT,ISZ)=RLOSS1*(A0(JT,ISZ)*(EX1-1.)/-RLOSS1+GRPART(JT,
     @  ISZ)*DELT/RLOSS1+GRPART(JT,ISZ)*(EX1-1.)/RLOSS1**2.)
        B(JT,ISZ)=0.
        BLOSS(JT,ISZ)=0.
    3   CONTINUE
        GO TO 4
      END IF
      TVSET=VSET1*AFLOOR
      TVBD=VBDC*AFLOOR+VBDW*AHL
      TVTH=VT*(AHL+AFLOOR)
      TVD=VDC*AFLOOR+VDW*AHL
      CEIL=(VBDC+VT+VDC)*AFLOOR
      WALL=(VBDW+VT+VDW)*AHL
      TVHL=TVSET+TVBD+TVTH+TVD+FHL
      RLOSS1=TVHL/VHL
      CALL DIFFU(DPART(ISZ),VISAIR,TCL,AMWC,PCOMP,DIFUS,CM,ELAM)
      CALL VSETL(CM,DPART(ISZ),VISAIR,AMWC,PCOMP,TCL,RHOGAS,VSET2)
      TVCL=VSET2*AFLOOR+FCL+FE
      FLOOR=VSET2*AFLOOR
      RLOSS2=TVCL/VCL
      IF(FLAG.EQ.1.)THEN
        EX1=EXP(-RLOSS1*DELT)
        EX2=EXP(-RLOSS2*DELT)
        XX=(VSET1*AFLOOR/VHL)/(RLOSS1-RLOSS2)
        DO 10 JT=1,2
        A(JT,ISZ)=A0(JT,ISZ)*EX1
        B(JT,ISZ)=B0(JT,ISZ)*EX2+XX*A0(JT,ISZ)*(EX2-EX1)
        ALOSS(JT,ISZ)=A0(JT,ISZ)*(1-EX1)
        BLOSS(JT,ISZ)=(B0(JT,ISZ)+XX*A0(JT,ISZ))*(1-EX2)+RLOSS2*XX*
     @A0(JT,ISZ)*(EX1-1)/RLOSS1
```

```
 10    CONTINUE
       GO TO 6
     END IF
     TV=TVHL+TVCL
     XN=(-RLOSS1-RLOSS2-SQRT(RLOSS2**2.+RLOSS1**2.-2.*RLOSS1*RLOSS2
    @+(VSET1*XMID)/VCL))/2.
     XM=-RLOSS2-RLOSS1-XN
     DO 6 JT=1,2
     CALL DEPLETE(A0(JT,ISZ),B0(JT,ISZ),GRPART(JT,ISZ),A(JT,ISZ),
    @B(JT,ISZ),ALOSS(JT,ISZ),BLOSS(JT,ISZ))
   6 CONTINUE
     FRAC(6,ISZ)=VSET2*AFLOOR/TVCL
     FRAC(7,ISZ)=FCL/TVCL
     FRAC(8,ISZ)=FE/TVCL
     FRACF(ISZ)=FLOOR/TVCL
   4 FRAC(1,ISZ)=(TVSET)/TVHL
     FRAC(2,ISZ)=TVBD/TVHL
     FRAC(3,ISZ)=TVTH/TVHL
     FRAC(4,ISZ)=TVD/TVHL
     FRAC(5,ISZ)=FHL/TVHL
     FRACW(ISZ)=WALL/TVHL
     FRACC(ISZ)=CEIL/TVHL
   5 CONTINUE
     RETURN
     END
     SUBROUTINE VISC(TB,XH2O,XO2,XN2,XCO,XCO2,AMW,VISMIX,AKG)
     DIMENSION Y(5),VS(5),WM(5),Z(5),PHI(5,5),VK(5)
     SQRTTB=SQRT(TB)
     EPSH2O=809.1
     EPSO2=113.0
     EPSN2=91.5
     EPSCO=110.
     EPSCO2=190.
     SIGH2O=2.641
     SIGO2=3.433
     SIGN2=3.681
     SIGCO=3.59
     SIGCO2=3.996
     AMW=XCO2*44.+XCO*28.+XH2O*18.+XO2*32.+XN2*28.
     OMH2O=0.765+0.82*EPSH2O/TB
     VISH2O=2.6693E-05*SQRT(18.*TB)/((SIGH2O**2.)*OMH2O)
     OMO2=0.765+0.82*EPSO2/TB
     OMN2=0.765+0.82*EPSN2/TB
     OMCO=0.765+0.82*EPSCO/TB
     OMCO2=0.765+0.82*EPSCO2/TB
     VISO2=2.6693E-5*SQRT(32.*TB)/((SIGO2**2.)*OMO2)
     VISN2=2.6693E-5*SQRT(28.*TB)/((SIGN2**2.)*OMN2)
     VISCO=2.6693E-5*SQRT(28.*TB)/((SIGCO**2.)*OMCO)
     VISCO2=2.6693E-5*SQRT(44.*TB)/((SIGCO2**2.)*OMCO2)
     AKGH2O=(.3268*SQRTTB-3.9179)/10000.
     AKGO2=(.2982*SQRTTB-2.4864)/10000.
     AKGN2=(.2695*SQRTTB-2.0577)/10000.
     AKGCO=(.2583*SQRTTB-1.9407)/10000.
     AKGCO2=(.2795*SQRTTB-3.1296)/10000.
C     AKG IN WATTS/CM/K
     Y(1)=XH2O
     Y(2)=XO2
     Y(3)=XN2
     Y(4)=XCO
     Y(5)=XCO2
     VS(1)=VISH2O
```

```
      VS(2)=VISO2
      VS(3)=VISN2
      VS(4)=VISCO
      VS(5)=VISCO2
      VK(1)=AKGH2O
      VK(2)=AKGO2
      VK(3)=AKGN2
      VK(4)=AKGCO
      VK(5)=AKGCO2
      WM(1)=18.
      WM(2)=32.
      WM(3)=28.
      WM(4)=28.
      WM(5)=44.
      DO 301 J=1,5
      DO 301 I=1,5
      PHI(I,J)=1./(((1.+WM(I)/WM(J))*8.)**.5)*(1.+SQRT(VS(I)/VS(J))
     0*(WM(J)/WM(I))**.25)**2
  301 CONTINUE
      DO 302 I=1,5
      Z(I)=0.
      DO 302 J=1,5
      Z(I)=Z(I)+Y(J)*PHI(I,J)
  302 CONTINUE
      AKG=0.
      VISMIX=0.
      DO 303 I=1,5
      VISMIX=VISMIX+Y(I)*VS(I)/Z(I)
      AKG=AKG+Y(I)*VK(I)/Z(I)
  303 CONTINUE
C
C     VISMIX IN POISES.  CALCULATIONS USE BSL PAGE 24
C
      RETURN
      END
      SUBROUTINE DIFFU(DPART,VISMIX,TAV,AMW,PGAS,DIFUS,CM,ELAM)
C
C     THIS SUBROUTINE CALCULATES PARTICLE DIFFUSIVITY, DIF(N)
C     AS A FUNCTION OF PARTICLE SIZE
C
C     INPUTS:
C     DPART,VISMIX,TAV,AMW,PGAS
C
C     CUNNINGHAM FACTOR, CM AND ELAM, MEAN FREE PATH OF GAS
C
      PI=3.14159265
      ELAM=1.245E-02*((TAV/AMW)**.5)*VISMIX/PGAS
      IF(DPART.LT.1.E+3)GO TO 95
      RATD=ELAM/DPART
      CM=1.+2.492*RATD+0.84*RATD*EXP(-0.435/RATD)
      GO TO 90
   95 CM=1.
   90 CONTINUE
      DIFUS=1.38E-16*TAV*CM/(3.*PI*VISMIX*DPART)
C
C     OUTPUT: DIFFUSIVITY, DIFUS IN CM**2/SEC
C
      RETURN
      END
      SUBROUTINE VSETL(CM,DPART,VISMIX,AMW,PGAS,TAV,RHOGAS,VSET1)
C     CALCULATE SETTLING VELOCITIES NOW (VSET1)
```

```
      G=980.
      RG=82.06
      VSET1=G*CM*(DPART)**2./(18.*VISMIX)
C
C      FOLLOWING TAKEN FORM BNWL-1326, PAGE 12-13
C
      RHOGAS=AMW*PGAS/(RG*TAV)
      FDRE2=1.3333*RHOGAS*G*((DPART)**3.)/(VISMIX**2)
      IF(FDRE2.GT.9.6.AND.FDRE2.LT.93.6)RE=(FDRE2/27.)**(1./1.13)
      IF(FDRE2.GE.93.6.AND.FDRE2.LT.410.)RE=(FDRE2/24.32)**(1./2.227)
      IF(FDRE2.GE.410..AND.FDRE2.LT.1.07E+4)RE=(FDRE2/15.71)**
     @(1./1.417)
      IF(FDRE2.GE.1.07E+4.AND.FDRE2.LT.2.45E+5)RE=(FDRE2/6.477)**
     @(1./1.609)
      IF(FDRE2.GE.2.45E+5)RE=(FDRE2/1.194)**(1./1.867)
      IF(FDRE2.GT.9.6)VSET1=RE*VISMIX/(DPART*RHOGAS)
      VSET1=VSET1/100.      !VSET1 IN M/S
      RETURN
      END
      SUBROUTINE VBROWN(T,TAVG,VISMIX,RHOGAS,DELTAX,DIFUS,VBD)
      IF(T.LT.TAVG)THEN
      VBD=0.
      GO TO 5
      END IF
      DELTAT=(T-TAVG)
      GR=(980./(VISMIX/RHOGAS)**2.)*DELTAT/TAVG*(DELTAX**3)
      SC=VISMIX/(RHOGAS*DIFUS)
      VBD=0.13*(GR*SC)**(1./3.)*(DIFUS/DELTAX)
    5 CONTINUE
      RETURN
      END
      SUBROUTINE VDIFFU(XH2O,XNC,PCOMP,AMW,TAVW,RHOGAS,VD)
      AAP=3.2437814
      BP=5.868263E-03
      CP=1.17023793E-08
      DP=2.1878462E-03
      X2A=647.27-TAVW
      IF(X2A.LE.0.)GO TO 90
      XPONEN=-(X2A/TAVW)*(AAP+BP*X2A+CP*(X2A**3.))/(1.+DP*X2A)
      P2A=218.167*10.**XPONEN
      PSAT=XH2O*PCOMP
      IF(P2A.GE.PSAT)GO TO 90
      IF(XH2O.LE.0.)GO TO 5
      HC=4.502E-02*(XH2O/(XNC-XH2O))**0.8
      IF(HC.GT.0.15889)HC=0.15889     !HC in watt/(cm2*k)
      GO TO 10
    5 HC=0.
   10 CONTINUE
      XLAM=2267.
      FLUX=(HC/XLAM)*(THL-TAVW)
      if(flux.lt.0.)flux=0.
      VD=(1.0-0.13*XNC)*FLUX/RHOGAS/100.    !VD IN M/S
      GO TO 100
   90 VD=0.
  100 RETURN
      END
      SUBROUTINE DEPLETE(A0,B0,XMI,A,B,ALOSS,BLOSS)
      DOUBLE PRECISION XN,XM,RLOSS1,RLOSS2,B2,A,B,ALOSS,BLOSS
      COMMON/DEPL/VCL,RLOSS2,VSET1,AFLOOR,VHL,XM,XN,RLOSS1
      COMMON/PARA7/FE,DELT,THL,TCL
      C0=FE*B0/VCL+RLOSS2*A0+XMI
```

```
 D0=XMI*RLOSS2
 A2=(VSET1*AFLOOR)/VHL
 B2=-RLOSS2
 X0=A2*A0
 Y0=A2*C0
 Z0=A2*D0
 XMIN=-300/DELT
 IF(XM.LT.XMIN)XM=XMIN
 IF(XN.LT.XMIN)XN=XMIN
 IF(B2.LT.XMIN)B2=XMIN
 EX1=EXP(XM*DELT)
 EX2=EXP(XN*DELT)
 EX3=EXP(B2*DELT)
 D1=XM-XN
 D2=XM-B2
 D3=XN-B2
 A=(A0*(XM*EX1-XN*EX2)+C0*(EX1-EX2))/D1+D0*(1./(XM*XN)+
@EX2/(-1.*XN*D1)+EX1/(XM*D1))
 T1=EX3/(D2*D3)
 T2=EX1/(D2*D1)
 T3=EX2/(D3*-1.*D1)
 B=X0*(B2*T1+XM*T2+XN*T3)+B0*EX3+Y0*(T1+T2+T3)+Z0*
@(-1./(B2*XM*XN)+T2/XM+T3/XN+T1/B2)
 EX4=EX1-1.
 EX5=EX2-1.
 EX6=EX3-1.
 ALOSS=A0*(EX4-EX5)/D1+C0*(EX4/XM-EX5/XN)/D1+D0*(DELT/
@(XM*XN)+EX5/(-1.*D1*XN**2.)+EX4/(D1*XM**2.))
 ALOSS=ALOSS*RLOSS1
 T4=EX6/(D2*D3)
 T5=EX4/(D2*D1)
 T6=EX5/(-1.*D1*D3)
 BLOSS=B0*EX6/B2+X0*(T4+T5+T6)+Y0*(T4/B2+T5/XM
@+T6/XN)+Z0*(DELT/(-1.*B2*XM*XN)+T5/XM**2.+T6/XN**2.
@+T4/B2**2.)
 BLOSS=BLOSS*RLOSS2
 RETURN
 END
```

APPENDIX D

FIRIN PARAMETER DEFINITIONS

TABLE D.1. Variables with Only One Dimension

Name	Description
A1	Constant used in concrete decomposition model
ABLOSS	Total mass of particles depleted onto floor, g
AD52	Moles of air above powder in type 2 vessel, g moles
AE	Equivalent wall area receiving direct flame radiation, m^3
AFLOOR	Floor area, m^2
AHL	Wall area in the hot layer, m^2
AI	Equipment area exposed to heat transfer for type 3 equipment, m^2
AIRIN	Air flow into hot layer, g mole
AIROUT	Airflow out of hot layer, g mole
AK	Sherwood number mass transfer coefficient for nonboiling surface, m/s
AMCL	Moles of gas in cold layer, g mole
AMHL	Moles of gas in hot layer, g mole
ANAIR	Moles of air in vessel type 3, g mole
ARAD	Total area of equipment exposed to flame radiant heat transfer, m^2
AW1	One wall area (length x height), m^2
AW2	Other wall area (width x height), m^2
BTMAX	Maximum burn time, s
CCN2	Moles of nitrogen in cold layer, g moles
CCO2	Moles of oxygen in cold layer, g moles
CGRAD	Concentration of radioactive particles in the hot layer, g/m^3
CHCH4	Moles of methane in the hot layer, g moles
CHCO1	Moles of carbon monoxide in the hot layer, g moles
CHCO2	Moles of carbon dioxide in the hot layer, g moles
CHH2O	Moles of water vapor in the hot layer, g moles
CHHCL	Moles of hydrochloric acid in the hot layer, g moles
CHN2	Moles of nitrogen in the hot layer, g moles
CHO2	Moles of oxygen in the hot layer, g moles
CKDC	Conductivity/DXC, intermediate in ceiling heat transfer calculations, kJ/m
CKDF	Same as CKDC for floor
CKDW	Same as CKDC for wall
CONSUM	Percent of total fuel consumed in the fire
CP	Heat capacity, kJ/g mole K
CPAIR	Heat capacity of air, kJ/g mole K
CPL	Heat capacity of water, kJ/cm^3 K
CSMOKE	Concentration of smoke in the hot layer, g/m^3
DELP	Compartment pressure minus alternate flow path pressure, bars
DELT	Time step increment, s
DENOM1	Denominator in filter plugging model for inlet filter, $(atm\ s)/m^3$
DENOM2	Denominator in filter plugging model for inlet filter, $(atm\ s)/m^3$
DFT	Change in temperature across the walls of equipment types 2 and 3, K
DR	Equivalent diameter of floor, m
DRHODX	Density of air minus density of water vapor over type 4 vessel, g/m^3

TABLE D.1. (contd)

Name	Description
DX	Distance between vertical wall nodes, m
DXC	Distance between ceiling nodes, m
DXF	Distance between floor nodes, m
DXW	Distance between wall nodes, m
EFFIC	Efficiency of filters at start of fire, fraction
EIG	Ignition energy available from previous time step, kJ/m^2
EIGN	Total ignition energy available, kJ/m^2
EL	Height of gas layer in equipment types 2 and 3, m
ELV	Constant in determining internal temperature and pressure of type 3 equipment
EML	Intermediate in determining internal temperature and pressure of type 3 equipment, g
EML2	Intermediate similar to EML, g
EMV	Intermediate similar to EML, g
EQT	Total heat transferred to equipment, kJ
EQUIP	Equals 1 if modelling equipment option is implemented
ERAD	Radiative heat flux to equipment from flame, kJ
FCL	Volumetric flow rate of gas into cold layer, m^3/s
FE	Volumetric flow of gases into hot layer, m^3
FHL	Volumetric flow rate of gas into hot layer, m^3/s
FIF	Molar flow rate thru inlet filter, g mole/s
FIP	Molar flow rate into the plume, g mole/s
FLAG	Equals 1 if fire has stopped burning
FM	Molar flow rate of gases into hot layer, g mole/s
FMCH4	Molar fraction of methane in the hot layer
FMCO1	Molar fraction of carbon monoxide in the hot layer
FMCO2	Molar fraction of carbon dioxide in the hot layer
FMH2O	Molar fraction of water vapor in the hot layer
FMHCL	Molar fraction of hydrochloric acid in the hot layer
FMHN2	Molar fraction of nitrogen in the hot layer
FMHO2	Molar fraction of oxygen in the hot layer
FMIF	Molar flow rate of gases into the flame, g mole/s
FMO2	Mole percent of oxygen in the cold layer
FMO2B	Molar rate of oxygen consumed, g mole/s
FMOF	Molar flow rate of gases out of the flame, g mole/s
FN2IF	Molar flow rate of N_2 into the flames from the cold layer, g mole/s
FN2IP	Molar flow rate of N_2 into the plume
FO2IF	Molar flow rate of O_2 into the flame from the cold layer, g mole/s
FO2IP	Molar flow rate of O_2 into the plume
FOF	Molar flow rate through outlet filter, g mole/s
FPICLT	Molar flow rate into cold layer from alternate flow paths, g mole/s
FPOCLT	Molar flow rate out of cold layer to alternate flow paths, g mole/s
FPOCLV	Volumetric flow rate of gases from the cold layer out alternate flow paths, m^3/s

TABLE D.1. (contd)

Name	Description
FPOHLT	Molar flow rate out of hot layer to alternate flow paths, g mole/s
FPOHLV	Same as FPOCLV but for hot layer, m^3/s
FPRAD	Mass flow rate of radioactive particles out of additional flow paths, g/s
FPSMOK	Rate of smoke out of additional flow paths, g/s
FUN	Molar flow rate of unreacted gases out of the flame, g mole/s
GHL	Total moles of gas in hot layer, g mole
GMOL	Total moles of gas inside equipment type 2, g mole/s
GR	Acceleration due to gravity, m/s^2
GRAD	Mass of radioactive material made airborne from release mechanism, g
GTMASS	Mass burned from all fuels, summed over time, g
HLR	Heat loss to room surfaces in hot layer, kW
HLRAD	Radiative heat from the fire to the hot layer, kJ
I	Fuel type
IBO	Burn order
IE	Type of equipment
IFORM	Form of radioactive material for release mechanisms 1 and 2
IFP	Number of alternate flow path
IGNITE	Equals 1 if autoignition energy option implemented
INPUTFILE	Dummy name for file holding input data
IPRINT	Number of iterations between printouts
ISIZE	Bin size for radioactive particle size distributions
ISZ	Bin size for radioactive particle size distributions
ITSTEP	Number of time steps
IVES	Number of vessels for radioactive release mechanisms 4, 5, and 6
IW	Vertical wall nodes
J	Ventilation conditions (1 = overventilated, 2 = semiventilated, 3 = underventilated)
J1	Integer used to initialize arrays
J2	Nodes in ceiling
J3	Integerused to initialize arrays
JACT	Radioactivity identifier
JACTO	First JACT printout, 0
JC	Nodes in wall, ceiling, floor
JE	Number of equipment of type IE
JF	Floor nodes
JFORM	Form of radioactive material for release mechanism
JT	1 = radioactive, 2 = smoke
JW	Horizontal wall nodes
K	Same as J
K3	Iterations for determining internal T and P of type 3 vessel
LR	Length of room, m

TABLE D.1. (contd)

Name	Description
M	Single integer for type of construction material
MATERC	Ceiling construction material
MATERF	Floor construction material
MATERW	Wall construction material
MIBO	Maximum burn order
N2X2IF	Size equivalent of inlet filter in multiples of 2' x 2', integer
N2X2OF	Same as N2X2IF except for outlet filter, integer
NC	Lowest vertical wall node in hot layer
NFLAGC	Equals 1 when heat transfer calculations are made for ceiling nodes in the cold layer
NFLAGF	Same as NFLAGC, but for wall nodes
NFLAGW	Same as NFLAGC, but for floor nodes
NFP	Number of alternate flow paths
NJ	Combination of IFORM and I to make one parameter
NRST	Number of the radioactive source term mechanism
NT	Vertical wall node
NW	Number of wall nodes in the hot layer
OKCL	Equals 1 if flow is from cold layer out inlet filter
OKCL1	Equals 1 if flow is from inlet filter to compartment cold layer
OKCL2	Equals 1 if outlet filter is in cold layer
OKCLF	Equals 1 if base of the fire is in the cold layer
OKDP	Equals 1 if flow is into compartment through inlet vent
OKE1	Equals 1 if the hot layer transfers heat to equipment type 1
OKE2	Equals 1 if the hot layer transfers heat to equipment type 2
OKE3	Equals 1 if the hot layer transfers heat to equipment type 3
OKE4	Equals 1 if the hot layer transfers heat to equipment type 4
OKHL	Equals 1 if flow from inlet filter is into compartment hot layer
OKHL1	Equals 1 if flow is from compartment hot layer out of inlet filter
OKHL2	Equals 1 if outlet filter is in hot layer
OKHLF	Equals 1 if base of the fire is in the hot layer
OKPF	Equals 1 if plume height greater than 0.0
P1	Initial pressure on other side of inlet vent, atm
P1COM	Compartment pressure in previous time step, atm
P2	Initial pressure on other side of outlet vent, atm
PCOMP	Compartment, pressure, atm
PG1	Intermediate pressure in determining internal T and P for type 3 equipment, atm
PG2	Intermediate pressure in determining internal T and P for type 3 equipment, atm
PI	π
PINIT	Initial pressure in fire compartment, atm
PLOTANS	Equals "Y" if user wants to output data to files to be input to graphics packages
PLP	Compartment pressure, bars
PNC	Number of vertical wall nodes in cold layer
PNW	Number of vertical wall nodes in hot layer

TABLE D.1. (contd)

Name	Description
PR	Prandl number
PTEST	Test to see if the internal pressure of vessels type 2 and 3 exceed rupture pressure
PVAP	Vapor pressure of radioactive liquid in type 4 vessels, atm
Q3	Heat rate to equipment type 3, kW
QC	Convective heat transfer to the ceiling, kW
QCA	Convective heat transfer to the ceiling, kW/m^2
QCOMB	Convective and radiative heat from the fire to the hot layer, kJ
QE	External heat flux, kW/m^2 (negative of QFA)
QF	Convective heat transfer to the floor, kW
QFA	Convective heat transfer to the floor, kW/m^2
QFRMAX	Maximum radiative heat flux from flame to fuel, kW/m^2
QHL	Heat in the hot layer, kJ
QIL	Heat transferred to liquid in type 4 vessel, kW
QLOSSN	Heat loss rate to all surfaces, Btu/h
QLOSSR	Rate of heat loss to all surfaces, kW
QLOST	Heat loss to all surfaces, kJ
QT	Total heat flux to burning fuel, kW/m^2
QW	Convective heat transfer to the wall, kW
QWB	Convective heat transferred to the wall in the hot layer for one time step, kW/m^2
QWC	Convective heat transfer to the wall in the cold layer, kW
QWD	Convective heat transfer to the wall in the cold layer for one time step, kW/m^2
QWH	Convective heat transfer to the wall in the hot layer, kW
QZ	Intermediate in Zukowski plume equation
QZM	Intermediate in Zukowski plume equation
R	Gas constant, atm m^3/g mole K
RESISTI	Initial filter resistance of inlet filter, atm m/s
RESISTO	Initial filter resistance of outlet filter, atm m/s
REVAP	Boil-off rate of liquid in type 4 vessel, ml/s
RHOGM	Density of air above type 4 vessel, g/m^3
RHOV	Molar density of radioactive liquid evaporated from type 4 equipment, g $moles/m^3$
RHOVM	Density of air and vapor above type 4 vessel, g/m^3
RSMOK	Smoke release rate, g/s
SCALE	Linear interpolation value for scaling combustion parameters to lower and oxygen concentrations
SIG	Stefan-Boltzmann constant, kW/m^2 K^4
SMOKER	Weight fraction of fuel that is emitted as smoke
T	Floor temperature, C
T1HL	Temperature of the hot layer in the previous time step, K
TA	Temperature of air through inlet filter, K
TAREC	Total burning surface area of combustibles, m^2
TAVWC	Average wall temperature in the cold layer, K
TAVWH	Average wall temperature in the hot layer, K

TABLE D.1. (contd)

Name	Description
TB	Average temperature of type 2 and 3 equipment wall, K
TBG	Temperature of the air above liquid in type 4 vessel, K
TCO	Initial ceiling tempeerature
TCAV	Ceiling temperature, KL
TCCO2	Carbon dioxides released from ceiling concrete in time step, g
TCH2O	Water released from ceiling concrete in time step, g
TCL	Temperature of the cold layer, K
TECL	Time when the outlet ventilation duct and fire elevation are in hot layer, s
TFAV	Floor temperature, K
TFCO2	Carbon dioxide released from floor concrete in time step, g
TFH2O	Water released from floor concrete in time step, g
TFILM	Film temperature above liquid in type 4 vessel, K
TFUEL	Total weight of fuel, g
TGCH4	Total weight of CH4 generated from all fuels in each time step, g
TGCO1	Total weight of CO generated from all fuels in each time step, g
TGCO2	Total weight of CO2 generated from all fuels in each time step, g
TGH2O	Total weight of H2O generated from all fuels in each time step, g
TGHCL	Total weight of HCL generated from all fuels in each time step, g
TGRAD	Total rate of radioactive particles generated in each time step, g/s
THL	Temperature of the hot layer, K
THLC	Temperature of gases touching the floor, K
THLUC	Temperature of the hot layer, F
TIF	Temperature of air through outlet filter, K
TIN	Internal temperature of equipment type 3, K
TINIT	Initial temperature in compartment, K
TLTEST	Increase in temperature of liquid in type 4 vessel, K
TM	Temperature at interface of hot layer and plume
TMASS	Mass burned in the fire from all fuels for current time step, g
TMASSN	Mass burned in the fire plus concrete decomposition products for current time step, lb/hr
TMASSR	TMASSN in g/s
TMC	Carbon in combustion products for one time step, g
TMCL	Chlorine in combustion products for one time step, g
TMH	Hydrogen in combustion products for one time step, g
TMO	Oxygen in combustion products for one time step, g
TMOLEN	Total moles generated in the fire for current time step, g mole/s
TOF	Temperature outside the flame (near the tip of the flame in the plume), K
TOTAL-RAD-MASS	Total cumulative mass of radioactive material emitted from fire, g
TOTAL-SMK-MASS	Same as TOTAL-RAD-MASS, but for smoke, g
TQACT	Total heat release from all fuels in each time step, kJ
TQACTN	Rate of heat release from all fuels in each time step, Btu/hr
TQACTR	TQACTN in kw
TQCON	Convective fraction of TQACT, kJ

TABLE D.1. (contd)

Name	Description
TQNET	Net heat to gases in current time step, Btu/hr
TQNETR	TQNET in kW
TQRAD	Radioactive fraction of TQACT, kJ
TR1	Intermediate in determining internal T and P of type 3 equipment
TR5	Temperature intermediate in vapor pressure equipment for equipment type 4, K
TRED	Intermediate in determining internal T and P of type 3 equipment
TS	Temperature outside vessel type 2 and 3, K
TSMOK	Total weight of smoke generated from all fuels in each time step, g
TSPEC	Maximum time step, s
TSTEP	Time step, s
TSTEPO	First time step printout, 0,0s
TVH2O	Intermediate in determining internal T and P of type 3 equipment
TWCO2	Carbon dioxide released from wall concrete in time step, g
TWH2O	Water released from wall concrete in time step, g
TWO	Initial wall temperature, K
TZL	Hot layer temperature in the initial time step, K
UI4	Internal heat transfer coefficient to liquid in type 4 vessel, kW/m^{2}K
UIN	Internal heat transfer coefficient, kW/m^{2}K
UMIN	Minimum convective heat transfer coefficient, kW/K
UO	Outside convective heat transfer coefficient, kW/K
UT4	Heat transfer from top of type 4 vessel, kW/m^{2}K
V10	Volume of liquid in type 4 vessel, ml
V1HL	Hot layer volume in previous time step
VC	Ceiling volume x A1 for concrete decomposition model
VEL	Volumetric flow of gases into the plume divided by combustion area, m/s
VENT	Mass of particles challenging the outlet filters, g
VF	Floor volume x A1 for concrete decomposition model
VIF	Flow from inlet filter, m/s
VOF	Flow from outlet filter, m/s
VOLCL	Cold layer volume, m^3
VOLHL	Hot layer volume, m^3
VOLRM	Fire compartment volume, m^3
VW	Wall volume exposed to hot layer x A1 for concrete decomposition model
WDT	Width of vessel type 2 and 3, m
WDW	Width of vessel type 4, ft
WR	Width of room, m
WRAD	Radiative heat from the fire to the cold layer, kJ
WRADF	Radiative heat flux from the flame to the wall, kW/m^2
WRADI	Radioactive particles on inlet filter from current time step, g
WRADIF	Radioactive particles on inlet filter, g
WRADO	Radioactive particles on outlet filter from current time step, g
WRADOF	Radioactive particles on outlet filter, g

TABLE D.1. (contd)

Name	Description
WSMI	Smoke deposited on inlet filter from current time step, g
WSMIF	Smoke deposited on inlet filter, g
WSMO	Smoke deposited on outlet filter from current time step, g
WSMOF	Smoke deposited on outlet filter, g
WSMOKE	Smoke mass in the hot layer, g
WTOT1	Total loading on inlet filters from smoke and radioactive particles, g
WTOT2	Same as WTOT1, but for outlet filters, g
XCEIL	Ceiling thickness, m
XFLOOR	Floor thickness, m
XWALL	Wall Thickness, m
ZETA	Density of air minus water vapor/Density of air plus water vapor above type 4 vessel
ZFIRE	Fire elevation above floor, m
ZFLAME	Flame height, m
ZHL	Hot layer thickness, m
ZIF	Elevation of midpoint of inlet vent, m
ZM	Height of cold layer, m
ZOF	Elevation of midpoint of outlet vent, m
ZPL	Plume height, m
ZR	Room height, m
ZTEST1	Change in pressure across inlet filter, atm
ZTEST2	Elevation of inlet filter minus height of cold layer, m
ZTEST3	Height of cold layer minus elevation of outlet filter, m
ZTEST4	Fire elevation minus cold layer height, m
ZTEST5	Hot/cold layer interface minus fire elevation, m
ZTEST6	Hot/cold layer interface minus center line of exhaust ventilation, m
ZW	Distance between wall nodes, m (vertical)
ZZ	Room height minus (elevation of fire and flame height)

TABLE D.2. Dimensioned Variables

Name	Description
A	Mass of particles in hot layer in current time step, g
AO	Mass of particles in hot layer in previous time step, g
AFLOSS	Mass of particles depleted from fire compartment by mechanism of release, g
ALOSS	Total mass of particles depleted from hot layer by all mechanisms, g
ARBL	Boiling area of type 4 vessels, m^2
AREC	Burning surface area of combustibles, m^2
ARER	Equipment area exposed to flame radiant heat transfer, m^2
ARHT	Equipment area exposed to heat transfer, m^2
B	Mass of particles in cold layer in current time step, g
BO	Mass of particles in cold layer in previous time step, g
BLOSS	Total mass of particles depleted from cold layer by all mechanisms, g
BRATE	Mass burn rate, g/s
CMASS	Mass of particles depleted onto ceiling, g
COND	Thermal conductivity of construction material, kJ/m s K
CONDM	Slope of change in thermal conductivity with temperature, kJ/m
CPCA	Heat capacity of construction material, kJ/kg K
CPCAM	Slope of change in heat capacity with temperature, kJ/kg
DFP	Equivalent diameter of alternate flow path, m
DPART	Average particle size for bins, micron
EMIS	Emissivity of construction material
EQ	Heat transfered to equipment, kJ
FAIL2	Equals 1 if type 2 vessel fails
FAIL3	Equals 1 if type 3 vessel fails
FMASS	Mass of particles depleted onto floor, g
FPICL	Flow into cold layer from alternate flow paths, m^3/s
FPIHL	Flow into hot layer from alternate flow paths, m^3/s
FPOCL	Flow out of cold layer to alternate flow paths, m^3/s
FPOHL	Flow out of hot layer to alternate flow paths, m^3/s
FRAC	Fraction of total loss attributed to each depletion mechanism for each bin size
FRACC	Fraction of particles depleted during current time step that deplete onto ceiling
FRACF	Same as FRACC, but for floor
FRACW	Same as FRACC, but for wall
FUEL	Mass loading of combustibles, g
GCH4	Weight of methane generated per materials for each time step, g
GCO1	Same as GCH4, but for carbon monoxide, g
GCO2	Same as GCH4, but for carbon dioxide, g
GH2O	Same as GCH4, but for water vapor, g
GHCL	Same as GCH4, but for hydrochloric acid, g
GRPART	Mass rate of particles generated in current time step, g/s
HEATC	Net heat of complete combustion, kJ/g
HEATV	Heat required to generate a unit mass of vapor, kJ/g

TABLE D.2. (contd)

Name	Description
HEQ	Vessel height exposed to flame
HFP	Elevation of alternate flow path above floor, m
HTF	Base height of vessel above floor, m
MASS	Mass burned from each fuel during each time step, g
MATERE	Construction material of specified vessel
MJE	Maximum number of each type of vessel
NBO	Indicates use of autoignition energy option
NRAD	Number of inputs to each radioactive release mechanisms
OFUEL	Original mass loading of combustibles, g
OKFHL	Equals 1 if alternate flow path is in the hot layer
OKFP	Equals 1 if alternate flow path is opened
OKPFI	Equals 1 if flow is from alternate flow paths into compartment
OKPFO	Equals 1 if flow is out of compartment through alternate flow paths
OUTVEN	Mass of particles that escape out the vent, g
PDEN	Theoretical density of powder involved in powder pressurized release, g/m^3
PF2	Failure pressure of vessel type 2, atm
PF3	Failure pressure of vessel type 3, atm
PFP	Initial pressure on other side of alternate flow path, atm
PI2	Internal pressure of type 2 equipment, atm
PI21	Initial internal pressure of type 2 equipment, atm
PI3	Internal pressure of type 3 equipment, atm
QACT	Total heat release from burning during each time step, kJ
QCHEAT	Energy at which combustible auto ignites, kJ/m
QCON	Convective fraction of QACT, kJ
QE1	Heat transferred to equipment type 1, kW/m^2
QE2	Heat transferred to equipment type 2, kW/m^2
QE3	Heat transferred to equipment type 3, kW/m^2
QE4	Heat transferred to equipment type 4, kW/m^2
QFC	Convective heat flux from flame to fuel, kW/m^2
QFRR	Radiative heat flux from flame to fuel, kW/m^2
QI2	Heat transfer inside vessel type 2, kW/m^2
QI3	Heat transfer inside vessel type 3, kW/m^2
QMR	Mass rate of radioactive materials in each size bin, g/s
QRAD	Radiative fraction of QACT, kJ
QRAD1	Mass of radioactive material for release mechanism 1, g
QRAD2	Same as QRAD1, but for mechanism 2, g
QRAD3	Same as QRAD1, but for mechanism 3, g
QRAD4	Same as QRAD1, but for mechanism 4, g
QRAD5	Same as QRAD1, but for mechanism 5, g
QRAD6	Same as QRAD1, but for mechanism 6, g
QRAD7	Same as QRAD1, but for mechanism 7, g
QRR	Fuel material surface reradiation, kW/m^2
QWA	Convective heat transfer to the wall, kW/m^2
RBOIL	Boiling rate of liquid in vessel type 4, ml/min
RHOO	Density of construction material, kg/m^3
SMOK	Weight of smoke generated per materials each time step, g

TABLE D.2. (contd)

Name	Description
SMSZ	Fraction of smoke particles in each bin
SQ	Size of individual pyrophoric metal pieces, g
TBCL	Time the hot layer starts heat transfer to equipment, s
TBURN	Maximum burning time based on amount of fuel and burn rate, s
TC	Temperature of ceiling nodes, K
TDIFC	Thermal diffusivity of ceiling, m^2/s
TDIFF	Thermal diffusivity of floor, m^2/s
TDIFW	Thermal diffusivity of wall, m^2/s
TE1	Temperature outside vessel type 1, K
TE2	Temperature outside vessel type 2, K
TE3	Temperature outside vessel type 3, K
TE4	Temperature outside vessel type 4, K
TEND	Time at which fuel is burned up, s
TF	Temperature of floor nodes, K
TFP	Time alternate flow path develops, s
TI2	Initial temperature inside vessel type 2, K
TI3	Initial temperature inside vessel type 3, K
TL	Initial temperature of liquid in vessel type 4, K
TSTART	Time at which fuel starts burning, s
TW	Temperature of wall nodes, K
VEMASS	Mass of particles that deplete onto the vent, g
VGAS2	Volume of gas above powder for type 2 vessel, m^3
VGAS3	Volume of gas above liquid for type 3 vessel, m^3
VOL	Volume of liquid in type 4 vessel, m^3
VOLP	Volume of type 3 container, m^3
VPWD	Volume of powder in type 2 vessel, m^3
WAMASS	Mass of particles depleted onto wall, g
WD	Vessel width exposed to flame, m
WFC	Weight fraction of carbon in fuel
WFCL	Weight fraction of chlorine in fuel
WFH	Weight fraction of hydrogen in fuel
WFO	Weight fraction of oxygen in fuel
WH2O2	Moisture content of powder in type 2 vessel, g H_2O
WH2O3	Weight of liquid in type 3 vessel, g
WMASS	Weight of vessel when empty, kg
XA	Combustion efficiency
XC	Convective fraction of XA
XMAX1	Cumulative amount of radioactive powder made airborne from burning contaminated combustible solids, g
XMAX2	Same as XMAX1, but for air dried nitrate instead of powder, g
XMAX3	Same as XMAX1, but for nitrate solution instead of powder, g
XR	Radiative fraction of XA
YCC	Fraction of CO_2 escaped from heated concrete ceiling
YCF	Same as YCC, but for floor
YCW	Same as YCC, but for wall
YEC	Fraction of evaporable water escaped from heated concrete ceiling
YEF	Same as YEC, but for floor

TABLE D.2. (contd)

Name	Description
YEW	Same as YEC, but for wall
YFCH4	Fractional yield of methane
YFCO1	Fractional yield of carbon monoxide
YFCO2	Fractional yield of carbon dioxide
YFH2O	Fractional yield of water vapor
YFHCL	Fractional yield of hydrochloric acid
YHC	Fraction of chemically bonded water escaped from heated concrete ceiling
YHF	Same as YHC, but for floor
YHW	Same as YHC, but for wall
YSMOK	Fractional yield of smoke
ZCL	Midpoint of equipment height above floor, m

APPENDIX E

OUTPUT FILES FROM PROBLEM ONE

TABLE E.1. PRINT.DAT File from Problem One

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                                  OUTPUT FOR COMPARTMENT EFFECTS

          COMPARTMENT    OXYGEN    HOT LAYER   VOLUMETRIC FLOW RATE    HOT LAYER    MASS BURN   HEAT GEN.   HEAT LOSS    HEAT TO
  TIME     PRESSURE      CONC.     THICKNESS     INLET      OUTLET    TEMPERATURE     RATE       BY FIRE    TO WALLS    FIRE GAS
( SEC )    ( ATM )    (VOL FRACT)    ( M )    ( M**3/S )  ( M**3/S )     ( F )      ( G/S )      ( KW )      ( KW )      ( KW )
-----------------------------------------------------------------------------------------------------------------------------------

   0.00     0.9950      0.2100      0.0000      1.5000     -1.5000      76.4000      0.0000      0.0000      0.0000      0.0000
  20.00     0.9954      0.2100      0.4032      1.3815     -1.6185     115.3005     10.5429    359.7645   -344.5267     15.2378
  40.00     0.9953      0.2100      0.7918      1.3966     -1.6034     112.2768     10.5414    359.7131   -334.4408     25.2722
  60.00     0.9953      0.2100      1.1342      1.4002     -1.5998     111.9967     10.5402    359.6726   -326.0364     33.6362
  80.00     0.9953      0.2100      1.4399      1.4003     -1.5997     112.5872     10.5392    359.6376   -319.4371     40.2005
 100.00     0.9954      0.2100      1.7348      1.3921     -1.6079     113.5621     10.5382    359.6062   -313.7714     45.8348
 120.00     0.9956      0.2100      2.0068      1.3317     -1.6683     112.1149      2.4308     21.3886    -36.0367    -14.6481
 140.00     0.9949      0.2100      2.1883      1.5156     -1.4844     108.0533      2.4313     21.3928    -35.8402    -14.4474
 160.00     0.9949      0.2100      2.3644      1.5158     -1.4842     104.7199      2.4314     21.3944    -34.5921    -13.1978
 180.00     0.9949      0.2100      2.5359      1.5150     -1.4850     101.9597      2.4315     21.3953    -33.1885    -11.7932
 200.00     0.9950      0.2100      2.7035      1.5139     -1.4861      99.6523      2.4316     21.3959    -31.8250    -10.4291
 220.00     0.9950      0.2100      2.8690      1.5120     -1.4880      97.7054      2.4317     21.3964    -30.5638     -9.1674
 240.00     0.9950      0.2100      3.0347      1.5104     -1.4896      96.0493      2.4317     21.3968    -29.4319     -8.0351
 260.00     0.9949      0.2100      3.1986      1.5249     -1.4751      94.4560      1.5307      8.7864    -23.3760    -14.5896
 280.00     0.9949      0.2100      3.3578      1.5187     -1.4813      92.8679      1.5307      8.7865    -21.9379    -13.1514
 300.00     1.0089      0.2046      3.5204     -2.6842     -5.6842     106.1561    162.9438   3011.3425  -1803.8683   1207.4742
 320.00     1.0012      0.1983      3.8534     -0.3350     -3.3513     160.8076    163.5692   3023.8186  -1887.4059   1136.4127
 340.00     1.0084      0.1917      4.0000     -1.9335     -3.5355     244.6716    156.0263   2873.3374   -894.4583   1978.8792
 360.00     1.0102      0.1843      4.0000     -1.5290     -2.1880     333.2971    162.2772   2998.0435  -1702.0354   1296.0081
 380.00     1.0010      0.1767      4.0000     -0.1180     -0.8657     376.4951    102.0798   2418.0659  -2131.2954    286.7705
 400.00     1.0001      0.1693      4.0000     -0.0064     -0.6889     391.8969    102.6818   2432.3267  -2222.4307    209.8960
 420.00     0.9996      0.1618      4.0000      0.0409     -0.5935     403.3500    103.0873   2441.9312  -2279.1914    162.7397
 440.00     0.9995      0.1544      4.0000      0.0613     -0.5324     412.2040    103.3489   2448.1277  -2312.1697    135.9580
 460.00     0.9984      0.1470      4.0000      0.1823     -0.4379     417.3847    100.1799   2304.3577  -2318.2805    -13.9229
 480.00     0.9948      0.1416      4.0000      0.5976     -0.2393     402.8062     91.1003   1943.5426  -2105.7485   -162.2059
 500.00     0.9945      0.1377      4.0000      0.6326     -0.2166     383.6743     83.9528   1690.6040  -1853.5145   -162.9105
 520.00     0.9948      0.1344      4.0000      0.6009     -0.2215     366.3522     78.0900   1496.5461  -1642.6213   -146.0752
 540.00     0.9951      0.1317      4.0000      0.5637     -0.2272     351.2458     73.1433   1341.2605  -1470.7566   -129.5061
 560.00     0.9954      0.1293      4.0000      0.5293     -0.2305     338.0438     68.8902   1213.8297  -1329.1017   -115.2720
 580.00     0.9957      0.1272      4.0000      0.4982     -0.2313     326.4149     65.1799   1107.2998  -1210.6145   -103.3147
 600.00     0.9959      0.1253      4.0000      0.4703     -0.2302     316.0846     61.9039   1016.8616  -1110.1416    -93.2800
 620.00     0.9962      0.1236      4.0000      0.4450     -0.2274     306.8351     58.9819    939.0893  -1023.9113    -84.8220
 640.00     0.9964      0.1221      4.0000      0.4220     -0.2235     298.4929     56.3526    871.4600   -949.1132    -77.6532
 660.00     0.9965      0.1207      4.0000      0.4011     -0.2187     290.9198     53.9684    812.0829   -883.6204    -71.5375
 680.00     0.9967      0.1194      4.0000      0.3818     -0.2133     284.0035     51.7922    759.5112   -825.7933    -66.2821
 700.00     0.9969      0.1182      4.0000      0.3641     -0.2075     277.6532     49.7940    712.6201   -774.3571    -61.7370
 720.00     0.9970      0.1171      4.0000      0.3477     -0.2015     271.7943     47.9497    670.5220   -728.3005    -57.7785
 740.00     0.9971      0.1161      4.0000      0.3326     -0.1955     266.3646     46.2397    632.5088   -686.8120    -54.3032
 760.00     0.9972      0.1151      4.0000      0.3185     -0.1894     261.3131     44.6478    598.0068   -649.2415    -51.2346
 780.00     0.9974      0.1142      4.0000      0.3054     -0.1834     256.5983     43.1603    566.5473   -615.0513    -48.5040
 800.00     0.9975      0.1134      4.0000      0.2932     -0.1775     252.1777     41.7659    537.7449   -583.8048    -46.0599
 820.00     0.9976      0.1126      4.0000      0.2818     -0.1718     248.0261     40.4550    511.2757   -555.1332    -43.8575
 840.00     0.9977      0.1119      4.0000      0.2711     -0.1662     244.1151     39.2194    486.8686   -528.7316    -41.8630
 860.00     0.9977      0.1111      4.0000      0.2611     -0.1609     240.4213     38.0519    464.2953   -504.3385    -40.0432
 880.00     0.9978      0.1105      4.0000      0.2517     -0.1557     236.9252     36.9464    443.3596   -481.7365    -38.3769
ALL COMBUSTIBLE MATERIALS WERE CONSUMED BY:  890.0000 SEC

 900.00     0.9909      0.1114      4.0000      1.0510     -0.0177     222.0959      0.0000      0.0000   -392.3703   -392.3703
 920.00     0.9924      0.1146      4.0000      0.8778     -0.0462     201.6803      0.0000      0.0000   -258.5367   -258.5367
 940.00     0.9943      0.1169      4.0000      0.6600     -0.0807     188.1795      0.0000      0.0000   -183.4765   -183.4765
 960.00     0.9954      0.1186      4.0000      0.5269     -0.0999     178.5825      0.0000      0.0000   -137.2334   -137.2334
 980.00     0.9962      0.1199      4.0000      0.4391     -0.1107     171.3725      0.0000      0.0000   -106.6377   -106.6377
1000.00     0.9967      0.1211      4.0000      0.3776     -0.1168     165.7341      0.0000      0.0000    -85.3472    -85.3472
```

TABLE E.2. SMKCL.DAT File from Problem One

```
                                                      OUTPUT FOR SMOKE SOURCE TERM

MASS IN COLD LAYER, G
            AIRBORNE     HOT LAYER      TOTAL      AIRBORNE    FRACTION OF LOSSES DUE TO:
   TIME,S     AT TO    (+) SETTLING(-) LOSSES    (=) AT T     SETTLING  OUT VENT  PLUME GAS
     0.00    0.00E+00    0.00E+00    0.00E+00    0.00E+00      0.0000    0.0000    0.0000
    20.00    0.53E-01    0.64E-02    0.70E-03    0.58E-01      0.0117    0.3576    0.6306
    40.00    0.11E+00    0.67E-02    0.15E-02    0.11E+00      0.0125    0.3977    0.5898
    60.00    0.16E+00    0.72E-02    0.23E-02    0.16E+00      0.0133    0.4390    0.5477
    80.00    0.21E+00    0.76E-02    0.30E-02    0.21E+00      0.0139    0.4713    0.5148
   100.00    0.25E+00    0.77E-02    0.39E-02    0.25E+00      0.0151    0.4720    0.5129
   120.00    0.29E+00    0.78E-02    0.31E-02    0.29E+00      0.0247    0.8295    0.1457
   140.00    0.33E+00    0.74E-02    0.35E-02    0.34E+00      0.0280    0.8369    0.1350
   160.00    0.37E+00    0.70E-02    0.41E-02    0.37E+00      0.0288    0.8598    0.1115
   180.00    0.39E+00    0.68E-02    0.48E-02    0.39E+00      0.0293    0.8808    0.0898
   200.00    0.41E+00    0.65E-02    0.55E-02    0.41E+00      0.0300    0.8996    0.0704
   220.00    0.41E+00    0.63E-02    0.64E-02    0.41E+00      0.0301    0.9006    0.0693
   240.00    0.41E+00    0.61E-02    0.73E-02    0.41E+00      0.0300    0.9007    0.0692
   260.00    0.39E+00    0.60E-02    0.80E-02    0.39E+00      0.0316    0.9448    0.0235
   280.00    0.36E+00    0.58E-02    0.93E-02    0.36E+00      0.0315    0.9451    0.0235
   300.00    0.26E+00    0.91E-02    0.80E-01    0.19E+00      0.0030    0.3471    0.6499
   320.00    0.36E-01    0.29E-01    0.34E-01    0.31E-01      0.0035    0.2373    0.7592
ALL COMBUSTIBLE MATERIALS WERE CONSUMED BY:  890.0000 SEC

TIME EXCEEDS USER SPECIFIED TIME AT: 1000.0000 SEC
```

TABLE E.3. SMKHL.DAT File from Problem One

```
                                       OUTPUT FOR SMOKE SOURCE TERM

MASS IN HOT LAYER, G
            AIRBORNE    GENERATED     ENTRAINED      TOTAL       AIRBORNE    FRACTION OF LOSSES DUE TO:
   TIME,S    AT T0 (+)  BY FIRE (+)  W PLUME (-)  LOSSES  (=)  AT T         SETTLING  B. DIFFUS THERMOPH. DIFFUSIO.  OUT VENT
     0.00   0.00E+00     0.00E+00     0.00E+00     0.00E+00     0.00E+00     0.0000    0.0000    0.0000    0.0000    0.0000
    20.00   0.15E+02     0.17E+01     0.44E-03     0.90E-02     0.17E+02     0.7050    0.2901    0.0050    0.0000    0.0000
    40.00   0.32E+02     0.17E+01     0.86E-03     0.98E-02     0.33E+02     0.6885    0.3066    0.0048    0.0000    0.0000
    60.00   0.48E+02     0.17E+01     0.12E-02     0.11E-01     0.50E+02     0.6678    0.3273    0.0049    0.0000    0.0000
    80.00   0.65E+02     0.17E+01     0.16E-02     0.12E-01     0.67E+02     0.6411    0.3538    0.0051    0.0000    0.0000
   100.00   0.82E+02     0.17E+01     0.20E-02     0.12E-01     0.83E+02     0.6347    0.3603    0.0050    0.0000    0.0000
   120.00   0.95E+02     0.27E+00     0.45E-03     0.13E-01     0.96E+02     0.6267    0.3721    0.0012    0.0000    0.0000
   140.00   0.98E+02     0.27E+00     0.47E-03     0.12E-01     0.98E+02     0.6287    0.3701    0.0012    0.0000    0.0000
   160.00   0.10E+03     0.27E+00     0.46E-03     0.11E-01     0.10E+03     0.6297    0.3693    0.0011    0.0000    0.0000
   180.00   0.10E+03     0.27E+00     0.43E-03     0.11E-01     0.10E+03     0.6310    0.3680    0.0010    0.0000    0.0000
   200.00   0.11E+03     0.27E+00     0.39E-03     0.10E-01     0.11E+03     0.6338    0.3653    0.0010    0.0000    0.0000
   220.00   0.11E+03     0.27E+00     0.44E-03     0.99E-02     0.11E+03     0.6362    0.3629    0.0009    0.0000    0.0000
   240.00   0.11E+03     0.27E+00     0.51E-03     0.96E-02     0.11E+03     0.6362    0.3629    0.0009    0.0000    0.0000
   260.00   0.11E+03     0.26E+00     0.19E-03     0.94E-02     0.11E+03     0.6345    0.3647    0.0008    0.0000    0.0000
   280.00   0.12E+03     0.26E+00     0.22E-03     0.91E-02     0.12E+03     0.6404    0.3589    0.0007    0.0000    0.0000
   300.00   0.17E+03     0.52E+02     0.52E-01     0.16E+01     0.22E+03     0.0058    0.0035    0.0003    0.0000    0.9905
   320.00   0.69E+03     0.52E+02     0.25E-01     0.71E+00     0.74E+03     0.0403    0.0418    0.0027    0.0000    0.9152
   340.00   0.11E+04     0.51E+02     0.00E+00     0.17E+02     0.12E+04     0.0025    0.0051    0.0003    0.0000    0.9922
   360.00   0.15E+04     0.52E+02     0.00E+00     0.15E+02     0.15E+04     0.0033    0.0081    0.0008    0.0000    0.9878
   380.00   0.17E+04     0.43E+01     0.00E+00     0.46E+01     0.17E+04     0.0117    0.0299    0.0039    0.0000    0.9545
   400.00   0.17E+04     0.43E+01     0.00E+00     0.33E+01     0.17E+04     0.0161    0.0414    0.0058    0.0000    0.9367
   420.00   0.17E+04     0.43E+01     0.00E+00     0.29E+01     0.17E+04     0.0185    0.0480    0.0070    0.0000    0.9265
   440.00   0.17E+04     0.43E+01     0.00E+00     0.26E+01     0.17E+04     0.0204    0.0530    0.0079    0.0000    0.9187
   460.00   0.17E+04     0.69E+01     0.00E+00     0.22E+01     0.17E+04     0.0244    0.0631    0.0096    0.0000    0.9030
   480.00   0.18E+04     0.12E+02     0.00E+00     0.14E+01     0.18E+04     0.0419    0.1057    0.0146    0.0000    0.8378
   500.00   0.19E+04     0.15E+02     0.00E+00     0.14E+01     0.20E+04     0.0465    0.1136    0.0137    0.0000    0.8262
   520.00   0.21E+04     0.17E+02     0.00E+00     0.15E+01     0.21E+04     0.0464    0.1104    0.0117    0.0000    0.8315
   540.00   0.23E+04     0.18E+02     0.00E+00     0.16E+01     0.23E+04     0.0462    0.1070    0.0101    0.0000    0.8367
   560.00   0.24E+04     0.19E+02     0.00E+00     0.18E+01     0.24E+04     0.0463    0.1047    0.0089    0.0000    0.8401
   580.00   0.26E+04     0.20E+02     0.00E+00     0.19E+01     0.26E+04     0.0468    0.1035    0.0079    0.0000    0.8418
   600.00   0.28E+04     0.20E+02     0.00E+00     0.20E+01     0.28E+04     0.0475    0.1030    0.0072    0.0000    0.8422
   620.00   0.30E+04     0.21E+02     0.00E+00     0.21E+01     0.30E+04     0.0485    0.1032    0.0066    0.0000    0.8416
   640.00   0.32E+04     0.21E+02     0.00E+00     0.22E+01     0.32E+04     0.0497    0.1039    0.0062    0.0000    0.8402
   660.00   0.33E+04     0.21E+02     0.00E+00     0.23E+01     0.34E+04     0.0511    0.1050    0.0058    0.0000    0.8382
   680.00   0.35E+04     0.21E+02     0.00E+00     0.24E+01     0.35E+04     0.0526    0.1064    0.0055    0.0000    0.8355
   700.00   0.37E+04     0.20E+02     0.00E+00     0.24E+01     0.37E+04     0.0542    0.1081    0.0052    0.0000    0.8325
   720.00   0.39E+04     0.20E+02     0.00E+00     0.25E+01     0.39E+04     0.0559    0.1099    0.0050    0.0000    0.8291
   740.00   0.41E+04     0.20E+02     0.00E+00     0.25E+01     0.41E+04     0.0577    0.1120    0.0048    0.0000    0.8255
   760.00   0.42E+04     0.20E+02     0.00E+00     0.26E+01     0.42E+04     0.0596    0.1142    0.0046    0.0000    0.8215
   780.00   0.44E+04     0.20E+02     0.00E+00     0.26E+01     0.44E+04     0.0616    0.1165    0.0045    0.0000    0.8174
   800.00   0.46E+04     0.20E+02     0.00E+00     0.26E+01     0.46E+04     0.0636    0.1189    0.0043    0.0000    0.8132
   820.00   0.47E+04     0.19E+02     0.00E+00     0.27E+01     0.48E+04     0.0656    0.1214    0.0042    0.0000    0.8088
   840.00   0.49E+04     0.19E+02     0.00E+00     0.27E+01     0.49E+04     0.0678    0.1239    0.0041    0.0000    0.8043
   860.00   0.51E+04     0.19E+02     0.00E+00     0.27E+01     0.51E+04     0.0699    0.1265    0.0040    0.0000    0.7997
   880.00   0.52E+04     0.19E+02     0.00E+00     0.27E+01     0.52E+04     0.0720    0.1290    0.0039    0.0000    0.7950
 ALL COMBUSTIBLE MATERIALS WERE CONSUMED BY:  890.0000 SEC

   900.00   0.53E+04     0.00E+00     0.00E+00     0.80E+00     0.53E+04     0.2519    0.4260    0.0108    0.0000    0.3113
   920.00   0.53E+04     0.00E+00     0.00E+00     0.12E+01     0.53E+04     0.1743    0.2705    0.0047    0.0000    0.5505
   940.00   0.53E+04     0.00E+00     0.00E+00     0.16E+01     0.53E+04     0.1263    0.1835    0.0023    0.0000    0.6879
   960.00   0.53E+04     0.00E+00     0.00E+00     0.19E+01     0.53E+04     0.1103    0.1519    0.0015    0.0000    0.7363
   980.00   0.53E+04     0.00E+00     0.00E+00     0.20E+01     0.53E+04     0.1034    0.1362    0.0011    0.0000    0.7593
  1000.00   0.52E+04     0.00E+00     0.00E+00     0.21E+01     0.52E+04     0.1003    0.1272    0.0008    0.0000    0.7717

 TIME EXCEEDS USER SPECIFIED TIME AT: 1000.0000 SEC
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TABLE E.4. RSTCL.DAT File from Problem One

```
                                                 OUTPUT FOR RADIOACTIVE SOURCE TERM

MASS IN COLD LAYER, G
            AIRBORNE    HOT LAYER     TOTAL     AIRBORNE   FRACTION OF LOSSES DUE TO:
   TIME,S      AT TO   (+) SETTLING(-) LOSSES  (=) AT T    SETTLING  OUT VENT  PLUME GAS
     0.00    0.00E+00   0.00E+00   0.00E+00   0.00E+00   0.0000    0.0000    0.0000
    20.00    0.23E-03   0.29E-04   0.37E-05   0.26E-03   0.1328    0.3138    0.5534
    40.00    0.48E-03   0.31E-04   0.75E-05   0.50E-03   0.1453    0.3442    0.5105
    60.00    0.70E-03   0.31E-04   0.11E-04   0.72E-03   0.1545    0.3762    0.4693
    80.00    0.88E-03   0.32E-04   0.15E-04   0.90E-03   0.1578    0.4025    0.4397
   100.00    0.10E-02   0.32E-04   0.19E-04   0.10E-02   0.1521    0.4064    0.4416
   120.00    0.12E-02   0.31E-04   0.16E-04   0.12E-02   0.2262    0.6582    0.1156
   140.00    0.13E-02   0.29E-04   0.17E-04   0.13E-02   0.2424    0.6523    0.1053
   160.00    0.14E-02   0.27E-04   0.20E-04   0.14E-02   0.2418    0.6711    0.0870
   180.00    0.14E-02   0.25E-04   0.22E-04   0.14E-02   0.2412    0.6886    0.0702
   200.00    0.14E-02   0.24E-04   0.25E-04   0.14E-02   0.2402    0.7046    0.0552
   220.00    0.14E-02   0.23E-04   0.28E-04   0.14E-02   0.2353    0.7101    0.0546
   240.00    0.14E-02   0.22E-04   0.31E-04   0.13E-02   0.2300    0.7150    0.0550
   260.00    0.12E-02   0.21E-04   0.32E-04   0.12E-02   0.2349    0.7465    0.0186
   280.00    0.11E-02   0.20E-04   0.36E-04   0.11E-02   0.2277    0.7536    0.0187
   300.00    0.11E-02   0.71E-03   0.45E-03   0.13E-02   0.0374    0.3351    0.6275
   320.00    0.14E-02   0.12E-02   0.14E-02   0.12E-02   0.0884    0.2171    0.6946
ALL COMBUSTIBLE MATERIALS WERE CONSUMED BY:  890.0000 SEC

TIME EXCEEDS USER SPECIFIED TIME AT: 1000.0000 SEC
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TABLE E.5. RSTHL.DAT File from Problem One

```
                                      OUTPUT FOR RADIOACTIVE SOURCE TERM

MASS IN HOT LAYER, G
           AIRBORNE   GENERATED   ENTRAINED     TOTAL     AIRBORNE    FRACTION OF LOSSES DUE TO:
  TIME,S   AT T0 (+)  BY FIRE (+) W PLUME (-) LOSSES  (=) AT T        SETTLING  B. DIFFUS THERMOPH. DIFFUSIO. OUT VENT
     0.00   0.00E+00    0.00E+00    0.00E+00    0.00E+00    0.00E+00     0.0000    0.0000    0.0000    0.0000    0.0000
    20.00   0.42E-01    0.47E-02    0.20E-05    0.42E-04    0.47E-01     0.6859    0.3111    0.0030    0.0000    0.0000
    40.00   0.89E-01    0.47E-02    0.38E-05    0.46E-04    0.94E-01     0.6704    0.3267    0.0029    0.0000    0.0000
    60.00   0.13E+00    0.43E-02    0.53E-05    0.48E-04    0.14E+00     0.6486    0.3484    0.0030    0.0000    0.0000
    80.00   0.18E+00    0.43E-02    0.65E-05    0.51E-04    0.18E+00     0.6244    0.3724    0.0032    0.0000    0.0000
   100.00   0.22E+00    0.43E-02    0.85E-05    0.52E-04    0.22E+00     0.6166    0.3802    0.0032    0.0000    0.0000
   120.00   0.25E+00    0.13E-04    0.18E-05    0.51E-04    0.25E+00     0.6062    0.3930    0.0008    0.0000    0.0000
   140.00   0.25E+00    0.13E-04    0.18E-05    0.47E-04    0.25E+00     0.6093    0.3900    0.0007    0.0000    0.0000
   160.00   0.25E+00    0.13E-04    0.17E-05    0.44E-04    0.25E+00     0.6126    0.3867    0.0007    0.0000    0.0000
   180.00   0.25E+00    0.13E-04    0.16E-05    0.41E-04    0.25E+00     0.6159    0.3835    0.0006    0.0000    0.0000
   200.00   0.25E+00    0.13E-04    0.14E-05    0.38E-04    0.25E+00     0.6190    0.3804    0.0006    0.0000    0.0000
   220.00   0.25E+00    0.13E-04    0.15E-05    0.36E-04    0.25E+00     0.6220    0.3774    0.0006    0.0000    0.0000
   240.00   0.25E+00    0.13E-04    0.17E-05    0.34E-04    0.25E+00     0.6247    0.3748    0.0005    0.0000    0.0000
   260.00   0.25E+00    0.13E-04    0.60E-06    0.33E-04    0.25E+00     0.6281    0.3714    0.0005    0.0000    0.0000
   280.00   0.25E+00    0.13E-04    0.67E-06    0.31E-04    0.25E+00     0.6326    0.3670    0.0004    0.0000    0.0000
   300.00   0.16E+01    0.18E-01    0.28E-03    0.14E-01    0.16E+01     0.0518    0.0024    0.0003    0.0000    0.9455
   320.00   0.18E+01    0.18E-01    0.98E-03    0.29E-02    0.18E+01     0.4165    0.0175    0.0017    0.0000    0.5644
   340.00   0.18E+01    0.17E-01    0.00E+00    0.27E-01    0.18E+01     0.0527    0.0031    0.0002    0.0000    0.9439
   360.00   0.17E+01    0.18E-01    0.00E+00    0.19E-01    0.17E+01     0.0850    0.0045    0.0007    0.0000    0.9098
   380.00   0.17E+01    0.15E-05    0.00E+00    0.62E-02    0.17E+01     0.2659    0.0131    0.0030    0.0000    0.7180
   400.00   0.16E+01    0.17E-05    0.00E+00    0.47E-02    0.16E+01     0.3292    0.0169    0.0040    0.0000    0.6498
   420.00   0.16E+01    0.18E-05    0.00E+00    0.41E-02    0.16E+01     0.3568    0.0190    0.0047    0.0000    0.6195
   440.00   0.16E+01    0.19E-05    0.00E+00    0.37E-02    0.16E+01     0.3744    0.0206    0.0052    0.0000    0.5998
   460.00   0.15E+01    0.19E-05    0.00E+00    0.32E-02    0.15E+01     0.4129    0.0234    0.0059    0.0000    0.5578
   480.00   0.15E+01    0.18E-05    0.00E+00    0.23E-02    0.15E+01     0.5507    0.0312    0.0072    0.0000    0.4109
   500.00   0.15E+01    0.16E-05    0.00E+00    0.22E-02    0.15E+01     0.5720    0.0324    0.0065    0.0000    0.3891
   520.00   0.15E+01    0.14E-05    0.00E+00    0.22E-02    0.15E+01     0.5654    0.0321    0.0056    0.0000    0.3969
   540.00   0.14E+01    0.13E-05    0.00E+00    0.21E-02    0.14E+01     0.5574    0.0318    0.0049    0.0000    0.4059
   560.00   0.14E+01    0.12E-05    0.00E+00    0.21E-02    0.14E+01     0.5513    0.0317    0.0044    0.0000    0.4126
   580.00   0.14E+01    0.11E-05    0.00E+00    0.20E-02    0.14E+01     0.5472    0.0318    0.0039    0.0000    0.4170
   600.00   0.14E+01    0.10E-05    0.00E+00    0.20E-02    0.14E+01     0.5447    0.0320    0.0036    0.0000    0.4197
   620.00   0.14E+01    0.97E-06    0.00E+00    0.19E-02    0.14E+01     0.5435    0.0324    0.0033    0.0000    0.4208
   640.00   0.13E+01    0.91E-06    0.00E+00    0.19E-02    0.13E+01     0.5432    0.0328    0.0031    0.0000    0.4209
   660.00   0.13E+01    0.86E-06    0.00E+00    0.18E-02    0.13E+01     0.5437    0.0333    0.0029    0.0000    0.4201
   680.00   0.13E+01    0.81E-06    0.00E+00    0.18E-02    0.13E+01     0.5447    0.0339    0.0028    0.0000    0.4186
   700.00   0.13E+01    0.77E-06    0.00E+00    0.17E-02    0.13E+01     0.5461    0.0346    0.0026    0.0000    0.4167
   720.00   0.13E+01    0.74E-06    0.00E+00    0.16E-02    0.13E+01     0.5478    0.0353    0.0025    0.0000    0.4144
   740.00   0.13E+01    0.70E-06    0.00E+00    0.16E-02    0.13E+01     0.5496    0.0361    0.0024    0.0000    0.4119
   760.00   0.12E+01    0.67E-06    0.00E+00    0.15E-02    0.12E+01     0.5516    0.0369    0.0023    0.0000    0.4092
   780.00   0.12E+01    0.65E-06    0.00E+00    0.15E-02    0.12E+01     0.5535    0.0378    0.0022    0.0000    0.4064
   800.00   0.12E+01    0.62E-06    0.00E+00    0.14E-02    0.12E+01     0.5555    0.0387    0.0022    0.0000    0.4037
   820.00   0.12E+01    0.60E-06    0.00E+00    0.14E-02    0.12E+01     0.5576    0.0396    0.0021    0.0000    0.4009
   840.00   0.12E+01    0.58E-06    0.00E+00    0.13E-02    0.12E+01     0.5593    0.0405    0.0020    0.0000    0.3981
   860.00   0.12E+01    0.56E-06    0.00E+00    0.13E-02    0.12E+01     0.5611    0.0415    0.0020    0.0000    0.3954
   880.00   0.12E+01    0.54E-06    0.00E+00    0.12E-02    0.12E+01     0.5628    0.0425    0.0019    0.0000    0.3928
ALL COMBUSTIBLE MATERIALS WERE CONSUMED BY:  890.0000 SEC

   900.00   0.11E+01    0.46E-06    0.00E+00    0.77E-03    0.11E+01     0.8647    0.0635    0.0024    0.0000    0.0694
   920.00   0.11E+01    0.37E-06    0.00E+00    0.84E-03    0.11E+01     0.7801    0.0542    0.0014    0.0000    0.1643
   940.00   0.11E+01    0.31E-06    0.00E+00    0.93E-03    0.11E+01     0.6937    0.0465    0.0009    0.0000    0.2589
   960.00   0.11E+01    0.28E-06    0.00E+00    0.97E-03    0.11E+01     0.6509    0.0427    0.0006    0.0000    0.3059
   980.00   0.11E+01    0.25E-06    0.00E+00    0.98E-03    0.11E+01     0.6264    0.0405    0.0005    0.0000    0.3327
  1000.00   0.11E+01    0.23E-06    0.00E+00    0.97E-03    0.11E+01     0.6109    0.0392    0.0004    0.0000    0.3495

TIME EXCEEDS USER SPECIFIED TIME AT: 1000.0000 SEC
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TABLE E.6. SSZCL.DAT File from Problem One

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                                      OUTPUT FOR SMOKE SOURCE TERM

MASS IN COLD LAYER, G
                                                   PARTICLE DIAMETER (MICRONS)
   TIME     0.100      0.173      0.387      0.592      0.794      0.995      1.480      3.460      7.750     14.140     20.000      TOTAL
    0.00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
   20.00 0.000E+00 0.274E-04 0.350E-03 0.992E-03 0.178E-02 0.219E-02 0.123E-01 0.405E-01 0.000E+00 0.000E+00 0.000E+00 0.582E-01
   40.00 0.000E+00 0.525E-04 0.674E-03 0.192E-02 0.344E-02 0.425E-02 0.239E-01 0.783E-01 0.000E+00 0.000E+00 0.000E+00 0.113E+00
   60.00 0.000E+00 0.760E-04 0.981E-03 0.279E-02 0.501E-02 0.619E-02 0.347E-01 0.114E+00 0.000E+00 0.000E+00 0.000E+00 0.164E+00
   80.00 0.000E+00 0.983E-04 0.127E-02 0.361E-02 0.647E-02 0.799E-02 0.449E-01 0.147E+00 0.000E+00 0.000E+00 0.000E+00 0.211E+00
  100.00 0.000E+00 0.120E-03 0.151E-02 0.433E-02 0.776E-02 0.958E-02 0.538E-01 0.176E+00 0.000E+00 0.000E+00 0.000E+00 0.253E+00
  120.00 0.000E+00 0.139E-03 0.174E-02 0.501E-02 0.898E-02 0.111E-01 0.623E-01 0.203E+00 0.000E+00 0.000E+00 0.000E+00 0.292E+00
  140.00 0.000E+00 0.160E-03 0.201E-02 0.578E-02 0.104E-01 0.128E-01 0.718E-01 0.234E+00 0.000E+00 0.000E+00 0.000E+00 0.337E+00
  160.00 0.000E+00 0.176E-03 0.222E-02 0.636E-02 0.114E-01 0.141E-01 0.791E-01 0.257E+00 0.000E+00 0.000E+00 0.000E+00 0.371E+00
  180.00 0.000E+00 0.188E-03 0.238E-02 0.678E-02 0.122E-01 0.150E-01 0.844E-01 0.273E+00 0.000E+00 0.000E+00 0.000E+00 0.394E+00
  200.00 0.000E+00 0.196E-03 0.245E-02 0.704E-02 0.127E-01 0.156E-01 0.877E-01 0.283E+00 0.000E+00 0.000E+00 0.000E+00 0.409E+00
  220.00 0.000E+00 0.196E-03 0.250E-02 0.711E-02 0.129E-01 0.158E-01 0.888E-01 0.286E+00 0.000E+00 0.000E+00 0.000E+00 0.413E+00
  240.00 0.000E+00 0.184E-03 0.247E-02 0.703E-02 0.127E-01 0.156E-01 0.874E-01 0.280E+00 0.000E+00 0.000E+00 0.000E+00 0.406E+00
  260.00 0.000E+00 0.180E-03 0.231E-02 0.677E-02 0.122E-01 0.150E-01 0.838E-01 0.268E+00 0.000E+00 0.000E+00 0.000E+00 0.388E+00
  280.00 0.000E+00 0.167E-03 0.215E-02 0.629E-02 0.114E-01 0.139E-01 0.779E-01 0.247E+00 0.000E+00 0.000E+00 0.000E+00 0.359E+00
  300.00 0.000E+00 0.858E-04 0.114E-02 0.332E-02 0.598E-02 0.733E-02 0.410E-01 0.130E+00 0.000E+00 0.000E+00 0.000E+00 0.188E+00
  320.00 0.000E+00 0.147E-04 0.185E-03 0.526E-03 0.949E-03 0.117E-02 0.658E-02 0.217E-01 0.000E+00 0.000E+00 0.000E+00 0.311E-01
ALL COMBUSTIBLE MATERIALS WERE CONSUMED BY:  890.0000 SEC

TIME EXCEEDS USER SPECIFIED TIME AT: 1000.0000 SEC
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TABLE E.7. SSZHL.DAT File from Problem One

```
                                   OUTPUT FOR SMOKE SOURCE TERM

MASS IN HOT LAYER, G
                                                   PARTICLE DIAMETER (MICRONS)
   TIME     0.100     0.173     0.387     0.592     0.794     0.995     1.480     3.460     7.760    14.140    20.000     TOTAL
   0.00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  20.00 0.000E+00 0.749E+00 0.192E+01 0.233E+01 0.233E+01 0.183E+01 0.466E+01 0.280E+01 0.000E+00 0.000E+00 0.000E+00 0.166E+02
  40.00 0.000E+00 0.150E+01 0.384E+01 0.467E+01 0.467E+01 0.367E+01 0.933E+01 0.560E+01 0.000E+00 0.000E+00 0.000E+00 0.333E+02
  60.00 0.000E+00 0.225E+01 0.575E+01 0.701E+01 0.701E+01 0.551E+01 0.140E+02 0.840E+01 0.000E+00 0.000E+00 0.000E+00 0.499E+02
  80.00 0.000E+00 0.300E+01 0.767E+01 0.934E+01 0.934E+01 0.734E+01 0.187E+02 0.112E+02 0.000E+00 0.000E+00 0.000E+00 0.666E+02
 100.00 0.000E+00 0.374E+01 0.959E+01 0.117E+02 0.117E+02 0.917E+01 0.233E+02 0.140E+02 0.000E+00 0.000E+00 0.000E+00 0.832E+02
 120.00 0.000E+00 0.430E+01 0.110E+02 0.134E+02 0.134E+02 0.105E+02 0.268E+02 0.161E+02 0.000E+00 0.000E+00 0.000E+00 0.956E+02
 140.00 0.000E+00 0.441E+01 0.113E+02 0.138E+02 0.138E+02 0.108E+02 0.275E+02 0.165E+02 0.000E+00 0.000E+00 0.000E+00 0.981E+02
 160.00 0.000E+00 0.453E+01 0.116E+02 0.141E+02 0.141E+02 0.111E+02 0.282E+02 0.169E+02 0.000E+00 0.000E+00 0.000E+00 0.101E+03
 180.00 0.000E+00 0.464E+01 0.119E+02 0.145E+02 0.145E+02 0.114E+02 0.290E+02 0.173E+02 0.000E+00 0.000E+00 0.000E+00 0.103E+03
 200.00 0.000E+00 0.476E+01 0.122E+02 0.149E+02 0.149E+02 0.117E+02 0.297E+02 0.177E+02 0.000E+00 0.000E+00 0.000E+00 0.106E+03
 220.00 0.000E+00 0.487E+01 0.125E+02 0.152E+02 0.152E+02 0.120E+02 0.304E+02 0.181E+02 0.000E+00 0.000E+00 0.000E+00 0.108E+03
 240.00 0.000E+00 0.498E+01 0.128E+02 0.156E+02 0.156E+02 0.123E+02 0.311E+02 0.185E+02 0.000E+00 0.000E+00 0.000E+00 0.111E+03
 260.00 0.000E+00 0.510E+01 0.131E+02 0.160E+02 0.160E+02 0.125E+02 0.319E+02 0.189E+02 0.000E+00 0.000E+00 0.000E+00 0.113E+03
 280.00 0.000E+00 0.521E+01 0.134E+02 0.163E+02 0.163E+02 0.128E+02 0.326E+02 0.193E+02 0.000E+00 0.000E+00 0.000E+00 0.116E+03
 300.00 0.000E+00 0.979E+01 0.251E+02 0.306E+02 0.306E+02 0.240E+02 0.611E+02 0.367E+02 0.000E+00 0.000E+00 0.000E+00 0.218E+03
 320.00 0.000E+00 0.331E+02 0.848E+02 0.103E+03 0.103E+03 0.811E+02 0.206E+03 0.125E+03 0.000E+00 0.000E+00 0.000E+00 0.737E+03
 340.00 0.000E+00 0.519E+02 0.133E+03 0.162E+03 0.162E+03 0.127E+03 0.323E+03 0.196E+03 0.000E+00 0.000E+00 0.000E+00 0.115E+04
 360.00 0.000E+00 0.678E+02 0.174E+03 0.212E+03 0.212E+03 0.166E+03 0.423E+03 0.256E+03 0.000E+00 0.000E+00 0.000E+00 0.151E+04
 380.00 0.000E+00 0.757E+02 0.194E+03 0.236E+03 0.236E+03 0.186E+03 0.473E+03 0.286E+03 0.000E+00 0.000E+00 0.000E+00 0.169E+04
 400.00 0.000E+00 0.759E+02 0.194E+03 0.237E+03 0.237E+03 0.186E+03 0.474E+03 0.287E+03 0.000E+00 0.000E+00 0.000E+00 0.169E+04
 420.00 0.000E+00 0.763E+02 0.196E+03 0.239E+03 0.239E+03 0.188E+03 0.478E+03 0.289E+03 0.000E+00 0.000E+00 0.000E+00 0.170E+04
 440.00 0.000E+00 0.770E+02 0.198E+03 0.241E+03 0.241E+03 0.190E+03 0.483E+03 0.292E+03 0.000E+00 0.000E+00 0.000E+00 0.172E+04
 460.00 0.000E+00 0.780E+02 0.200E+03 0.244E+03 0.245E+03 0.192E+03 0.489E+03 0.296E+03 0.000E+00 0.000E+00 0.000E+00 0.174E+04
 480.00 0.000E+00 0.817E+02 0.210E+03 0.256E+03 0.257E+03 0.202E+03 0.513E+03 0.310E+03 0.000E+00 0.000E+00 0.000E+00 0.183E+04
 500.00 0.000E+00 0.873E+02 0.225E+03 0.274E+03 0.274E+03 0.216E+03 0.549E+03 0.331E+03 0.000E+00 0.000E+00 0.000E+00 0.196E+04
 520.00 0.000E+00 0.939E+02 0.242E+03 0.295E+03 0.295E+03 0.232E+03 0.591E+03 0.357E+03 0.000E+00 0.000E+00 0.000E+00 0.211E+04
 540.00 0.000E+00 0.101E+03 0.261E+03 0.318E+03 0.318E+03 0.250E+03 0.637E+03 0.384E+03 0.000E+00 0.000E+00 0.000E+00 0.227E+04
 560.00 0.000E+00 0.109E+03 0.280E+03 0.342E+03 0.343E+03 0.269E+03 0.686E+03 0.413E+03 0.000E+00 0.000E+00 0.000E+00 0.244E+04
 580.00 0.000E+00 0.117E+03 0.301E+03 0.367E+03 0.368E+03 0.289E+03 0.736E+03 0.443E+03 0.000E+00 0.000E+00 0.000E+00 0.262E+04
 600.00 0.000E+00 0.125E+03 0.322E+03 0.393E+03 0.393E+03 0.309E+03 0.787E+03 0.474E+03 0.000E+00 0.000E+00 0.000E+00 0.280E+04
 620.00 0.000E+00 0.133E+03 0.343E+03 0.418E+03 0.419E+03 0.329E+03 0.839E+03 0.505E+03 0.000E+00 0.000E+00 0.000E+00 0.299E+04
 640.00 0.000E+00 0.141E+03 0.364E+03 0.444E+03 0.445E+03 0.350E+03 0.890E+03 0.536E+03 0.000E+00 0.000E+00 0.000E+00 0.317E+04
 660.00 0.000E+00 0.149E+03 0.385E+03 0.470E+03 0.471E+03 0.370E+03 0.942E+03 0.567E+03 0.000E+00 0.000E+00 0.000E+00 0.335E+04
 680.00 0.000E+00 0.157E+03 0.406E+03 0.496E+03 0.496E+03 0.390E+03 0.993E+03 0.597E+03 0.000E+00 0.000E+00 0.000E+00 0.354E+04
 700.00 0.000E+00 0.165E+03 0.427E+03 0.521E+03 0.522E+03 0.410E+03 0.104E+04 0.628E+03 0.000E+00 0.000E+00 0.000E+00 0.372E+04
 720.00 0.000E+00 0.173E+03 0.447E+03 0.546E+03 0.547E+03 0.430E+03 0.109E+04 0.658E+03 0.000E+00 0.000E+00 0.000E+00 0.390E+04
 740.00 0.000E+00 0.181E+03 0.467E+03 0.571E+03 0.572E+03 0.450E+03 0.114E+04 0.687E+03 0.000E+00 0.000E+00 0.000E+00 0.407E+04
 760.00 0.000E+00 0.189E+03 0.487E+03 0.595E+03 0.596E+03 0.469E+03 0.119E+04 0.717E+03 0.000E+00 0.000E+00 0.000E+00 0.425E+04
 780.00 0.000E+00 0.196E+03 0.507E+03 0.620E+03 0.621E+03 0.488E+03 0.124E+04 0.745E+03 0.000E+00 0.000E+00 0.000E+00 0.442E+04
 800.00 0.000E+00 0.204E+03 0.527E+03 0.644E+03 0.645E+03 0.507E+03 0.129E+04 0.774E+03 0.000E+00 0.000E+00 0.000E+00 0.459E+04
 820.00 0.000E+00 0.211E+03 0.546E+03 0.667E+03 0.668E+03 0.525E+03 0.134E+04 0.802E+03 0.000E+00 0.000E+00 0.000E+00 0.476E+04
 840.00 0.000E+00 0.218E+03 0.565E+03 0.690E+03 0.691E+03 0.544E+03 0.138E+04 0.829E+03 0.000E+00 0.000E+00 0.000E+00 0.492E+04
 860.00 0.000E+00 0.226E+03 0.583E+03 0.713E+03 0.714E+03 0.562E+03 0.143E+04 0.856E+03 0.000E+00 0.000E+00 0.000E+00 0.508E+04
 880.00 0.000E+00 0.232E+03 0.602E+03 0.735E+03 0.737E+03 0.579E+03 0.148E+04 0.883E+03 0.000E+00 0.000E+00 0.000E+00 0.524E+04
ALL COMBUSTIBLE MATERIALS WERE CONSUMED BY:  890.0000 SEC

 900.00 0.000E+00 0.236E+03 0.610E+03 0.746E+03 0.747E+03 0.587E+03 0.150E+04 0.894E+03 0.000E+00 0.000E+00 0.000E+00 0.531E+04
 920.00 0.000E+00 0.235E+03 0.609E+03 0.744E+03 0.746E+03 0.587E+03 0.149E+04 0.892E+03 0.000E+00 0.000E+00 0.000E+00 0.531E+04
 940.00 0.000E+00 0.234E+03 0.607E+03 0.742E+03 0.744E+03 0.585E+03 0.149E+04 0.889E+03 0.000E+00 0.000E+00 0.000E+00 0.529E+04
 960.00 0.000E+00 0.233E+03 0.605E+03 0.740E+03 0.742E+03 0.583E+03 0.148E+04 0.885E+03 0.000E+00 0.000E+00 0.000E+00 0.527E+04
 980.00 0.000E+00 0.232E+03 0.603E+03 0.737E+03 0.739E+03 0.581E+03 0.148E+04 0.881E+03 0.000E+00 0.000E+00 0.000E+00 0.525E+04
1000.00 0.000E+00 0.231E+03 0.600E+03 0.735E+03 0.737E+03 0.579E+03 0.147E+04 0.876E+03 0.000E+00 0.000E+00 0.000E+00 0.523E+04

TIME EXCEEDS USER SPECIFIED TIME AT: 1000.0000 SEC
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TABLE E.8. RSZCL.DAT File from Problem One

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                                          OUTPUT FOR RADIOACTIVE SOURCE TERM

MASS IN COLD LAYER, G
                                                               PARTICLE DIAMETER (MICRONS)
    TIME     0.100     0.173     0.387     0.592     0.794     0.995     1.480     3.460     7.750    14.140    20.000     TOTAL
    0.00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
   20.00 0.659E-07 0.328E-06 0.117E-05 0.362E-05 0.357E-05 0.306E-05 0.907E-05 0.721E-04 0.856E-04 0.333E-04 0.459E-04 0.258E-03
   40.00 0.136E-06 0.630E-06 0.225E-05 0.700E-05 0.691E-05 0.594E-05 0.176E-04 0.141E-03 0.165E-03 0.638E-04 0.896E-04 0.499E-03
   60.00 0.200E-06 0.912E-06 0.328E-05 0.102E-04 0.101E-04 0.863E-05 0.256E-04 0.205E-03 0.238E-03 0.908E-04 0.124E-03 0.717E-03
   80.00 0.245E-06 0.118E-05 0.423E-05 0.132E-04 0.130E-04 0.112E-04 0.330E-04 0.262E-03 0.305E-03 0.113E-03 0.142E-03 0.899E-03
  100.00 0.269E-06 0.143E-05 0.505E-05 0.158E-04 0.156E-04 0.134E-04 0.395E-04 0.311E-03 0.363E-03 0.131E-03 0.150E-03 0.105E-02
  120.00 0.284E-06 0.165E-05 0.580E-05 0.182E-04 0.180E-04 0.154E-04 0.456E-04 0.356E-03 0.415E-03 0.146E-03 0.153E-03 0.117E-02
  140.00 0.309E-06 0.189E-05 0.664E-05 0.208E-04 0.206E-04 0.176E-04 0.521E-04 0.404E-03 0.469E-03 0.159E-03 0.158E-03 0.131E-02
  160.00 0.323E-06 0.206E-05 0.726E-05 0.227E-04 0.225E-04 0.192E-04 0.569E-04 0.438E-03 0.504E-03 0.165E-03 0.160E-03 0.140E-02
  180.00 0.337E-06 0.217E-05 0.767E-05 0.240E-04 0.237E-04 0.203E-04 0.599E-04 0.459E-03 0.523E-03 0.166E-03 0.158E-03 0.144E-02
  200.00 0.338E-06 0.224E-05 0.783E-05 0.245E-04 0.243E-04 0.208E-04 0.615E-04 0.468E-03 0.526E-03 0.161E-03 0.152E-03 0.145E-02
  220.00 0.334E-06 0.221E-05 0.785E-05 0.245E-04 0.243E-04 0.208E-04 0.614E-04 0.465E-03 0.514E-03 0.152E-03 0.142E-03 0.141E-02
  240.00 0.344E-06 0.207E-05 0.766E-05 0.238E-04 0.237E-04 0.202E-04 0.596E-04 0.449E-03 0.487E-03 0.138E-03 0.129E-03 0.134E-02
  260.00 0.357E-06 0.198E-05 0.709E-05 0.226E-04 0.224E-04 0.191E-04 0.563E-04 0.422E-03 0.447E-03 0.121E-03 0.113E-03 0.123E-02
  280.00 0.370E-06 0.181E-05 0.647E-05 0.206E-04 0.205E-04 0.174E-04 0.514E-04 0.382E-03 0.395E-03 0.101E-03 0.953E-04 0.109E-02
  300.00 0.957E-07 0.895E-06 0.347E-05 0.108E-04 0.112E-04 0.101E-04 0.380E-04 0.320E-03 0.363E-03 0.437E-03 0.132E-03 0.133E-02
  320.00 0.358E-08 0.264E-07 0.227E-06 0.609E-06 0.994E-06 0.132E-05 0.109E-04 0.115E-03 0.161E-03 0.384E-03 0.509E-03 0.118E-02
ALL COMBUSTIBLE MATERIALS WERE CONSUMED BY:   890.0000 SEC


TIME EXCEEDS USER SPECIFIED TIME AT: 1000.0000 SEC
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TABLE E.9. RSZHL.DAT File from Problem One

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                                            OUTPUT FOR RADIOACTIVE SOURCE TERM

MASS IN HOT LAYER, G
                                                          PARTICLE DIAMETER (MICRONS)
  TIME     0.100      0.173      0.387      0.592      0.794      0.995      1.480      3.460      7.750     14.140     20.000     TOTAL
   0.00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  20.00 0.573E-02 0.899E-02 0.641E-02 0.852E-02 0.469E-02 0.256E-02 0.343E-02 0.506E-02 0.118E-02 0.141E-03 0.104E-03 0.468E-01
  40.00 0.118E-01 0.180E-01 0.128E-01 0.171E-01 0.938E-02 0.512E-02 0.687E-02 0.102E-01 0.237E-02 0.284E-03 0.211E-03 0.940E-01
  60.00 0.153E-01 0.269E-01 0.192E-01 0.256E-01 0.141E-01 0.768E-02 0.103E-01 0.149E-01 0.354E-02 0.410E-03 0.263E-03 0.138E+00
  80.00 0.174E-01 0.358E-01 0.256E-01 0.341E-01 0.187E-01 0.102E-01 0.137E-01 0.195E-01 0.470E-02 0.528E-03 0.292E-03 0.180E+00
 100.00 0.194E-01 0.447E-01 0.319E-01 0.425E-01 0.234E-01 0.128E-01 0.171E-01 0.240E-01 0.586E-02 0.647E-03 0.327E-03 0.223E+00
 120.00 0.207E-01 0.500E-01 0.357E-01 0.476E-01 0.262E-01 0.143E-01 0.191E-01 0.267E-01 0.653E-02 0.714E-03 0.362E-03 0.248E+00
 140.00 0.206E-01 0.499E-01 0.357E-01 0.476E-01 0.262E-01 0.143E-01 0.191E-01 0.267E-01 0.644E-02 0.701E-03 0.390E-03 0.248E+00
 160.00 0.206E-01 0.499E-01 0.357E-01 0.476E-01 0.262E-01 0.143E-01 0.191E-01 0.266E-01 0.636E-02 0.691E-03 0.418E-03 0.247E+00
 180.00 0.206E-01 0.498E-01 0.357E-01 0.475E-01 0.262E-01 0.143E-01 0.191E-01 0.265E-01 0.630E-02 0.684E-03 0.446E-03 0.247E+00
 200.00 0.205E-01 0.498E-01 0.356E-01 0.475E-01 0.262E-01 0.143E-01 0.191E-01 0.265E-01 0.623E-02 0.679E-03 0.473E-03 0.247E+00
 220.00 0.205E-01 0.497E-01 0.356E-01 0.475E-01 0.261E-01 0.143E-01 0.191E-01 0.264E-01 0.617E-02 0.675E-03 0.501E-03 0.247E+00
 240.00 0.205E-01 0.497E-01 0.356E-01 0.475E-01 0.261E-01 0.143E-01 0.191E-01 0.264E-01 0.612E-02 0.674E-03 0.528E-03 0.246E+00
 260.00 0.205E-01 0.496E-01 0.356E-01 0.474E-01 0.261E-01 0.143E-01 0.191E-01 0.264E-01 0.607E-02 0.673E-03 0.555E-03 0.246E+00
 280.00 0.204E-01 0.496E-01 0.356E-01 0.474E-01 0.261E-01 0.142E-01 0.190E-01 0.263E-01 0.602E-02 0.673E-03 0.582E-03 0.246E+00
 300.00 0.202E-01 0.491E-01 0.915E-01 0.105E+00 0.935E-01 0.814E-01 0.308E+00 0.587E+00 0.157E+00 0.107E+00 0.179E-01 0.162E+01
 320.00 0.200E-01 0.486E-01 0.906E-01 0.104E+00 0.962E-01 0.820E-01 0.312E+00 0.608E+00 0.175E+00 0.136E+00 0.106E+00 0.178E+01
 340.00 0.183E-01 0.444E-01 0.827E-01 0.946E-01 0.913E-01 0.763E-01 0.291E+00 0.580E+00 0.177E+00 0.151E+00 0.175E+00 0.178E+01
 360.00 0.162E-01 0.393E-01 0.734E-01 0.840E-01 0.843E-01 0.690E-01 0.264E+00 0.540E+00 0.175E+00 0.160E+00 0.230E+00 0.174E+01
 380.00 0.151E-01 0.368E-01 0.687E-01 0.786E-01 0.807E-01 0.654E-01 0.251E+00 0.518E+00 0.172E+00 0.162E+00 0.248E+00 0.170E+01
 400.00 0.147E-01 0.359E-01 0.672E-01 0.769E-01 0.790E-01 0.640E-01 0.245E+00 0.506E+00 0.168E+00 0.155E+00 0.233E+00 0.165E+01
 420.00 0.144E-01 0.353E-01 0.660E-01 0.756E-01 0.776E-01 0.628E-01 0.241E+00 0.497E+00 0.164E+00 0.149E+00 0.219E+00 0.160E+01
 440.00 0.142E-01 0.347E-01 0.649E-01 0.744E-01 0.764E-01 0.618E-01 0.237E+00 0.489E+00 0.160E+00 0.144E+00 0.207E+00 0.156E+01
 460.00 0.140E-01 0.341E-01 0.639E-01 0.733E-01 0.753E-01 0.610E-01 0.234E+00 0.482E+00 0.157E+00 0.139E+00 0.196E+00 0.153E+01
 480.00 0.138E-01 0.338E-01 0.633E-01 0.726E-01 0.746E-01 0.604E-01 0.232E+00 0.477E+00 0.155E+00 0.135E+00 0.186E+00 0.150E+01
 500.00 0.137E-01 0.335E-01 0.629E-01 0.721E-01 0.741E-01 0.600E-01 0.230E+00 0.474E+00 0.153E+00 0.131E+00 0.177E+00 0.148E+01
 520.00 0.135E-01 0.332E-01 0.624E-01 0.716E-01 0.736E-01 0.596E-01 0.229E+00 0.470E+00 0.151E+00 0.127E+00 0.168E+00 0.146E+01
 540.00 0.134E-01 0.329E-01 0.620E-01 0.711E-01 0.731E-01 0.592E-01 0.227E+00 0.466E+00 0.149E+00 0.124E+00 0.160E+00 0.144E+01
 560.00 0.133E-01 0.327E-01 0.615E-01 0.706E-01 0.726E-01 0.588E-01 0.226E+00 0.463E+00 0.147E+00 0.120E+00 0.151E+00 0.142E+01
 580.00 0.132E-01 0.324E-01 0.611E-01 0.701E-01 0.721E-01 0.584E-01 0.224E+00 0.459E+00 0.145E+00 0.117E+00 0.144E+00 0.140E+01
 600.00 0.130E-01 0.321E-01 0.606E-01 0.696E-01 0.716E-01 0.580E-01 0.223E+00 0.456E+00 0.143E+00 0.113E+00 0.136E+00 0.138E+01
 620.00 0.129E-01 0.319E-01 0.602E-01 0.691E-01 0.711E-01 0.576E-01 0.221E+00 0.452E+00 0.141E+00 0.110E+00 0.129E+00 0.136E+01
 640.00 0.128E-01 0.316E-01 0.597E-01 0.686E-01 0.706E-01 0.572E-01 0.220E+00 0.448E+00 0.139E+00 0.107E+00 0.122E+00 0.134E+01
 660.00 0.127E-01 0.314E-01 0.593E-01 0.682E-01 0.701E-01 0.568E-01 0.218E+00 0.445E+00 0.137E+00 0.104E+00 0.116E+00 0.132E+01
 680.00 0.126E-01 0.311E-01 0.589E-01 0.677E-01 0.697E-01 0.565E-01 0.217E+00 0.442E+00 0.136E+00 0.100E+00 0.110E+00 0.130E+01
 700.00 0.125E-01 0.309E-01 0.585E-01 0.673E-01 0.692E-01 0.561E-01 0.215E+00 0.439E+00 0.134E+00 0.974E-01 0.104E+00 0.128E+01
 720.00 0.124E-01 0.306E-01 0.581E-01 0.668E-01 0.688E-01 0.558E-01 0.214E+00 0.435E+00 0.132E+00 0.945E-01 0.983E-01 0.127E+01
 740.00 0.123E-01 0.304E-01 0.577E-01 0.664E-01 0.684E-01 0.554E-01 0.213E+00 0.432E+00 0.130E+00 0.917E-01 0.930E-01 0.125E+01
 760.00 0.122E-01 0.302E-01 0.574E-01 0.660E-01 0.680E-01 0.551E-01 0.211E+00 0.429E+00 0.129E+00 0.890E-01 0.881E-01 0.124E+01
 780.00 0.121E-01 0.300E-01 0.570E-01 0.656E-01 0.676E-01 0.548E-01 0.210E+00 0.427E+00 0.127E+00 0.863E-01 0.833E-01 0.122E+01
 800.00 0.120E-01 0.298E-01 0.567E-01 0.653E-01 0.672E-01 0.545E-01 0.209E+00 0.424E+00 0.126E+00 0.838E-01 0.788E-01 0.121E+01
 820.00 0.119E-01 0.296E-01 0.563E-01 0.649E-01 0.668E-01 0.542E-01 0.208E+00 0.421E+00 0.124E+00 0.813E-01 0.746E-01 0.119E+01
 840.00 0.118E-01 0.294E-01 0.560E-01 0.646E-01 0.665E-01 0.539E-01 0.207E+00 0.418E+00 0.122E+00 0.789E-01 0.706E-01 0.118E+01
 860.00 0.117E-01 0.292E-01 0.557E-01 0.642E-01 0.661E-01 0.536E-01 0.206E+00 0.416E+00 0.121E+00 0.766E-01 0.667E-01 0.117E+01
 880.00 0.117E-01 0.290E-01 0.554E-01 0.639E-01 0.658E-01 0.534E-01 0.205E+00 0.413E+00 0.120E+00 0.743E-01 0.631E-01 0.115E+01
ALL COMBUSTIBLE MATERIALS WERE CONSUMED BY:  890.0000 SEC

 900.00 0.116E-01 0.289E-01 0.552E-01 0.637E-01 0.656E-01 0.532E-01 0.204E+00 0.411E+00 0.118E+00 0.722E-01 0.598E-01 0.114E+01
 920.00 0.115E-01 0.288E-01 0.551E-01 0.636E-01 0.655E-01 0.531E-01 0.204E+00 0.410E+00 0.117E+00 0.702E-01 0.566E-01 0.114E+01
 940.00 0.115E-01 0.287E-01 0.549E-01 0.634E-01 0.653E-01 0.530E-01 0.203E+00 0.409E+00 0.116E+00 0.682E-01 0.536E-01 0.113E+01
 960.00 0.114E-01 0.286E-01 0.548E-01 0.632E-01 0.651E-01 0.528E-01 0.203E+00 0.407E+00 0.115E+00 0.662E-01 0.506E-01 0.112E+01
 980.00 0.114E-01 0.285E-01 0.546E-01 0.630E-01 0.649E-01 0.526E-01 0.202E+00 0.405E+00 0.114E+00 0.642E-01 0.478E-01 0.111E+01
1000.00 0.113E-01 0.284E-01 0.543E-01 0.627E-01 0.646E-01 0.524E-01 0.201E+00 0.403E+00 0.112E+00 0.623E-01 0.450E-01 0.110E+01

TIME EXCEEDS USER SPECIFIED TIME AT: 1000.0000 SEC
```

TABLE E.10. ARAD.DAT File from Problem One

```
                                       OUTPUT FOR RADIOACTIVE SOURCE TERM

 TIME  ACCUMULATED MASS (G) ON:
 (S)     FLOOR      WALL      CEILING    VENTS    ENVIRON
   0.00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  20.00 0.240E-05 0.811E-05 0.113E-03 0.573E-05 0.287E-08
  40.00 0.105E-04 0.327E-04 0.233E-03 0.250E-04 0.125E-07
  60.00 0.250E-04 0.728E-04 0.356E-03 0.596E-04 0.298E-07
  80.00 0.457E-04 0.127E-03 0.479E-03 0.111E-03 0.554E-07
 100.00 0.723E-04 0.194E-03 0.605E-03 0.180E-03 0.900E-07
 120.00 0.105E-03 0.274E-03 0.730E-03 0.267E-03 0.134E-06
 140.00 0.144E-03 0.352E-03 0.843E-03 0.370E-03 0.185E-06
 160.00 0.189E-03 0.426E-03 0.944E-03 0.495E-03 0.248E-06
 180.00 0.241E-03 0.499E-03 0.103E-02 0.640E-03 0.320E-06
 200.00 0.298E-03 0.568E-03 0.112E-02 0.806E-03 0.403E-06
 220.00 0.361E-03 0.635E-03 0.119E-02 0.994E-03 0.497E-06
 240.00 0.430E-03 0.700E-03 0.126E-02 0.120E-02 0.602E-06
 260.00 0.503E-03 0.764E-03 0.132E-02 0.144E-02 0.718E-06
 280.00 0.582E-03 0.825E-03 0.138E-02 0.169E-02 0.846E-06
 300.00 0.673E-03 0.957E-03 0.149E-02 0.151E-01 0.754E-05
 320.00 0.144E-02 0.125E-02 0.168E-02 0.330E-01 0.165E-04
 340.00 0.107E-01 0.160E-02 0.193E-02 0.197E+00 0.983E-04
 360.00 0.262E-01 0.197E-02 0.222E-02 0.405E+00 0.202E-03
 380.00 0.431E-01 0.236E-02 0.253E-02 0.516E+00 0.258E-03
 400.00 0.592E-01 0.274E-02 0.283E-02 0.551E+00 0.276E-03
 420.00 0.744E-01 0.312E-02 0.313E-02 0.578E+00 0.289E-03
 440.00 0.887E-01 0.349E-02 0.343E-02 0.601E+00 0.301E-03
 460.00 0.102E+00 0.385E-02 0.372E-02 0.622E+00 0.311E-03
 480.00 0.116E+00 0.420E-02 0.400E-02 0.634E+00 0.317E-03
 500.00 0.128E+00 0.453E-02 0.427E-02 0.643E+00 0.322E-03
 520.00 0.141E+00 0.485E-02 0.453E-02 0.651E+00 0.326E-03
 540.00 0.153E+00 0.516E-02 0.478E-02 0.660E+00 0.330E-03
 560.00 0.165E+00 0.545E-02 0.502E-02 0.669E+00 0.334E-03
 580.00 0.177E+00 0.574E-02 0.525E-02 0.677E+00 0.339E-03
 600.00 0.188E+00 0.601E-02 0.548E-02 0.686E+00 0.343E-03
 620.00 0.199E+00 0.628E-02 0.570E-02 0.694E+00 0.347E-03
 640.00 0.210E+00 0.654E-02 0.591E-02 0.702E+00 0.351E-03
 660.00 0.220E+00 0.680E-02 0.612E-02 0.710E+00 0.355E-03
 680.00 0.230E+00 0.705E-02 0.633E-02 0.717E+00 0.359E-03
 700.00 0.239E+00 0.729E-02 0.653E-02 0.724E+00 0.362E-03
 720.00 0.249E+00 0.753E-02 0.672E-02 0.731E+00 0.366E-03
 740.00 0.257E+00 0.776E-02 0.692E-02 0.738E+00 0.369E-03
 760.00 0.266E+00 0.799E-02 0.711E-02 0.744E+00 0.372E-03
 780.00 0.275E+00 0.822E-02 0.729E-02 0.750E+00 0.375E-03
 800.00 0.283E+00 0.844E-02 0.747E-02 0.756E+00 0.378E-03
 820.00 0.290E+00 0.866E-02 0.765E-02 0.761E+00 0.381E-03
 840.00 0.298E+00 0.887E-02 0.783E-02 0.767E+00 0.384E-03
 860.00 0.305E+00 0.908E-02 0.801E-02 0.772E+00 0.386E-03
 880.00 0.312E+00 0.929E-02 0.818E-02 0.777E+00 0.389E-03
 900.00 0.319E+00 0.949E-02 0.834E-02 0.780E+00 0.390E-03
 920.00 0.326E+00 0.967E-02 0.850E-02 0.781E+00 0.391E-03
 940.00 0.333E+00 0.985E-02 0.865E-02 0.783E+00 0.392E-03
 960.00 0.339E+00 0.100E-01 0.879E-02 0.786E+00 0.393E-03
 980.00 0.346E+00 0.102E-01 0.892E-02 0.789E+00 0.395E-03
1000.00 0.352E+00 0.103E-01 0.905E-02 0.792E+00 0.396E-03
```

TABLE E.11. ASMK.DAT File from Problem One

```
                                                   OUTPUT FOR SMOKE SOURCE TERM

 TIME  ACCUMULATED MASS (G) ON:
 (S)     FLOOR      WALL      CEILING     VENTS    ENVIRON
   0.00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  20.00 0.399E-04 0.166E-02 0.236E-01 0.124E-02 0.621E-06
  40.00 0.174E-03 0.662E-02 0.478E-01 0.565E-02 0.283E-05
  60.00 0.419E-03 0.149E-01 0.730E-01 0.137E-01 0.687E-05
  80.00 0.785E-03 0.265E-01 0.997E-01 0.255E-01 0.128E-04
 100.00 0.130E-02 0.414E-01 0.127E+00 0.419E-01 0.210E-04
 120.00 0.198E-02 0.595E-01 0.156E+00 0.635E-01 0.317E-04
 140.00 0.286E-02 0.778E-01 0.183E+00 0.895E-01 0.448E-04
 160.00 0.395E-02 0.959E-01 0.207E+00 0.122E+00 0.610E-04
 180.00 0.526E-02 0.114E+00 0.229E+00 0.161E+00 0.806E-04
 200.00 0.680E-02 0.131E+00 0.250E+00 0.207E+00 0.104E-03
 220.00 0.860E-02 0.149E+00 0.269E+00 0.261E+00 0.131E-03
 240.00 0.107E-01 0.166E+00 0.287E+00 0.323E+00 0.162E-03
 260.00 0.131E-01 0.184E+00 0.304E+00 0.395E+00 0.198E-03
 280.00 0.158E-01 0.201E+00 0.320E+00 0.477E+00 0.239E-03
 300.00 0.188E-01 0.222E+00 0.338E+00 0.214E+01 0.107E-02
 320.00 0.202E-01 0.323E+00 0.406E+00 0.663E+01 0.332E-02
 340.00 0.396E+00 0.604E+00 0.611E+00 0.100E+03 0.503E-01
 360.00 0.119E+01 0.105E+01 0.955E+00 0.257E+03 0.128E+00
 380.00 0.218E+01 0.163E+01 0.142E+01 0.362E+03 0.181E+00
 400.00 0.319E+01 0.223E+01 0.190E+01 0.397E+03 0.199E+00
 420.00 0.421E+01 0.285E+01 0.239E+01 0.426E+03 0.213E+00
 440.00 0.523E+01 0.346E+01 0.288E+01 0.451E+03 0.226E+00
 460.00 0.627E+01 0.409E+01 0.338E+01 0.474E+03 0.237E+00
 480.00 0.732E+01 0.472E+01 0.389E+01 0.488E+03 0.244E+00
 500.00 0.844E+01 0.537E+01 0.442E+01 0.499E+03 0.250E+00
 520.00 0.964E+01 0.605E+01 0.497E+01 0.511E+03 0.256E+00
 540.00 0.109E+02 0.676E+01 0.555E+01 0.524E+03 0.262E+00
 560.00 0.123E+02 0.751E+01 0.617E+01 0.538E+03 0.269E+00
 580.00 0.138E+02 0.831E+01 0.682E+01 0.554E+03 0.277E+00
 600.00 0.154E+02 0.914E+01 0.750E+01 0.570E+03 0.285E+00
 620.00 0.171E+02 0.100E+02 0.822E+01 0.588E+03 0.294E+00
 640.00 0.189E+02 0.109E+02 0.897E+01 0.606E+03 0.303E+00
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The U.S. Nuclear Regulatory Commission has sponsored a research program to better estimate the source term, or amount and characteristics of radioactive material made airborne, from several types of accidents. The most concentrated work has been done on fires, resulting in the development of FIRIN, a compartment fire code that estimates the release and distribution of radioactive materials within a room from fires involving radioactive materials. The User's Manual describes the technical basis of the code and provides input and output information for code users.

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