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Numerical field model simulation of full scale fire tests in a closed vessel.

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NAVAL POSTGRADUATE SCHOOL

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NUMERICAL FIELD MODEL SIMULATION
OF FULL SCALE FIRE TESTS
IN A CLOSED VESSEL

by

Gerald F. Nies

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Numerical Field Model Simulation of Full Scale Fire Tests in a Closed Vessel

by

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Submitted in partial fulfillment of the requirements for the degrees of

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ABSTRACT

A numerical finite difference field model was developed to simulate full scale fires in closed vessels. In particular the model was developed to simulate tests in the Fire 1 Test Facility at the Naval Research Laboratory in Washington, D.C. As a first step a rectangular 3-dimensional geometry was used to approximate the actual geometry in the computer model. Then a model with the actual spherical/cylindrical geometry was developed. The computer code produced pressure, temperature, density, and velocity fields from given heat input data for the fires. The most important feature of the model was that it accounts for the pressure buildup due to the fire in a pressure vessel such as Fire 1 or any other closed vessel such as a submarine. Other features include surface radiation exchange and heat losses through the wall. Model results were validated with experimental data from Fire 1. The envisioned use of the model is in simulating fires in Fire 1 and eventually in submarines.

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I. INTRODUCTION

A. THE SIGNIFICANCE OF FIRE PROBLEMS IN THE NAVY

For many years fires have been a significant problem in the Navy. Many lives have been lost and numerous injuries have resulted from these fires. The necessary repairs to the ships adversely affect naval readiness and also cost millions of dollars. Table 1 [Ref. 1: p.65] shows the magnitude of the problem by listing average yearly losses and citing several specific fires.

TABLE 1

PERSONNEL CASUALTIES AND LOST OPERATING DAYS FROM FIRES, 1973 - 1980

Calendar Year *	Injuries	Fatalities	Operating Days Lost
1980	44	0	75
1979	33	2	81
1978	7	0	287
1977	10	0	146
1976	12	0	165
1975	73	12	973
1974	30	1	197
1973	57	9	211
Avg.	35	3	284

Major Aircraft Carrier Flight Deck Fires:

USS Enterprise	14 JAN 1969	$56 Mil	28 Fatalities
USS Nimitz	26 MAY 1981	$75 Mil	13 Fatalities

* Up to June 1980

The computer model developed in this thesis provides a tool to simulate fires in closed compartments such as those found in submarines. Hopefully this model and its successors can be used to reduce the damage caused by shipboard fires.

B. NAVY FIRE RESEARCH

In an effort to reduce the loss of life and damage caused by fires the Navy has undertaken for many years programs to reduce the likelyhood of fires and to more effectively combat fires once they start. Many facilities are used to evaluate fire damage from various scenarios. These scenarios generally involve the evaluation of new fire extinguishing equipment or fire resistant materials such as prospective hull insulation. The Fire I Test Facility at the Naval Research Laboratory is one such facility which is specifically designed to simulate fires aboard a submarine where the pressure buildup due to the fire is not vented. The computer code developed here is specifically designed to simulate fires in the Fire 1 Test Facility.

Other related Naval and Coast Guard research involves the accurate evauation of the fire hazard aboard ships in the fleet. The most spectacular and expensive tests of this variety are full scale instrumented fire tests aboard recently decommissioned ships. Projects are currently in the planning stages to conduct such tests aboard a submarine and a surface ship. The computer model presented here is a first step toward modeling the complex phenomena of a fire in these full scale conditions.

C. PURPOSE AND FEATURES OF THE NUMERICAL MODEL

One might ask, "What is the usefulness of a computer model for Fire 1?" Several answers immediately come to mind. First, the actual test runs in the facility are expensive. They are on the order of $75,000 for an involved test. Obviously, a computer model that could eliminate the need for even a few tests would be useful. Test cost and physical limitations of the facility also limit the number of actual fire scenarios that can be tested. The computer model could be used to evaluate many scenarios that would not normally be looked at. In this way the computer code could be used to screen scenarios. Then actual tests would be run on those situations that show up as the most dangerous on the computer. Also, the program might show areas inside the test vessel where additional instrumentation is required. As a simple example, Fire I now has available portable thermocouple racks. Test cases on the computer would indicate the most favorable placement of these portable racks to record the data desired. Finally, since the geometry simulated by the computer is much more easily changed than the geometry of the physical model. once the computer code is validated by Fire I it could be used to simulate other fires in facilities or ships which have much different dimensions than Fire I.

The actual numerical model used here to simulate the fire is referred to as a field model. In a field model the space is divided up into a large number of small cells and all the pertinent values for temperature, pressure, density, species concentration, and velocities are calculated. Interaction effects such as radiation, and turbulence, and others are easily integrated in a field model but the overall results are very dependent on how accurate the particular radiation or turbulence model is. Thus improvement of the field model accuracy depends on research in many separate areas. Field models in general require a large amount of computer resources because of the large number of cells required for satisfactorily accurate results. As a consequence of this complexity and the limitations of present computers, real time simulations with a field model are not feasible.

The three-dimensional model developed here is a direct extension of the two-dimensional model used in the study of aircraft fires at the University of Notre Dame [Refs. 2,3: pp. 107-118, pp.177-184]. There are a number of other Field models available. In [Ref. 4: pp. 55-77] a three-dimensional model of buoyant convection and aerosol dynamics using the time dependent inviscid Boussinesq equations is presented. A simple combustion model is included in the field model described in [Ref. 5: pp. 107-111] and in [Ref. 6: pp. 115-124] another three dimensional model of a fire in enclosures is developed.

This Fire I numerical model has a number of important features. The model is three dimensional. Primarily as a consequence, primitive variables have been used. The choice of primitive variables rather than the stream function, vorticity, and velocity potential approach also makes the application of boundary conditions much easier. The major problem with using primitive variables is the necessity and difficulty of determining the local pressure field. This procedure will be described in detail in this report. Another feature critical to this model is a global pressure correction that allows for the pressure buildup in the closed system that is being simulated. A radiation model is also included but it only deals with surface to surface radiation effects. Gas radiation effects are not accounted for. A simple conduction model is provided to simulate the heat loss through the vessel walls. The overall numerical scheme employs the finite difference method.

D. THE FIRE 1 TEST FACILITY

Since the Fire I test facility is the specific subject of this computer model and since the experimental data from this facility is the basis of the model validation, a short description of Fire I is provided here. A detailed report about the facility is provided by Alexander, et.al. in [Ref. 7]. and the facts presented here are excerpts from that reference. Figure 1.1 [Ref. 7: p. 2] provides a blueprint drawing showing the overall dimensions of Fire 1. The tank shell consists of a cylindrical central body 27.4 ft long with hemispherical endcaps. The radius of the endcaps and the cylinder is 9.6 ft giving a total volume of 11640 ft^3 or 324 m^3 . The test vessel is made of ASTM 285 Grade C steel 3/8 in thick. The design pressure is 89.7 psia at 450°F with a hydrostatic test pressure of 127.2 psia. Rupture discs are installed to prevent pressurization above 89.7 psia. [Ref. 7: p. 4]

Within the basic shell modifications have been made to provide instrumentation for fire testing and to simulate the shipboard environment. Figure 1.2 [Ref. 7: p. 32] provides a side view drawing which shows the location of the thermocouples and radiometers. A total of 20 thermocouples are arranged on two arrays at the north and south ends of the tank. The figure shows their exact locations. The thermocouples consist of chrome-alumel wire 0.2 mm in diameter with ceramic insulation enclosed in Type 304 stainless steel jackets 1 mm in diameter. These thermocouples are provided with steel radiation shields. In addition to the 20 permanent thermocouples, in many tests additional temporary thermocouples are placed in locations of interest. Both wide angle (135°) and narrow angle (75°) radiometers are provided inside the tank near the permanent thermocouple arrays. In addition one wide angle radiometer array is installed near the center of the tank on the lower deck. Pressure readings are taken from two transducers, one taps into the north end of the tank and the other into the south end. The test chamber is also equipped to measure smoke obscuration levels, gas composition, and the progress of the fire with video cameras. Figure 1.2 shows several features which are similar to a submarine interior. First are the frame bays which can provide a ducting or chimney effect for fires located near them. Second are the decks, one about 3 ft above the low point of the tank and one at the tank mid-plane. These decks may be either grates or solid and may be fully or partially removed as desired in a particular test. A system of interior fans is provided so that the effects of forced circulation on a fire in the closed vessel may also be evaluated. Finally, the facilty is equiped with a nitrogen pressurization system to extinguish the fire. It raises

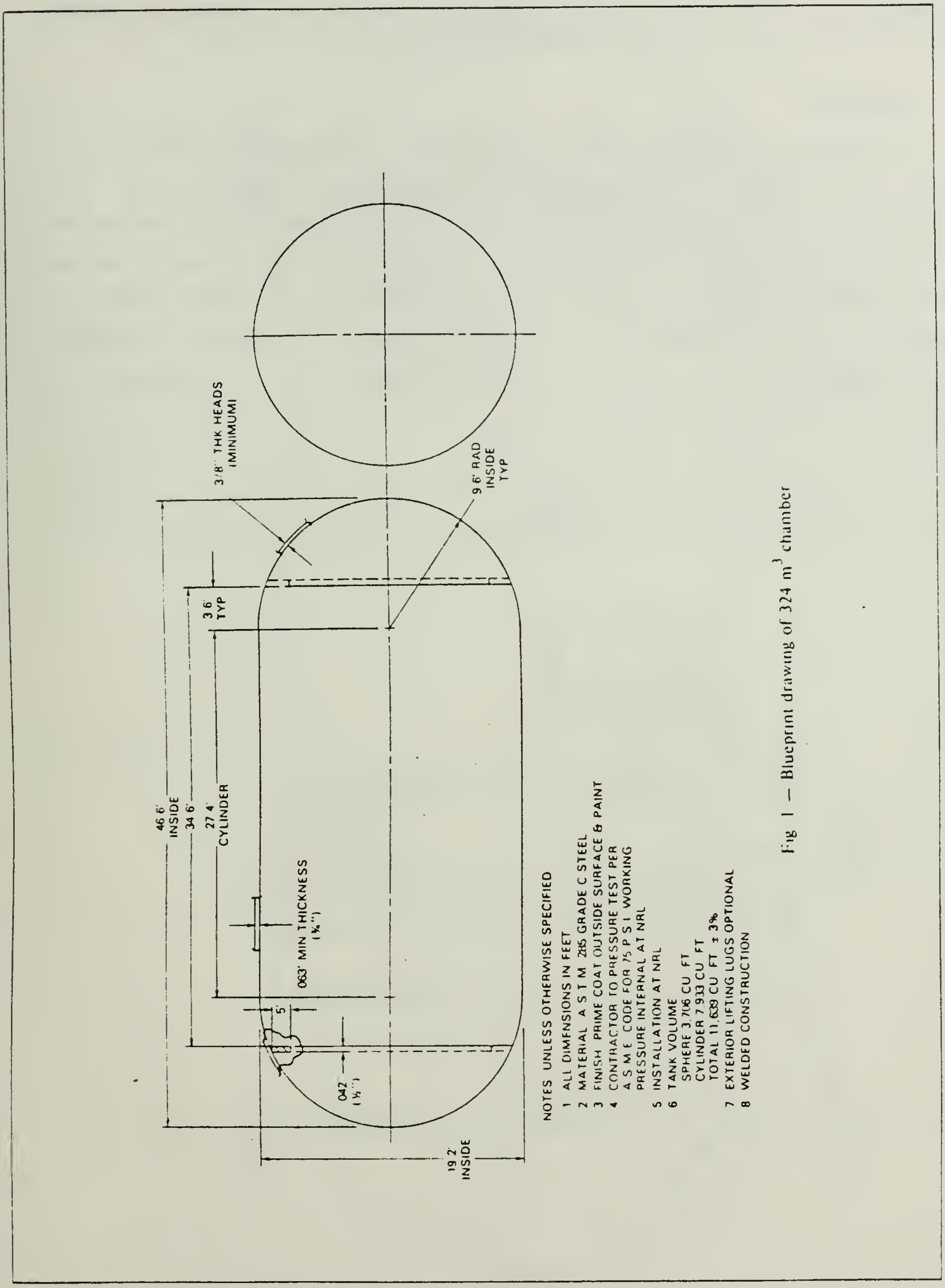

Figure 1.1 Blueprint Drawing of the Fire I Test Vessel.

the pressure to 2 atm in 10 sec and extinguishes the fire by lowering the partial pressure of the oxygen to less than 10.5%. [Ref. 7: pp. 14-33]

E. OUTLINE

The balance of this thesis describes the details of the numerical model and its validation. In Chapter II the governing equations are described and non-dimensionalized. Then the specific finite difference equations for the rectangular geometry are derived. This is followed by an explanation of the pressure correction. radiation model, conduction model, and the application of boundary conditions. Chapter II ends with an outline of the solution procedure. In Chapter III the results of the validation of the model with the experimental data are presented. The conclusions and recommendations for future work are given in Chapter IV. The derivations for the finite difference equations for the actual cylindrical spherical geometry are presented in the Appendices. Future work will contain the validation results. The other appendices contain the code listings and several miscellaneous items.

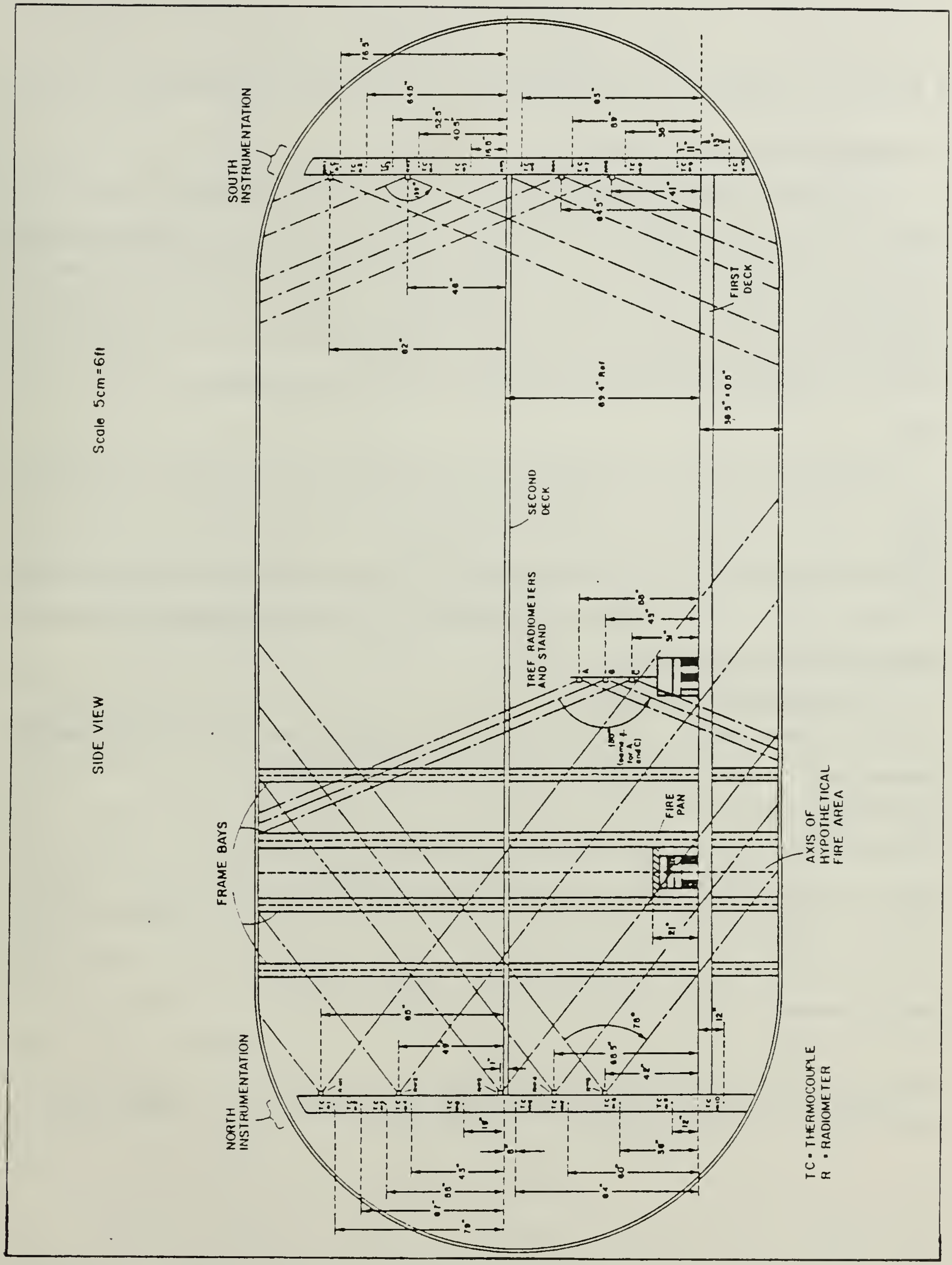

Figure 1.2 Side View of Fire I with Sensor Locations.

II. FORMULATION AND DESCRIPTION OF THE NUMERICAL MODEL

A. GOVERNING EQUATIONS

In this section the governing differential equations for the computer model are presented and then simplified by deleting terms not significant in this particular application. Patankar in [Ref. 8: pp. 11-17] provides the general form of the equations while White in [Ref. 9: pp. 671-674] provides the equations for the rectangular geometry. The general form of the equations, their simplication, and the development of the finite difference equations follows the form of Doria in reference [Ref. 10: pp. 1-44].

In the development of the equations, an assumption of no chemical reactions is made. The fire is modeled by volumetric heat input only and the chemical composition changes due to combustion reactions are ignored. In addition, laminar transport properties are taken to be constant, while density is allowed to vary in accordance with the ideal gas law. The justification is that the flow and temperature fields are dominated by turbulent transport.

1. Equations in General Form

In general form not specific to any geometry, the governing differential equations are:

Continuity Equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \underline{v}) = 0 \qquad \text{(eqn 2.1)}$$

Energy Equation:

$$\frac{\partial}{\partial t}(\rho h) + \nabla \cdot (\rho \underline{v} h) = \nabla \cdot (k \nabla T) + \frac{DP}{Dt} + \varphi_D + S_h \qquad \text{(eqn 2.2)}$$

Momentum Equations:

$$\frac{\partial}{\partial t}(\rho v_1) + \nabla \cdot (\rho \underline{v} v_1) = \nabla \cdot (\mu \nabla v_1) - \frac{\partial P}{\partial x_1} + B_{x_1} \qquad \text{(eqn 2.3)}$$

$$\frac{\partial}{\partial t}(\rho v_2) + \nabla \bullet (\rho \underline{v} v_2) = \nabla \bullet (\mu \nabla v_2) - \frac{\partial P}{\partial x_2} + B_{x_2} \qquad \text{(eqn 2.4)}$$

$$\frac{\partial}{\partial t}(\rho v_3) + \nabla \bullet (\rho \underline{v} v_3) = \nabla \bullet (\mu \nabla v_3) - \frac{\partial P}{\partial x_3} + B_{x_3} \qquad \text{(eqn 2.4)}$$

Equations of State:

$$P = \rho R T \qquad \text{(eqn 2.6)}$$

$$h = C_p (T-T_R) \qquad \text{(eqn 2.7)}$$

The energy equation above assumes the use of Fourier's Law while the momentum equations assume the use of Stokes' Hypothesis.

In the energy equation DP/Dt is the pressure work term, φ_d is the dissipation, and S_h is the heat source term. The low speed flows considered in this model make the pressure work and dissipation terms small. As a result they are assumed negligible from this point and eliminated from the equations. Since the effects of gas radiation are not treated here, the heat source term is non-zero only in the region of the fire. In the momentum equations, the subscripts 1, 2, and 3 indicate the three orthogonal directions of the particular coordinate system selected. B represents a body force. The energy and momentum equations both contain terms of the form $\nabla \cdot (\Gamma \nabla \varphi)$ where Γ is the diffusion coefficient and φ is a dependent variable. In the laminar case, the values of Γ are properties of the fluid. However in this numerical model where the turbulent case must be considered, the value of Γ is replaced by a Γ_{eff} or an effective value of the diffusion property which increases the original laminar value of Γ by a turbulent contribution [Ref. 10: p. 5]. Thus the conductivity k becomes k_{eff} and μ becomes μ_{eff}. T_R in the equation for the enthalpy is a reference temperature.

2. Governing Equations in Cartesian Coordinates

From the general forms of the differential equations just presented the equations for the Cartesian or rectangular geometry may be developed. In the rectangular geometry the three coordinate directions are x, y, and z and the corresponding velocities are u, v, and w.

Now that the coordinate system has been selected several items may be specified. The divergence and gradient in rectangular coordinates are given in Equations 2.8 and 2.9, respectively.

$$\nabla \cdot \underline{v} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \qquad \text{(eqn 2.8)}$$

$$\nabla T = \frac{\partial T}{\partial x}\hat{i} + \frac{\partial T}{\partial y}\hat{j} + \frac{\partial T}{\partial z}\hat{k} \qquad \text{(eqn 2.9)}$$

where $\hat{i}$, $\hat{j}$, and $\hat{k}$ are unit vectors in the x, y, and z directions. In the momentum equation the only body force B of significance is gravity. It acts in the negative z direction. As a result:

$$B_x = 0 \qquad B_y = 0 \qquad B_z = -\rho g \qquad \text{(eqn 2.10)}$$

For convenience the static equilibrium equation

$$0 = -\partial P_{Eq}/\partial z - \rho_{Eq} g \qquad \text{(eqn 2.11)}$$

is subtracted from the z-momentum equation. In equation 2.11, P_{Eq} is the equilibrium pressure and ρ_{Eq} is the equilibrium density. The resulting modified z-momentum equation shows the effects of the buoyancy more clearly. To further simplify the equations the following definitions for the heat flux q and the shear stresses τ are substituted:

$$q_x = -k_{eff}\,\partial T/\partial x \qquad \text{(eqn 2.12)}$$

$$q_y = -k_{eff}\,\partial T/\partial y \qquad \text{(eqn 2.13)}$$

$$q_z = -k_{eff}\, \partial T/\partial z \qquad \text{(eqn 2.14)}$$

$$\tau_{xx} = 2\, \mu_{eff} (\partial u/\partial x) \qquad \text{(eqn 2.15)}$$

$$\tau_{xy} = \mu_{eff} (\partial v/\partial x + \partial u/\partial y) \qquad \text{(eqn 2.16)}$$

$$\tau_{xz} = \mu_{eff} (\partial w/\partial x + \partial u/\partial z) \qquad \text{(eqn 2.17)}$$

$$\tau_{yx} = \tau_{xy} \qquad \text{(eqn 2.18)}$$

$$\tau_{yy} = 2\, \mu_{eff} (\partial v/\partial y) \qquad \text{(eqn 2.19)}$$

$$\tau_{yz} = \mu_{eff} (\partial w/\partial y + \partial v/\partial z) \qquad \text{(eqn 2.20)}$$

$$\tau_{zx} = \tau_{xz} \qquad \text{(eqn 2.21)}$$

$$\tau_{zy} = \tau_{yz} \qquad \text{(eqn 2.22)}$$

$$\tau_{zz} = 2\, \mu_{eff} (\partial w/\partial z) \qquad \text{(eqn 2.23)}$$

Incorporating these constitutive equations governing equations in rectangular coordinates become:

Continuity Equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0 \qquad \text{(eqn 2.24)}$$

Energy Equation:

$$\frac{\partial}{\partial t}(\rho h) + \frac{\partial}{\partial x}(\rho uh) + \frac{\partial}{\partial y}(\rho vh) + \frac{\partial}{\partial z}(\rho wh) = -\frac{\partial q_x}{\partial x} - \frac{\partial q_y}{\partial y} - \frac{\partial q_z}{\partial z} + S_h \qquad \text{(eqn 2.25)}$$

Momentum Equations:

$$\frac{\partial}{\partial t}(\rho u) + \frac{\partial}{\partial x}(\rho u^2) + \frac{\partial}{\partial y}(\rho uv) + \frac{\partial}{\partial z}(\rho uw) = \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z} - \frac{\partial P}{\partial x} \qquad \text{(eqn 2.26)}$$

$$\frac{\partial}{\partial t}(\rho v) + \frac{\partial}{\partial x}(\rho vu) + \frac{\partial}{\partial y}(\rho v^2) + \frac{\partial}{\partial z}(\rho vw) = \frac{\partial \tau_{yx}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z} - \frac{\partial P}{\partial y} \qquad \text{(eqn 2.27)}$$

$$\frac{\partial}{\partial t}(\rho w) + \frac{\partial}{\partial x}(\rho wu) + \frac{\partial}{\partial y}(\rho wv) + \frac{\partial}{\partial z}(\rho w^2) = \frac{\partial \tau_{zx}}{\partial x} + \frac{\partial \tau_{zy}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} - \frac{\partial (P - P_{Eq})}{\partial z} - (\rho - \rho_{Eq})g \qquad \text{(eqn 2.28)}$$

3. Comment on the Equations

These equations developed for rectangular coordinates are the basis of the numerical model. They are parabolic in time and elliptic in space. The initial conditions for the dependent variables must be supplied for every point in the calculation domain and boundary conditions for the dependent variables must be supplied for every time instant. When these conditions are met a solution is possible.

Similar but more complex equations for spherical and cylindrical coordinate systems are presented in Appendix A.

B. NON-DIMENSIONAL EQUATIONS

1. The Non-Dimensional Governing Differential Equations

For convenience in developing the numerical model the governing equations may be placed in non-dimensional form. The following non-dimensional quantities are used to form the dimensionless equations. These individual equations for the dimensionless quantities are solved for the dimensional quantity and substituted in the dimensional equations from the previous section (Equations 2.24 to 2.28).

$$\tilde{x} = x/H \qquad \tilde{y} = y/H \qquad \tilde{z} = z/H \qquad \text{(eqn 2.29)}$$

$$\tilde{u} = u/V_R \qquad \tilde{v} = v/V_R \qquad \tilde{w} = w/V_R \qquad \text{(eqn 2.30)}$$

$$\tilde{t} = t\,V_R/H \qquad \text{(eqn 2.31)}$$

$$\tilde{\rho} = \rho/\rho_R \qquad \tilde{\rho}_{Eq} = \rho_{Eq}/\rho_R \qquad \text{(eqn 2.32)}$$

$$\tilde{P} = (P - P_{Eq})/(\rho_R V_R^2) \qquad \tilde{P}_{Eq} = P_{Eq}/(\rho_R R_R T_R) \qquad \text{(eqn 2.33)}$$

$$\tilde{h} = h/C_{pR}T_R \qquad \text{(eqn 2.34)}$$

$$\tilde{\tau} = \tau/(\rho_R V_R^2) \qquad \text{(eqn 2.35)}$$

$$\tilde{q} = q\,/(\rho_R V_R C_{pR} T_R) \qquad \text{(eqn 2.36)}$$

$$\tilde{S}_h = (S_h\, H)/(\rho_R V_R C_{pR} T_R) \qquad \text{(eqn 2.37)}$$

In defining these non-dimensional quantities a number of reference values have been used. H, the height of the tank is used as a reference length. The reference values for velocity, density, temperature, specific heat at constant pressure, and the gas constant are V_R, ρ_R, T_R, C_{pR}, and R_R, respectively.

Once the substitutions for the dimensional quantities are made in the equations, several other non-dimensional quantities appear. These quantities are the turbulent Reynolds Number (Re_t), the turbulent Prandtl Number (Pr_t), the square of the Froude Number (F), and a number proportional to the square of the Mach Number (C). The definitions of these nondimensional quantities are:

$$Re_t = \rho_R V_R H / \mu_{eff} \qquad \text{(eqn 2.38)}$$

$$Pr_t = \mu_{eff} C_{pR} / k_{eff} \qquad \text{(eqn 2.39)}$$

$$F = V_R^2 / gH \qquad \text{(eqn 2.40)}$$

$$C = V_R^2 / (C_{pR} T_R) \qquad \text{(eqn 2.41)}$$

The last substitutions necessary to convert from dimensional to non-dimensional form are for the heat fluxes and shear stresses. For rectangular coordinates these quantities are:

$$\tilde{q}_x = -(\partial T/\partial x) / (Re_t Pr_t) \qquad \text{(eqn 2.42)}$$

$$\tilde{q}_y = -(\partial T/\partial y) / (Re_t Pr_t) \qquad \text{(eqn 2.43)}$$

$$\tilde{q}_z = -(\partial T/\partial z) / (Re_t Pr_t) \qquad \text{(eqn 2.44)}$$

$$\tilde{\tau}_{xx} = 2\,(\partial u/\partial x) / Re_t \qquad \text{(eqn 2.45)}$$

$$\tilde{\tau}_{xy} = (\partial v/\partial x + \partial u/\partial y) / Re_t \qquad \text{(eqn 2.46)}$$

$$\tilde{\tau}_{xz} = (\partial w/\partial x + \partial u/\partial z) / Re_t \qquad \text{(eqn 2.47)}$$

$$\tilde{\tau}_{yx} = \tau_{xy} \qquad \text{(eqn 2.48)}$$

$$\tilde{\tau}_{yy} = 2\,(\partial v/\partial y) / Re_t \qquad \text{(eqn 2.49)}$$

$$\tilde{\tau}_{yz} = (\partial w/\partial y + \partial v/\partial z) / Re_t \qquad \text{(eqn 2.50)}$$

$$\tilde{\tau}_{zx} = \tau_{xz} \qquad \text{(eqn 2.51)}$$

$$\tilde{\tau}_{zy} = \tau_{yz} \quad \text{(eqn 2.52)}$$

$$\tilde{\tau}_{zz} = 2\,(\partial w / \partial z)\,/\,Re_t \quad \text{(eqn 2.53)}$$

Making the specified substitutions in the dimensional equations results in the non-dimensional equations. These equations are listed below but the tildes have been dropped for simplicity.

Continuity Equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0 \quad \text{(eqn 2.55)}$$

Energy Equation:

$$\frac{\partial}{\partial t}(\rho h) + \frac{\partial}{\partial x}(\rho u h) + \frac{\partial}{\partial y}(\rho v h) + \frac{\partial}{\partial z}(\rho w h) = -\frac{\partial q_x}{\partial x} - \frac{\partial q_y}{\partial y} - \frac{\partial q_z}{\partial z} + S_h \quad \text{(eqn 2.56)}$$

Momentum Equations:

$$\frac{\partial}{\partial t}(\rho u) + \frac{\partial}{\partial x}(\rho u^2) + \frac{\partial}{\partial y}(\rho u v) + \frac{\partial}{\partial z}(\rho u w) = \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z} - \frac{\partial P}{\partial x} \quad \text{(eqn 2.57)}$$

$$\frac{\partial}{\partial t}(\rho v) + \frac{\partial}{\partial x}(\rho v u) + \frac{\partial}{\partial y}(\rho v^2) + \frac{\partial}{\partial z}(\rho v w) = \frac{\partial \tau_{yx}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z} - \frac{\partial P}{\partial y} \quad \text{(eqn 2.58)}$$

$$\frac{\partial}{\partial t}(\rho w) + \frac{\partial}{\partial x}(\rho w u) + \frac{\partial}{\partial y}(\rho w v) + \frac{\partial}{\partial z}(\rho w^2) = \quad \text{(eqn 2.59)}$$

$$\frac{\partial \tau_{zx}}{\partial x} + \frac{\partial \tau_{zy}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} - \frac{\partial P}{\partial z} - \frac{1}{F}(\rho - \rho_{Eq})g$$

Equations of State:

$$P\,C + P_{Eq} = \rho\,T \qquad \text{(eqn 2.60)}$$

$$h = T - 1 \qquad \text{(eqn 2.61)}$$

In all of the following sections non-dimensional quantities will be used throughout with the tildes omitted.

2. Non-Dimensional Equations in Integral Form

Thus far all of the governing equations have been expressed in differential form. In order to implement a finite difference scheme however, the conservation equations (mass, energy, and momentum) must be transformed into an integral form. This form allows the determination of the dependent variables in small but finite volumes because the integral equations are written for one such control volume. The non-dimensional integral equations below are presented in a format for rectangular coordinates. This is easily altered by shifting the x, y, and z subscripts to the appropriate independent spacial variables for whatever geometry is selected.

Continuity Equation:

$$\frac{d}{dt}\int_V \rho\, dV = -\int_S \rho\, \underline{v} \cdot \underline{n}\, dS \qquad \text{(eqn 2.62)}$$

Energy Equation:

$$\frac{d}{dt}\int_V \rho h\, dV = -\int_S \rho h\, \underline{v} \cdot \underline{n}\, dS + \int_V S_h\, dV \qquad \text{(eqn 2.63)}$$

$$- \int_S (q_x n_x + q_y n_y + q_z n_z)\, dS$$

Momentum Equations:

$$\frac{d}{dt}\int_V \rho u dV = -\int_S \rho u \underline{v} \cdot \underline{n} dS - \int_S P n_x ds$$ (eqn 2.64)

$$+ \int_S (\tau_{xx} n_x + \tau_{xy} n_y + \tau_{xz} n_z) dS$$

$$\frac{d}{dt}\int_V \rho v dV = -\int_S \rho v \underline{v} \cdot \underline{n} dS - \int_S P n_y ds$$ (eqn 2.65)

$$+ \int_S (\tau_{yx} n_x + \tau_{yy} n_y + \tau_{yz} n_z) dS$$

$$\frac{d}{dt}\int_V \rho w dV = -\int_S \rho w \underline{v} \cdot \underline{n} dS - \int_S P n_z ds$$ (eqn 2.66)

$$+ \int_S (\tau_{zx} n_x + \tau_{zy} n_y + \tau_{zz} n_z) dS - (\rho - \rho_{Eq}) g/F$$

In these equations V is the control volume, S is a surface of the control volume and n is and outward pointing normal at a particular surface. [Ref. 10: pp. 8-13]

C. FINITE DIFFERENCE EQUATIONS

In order to develop a finite difference algorithm the total volume to be modeled must be divided into a large number of finite cells. The conservation equations are applied to each volume with the boundary conditions applied at the appropriate surfaces. The rectangular geometry described here has a uniform grid. The cells are therefore all identical and the derivation of the equations is relatively simple. In the cylindrical/spherical geometry discussed in Appendix A the radial grid is non-uniform and more complex. To make the application of the boundary conditions easier the cell boundaries coincide with the physical boundaries. In this finite difference algorithm the temperature, density, and pressure are calculated at the basic grid points. The velocity grids are staggered one half of a cell from the basic grid. Patankar gives a detailed explanation of the reasons for using a staggered grid in [Ref. 8: pp. 118-120]. Basically, there are two reasons for the staggered grid. First the velocity is easily calculated as a function of the pressures of the basic cells on either side of the staggered cell. Figure 2.1 illustrates this for a one dimensional system. With the pressure known at basic cells A and B it is easier to calculate the velocity at B* the center of the staggered cell rather than at either of the basic cells A or B. The second reason for using a staggered grid is that the difference of adjacent velocities is used in the continuity equation which eliminates an unrealistic oscillating solution. [Ref. 8: p.120]

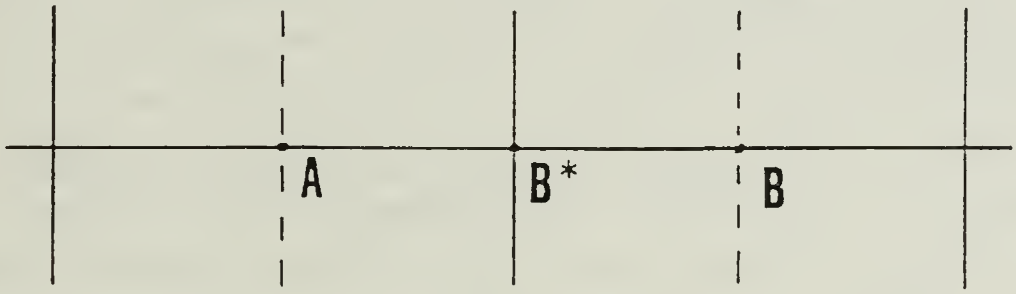

Figure 2.1 One-Dimensional Staggered Cell.

In developing the finite difference equations finite quantities are substituted for the differential element in the integral form of the equations. For example. $dV = \Delta x \Delta y \Delta z$ where the Δ quantities are finite quantities. Similar substitutions are made for the various fluxes across the cell boundaries. Two distinct differencing techniques are used in this numerical scheme. Forward differencing is used for the time steps and upwind differencing [Ref. 8: pp. 83-85] is used for the energy and momentum fluxes. In the forward difference technique a future value of the dependent variable is predicted from a previous one plus a known slope multiplied by the time step. For the continuity equation

$$\rho = \rho^{\circ} + m\,\Delta t \qquad \text{(eqn 2.67)}$$

where ρ° is the value of the density at the previous time step. ρ is the new value. and m is a slope. Using this scheme for the time dependent term in the continuity equation

$$\frac{d}{dt}\int_V \rho\, dV = \frac{\partial \rho}{\partial t}_{cell}\, dV = \frac{\rho - \rho^{\circ}}{\Delta t}\Delta x \Delta y \Delta z \qquad \text{(eqn 2.68)}$$

As previously stated upwind differencing is employed in the calculation of the fluxes across the cell surfaces. Using the energy equation as an example, the value of the enthalpy h and hence the temperature in the cell under consideration depends on the enthalpy in the upwind cell, not the downwind cell. The upwind cell is defined as the cell from which the flow or velocity is coming.

The basic cell shown in Figure 2.2 is used for the continuity and energy equations. To ease the development of the equations, directions have been assigned to the coordinate axes. East is in the positive x direction, west is negative. North is in the positive y direction, south is negative and top is in the positive z direction while bottom is negative. The center cell P is the control volume under consideration. The cell to the east is E and the boundary surface between them is e. The other adjacent cells follow the same convention. Since the velocity cells are staggered, velocities are known at the boundaries between the basic cells. The temperature, pressure, and density are known at the basic cells.

To simplify the equations mass fluxes at the basic P cell boundaries are defined as follows:

$$G_e = .5\,(\rho_E + \rho_P)\,u_e \qquad \text{(eqn 2.69)}$$

$$G_w = .5\,(\rho_P + \rho_W)\,u_w \qquad \text{(eqn 2.70)}$$

$$G_n = .5\,(\rho_N + \rho_P)\,v_n \qquad \text{(eqn 2.71)}$$

$$G_s = .5\,(\rho_P + \rho_S)\,v_s \qquad \text{(eqn 2.72)}$$

$$G_t = .5\,(\rho_T + \rho_P)\,w_t \qquad \text{(eqn 2.73)}$$

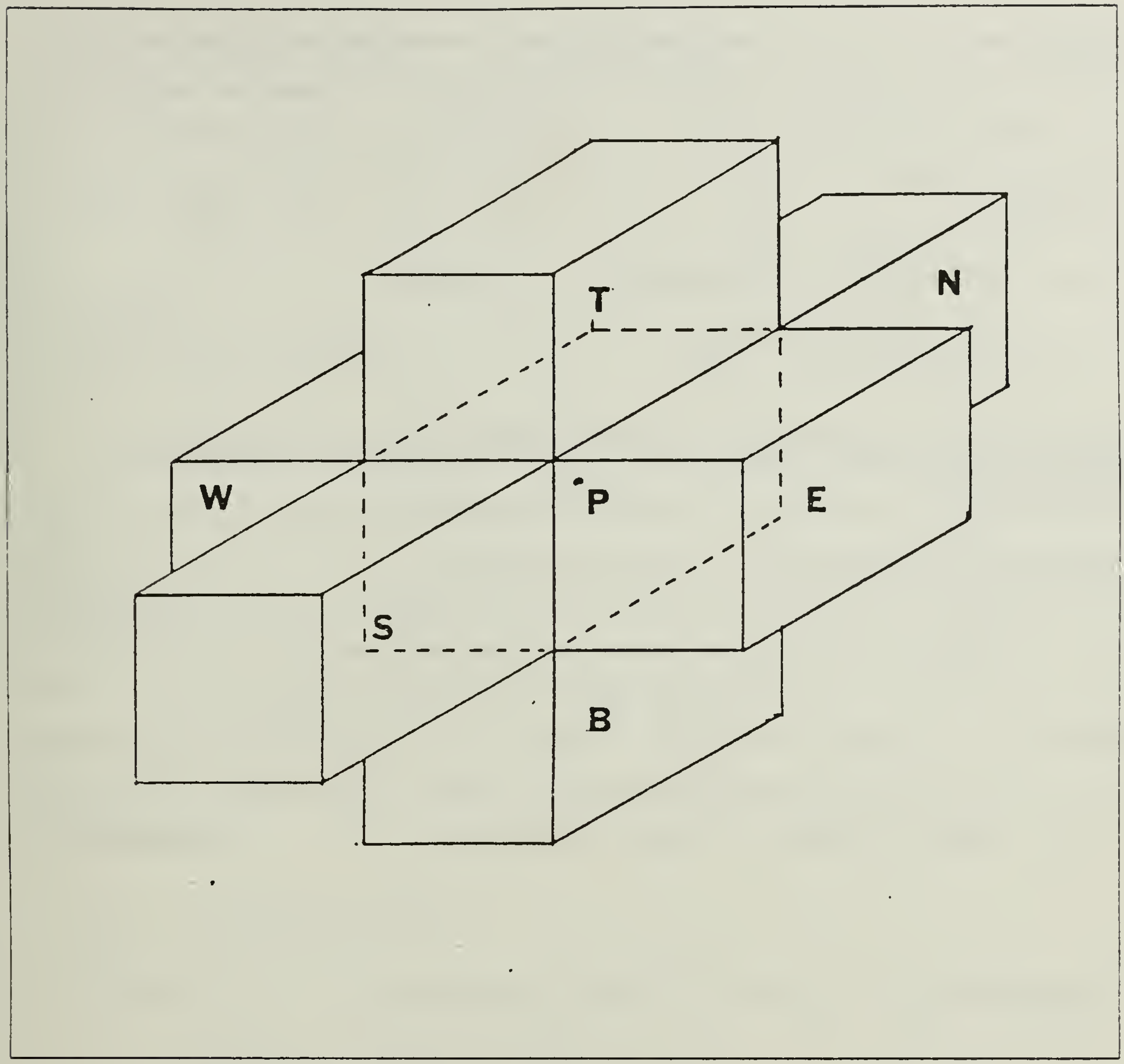

Figure 2.2 Basic Rectangular Cell Grid.

$$G_b = .5\,(\rho_P + \rho_B)\,w_b \qquad \text{(eqn 2.74)}$$

Ideally in the continuity equation the sum of the mass fluxes entering the cell is zero but for the iterative numerical solution this will not be true, especially initially. The sum of the mass fluxes will equal a finite non-zero value which is called the mass source term S_m. As the solution is iterated and converges, the mass source term becomes smaller and smaller until it is less than a cutoff value which is made close to zero. With infinite iterations and infinite machine accuracy Sm would become

identically equal to zero and the continuity equation would be satisfied exactly. In the actual numerical solution it is satisfied only approximately. Utilizing the definitions for the mass fluxes and the mass source the continuity equation in finite difference form is:
Continuity Equation:

$$(\rho_P - \rho^\circ_P)\Delta x\Delta y\Delta z/\delta t + (G_e - G_w)\Delta y\Delta z + (G_n - G_s)\Delta z\Delta x + (G_t - G_b)\Delta x\Delta y = Sm_P \qquad \text{(eqn 2.75)}$$

The other conservation equation that utilizes the basic cell is the energy equation.
Energy Equation:

$$[{}^hA_P + \rho^\circ_P \Delta x\Delta y\Delta z/\Delta t]\, h_P = {}^hA_E h_E + {}^hA_W h_W + {}^hA_N h_N + {}^hA_S h_S + {}^hA_T h_T + {}^hA_B h_B + {}^hS_P \qquad \text{(eqn 2.76)}$$

where

$${}^hA_E = .5(|G_e| - G_e)\Delta y\Delta z + (1/Re_tPr_t)_e\, \Delta y\Delta z/\Delta x \qquad \text{(eqn 2.77)}$$

$${}^hA_W = .5(|G_w| + G_w)\Delta y\Delta z + (1/Re_tPr_t)_w\, \Delta y\Delta z/\Delta x \qquad \text{(eqn 2.78)}$$

$${}^hA_N = .5(|G_n| - G_n)\Delta z\Delta x + (1/Re_tPr_t)_n\, \Delta z\Delta x/\Delta y \qquad \text{(eqn 2.79)}$$

$${}^hA_S = .5(|G_s| + G_s)\Delta z\Delta x + (1/Re_tPr_t)_s\, \Delta z\Delta x/\Delta y \qquad \text{(eqn 2.80)}$$

$${}^hA_T = .5(|G_t| - G_t)\Delta x\Delta y + (1/Re_tPr_t)_t\, \Delta x\Delta y/\Delta z \qquad \text{(eqn 2.81)}$$

$$ {}^{h}A_B = .5(|G_b| + G_b)\Delta x\Delta y + (1/Re_t Pr_t)_b \, \Delta x\Delta y/\Delta z \quad \text{(eqn 2.82)} $$

$$ {}^{h}A_P = {}^{h}A_E + {}^{h}A_W + {}^{h}A_N + {}^{h}A_S + {}^{h}A_T + {}^{h}A_B \quad \text{(eqn 2.83)} $$

$$ {}^{h}S_P = \rho^{\circ}{}_P \, h^{\circ}{}_P \, \Delta x\Delta y\Delta z \quad \text{(eqn 2.84)} $$

The momentum equations are slightly more complex because of the staggered cells and the additional terms introduced by the shear stress tensor. The grid for the x-momentum equation is shifted one half cell to the left (the negative x-direction) and quantities in this grid are designated with a ^{a} superscript. Similarly, the staggered grids for the y and z-momentum equations are shifted one half cell in the negative y and z directions from the basic cell and these are designated with ^{b} and ^{c} superscripts, respectively. Figures 2.3, 2.4, and 2.5 show these grids with respect to the basic grid for the xy, yz, and zx planes. The finite difference momentum equations are:

X-Momentum:

$$ [A_{P^a} + \rho^{\circ}{}_{P^a} \, \Delta x\Delta y\Delta z/\Delta t] \, u_{P^a} = $$

$$ A_{E^a} u_{E^a} + A_{W^a} u_{W^a} + A_{N^a} u_{N^a} \quad \text{(eqn 2.85)} $$

$$ + A_{S^a} u_{S^a} + A_{T^a} u_{T^a} + A_{B^a} u_{B^a} + S_{P^a} $$

where

$$ A_{E^a} = [.5(|G_{e^a}| - G_{e^a}) + (1/Re_t)_{e^a} /\Delta x] \, \Delta y\Delta z \quad \text{(eqn 2.86)} $$

$$ A_{W^a} = [.5(|G_{w^a}| + G_{w^a}) + (1/Re_t)_{w^a} /\Delta x] \, \Delta y\Delta z \quad \text{(eqn 2.87)} $$

$$ A_{N^a} = [.5(|G_{n^a}| - G_{n^a}) + (1/Re_t)_{n^a} /\Delta y] \, \Delta z\Delta x \quad \text{(eqn 2.88)} $$

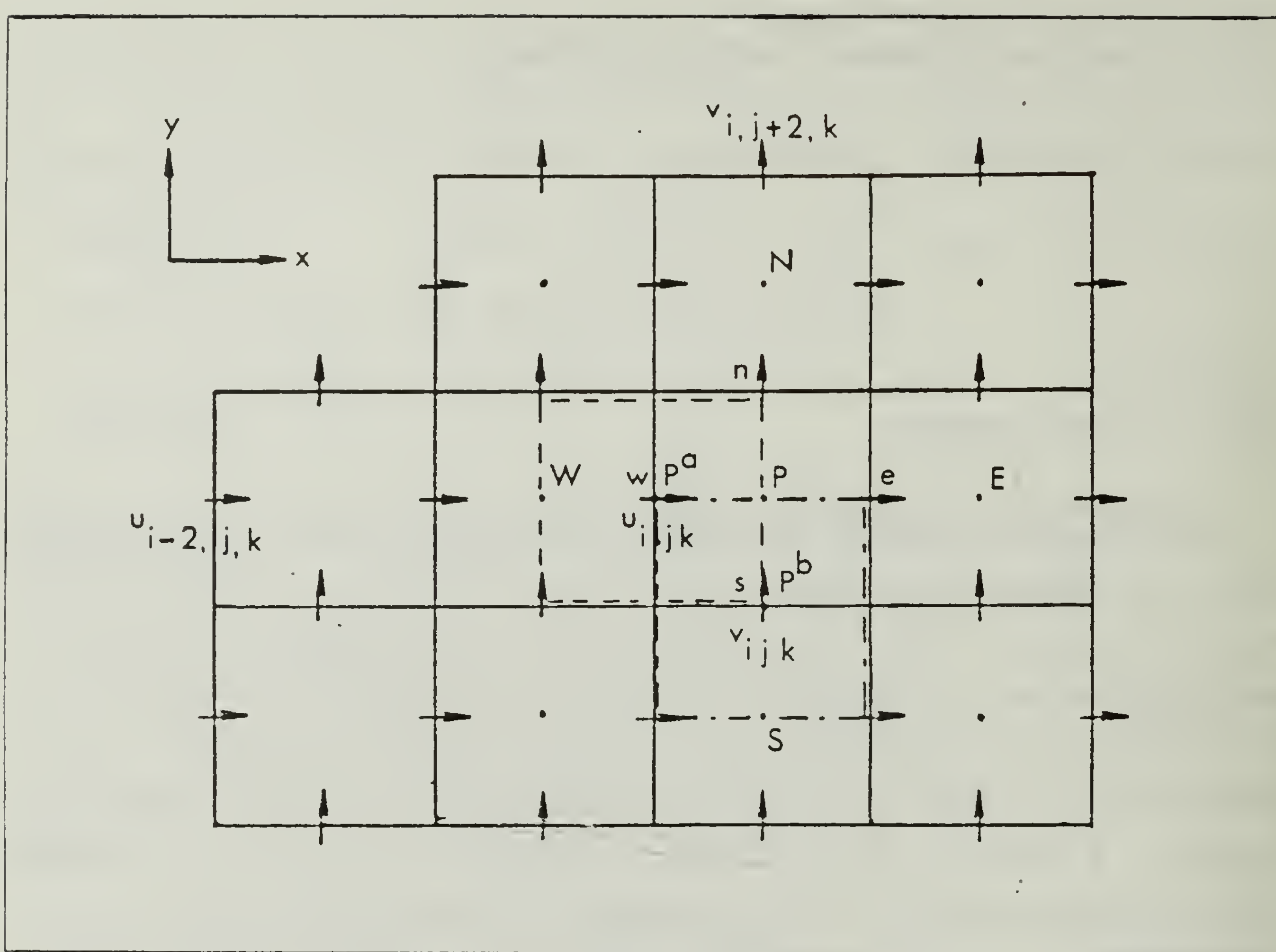

Figure 2.3 Staggered Grid XY Plane.

$$A_S a = [.5(|G_s a| + G_s a) + (1\ Re_t)_s a\ \Delta y]\ \Delta z \Delta x \qquad \text{(eqn 2.89)}$$

$$A_T a = [.5(|G_t a| - G_t a) + (1\ Re_t)_t a\ \Delta z]\ \Delta x \Delta y \qquad \text{(eqn 2.90)}$$

$$A_B a = [.5(|G_b a| - G_b a) + (1\ Re_t)_b a\ \Delta z]\ \Delta x \Delta y \qquad \text{(eqn 2.91)}$$

$$A_P a = A_E a + A_W a + A_N a + A_S a + A_T a + A_B a \qquad \text{(eqn 2.92)}$$

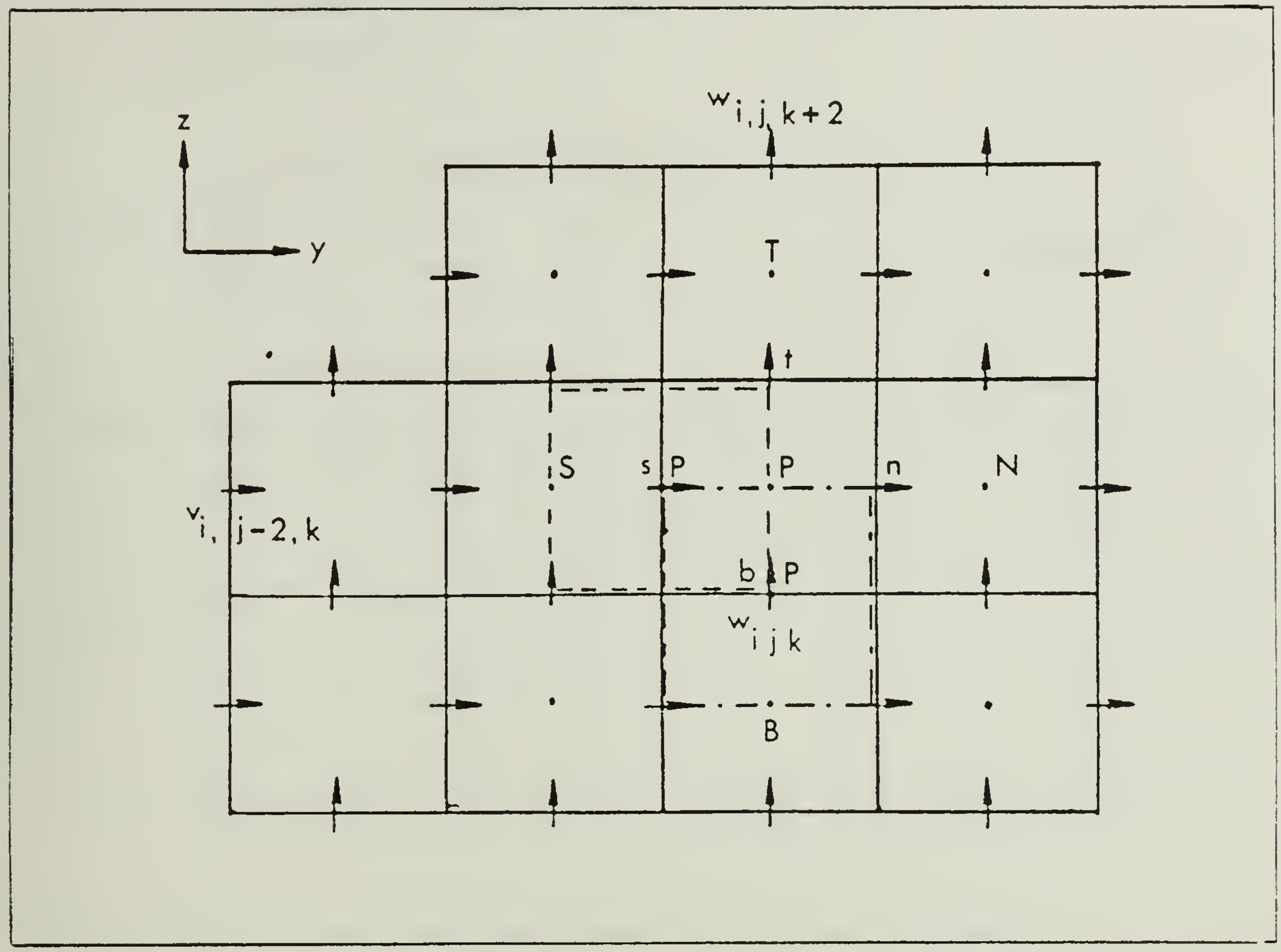

Figure 2.4 Staggered Grid YZ Plane.

$$S_{pa} = \rho^{\circ}_{pa} u^{\circ}_{pa} \Delta x \Delta y \Delta z / \Delta t - (P_P - P_W)\Delta y \Delta z$$

$$+ (u_{ea} - u_{wa})(1/Re_t)_{ea} \Delta y \Delta z / \Delta x$$

$$- (u_{wa} - u_{i-1,j,k})(1/Re_t)_{wa} \Delta y \Delta z / \Delta x \qquad \text{(eqn 2.93)}$$

$$+ [(v_{i,j+1,k} - v_{i-1,j+1,k})(1/Re_t)_{na} - (v_{i,j,k} - v_{i-1,j,k})(1/Re_t)_{sa}]\Delta z$$

$$+ [(w_{i,j,k+1} - w_{i-1,j,k+1})(1/Re_t)_{ta} - (w_{i,j,k} - w_{i-1,j,k})(1/Re_t)_{ba}]\Delta y$$

and in these equations

$$\rho^{\circ}_{pa} = (\rho^{\circ}_P + \rho^{\circ}_W)/2 \qquad \text{(eqn 2.94)}$$

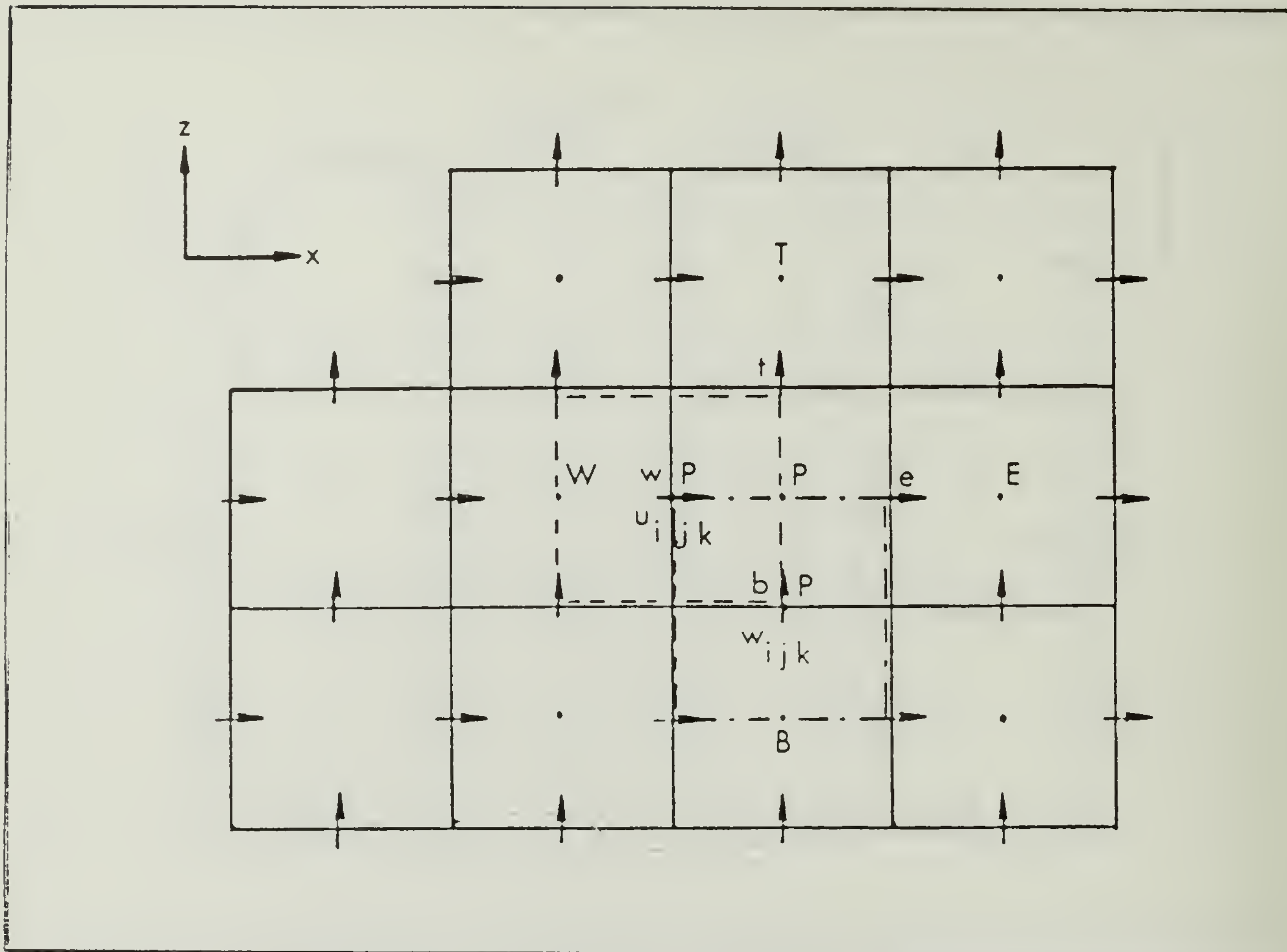

Figure 2.5 Staggered Grid ZX Plane.

$$u_{i,j,k} = u_w \qquad u_{i+1,j,k} = u_e \qquad \text{(eqn 2.95)}$$

$$u_e{}^a = (u_e + u_w)\ 2 \qquad \text{(eqn 2.96)}$$

$$u_w{}^a = (u_w + u_{i-1,j,k})\ 2 \qquad \text{(eqn 2.97)}$$

$$u_n{}^a = (u_{i,j+1,k} + u_w)\ 2 \qquad \text{(eqn 2.98)}$$

$$u_s^a = (u_w + u_{i,j-1,k}) / 2 \qquad \text{(eqn 2.99)}$$

$$u_t^a = (u_{i,j,k+1} + u_w) / 2 \qquad \text{(eqn 2.100)}$$

$$u_b^a = (u_w + u_{i,j,k-1}) / 2 \qquad \text{(eqn 2.101)}$$

$$\rho_{i,j,k} = \rho_P \qquad \text{(eqn 2.102)}$$

$$G_e^a = \rho_P u_e^a \qquad \text{(eqn 2.103)}$$

$$G_w^a = \rho_W u_w^a \qquad \text{(eqn 2.104)}$$

$$G_n^a = [.5(\rho_N + \rho_P)v_n + .5(\rho_{i-1,j+1,k} + \rho_W)\, v_{i-1,j+1,k}] / 2 \qquad \text{(eqn 2.105)}$$

$$G_s^a = [.5(\rho_P + \rho_S)v_s + .5(\rho_W + \rho_{i-1,j-1,k})\, v_{i-1,j,k}] / 2 \qquad \text{(eqn 2.106)}$$

$$G_t^a = [.5(\rho_T + \rho_P)w_t + .5(\rho_{i-1,j,k+1} + \rho_W)\, w_{i-1,j,k+1}] / 2 \qquad \text{(eqn 2.107)}$$

$$G_b^a = [.5(\rho_P + \rho_B)w_b + .5(\rho_W + \rho_{i-1,j,k-1})\, w_{i-1,j,k}] / 2 \qquad \text{(eqn 2.108)}$$

Y-Momentum:

$$[A_P{}^b + \rho^\circ{}_P{}^b \Delta x \Delta y \Delta z / \Delta t]\, v_P{}^b =$$

$$A_E{}^b v_E{}^b + A_W{}^b v_W{}^b + A_N{}^b v_N{}^b \qquad \text{(eqn 2.109)}$$

$$+ A_S{}^b v_S{}^b + A_T{}^b v_T{}^b + A_B{}^b v_B{}^b + S_P{}^b$$

where

$$A_E{}^b = [.5(|G_e{}^b| - G_e{}^b)$$

$$+ (1/Re_t)_e{}^b / \Delta x]\, \Delta y \Delta z \qquad \text{(eqn 2.110)}$$

$$A_W{}^b = [.5(|G_w{}^b| + G_w{}^b)$$

$$+ (1/Re_t)_w{}^b / \Delta x]\, \Delta y \Delta z \qquad \text{(eqn 2.111)}$$

$$A_N{}^b = [.5(|G_n{}^b| - G_n{}^b)$$

$$+ (1/Re_t)_n{}^b / \Delta y]\, \Delta z \Delta x \qquad \text{(eqn 2.112)}$$

$$A_S{}^b = [.5(|G_s{}^b| + G_s{}^b)$$

$$+ (1/Re_t)_s{}^b / \Delta y]\, \Delta z \Delta x \qquad \text{(eqn 2.113)}$$

$$A_T{}^b = [.5(|G_t{}^b| - G_t{}^b)$$

$$+ (1/Re_t)_t{}^b / \Delta z]\, \Delta x \Delta y \qquad \text{(eqn 2.114)}$$

$$A_B{}^b = [.5(|G_b{}^b| - G_b{}^b)$$
$$+ (1/Re_t)_b{}^b / \Delta z]\, \Delta x \Delta y \qquad \text{(eqn 2.115)}$$

$$A_P{}^b = A_E{}^b + A_W{}^b + A_N{}^b + A_S{}^b$$

$$+ A_T{}^b + A_B{}^b \qquad \text{(eqn 2.116)}$$

$$S_P{}^a = \rho^\circ{}_P{}^b v^\circ{}_P{}^b \Delta x \Delta y \Delta z / \Delta t - (P_P - P_S) \Delta z \Delta x$$

$$+ (u_{i+1,j,k} + u_{i+1,j-1,k})(1/Re_t)_e{}^b \Delta y$$

$$- (u_{i,j,k} - u_{i,j-1,k})(1/Re_t)_w{}^b \Delta y$$

$$+ (v_n{}^b - v_s{}^b)(1/Re_t)_n{}^b\ \Delta z\Delta x/\Delta y \quad \text{(eqn 2.117)}$$

$$- (v_s{}^b - v_{i,j-1,k})(1/Re_t)_s{}^b\ \Delta z\Delta x/\Delta y$$

$$+ (w_{i,j,k+1} - w_{i,j-1,k+1})(1/Re_t)_t{}^b\ \Delta x$$

$$- (w_{i,j,k} - w_{i,j-1,k})(1/Re_t)_b{}^b\ \Delta x$$

Equations similar to Equations 2.94 to 2.108 may be easily formulated for the Y and Z momentum equations but they are omitted here for the sake of brevity.
Z-Momentum:

$$[A_P{}^c + \rho^\circ{}_P{}^c\ \Delta x\Delta y\Delta z/\Delta t]\ w_P{}^c =$$

$$A_E{}^c\ w_E{}^c + A_W{}^c\ w_W{}^c + A_N{}^c\ w_N{}^c \quad \text{(eqn 2.118)}$$

$$+ A_S{}^c\ w_S{}^c + A_T{}^c\ w_T{}^c + A_B{}^c\ w_B{}^c + S_P{}^c$$

where

$$A_E{}^c = [.5(|G_e{}^c| - G_e{}^c) + (1/Re_t)_e{}^c/\Delta x]\ \Delta y\Delta z \quad \text{(eqn 2.119)}$$

$$A_W{}^c = [.5(|G_w{}^c| + G_w{}^c) + (1/Re_t)_w{}^c/\Delta x]\ \Delta y\Delta z \quad \text{(eqn 2.120)}$$

$$A_N{}^c = [.5(|G_n{}^c| - G_n{}^c) + (1/Re_t)_n{}^c/\Delta y]\ \Delta z\Delta x \quad \text{(eqn 2.121)}$$

$$A_S{}^c = [.5(|G_s{}^c| + G_s{}^c) + (1/Re_t)_s{}^c/\Delta y]\ \Delta z\Delta x \quad \text{(eqn 2.122)}$$

$$A_T{}^c = [.5(|G_t{}^c| - G_t{}^c) + (1/Re_t)_t{}^c/\Delta z]\ \Delta x\Delta y \quad \text{(eqn 2.123)}$$

$$A_{B^c} = [.5(|G_{b^c}| - G_{b^c}) + (1/Re_t)_{b^c}/\Delta z]\,\Delta x \Delta y \qquad \text{(eqn 2.124)}$$

$$A_{P^c} = A_{E^c} + A_{W^c} + A_{N^c} + A_{S^c} + A_{T^c} + A_{B^c} \qquad \text{(eqn 2.125)}$$

$$\begin{aligned} S_{P^c} = {} & \rho^\circ_{P^c}\, w^\circ_{P^c}\, \Delta x \Delta y \Delta z/\Delta t - (P_P - P_B)\Delta x \Delta y \\ & - (\rho^\circ_{P^c} - \rho_{Eq,P^c})\Delta x \Delta y \Delta z/F \\ & + (u_{i+1,j,k} + u_{i+1,j,k-1})(1/Re_t)_{e^c}\,\Delta z \\ & - (u_{i,j,k} - u_{i,j,k-1})(1/Re_t)_{w^c}\,\Delta z \\ & + (v_{i,j+1,k} - v_{i,j+1,k-1})(1/Re_t)_{n^c}\,\Delta x \\ & - (v_{i,j,k} - v_{i,j,k-1})(1/Re_t)_{s^c}\,\Delta x \\ & + (w_{t^c} - w_{b^c})(1/Re_t)_{t^c}\,\Delta x \Delta y/\Delta z \\ & - (w_{b^c} - w_{i,j,k-1})(1/Re_t)_{b^c}\,\Delta x \Delta y/\Delta \end{aligned} \qquad \text{(eqn 2.126)}$$

In each equation, velocities corresponding to the primary direction of momentum transfer in each momentum equation are expressed with the e, w, n, s, t, and b subscripts. Thus in the x-momentum equation u velocities have these subscripts. Because of the complexity of the equations the other velocities such as v and w velocities in the x momentum equation have i, j, and k subscripts. When using this notation $v_{i,j,k}$ is the v velocity at P^b or the center of the v grid. Similarly $w_{i,j,k}$ is at P^c and $u_{i,j,k}$ is at P^a.

D. INITIAL CONDITIONS AND BOUNDARY CONDITIONS

In order to obtain solutions to the governing equations initial and boundary conditions must be applied to the model. Because of the setup of the model with the cell boundaries corresponding to the physical boundaries the applications of these conditions is relatively easy.

1. **Initial Conditions**

The initial conditions correspond to the Fire I test vessel just prior to a test. The air is initially motionless so the velocity field is set equal to zero. The pressure distribution is the static equilibrium distribution in the tank. The ambient temperature is an input to the program and corresponds to a non-dimensional temperature of 1 at all points.

2. **Boundary Conditions**

Because the chamber is sealed no mass flows across any of its surfaces. Thus the velocity and hence the mass flux normal to any surface is zero. No slip conditions are also taken at the walls so all velocities at the walls are zero. The boundary conditions for the energy equations are more complex because thermal radiation energy is deposited at the interior wall surfaces and the steel walls conduct energy to the exterior walls where it is convected away. In this model the innermost wall cell is the outermost cell for the cavity calculation domain. The determination of the temperatures in the wall cells is discussed in detail in the conduction model section. The effect of the energy transported to the wall by the thermal radiation is also discussed there.

E. TURBULENCE MODEL

The turbulence model used in the algorithm is an algebraic model. The relatively simple algebraic type of model was selected because the desired outputs of the program are the average values of the dependent variables which the algebraic model predicts adequately while using much less computational time than its rivals. More complex models are required when computation of turbulent characteristics is desired. Nee and Liu presented in [Ref. 11: p. 107] a model which is satisfactory for obtaining the effective viscosity (μ_{eff}) in recirculating buoyant flows with large variations in the turbulence level. In dimensionless form, when generalized to three dimensional flows, the equation is

$$\frac{\mu_{eff}}{\mu_o} = 1 + \frac{(u_y{}^2+v_x{}^2+v_y{}^2+w_z{}^2+w_x{}^2+u_z{}^2)^{1/2}(1/H)^2}{2 + \dfrac{Ri}{Pr_t}} \qquad \text{(eqn 2.127)}$$

where Ri is the Richardson number defined as

$$Ri = \frac{gH}{V_R^2} \frac{(\partial T/\partial z)}{(\partial u/\partial z)^2 + (\partial v/\partial z)^2} \qquad \text{(eqn 2.128)}$$

Pr_t is the turbulent Prandtl number, 1 H is the non-dimensional mixing length given as

$$\frac{1}{H} = K \left[\frac{\sqrt{\sum_i u_i^2}}{\sqrt{\sum_{i,j} \left[\frac{\partial u_i}{\partial x_j}\right]^2}} + \frac{\sqrt{\sum_{i,j} \left[\frac{\partial u_i}{\partial x_j}\right]^2}}{\sqrt{\sum_i \left[\frac{\partial u_i}{\partial x_j \partial x_j}\right]^2}} \right] \qquad \text{(eqn 2.129)}$$

and K in the mixing length equation is an adjustable constant. The effective conductivity is related to the effective velocity by the following equation:

$$k_{eff} = \frac{1}{Pr} + \frac{1}{Pr_t} \frac{\mu_{eff}}{\mu_o} \qquad \text{(eqn 2.130)}$$

where Pr is the molecular Prandtl number.

F. CONDUCTION MODEL

In the later stages of the fire tests in the Fire I Test Chamber the bulk of the heat energy transferred into the cavity is lost through the walls. As a result the incorporation of a conduction model in the numerical model is vital if the numerical simulation is to bear any resemblence to the actual test results.

A simple one dimensional model described by Chang and Yang in [Ref. 12: pp. 24-27] is used here. The model consists of 2.5 cells through the wall thickness. A constant thermal conductivity for the steel is used and an appropriate convection coefficient for the outside wall must be selected. Figure 2.6 shows the setup of the wall cells. Three types of equations are necessary to describe this situation: One for the cells in contact with the outside, one for the center cells, and one for the inside wall cells. The equations shown below are written for a wall section at the bottom of the rectangular box so the area for the heat transfer is $\Delta x \Delta y$ and the outward normal is in the negative z direction. The equations are shown in dimensional form. Starting from the outside where the cell is 1/2 the thickness of the interior cells the one dimensional equation using the convection boundary condition on the outside is:

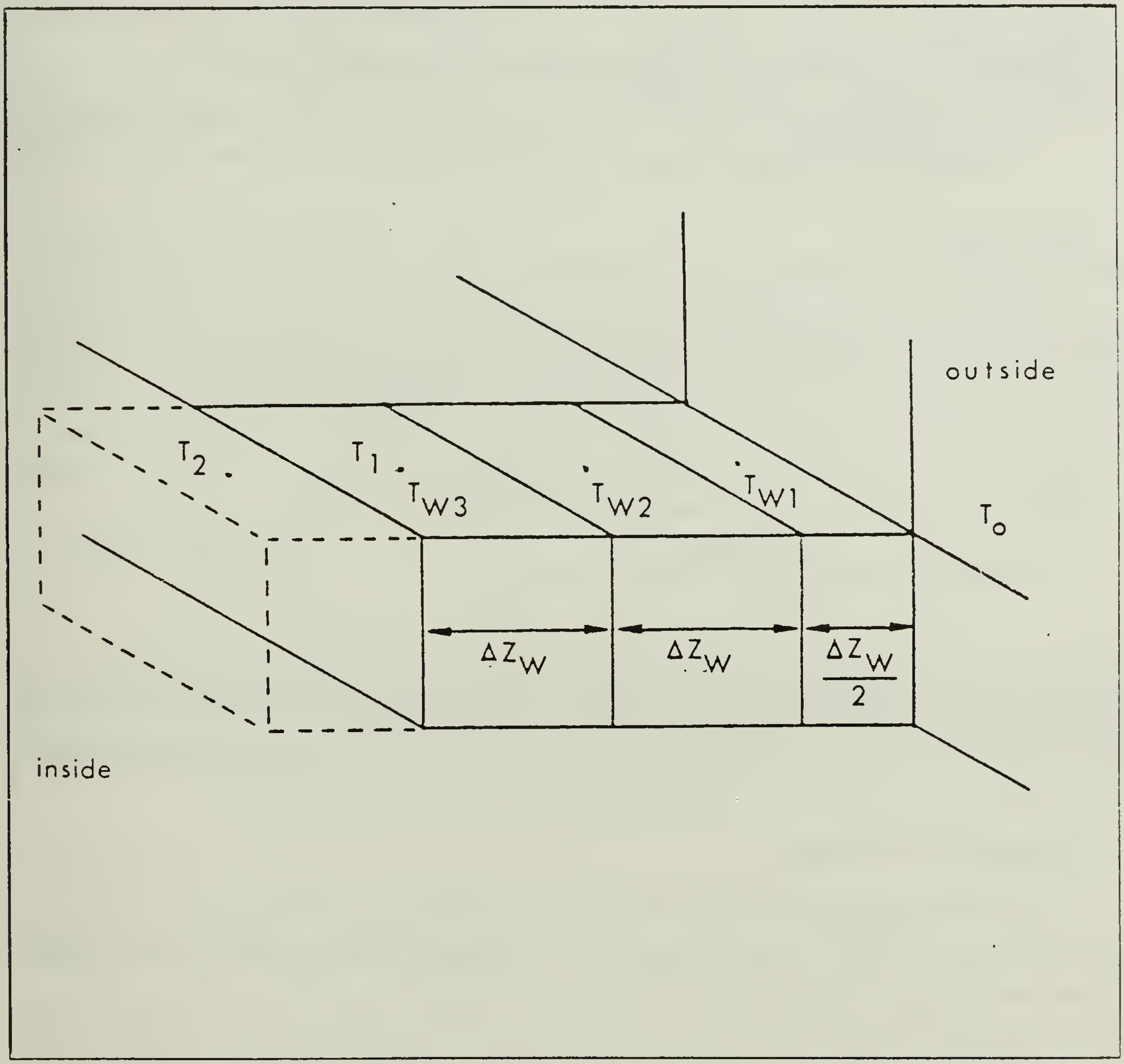

Figure 2.6 Arrangement of Cells in the Wall Conduction Model.

$$\frac{k_W}{\Delta z_W}\Delta x \Delta y(T^\circ_{W2} - T^\circ_{W1}) - h\Delta x\Delta y(T^\circ_{W1} - T^\circ_{o}) = \qquad \text{(eqn 2.131)}$$

$$\rho C_{pW}\frac{\Delta x\Delta y\Delta z}{2\ \Delta t}(T_{W1}-T^{\circ}_{W1})$$

For a center cell the equation is:

$$\frac{k_W}{\Delta z_W}\Delta x\Delta y(T^{\circ}_{W3} - T^{\circ}_{W2}) - \frac{k_W}{\Delta z_W}\Delta x\Delta y(T^{\circ}_{W2} - T^{\circ}_{W1}) = \rho C_{pW}\frac{\Delta x\Delta y\Delta z}{\Delta t}(T_{W2}-T^{\circ}_{W2}) \qquad \text{(eqn 2.132)}$$

On the inside wall the wall cell is also included in the cavity domain so T_{W3} in the wall is the same a T_1 for the cavity calculations. T_2 is the first non-wall cell in the cavity. Using this nomenclature the equation for the inside of the cavity wall cell is:

$$\frac{k_W}{\Delta z_{W/2}}\Delta x\Delta y(T^{\circ}_{2} - T^{\circ}_{1}) - \frac{k_W}{\Delta z_W}\Delta x\Delta y(T^{\circ}_{W3} - T^{\circ}_{W2}) + Q_r = \rho C_{pW}\frac{\Delta x\Delta y\Delta z}{\Delta t}(T_{W3} - T^{\circ}_{W3}) \qquad \text{(eqn 2.133)}$$

In these equations k_W is the wall conductivity, Δz_W is the thickness of a full size wall cell, ρC_{pW} is the heat capacitance of the wall material and in the inside wall cell equation Q_r is the heat input to the inside cell by thermal radiation.

G. RADIATION MODEL

The radiation model used in the numerical model only accounts for the surface to surface radiation effects. The gas inside the test vessel is assumed to be transparent and nonparticipating. This assumption tends to increase the heat transfer to the inside vessel walls [Ref. 13: pp. 142-161]. The effect of the model therefore is to take energy directly from the location of the fire and deposit it on the walls of the tank thereby affecting the boundary conditions for the energy equation at these walls. The term for this addition of energy at the wall has already been utilized in the conduction model. The surfaces of the tank and the fire are assumed to be gray. All radiation whether reflected or emitted from a surface is assumed to be diffuse.

1. **The Method for Calculating the Radiant Heat Transfer.**

The net radiosity method for the interchange of radiation between gray surfaces as described by Sparrow and Cess in [Ref. 14: pp. 90-94] is the basis of the radiation model. The aim is to accurately model the radiation effects while using as little computation time as possible.

In order to understand the radiation model a number of terms must be defined. The net rate of energy loss by a surface (i) due to radiation is equal to the energy emitted minus the energy absorbed or

$$Q_i/A_i = \varepsilon_i \sigma T_i^4 - \alpha_i H_i \qquad \text{(eqn 2.134)}$$

where ε_i is the emittance, σ is the Stephan-Boltzman constant, α_i is the absorptance, and H_i is the incident radiant energy per unit time and area. The radiosity B_i is the rate at which radiant energy leaves a surface and equals the radiation emitted plus the radiation reflected.

$$B_i = \varepsilon_i \sigma T_i^4 + \rho_i H_i \qquad \text{(eqn 2.135)}$$

In this equation ρ_i is the reflectance of the surface. Since the tank surface is assumed opaque no thermal radiation is transmitted through the material so it must be either reflected or absorbed and

$$\rho_i + \alpha_i = 1 \qquad \text{(eqn 2.136)}$$

Also since the surfaces are assumed gray

$$\alpha_i = \varepsilon_i \qquad \text{(eqn 2.137)}$$

Combining this with Equation 2.136

$$\rho_i = 1 - \varepsilon_i \qquad \text{(eqn 2.138)}$$

With the definitions above the calculation procedure for the radiation energy fluxes can be developed. Substituting for ρ_i in Equation 2.135

$$B_i = \varepsilon_i \sigma T_i^4 + (1 - \varepsilon_i) H_i \qquad \text{(eqn 2.139)}$$

Now recalling that H_i is the energy incident on surface (i), H_i can be defined as the sum of the radiosities B_j for each of the surfaces in the enclosure multiplied by the shape factor F_{ij} where F_{ij} is the fraction of energy emitted from surface (j) that is incident on surface (i).

$$H_i = \sum B_j F_{ij} \qquad \text{(eqn 2.140)}$$

The radiosity now becomes

$$B_i = \varepsilon_i \sigma T_i^4 + (1 - \varepsilon_i) \sum B_j F_{ij} \qquad \text{(eqn 2.141)}$$

where $1 \leq i \leq N$ which gives N equations for N surfaces. To find the net heat loss at a particular surface substitute B_i from Equation 2.139 into

$$\frac{Q_i}{A_i} = \frac{\varepsilon_i}{1 - \varepsilon_i} (\sigma T_i^4 - B_i^4) \qquad \text{(eqn 2.142)}$$

This equation, Equation 2.142 was found by solving for H_i in Equation 2.139 and substituting into equation 2.134.

As just mentioned, the heat loss from each surface may be found by solving the N simultaneous equations resulting from Equation 2.141 and then substituting into Equation 2.142. In order to solve the N simultaneous equations the temperature and emittance of each of the N surfaces must be known as well as the view factors from every surface to every other surface. By manipulation of the equations it is possible to set up a situation where the simultaneous equations need only to be solved once and then the temperatures raised to the fourth power in vector form are multiplied by an unchanging square matrix to yield the heat loss rates for each surface. In the equations which follow, [] brackets enclose a square matrix and < > brackets enclose a column vector. Using matrix notation Equation 2.141 is written as

$$[C] <B> = \sigma <T^4> \qquad \text{(eqn 2.143)}$$

where each element in the C matrix is defined by

$$C_{ij} = [\delta_{ij} - (1-\varepsilon_i) F_{ij}] / \varepsilon_i \qquad \text{(eqn 2.144)}$$

In Equation 2.144, δ_{ij} is the Kronecker delta so if $i = j$ then δ_{ij} is one, otherwise δ_{ij} is zero. Solving Equation 2.143 for $<B>$

$$<B> = [C]^{-1} \sigma <T^4> \qquad \text{(eqn 2.145)}$$

Now to solve for the heat loss rate substitute Equation 2.145 into Equation 2.142 so that

$$<Q_i/A_i> = [G] \sigma <T^4> \qquad \text{(eqn 2.146)}$$

where

$$G_{ij} = (\delta_{ij} - D_{ij}) \varepsilon_i / (1 - \varepsilon_i) \qquad \text{(eqn 2.147)}$$

and

$$[D] = [C]^{-1} \qquad \text{(eqn 2.148)}$$

In this scheme the [G] matrix is found using the emittance and view factors and need only be calculated once. Then to find $<Q_i/A_i>$ the temperatures for each surface are substituted into Equation 2.146.

To reduce the calculations necessary for the radiation model further, the number of surface radiation zones is made significantly less than the number of cells with boundaries touching the surface. This is accomplished by grouping 20-30 surface cells into each surface radiation zone. Then the temperatures raised to the fourth power for the cells are averaged to get a T^4 value for each zone. This reduces enormously the number of view factors and the number of radiant heat fluxes that must be calculated.

2. View Factor Calculations

In order to implement the radiation calculations just described the view factors, which are the ratio of radiant energy leaving one surface that is incident on another, must be calculated. In the rectangular box which is the calculation domain for this system, the "flame" is modeled as a specified group of cells in the interior of the cavity where energy representing the heat input of the fire is added. In this model the flame surfaces are therefore also rectangular in shape. Thus the view factors are of two types: Radiation exchange between parallel rectangular surfaces and radiation exchange between perpendicular rectangular surfaces.

Sparrow and Cess in [Ref. 14: p. 125] provide the general definition of the shape factor.

$$F_{21} = (1/A_2) \iint \cos\theta_1 \cos\theta_2 (\pi r^2)\, dA_1 dA_2 \qquad \text{(eqn 2.149)}$$

Figure 2.7 illustrates the configuration of the two surfaces used in this definition. Although equations are tabulated for the geometries in [Ref. 14: pp. 339-344] and many others they are complex and tedious. Instead of using these equations a direct numerical method employed by Chang and Yang in [Ref. 12: pp. 15-18] has been used. Figure 2.8 illustrates the arrangement of the two perpendicular rectangular surfaces. The equation for the view factor corresponding to this geometry is

$$F_{2-1} = \sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2}\sum_{l=1}^{2} (-1)^{(i+j+k+l)}\, G(AL_{li}, BE_{jk}) \qquad \text{(eqn 2.150)}$$

where i, j, k, and l are the indices for the coordinates shown in Figure 2.8 and

$$AL_{li} = (a_l^2 + x_i^2)^{1/2} \qquad \text{(eqn 2.151)}$$

$$BE_{jk} = (y_j - b_k) \qquad \text{(eqn 2.152)}$$

$$G(AL_{li}, BE_{jk})$$

$$= \{BE_{kj}\, AL_{li} \tan^{-1}(BE_{kj}/AL_{li})$$

$$- .5\,(AL_{li}^2 - BE_{kj}^2) \ln[(AL_{li}^2 + BE_{kj}^2)^{1/2}] \qquad \text{(eqn 2.153)}$$

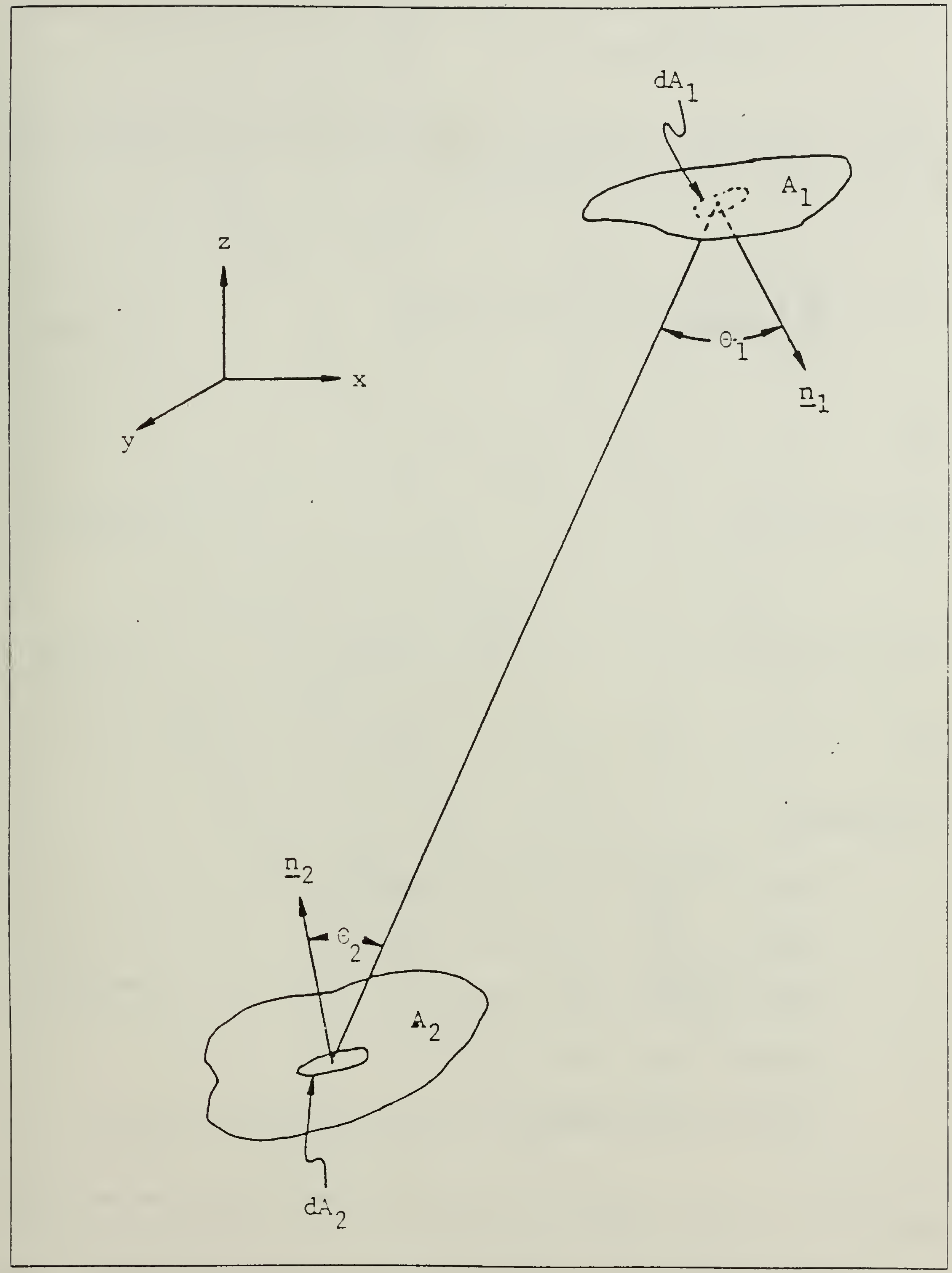

Figure 2.7 Configuration of Surfaces for View Factor Determination.

$$+ .5\,[AL_{li}^2 \ln(AL_{li})]\} \;/\; 2\pi$$

The second configuration consisting of two parallel plates is shown in Figure 2.9. The equation of the view factor for this geometry is

$$F_{2-1} = \sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2}\sum_{l=1}^{2}(-1)^{(i+j+k+l)}\, G(AL_{li}, BE_{jk}) \qquad \text{(eqn 2.154)}$$

where

$$AL_{li} = a_l/z + x_i/z \qquad \text{(eqn 2.155)}$$

$$BE_{jk} = b_k/z + y_j/z \qquad \text{(eqn 2.156)}$$

and

$$\begin{aligned} G(AL_{li},BE_{jk}) &= AL_{li}(1+BE_{kj})^{1/2} \tan^{-1}[AL_{li}/(1+BE_{kj}^2)^{1/2}] \\ &+ BE_{kj}(1+AL_{li})^{1/2} \tan^{-1}[BE_{kj}/(1+AL_{li}^2)^{1/2}] \\ &- BE_{kj} \tan^{-1}(BE_{kj}) + \ln[(1+BE_{kj}^2)^{1/2}] \\ &- AL_{li} \tan^{-1}(AL_{li}) + \ln[(1+AL_{li}^2)^{1/2}] \\ &- .5 \ln(1 + AL_{li}^2 + BE_{kj}^2) \end{aligned} \qquad \text{(eqn 2.157)}$$

From these two view factor equations all the necessary view factors for the rectangular geometry may be calculated. [Ref. 12: pp. 15-16]

Appendix B lists the fortran program which calculates the view factors. These view factors are calculated for a particular fire location and then utilized when the main program is run.

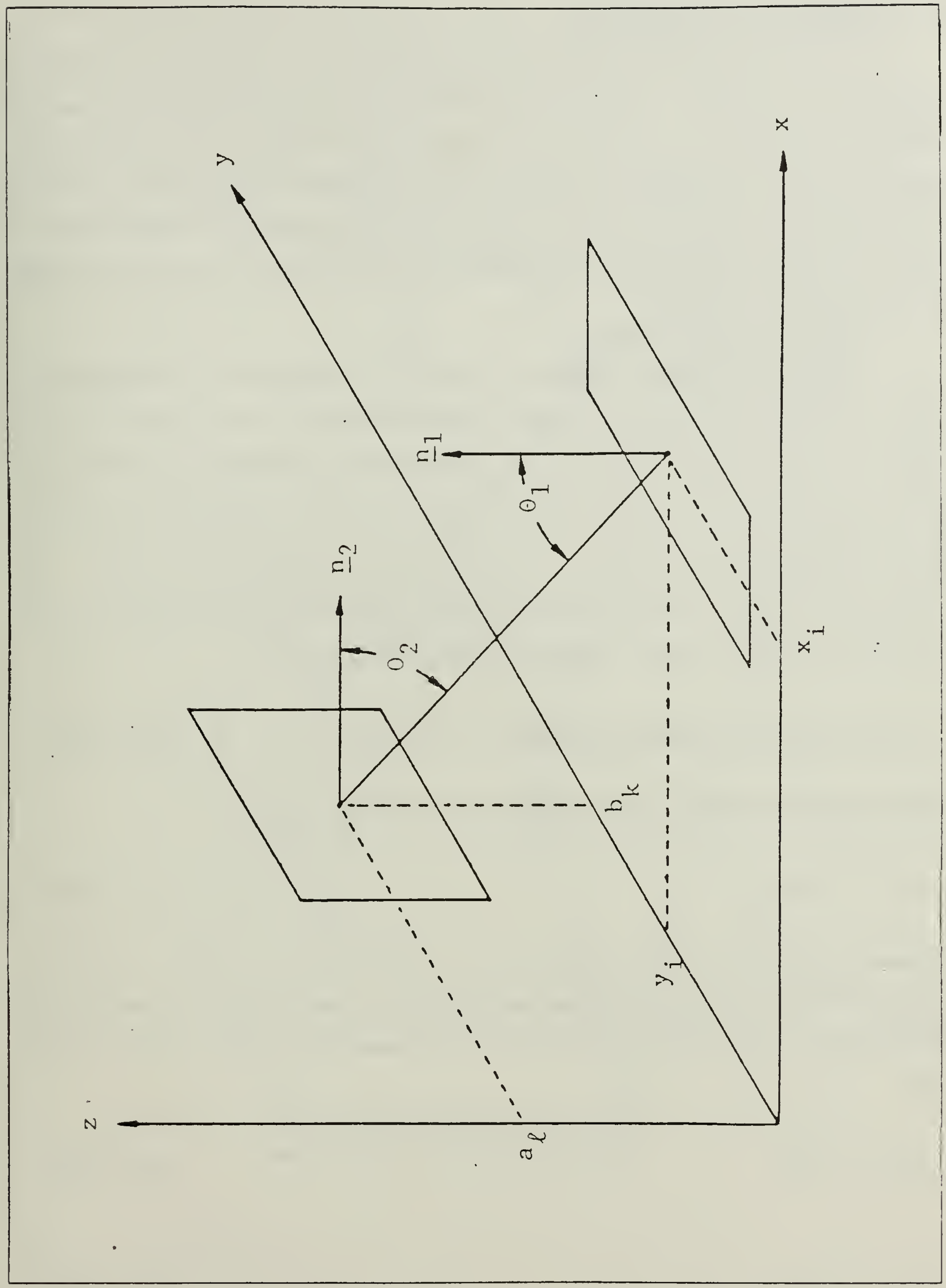

Figure 2.8 Geometry for View Factor Calculation between Perpendicular Plane Surfaces.

H. PRESSURE CORRECTION

One of the difficulties arising from the use of primitive variables is the difficulty of calculating the pressure. In the closed system modeled here the pressure changes are divided into two parts: 1.) Changes due to a net energy change in the system which raises or or lowers the pressure everywhere, and 2.) Changes in pressure within regions of the tank which determine the velocity field. To account for these changes in pressure a global pressure correction is applied for the first case and a local pressure correction for the second.

1. Global Pressure Correction

The global pressure correction is based on a scheme for a two dimensional uniform grid as developed by Nicolette, Yang, and Lloyd in [Ref. 15: pp. 1724-1725]. Using this method overall pressure levels are increased or decreased depending upon whether energy is added or removed from a system with constant mass and volume. At any particular time step (n) in such a system the sum over all the cells of the cell density times the volume is equal to a constant which is the mass of the system. This is of course the same as the sum using the initial equilibrium densities because the mass in the vessel does not change. Therefore summing over N cells:

$$\Sigma\ \rho_i^n(\Delta x \Delta y \Delta z)_i = \Sigma\ \rho_{Eq,i}(\Delta x \Delta y \Delta z)_i \qquad \text{(eqn 2.158)}$$

Since the cells are uniform, $(\Delta x \Delta y \Delta z)_i$ may be divided out so that

$$\Sigma\ \rho_i^n = \Sigma\ \rho_{Eq,i} \qquad \text{(eqn 2.159)}$$

Assuming an ideal gas and recalling that the volume is constant, ρ the density is a function of P and T only. Now expressing the exact or true values of the pressure and temperature at a time step as the sum of an estimated value and a global correction then:

$$P = P^* + P_g' \qquad \text{(eqn 2.160)}$$

$$T = T^* + T_g' \qquad \text{(eqn 2.161)}$$

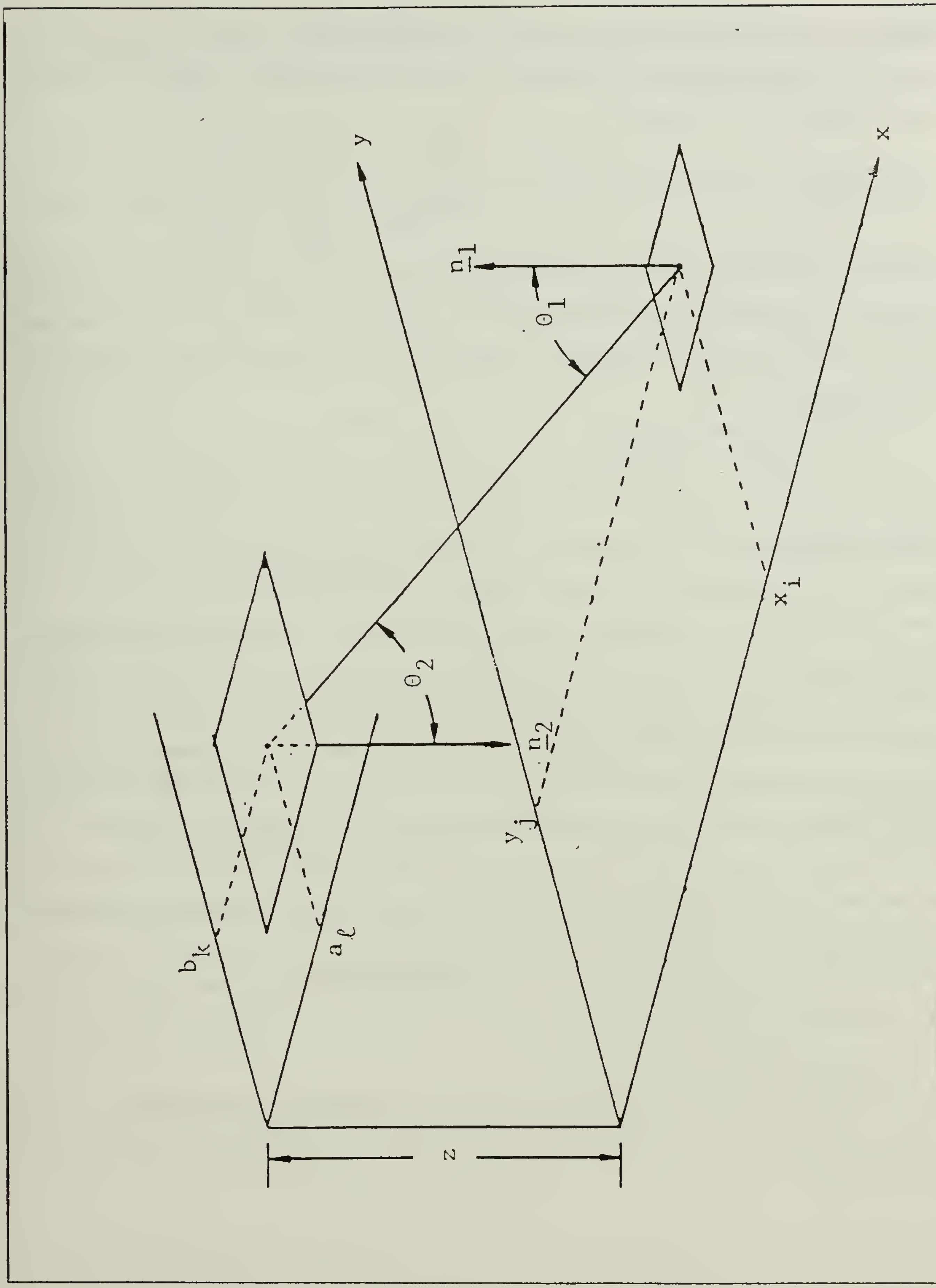

Figure 2.9 Geometry for View Factor Calculation between Parallel Plane Surfaces.

where the * superscript is the guessed or estimated value and the ′ subscript g is the correction. Substituting these equations, 2.160 and 2.161 into Equation 2.159 and using the ideal gas law results in

$$P_g' = \{\Sigma P_{Eq}[1/T_i - 1/T^*] - \Sigma(P^*/T^*)\} / \Sigma(1/T^*) \qquad \text{(eqn 2.162)}$$

Generally the first guess for P^* is the value from the previous time step. Then a P_g' is computed and added to the estimated value in every cell. This procedure is continued until a globally corrected pressure is obtained which conserves mass in every cell [Ref. 15: pp. 1724-1725].

2. **Local Pressure Correction**

The difficulty in determining the pressure field results from the fact that the pressure appears in equation of state multiplied by C which is a non-dimensional number proportional to the square of the Mach number. Since the velocities are relatively low compared to the speed of sound in this natural convectionsystem. C is extremely small and the pressure is very weakly linked to the system of equations. Trying to extract the pressure from the equation of state by using a numerical method is doomed to failure. Instead, an iterative technique using the mass conservation equation to find the pressure is employed. In it the pressure field is guessed. Then the velocities are computed based on this pressure distribution. With the velocities known the mass source term S_m, also called the residual mass is computed for each cell. The size of S_m is a check on the conservation of mass in each cell and a sum of the absolute values of S_m gives an overall error for conservation of mass in the system. If S_m is near zero the pressure guess is good. Otherwise, a local pressure correction is computed based on the size of S_m and the procedure is continued until S_m is reduced to a satisfactory value. The equation of state is used (with the pressure now known) to find the densities for the next time step.

Doria outlined in [Ref. 10: pp. 26-32] a procedure for computing the local pressure correction. As in the global correction the actual pressure equals a guess plus a correction

$$P = P^* + P' \qquad \text{(eqn 2.163)}$$

Doria's method provides a finite difference equation for the pressure correction similar in form to the finite difference conservation equations. The equation for P′ is :

$$A_P P_P' = A_E P_E' + A_W P_W' + A_N P_N' + A_S P_S' + A_T P_T' + A_B P_B' - S_{mP}\, \Delta x \Delta y \Delta z \qquad \text{(eqn 2.164)}$$

where

$$A_E = \rho_e (\Delta y \Delta z)^2 / (A_{p}a_{i+1,j,k} + \rho_e \Delta x \Delta y \Delta z / \Delta t) \qquad \text{(eqn 2.165)}$$

$$A_W = \rho_w (\Delta y \Delta z)^2 / (A_{p}a + \rho_w \Delta x \Delta y \Delta z / \Delta t) \qquad \text{(eqn 2.166)}$$

$$A_N = \rho_n (\Delta z \Delta x)^2 / (A_{p}b_{i,j+1,k} + \rho_n \Delta x \Delta y \Delta z / \Delta t) \qquad \text{(eqn 2.167)}$$

$$A_S = \rho_s (\Delta z \Delta x)^2 / (A_{p}b + \rho_s \Delta x \Delta y \Delta z / \Delta t) \qquad \text{(eqn 2.168)}$$

$$A_T = \rho_t (\Delta x \Delta y)^2 / (A_{p}c_{i,j,k+1} + \rho_t \Delta x \Delta y \Delta z / \Delta t) \qquad \text{(eqn 2.169)}$$

$$A_B = \rho_b (\Delta x \Delta y)^2 / (A_{p}c + \rho_b \Delta x \Delta y \Delta z / \Delta t) \qquad \text{(eqn 2.170)}$$

$$A^P = A^E + A^W + A^N + A^S + A^T + A^B \qquad \text{(eqn 2.171)}$$

At the solid boundaries where the mass flux is zero the coefficient A in the P′ equation corresponding to that boundary is set equal to zero. Once the P correction (P′) is computed and added to p^*, new velocities maybe computed from the following equations:

$$u = u^* + u' \quad \text{(eqn 2.172)}$$

$$v = v^* + v' \quad \text{(eqn 2.173)}$$

$$w = w^* + w' \quad \text{(eqn 2.174)}$$

where

$$u' = (P_P' - P_W')\,\Delta y \Delta z \,/\, (A_{pa} + \rho_w\, \Delta x \Delta y \Delta z / \Delta t) \quad \text{(eqn 2.175)}$$

$$v' = (P_P' - P_S')\,\Delta z \Delta x \,/\, (A_{pb} + \rho_s\, \Delta x \Delta y \Delta z / \Delta t) \quad \text{(eqn 2.176)}$$

$$w' = (P_P' - P_B')\,\Delta x \Delta y \,/\, (A_{pc} + \rho_b\, \Delta x \Delta y \Delta z / \Delta t) \quad \text{(eqn 2.177)}$$

Then S_m is computed. If it is small enough the procedure stops, otherwise a new P' is computed and the cycle continues.

I. SOLUTION PROCEDURE

Figure 2.10 shows a flow chart detailing the calculation procedure. As shown by this flow chart, the first few steps set up the initial parameters. The view factor data must be read in from a file because the view factors are computed in a separate program. Subroutine CALVIS is called to calculate the effective viscosity for the time step. Every ten time steps the energy fluxes to the interior walls of the vessel are computed. In the interim the last value calculated is used. Subroutine CALT is then called to determine the temperatures in the interior cavity and the walls of the vessel.

All of these subroutines use an implicit technique to solve the matrices formed by employing the finite difference equations on each cell. Next the global pressure correction is computed followed by the density. Then subroutines are called to find the three velocities and the pressure in each cell. From the new cell pressures a corrected velocity estimate is made. With these velocities the continuity equation is applied to each cell and the residual mass or the error in the cell mass balance is determined. The sum of the absolute value of these cell residual masses is called the residual mass source (Resorm). The size of this term is really a check of the global and local pressure corrections. If the Resorm is too large (greater than the tolerance ε) then the solution is iterated. In order to minimize the CPU time required to run the program, the CALT subroutine and the global pressure correction are not computed on every iteration. In the present scheme where the maximum number of iterations is 9, CALT is only run on the first, fourth, and seventh iterations. On the other iterations only the velocities and the pressure are recalculated. When the Resorm is less than the tolerance or the maximum number of iterations have been reached the program proceeds to the next time step or stops the calculations if the maximum time has been reached.

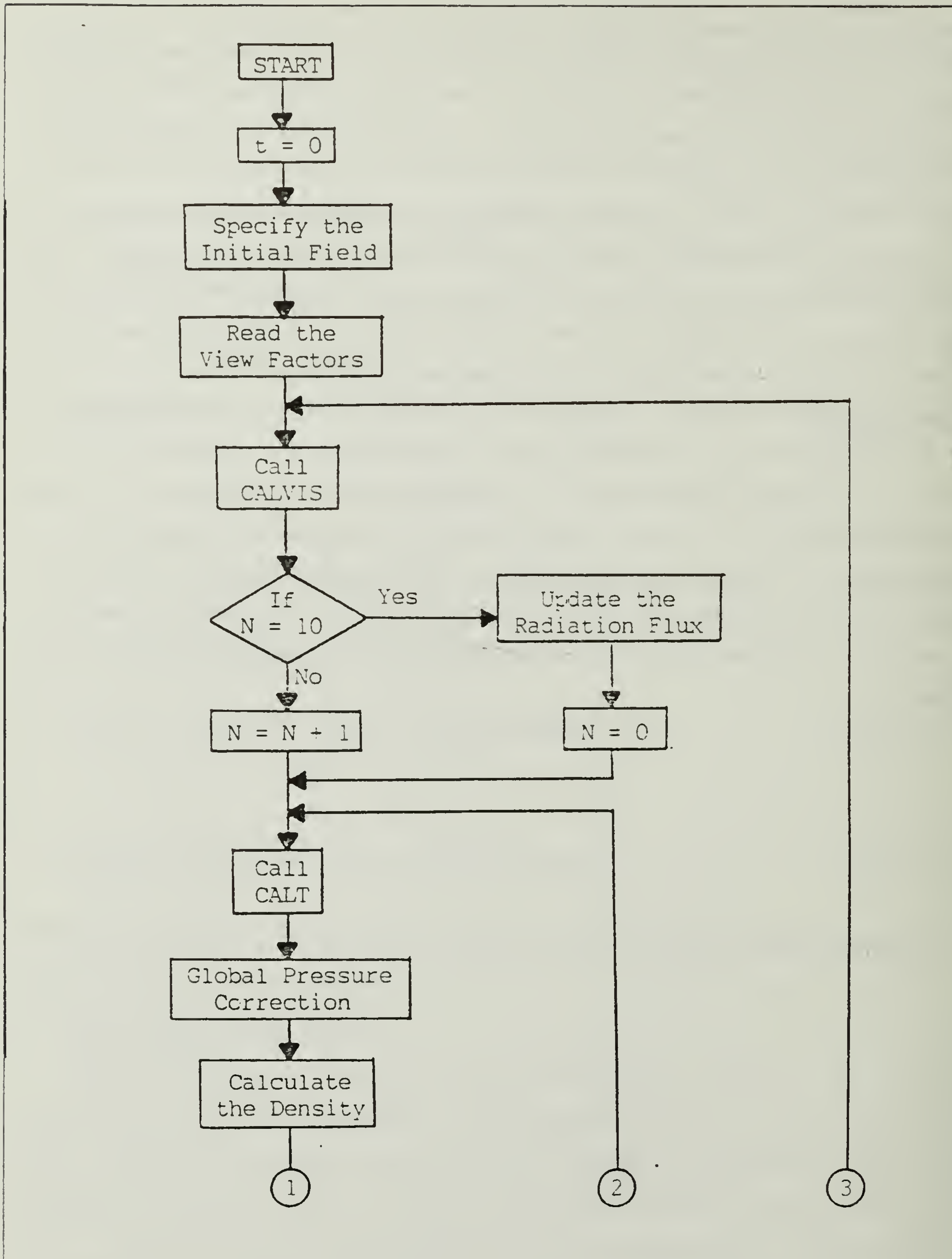

Figure 2.10 Flowchart for the Numerical Calculation Procedure.

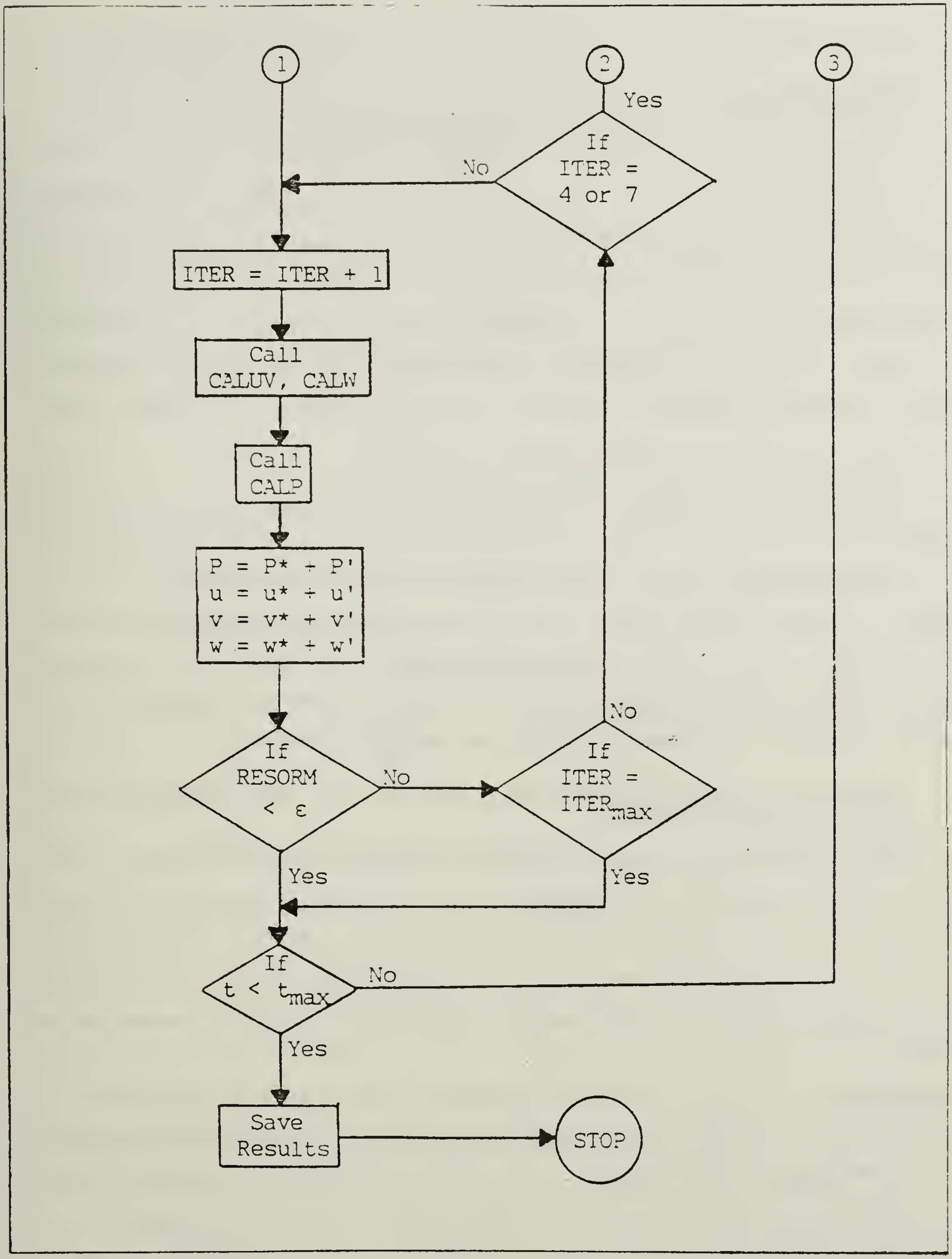

Figure 2.10 Continued.

III. COMPARISON OF THE NUMERICAL RESULTS WITH THE EXPERIMENTAL DATA

In an attempt to validate the numerical model comparisons were run with experimental data provided by the Naval Research Laboratory for the Fire I Test Facility. As a background for the discussion of the results, the data necessary to implement the numerical model in a particular situation is presented. This is followed by a specific listing of the parameters used for the test case in which the numerical versus experimental results were compared. Finally the analysis of the results is made.

A. IMPLEMENTING THE NUMERICAL MODEL

When modeling a specific scenario for the Fire I test vessel a number of parameters must be known. First the type of fuel and its burn rate must be known. With this data the heat release rate as a function of time can be calculated. Next the location of the fire or fires in the vessel is required. The location of any temporary instrumentation such as the movable thermocouple racks must also be recorded. Finally ambient conditions which consist of the initial pressure and temperature in the vessel are necessary. With this information the simulation may be run.

B. NUMERICAL SIMULATION PARAMETERS AND BACKGROUND DATA FOR THE FIRE TEST CASE

Details of the actual parameters used in the numerical model are listed in Table 2. The material properties and thickness of the wall listed in the table are for the ASTM-285 Grade C steel used in Fire I. In order to best simulate the actual Fire I geometry with a rectangular box several considerations were used in determining the size and shape of the box. First the volume of the box was taken to be the same as the volume for the actual text vessel (11,640 ft^3). Next the cross sectional area of the box perpendicular to the long axis was the same as the cross sectional area of the cylindrical section of Fire I. Using these two parameters as guidelines the dimensions of the rectangular box work out to be 17 ft × 17 ft × 40.2 ft. The height of 17 ft was also selected as the reference length H which was used in non-dimensionalizing the governing equations. The grid as indicated in Table 2 by the values of Δx, Δy, and Δz was relatively course. This was necessary because of the large amount of CPU time required even for this grid. The size of the time step was determined by selecting a Δt

which permitted performing calculations for the duration of the experimental fire in a reasonable length of CPU time while still maintaining stabilty in the computational results. Calculations using time steps of .017 and .0085 sec did not show any significant deviation from the larger value of .17 sec which was used for the bulk of the calculations.

TABLE 2
NUMERICAL MODEL PARAMETERS

Δx = 2 ft Δy = 1.1 ft Δz = 1.1 ft

Total number of interior cells		5120 (20 × 16 × 16)
Total number of wall radiation zones		66
Wall Characteristics:		
	Thickness	3/8″
	c_{pW}	0.1 Btu/(lbm °F)
	k_W	25 Btu/(hr ft °F)
	ρ_W	487 lbm/(ft^3)
External heat transfer coefficient		7.5 Btu/(hr ft^2 °F)
Time step		.17 sec.

The background data is shown in Table 3 for the actual fire with which the numerical results were compared. Heptane has a heating value of 20854 Btu/lbm [Ref. 16: p. 388]. As shown in the table the burn rate date was unavailable. The steps taken to overcome this difficulty are explained in detail in the following section. The fire was extinguished after 422 seconds by injecting an amount of nitrogen sufficient to lower the partial pressure of oxygen below the critical value required for combustion. The interior setup of Fire I in this test differed from the numerical model because

Fire I had a grate installed in the north end of the tank at mid height. The grate did not extend into the spherical endcap. The data from this configuration was the closest to a completely empty interior that was available.

TABLE 3
FIRE BACKGROUND DATA

Fuel	Heptane
Burn rate	Unavailable
Duration of the Fire	422 sec
Initial temperature	35.7°C or 96°F
Initial pressure	1 atm

C. RESULTS

1. Generating the Heat Release Rate

Due to a failure of the instrument which measures the burn rate of the fuel at the Fire I facility no experimental data for the actual heat release rate was available. Since this latter quantity is a necessary input to the program the lack of data presented a significant problem. A temporary solution pending the availabilty of the actual burn rate data was developed. The guiding principles are simple. The energy input to the cavity produces three effects: It raises the pressure, it is lost by conduction through the walls, and it goes into the motion of the gas. Because of the low natural convection velocities involved the last effect as a percentage of the input energy is small. Also initially when the temperatures inside the tank are close to the external temperatures the conduction loss is a small part of the energy loss. Thus for a significant interval the heat input is almost exclusively used in raising the pressure.

Using the ideal gas law $P = \rho RT$ and $P = \rho RT$ if ρ and R are constant. Now making the gross assumption that the heat input is uniform, the gas density remains constant in the tank because the enclosed volume of gas as well as its mass is constant. The rate of heat input is just a constant times T and therefore the heat release rate is proportional to the change in pressure with respect to time. This quantity dP/dt is available experimentally in terms of the slope of the pressure curve.

The scheme to artificially develop a heat release curve is based on using the experimental pressure curve as an input. From the slope of this curve a first approximation of the heat input is determined. Initially for the reasons mentioned above this guess is fairly good but as conduction losses mount it proves inadequate. To overcome this difficulty the initial guess is corrected so that the calculated pressure results follow the experimental values. To illustrate how this works, the following example is provided. Figure 3.1 shows a typical experimental pressure curve.

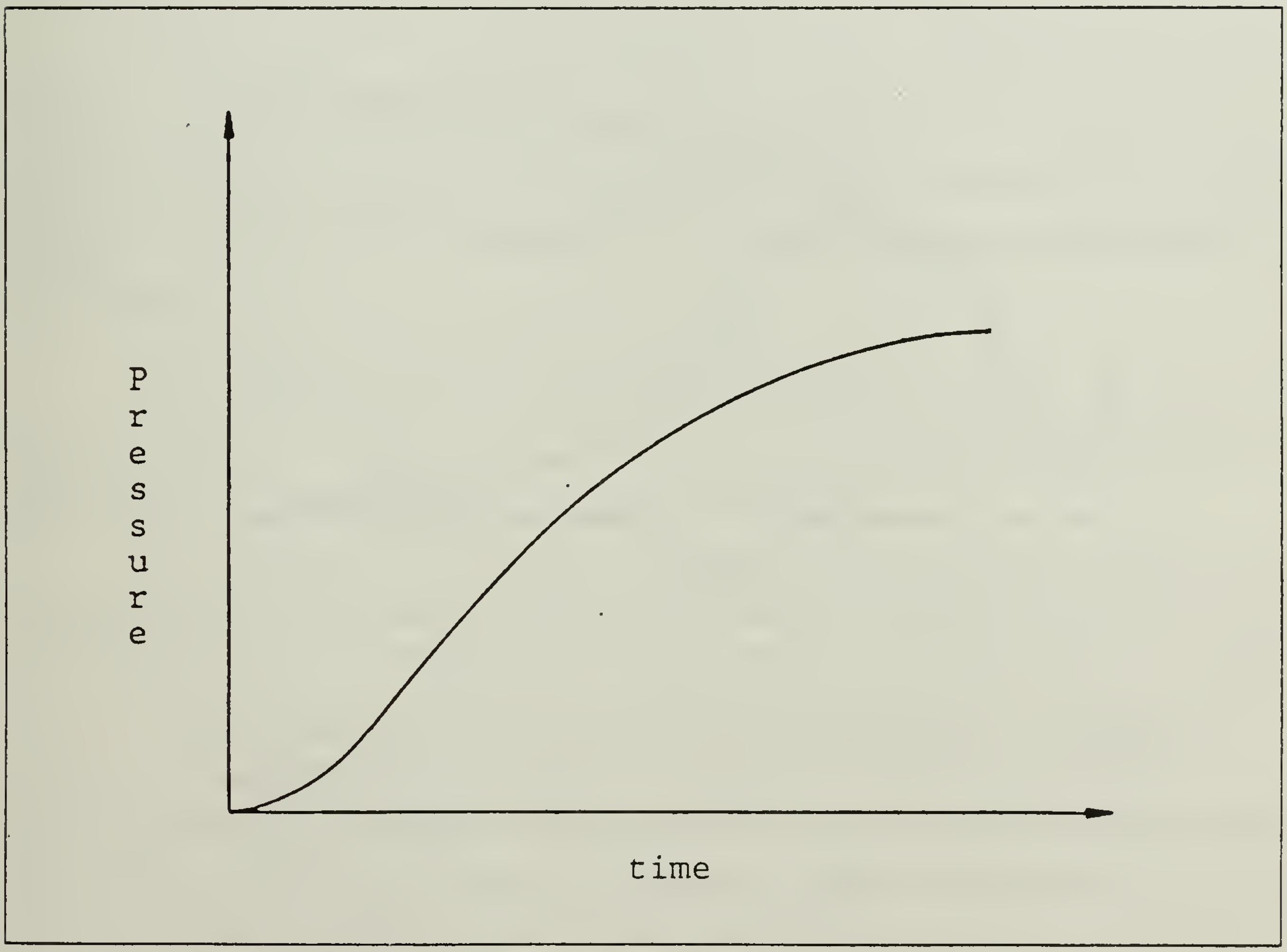

Figure 3.1 Typical Experimental Pressure versus Time Curve.

Throughout the time period shown the actual fire strength or heat input is increasing. Initially the slope is large so the estimated heat input is large. As the fire progresses the slope falls off and more of the heat is going into conduction losses. Thus the increasing total fire strength is not reflected since the estimated value actually decreases. To account for this error in heat input the estimated value from the slope is multiplied by a correction factor. In order to prevent this correction factor from becoming too large an additional alteration is made. This can best be explained by looking at Figure 3.2.

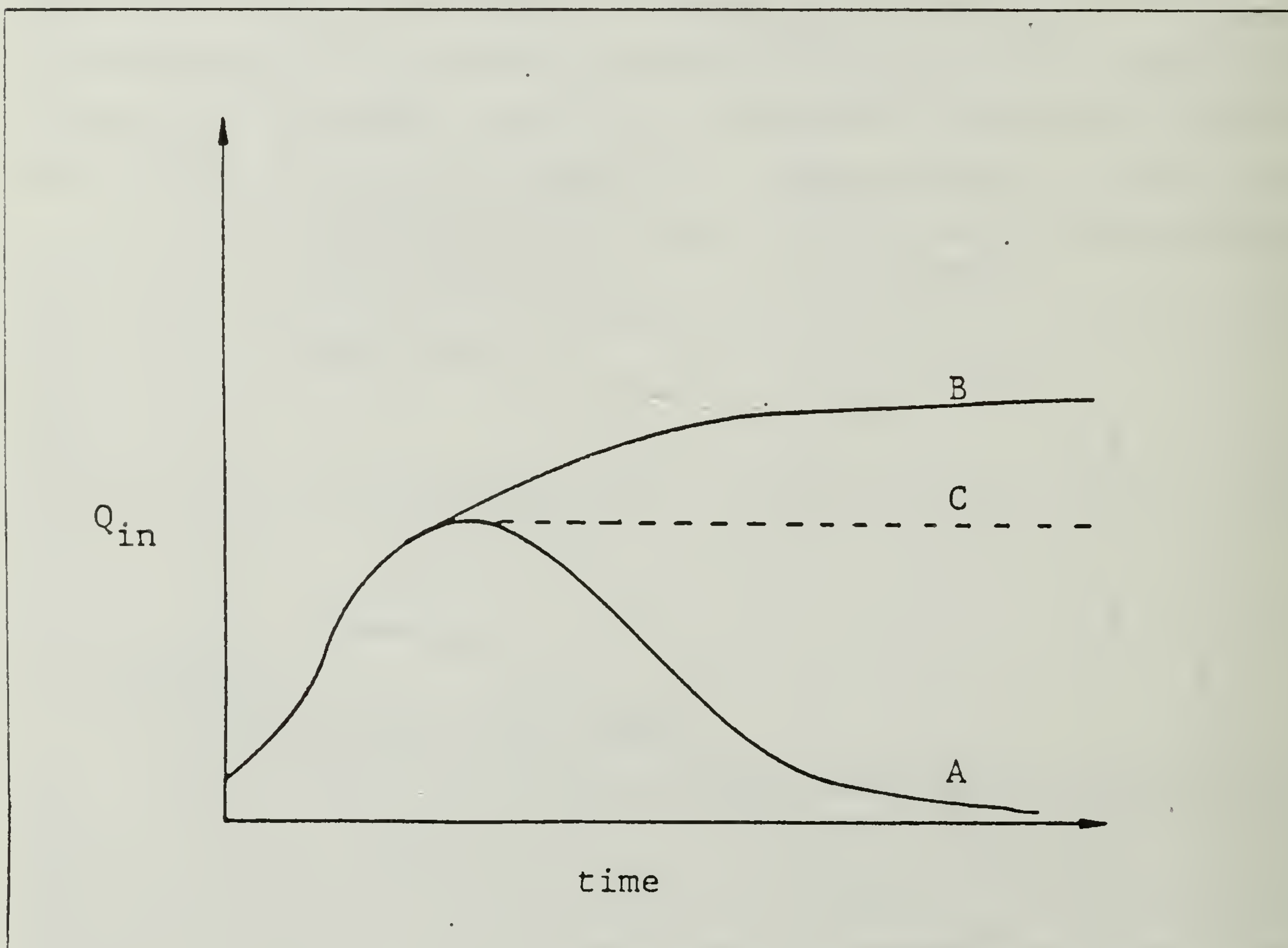

Figure 3.2 Comparison of Actual to Estimated Heat Input Curves.

Curve A shows the estimated heat input corresponding to the slope of Figure 3.1 while curve B is the actual heat input required by the numerical model to match the experimental pressure curve. The correction factor is the number at each time step that curve A must be multiplied by to get curve B. At the later time steps when curve A is near zero due to the small slope of the pressure curve this correction factor must be very large. To limit this correction to a more reasonable number which produces a more stable result curve C is used as the estimated heat input. Figure 3.3 shows a block diagram of the correction routine. The correction factor was computed as follows:

$$\text{Correction} = \frac{P_{data} - P_{comp}}{P_{data}} - \frac{P_{comp} - P^{\circ}_{comp}}{P_{data}} + 1 \qquad \text{(eqn 3.2)}$$

where P_{comp} is the computed pressure and P°_{comp} is the computed pressure from the last time step. The first term provides a position error type of correction. If the calculated value of the pressure is too large the heat input is reduced or vice versa if the pressure is too low. The second term provides a rate error correction to reduce oscillations. If the correction causes the computed curve to approach the actual curve too fast this term slows the rate of closure to prevent overshooting.

Figure 3.4 shows the computed heat input curve. Oscillations are obviously present. These are due to the stability problems that arise from taking the derivative of numerical data and the problems with the correcting scheme. The average heat release rate for the time period shown does correspond with similar data available from NRL. Without the precise burn rate data this is the best method available to provide a test of the program.

2. Numerical Results versus Experimental Data

The calculated pressure values follow the experimental data very closely as shown in Figure 3.5. This is of course the way the correction scheme was designed to work so such a comparison is not a validation of the model.

A comparison of the calculated temperature versus the actual temperature is the only method now available for comparison. Before discussing the graphs showing the temperature plots it is important to understand how the numerically determined temperatures were selected to correspond with the locations of the thermocouples in the actual cylindrical/spherical geometry. A point at the center of each geometry was selected as a reference. Then the volume in the actual geometry between this reference point and the thermocouple rack was determined. A length corresponding to the same volume between the center reference point in the rectangular box and a YZ plane was then determined. A line half way across this YZ plane pointing up in the Z direction was then selected as corresponding to the thermocouple rack. The position of each

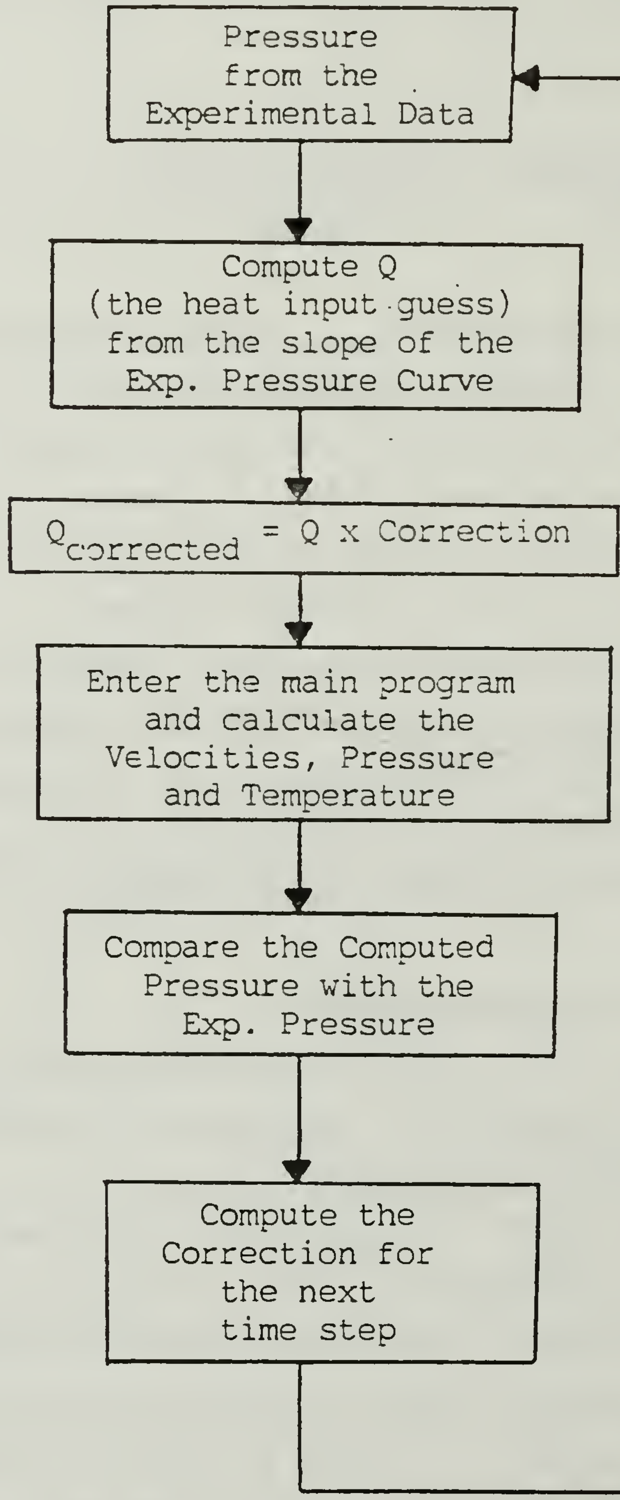

Figure 3.3 Block Diagram for the Heat Input Correction Routine.

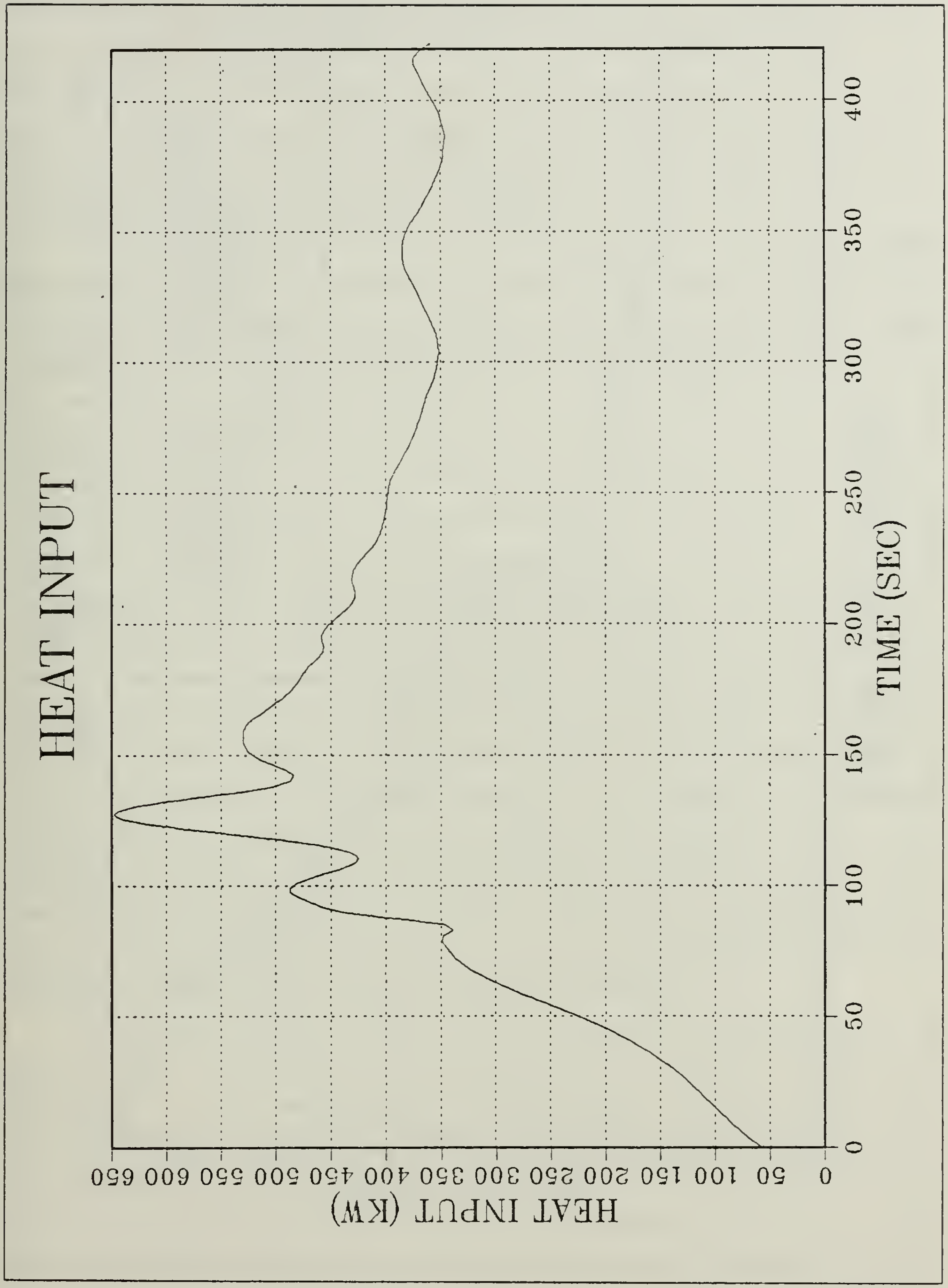

Figure 3.4 Computed Heat Input.

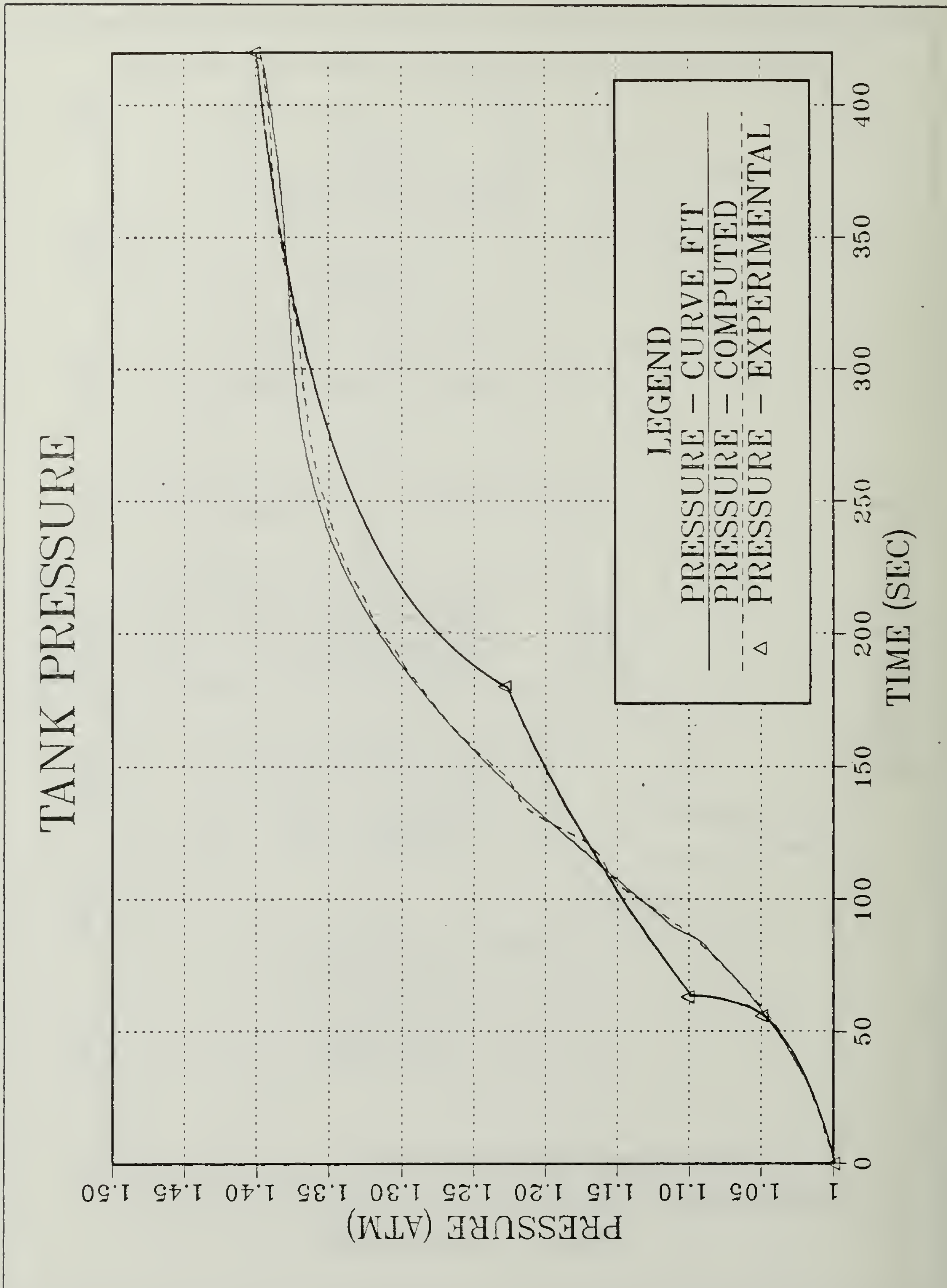

Figure 3.5 Numerical and Experimental Pressure Curves.

thermocouple in the actual vessel was measured as a ratio of its height from the bottom divided by the total height at that point. This ratio was then applied to the line representing the thermocouples in the rectangular box and the temperatures of the grid cell in which the themocouple positions were located was the temperature used for comparison. Figure 3.6 shows a cross sectional view of the rectangular box with the location of the fire and the thermocouples specified.

In order to compare the results the temperatures from three thermocouples were selected and plotted: Thermocouple #2 near the top, thermocouple #4 at about 3/4's of the distance from the bottom, and thermocouple #6 about half way up. Figure 3.7 shows the results which were plotted until the fire was extinguished at 422 seconds. The temperatures computed numerically for the upper region of the tank are significantly higher (about 150°C) than the actual temperatures. In the mid region the computed and experimental results correspond quite well. Results in the lower portion of the tank were not compared because the experimentel and numerically computed temperatures change only slightly in this stagnant region. The main reason for the discrepancy in the upper region is the difference in the geometry of the two cases. The actual thermocouples are located in the spherical end region and are about 6 ft from the end of the tank. In the rectangular geometry the thermocouples are about 3 ft from the end of the tank. The difference is illustrated in Figure 3.8. The problem is that the upper thermocouples in the rectangular geometry are in the region where the hot gas from the fire turns the corner and returns in a recirculating flow to the center of the tank. In the actual case the hot gas follows the curvature of the tank in the spherical region and penetrates further before returning. Thus the hot gas flows above thermocouples #2 and #4 and the experimental temperatures are significantly lower. Since no velocity measurements are made in the tank the only way to verify this supposition will be to run the code using the actual geometry.

The general spacing and shape of the experimental and numerical curves are similar. Except in the region of 120-220 sec the spacing between the numerical and experimental curves for thermocouples #2 and #4 is similar. All the curves level off at about the same time. This indicates that the same time is predicted for a quasi-steady state where heat in equals heat out for both the model and the actual vessel. It should also be noted that the smooth appearance of the experimental curves is due to their reconstruction from a small number of points taken from the original experimental plots. These original plots show much more evidence of turbulent oscillations as seen in Figure 3.9 from NRL.

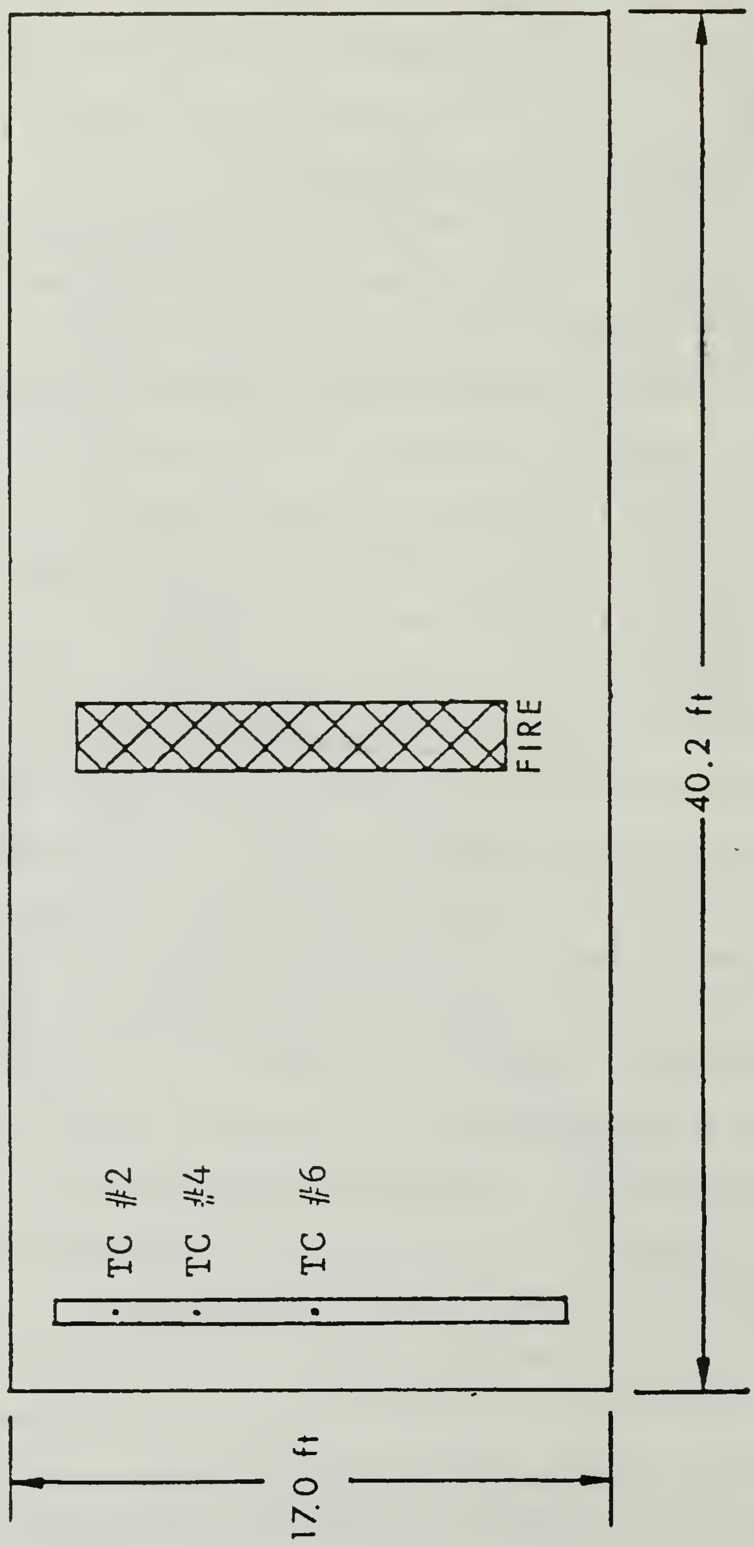

Figure 3.6 Fire and Thermocouple Location in the Rectangular Model.

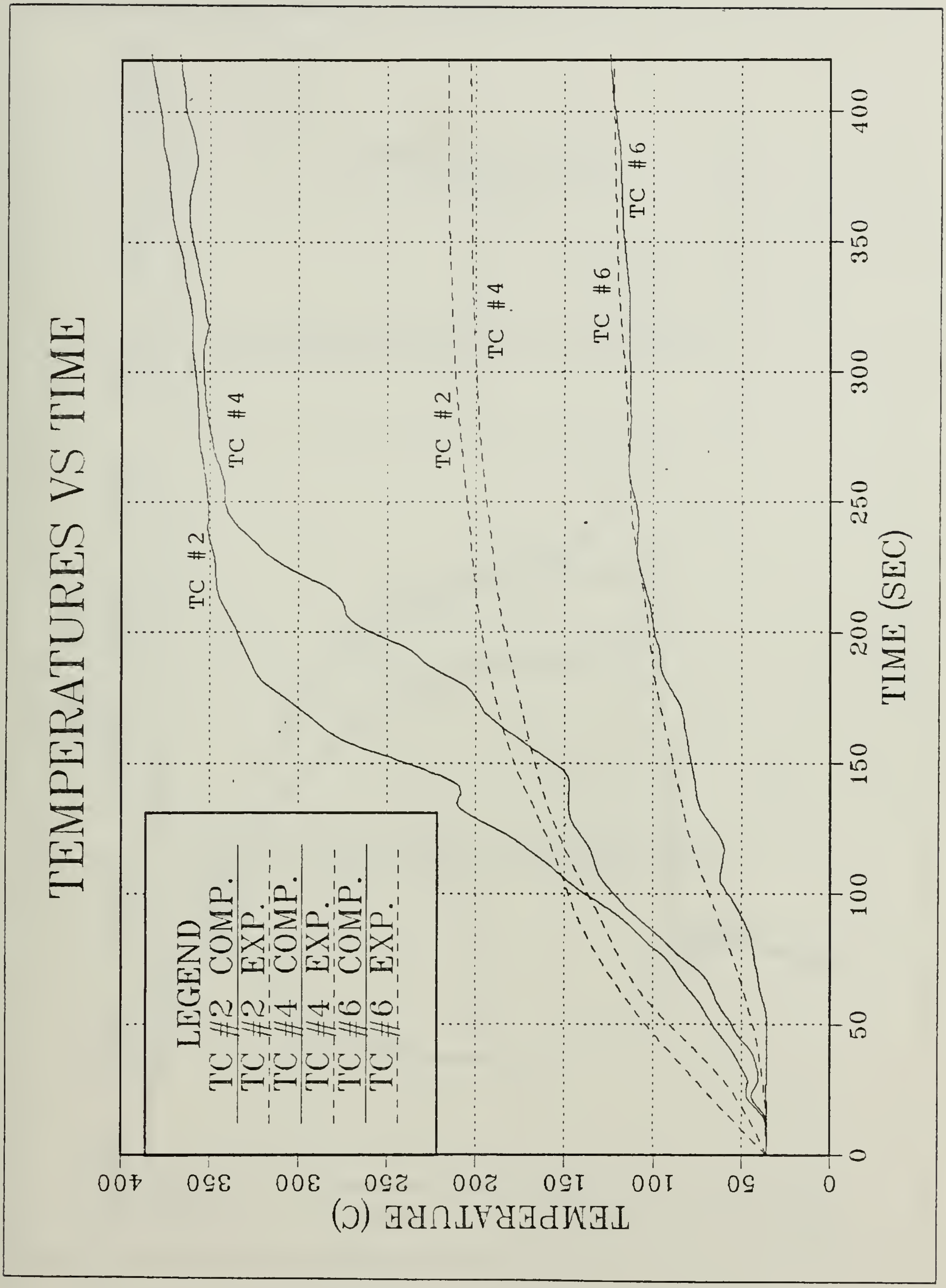

Figure 3.7 Temperature Plots for Thermocouples #2, #4, and #6.

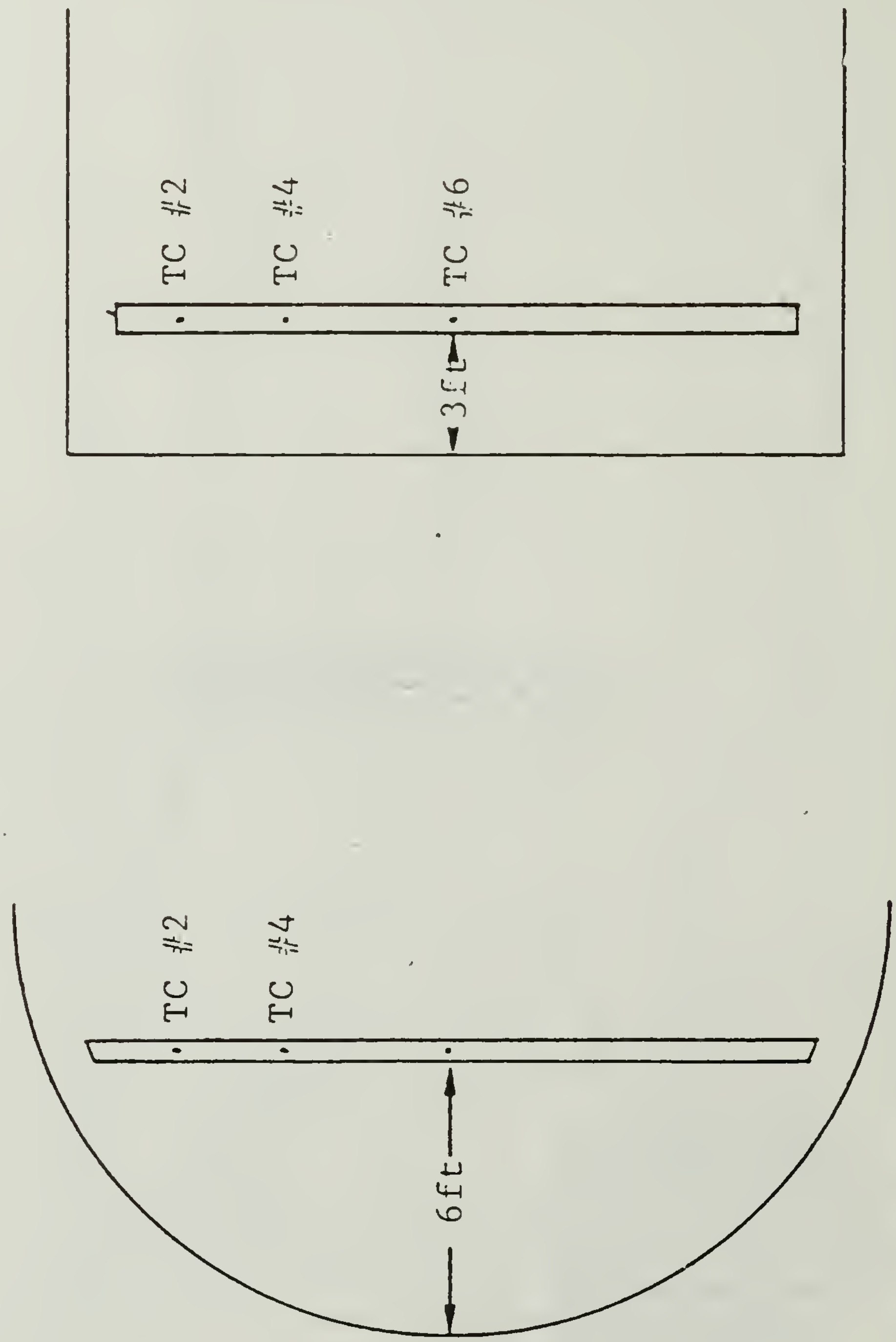

Figure 3.8 Model and Actual End Region Geometry.

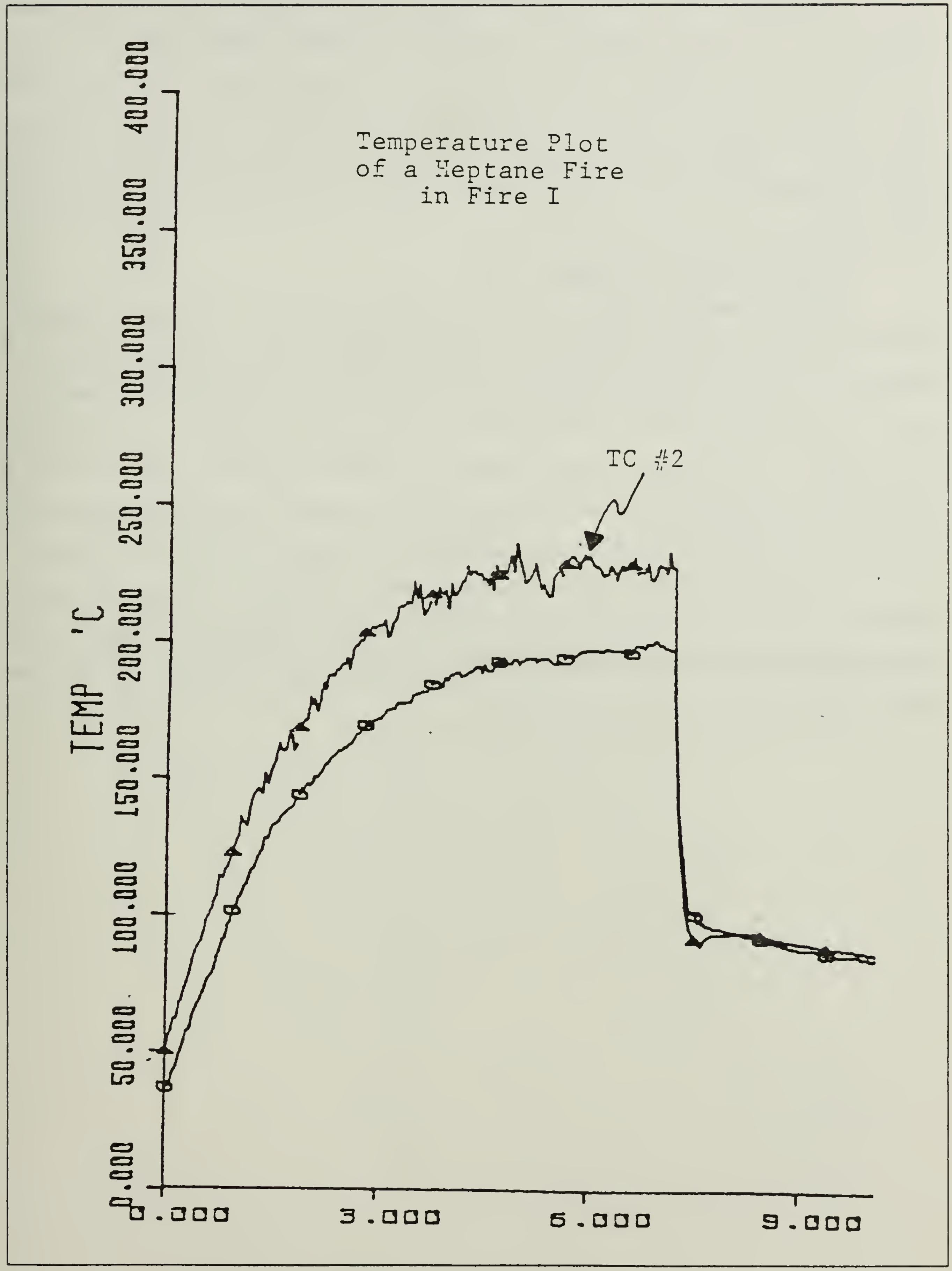

Figure 3.9 Experimental Temperature Plot for Thermocouple #2 from NRL.

Another source of error in the model is the assumption of a uniform spacial heat input. In a real fire more heat is added in the middle region than in the top or bottom portion of the flame. This error in the model does not have a significant effect on the results shown here because the sensors are so far from the fire that temperature effects due to non-uniform heat input are lost in the turbulent mixing between the fire and the sensors. For data from a sensor close to the fire this effect should be considered.

3. **Velocity Profile and Isotherm Plots**

Velocity profile and isotherm plots are shown for the XZ and YZ planes that intersect the fire. Figure 3.10 shows the location of these cross sections. Figures 3.11 through 3.24 shown XZ and YZ plane views of velocity and isotherm plots starting at 60 sec and ending at 420 sec. The figures at 128 sec show the plots at the maximum fire strength. The velocity vector scales are shown on each figure while the temperatures of the isotherms are the same for all the plots. As might be expected the plots show the development of the recirculating flow with time. The downward flow of the hot gas in the region of the thermocouples is evident. The densely packed isotherms at the top of the tank indicate the high heat transfer in that region. The lowering height of the isotherms show the penetration of heat with time into the lower regions of the tank.

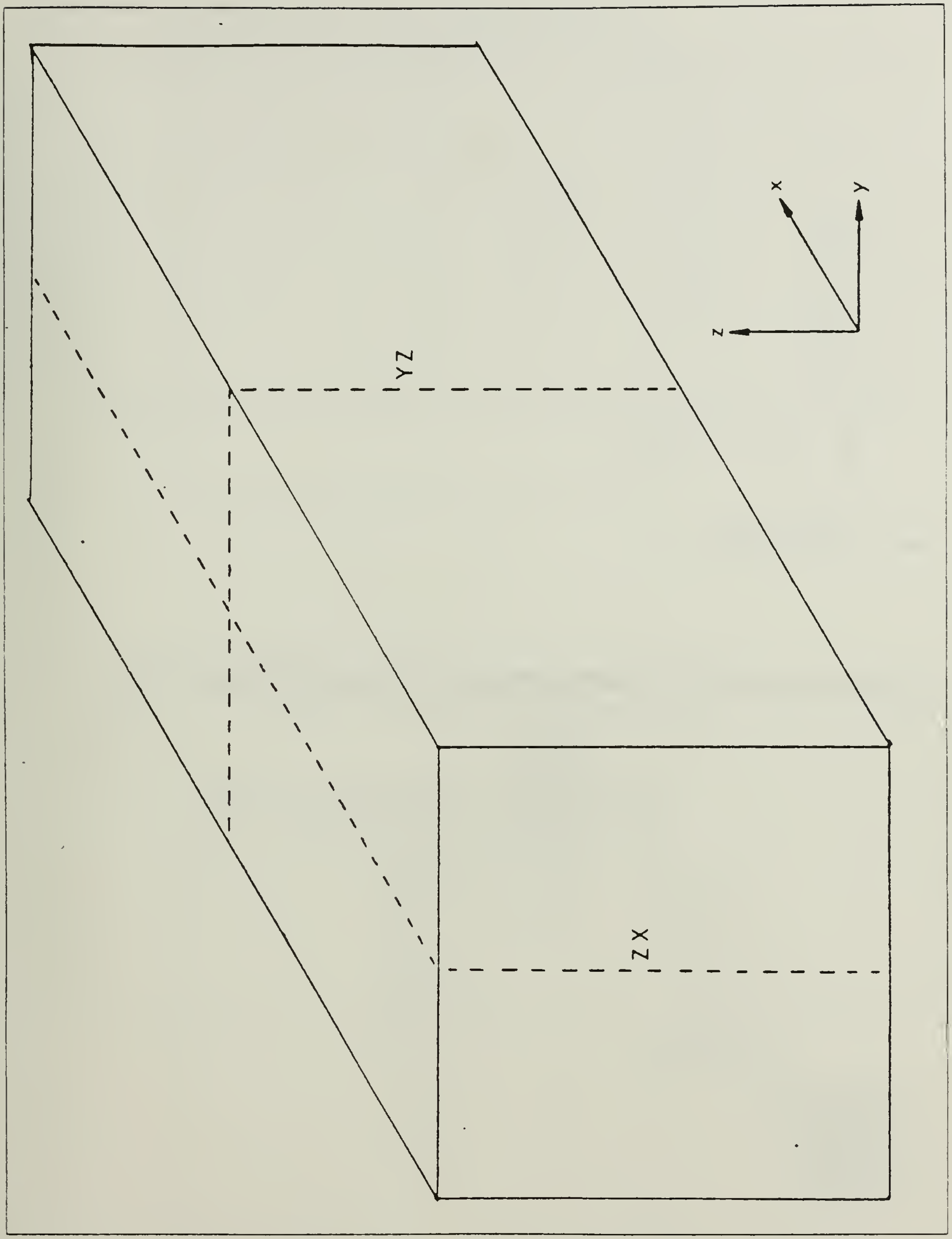

Figure 3.10 Location of Cross Sections used for Isotherm and Velocity Plots.

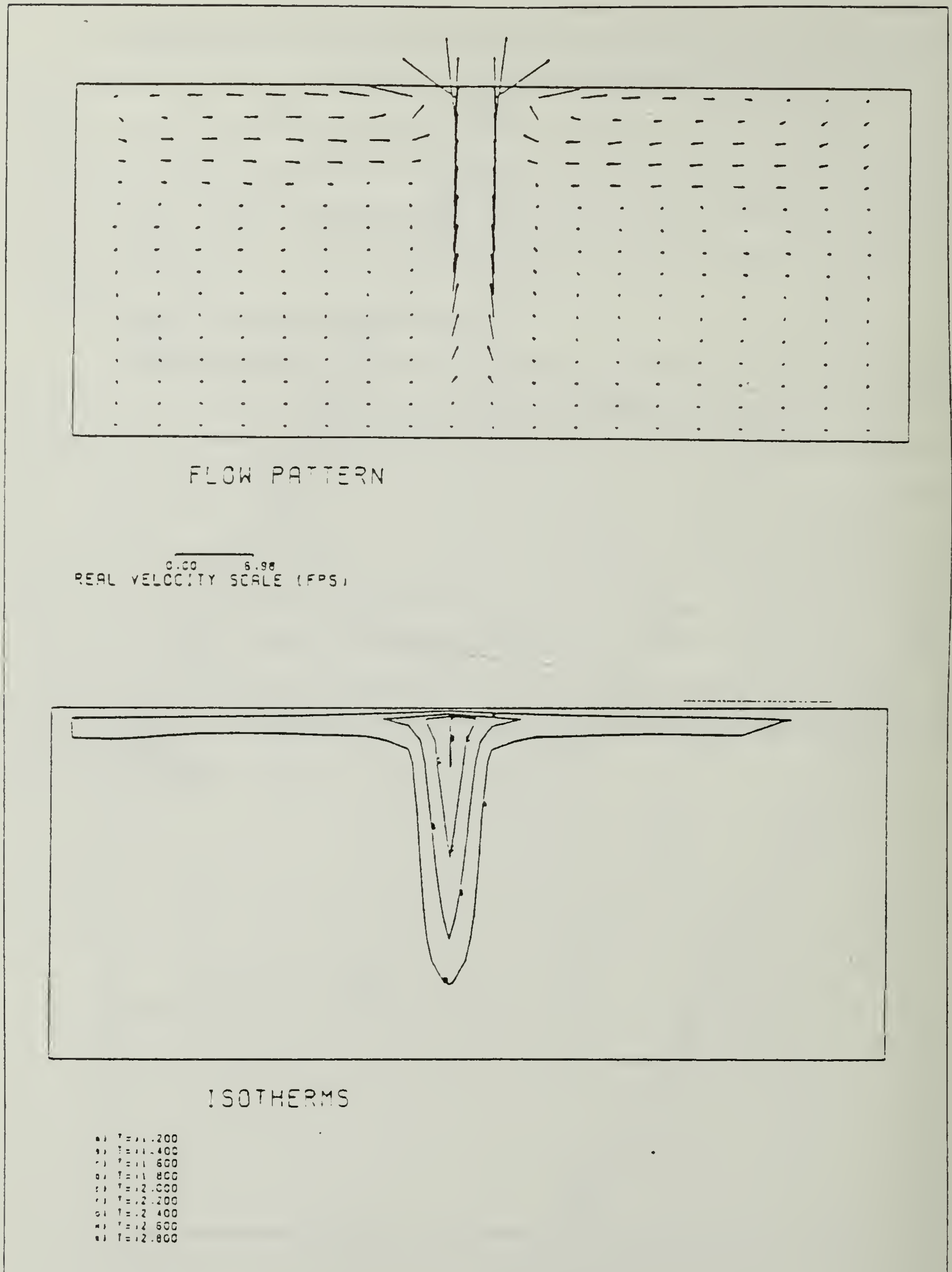

Figure 3.11 Velocity and Isotherm Plots after 63 sec on the XZ Plane.

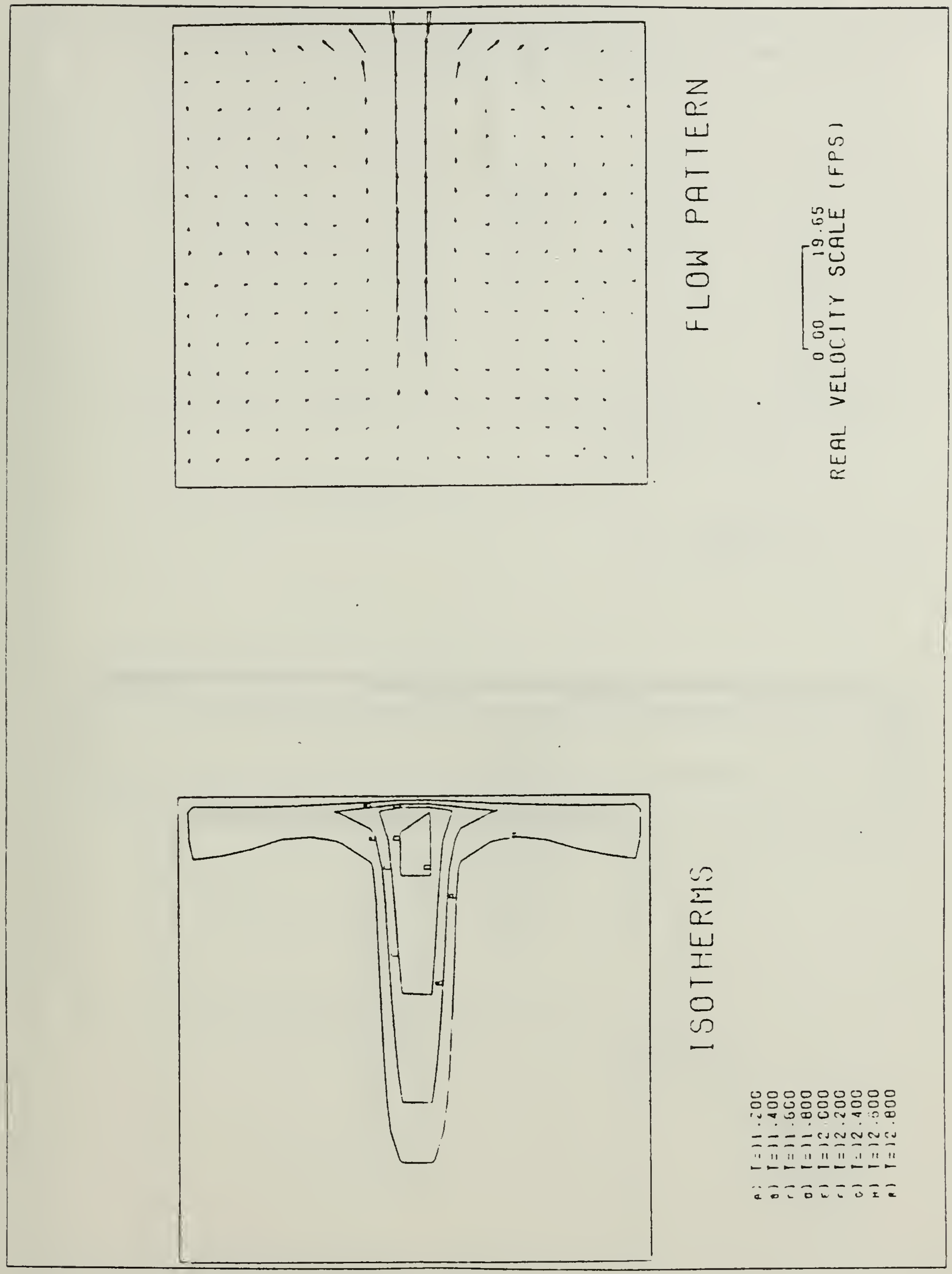

Figure 3.12 Velocity and Isotherm Plots after 63 sec on the YZ Plane.

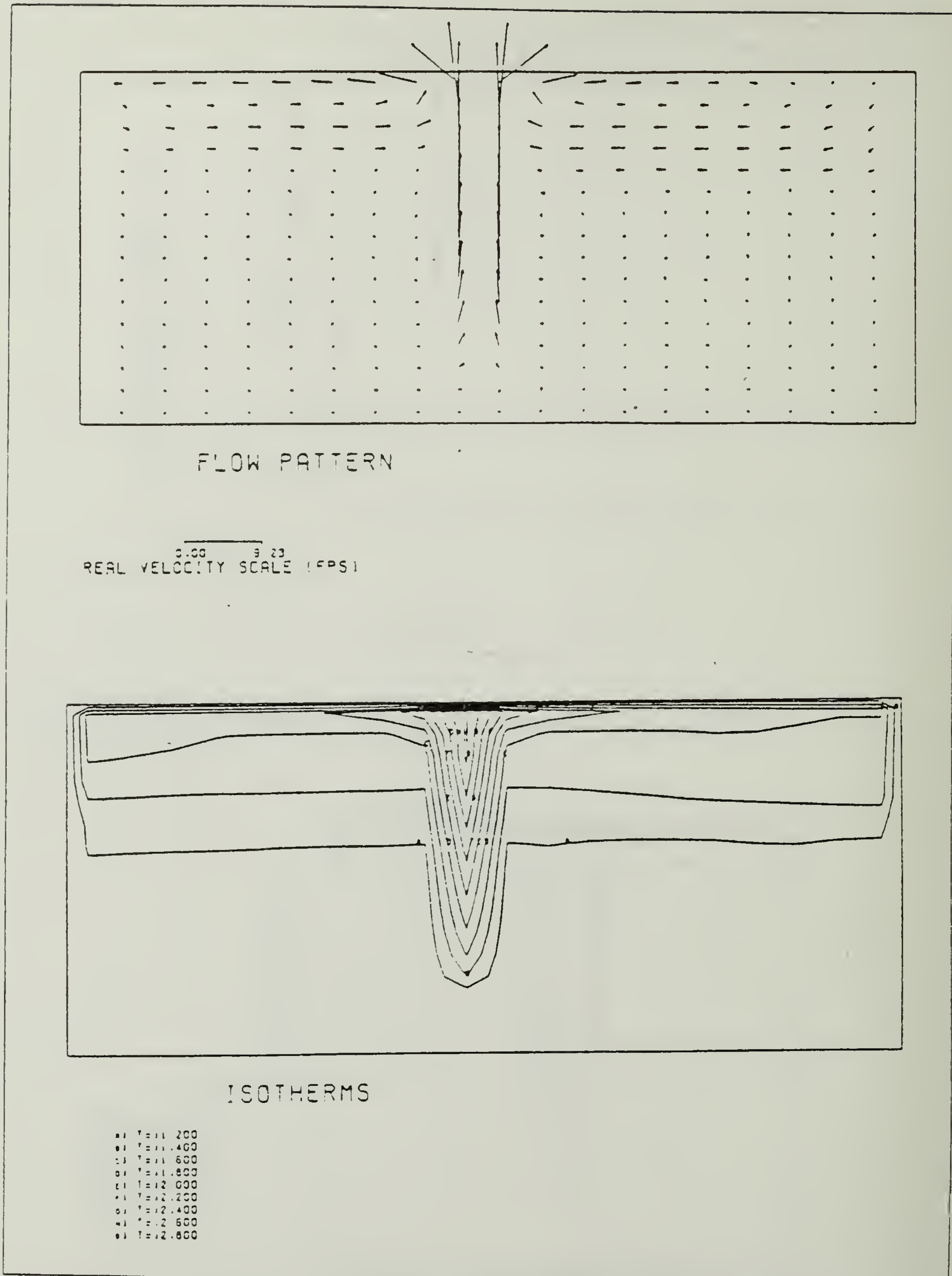

Figure 3.13 Velocity and Isotherm Plots after 128 sec on the XZ Plane.

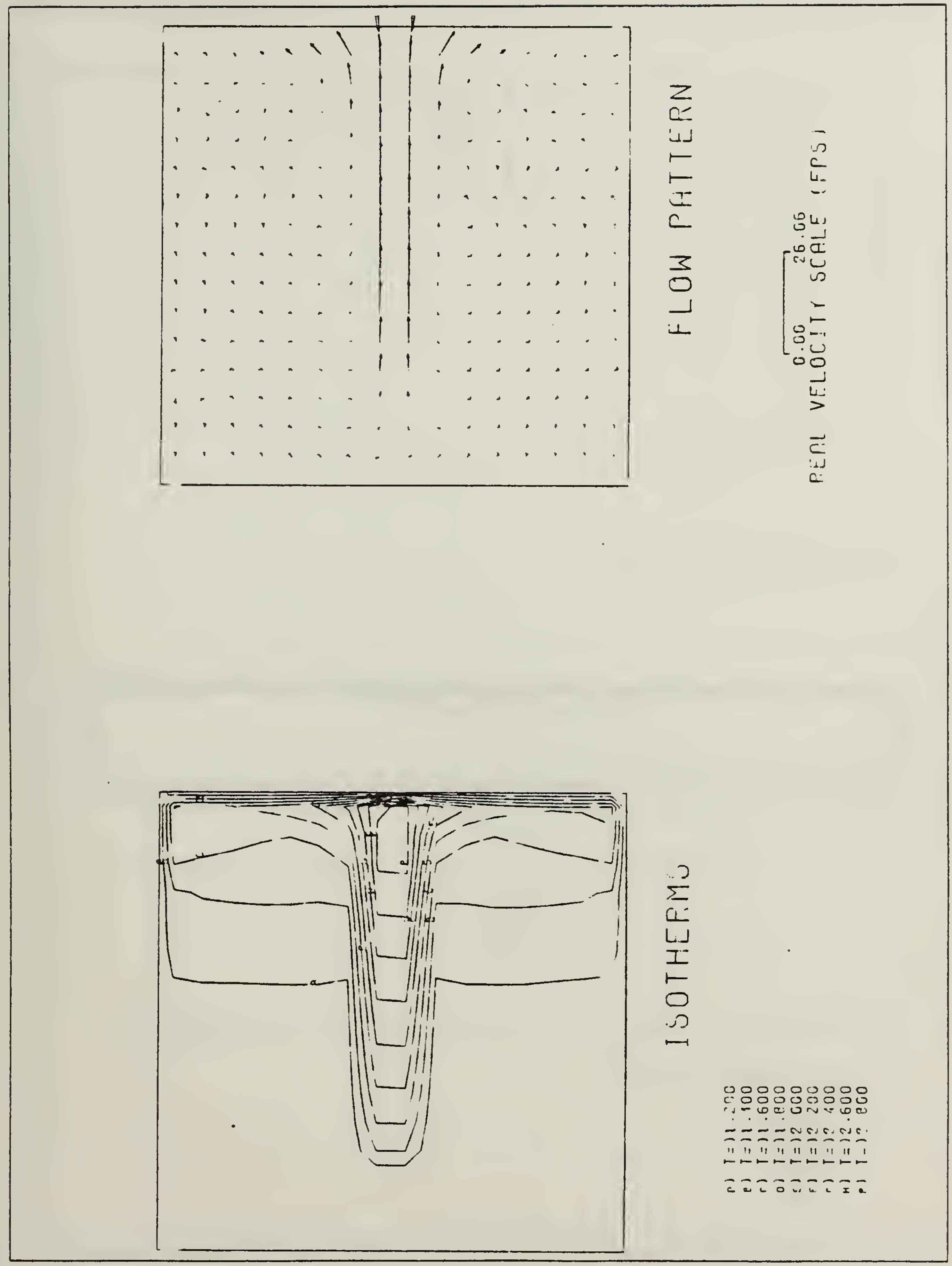

Figure 3.14 Velocity and Isotherm Plots after 128 sec on the YZ Plane.

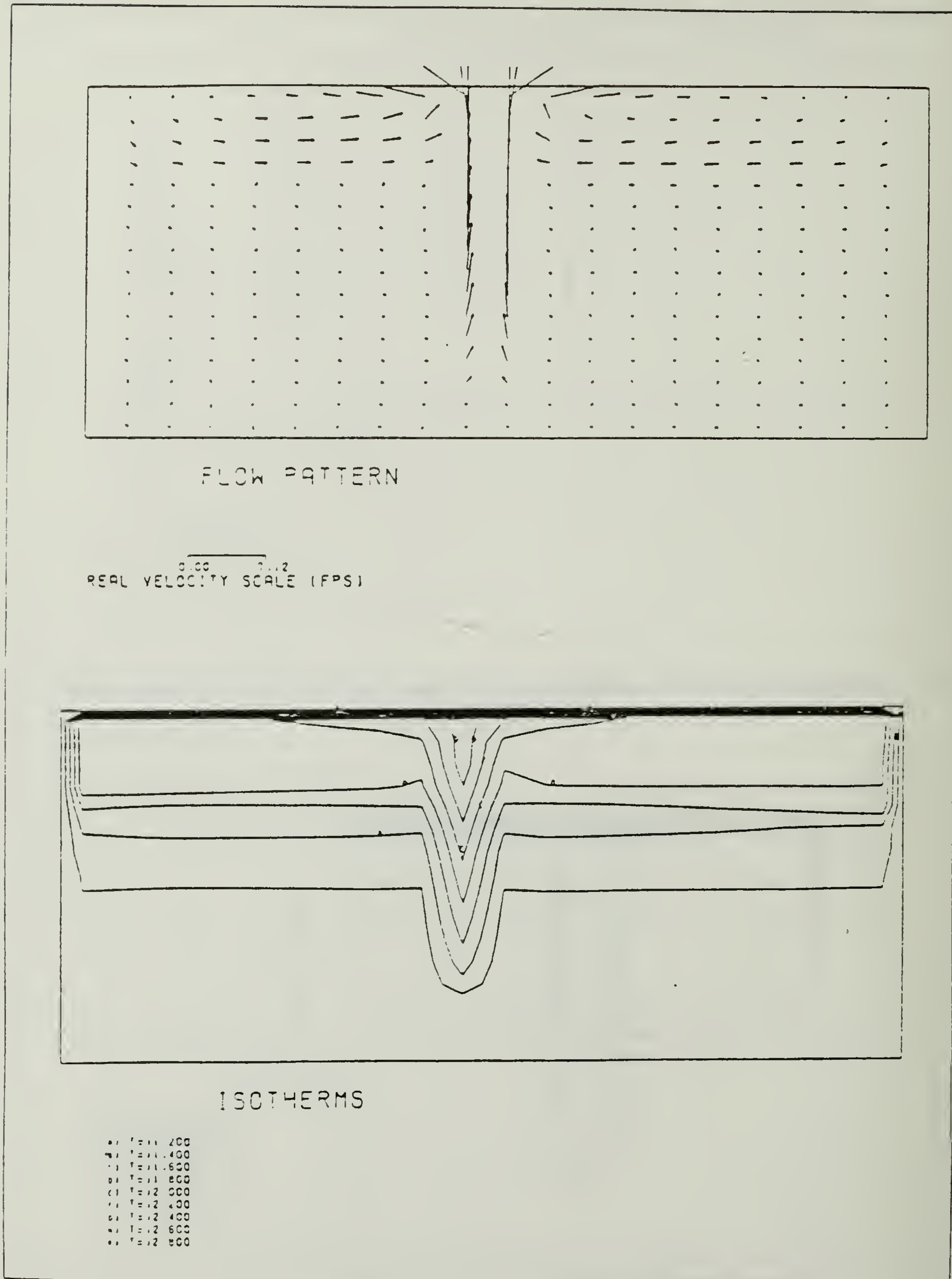

Figure 3.15 Velocity and Isotherm Plots after 181 sec on the XZ Plane.

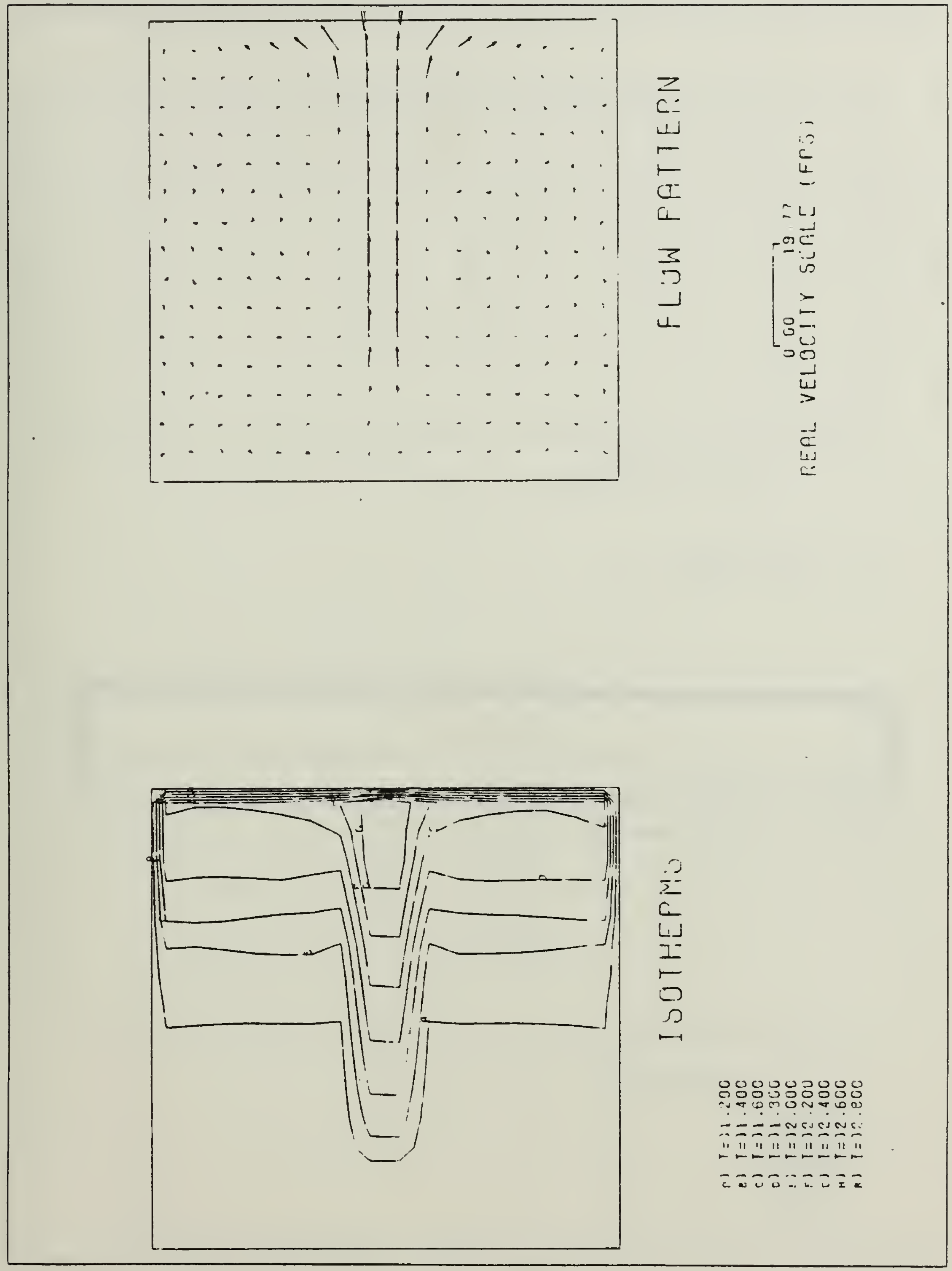

Figure 3.16 Velocity and Isotherm Plots after 181 sec on the YZ Plane.

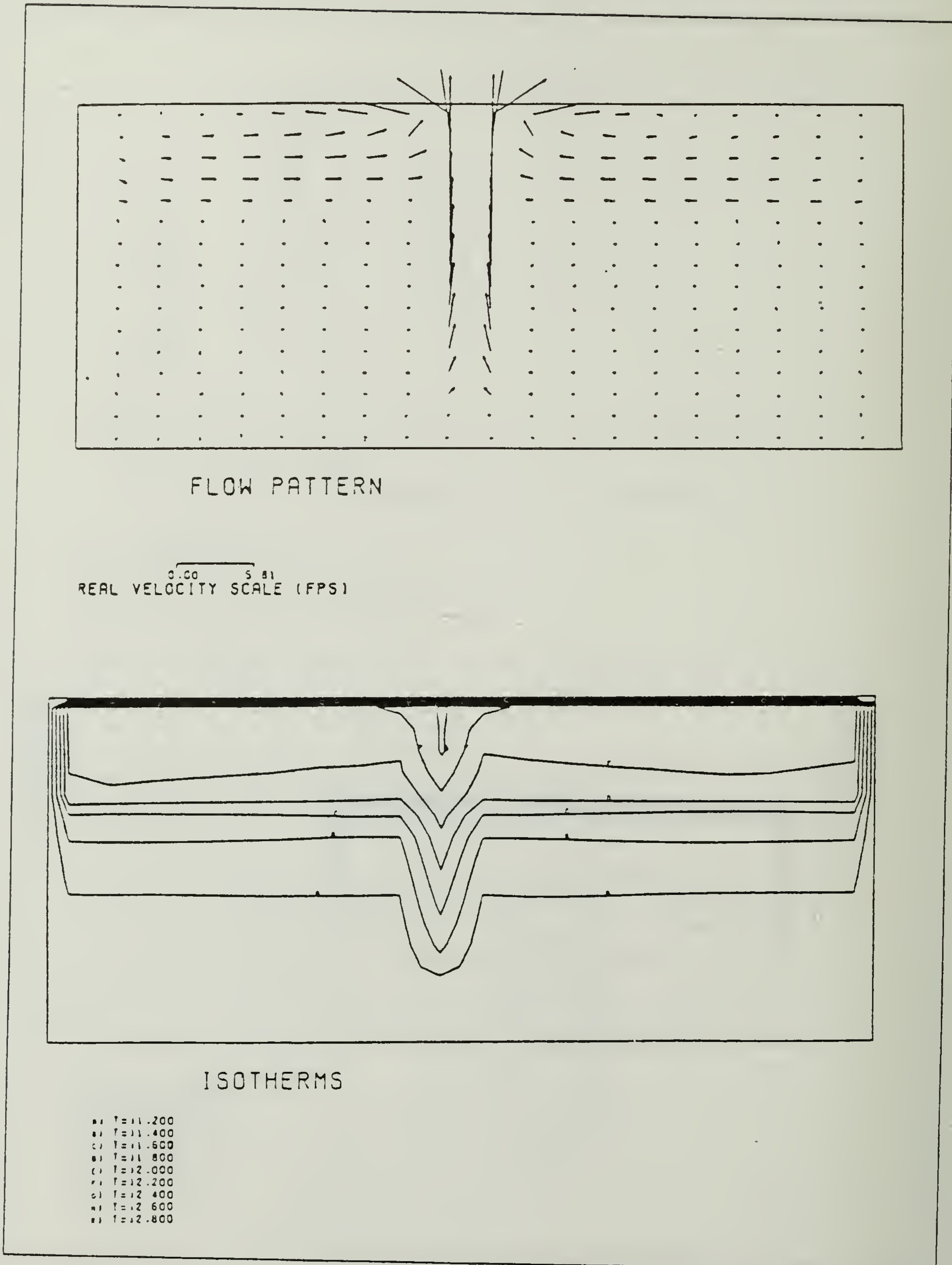

Figure 3.17 Velocity and Isotherm Plots after 245 sec on the XZ Plane.

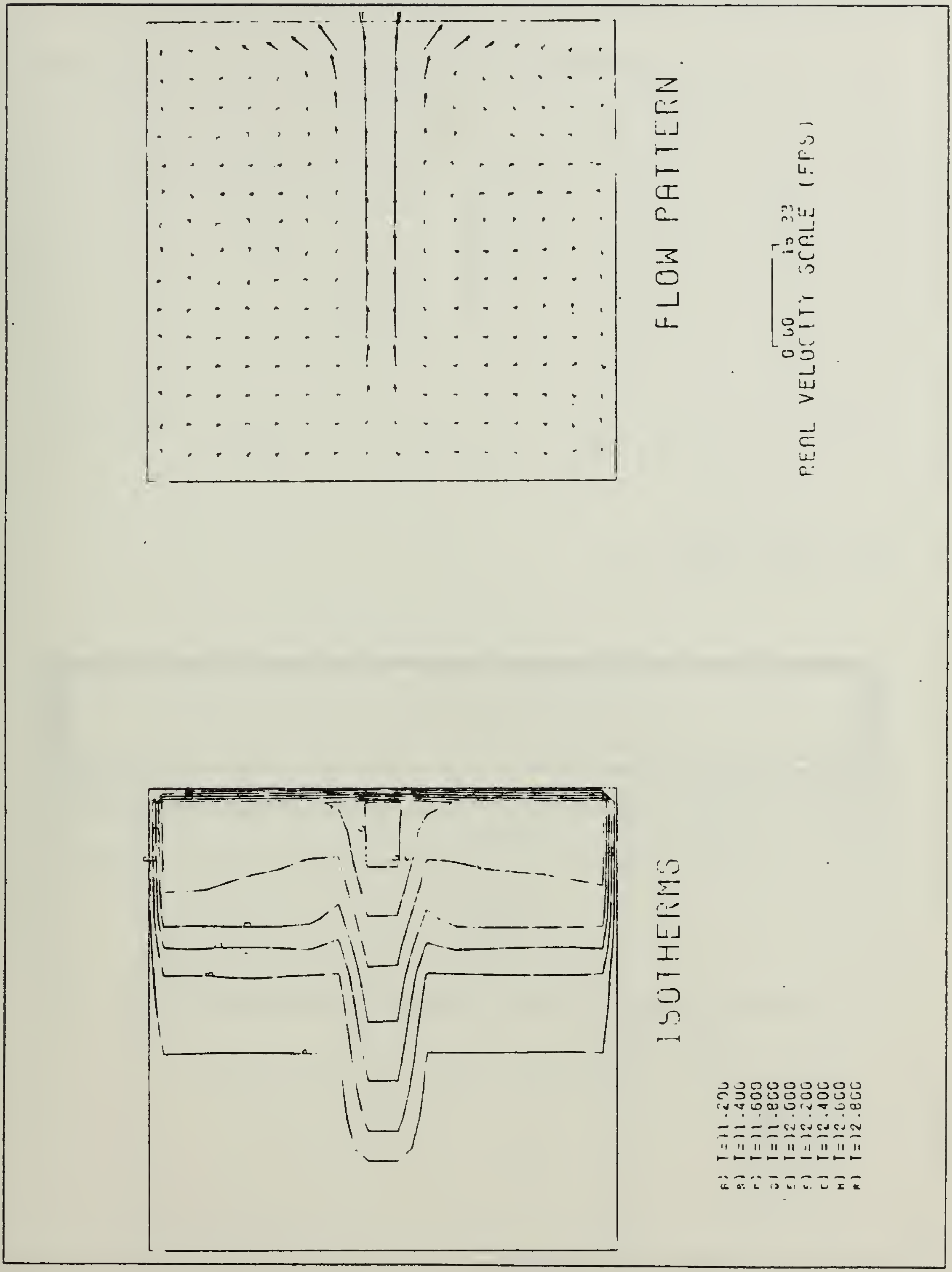

Figure 3.18 Velocity and Isotherm Plots after 245 sec on the YZ Plane.

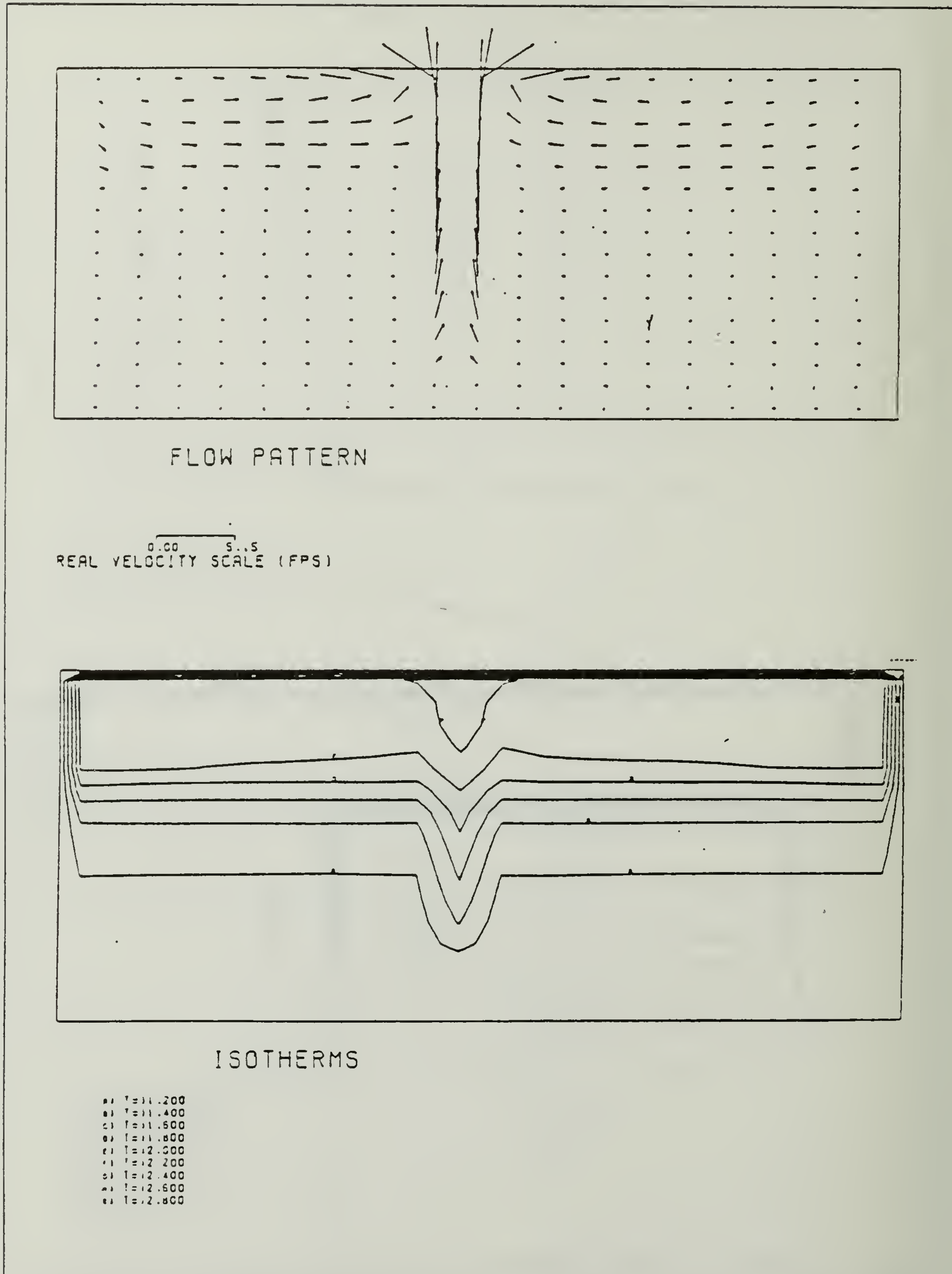

Figure 3.19 Velocity and Isotherm Plots after 299 sec on the XZ Plane.

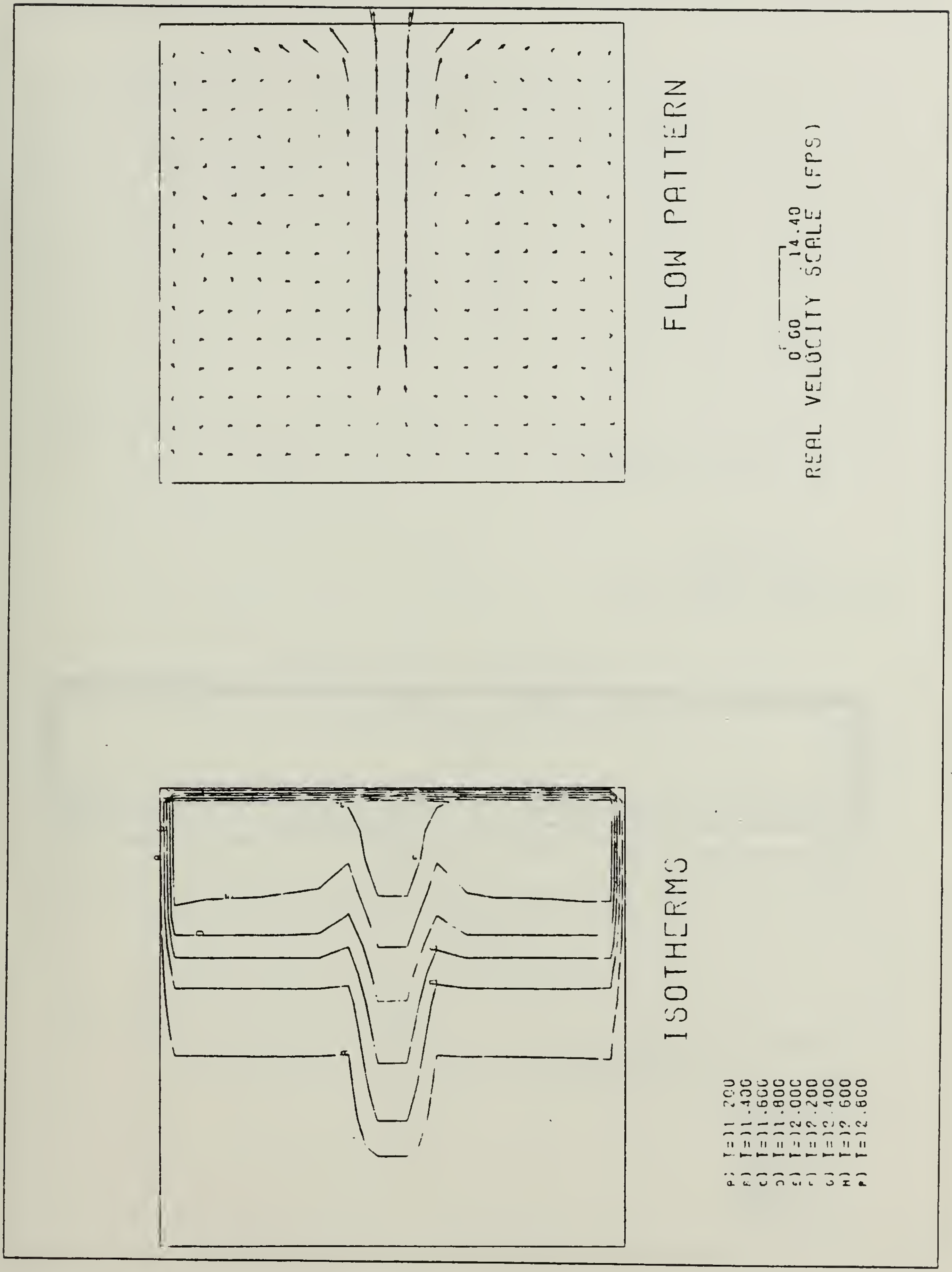

Figure 3.20 Velocity and Isotherm Plots after 299 sec on the YZ Plane.

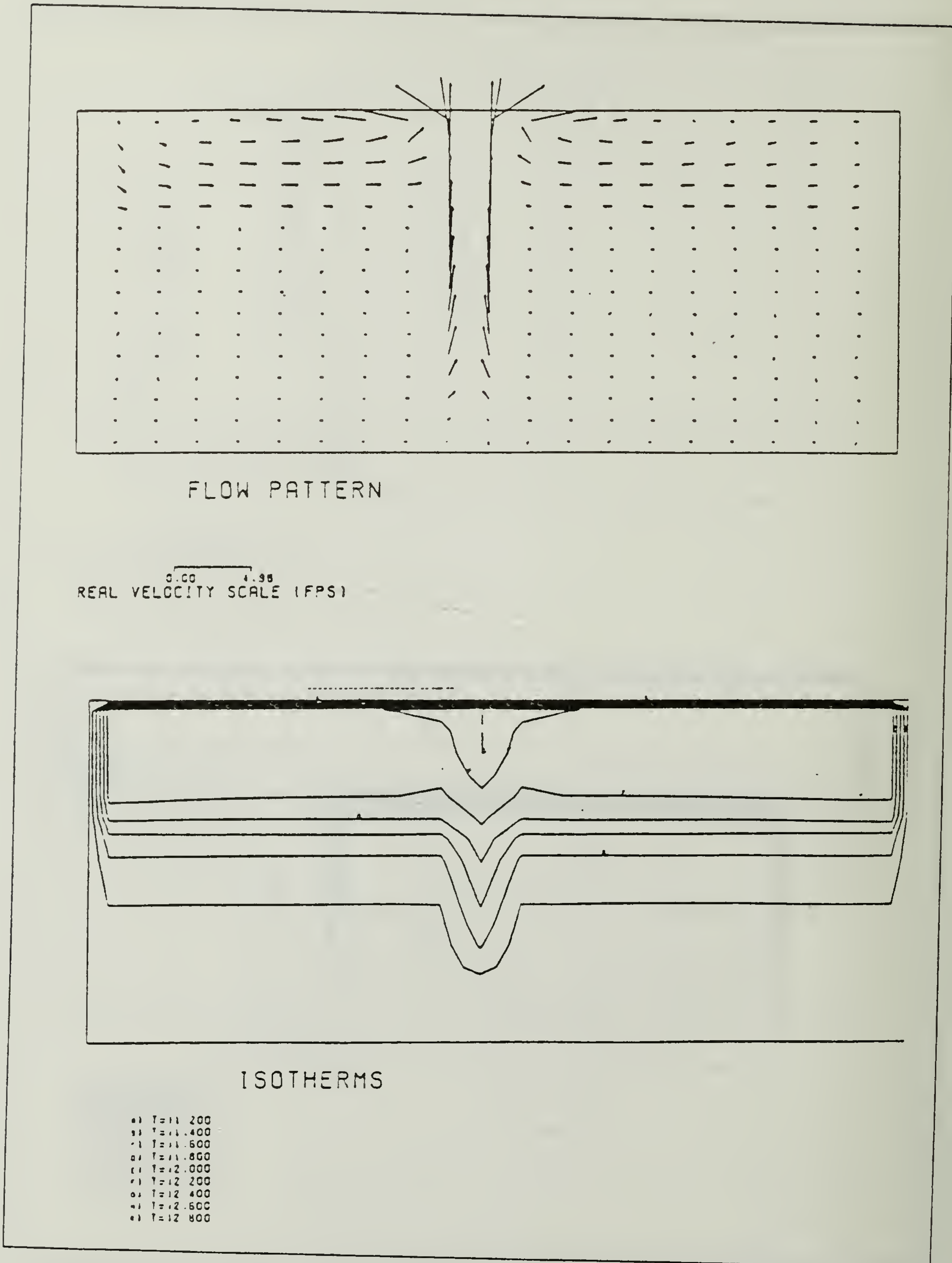

Figure 3.21 Velocity and Isotherm Plots after 364 sec on the XZ Plane.

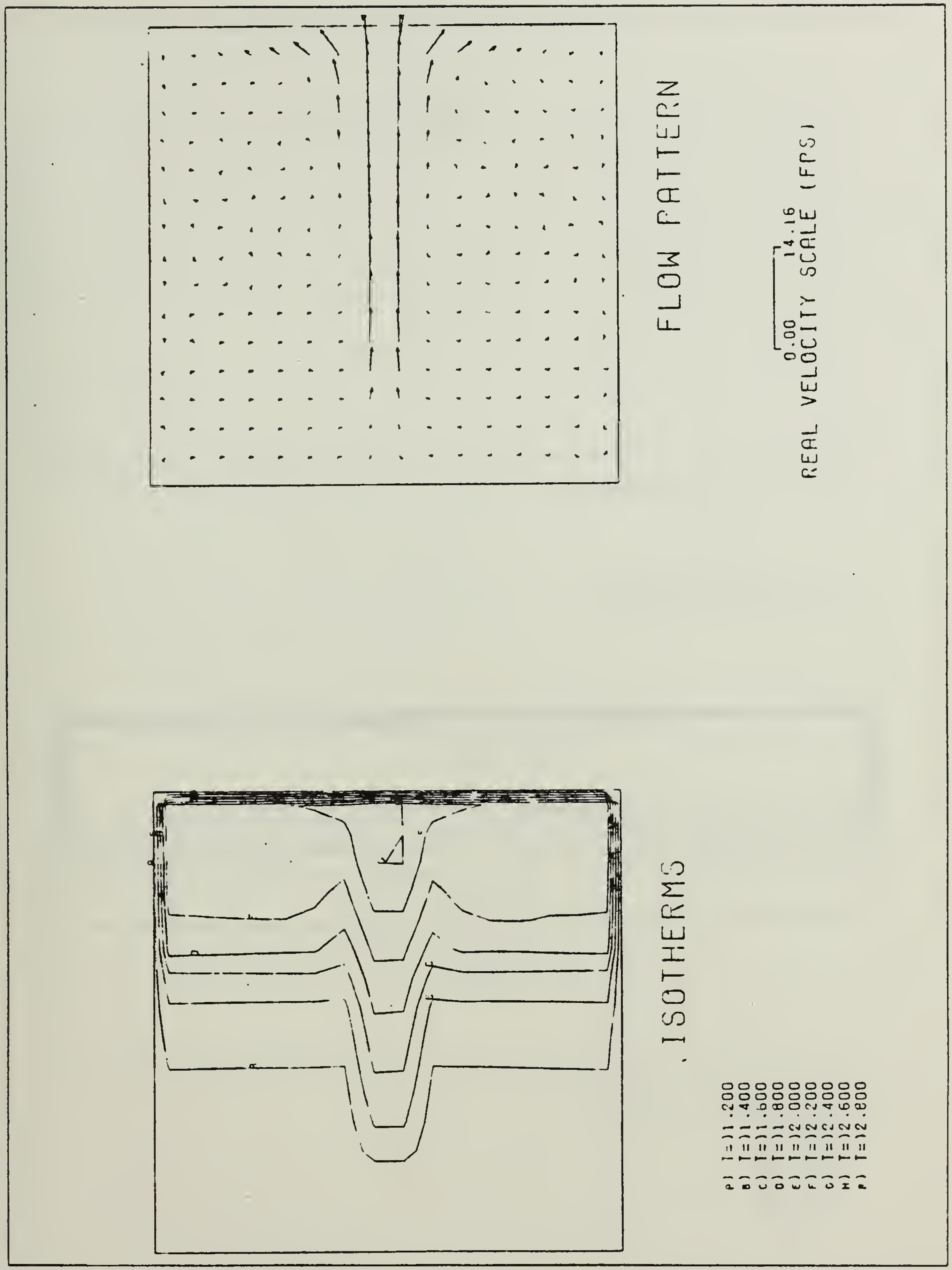

Figure 3.22 Velocity and Isotherm Plots after 364 sec on the YZ Plane.

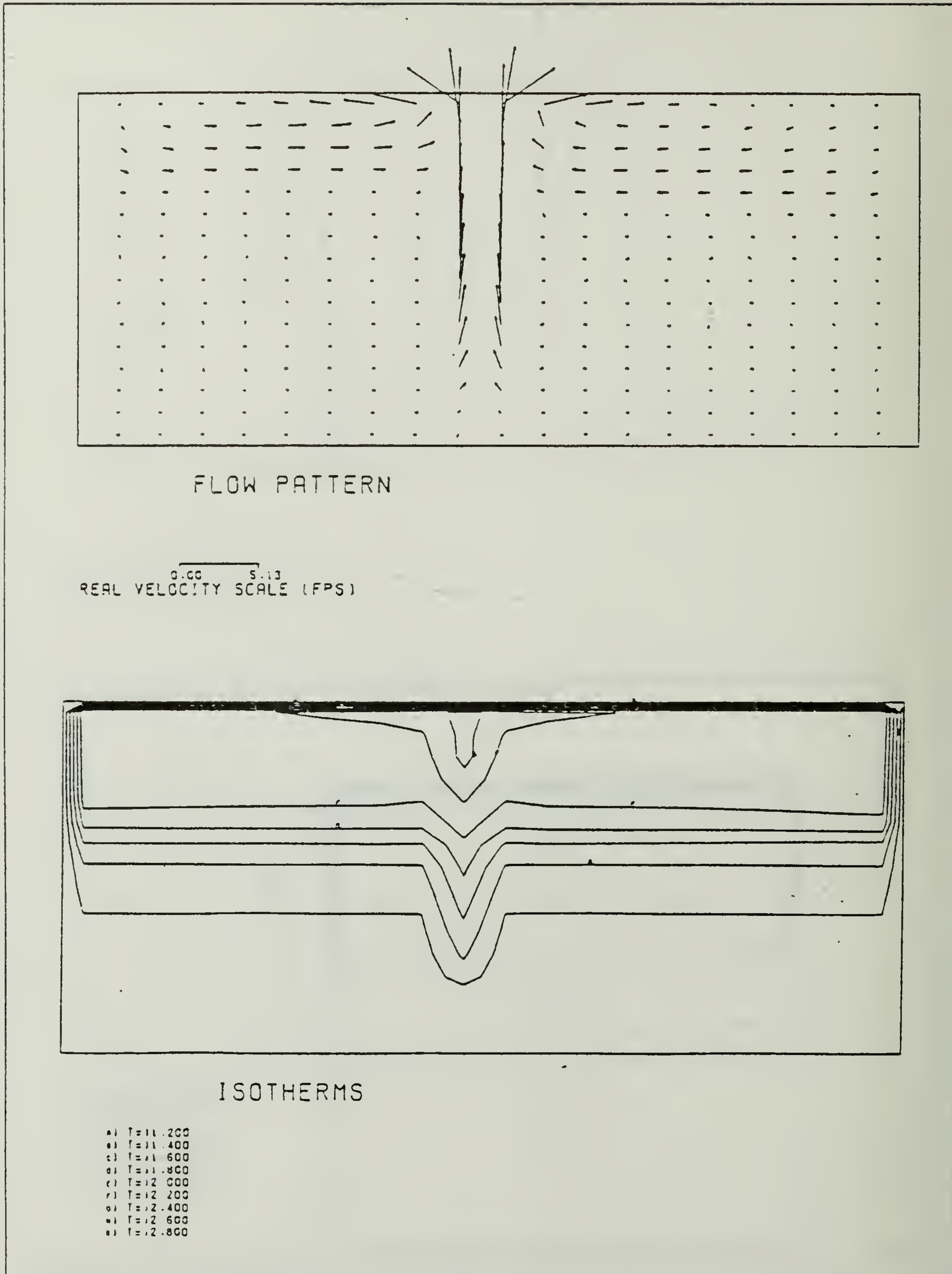

Figure 3.23 Velocity and Isotherm Plots after 420 sec on the XZ Plane.

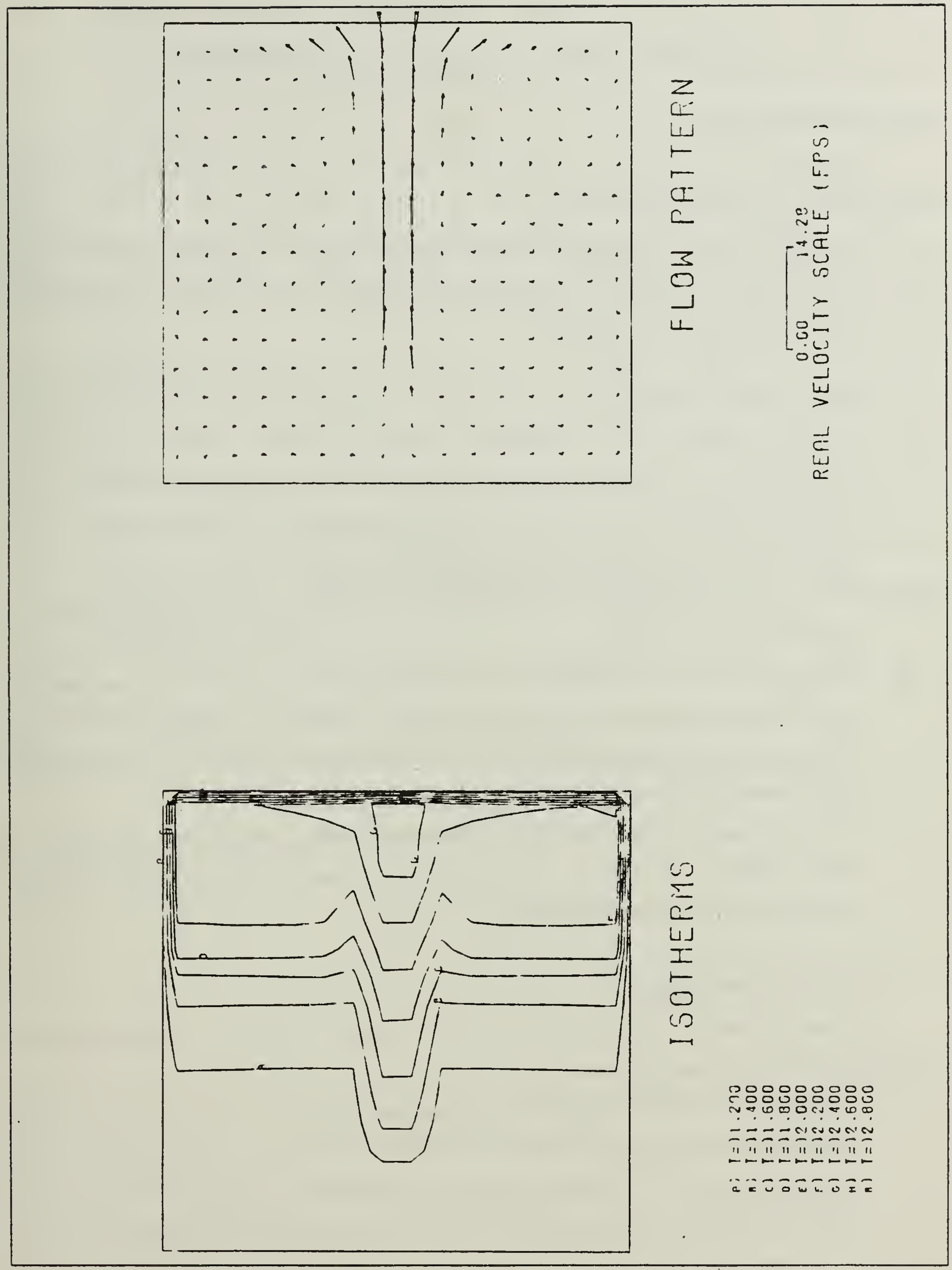

Figure 3.24 Velocity and Isotherm Plots after 420 sec on the YZ Plane.

IV. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSIONS

A number of conclusions may be drawn from this initial simulation of the Fire I test vessel with a numerical model:

1) Despite a lack of experimental heat release rate data preliminary validation of the model is possible by numerically generating a heat release curve from the other data that was available.
2) The rectangular model does not predict the temperatures accurately in the upper region of the tank near the tank endcaps primarily due to the difference in the geometries. The uncertainty in the heat release rate also plays a role. Lower in the tank away from the downward recirculating flow the calculated temperatures are more accurate. The overall shape and spacing of the curves from the model and experimental curves are similar.
3) The expected pattern of recirculating flow in both the XZ and YZ planes is predicted by the model.
4) Since the Fire I test facility has no velocity sensors, details of the flow field are now available that were unavailable before. Thus some useful information on the approximate magnitude of the velocities and the height of the recirculating flow zone may be extracted from the model.
5) More extensive validation of the numerical scheme requires the availabilty of heat release rate data and the change to the actual cylindrical/spherical geometry in the numerical model.

B. RECOMMENDATIONS

In order to better simulate the Fire I test vessel a number of recommendations for future work are presented here:

1) Validate the cylindrical/spherical numerical model with data from as many locations away from the endcaps as possible. With the current setup the two permanent racks of thermocouples and radiometers located at symmetrically opposite ends of the tank provide only one set of data for validation purposes.

2) Validate the model with experimental heat release rate data. This will allow using the pressure as a validating parameter rather than an input. The pressure check is much more desirable because it is a global check unlike the temperature which is a check at only one point and is much more subject to variations.

3) Add more components to the numerical model including decks and recirculating fans to better simulate the tests in the Fire I test facility.

4) Add an ability to simulate the nitrogen pressurization capability of Fire I. This would allow an excellent ability to validate the conduction model after the fire is out.

5) Incorporate a combustion model and a gas radiation model. Both of these items would add greatly to the capability of the model. The combustion model in particular would eliminate the need for specifying the flame envelope and the distribution of the heat release rates from combustion throughout the flame. In addition, the combustion model would provide a basis for the oxygen depletion rate and eventually the effectiveness of a nitrogen gas extinguishing system.

APPENDIX A

THE FINITE DIFFERENCE EQUATIONS IN OTHER COORDINATE SYSTEMS

The finite difference equations for the numerical model in cylindrical and spherical coordinates are presented in this appendix. One important difference between these equations and the rectangular equations presented earlier is the use of a non-uniform grid. Specifically, the spacing in the r-direction is variable. This was done to try to keep the cells as square shaped as possible and avoid long thin cells that tend to reduce the accuracy of the program.

1. THE FINITE DIFFERENCE EQUATIONS IN CYLINDRICAL COORDINATES

In the cylindrical geometry the three coordinates are r, θ, and z. The velocities in these directions are V_r, V_θ, and V_z, respectively. Unlike the rectangular geometry where gravity only acts in the z-direction, here it acts in both the r and θ directions so an appropriate term is included in the r-momentum and θ-momentum equations.
Continuity Equation:

$$(\rho_P - \rho^\circ_P)\Delta V/\Delta t + (r_e G_e - r_w G_w)\Delta\theta\Delta z + (G_n - G_s)\Delta r_P \Delta z + (G_t - G_b) r_P \Delta r_P \Delta\theta = Sm_P \Delta V \quad \text{(eqn A.1)}$$

where the mass fluxes at the boundaries are:

$$G_e = [(\Delta r_P \rho_E + \Delta r_E \rho_P) / (\Delta r_E + \Delta r_P)] \; V_{r_e} \quad \text{(eqn A.2)}$$

$$G_w = [(\Delta r_W \rho_P + \Delta r_P \rho_W) / (\Delta r_P + \Delta r_W)] \; V_{r_w} \quad \text{(eqn A.3)}$$

$$G_n = .5\,(\rho_N + \rho_P)\, V_{\theta n} \quad \text{(eqn A.4)}$$

$$G_s = .5\,(\rho_P + \rho_S)\,V_{\theta s} \qquad \text{(eqn A.5)}$$

$$G_t = .5\,(\rho_T + \rho_P)\,V_{z_t} \qquad \text{(eqn A.6)}$$

$$G_b = .5\,(\rho_P + \rho_B)\,V_{z_b} \qquad \text{(eqn A.7)}$$

Energy Equation:

$$[{}^hA_P + \rho^\circ{}_P\,\Delta V/\Delta t]\,h_P = {}^hA_E\,h_E + {}^hA_W\,h_W + {}^hA_N\,h_N + {}^hA_S\,h_S + {}^hA_T\,h_T + {}^hA_B\,h_B + {}^hS_P \qquad \text{(eqn A.8)}$$

where

$${}^hA_E = \{.5(|G_e| - G_e) + 1/[(Re_tPr_t)_e(r_E - r_P)]\}\,r_E\Delta\theta\Delta z \qquad \text{(eqn A.9)}$$

$${}^hA_W = \{.5(|G_w| + G_w) + 1/[(Re_tPr_t)_w(r_P - r_W)]\}\,r_W\Delta\theta\Delta z \qquad \text{(eqn A.10)}$$

$${}^hA_N = \{.5(|G_n| - G_n) + 1/[(Re_tPr_t)_n\,r_P\Delta\theta]\}\,\Delta r_P\Delta z \qquad \text{(eqn A.11)}$$

$${}^hA_S = \{.5(|G_s| + G_n) + 1/[(Re_tPr_t)_s\,r_P\Delta\theta]\}\,\Delta r_P\Delta z \qquad \text{(eqn A.12)}$$

$${}^hA_T = \{.5(|G_t| - G_t) + 1/[(Re_tPr_t)_t\,\Delta z]\}\,r_P\Delta r_P\Delta\theta \qquad \text{(eqn A.13)}$$

$${}^hA_B = \{.5(|G_b| - G_b) + 1/[(Re_tPr_t)_b\,\Delta z]\}\,r_P\Delta r_P\Delta\theta \qquad \text{(eqn A.14)}$$

$$
{}^{h}A_P = \{.5(|G_e| + G_e)r_P - G_e r_e + r_P [(Re_t Pr_t)_e (r_E - r_P)]\} \Delta\theta\Delta z
$$

$$
+ \{.5(|G_w| - G_w)r_P + G_w r_w + r_P [(Re_t Pr_t)_w (r_P - r_W)]\} \Delta\theta\Delta z \quad \text{(eqn A.15)}
$$

$$
+ {}^{h}A_N + {}^{h}A_S + {}^{h}A_T + {}^{h}A_B
$$

$$
{}^{h}S_P = \rho^{\circ}_P \, h^{\circ}_P \, \Delta V / \Delta t \quad \text{(eqn A.16)}
$$

The momentum equations are slightly more complex because of the staggered cells and the additional terms introduced by the shear stress tensor. The grid for the r-momentum equation is shifted one half cell in the negative r-direction and quantities in this grid are designated with an ^{a} superscript. Similarly, the staggered grids for the θ and z-momentum equations are shifted one half cell in the negative θ and z directions from the basic cell and these are designated with ^{b} and ^{c} superscripts, respectively. Because of the complexity of the equations, variables with i, j, and k subscripts are used to identify the grid location of many variables. The following equations define the location of these subscripted variables:

$$
\rho_P = \rho_{i,j,k} \quad \text{(eqn A.17)}
$$

$$
V_{r_w} = V_{r_{i,j,k}} \quad \text{(eqn A.18)}
$$

$$
V_{\theta s} = V_{\theta i,j,k} \quad \text{(eqn A.19)}
$$

$$
V_{z_b} = V_{z_{i,j,k}} \quad \text{(eqn A.20)}
$$

$$
r_w = r_i \quad \text{(eqn A.21)}
$$

$$r_P = r_I \qquad \text{(eqn A.22)}$$

$$\Delta r_P = \Delta r_i \qquad \text{(eqn A.23)}$$

The finite difference momentum equations are:

R-Momentum:

$$[A_P{}^a + \rho^\circ{}_P{}^a \quad \Delta V^a / \Delta t] \, V_{r_P{}^a} =$$

$$A_E{}^a V_{r_E{}^a} + A_W{}^a V_{r_W{}^a} + A_N{}^a V_{r_N{}^a} \qquad \text{(eqn A.24)}$$

$$+ A_S{}^a V_{r_S{}^a} + A_T{}^a V_{r_T{}^a} + A_B{}^a V_{r_B{}^a} + S_P{}^a$$

where

$$A_E{}^a = \{.5(|G_e{}^a| - G_e{}^a) + 1/[(Re_t)_e{}^a \, \Delta r_P \,]\} \, r_e \Delta\theta \Delta z \qquad \text{(eqn A.25)}$$

$$A_W{}^a = \{.5(|G_w{}^a| + G_w{}^a) + 1/[(Re_t)_w{}^a \, \Delta r_W \,]\} \, r_{i-1} \Delta\theta \Delta z \qquad \text{(eqn A.26)}$$

$$A_N{}^a = \{.5(|G_n{}^a| - G_n{}^a) + 1/[(Re_t)_n{}^a \, r_w \Delta\theta \,]\} \, \Delta r_P{}^a \Delta z \qquad \text{(eqn A.27)}$$

$$A_S{}^a = \{.5(|G_s{}^a| + G_s{}^a) + 1/[(Re_t)_s{}^a \, r_w \Delta\theta \,]\} \, \Delta r_P{}^a \Delta z \qquad \text{(eqn A.28)}$$

$$A_T{}^a = \{.5(|G_t{}^a| - G_t{}^a) + 1/[(Re_t)_t{}^a \, \Delta z \,]\} \, r_w \Delta r_P{}^a \Delta\theta \qquad \text{(eqn A.29)}$$

$$A_B{}^a = \{.5(|G_b{}^a| - G_b{}^a) \qquad \text{(eqn A.31)}$$

$$+ \; 1/[(Re_t)_b{}^a \; \Delta z \;]\} \; r_W \Delta r_{Pa} \Delta\theta$$

$$A_{Pa} = \{.5(|G_e{}^a| + G_e{}^a) r_w - G_e{}^a r_P + r_w/[(Re_t)_e{}^a \; \Delta r_P \;]\} \times \Delta\theta\Delta z + \{.5(|G_w{}^a| - G_w{}^a) \; r_{i-1} + G_w{}^a \; r_W + r_{i-1}/[(Re_t)_w{}^a \; \Delta r_W \;]\} \times \Delta\theta\Delta z + A_N{}^a + A_S{}^a + A_T{}^a + A_B{}^a \qquad \text{(eqn A.32)}$$

$$\begin{aligned} S_{Pa} = {} & \rho^\circ{}_{Pa} \; V^\circ{}_{r_{Pa}} \; \Delta V^a/\Delta t - (r_P P_P - r_W P_W) \; \Delta\theta\Delta z \\ & - (\rho^\circ{}_{Pa} - \rho_{Eq,Pa}) \sin\theta_P \; \Delta V^a / F \\ & + (r_e V_{r_e a} - r_w V_{r_w a})(1/Re_t)_e{}^a \; \Delta\theta\Delta z/\Delta r_P \\ & - (r_w V_{r_w a} - r_{i-1} V_{r_{i-1,j,k}})(1/Re_t)_w{}^a \; \Delta\theta\Delta z/\Delta r_W \\ & + (V_{\theta i,j+1,k} - V_{\theta i-1,j+1,k})(1/Re_t)_n{}^a \; \Delta z \\ & - (V_{\theta i,j,k} - V_{\theta i-1,j,k})(1/Re_t)_s{}^a \; \Delta z \\ & + (V_{z_{i,j,k+1}} - V_{z_{i-1,j,k+1}})(1/Re_t)_t{}^a \; \Delta\theta \\ & - (V_{z_{i,j,k}} - V_{z_{i-1,j,k}})(1/Re_t)_b{}^a \; \Delta\theta \end{aligned} \qquad \text{(eqn A.33)}$$

and in these equations

$$\Delta r_{Pa} = (\Delta r_P + \Delta r_W) \; / \; 2 \qquad \text{(eqn A.34)}$$

$$\begin{aligned} \Delta V^a & = r_{Pa} \Delta r_{Pa} \Delta\theta\Delta z \\ & = r_w(\Delta r_P + \Delta r_W) \; \Delta\theta\Delta z \; / \; 2 \end{aligned} \qquad \text{(eqn A.35)}$$

$$G_e{}^a = .5 \; \rho_P \; (r_e V_{r_e} + r_w V_{r_w}) \; / \; r_P \qquad \text{(eqn A.36)}$$

$$G_w{}^a = .5\, \rho_W (r_w V_{r_w} + r_{i-1} V_{r_{i-1,j,k}}) / r_W \qquad \text{(eqn A.37)}$$

$$G_n{}^a = [.5(\rho_N + \rho_P)\, \Delta r_W V_{\theta n}$$
$$+ .5(\rho_{i-1,j+1,k} + \rho_W)\, \Delta r_P V_{\theta i-1,j+1,k}] \qquad \text{(eqn A.38)}$$
$$/ (\Delta r_P + \Delta r_W)$$

$$G_s{}^a = [.5(\rho_P + \rho_S)\, \Delta r_W V_{\theta s}$$
$$+ .5(\rho_W + \rho_{i-1,j-1,k})\, \Delta r_P V_{\theta i-1,j,k}] \qquad \text{(eqn A.39)}$$
$$/ (\Delta r_P + \Delta r_W)$$

$$G_t{}^a = [.5(\rho_T + \rho_P)\, \Delta r_W V_{z_t}$$
$$+ .5(\rho_{i-1,j,k+1} + \rho_W)\, \Delta r_P V_{z_{i-1,j,k+1}}] \qquad \text{(eqn A.40)}$$
$$/ (\Delta r_P + \Delta r_W)$$

$$G_b{}^a = [.5(\rho_P + \rho_B)\, \Delta r_W V_{z_b}$$
$$+ .5(\rho_W + \rho_{i-1,j,k-1})\, \Delta r_P V_{z_{i-1,j,k}}] \qquad \text{(eqn A.41)}$$
$$/ (\Delta r_P + \Delta r_W)$$

θ-Momentum:

$$[A_P{}^b + \rho^\circ{}_P{}^b\, \Delta V^b / \Delta t]\, V_{\theta P}{}^b =$$
$$A_E{}^b\, V_{\theta E}{}^b + A_W{}^b\, V_{\theta W}{}^b + A_N{}^b\, V_{\theta N}{}^b \qquad \text{(eqn A.42)}$$
$$+ A_S{}^b\, V_{\theta S}{}^b + A_T{}^b\, V_{\theta T}{}^b + A_B{}^b\, V_{\theta B}{}^b + S_P{}^b$$

where

$$A_E{}^b = \{.5(|G_e{}^b| - G_e{}^b)$$
$$+ 1/[(Re_t)_e{}^b\, (\Delta r_E + \Delta r_P)/2\,]\}\, r_E \Delta\theta \Delta z \qquad \text{(eqn A.43)}$$

$$A_W{}^b = \{.5(|G_w{}^b| + G_w{}^b) + 1/[(Re_t)_w{}^b\,(\Delta r_P + \Delta r_W)/2\,]\}\; r_W \Delta\theta \Delta z \qquad \text{(eqn A.44)}$$

$$A_N{}^b = \{.5(|G_n{}^b| - G_n{}^b) + 1/[(Re_t)_n{}^b\, r_P \Delta\theta\,]\}\; \Delta r_P \Delta z \qquad \text{(eqn A.45)}$$

$$A_S{}^b = \{.5(|G_s{}^b| + G_s{}^b) + 1/[(Re_t)_s{}^b\, r_P \Delta\theta\,]\}\; \Delta r_P \Delta z \qquad \text{(eqn A.46)}$$

$$A_T{}^b = \{.5(|G_t{}^b| - G_t{}^b) + 1/[(Re_t)_t{}^b\, \Delta z\,]\}\; r_P \Delta r_P \Delta\theta \qquad \text{(eqn A.47)}$$

$$A_B{}^b = \{.5(|G_b{}^b| - G_b{}^b) + 1/[(Re_t)_b{}^b\, \Delta z\,]\}\; r_P \Delta r_P \Delta\theta \qquad \text{(eqn A.48)}$$

$$\begin{aligned} A_P{}^b = {} & \{.5(|G_e{}^b| + G_e{}^b) r_P - G_e{}^b r_e \\ & + r_P/[(Re_t)_e{}^b\,(\Delta r_E + \Delta r_P)/2\,]\}\; \Delta\theta\Delta z \\ & + \{.5(|G_w{}^b| - G_w{}^b) r_P + G_w{}^b r_W \\ & + r_P/[(Re_t)_w{}^b\,(\Delta r_P + \Delta r_W)/2\,]\}\; \Delta\theta\Delta z \\ & + A_N{}^b + A_S{}^b + A_T{}^b + A_B{}^b \end{aligned} \qquad \text{(eqn A.49)}$$

$$\begin{aligned} S_P{}^b = {} & \rho^\circ{}_P{}^b\, V^\circ{}_{\theta P}{}^b\, \Delta V^b/\Delta t - (P_P - P_S)\, \Delta r_P \Delta z \\ & - (\rho^\circ{}_P{}^b - \rho_{Eq,P}{}^b) \cos\theta_P\, \Delta V^b / F \\ & + (V_{r_{i+1,j,k}} - V_{r_{i+1,j-1,k}})\,(1/Re_t)_e{}^b\, \Delta z \\ & - (V_{r_{i,j,k}} - V_{r_{i,j-1,k}})\,(1/Re_t)_w{}^b\, \Delta z \\ & + (V_{\theta n} - V_{\theta s})(1/Re_t)_n{}^b\, \Delta r_P \Delta z\, /(r_P \Delta\theta) \\ & - (V_{\theta s} - V_{\theta i,j-1,k})\,(1/Re_t)_s{}^b\, \Delta r_P \Delta z\, /\, (r_P \Delta\theta) \end{aligned} \qquad \text{(eqn A.50)}$$

$$+ (V_{z_{i,j,k+1}} - V_{z_{i,j-1,k+1}}) (1/Re_t)_{t^b} \Delta r_P$$

$$- (V_{z_{i,j,k}} - V_{z_{i,j-1,k}}) (1/Re_t)_{b^b} \Delta r_P$$

and in these equations

$$\Delta r_{P^b} = \Delta r_P \qquad \text{(eqn A.51)}$$

$$\Delta V^b = r_{P^b} \Delta r_{P^b} \Delta\theta \Delta z = r_P \Delta r_P \Delta\theta \Delta z = \Delta V \qquad \text{(eqn A.52)}$$

$$G_{e^b} = \{[(\Delta r_P \rho_E + \Delta r_E \rho_P) / (\Delta r_P + \Delta r_E)] \ V_{r_e} + [(\Delta r_P \rho_{i+1,j-1,k} + \Delta r_E \rho_S) / (\Delta r_P + \Delta r_E)] \ V_{r_{i+1,j-1,k}}]\} / 2 \qquad \text{(eqn A.53)}$$

$$G_{w^b} = \{[(\Delta r_W \rho_P + \Delta r_P \rho_W) / (\Delta r_W + \Delta r_P)] \ V_{r_w} + [(\Delta r_W \rho_S + \Delta r_P \rho_{i-1,j-1,k}) / (\Delta r_W + \Delta r_P)] \ V_{r_{i,j-1,k}}]\} / 2 \qquad \text{(eqn A.54)}$$

$$G_{n^b} = .5 \ \rho_P \ (V_{\theta n} + V_{\theta s}) \qquad \text{(eqn A.55)}$$

$$G_{s^b} = .5 \ \rho_S \ (V_{\theta s} + V_{\theta i,j-1,k}) \qquad \text{(eqn A.56)}$$

$$G_{t^b} = [.5(\rho_T + \rho_P) \ V_{z_t} + .5(\rho_{i,j-1,k+1} + \rho_S) \ V_{z_{i,j-1,k+1}}] / 2 \qquad \text{(eqn A.57)}$$

$$G_{b^b} = [.5(\rho_P + \rho_B) \ V_{z_b} + .5(\rho_S + \rho_{i,j-1,k-1}) \ V_{z_{i,j-1,k}}] / 2 \qquad \text{(eqn A.58)}$$

Z-Momentum:

$$[A_{Pc} + \rho^{\circ}_{Pc} \ \Delta V^c / \Delta t] \ V_{z_{Pc}} =$$

$$A_{E^c} V_{z_{E^c}} + A_{W^c} V_{z_{W^c}} + A_{N^c} V_{z_{N^c}} + A_{S^c} V_{z_{S^c}} + A_{T^c} V_{z_{T^c}} + A_{B^c} V_{z_{B^c}} + S_{P^c} \qquad \text{(eqn A.59)}$$

where

$$A_{E^c} = \{.5(|G_{e^c}| - G_{e^c}) + 1/[(Re_t)_{e^c} (\Delta r_E + \Delta r_P)/2]\} r_E \Delta\theta\Delta z \qquad \text{(eqn A.60)}$$

$$A_{W^c} = \{.5(|G_{w^c}| + G_{w^c}) + 1/[(Re_t)_{w^c} (\Delta r_E + \Delta r_P)/2]\} r_W \Delta\theta\Delta z \qquad \text{(eqn A.61)}$$

$$A_{N^c} = \{.5(|G_{n^c}| - G_{n^c}) + 1/[(Re_t)_{n^c} r_P \Delta\theta]\} \Delta r_P \Delta z \qquad \text{(eqn A.62)}$$

$$A_{S^c} = \{.5(|G_{s^c}| + G_{s^c}) + 1/[(Re_t)_{s^c} r_P \Delta\theta]\} \Delta r_P \Delta z \qquad \text{(eqn A.63)}$$

$$A_{T^c} = \{.5(|G_{t^c}| - G_{t^c}) + 1/[(Re_t)_{t^c} \Delta z]\} r_P \Delta r_P \Delta\theta \qquad \text{(eqn A.64)}$$

$$A_{B^c} = \{.5(|G_{b^c}| - G_{b^c}) + 1/[(Re_t)_{b^c} \Delta z]\} r_P \Delta r_P \Delta\theta \qquad \text{(eqn A.65)}$$

$$A_{P^c} = \{.5(|G_{e^c}| + G_{e^c}) r_P - G_{e^c} r_e + r_P/[(Re_t)_{e^c} (\Delta r_E + \Delta r_P)/2]\} \Delta\theta\Delta z + \{.5(|G_{w^c}| - G_{w^c}) r_P + G_{w^c} r_w + r_P/[(Re_t)_{w^c} (\Delta r_P + \Delta r_W)/2]\} \Delta\theta\Delta z + A_{N^c} + A_{S^c} + A_{T^c} + A_{B^c} \qquad \text{(eqn A.66)}$$

$$S_{P^c} = \rho^\circ{}_{P^c} V^\circ{}_{z_{P^c}} \Delta V^c/\Delta t - (P_P - P_B)\, r_P \Delta_P \Delta z$$
$$+ (V_{r_{i+1,j,k}} - V_{r_{i+1,j,k-1}})\,(1/Re_t)_{e^c}\, r_e \Delta\theta$$
$$- (V_{r_{i,j,k}} - V_{r_{i,j,k-1}})\,(1/Re_t)_{w^c}\, r_w \Delta\theta$$
$$+ (V_{\theta i,j+1,k} - V_{\theta i,j+1,k-1})\,(1/Re_t)_{n^c}\, \Delta r_P \qquad \text{(eqn A.67)}$$
$$- (V_{\theta i,j,k} - V_{\theta i,j,k-1})\,(1/Re_t)_{s^c}\, \Delta r_P$$
$$+ (V_{z_t} - V_{z_b})\,(1/Re_t)_{t^c}\, r_P \Delta r_P \Delta\theta / \Delta z$$
$$- (V_{z_b} - V_{z_{i,j,k-1}})\,(1/Re_t)_{b^c}\, r_P \Delta r_P \Delta\theta$$

and in these equations

$$\Delta r_{P^c} = \Delta r_P \qquad \text{(eqn A.68)}$$

$$\Delta V^c = r_{P^c} \Delta r_{P^c} \Delta\theta \Delta z$$
$$= r_P \Delta r_P \Delta\theta \Delta z = \Delta V \qquad \text{(eqn A.69)}$$

$$G_{e^c} = \{[(\Delta r_P \rho_E + \Delta r_E \rho_P) / (\Delta r_P + \Delta r_E)]\; V_{r_e}$$
$$+ [(\Delta r_P \rho_{i+1,j,k-1} + \Delta r_E \rho_B) / (\Delta r_P + \Delta r_E)]\; V_{r_{i+1,j,k-1}}\,]\} / 2 \qquad \text{(eqn A.70)}$$

$$G_{w^c} = \{[(\Delta r_W \rho_P + \Delta r_P \rho_W) / (\Delta r_W + \Delta r_P)]\; V_{r_w}$$
$$+ [(\Delta r_W \rho_B + \Delta r_P \rho_{i-1,j,k-1}) / (\Delta r_W + \Delta r_P)]\; V_{r_{i,j,k-1}}\,]\} / 2 \qquad \text{(eqn A.71)}$$

$$G_{n^c} = [.5(\rho_N + \rho_P)\, V_{\theta n}$$
$$+ .5(\rho_{i,j+1,k-1} + \rho_B)\, V_{\theta i,j+1,k-1}\,] / 2 \qquad \text{(eqn A.72)}$$

$$G_{s^c} = [.5(\rho_P + \rho_S)\, V_{\theta s}$$
$$+ .5(\rho_B + \rho_{i,j-1,k-1})\, V_{\theta i,j,k-1}\,] / 2 \qquad \text{(eqn A.73)}$$

$$G_{t^c} = .5\, \rho_P\, (V_{z_t} + V_{x_t}) \qquad \text{(eqn A.74)}$$

Pressure Equation:

$$A_P P_P' = A_E P_E' + A_W P_W' + A_N P_N' + A_S P_S'$$
$$+ A_T P_T' + A_B P_B' - S^*_{mP} \; \Delta V \qquad \text{(eqn A.75)}$$

where

$$A_E = \rho_e (r_e \Delta\theta \Delta z)^2$$
$$/ (A_{p\,i+1,j,k}^{a} + \rho_e \Delta V^a_{i+1,j,k} / \Delta t) \qquad \text{(eqn A.76)}$$

$$A_W = \rho_w (r_w \Delta\theta \Delta z)^2$$
$$/ (A_p^a + \rho_w \Delta V^a / \Delta t) \qquad \text{(eqn A.77)}$$

$$A_N = \rho_n (\Delta r_P \Delta z)^2$$
$$/ (A_{p\,i,j+1,k}^{b} + \rho_n \Delta V^b_{i,j+1,k} / \Delta t) \qquad \text{(eqn A.78)}$$

$$A_S = \rho_s (\Delta r_P \Delta z)^2$$
$$/ (A_p^b + \rho_s \Delta V^b / \Delta t) \qquad \text{(eqn A.79)}$$

$$A_T = \rho_t (r_P \Delta r_P \Delta\theta)^2$$
$$/ (A_{p\,i,j,k+1}^{c} + \rho_t \Delta V^c_{i,j,k+1} / \Delta t) \qquad \text{(eqn A.80)}$$

$$A_B = \rho_b (r_P \Delta r_P \Delta\theta)^2$$
$$/ (A_p^c + \rho_b \Delta V^c / \Delta t) \qquad \text{(eqn A.81)}$$

$$A_P = A_E + A_W + A_N + A_S + A_T + A_B \qquad \text{(eqn A.82)}$$

2. THE FINITE DIFFERENCE EQUATIONS IN SPHERICAL COORDINATES

In the spherical system the three coordinates are r, θ, and φ. The velocities in these directions are V_r, V_θ, and V_φ, respectively. Unlike the rectangular geometry where gravity only acted in the z-direction, here it acts in all three directions so an appropriate term is included in the r-momentum, θ-momentum, and φ-momentum equations.

$$(\rho_P - \rho^\circ_P)\Delta V/\Delta t + (r_e^2 G_e - r_w^2 G_w)\sin\varphi_P \Delta\theta\Delta\varphi + (G_n - G_s) r_P \Delta r_P \Delta\varphi + (G_t \sin\varphi_t - G_b \sin\varphi_b) r_P \Delta r_P \Delta\theta = Sm_P \Delta V \quad \text{(eqn A.83)}$$

where the mass fluxes at the boundaries are:

$$G_e = [(\Delta r_P \rho_E + \Delta r_E^2 \rho_P) / (\Delta r_E + \Delta r_P)]\, V_{r_e} \quad \text{(eqn A.84)}$$

$$G_w = [(\Delta r_W^2 \rho_P + \Delta r_P \rho_W) / (\Delta r_P + \Delta r_W)]\, V_{r_w} \quad \text{(eqn A.85)}$$

$$G_n = .5\,(\rho_N + \rho_P)\, V_{\theta n} \quad \text{(eqn A.86)}$$

$$G_s = .5\,(\rho_P + \rho_S)\, V_{\theta s} \quad \text{(eqn A.87)}$$

$$G_t = .5\,(\rho_T + \rho_P)\, V_{\varphi t} \quad \text{(eqn A.88)}$$

$$G_b = .5\,(\rho_P + \rho_B)\, V_{\varphi b} \quad \text{(eqn A.89)}$$

Energy Equation:

$$[{}^{h}A_P + \rho^{\circ}_P \, \Delta V/\Delta t] \, h_P = {}^{h}A_E \, h_E + {}^{h}A_W \, h_W + {}^{h}A_N \, h_N + {}^{h}A_S \, h_S + {}^{h}A_T \, h_T + {}^{h}A_B \, h_B + {}^{h}S_P \quad \text{(eqn A.90)}$$

where

$${}^{h}A_E = \{.5(|G_e| - G_e) + 1/[(Re_tPr_t)_e(r_E - r_P)]\} \times r_E{}^2 \sin\varphi_P \Delta\theta\Delta\varphi \quad \text{(eqn A.91)}$$

$${}^{h}A_W = \{.5(|G_w| + G_w) + 1/[(Re_tPr_t)_w(r_P - r_W)]\} \times r_W{}^2 \sin\varphi_P \Delta\theta\Delta\varphi \quad \text{(eqn A.92)}$$

$${}^{h}A_N = \{.5(|G_n| - G_n) + 1/[(Re_tPr_t)_n \, r_P \sin\varphi_P \Delta\theta]\} \times r_P \Delta r_P \Delta\varphi \quad \text{(eqn A.93)}$$

$${}^{h}A_S = \{.5(|G_s| + G_n) + 1/[(Re_tPr_t)_s \, r_P \sin\varphi_P \Delta\theta]\} \times r_P \Delta r_P \Delta\varphi \quad \text{(eqn A.94)}$$

$${}^{h}A_T = \{.5(|G_t| - G_t) + 1/[(Re_tPr_t)_t \, r_P \Delta\varphi]\} \times r_P \Delta r_P \sin\varphi_T \Delta\theta \quad \text{(eqn A.95)}$$

$${}^{h}A_B = \{.5(|G_b| - G_b) + 1/[(Re_tPr_t)_b \, r_P \Delta\varphi]\} \times r_P \Delta r_P \sin\varphi_B \Delta\theta \quad \text{(eqn A.96)}$$

$$\begin{aligned}{}^{h}A_P = {} & \{.5(|G_e| + G_e) r_P{}^2 - G_e r_e{}^2 + r_P{}^2/[(Re_tPr_t)_e(r_E - r_P)]\} \\ & \times \sin\varphi_P \Delta\theta\Delta\varphi \\ & + \{.5(|G_w| - G_w) r_P{}^2 + G_w r_W{}^2 + r_P{}^2/[(Re_tPr_t)_w (r_P - r_W)]\} \\ & \times \sin\varphi_P \Delta\theta\Delta\varphi \\ & + {}^{h}A_N + {}^{h}A_S \quad \text{(eqn A.97)} \\ & + \{.5(|G_t| + G_t)\sin\varphi^P - G_t \sin\varphi_t + \sin\varphi_P/[(Re_tPr_t)_t \, r_P \Delta\varphi]\}\end{aligned}$$

$$\times\ r_P \Delta r_P \Delta\theta$$

$$+ \{.5(|G_b| - G_b)\sin\varphi^P + G_b \sin\varphi_b + \sin\varphi_P [(Re_t Pr_t)_b\ r_P \Delta\varphi]\}$$

$$\times\ r_P \Delta r_P \Delta\theta$$

$$^{h}S_P = \rho^{\circ}{}_P\ h^{\circ}{}_P\ \Delta V / \Delta t \qquad \text{(eqn A.98)}$$

The momentum equations are slightly more complex because of the staggered cells and the additional terms introduced by the shear stress tensor. The grid for the r-momentum equation is shifted one half cell in the negative r-direction and quantities in this grid are designated with an ^{a} superscript. Similarly, the staggered grids for the θ and z-momentum equations are shifted one half cell in the negative θ and z directions from the basic cell and these are designated with ^{b} and ^{c} superscripts, respectively. Because of the complexity of the equations, variables with i, j, and k subscripts are used to identify the grid location of many variables. The following equations define the location of these subscripted variables:

$$\rho_P = \rho_{i,j,k} \qquad \text{(eqn A.99)}$$

$$V_{r_w 2} = V_{r_{i,j,k}} \qquad \text{(eqn A.100)}$$

$$V_{\theta s} = V_{\theta i,j,k} \qquad \text{(eqn A.101)}$$

$$V_{\varphi b} = V_{\varphi i,j,k} \qquad \text{(eqn A.102)}$$

$$r_w{}^2 = r_i \qquad \text{(eqn A.103)}$$

$$r_P = r_I \qquad \text{(eqn A.104)}$$

$$\Delta r_P = \Delta r_i \qquad \text{(eqn A.105)}$$

The finite difference momentum equations are:

R-Momentum:

$$[A_{P}a + \rho^{\circ}{}_{P}a\, \Delta V^{a}/\Delta t]\, V_{r_{P}a} = A_{E}a\, V_{r_E}{}^{2a} + A_{W}a\, V_{r_W}{}^{2a} + A_{N}a\, V_{r_N}a + A_{S}a\, V_{r_S}a + A_{T}a\, V_{r_T}a + A_{B}a\, V_{r_B}a + S_{P}a \qquad \text{(eqn A.106)}$$

where

$$A_{E}a = \{.5(|G_{e}a| - G_{e}a) + 1/[(Re_t)_{e}a\, \Delta r_P]\} \times r_e{}^2 \sin\varphi_P \Delta\theta\Delta\varphi \qquad \text{(eqn A.107)}$$

$$A_{W}a = \{.5(|G_{w}a| + G_{w}a) + 1/[(Re_t)_{w}a\, \Delta r_W]\} \times r_{i-1}{}^2 \sin\varphi_P \Delta\theta\Delta\varphi \qquad \text{(eqn A.108)}$$

$$A_{N}a = \{.5(|G_{n}a| - G_{n}a) + 1/[(Re_t)_{n}a\, r_w \sin\varphi_P \Delta\theta]\} \times r_w \Delta r_{P}a \Delta\varphi \qquad \text{(eqn A.109)}$$

$$A_{S}a = \{.5(|G_{s}a| + G_{s}a) + 1/[(Re_t)_{s}a\, r_w \sin\varphi_P \Delta\theta]\} \times r_w \Delta r_{P}a \Delta\varphi \qquad \text{(eqn A.110)}$$

$$A_{T}a = \{.5(|G_{t}a| - G_{t}a) + 1/[(Re_t)_{t}a\, r_w \Delta\varphi]\} \times r_w \sin\varphi_T \Delta r_{P}a \Delta\theta \qquad \text{(eqn A.111)}$$

$$A_{B}a = \{.5(|G_{b}a| - G_{b}a) + 1/[(Re_t)_{b}a\, r_w \Delta\varphi]\} \qquad \text{(eqn A.112)}$$

$$\times\ r_w \sin\varphi_B \Delta r_{Pa} \Delta\theta$$

$$A_P = \{.5(|G_ea| + G_ea) r_w^2 - G_e a r_P^2$$

$$+ r_w^2 / [(Re_t)_e a\ \Delta r_P\ ]\} \sin\varphi_P \Delta\theta\Delta\varphi$$

$$+ \{.5(|G_wa| - G_wa) r_{i-1} + G_w a r_W^2$$

$$+ r_{i-1} / [(Re_t)_w a\ \Delta r_W^2\ ]\} \sin\varphi_P \Delta\theta\Delta\varphi$$

$$+ A_N a + A_S a \qquad \text{(eqn A.113)}$$

$$+ \{.5(|G_ta| + G_ta)\sin\varphi^P - G_t a \sin\varphi_t$$

$$+ \sin\varphi_P\ [(Re_t)_t a\ r_w \Delta\varphi]\}\ r_w \Delta r_{Pa} \Delta\theta$$

$$+ \{.5(|G_ba| - G_ba)\sin\varphi^P + G_b a \sin\varphi_b$$

$$+ \sin\varphi_P / [(Re_t)_b a\ r_P \Delta\varphi]\}\ r_P \Delta r_{Pa} \Delta\theta$$

$$S_{Pa} = \rho°_{Pa}\ V°_{r_{Pa}}\ \Delta V^a / \Delta t$$

$$- (r_P^2 P_P - r_W^2 P_W) \sin\varphi_P \Delta\theta\Delta\varphi$$

$$- (\rho°_{Pa} - \rho_{Eq,Pa}) \sin\theta_P \sin\varphi_P\ \Delta V^a / F$$

$$+ (r_e^2 V_{r_e} - r_w^2 V_{r_w})$$

$$\times\ (1/Re_t)_e a\ \sin\varphi_P \Delta\theta\Delta\varphi / \Delta r_P$$

$$- (r_w^2 V_{r_w} - r_{i-1}^2 V_{r_{i-1,j,k}})$$

$$\times\ (1/Re_t)_w a\ \sin\varphi_P \Delta\theta\Delta\varphi / \Delta r_W$$

$$+ (V_{\theta i,j+1,k} - V_{\theta i-1,j+1,k})(1/Re_t)_n a\ r_w \Delta\varphi \qquad \text{(eqn A.114)}$$

$$- (V_{\theta i,j,k} - V_{\theta i-1,j,k})(1/Re_t)_s a\ r_w \Delta\varphi$$

$$+ (V_{\varphi i,j,k+1} - V_{\varphi i-1,j,k+1})(1/Re_t)_t a\ r_w \sin\varphi_t \Delta\theta$$

$$- (V_{\varphi i,j,k} - V_{\varphi i-1,j,k})(1/Re_t)_b a\ r_w \sin\varphi_b \Delta\theta$$

and in these equations

$$\Delta r_{Pa} = (\Delta r_P + \Delta r_W) / 2 \qquad \text{(eqn A.115)}$$

$$\Delta V^a = r_{Pa}2 \sin\varphi_P \Delta r_{Pa} \Delta\theta\Delta\varphi$$

$$= r_w^2 \sin\varphi_P (\Delta r_P + \Delta r_W^2) \Delta\theta\Delta\varphi / 2 \qquad \text{(eqn A.116)}$$

$$G_e{}^a = .5\, \rho_P (r_e V_{r_e} + r_w V_{r_w}) / r_P \qquad \text{(eqn A.117)}$$

$$G_w{}^a = .5\, \rho_W (r_w V_{r_w} + r_{i-1} V_{r_{i-1,j,k}}) / r_W \qquad \text{(eqn A.118)}$$

$$G_n{}^a = [.5(\rho_N + \rho_P) \Delta r_W V_{\theta n}$$

$$+ .5(\rho_{i-1,j+1,k} + \rho_W) \Delta r_P V_{\theta i-1,j+1,k}] \qquad \text{(eqn A.119)}$$

$$/ (\Delta r_P + \Delta r_W)$$

$$G_s{}^a = [.5(\rho_P + \rho_S) \Delta r_W V_{\theta s}$$

$$+ .5(\rho_W + \rho_{i-1,j-1,k}) \Delta r_P V_{\theta i-1,j,k}] \qquad \text{(eqn A.120)}$$

$$/ (\Delta r_P + \Delta r_W)$$

$$G_t{}^a = [.5(\rho_T + \rho_P) \Delta r_W V_{\varphi t}$$

$$+ .5(\rho_{i-1,j,k+1} + \rho_W) \Delta r_P V_{\varphi i-1,j,k+1}] \qquad \text{(eqn A.121)}$$

$$/ (\Delta r_P + \Delta r_W)$$

$$G_b{}^a = [.5(\rho_P + \rho_B) \Delta r_W V_{\varphi b}$$

$$+ .5(\rho_W + \rho_{i-1,j,k-1}) \Delta r_P V_{\varphi i-1,j,k}] \qquad \text{(eqn A.122)}$$

$$/ (\Delta r_P + \Delta r_W)$$

θ-Momentum:

$$[A_{P^b} + \rho^\circ{}_{P^b}\,\Delta V^b/\Delta t]\, V_{\theta P^b} =$$

$$A_{E^b} V_{\theta E^b} + A_{W^b} V_{\theta W^b} + A_{N^b} V_{\theta N^b} \qquad \text{(eqn A.123)}$$

$$+ A_{S^b} V_{\theta S^b} + A_{T^b} V_{\theta T^b} + A_{B^b} V_{\theta B^b} + S_{P^b}$$

where

$$A_{E^b} = \{.5(|G_{e^b}| - G_{e^b})$$

$$+ 1/[(Re_t)_{e^b} (\Delta r_E + \Delta r_P)/2]\}\, r_E{}^2 \sin\varphi_P \Delta\theta\Delta\varphi \qquad \text{(eqn A.124)}$$

$$A_{W^b} = \{.5(|G_{w^b}| + G_{w^b})$$

$$+ 1/[(Re_t)_{w^b} (\Delta r_P + \Delta r_W)/2]\}\, r_W{}^2 \sin\varphi_P \Delta\theta\Delta\varphi \qquad \text{(eqn A.125)}$$

$$A_{N^b} = \{.5(|G_{n^b}| - G_{n^b})$$

$$+ 1/[(Re_t)_{n^b}\, r_P\Delta\theta]\}\, r_P \Delta r_P \Delta\varphi \qquad \text{(eqn A.126)}$$

$$A_{S^b} = \{.5(|G_{s^b}| + G_{s^b})$$

$$+ 1/[(Re_t)_{s^b}\, r_P\Delta\theta]\}\, r_P \Delta r_P \Delta\varphi \qquad \text{(eqn A.127)}$$

$$A_{T^b} = \{.5(|G_{t^b}| - G_{t^b})$$

$$+ 1/[(Re_t)_{t^b}\, r_P\Delta\varphi]\}\, r_P \sin\varphi_T \Delta r_P \Delta\theta \qquad \text{(eqn A.128)}$$

$$A_{B^b} = \{.5(|G_{b^b}| - G_{b^b})$$

$$+ 1/[(Re_t)_{b^b}\, r_P\Delta\varphi]\}\, r_P \sin\varphi_B \Delta r_P \Delta\theta \qquad \text{(eqn A.129)}$$

$$A_P = \{.5(|G_{e^b}| + G_{e^b}) r_P{}^2 - G_{e^b} r_e{}^2$$

$$+ r_P{}^2/[(Re_t)_{e^b} (\Delta r_E + \Delta r_P)/2]\}\, \sin\varphi_P \Delta\theta\Delta\varphi$$

$$+ \{.5(|G_{w^b}| - G_{w^b}) r_P{}^2 + G_{w^b} r_w{}^2$$

$$+ r_P{}^2/[(Re_t)_{w^b} (\Delta r_P + \Delta r_W)/2]\}\, \sin\varphi_P \Delta\theta\Delta\varphi$$

$$+ A_{N^b} + A_{S^b} \qquad \text{(eqn A.130)}$$

$$+ \{.5(|G_t{}^b| + G_t{}^b)\sin\varphi^P - G_t{}^b \sin\varphi_t$$

$$+ \sin\varphi_P [(Re_t)_t{}^b\, r_w \Delta\varphi]\}\; r_P \Delta r_P \Delta\theta$$

$$+ \{.5(|G_b{}^b| - G_b{}^b)\sin\varphi^P + G_b{}^b \sin\varphi_b$$

$$+ \sin\varphi_P [(Re_t)_b{}^b\, r_w \Delta\varphi]\}\; r_P \Delta r_P \Delta\theta$$

$$S_P{}^b = \rho^\circ{}_P{}^b\, V^\circ{}_\theta{}_P{}^b\, \Delta V^b / \Delta t - (P_P - P_S)\, r_P \Delta r_P \Delta\varphi$$

$$- (\rho^\circ{}_P{}^b - \rho_{Eq,P}{}^b)\cos\theta_P \sin\varphi_P\, \Delta V^b / F$$

$$+ (V_{r_{i+1,j,k}} - V_{r_{i+1,j-1,k}})\,(1/Re_t)_e{}^b\, r_e \Delta\varphi$$

$$- (V_{r_{i,j,k}} - V_{r_{i,j-1,k}})\,(1/Re_t)_w{}^b\, r_w \Delta\varphi$$

$$+ (V_{\theta n} - V_{\theta s})(1/Re_t)_n{}^b\, r_P \Delta r_P \Delta\varphi / (r_P \sin\varphi_P \Delta\theta) \qquad \text{(eqn A.131)}$$

$$- (V_{\theta s} - V_{\theta i,j-1,k})(1/Re_t)_s{}^b\, r_P \Delta r_P \Delta\varphi / (r_P \sin\varphi_P \Delta\theta)$$

$$+ (V_{\varphi i,j,k+1} - V_{\varphi i,j-1,k+1})\,(1/Re_t)_t{}^b \sin\varphi_t \Delta r_P$$

$$- (V_{\varphi i,j,k} - V_{\varphi i,j-1,k})\,(1/Re_t)_b{}^b \sin\varphi_b \Delta r_P$$

and in these equations

$$\Delta r_P{}^b = \Delta r_P \qquad \text{(eqn A.132)}$$

$$\Delta V^b = r_P{}^b \sin\varphi_P \Delta r_P{}^b \Delta\theta \Delta\varphi$$

$$= r_P \sin\varphi_P \Delta r_P \Delta\theta \Delta\varphi = \Delta V \qquad \text{(eqn A.133)}$$

$$G_e{}^b = \{[(\Delta r_P \rho_E + \Delta r_E \rho_P) / (\Delta r_P + \Delta r_E)]\; V_{r_e}$$

$$+ [(\Delta r_P \rho_{i+1,j-1,k} + \Delta r_E \rho_S) / (\Delta r_P + \Delta r_E)]\; V_{r_{i+1,j-1,k}}\,]\} / 2 \qquad \text{(eqn A.134)}$$

$$G_w{}^b = \{[(\Delta r_W \rho_P + \Delta r_P \rho_W) / (\Delta r_W + \Delta r_P)]\; V_{r_w} \qquad \text{(eqn A.135)}$$

$$+ \ 1/[(Re_t)_s^c \, r_P \sin\varphi_b \Delta\theta \,]\} \, r_P \Delta r_P \Delta\varphi \qquad \text{(eqn A.144)}$$

$$A_T^c = \{.5(|G_t^c| - G_t^c)$$

$$+ \ 1/[(Re_t)_t^c \, r_P \Delta\varphi \,]\} \, r_P \sin\varphi_T \Delta r_P \Delta\theta \qquad \text{(eqn A.145)}$$

$$A_B^c = \{.5(|G_b^c| - G_b^c)$$

$$+ \ 1/[(Re_t)_b^c \, r_P \Delta\varphi \,]\} \, r_P \sin\varphi_B \Delta r_P \Delta\theta \qquad \text{(eqn A.146)}$$

$$A_P = \{.5(|G_e^c| + G_e^c) r_P^2 - G_e^c r_e^2$$

$$+ \ r_P^2 / [(Re_t)_e^c \, (\Delta r_E + \Delta r_P)/2 \,]\} \sin\varphi_b \Delta\theta\Delta\varphi$$

$$+ \ \{.5(|G_w^c| - G_w^c) r_P^2 + G_w^c r_w^2 \qquad \text{(eqn A.147)}$$

$$+ \ r_P^2 / [(Re_t)_w^c \, (\Delta r_P + \Delta r_W)/2 \,]\} \sin\varphi_b \Delta\theta\Delta\varphi$$

$$+ \ A_N^c + A_S^c$$

$$+ \ \{.5(|G_t^c| + G_t^c)\sin\varphi^b - G_t^c \sin\varphi_B$$

$$+ \ \sin\varphi_b / [(Re_t)_t^c \, r_P \Delta\varphi]\} \, r_P \Delta r_P \Delta\theta$$

$$+ \ \{.5(|G_b^c| - G_b^c)\sin\varphi_{k-1} + G_b^c \sin\varphi_{Bb}$$

$$+ \ \sin\varphi_{k-1} / [(Re_t)_b^c \, r_P \Delta\varphi]\} \, r_P \Delta r_P \Delta\theta$$

$$S_P^c = \rho^\circ{}_P{}^c \, V^\circ{}_{\varphi P}{}^c \, \Delta V^c / \Delta t - (P_P - P_B) \, r_P \Delta r_P \Delta\varphi$$

$$- \ (\rho^\circ{}_P{}^c - \rho_{Eq,P}{}^c) \, [\sin\theta_P / ABS(\sin\theta_P)] \cos\varphi_b \, \Delta V^c / F$$

$$+ \ (V_{r_{i+1,j,k}} - V_{r_{i+1,j,k-1}}) \, (1/Re_t)_e^c \, r_e \sin\varphi_b \Delta\theta$$

$$- \ (V_{r_{i,j,k}} - V_{r_{i,j,k-1}}) \, (1/Re_t)_w^c \, r_w \sin\varphi_b \Delta\theta$$

$$+ \ (V_{\theta i,j+1,k} - V_{\theta i,j+1,k-1}) \, (1/Re_t)_n^c \, \Delta r_P \qquad \text{(eqn A.148)}$$

$$- \ (V_{\theta i,j,k} - V_{\theta i,j,k-1}) \, (1/Re_t)_s^c \Delta r_P$$

$$+ \ (V_{\varphi t} \sin\varphi_t - V_{\varphi b} \sin\varphi_b \,) \, (1/Re_t)_t^c \, \Delta r_P \Delta\theta \, / \, \Delta\varphi$$

$$- (V_{\varphi b} \sin\varphi_b - V_{\varphi i,j,k-1} \sin\varphi_{k-1})(1/Re_t)_b{}^c \Delta r_P \Delta\theta / \Delta\varphi$$

and in these equations

$$\Delta r_{P^c} = \Delta r_P \qquad \text{(eqn A.149)}$$

$$\Delta V^c = r_{P^c}{}^2 \sin\varphi_{P^c} \Delta r_{P^c} \Delta\theta\Delta\varphi$$
$$= r_P{}^2 \sin\varphi_b \Delta r_P \Delta\theta\Delta\varphi \qquad \text{(eqn A.150)}$$

$$G_{e^c} = \{[(\Delta r_P \rho_E + \Delta r_E \rho_P) / (\Delta r_P + \Delta r_E)] \; V_{r_e}$$
$$+ [(\Delta r_P \rho_{i+1,j,k-1} + \Delta r_E \rho_B) / (\Delta r_P + \Delta r_E)] \; V_{r_{i+1,j,k-1}}]\} / 2 \qquad \text{(eqn A.151)}$$

$$G_{w^c} = \{[(\Delta r_W \rho_P + \Delta r_P \rho_W) / (\Delta r_W + \Delta r_P)] \; V_{r_w}$$
$$+ [(\Delta r_W \rho_B + \Delta r_P \rho_{i-1,j,k-1}) / (\Delta r_W + \Delta r_P)] \; V_{r_{i,j,k-1}}]\} / 2 \qquad \text{(eqn A.152)}$$

$$G_{n^c} = [.5(\rho_N + \rho_P) \; V_{\theta n}$$
$$+ .5(\rho_{i,j+1,k-1} + \rho_B) \; V_{\theta i,j+1,k-1}] / 2 \qquad \text{(eqn A.153)}$$

$$G_{s^c} = [.5(\rho_P + \rho_S) \; V_{\theta s}$$
$$+ .5(\rho_B + \rho_{i,j-1,k-1}) \; V_{\theta i,j,k-1}] / 2 \qquad \text{(eqn A.154)}$$

$$G_{t^c} = .5 \, \rho_P \, (V_{\varphi t} + V_{\varphi t}) \qquad \text{(eqn A.155)}$$

$$G_{b^c} = .5 \, \rho_B \, (V_{\varphi b} + V_{\varphi i,j,k-1}) \qquad \text{(eqn A.156)}$$

Pressure Equation:

$$A_P P_P' = A_E P_E' + A_W P_W' + A_N P_N' + A_S P_S'$$
$$+ A_T P_T' + A_B P_B' - S^*_{mP} \, \Delta V \qquad \text{(eqn A.157)}$$

where

$$A_E = \rho_e \left(r_e{}^2 \sin\varphi_P \Delta\theta\Delta\varphi\right)^2$$

$$/ \left(A_{P}{}^{a}{}_{i+1,j,k} + \rho_e \Delta V^{a}{}_{i+1,j,k} / \Delta t\right) \qquad \text{(eqn A.158)}$$

$$A_W = \rho_w \left(r_w{}^2 \sin\varphi_P \Delta\theta\Delta\varphi\right)^2$$

$$/ \left(A_{P}{}^{a} + \rho_w \Delta V^{a} / \Delta t\right) \qquad \text{(eqn A.159)}$$

$$A_N = \rho_n \left(r_P \Delta r_P \Delta\varphi\right)^2$$

$$/ \left(A_{P}{}^{c}{}_{i,j+1,k} + \rho_n \Delta V^{c}{}_{i,j+1,k} / \Delta t\right) \qquad \text{(eqn A.160)}$$

$$A_S = \rho_s \left(r_P \Delta r_P \Delta\varphi\right)^2$$

$$/ \left(A_{P}{}^{b} + \rho_s \Delta V^{b} / \Delta t\right) \qquad \text{(eqn A.161)}$$

$$A_T = \rho_t \left(r_P \sin\varphi_t \Delta r_P \Delta\theta\right)^2$$

$$/ \left(A_{P}{}^{c}{}_{i,j,k+1} + \rho_t \Delta V^{c}{}_{i,j,k+1} / \Delta t\right) \qquad \text{(eqn A.162)}$$

$$A_B = \rho_b \left(r_P \sin\varphi_b \Delta r_P \Delta\theta\right)^2$$

$$/ \left(A_{P}{}^{c} + \rho_b \Delta V^{c} / \Delta t\right) \qquad \text{(eqn A.163)}$$

$$A_P = A_E + A_W + A_N + A_S + A_T + A_B \qquad \text{(eqn A.164)}$$

APPENDIX B

FORTRAN LISTING OF THE VIEW FACTOR PROGRAM

```
C      ****************************************************************
C      *   COMPUTER PROGRAM FOR THREE-DIMENSIONAL SURFACE RADIATION   *
C      *        FOR NAVY STORAGE TANK NUMERICAL SIMULATION            *
C      *                                                              *
C      *                     DEVELOPED BY                             *
C      *               K.V. LIU AND K.T. YANG                         *
C      *                                                              *
C      *      DEPARTMENT OF AEROSPACE & MECHANICAL ENGINEERING        *
C      *               UNIVERSITY OF NOTRE DAME                       *
C      *                NOTRE DAME, INDIANA 46556                     *
C      *                                                              *
C      *                      DEC. 1985                               *
C      ****************************************************************
C
C *** A GENERAL FORTRAN PROGRAM TO CALCULATE 3-DIMENSIONAL SURFACE
C     RADIATION VIEW FACTOR MATRIX COEFFICIENT
C *** THE SYSTEM INCLUDES AN ENCLOSURE AND ANY NUMBER OF HEAT SOURCES
C     OF SINKS INSIDE THE ENCLOSURE
C
C     IMPLICIT REAL*8(A-H,O-Z)
C
       COMMON/BL4/ WVFLR(3,3,3,3),WVFLRE(3,3,4,3),WVFLF(3,3,4,3),
      & WVFLT(3,3,4,3),WVFRRE(3,3,4,3),WVFRF(3,3,4,3),WVFRB(3,3,4,3),
      & WVFRT(3,3,4,3),WVFRL (3,3,3,3),WVFFL(4,3,3,3),WVFFB(4,3,4,3),
      & WVFFT(4,3,4,3),WVFFRE(4,3,4,3),WVFFR(4,3,3,3),WVFBT(4,3,4,3),
      & WVFBL(4,3,3,3),WVFBRE(4,3,4,3),WVFBF(4,3,4,3),WVFBR(4,3,3,3),
      & WVFTL(4,3,3,3),WVFTRE(4,3,4,3),WVFTF(4,3,4,3),WVFTR(4,3,3,3),
      & WVFRET(4,3,4,3),WVFREF(4,3,4,3),WVFRER(4,3,3,3),WVFTB(4,3,4,3),
      & WVFREL(4,3,3,3),WVFREB(4,3,4,3),WVFLB(3,3,4,3)
C
       COMMON/BL5/
      & VFHSR(3,3),VFHSF(4,3),VFHSRE(4,3),VFHST(4,3),VFHSB(4,3),
      & VFRHS(3,3),VFFHS(4,3),VFREHS(4,3),VFTHS(4,3),VFBHS(4,3),
      & VFHSL(3,3),VFLHS(3,3)
C
       COMMON /BL6/ VFLHT(3,3),VFRHT(3,3),VFFHT(4,3),VFREHT(4,3),
      & VFFHR(3,3),VFRHR(3,3),VFREHR(4,3),VFTHR(4,3),VFBHR(4,3),
      & VFLHL(3,3),VFFHL(4,3),VFREHL(4,3),VFTHL(4,3),VFBHL(4,3),
      & VFLHRE(3,3),VFRHRE(3,3),VREHRE(4,3),VFTHRE(4,3),VFBHRE(4,3),
      & VFLHF(3,3),VFRHF(3,3),VFFHF(3,3),VFTHF(4,3),VFBHF(4,3),
      & VFLHB(3,3),VFRHB(3,3),VFFHB(4,3),VFREHB(4,3),VFBHB(4,3),
      & VFTHT(4,3)
C
       COMMON /BL7/ VFHTL(3,3),VFHTR(3,3),VFHTF(4,3),VFHTRE(4,3),
      & VFHRF(3,3),VFHRR(3,3),VFHRRE(4,3),VFHRT(4,3),VFHRB(4,3),
      & VFHLL(3,3),VFHLF(4,3),VFHLRE(4,3),VFHLT(4,3),VFHLB(4,3),
      & VFHREL(3,3),VFHRER(3,3),VHRERE(4,3),VFHRET(4,3),VFHREB(4,3),
      & VFHFL(3,3),VFHFR(3,3),VFHFF(3,3),VFHFT(4,3),VFHFB(4,3),
      & VFHBL(3,3),VFHBR(3,3),VFHBF(4,3),VFHBRE(4,3),VFHBB(4,3),
      & VFHTT(4,3)
C
       COMMON /BL8/ X(22),Y(18),Z(18),NOD(22,18,18),
      &     RX(5),RY(4),RZ(4),AREA(67),ZX(5),ZY(4),ZZ(4)
C
       COMMON /BL9/ SWVFRE(4,3),SWVFL(3,3),SWVFR(3,3),SWVFF(4,3),
      &           SWVFT(4,3),SWVFB(4,3)
       COMMON /BL10/ NZ,DX,DY,DZ,DXY,DYZ,DZX,WC,DC,HC
C
       COMMON /BL1/ NI,NJ,NK,NIM1,NJM1,NKM1,NIM2,NJM2,NKM2,
      &  MI,MJ,MK,MII,MJJ,MKK,MIM,MIP,MJM,MJP,MKM,MKP,
      &  MIIM,MIIP,MJJM,MJJP,MKKM,MKKP,
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     &  IREGN1,IREGN2,IREGN3,IREGN4,IREGN5,IREGN6,IREGN7,
     &  MREGN1,MREGN2,MREGN3,MREGN4,MREGN5,MREGN6,MREGN7
C
      COMMON /BL2/ IB,IE,IBM1,IBP1,IEM1,IEP1,
     &             JB,JE,JBM1,JBP1,JEM1,JEP1,
     &             KB,KE,KBM1,KBP1,KEM1,KEP1
C
      COMMON/BL11/ MIIZ(9),MJJZ(9),MKKZ(9),IS(6),LTYPE(9,6),
     &             LI(9),LJ(9),LK(9),AYZ(9),AXY(9),AZX(9),
     &             NHSZ,ITHIN(9),JTHIN(9),KTHIN(9),
     &             IHSB(9),NHSW(9),JHSB(9),NHSD(9),KHSB(9),NHSH(9)
C
      COMMON/BL3/  VFMXR(67,67),SMXVFW(67),SMXVFH(67)
C
C ********************************************************************
C
C *** THE COORDINATE SYSTEM IS AS FOLLOWS;
C     X-DIRECTION IS FROM LEFT   TO  RIGHT
C     Y-DIRECTION IS FROM REAR   TO  FRONT
C     Z-DIRECTION IS FROM BOTTOM TO TOP
C     NEGATIVE GRAVITY, -G , IS IN POSITIVE Z-DIRECTION
C
C ********************************************************************
C ***THERE ARE 6 INTERIOR WALLS AND EACH WALL IS DIVIDED INTO CERTAIN
C     WALL ZONES
C *** TO DISTINGUISH INTERIOR WALLS, EACH WALL HAS A DESIGNATED SYMBOL
C    LEFT  WALL IS REGION 1, REPRESENTED BY LETTER  L
C    RIGHT WALL IS REGION 2, REPRESENTED BY LETTER  R
C    REAR  WALL IS REGION 3, REPRESENTED BY LETTER  RE
C    FRONT WALL IS REGION 4, REPRESENTED BY LETTER  F
C   BOTTOM WALL IS REGION 5, REPRESENTED BY LETTER  B
C    TOP   WALL IS REGION 6, REPRESENTED BY LETTER  T
C ***
C   HEAT SOURCE IS REGION 7, REPRESENTED BY LETTER  HS
C
C    IF THE HEAT SOURCE IS TREATED AS A SUBJECT WITH 6 SURFACES, THEN
C    LEFT    SURFACE OF THE HEAT SOURCE IS REPRESENTED BY LETTER  HL
C    RIGHT   SURFACE OF THE HEAT SOURCE IS REPRESENTED BY LETTER  HR
C    REAR    SURFACE OF THE HEAT SOURCE IS REPRESENTED BY LETTER  HRE
C    FRONT   SURFACE OF THE HEAT SOURCE IS REPRESENTED BY LETTER  HF
C    BOTTOM  SURFACE OF THE HEAT SOURCE IS REPRESENTED BY LETTER  HB
C    TOP     SURFACE OF THE HEAT SOURCE IS REPRESENTED BY LETTER  HT
C
C *** IF ONLY TWO SURFACES ARE CONSIDERED FOR HEAT SOURCE THEN CHOOSE
C     TWO OPPOSITE SURFACES SUCH AS HL AND HR AND ASSUME ZERO DISTANCE
C     BETWEEN THESE TWO SURFACES.
C
C *** THE VIEW FACTOR CAN BE SORTED AS
C     (1) INTERIOR WALL SURFACE VS WALL SURFACE
C     (2) INTERIOR WALL SURFACE VS HEAT SOURCE SURFACE
C     (3) INTERIOR WALL SURFACE VS WHOLE HEAT SOURCE
C
C *** EACH WALL SURFACE  IS DIVIDED INTO SERVERAL WALL ZONES
C     FOR INSTANCE, THE LEFT WALL L, LOCATED AT X=0 OR I=1,
C     IT CAN HAVE MJ DIVISIONS IN J DIRECTION AND MK DIVISIONS IN
C     K DIRECTION, THEREFORE, THERE IS MJ*MK ZONES ON LEFT WALL
C *** ACCORDINGLY,
C     RIGHT  WALL HAS MJ1*MK1 ZONES AND MJ1 AND MJ MAY HAVE EQUAL NO.
C                                   AND MK1 AND MK MAY HAVE EQUAL NO.
C     REAR   WALL HAS MI *MK2 ZONES AND MK2 AND MK MAY HAVE EQUAL NO.
C     FRONT  WALL HAS MI1*MK3 ZONES AND MI1 AND MI MAY HAVE EQUAL NO.
C                                   AND MK3 AND MK MAY HAVE EQUAL NO.
C     BOTTOM WALL HAS MI2*MJ2 ZONES AND MI2 AND MI MAY HAVE EQUAL NO.
C                                   AND MJ2 AND MJ MAY HAVE EQUAL NO.
C     TOP    WALL HAS MI3*MJ3 ZONES AND MI3 AND MI MAY HAVE EQUAL NO.
C                                   AND MJ3 AND MJ MAY HAVE EQUAL NO.
C
C *** NORMALLY THE WALL ZONES IS DIVIDED IN SUCH WAY SO THE HEAT
C     SOURCE IS ALIGNED WITH ONE OR FEW WALL ZONES
```

```
C
C *** AFTER THE WALL ZONES ARE ASSIGNED THEN ALL ZONES IN ALL  WALL
C     SURFACES ARE GIVEN AN INDEX NUMBER
C
C ***IF THERE ARE MI DIVISIONS IN X-DIRECTION
C                 MJ DIVISIONS IN Y-DIRECTION
C             AND MK DIVISIONS IN Z-DIRECTION, THEN FOR A GENERAL CASE
C
C     THERE ARE MJ*MK ZONES IN LEFT WALL AND INDEXED FROM 1 TO MJ*MK
C   MJ*MK ZONES IN R  WALL AND INDEXED FROM MJ*MK+1   TO 2*MJ*MK
C   MI*MK ZONES IN RE WALL AND INDEXED FROM 2*MJ*MK+1 TO 2*MJ*MK+MI*MK
C   MI*MK ZONES IN F  WALL AND INDEXED FROM 2*MJ*MK+MI*MK+1 TO
C                                           2*(MI+MJ)*MK
C   MI*MJ ZONES IN B  WALL AND INDEXED FROM 2*(MI+MJ)*MK +1 TO
C                                           2*(MI+MJ)*MK+MI*MK
C   MI*MJ ZONES IN T  WALL AND INDEXED FROM 2*(MI+MJ)*MK+MI*MK+1 TO
C                                           2*(MI*MJ+MI*MK+MJ*MK)
C *** FINALLY THE HEAT SOURCE IS THE LAST ZONE AND INDEXED AS
C                                           2*(MI*MJ+MJ*MK+MI*MK)+1
C
C *** IF MI=4, MJ=3 AND MK=3, THEN THERE ARE 2*(4*3+3*3+3*4)=66
C     WALL SURFACE ZONES AND 1 HEAT SOURCE ZONE
C
C    IF WE DIVIDE ONE WALL SURFACE INTO 4*3 ZONES, AND THE HEAT SOURCE
C    CAN BE VIEWED THROUGH THE WALL. IT IS SEEN TO OCCUPIED THE ZONE
C    OF (2,2).
C    IF THE RADIATION ZONE OF HEAT SOURCE IS TREATED AS AN INFINITE
C    THIN SHEET OF PLANE THEN WE HAVE ONLY TWO SURFACES IN THE HEAT
C    SOURCE AND IT CAN BE CONSIDERED AT THE INTER FACE OF ZONE (2,2)
C    AND (3,2) AND THE WHOLE AREA FACES TO THE LEFT TANK WALL AT THE
C    ZONE OF MJ=2 AND MK=2.
C
C *** THE INDEX OF EACH ZONE IN A WALL OF 4*3 ZONES IS ASSIGNED AS
C
C      |(1,3)|(2,3)|(3,3)|(4,3)|  ABOVE THE HEAT SOURCE,     KHT TO NK
C
C      |(1,2)|(2,2)|(3,2)|(4,2)|  SAME LEVEL AS HEAT SOURCE, KHB TO KHT
C
C      |(1,1)|(2,1)|(3,1)|(4,1)|  BELOW THE HEAT SOURCE,     2,  TO KHB
C      -------------------------
C
CWALL TO 1ST ZONE, LEFT OF HEAT SOURCE, RIGHT OF HEAT SOURCE, 4TH ZONE
C     TO ANOTHER SIDE OF THE WALL
C
C     THE STRUCTURE OF MATRIX IS
C
C    J=L  ,R ,RE ,F ,B ,T , HS.  TOTAL IS NZ TERM
C   I=L                                                               |
C   I=R   ------------------------------------------------------------|
C   I=RE  |       THE ARRAY IS LAID OUT AS FOLLOWS
C   I=F   |       L(1,1)(1,2),..(1,MK),(2,1)...(2,MK),(MJ,1)..(MJ,MK)  |
C   I=B   |R  IS FROM (1,1)...TO...(MJ,MK) OR FROM MJ*MK+1   TO 2*MJ*MK|
C   I=T   |RE IS FROM (1,1)...TO...(MI,MK) OR FROM 2*MJ*MK+1 TO 2*MJ*MK|
C   I=HS  |                                        +MI*MK               |
C         |F  IS FROM (1,1)...TO...(MI,MK) OR FROM 2*(MJ*MK)+MI*MK+1 TO
C         |                                        2*(MI+MJ)*MK
C         |B  IS FROM (1,1)...TO...(MI,MJ) OR FROM 2*(MI+MJ)*MK+1    TO
C         |                                        2*(MI+MJ)*MK+MI*MJ
C         |T  IS FROM (1,1)...TO...(MI,MJ) OR FROM 2*(MI*MJ)*MK+MI*MJ+1
C         |                                     TO 2*(MI*MJ+MJ*MK+MK*MI)|
C         |HS HAS 1 ZONE        TO 2*(MI*MK+MJ*MK+MI*MJ)+1              |
C         -------------------------------------------------------------
C
C *********************************************************************
C
C *** ALL VARIABLE NAMES USED IN THE INPUT DATA STATEMENT ARE THE SAME
C     ONES USED IN MAIN PROGRAM
C
C *** WC : WIDTH OF THE TANK, IN X-DIRECTION, (FT)
C     DC : DEPTH OF THE TANK, IN Y-DIRECTION, (FT)
```

```
C      HC : HEIGHT OF THE TANK, IN Z-DIRECTION, (FT)
C  *** NI : TOTAL NUMBER CELLS IN X-DIRECTION
C      NJ : TOTAL NUMBER CELLS IN Y-DIRECTION
C      NK : TOTAL NUMBER CELLS IN Z-DIRECTION
C  *** AREA() : SURFACE AREA OF RADIATION ZONES (FT**2)
C  *** NHSZ : # OF HEAT SOURCES
C  *** LTYPE() : TYPE OF HEAT SOURCE SURFACES, 1 FOR   ACTIVE
C  *** IHSB() : STARTING CELL NUMBER FOR EACH HEAT SOURCE IN X-DIRECTION
C      JHSB() :                                               Y-DIRECTION
C      KHSB() :                                               Z-DIRECTION
C  *** NHSW() : NUMBER OF CELLS FOR EACH HEAT SOURCE IN X-DIRECTION
C      NHSD() :                                         Y-DIRECTION
C      NHSH() :                                         Z-DIRECTION
C  *** NZ : TOTAL NUMBER OF SURFACE ZONES USED IN RADIATION EXCHANGE
C  *** MI  : NUMBER OF ZONES IN X-DIRECTION
C      MJ  :                    Y-DIRECTION
C      MK  :                    Z-DIRECTION
C  *** LI() : NUMBER OF CELLS FOR EACH ZONE IN X-DIRECTION
C      LJ() :                                   Y-DIRECTION
C      LK() :                                   Z-DIRECTION
C  * MIIZ() : LOCATION OF THE HEAT SOURCE, ZONE NUMBER IN X-DIRECTION
C    MJJZ() :                               ZONE NUMBER IN Y-DIRECTION
C    MKKZ() :                               ZONE NUMBER IN Z-DIRECTION
C  *  ITHIN() : 0 OR 1 ; ZERO OR 1 ZONE SPACE BETWEEN TWO OPPOSITE
C     JTHIN() :          SIDES OF A HEAT SOURCE/SINK IN
C     KTHIN() :          X;(I), Y;(J), AND Z;(K) DIRECTIONS
C              IF ITHIN=JTHIN=KTHIN=1 MEANS A RECTANGULAR SHAPE HEAT
C              SOURCE/SINK
C              IF ITHIN=JTHIN=KTHIN=0 MEANS AN INFINITE THIN SHEET OF
C              HEAT SOURCE/SINK IN ALL 3 DIMENSIONS
C
C  ***********************************************************************
C
C  ***********************************************************************
C
C   $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C   $  USER SHOULD ASSIGN VALUES FOR  MI,MJ,MK, MIIZ(),MJJZ(), MKKZ(),$
C   $                                 WC,DC,HC; NI,NJ,NK,              $
C   $                                 NHSZ, LTYPE() AND                $
C   $                                 IHSB,JHSB,KHSB, NHSW,NHSD,NHSH
C   $  THESE VARIABLES WILL BE USED IN MAIN PROGRAM ALSO               $
C   $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
C  *** $$$$$$$$$$$$$$$$$$
C      WC=40.2
C      DC=17.
C      HC=17.
C      NI=22
C      NJ=18
C      NK=18
C      MI=4
C      MJ=3
C      MK=3
C      NHSZ=1
C      LTYPE(1,1)=1
C      LTYPE(1,2)=1
C      LTYPE(1,3)=1
C      LTYPE(1,4)=1
C      LTYPE(1,5)=1
C      LTYPE(1,6)=1
C      MIIZ(1)=2
C      MJJZ(1)=2
C      MKKZ(1)=2
C  *** $$$$$$$$$$$$$$$$$$$$$
C
C  *** READ INPUT DATA
C
C  *** READ # 1
C  ============
```

```
C
      READ(5,*) WC,DC,HC,NI,NJ,NK
      WRITE(6,21) WC,DC,HC,NI,NJ,NK
   21 FORMAT(5X,'WC =',E11.4,' FT',3X,'DC =',E11.4,' FT',3X,
     &    'HC =',E11.4,' FT',/,
     & 5X,'NI =',I3,6X,'NJ =',I3,6X,'NK =',I3,//)
C
C *** READ # 2
C =============
C
      READ(5,*) NHSZ
C
      WRITE(6,31) NHSZ
   31 FORMAT(5X,'TOTAL NUMBER OF HEAT SOURCES, NHSZ :',I2,//)
C ***
C ****** IF NHSZ > 1, THEN READ NHSZ SET OF CARDS FOR READ GROUP 2 TO 4
C ***
      DO 11 I=1,NHSZ
C
C *** READ # 3
C =============
C
      READ(5,*) LTYPE(I,1),LTYPE(I,2),LTYPE(I,3),LTYPE(I,4),LTYPE(I,5),
     &          LTYPE(I,6)
C
C *** READ # 4
C =============
C
C *** READ POSITION AND SIZD DATA FOR HEAT SOURCE
C
      READ(5,*) IHSB(I),NHSW(I),JHSB(I),NHSD(I),KHSB(I),NHSH(I)
C
C *** READ # 5
C =============
C
      READ(5,*) MIIZ(I),MJJZ(I),MKKZ(I)
C
C *** READ # 6
C =============
C
      READ(5,*) ITHIN(I),JTHIN(I),KTHIN(I)
C
      WRITE(6,12) I,LTYPE(I,1),LTYPE(I,2),LTYPE(I,3),LTYPE(I,4),
     &          LTYPE(I,5),LTYPE(I,6),IHSB(I),JHSB(I),KHSB(I),
     &          NHSW(I),NHSD(I),NHSH(I),MIIZ(I),MJJZ(I),MKKZ(I),
     &          ITHIN(I),JTHIN(I),KTHIN(I)
  12  FORMAT(5X,'HEAT SOURCE NUMBER :',I2,//,
     & 10X,'ITS 6 SURFACE TYPIES ARE : LTYPE(I) =',6I2,//,
     &  8X,'LOCATION OF THIS HEAT SOURCE ........',//,
     & 10X,'STARTING CELL NUMBER IN X-DIRECTION : IHSB = ',I2,/,
     & 10X,'                        Y-DIRECTION : JHSB = ',I2,/,
     & 10X,'                        Z-DIRECTION : KHSB = ',I2,//,
     & 10X,'       AND THE CELLS IN X-DIRECTION : NHSW = ',I2,//,
     & 10X,'                        Y-DIRECTION : NHSD = ',I2,//,
     & 10X,'                        Z-DIRECTION : NHSH = ',I2,//,
     & 10X,'LOCATION OF THIS HEAT SOURCE RADIATION EXCHANGE ZONE',/,
     & 20X,'ZONE NUMBER IN X-DIRECTION : MIIZ(I) = MII = ',I2,/,
     & 20X,'               Y-DIRECTION : MJJZ(I) = MJJ = ',I2,/,
     & 20X,'               Z-DIRECTION : MKKZ(I) = MKK = ',I2,//,
     & 10X,'THIS HEAT SOURCE ZONE HAS ',//,
     & 20X,'ITHIN(I) =',I2,' ZONE THICKNESS IN X-DIRECTION',/,
     & 20X,'JTHIN(I) =',I2,' ZONE THICKNESS IN Y-DIRECTION',/,
     & 20X,'KTHIN(I) =',I2,' ZONE THICKNESS IN Z-DIRECTION',//)
   11 CONTINUE
C
C *** READ # 7
C =============
C
      READ(5,*) MI,MJ,MK
```

```
      READ(5,*) (LI(I),I=1,MI)
      READ(5,*) (LJ(I),I=1,MJ)
      READ(5,*) (LK(I),I=1,MK)
C
      WRITE(6,18) MI,(LI(I),I=1,MI)
   18 FORMAT(10X,'THERE IS ; MI =',I2,' ZONES IN X-DIRECTION',//,
     &   20X,'THE NUMBER OF CELLS IN EACH ZONE IS ; LI(I) =',10I3,/)
      WRITE(6,19) MJ,(LJ(J),J=1,MJ)
   19 FORMAT(10X,'THERE IS ; MJ =',I2,' ZONES IN Y-DIRECTION',//,
     &   20X,'THE NUMBER OF CELLS IN EACH ZONE IS ; LJ(I) =',10I3,/)
      WRITE(6,20) MK,(LK(K),K=1,MK)
   20 FORMAT(10X,'THERE IS ; MK =',I2,' ZONES IN Z-DIRECTION',//,
     &   20X,'THE NUMBER OF CELLS IN EACH ZONE IS ; LK(I) =',10I3,/)
C
      MZ=2*(MI*MJ+MJ*MK+MK*MI)
      WRITE(6,308) MZ
  308 FORMAT(5X,'TOTAL NUMBER OF ZONES ON TANK WALL =',I3,/)
C
      NZ=MZ+NHSZ
C
C *******************************************************************
C
C *** VARIABLE ARRAY NAMES FOR ALL SURFACE EXCHANGE ARE DEFINED AS
C     FOLLOWS;
C
C *** WVF-- : VIEW FACTOR BETWEEN TWO INTERIOR WALL ZONES
C     SWVF--: SUMMATION OF VIEW FACTOR FROM ONE WALL ZONE TO ALL OTHER
C             WALL ZONES
C     VF-H- : VIEW FACTOR BETWEEN HEAT SOURCE SURFACE TO INTERIOR WALL
C             ZONES
C     VF-HS : VIEW FACTOR BETWEEN WALL ZONE AND WHOLE HEAT SOURCE
C   & VFHS- : SURFACE
C     SVFHS : SUMMATION OF VIEW FACTOR FROM HEAT SOURCE TO WALL ZONES
C     VFMXR : VIEW FACTOR MATRIX COEFFICIENT
C  SMXVFW(I): SUMMATION OF VIEW FACTOR MATRIX COEFFICIENT FROM ANY
C             ONE ZONE TO ALL OTHER ZONES EXCEPT THE HEAT SOURCE
C             ZONE. THERE ARE NZ-1 VALUES
C     SMXVFH: SUMMATION OF VIEW FACTOR MATRIX COEFFICIENT FROM HEAT
C             SOURCE ZONE TO ALL OTHER WALL ZONES. ONLY ONE VALUE
C *******************************************************************
C
C *** DEFINE THE GRID SYSTEM
C
C *** DX,DY,DZ AND X,Y AND Z ARE DIMENSIONAL QUANTITIES (FT)
C
      DX=WC/(NI-2)
      DY=DC/(NJ-2)
      DZ=HC/(NK-2)
C
      NIM1=NI-1
      NJM1=NJ-1
      NKM1=NK-1
      NIM2=NI-2
      NJM2=NJ-2
      NKM2=NK-2
C
C *** DEFINE THE DISTANCE BETWEEN EACH CELL
C
      X(1)=-DX
      X(2)=0.
      DO 1 I=3,NI
      X(I)=DX*(I-2)
    1 CONTINUE
      Y(1)=-DY
      Y(2)=0.
      DO 233 J=3,NJ
      Y(J)=DY*(J-2)
  233 CONTINUE
      Z(1)=-DZ
```

```
      Z(2)=0.
      DO 3 K=3,NK
      Z(K)=DZ*(K-2)
    3 CONTINUE
      WRITE(6,100)(X(I),I=1,NI)
  100 FORMAT(2X,'X (FT)=',22(F5.1))
      WRITE(6,101)(Y(I),I=1,NJ)
  101 FORMAT(2X,'Y (FT)=',18(1X,F5.1))
      WRITE(6,102)(Z(I),I=1,NK)
  102 FORMAT(2X,'Z (FT)=',18(1X,F5.1))
C
      DXY=DX*DY
      DZX=DZ*DX
      DYZ=DY*DZ
C
      A1=2.*X(NI)*Y(NJ)+2.*Y(NJ)*Z(NZ)+2.*Z(NK)*X(NI)
C
      WRITE(6,776) DX,DY,DZ,DXY,DYZ,DZX,A1
  776 FORMAT(/,5X,'DX  =',E11.4,2X,'DY  =',E11.4,2X,'DZ  =',E11.4,/,
     &  5X,'DXY =',E11.4,2X,'DYZ =',E11.4,2X,'DZX =',E11.4,/,
     &/,5X,' ALL IN FT OR FT**2',//,5X,'TATAL INTERIOR SURFACE ',
     &  'AREA =',F8.3,' FT**2',/)
C
      MIM=MI-1
      MIP=MI+1
      MJM=MJ-1
      MJP=MJ+1
      MKM=MK-1
      MKP=MK+1
C
      MREGN1=0
      IREGN1=MJ*MK
      MREGN2=MREGN1+IREGN1
      IREGN2=MJ*MK
      MREGN3=MREGN2+IREGN2
      IREGN3=MI*MK
      MREGN4=MREGN3+IREGN3
      IREGN4=MI*MK
      MREGN5=MREGN4+IREGN4
      IREGN5=MI*MJ
      MREGN6=MREGN5+IREGN5
      IREGN6=MI*MJ
      MREGN7=MREGN6+IREGN6
      IREGN7=NHSZ
C
      WRITE(6,777) IREGN1,IREGN2,IREGN3,IREGN4,IREGN5,IREGN6,IREGN7,
     & MREGN1+1,MREGN2+1,MREGN3+1,MREGN4+1,MREGN5+1,MREGN6+1,MREGN7+1
  777 FORMAT(/,5X,'NUMBER OF ZONES IN EACH REGION, IREGN:',/,
     &  5X,'REGION 1 =',I3,2X,',REGION 2 =',I3,2X,',REGION 3 =',I3,2X,
     &    ',REGION 4 =',I3,2X,',REGION 5 =',I3,2X,',REGION 6 =',I3,2X,
     &    ',REGION 7 =',I3,//,5X,'THE STARTING INDEX NUMBER FOR EACH',
     & ' REGION, MREGN:',/,
     &  5X,'REGION 1 =',I3,2X,',REGION 2 =',I3,2X,',REGION 3 =',I3,2X,
     &    ',REGION 4 =',I3,2X,',REGION 5 =',I3,2X,',REGION 6 =',I3,2X,
     &    ',REGION 7 =',I3,/)
C
C *** DEFINE THE DISTANCE FOR THE ZONE COORDINATE
C
C
      DO 14 I=1,NHSZ
      IB=IHSB(I)
      IE=IHSB(I)+NHSW(I)-1
      JB=JHSB(I)
      JE=JHSB(I)+NHSD(I)-1
      KB=KHSB(I)
      KE=KHSB(I)+NHSH(I)-1
C
      IBM1 =IB-1
      IEM1 =IE-1
```

```
      JBM1 =JB-1
      JEM1 =JE-1
      IBP1 =IB+1
      IEP1 =IE+1
      JBP1 =JB+1
      JEP1 =JE+1
      KBM1 =KB-1
      KEM1 =KE-1
      KBP1 =KB+1
      KEP1 =KE+1
      WRITE(6,2) I,IHSB(I),NHSW(I),IB,IE, JHSB(I),NHSD(I),JB,JE,
     &           KHSB(I),NHSH(I),KB,KE
    2 FORMAT(//,2X,' *** POSITION PARAMETERS FOR HEAT SOURCE #',I2,
     & ' ***',//,5X,'ITS LOCATIONS IS',/,
     & 5X,'IHSB =',I3,2X,'NHSW =',I3,2X,'IB =',I3,2X,'IE =',I3,/,
     & 5X,'JHSB =',I3,2X,'NHSD =',I3,2X,'JB =',I3,2X,'JE =',I3,/,
     & 5X,'KHSB =',I3,2X,'NHSH =',I3,2X,'KB =',I3,2X,'KE =',I3,//)
C
      LZ=MZ+I
      AYZ(I)=(Y(JE+1)-Y(JB))*(Z(KE+1)-Z(KB))
      AXY(I)=(Y(JE+1)-Y(JB))*(X(IE+1)-X(IB))
      AZX(I)=(Z(KE+1)-Z(KB))*(X(IE+1)-X(IB))
      AREA(LZ)=(AYZ(I)+AZX(I)+AXY(I))*2
C
      WRITE(6,32) AXY(I),AYZ(I),AZX(I),AREA(LZ)
   32 FORMAT(10X,'THE SURFACE AREA OF THE HEAT SOURCE',//,
     &  20X,'AXY(I) =',E11.4,' FT**2 IN X-Y PLANE',/,
     &  20X,'AYZ(I) =',E11.4,' FT**2 IN Y-Z PLANE',/,
     &  20X,'AZX(I) =',E11.4,' FT**2 IN Z-X PLANE',/,
     &  15X,'THE TOTAL SURFACE AREA IS =',E11.4,' FT**2',/)
C
   14 CONTINUE
C
      RX(1)=0.
      II=1
      DO 15 I=1,MI
      I1=LI(I)+II
      RX(I+1)=X(I1+1)
      II=I1
   15 CONTINUE
      RY(1)=0.
      JJ=1
      DO 16 J=1,MJ
      J1=LJ(J)+JJ
      RY(J+1)=Y(J1+1)
      JJ=J1
   16 CONTINUE
      RZ(1)=0.
      KK=1
      DO 17 K=1,MK
      K1=LK(K)+KK
      RZ(K+1)=Z(K1+1)
      KK=K1
   17 CONTINUE
C
      DO 778 I=1,MI
  778 ZX(I)=RX(I+1)-RX(I)
      DO 779 J=1,MJ
  779 ZY(J)=RY(J+1)-RY(J)
      DO 780 K=1,MK
  780 ZZ(K)=RZ(K+1)-RZ(K)
   13 CONTINUE
C
      WRITE(6,103)(RX(I),I=1,MI+1),(RY(J),J=1,MJ+1),(RZ(K),K=1,MK+1)
     &           ,(ZX(I),I=1,  MI),(ZY(J),J=1,  MJ),(ZZ(K),K=1,  MK)
  103 FORMAT(/,5X,'THE POSITION OF ZONE BOUNDARY IN EACH DIRECTION ',
     &'(FT)',/,5X,'X=',5(1X,F6.3),1X,'Y=',4(1X,F6.3),1X,'Z=',4(1X,F6.3)
     &      ,//,5X,'THE SIZE OF THE ZONE IN EACH DIRECTION, (FT)','
     &  /,5X,'X=',4(1X,F6.3),1X,'Y=',3(1X,F6.3),1X,'Z=',3(1X,F6.3),//)
```

```
C
C *** DEFINE THE NUMBER OF CELLS IN EACH ZONE, WHICH WILL ALSO BE USED
C     AS THE AREA OF EACH ZONE WITH MULTIPLICATION OF UNIT AREA OF CELL
C *** REGION 1 AND 2, (L & R), NJ*MK ZONES
C
      ISUM1=MREGN1
      ISUM2=MREGN2
      DO 977 J=1,MJ
      DO 977 K=1,MK
      ISUM1=ISUM1+1
      ISUM2=ISUM2+1
      AREA(ISUM1)=ZY(J)*ZZ(K)
      AREA(ISUM2)=AREA(ISUM1)
  977 CONTINUE
C
C *** REGION 3 AND 4, (RE * F), MI*MK ZONES
C
      ISUM1=MREGN3
      ISUM2=MREGN4
      DO 978 I=1,MI
      DO 978 K=1,MK
      ISUM1=ISUM1+ 1
      ISUM2=ISUM2+ 1
      AREA(ISUM1)=ZX(I)*ZZ(K)
      AREA(ISUM2)=AREA(ISUM1)
  978 CONTINUE
C
C *** REGION 5 AND 6, (B & T), MI*MJ ZONES
C
      ISUM1=MREGN5
      ISUM2=MREGN6
      DO 979 I=1,MI
      DO 979 J=1,MJ
      ISUM1=ISUM1+ 1
      ISUM2=ISUM2+ 1
      AREA(ISUM1)=ZY(J)*ZX(I)
      AREA(ISUM2)=AREA(ISUM1)
  979 CONTINUE
C
      WRITE(6,50) (I,AREA(I),I=1,NZ)
   50 FORMAT(5X,'I =',I3,3X,'AREA =',F5.1,'  FT**2')
C
C *** CALCULATE THE WALL ZONE TO WALL ZONE VIEW FACTOR
C
C ********************************
      CALL WALL
C ********************************
C
C ***********************************************************************
C *** THE THIRD STEP IS TO
C *** CALCULATE THE COEFICIENTS OF THE MATRIX FOR THE SYSTEM OF SURFACE
C     RADIATIVE FLUX EQUATIONS
C ***********************************************************************
C
      DO 405 I=1,NZ
      DO 405 J=1,NZ
      VFMXR(I,J)=0.
  405 CONTINUE
C
C ***********************************************************************
C
C *** REGION 1, L VS -,R,RE,F,B,T
C
      KSM1=MERGN1
      DO 421 J=1,MJ
      DO 421 K=1,MK
      KSM1=KSM1+1
      KSM2=MREGN2
      KSM3=MREGN3
```

```
      KSM4=MREGN4
      DO 422 JJ=1,MJ
      DO 422 KK=1,MK
      KSM2=KSM2+1
      VFMXR(KSM1,KSM2)=WVFLR (J,K,JJ,KK)
      VFMXR(KSM2,KSM1)=WVFRL (JJ,KK,J,K)
  422 CONTINUE
      DO 522 II=1,MI
      DO 522 KK=1,MK
      KSM3=KSM3+1
      KSM4=KSM4+1
      VFMXR(KSM1,KSM3)=WVFLRE(J,K,II,KK)
      VFMXR(KSM1,KSM4)=WVFLF (J,K,II,KK)
      VFMXR(KSM3,KSM1)=WVFREL(II,KK,J,K)
      VFMXR(KSM4,KSM1)=WVFFL (II,KK,J,K)
  522 CONTINUE
      KSM5=MREGN5
      KSM6=MREGN6
      DO 423 II=1,MI
      DO 423 JJ=1,MJ
      KSM5=KSM5+1
      KSM6=KSM6+1
      VFMXR(KSM1,KSM5)=WVFLB (J,K,II,JJ)
      VFMXR(KSM1,KSM6)=WVFLT (J,K,II,JJ)
      VFMXR(KSM5,KSM1)=WVFBL (II,JJ,J,K)
      VFMXR(KSM6,KSM1)=WVFTL (II,JJ,J,K)
  423 CONTINUE
  421 CONTINUE
C
C ** REGION 2, R  VS  -,-,-,F,B,T,
C
      KSM2=MREGN2
      DO 428 J=1,MJ
      DO 428 K=1,MK
      KSM4=MREGN4
      KSM2=KSM2+1
      DO 429 II=1,MI
      DO 429 KK=1,MK
      KSM4=KSM4+1
      VFMXR(KSM2,KSM4)=WVFRF(J,K,II,KK)
      VFMXR(KSM4,KSM2)=WVFFR(II,KK,J,K)
  429 CONTINUE
      KSM5=MREGN5
      KSM6=MREGN6
      DO 430 II=1,MI
      DO 430 JJ=1,MJ
      KSM5=KSM5+1
      KSM6=KSM6+1
      VFMXR(KSM2,KSM5)=WVFRB(J,K,II,JJ)
      VFMXR(KSM2,KSM6)=WVFRT(J,K,II,JJ)
      VFMXR(KSM5,KSM2)=WVFBR(II,JJ,J,K)
      VFMXR(KSM6,KSM2)=WVFTR(II,JJ,J,K)
  430 CONTINUE
  428 CONTINUE
C
C *** REGION 3, RE VS -,R,-,F,B,T
C
      KSM3=MREGN3
      DO 425 I=1,MI
      DO 425 K=1,MK
      KSM3=KSM3+1
      KSM2=MREGN2
      KSM4=MREGN4
      DO 426 JJ=1,MJ
      DO 426 KK=1,MK
      KSM2=KSM2+1
      VFMXR(KSM3,KSM2)=WVFRER(I,K,JJ,KK)
      VFMXR(KSM2,KSM3)=WVFRRE(JJ,KK,I,K)
  426 CONTINUE
```

```
      DO 526 II=1,MI
      DO 526 KK=1,MK
      KSM4=KSM4+1
      VFMXR(KSM3,KSM4)=WVFREF(I,K,II,KK)
      VFMXR(KSM4,KSM3)=WVFFRE(II,KK,I,K)
  526 CONTINUE
      KSM5=MREGN5
      KSM6=MREGN6
      DO 427 II=1,MI
      DO 427 JJ=1,MJ
      KSM5=KSM5+1
      KSM6=KSM6+1
      VFMXR(KSM3,KSM5)=WVFREB(I,K,II,JJ)
      VFMXR(KSM3,KSM6)=WVFRET(I,K,II,JJ)
      VFMXR(KSM5,KSM3)=WVFBRE(II,JJ,I,K)
      VFMXR(KSM6,KSM3)=WVFTRE(II,JJ,I,K)
  427 CONTINUE
  425 CONTINUE
C
C ** REGION 4, F  VS -,-,-,-,B,T
C
      KSM4=MREGN4
      DO 438 I=1,MI
      DO 438 K=1,MK
      KSM4=KSM4+1
      KSM5=MREGN5
      KSM6=MREGN6
      DO 439 II=1,MI
      DO 439 JJ=1,MJ
      KSM5=KSM5+1
      KSM6=KSM6+1
      VFMXR(KSM4,KSM5)=WVFFB(I,K,II,JJ)
      VFMXR(KSM4,KSM6)=WVFFT(I,K,II,JJ)
      VFMXR(KSM5,KSM4)=WVFBF(II,JJ,I,K)
      VFMXR(KSM6,KSM4)=WVFTF(II,JJ,I,K)
  439 CONTINUE
  438 CONTINUE
C
C ** REGION 5, B VS -,-,-,-,-,T
C
      KSM5=MREGN5
      DO 448 I=1,MI
      DO 448 J=1,MJ
      KSM5=KSM5+1
      KSM6=MREGN6
      DO 449 II=1,MI
      DO 449 JJ=1,MJ
      KSM6=KSM6+1
      VFMXR(KSM5,KSM6)=WVFBT(I,J,II,JJ)
      VFMXR(KSM6,KSM5)=WVFTB(II,JJ,I,J)
  449 CONTINUE
  448 CONTINUE
C
C ********************************************************************
C
C *** VIEW FACTOR MATRIX COEFFICIENT FOR HEAT SOURCES
C
      DO 301 M=1,NHSZ
      LZ=MZ+M
      ISS=0
      DO 302 I=1,6
      IS(I)=LTYPE(M,I)
      ISS=ISS+IS(I)
  302 CONTINUE
      SN=ISS
      MII=MIIZ(M)
      MJJ=MJJZ(M)
      MKK=MKKZ(M)
      MIIM=MII-1
```

```
      MJJM=MJJ-1
      MKKM=MKK-1
C
      MIIP=MII+1
      MJJP=MJJ+1
      MKKP=MKK+1
      IP=ITHIN(M)
      JP=JTHIN(M)
      KP=KTHIN(M)
C
      DO 304 J=1,MJ
      DO 304 K=1,MK
      VFHSL(J,K)=0.
      VFLHS(J,K)=0.
      VFHSR(J,K)=0.
      VFRHS(J,K)=0.
  304 CONTINUE
      DO 305 I=1,MI
      DO 305 K=1,MK
      VFHSRE(I,K)=0.
      VFREHS(I,K)=0.
      VFHSF (I,K)=0.
      VFFHS (I,K)=0.
  305 CONTINUE
      DO 306 I=1,MI
      DO 306 J=1,MJ
      VFHSB(I,J)=0.
      VFBHS(I,J)=0.
      VFHST(I,J)=0.
      VFTHS(I,J)=0.
  306 CONTINUE
C
      WRITE(6,307) M,MII,MJJ,MKK,ISS,(IS(I),I=1,6)
  307 FORMAT(//,5X,'HEAT SOURCE #',I2,//,
     & 5X,'IT IS LOCATED AT MII =',I2,2X,'MJJ =',I2,2X,'MKK =',I2,//,
     & 5X,'NUMBER OF SURFACES ON THIS HEAT SOURCE IS ',I2,//,
     & 5X,'THE SURFACE TYPE LTYPE : =',6I2,//)
C
C *** CALCULATE VIEW FACTOR BETWEEN HEAT SOURCE AND ALL WALL ZONES
C
C ************************************************
      CALL HSTWAL(IS,KSS,IP,JP,KP)
C ************************************************
C
C ** REGION 7, HS VS L,R,RE,F,B,T
C
C *** HS VS  R & L
C
      KSM1=0
      KSM2=MREGN2
      DO 401 J=1,MJ
      DO 401 K=1,MK
      KSM1=KSM1+1
      KSM2=KSM2+1
      VFMXR(LZ,KSM1)=VFHSL(J,K)/SN
      VFMXR(KSM1,LZ)=VFLHS(J,K)/SN
      VFMXR(LZ,KSM2)=VFHSR(J,K)/SN
      VFMXR(KSM2,LZ)=VFRHS(J,K)/SN
  401 CONTINUE
C
C *** HS VS RE & F
C
      KSM3=MREGN3
      KSM4=MREGN4
      DO 402 I=1,MI
      DO 402 K=1,MK
      KSM3=KSM3+1
      KSM4=KSM4+1
      VFMXR(LZ,KSM3)=VFHSRE(I,K)/SN
```

```
      VFMXR(KSM3,LZ)=VFREHS(I,K)/SN
      VFMXR(LZ,KSM4)=VFHSF(I,K)/SN
      VFMXR(KSM4,LZ)=VFFHS(I,K)/SN
  402 CONTINUE
C
C *** HS VS T & B
C
      KSM5=MREGN5
      KSM6=MREGN6
      DO 403 I=1,MI
      DO 403 J=1,MJ
      KSM5=KSM5+1
      KSM6=KSM6+1
      VFMXR(LZ,KSM5)=VFHSB(I,J)/SN
      VFMXR(KSM5,LZ)=VFBHS(I,J)/SN
      VFMXR(LZ,KSM6)=VFHST(I,J)/SN
      VFMXR(KSM6,LZ)=VFTHS(I,J)/SN
  403 CONTINUE
C
  301 CONTINUE
C
C *******************************************************************
C
C ******************************************************************
C *** PRINT OUT THE VIEW FACTOR MATRIX COEFFICIENTS
C ******************************************************************
C
      DO 559 N=1,NHSZ
      LZ=MZ+N
      WRITE(6,560) N,LZ
  560 FORMAT(/,5X,'HEAT SOURCE ZONE #',I2,'; THE INDEX NUMBER IS',I4,//)
C
      DO 120 I=1,NZ
  120 SMXVFW(I)=0.
      WRITE(6,558)
  558 FORMAT(//,5X,'SUMMATION OF VIEW FACTOR MATRIX COEFFIENT',//,
     & '(1). ONE ZONE TO ALL OTHER ZONES EXCEPT   THE HEAT SOURCE',/
     & '(2). ONE ZONE TO ALL OTHER ZONES INCLUDES THE HEAT SOURCE',//)
      DO 550 I=1,NZ
      DO 557 J=1,NZ
      IF(J.LE.MZ) SMXVFW(I)=SMXVFW(I)+VFMXR(I,J)
      SMXVFH(I)=SMXVFH(I)+VFMXR(I,J)
  557 CONTINUE
      WRITE(6,553) I,SMXVFW(I),SMXVFH(I)
  553 FORMAT(5X,'I =',I3,2E16.4)
  550 CONTINUE
C
      WRITE(6,562)
  562 FORMAT(/,4X,'VF ; HS TO WALL (I)',6X,'VF ; WALL(I) TO HS',//)
C
      SUM1=0.
      SUM2=0.
      DO 782 I=1,MZ
      SUM1=SUM1+VFMXR(I,LZ)
      SUM2=SUM2+VFMXR(LZ,I)
      WRITE(6,783) I,VFMXR(LZ,I),VFMXR(I,LZ)
  783 FORMAT(10X,'I =',I3,2E15.4)
  782 CONTINUE
      WRITE(6,784) N,SUM1,SUM2
  784 FORMAT(3X,'SUMMATION OF VIEW FACTOR FROM ALL WALL ZONES TO ',
     & 'HEAT SOURCE #',I2,', THE VFMXR(I,LZ); =',E14.4,/,
     & 3X,'SUMMATION OF VIEW FACTOR FROM HEAT SOURCE TO ALL WALL ',
     & 'ZONES,',8X,' VFMXR(LZ,I);',E14.4,/)
C
C *** SMXVFF: SUMMATION OF VIEW FACTOR MATRIX
C
C *** VIEW FACTOR FROM HEAT SOURCE TO WALL ZONES; CALCULATED FROM
C     SURFACE AREA EXCHANGE MEHTOD
C
```

```
      WRITE(6,787)
  787 FORMAT(3X,'VIEW FACTOR FROM HEAT SOURCE TO WALL ZONES ',/,3X,
     & '(1) CALCULATED FROM WALL TO HEAT SOURCE RECIPROCAL METHOD',/,
     & 3X,'(2) CALCULATED FROM FORMULATION DIRECTLY',//)
C
      SMXVFF=0.
      DO 552 I=1,MREGN3
      AA=VFMXR(I,LZ)*AREA(I)/AREA(LZ)
      SMXVFF=SMXVFF+AA
      BB=VFMXR(LZ,I)
      WRITE(6,788) I,AA,BB
  788 FORMAT(5X,'I =',I3,2X,E13.4,2X,E13.4)
  552 CONTINUE
      DO 555 I=MREGN3+1,MREGN5
      AA=VFMXR(I,LZ)*AREA(I)/AREA(LZ)
      SMXVFF=SMXVFF+AA
      BB=VFMXR(LZ,I)
      WRITE(6,788) I,AA,BB
  555 CONTINUE
      DO 556 I=MREGN5+1,NZ-1
      AA=VFMXR(I,LZ)*AREA(I)/AREA(LZ)
      SMXVFF=SMXVFF+AA
      BB=VFMXR(LZ,I)
      WRITE(6,788) I,AA,BB
  556 CONTINUE
      WRITE(6,807) SMXVFF
  807 FORMAT(/,5X,'SUMMATION OF VIEW MATRIX COEFF. FROM HEAT SOURCE',
     & 'TO ALL WALL ZONES, SMXVFF =',E11.4,/)
C
  559 CONTINUE
C
      WRITE(6,551)
      WRITE(6,801)
  801 FORMAT(/,5X,' (J,K,(SWVFL (J,K),K=1,MK),J=1,MJ)',/)
      WRITE(6,809)((J,K,SWVFL (J,K),K=1,MK),J=1,MJ)
  809 FORMAT(2I4,1PE10.2)
      WRITE(6,802)
  802 FORMAT(/,5X,' (J,K,(SWVFR(J,K),K=1,MK),J=1,MJ)',/)
      WRITE(6,809)((J,K,SWVFR(J,K),K=1,MK),J=1,MJ)
      WRITE(6,803)
  803 FORMAT(/,5X,' (I,K,(SWVFRE(I,K),K=1,MK),I=1,MI)',/)
      WRITE(6,809)((I,K,SWVFRE(I,K),K=1,MK),I=1,MI)
      WRITE(6,804)
  804 FORMAT(/,5X,' (I,K,(SWVFF (I,K),K=1,MK),I=1,MI)',/)
      WRITE(6,809)((I,K,SWVFF (I,K),K=1,MK),I=1,MI)
      WRITE(6,805)
  805 FORMAT(/,5X,' (I,J,(SWVFB (I,J),J=1,MJ),I=1,MI)',/)
      WRITE(6,809)((I,J,SWVFB (I,J),J=1,MJ),I=1,MI)
      WRITE(6,806)
  806 FORMAT(/,5X,' (I,J,(SWVFT (I,J),J=1,MJ),I=1,MI)',/)
      WRITE(6,809)((I,J,SWVFT (I,J),J=1,MJ),I=1,MI)
C
  551 FORMAT(/,2X,'SUMMATION OF VIEW FACTOR')
C
C *** SAVE DATA ON A DISK FILE
C
      WRITE(9)
     & IREGN1,IREGN2,IREGN3,IREGN4,IREGN5,IREGN6,IREGN7,
     & MREGN1,MREGN2,MREGN3,MREGN4,MREGN5,MREGN6,MREGN7,
     & WC,DC,HC,NI,NJ,NK,AXY,AYZ,AZX,
     & MIIZ,MJJZ,MKKZ,MI,MJ,MK,LTYPE,MZ,NHSZ,NZ,LI,LJ,LK,
     & ITHIN,JTHIN,KTHIN,IHSB,JHSB,KHSB,NHSW,NHSD,NHSH,VFMXR,AREA
C
C     WRITE(6,773)
C 773 FORMAT(5X,'VIEW FACTOR MATRIX AT',//,5X,'I,(J,VFMXR(I,J),J=1,NZ)',
C    &   //)
C
C     M=1
C     J=1
```

```
C      MZ=NZ/8
C      DO 771 I=1,NZ
C 774  CONTINUE
C      IF(M.GT.MZ) GO TO 775
C      WRITE(6,772) I,(K,VFMXR(I,K),K=J,J+7)
C      J=J+8
C      M=M+1
C      GO TO 774
C775   WRITE(6,772) I,(K,VFMXR(I,K),K=J,NZ)
C      M=1
C      J=1
C 771  CONTINUE
C 772  FORMAT(1X,'I=',I3,8 (' J=',I3,1PE8.1,','),/)
C
        STOP
        END
        SUBROUTINE WALL
C
        COMMON/BL3/  VFMXR(67,67),SMXVFW(67),SMXVFH(67)
        COMMON/BL4/ WVFLR(3,3,3,3),WVFLRE(3,3,4,3),WVFLF(3,3,4,3),
      & WVFLT(3,3,4,3),WVFRRE(3,3,4,3),WVFRF(3,3,4,3),WVFRB(3,3,4,3),
      & WVFRT(3,3,4,3),WVFRL (3,3,3,3),WVFFL(4,3,3,3),WVFFB(4,3,4,3),
      & WVFFT(4,3,4,3),WVFFRE(4,3,4,3),WVFFR(4,3,3,3),WVFBT(4,3,4,3),
      & WVFBL(4,3,3,3),WVFBRE(4,3,4,3),WVFBF(4,3,4,3),WVFBR(4,3,3,3),
      & WVFTL(4,3,3,3),WVFTRE(4,3,4,3),WVFTF(4,3,4,3),WVFTR(4,3,3,3),
      & WVFRET(4,3,4,3),WVFREF(4,3,4,3),WVFRER(4,3,3,3),WVFTB(4,3,4,3),
      & WVFREL(4,3,3,3),WVFREB(4,3,4,3),WVFLB(3,3,4,3)
C
        COMMON/BL5/
      & VFHSR(3,3),VFHSF(4,3),VFHSRE(4,3),VFHST(4,3),VFHSB(4,3),
      & VFRHS(3,3),VFFHS(4,3),VFREHS(4,3),VFTHS(4,3),VFBHS(4,3),
      & VFHSL(3,3),VFLHS(3,3)
C
        COMMON /BL6/ VFLHT(3,3),VFRHT(3,3),VFFHT(4,3),VFREHT(4,3),
      & VFFHR(3,3),VFRHR(3,3),VFREHR(4,3),VFTHR(4,3),VFBHR(4,3),
      & VFLHL(3,3),VFFHL(4,3),VFREHL(4,3),VFTHL(4,3),VFBHL(4,3),
      & VFLHRE(3,3),VFRHRE(3,3),VREHRE(4,3),VFTHRE(4,3),VFBHRE(4,3),
      & VFLHF(3,3),VFRHF(3,3),VFFHF(3,3),VFTHF(4,3),VFBHF(4,3),
      & VFLHB(3,3),VFRHB(3,3),VFFHB(4,3),VFREHB(4,3),VFBHB(4,3),
      & VFTHT(4,3)
C
        COMMON /BL7/ VFHTL(3,3),VFHTR(3,3),VFHTF(4,3),VFHTRE(4,3),
      & VFHRF(3,3),VFHRR(3,3),VFHRRE(4,3),VFHRT(4,3),VFHRB(4,3),
      & VFHLL(3,3),VFHLF(4,3),VFHLRE(4,3),VFHLT(4,3),VFHLB(4,3),
      & VFHREL(3,3),VFHRER(3,3),VHRERE(4,3),VFHRET(4,3),VFHREB(4,3),
      & VFHFL(3,3),VFHFR(3,3),VFHFF(3,3),VFHFT(4,3),VFHFB(4,3),
      & VFHBL(3,3),VFHBR(3,3),VFHBF(4,3),VFHBRE(4,3),VFHBB(4,3),
      & VFHTT(4,3)
C
        COMMON /BL8/ X(22),Y(18),Z(18),NOD(22,18,18),
      &     RX(5),RY(4),RZ(4),AREA(67),ZX(5),ZY(4),ZZ(4)
C
        COMMON /BL9/ SWVFRE(4,3),SWVFL(3,3),SWVFR(3,3),SWVFF(4,3),
      &          SWVFT(4,3),SWVFB(4,3)
        COMMON /BL10/ NZ,DX,DY,DZ,DXY,DYZ,DZX,WC,DC,HC
C
        COMMON /BL1/ NI,NJ,NK,NIM1,NJM1,NKM1,NIM2,NJM2,NKM2,
      &  MI,MJ,MK,MII,MJJ,MKK,MIM,MIP,MJM,MJP,MKM,MKP,
      &  MIIM,MIIP,MJJM,MJJP,MKKM,MKKP,
      &  IREGN1,IREGN2,IREGN3,IREGN4,IREGN5,IREGN6,IREGN7,
      &  MREGN1,MREGN2,MREGN3,MREGN4,MREGN5,MREGN6,MREGN7
C
        COMMON /BL2/ IB,IE,IBM1,IBP1,IEM1,IEP1,
      &              JB,JE,JBM1,JBP1,JEM1,JEP1,
      &              KB,KE,KBM1,KBP1,KEM1,KEP1
C
        COMMON/BL11/ MIIZ(9),MJJZ(9),MKKZ(9),IS(6),LTYPE(9,6),
      &              LI(9),LJ(9),LK(9),AYZ(9),AXY(9),AZX(9),
      &              NHSZ,ITHIN(9),JTHIN(9),KTHIN(9),
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     &              IHSB(9),NHSW(9),JHSB(9),NHSD(9),KHSB(9),NHSH(9)
C
C
C ***********************************************************************
C *** WVF-- VIEW FACTOR BETWEEN TWO WALL ZONES
C     SWVF-- SUMMATION OF VIEW FACTOR FROM ONE WALL ZONE TO ALL OTHER
C            WALL ZONES
C *** THE VIEW FACTORS BETWEEN TANK INTERIOR WALL ZONES
C ************************************************************************
C
C *** 3 PAIRS OF PARALLEL WALLS INSIDE THE TANK
C
C  1.* LEFT WALL VS RIGHT WALL, (L VS R)
C
      GHZ=RX(MI+1)-RX(1)
      DO 500 J=1,MJ
      DO 500 K=1,MK
      DO 500 JJ=1,MJ
      DO 500 KK=1,MK
      DO 4 L=1,NHSZ
      IF(LTYPE(L,1).NE.1) GO TO 5
      IF(J .NE. MJJZ(L)) GO TO 4
      IF(K .NE. MKKZ(L)) GO TO 4
      IF(JJ.NE. MJJZ(L)) GO TO 4
      IF(KK.NE. MKKZ(L)) GO TO 4
      GO TO 500
    4 CONTINUE
    5 CONTINUE
      JP1=J+1
      KP1=K+1
      JJP1=JJ+1
      KKP1=KK+1
      DDD=PARLEL(RZ(K),RZ(KP1),RY(J),RY(JP1),RY(JJ),RY(JJP1),RZ(KK),
     &    RZ(KKP1),GHZ)*GHZ*GHZ
      WVFLR(J,K,JJ,KK)=DDD/(ZY(J)*ZZ(K))
      WVFRL(JJ,KK,J,K)=DDD/(ZY(JJ)*ZZ(KK))
      SWVFL(J,K)  =SWVFL(J,K)  +WVFLR(J,K,JJ,KK)
      SWVFR(JJ,KK)=SWVFR(JJ,KK)+WVFRL(JJ,KK,J,K)
  500 CONTINUE
C
      WRITE(6,51)
   51 FORMAT(2X,'J ,K ,SWVFL ( J, K) ** JJ,KK,WVFLR (J,K,JJ,KK),',
     & 'WVFRL (JJ,KK,J,K), SWVFR (JJ,KK)',/)
      DO 52 J=1,MJ
      DO 52 K=1,MK
      WRITE(6,53) J ,K ,SWVFL ( J, K)
   53 FORMAT(2X,' J=',I3,'  K=',I3,' SWVFL =',1PE10.2,/)
      WRITE(6,54) ((JJ,KK,WVFRL ( J, K,JJ,KK),WVFRL (JJ,KK, J, K),
     & SWVFR (JJ,KK),KK=1,MK),JJ=1,MJ)
   54 FORMAT(2I3,3E14.4)
   52 CONTINUE
C
C 2.* REAR WALL VS FRONT WALL, (RE VS F)
C
      GHZ=RY(MJ+1)-RY(1)
      DO 501 I=1,MI
      DO 501 K=1,MK
      DO 501 II=1,MI
      DO 501 KK=1,MK
      DO 6 L=1,NHSZ
      IF(LTYPE(L,3).NE.1) GO TO 7
      IF(I .NE. MIIZ(L)) GO TO 6
      IF(K .NE. MKKZ(L)) GO TO 6
      IF(II.NE. MIIZ(L)) GO TO 6
      IF(KK.NE. MKKZ(L)) GO TO 6
      GO TO 501
    6 CONTINUE
    7 CONTINUE
      IP1=I+1
```

```
      KP1=K+1
      IIP1=II+1
      KKP1=KK+1
      DDD=PARLEL(RZ(K),RZ(KP1),RX(I),RX(IP1),RX(II),RX(IIP1),RZ(KK),
     &    RZ(KKP1),GHZ)*GHZ*GHZ
      WVFREF(I,K,II,KK)=DDD/((RX(IP1)-RX(I))*(RZ(KP1)-RZ(K)))
      WVFFRE(II,KK,I,K)=DDD/((RX(IIP1)-RX(II))*(RZ(KKP1)-RZ(KK)))
      SWVFRE(I,K) =SWVFRE(I,K) +WVFREF(I,K,II,KK)
      SWVFF(II,KK)=SWVFF(II,KK)+WVFFRE(II,KK,I,K)
  501 CONTINUE
C
      WRITE(6,55)
   55 FORMAT(2X,' I, K,SWVFRE( I, K) ** II,KK,WVFREF(I,K,II,KK),',
     & 'WVFFRE(II,KK,I,K), SWVFF (II,KK)',/)
      DO 56 I=1,MI
      DO 56 K=1,MK
      WRITE(6,57)  I, K,SWVFRE( I, K)
   57 FORMAT(2X,' I=',I3,'  K=',I3,' SWVFRE=',1PE10.2,/)
      WRITE(6,54) ((II,KK,WVFREF( I, K,II,KK),WVFFRE(II,KK, I, K),
     & SWVFF (II,KK),KK=1,MK),II=1,MI)
   56 CONTINUE
C
C 3.* TOP WALL VS BOTTOM WALL, (T VS B)
C
      GHZ=RZ(MK+1)-RZ(1)
      DO 502 I=1,MI
      DO 502 J=1,MJ
      IP1=I+1
      JP1=J+1
      DO 502 II=1,MI
      DO 502 JJ=1,MJ
      DO 8 L=1,NHSZ
      IF(LTYPE(L,3).NE.1) GO TO 9
      IF(I .NE. MIIZ(L)) GO TO 8
      IF(J .NE. MJJZ(L)) GO TO 8
      IF(II.NE..MIIZ(L)) GO TO 8
      IF(JJ.NE. MJJZ(L)) GO TO 8
      GO TO 502
    8 CONTINUE
    9 CONTINUE
      IIP1=II+1
      JJP1=JJ+1
      DDD=PARLEL(RY(J),RY(JP1),RX(I),RX(IP1),RX(II),RX(IIP1),RY(JJ),
     &    RY(JJP1),GHZ)*GHZ*GHZ
      WVFBT (I,J,II,JJ)=DDD/(ZX(I)*ZY(J))
      WVFTB (II,JJ,I,J)=DDD/(ZX(II)*ZY(JJ))
      SWVFB ( I, J)=SWVFB ( I, J)+WVFBT (I,J,II,JJ)
      SWVFT (II,JJ)=SWVFT (II,JJ)+WVFTB (II,JJ,I,J)
  502 CONTINUE
C
      WRITE(6,110)
  110 FORMAT(2X,' I, J,SWVFB ( I, J) ** II,JJ,WVFBT (I,J,II,JJ),',
     & 'WVFTB (II,JJ,I,J), SWVFT (II,JJ)',/)
      DO 111 I=1,MI
      DO 111 J=1,MJ
      WRITE(6,112)  I, J,SWVFB ( I, J)
  112 FORMAT(2X,' I=',I3,'  J=',I3,' SWVFB =',1PE10.2,/)
      WRITE(6,54) ((II,JJ,WVFBT ( I, J,II,JJ),WVFTB (II,JJ, I, J),
     & SWVFT (II,JJ),JJ=1,MJ),II=1,MI)
  111 CONTINUE
C
C *** 12 PAIRS OF PERPENDICULAR WALL INSIDE THE TANK
C
C *** 1 === LEFT WALL VS BOTTOM (L VS B)
C
      DO 503 J=1,MJ
      DO 503 K=1,MK
      DO 503 II=1,MI
      DO 503 JJ=1,MJ
```

```
      GH1 =RX(II)
      GH2 =RX(II+1)
      GV1 =RY(JJ)
      GV2 =RY(JJ+1)
      SV1 =RY(J)
      SV2 =RY(J+1)
      SH1 =RZ(K)
      SH2 =RZ(K+1)
      DDD =PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      WVFLB(J,K,II,JJ)=DDD/((SH2-SH1)*(SV2-SV1))
      WVFBL(II,JJ,J,K)=DDD/((GH2-GH1)*(GV2-GV1))
      SWVFL(J,K)  =SWVFL(J,K)  +WVFLB (J,K,II,JJ)
      SWVFB(II,JJ)=SWVFB(II,JJ)+WVFBL(II,JJ,J,K)
  503 CONTINUE
C
      WRITE(6,59)
   59 FORMAT(2X,' J, K,SWVFL ( J, K) ** II,JJ,WVFLB (J,K,II,JJ),',
     & 'WVFBL (II,JJ,J,K), SWVFB (II,JJ)',/)
      DO 60 J=1,MJ
      DO 60 K=1,MK
      WRITE(6,61)  J, K,SWVFL ( J, K)
   61 FORMAT(2X,' J=',I3,'  K=',I3,' SWVFL =',1PE10.2,/)
      WRITE(6,54) ((II,JJ,WVFLB ( J, K,II,JJ),WVFBL (II,JJ, J, K),
     & SWVFB (II,JJ),JJ=1,MJ),II=1,MI)
   60 CONTINUE
C
C *** 2 === LEFT WALL VS REAR WALL (L VS RE)
C
      DO 504 J=1,MJ
      DO 504 K=1,MK
      DO 504 II=1,MI
      DO 504 KK=1,MK
      GH1 =RX(II)
      GH2 =RX(II+1)
      GV1 =RZ(KK)
      GV2 =RZ(KK+1)
      SH1 =RY(J)
      SH2 =RY(J+1)
      SV1 =RZ(K)
      SV2 =RZ(K+1)
      DDD =PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      WVFLRE(J,K,II,KK)=DDD/((SH2-SH1)*(SV2-SV1))
      WVFREL(II,KK,J,K)=DDD/((GH2-GH1)*(GV2-GV1))
      SWVFL(J,K)   =SWVFL(J,K)   +WVFLRE(J,K,II,KK)
      SWVFRE(II,KK)=SWVFRE(II,KK)+WVFREL(II,KK,J,K)
  504 CONTINUE
C
      WRITE(6,63)
   63 FORMAT(2X,' J, K,SWVFL ( J, K) ** II,KK,WVFLRE(J,K,II,KK),',
     & 'WVFREL(II,KK,J,K), SWVFRE(II,KK)',/)
      DO 64 J=1,MJ
      DO 64 K=1,MK
      WRITE(6,66)  J, K,SWVFL ( J, K)
   66 FORMAT(2X,' J=',I3,'  K=',I3,' SWVFL =',1PE10.2,/)
      WRITE(6,54) ((II,KK,WVFLRE( J, K,II,KK),WVFREL(II,KK, J, K),
     & SWVFRE(II,KK),KK=1,MK),II=1,MI)
   64 CONTINUE
C
C *** 3=== LEFT WALL VS FRONT WALL, (L VS F)
C
      DO 505 J=1,MJ
      DO 505 K=1,MK
      DO 505 II=1,MI
      DO 505 KK=1,MK
      GH1 =RX(II)
      GH2 =RX(II+1)
      GV1 =RZ(KK)
      GV2 =RZ(KK+1)
      SH2 =RY(MJ+1)-RY(J)
```

```
      SH1 =RY(MJ+1)-RY(J+1)
      SV1 =RZ(K)
      SV2 =RZ(K+1)
      DDD =PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      WVFLF(J,K,II,KK)=DDD/((SH2-SH1)*(SV2-SV1))
      WVFFL(II,KK,J,K)=DDD/((GH2-GH1)*(GV2-GV1))
      SWVFL(J,K)  =SWVFL(J,K)  +WVFLF(J,K,II,KK)
      SWVFF(II,KK)=SWVFF(II,KK)+WVFFL(II,KK,J,K)
  505 CONTINUE
C
      WRITE(6,70)
   70 FORMAT(2X,' J, K,SWVFL ( J, K) ** II,KK,WVFLF (J,K,II,KK),',
     & 'WVFFL (II,KK,J,K), SWVFF (II,KK)',/)
      DO 67 J=1,MJ
      DO 67 K=1,MK
      WRITE(6,69)  J, K,SWVFL ( J, K)
   69 FORMAT(2X,' J=',I3,'  K=',I3,' SWVFL =',1PE10.2,/)
      WRITE(6,54) ((II,KK,WVFLF ( J, K,II,KK),WVFFL (II,KK, J, K),
     & SWVFF (II,KK),KK=1,MK),II=1,MI)
   67 CONTINUE
C
C *** 4 === LEFT WALL VS TOP WALL, (L VS T)
C
      DO 506 J=1,MJ
      DO 506 K=1,MK
      DO 506 II=1,MI
      DO 506 JJ=1,MJ
      GH1 =RX(II)
      GH2 =RX(II+1)
      GV1 =RY(JJ)
      GV2 =RY(JJ+1)
      SV1 =RY(J)
      SV2 =RY(J+1)
      SH2 =RZ(MK+1)-RZ(K)
      SH1 =RZ(MK+1)-RZ(K+1)
      DDD =PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      WVFLT(J,K,II,JJ)=DDD/((SH2-SH1)*(SV2-SV1))
      WVFTL(II,JJ,J,K)=DDD/((GH2-GH1)*(GV2-GV1))
      SWVFL(J,K)  =SWVFL(J,K)  +WVFLT(J,K,II,JJ)
      SWVFT(II,JJ)=SWVFT(II,JJ)+WVFTL(II,JJ,J,K)
  506 CONTINUE
C
      WRITE(6,71)
   71 FORMAT(2X,' J, K,SWVFL ( J, K) ** II,JJ,WVFLT (J,K,II,JJ),',
     & 'WVFTL (II,JJ,J,K), SWVFT (II,JJ)',/)
      DO 72 J=1,MJ
      DO 72 K=1,MK
      WRITE(6,74)  J, K,SWVFL ( J, K)
   74 FORMAT(2X,' J=',I3,'  K=',I3,' SWVFL =',1PE10.2,/)
      WRITE(6,54) ((II,JJ,WVFLT ( J, K,II,JJ),WVFTL (II,JJ, J, K),
     & SWVFL (II,JJ),JJ=1,MJ),II=1,MI)
   72 CONTINUE
C
C *** 5 === REAR WALL VS BOTTOM WALL, (RE VS B)
C
      DO 507 I=1,MI
      DO 507 K=1,MK
      DO 507 II=1,MI
      DO 507 JJ=1,MJ
      GV1 =RX(II)
      GV2 =RX(II+1)
      GH1 =RY(JJ)
      GH2 =RY(JJ+1)
      SV1 =RX(I)
      SV2 =RX(I+1)
      SH1 =RZ(K)
      SH2 =RZ(K+1)
      DDD =PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      WVFREB(I,K,II,JJ)=DDD/((SH2-SH1)*(SV2-SV1))
```

```
      WVFBRE(II,JJ,I,K)=DDD/((GH2-GH1)*(GV2-GV1))
      SWVFRE(I,K) =SWVFRE(I,K) +WVFREB(I,K,II,JJ)
      SWVFB(II,JJ)=SWVFB(II,JJ)+WVFBRE(II,JJ,I,K)
  507 CONTINUE
C
      WRITE(6,75)
   75 FORMAT(2X,' I, K,SWVFRE( I, K) ** II,JJ,WVFREB(I,K,II,JJ),',
     & 'WVFBRE(II,JJ,I,K), SWVFB (II,JJ)',/)
      DO 76 I=1,MI
      DO 76 K=1,MK
      WRITE(6,78)  I, K,SWVFRE( I, K)
   78 FORMAT(2X,' I=',I3,'  K=',I3,' SWVFRE=',1PE10.2,/)
      WRITE(6,54) ((II,JJ,WVFREB( I, K,II,JJ),WVFBRE(II,JJ, I, K),
     & SWVFB (II,JJ),JJ=1,MJ),II=1,MI)
   76 CONTINUE
C
C *** 6 === REAR WALL VS RIGHT WALL, (RE VS R)
C
      DO 509 I=1,MI
      DO 509 K=1,MK
      DO 509 JJ=1,MJ
      DO 509 KK=1,MK
      GH1 =RY(JJ)
      GH2 =RY(JJ+1)
      GV1 =RZ(KK)
      GV2 =RZ(KK+1)
      SH2 =RX(MI+1)-RX(I)
      SH1 =RX(MI+1)-RX(I+1)
      SV1 =RZ(K)
      SV2 =RZ(K+1)
      DDD =PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      WVFRER(I,K,JJ,KK)=DDD/((SH2-SH1)*(SV2-SV1))
      WVFRRE(JJ,KK,I,K)=DDD/((GH2-GH1)*(GV2-GV1))
      SWVFRE(I,K) =SWVFRE(I,K) +WVFRER(I,K,JJ,KK)
      SWVFR(JJ,KK)=SWVFR(JJ,KK)+WVFRRE(JJ,KK,I,K)
  509 CONTINUE
C
      WRITE(6,79)
   79 FORMAT(2X,' I, K,SWVFRE( I, K) ** JJ,KK,WVFRER(I,K,JJ,KK),',
     & 'WVFRRE(JJ,KK,I,K), SWVFR (JJ,KK)',/)
      DO 80 I=1,MI
      DO 80 K=1,MK
      WRITE(6,82)  I, K,SWVFRE( I, K)
   82 FORMAT(2X,' I=',I3,'  K=',I3,' SWVFRE=',1PE10.2,/)
      WRITE(6,54) ((JJ,KK,WVFRER( I, K,JJ,KK),WVFRRE(JJ,KK, I, K),
     & SWVFRE(JJ,KK),KK=1,MK),JJ=1,MJ)
   80 CONTINUE
C
C *** 7 === REAR WALL VS TOP WALL, (RE VS T)
C
      DO 508 I=1,MI
      DO 508 K=1,MK
      DO 508 II=1,MI
      DO 508 JJ=1,MJ
      GV1 =RX(II)
      GV2 =RX(II+1)
      GH1 =RY(JJ)
      GH2 =RY(JJ+1)
      SV1 =RX(I)
      SV2 =RX(I+1)
      SH2 =RZ(MK+1)-RZ(K)
      SH1 =RZ(MK+1)-RZ(K+1)
      DDD =PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      WVFRET(I,K,II,JJ)=DDD/((SH2-SH1)*(SV2-SV1))
      WVFTRE(II,JJ,I,K)=DDD/((GH2-GH1)*(GV2-GV1))
      SWVFRE(I,K) =SWVFRE(I,K) +WVFRET(I,K,II,JJ)
      SWVFT(II,JJ)=SWVFT(II,JJ)+WVFTRE(II,JJ,I,K)
  508 CONTINUE
C
```

```
      WRITE(6,83)
   83 FORMAT(2X,' I, K,SWVFRE( I, K) ** II,JJ,WVFRET(I,K,II,JJ),',
     & 'WVFTRE(II,JJ,I,K), SWVFT (II,JJ)',/)
      DO 84 I=1,MI
      DO 84 K=1,MK
      WRITE(6,86)  I, K,SWVFRE( I, K)
   86 FORMAT(2X,' I=',I3,'  K=',I3,' SWVFRE=',1PE10.2,/)
      WRITE(6,54) ((II,JJ,WVFRET( I, K,II,JJ),WVFTRE(II,JJ, I, K),
     & SWVFT (II,JJ),JJ=1,MJ),II=1,MI)
   84 CONTINUE
C
C *** 8 === RIGHT WALL VS BOTTOM WALL, (R VS B)
C
      DO 512 J=1,MJ
      DO 512 K=1,MK
      DO 512 II=1,MI
      DO 512 JJ=1,MJ
      GH2 =RX(MI+1)-RX(II)
      GH1 =RX(MI+1)-RX(II+1)
      GV1 =RY(JJ)
      GV2 =RY(JJ+1)
      SV1 =RY(J)
      SV2 =RY(J+1)
      SH1 =RZ(K)
      SH2 =RZ(K+1)
      DDD =PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      WVFRB(J,K,II,JJ)=DDD/((SH2-SH1)*(SV2-SV1))
      WVFBR(II,JJ,J,K)=DDD/((GH2-GH1)*(GV2-GV1))
      SWVFR(J,K)  =SWVFR(J,K)  +WVFRB(J,K,II,JJ)
      SWVFB(II,JJ)=SWVFB(II,JJ)+WVFBR(II,JJ,J,K)
  512 CONTINUE
C
      WRITE(6,87)
   87 FORMAT(2X,' I, K,SWVFR ( I, K) ** II,JJ,WVFRB (I,K,II,JJ),',
     & 'WVFBR (II,JJ,I,K), SWVFB (II,JJ)',/)
      DO 88 I=1,MI
      DO 88 K=1,MK
      WRITE(6,90)  I, K,SWVFR ( I, K)
   90 FORMAT(2X,' I=',I3,'  K=',I3,' SWVFR =',1PE10.2,/)
      WRITE(6,54) ((II,JJ,WVFRB ( I, K,II,JJ),WVFBR (II,JJ, I, K),
     & SWVFB (II,JJ),JJ=1,MJ),II=1,MI)
   88 CONTINUE
C
C *** 9 === RIGHT WALL VS FRONT WALL, (R VS F)
C
      DO 510 J=1,MJ
      DO 510 K=1,MK
      DO 510 II=1,MI
      DO 510 KK=1,MK
      GH2 =RX(MI+1)-RX(II)
      GH1 =RX(MI+1)-RX(II+1)
      GV1 =RZ(KK)
      GV2 =RZ(KK+1)
      SH2 =RY(MJ+1)-RY(J)
      SH1 =RY(MJ+1)-RY(J+1)
      SV1 =RZ(K)
      SV2 =RZ(K+1)
      DDD =PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      WVFRF(J,K,II,KK)=DDD/((SH2-SH1)*(SV2-SV1))
      WVFFR(II,KK,J,K)=DDD/((GH2-GH1)*(GV2-GV1))
      SWVFR(J,K)  =SWVFR(J,K)  +WVFRF(J,K,II,KK)
      SWVFF(II,KK)=SWVFF(II,KK)+WVFFR(II,KK,J,K)
  510 CONTINUE
C
      WRITE(6,91)
   91 FORMAT(2X,' J, K,SWVFR ( J, K) ** II,KK,WVFRF (J,K,II,KK),',
     & 'WVFFR (II,KK,J,K), SWVFF (II,KK)',/)
      DO 92 J=1,MJ
      DO 92 K=1,MK
```

```
      WRITE(6,94)  J, K,SWVFR ( J, K)
   94 FORMAT(2X,' J=',I3,'  K=',I3,' SWVFR =',1PE10.2,/)
      WRITE(6,54) ((II,KK,WVFRF ( J, K,II,KK),WVFFR (II,KK, J, K),
     & SWVFF (II,KK),KK=1,MK),II=1,MI)
   92 CONTINUE
C
C *** 10 === RIGHT WALL VS TOP WALL, (R VS T)
C
      DO 511 J=1,MJ
      DO 511 K=1,MK
      DO 511 II=1,MI
      DO 511 JJ=1,MJ
      GH2 =RX(MI+1)-RX(II)
      GH1 =RX(MI+1)-RX(II+1)
      GV1 =RY(JJ)
      GV2 =RY(JJ+1)
      SV1 =RY(J)
      SV2 =RY(J+1)
      SH2 =RZ(MK+1)-RZ(K)
      SH1 =RZ(MK+1)-RZ(K+1)
      DDD =PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      WVFRT(J,K,II,JJ)=DDD/((SH2-SH1)*(SV2-SV1))
      WVFTR(II,JJ,J,K)=DDD/((GH2-GH1)*(GV2-GV1))
      SWVFR(J,K)  =SWVFR(J,K)  +WVFRT(J,K,II,JJ)
      SWVFT(II,JJ)=SWVFT(II,JJ)+WVFTR (II,JJ,J,K)
  511 CONTINUE
C
      WRITE(6,95)
   95 FORMAT(2X,' J, K,SWVFR ( J, K) ** II,JJ,WVFRT (J,K,II,JJ),',
     & 'WVFTR (II,JJ,J,K), SWVFT (II,JJ)',/)
      DO 96 J=1,MJ
      DO 96 K=1,MK
      WRITE(6,98)  J, K,SWVFR ( J, K)
   98 FORMAT(2X,' J=',I3,'  K=',I3,' SWVFR =',1PE10.2,/)
      WRITE(6,54) ((II,JJ,WVFRT ( J, K,II,JJ),WVFTR (II,JJ, J, K),
     & SWVFT (II,JJ),JJ=1,MJ),II=1,MI)
   96 CONTINUE
C
C *** 11 === FRONT WALL VS BOTTOM WALL, (F VS B)
C
      DO 593 I=1,MI
      DO 593 K=1,MK
      DO 593 II=1,MI
      DO 593 JJ=1,MJ
      GV1 =RX(II)
      GV2 =RX(II+1)
      GH2 =RY(MJ+1)-RY(JJ)
      GH1 =RY(MJ+1)-RY(JJ+1)
      SV1 =RX(I)
      SV2 =RX(I+1)
      SH1 = RZ(K)
      SH2 = RZ(K+1)
      DDD =PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      WVFFB(I,K,II,JJ)=DDD/((SH2-SH1)*(SV2-SV1))
      WVFBF(II,JJ,I,K)=DDD/((GH2-GH1)*(GV2-GV1))
      SWVFF(I,K)  =SWVFF(I,K)  +WVFFB(I,K,II,JJ)
      SWVFB(II,JJ)=SWVFB(II,JJ)+WVFBF(II,JJ,I,K)
  593 CONTINUE
C
      WRITE(6,43)
   43 FORMAT(2X,' I, K,SWVFF ( I, K) ** II,JJ,WVFFB (I,K,II,JJ),',
     & 'WVFBF (II,JJ,I,K), SWVFB (II,JJ)',/)
      DO 44 I=1,MI
      DO 44 K=1,MK
      WRITE(6,46)  I, K,SWVFF ( I, K)
   46 FORMAT(2X,' I=',I3,'  K=',I3,' SWVFF =',1PE10.2,/)
      WRITE(6,54) ((II,JJ,WVFFB ( I, K,II,JJ),WVFBF (II,JJ, I, K),
     & SWVFB (II,JJ),JJ=1,MJ),II=1,MI)
   44 CONTINUE
```

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C
C *** 12 === FRONT WALL VS TOP WALL, (F VS T)
C
      DO 513 I=1,MI
      DO 513 K=1,MK
      DO 513 II=1,MI
      DO 513 JJ=1,MJ
      GV1 =RX(II)
      GV2 =RX(II+1)
      GH2 =RY(MJ+1)-RY(JJ)
      GH1 =RY(MJ+1)-RY(JJ+1)
      SV1 =RX(I)
      SV2 =RX(I+1)
      SH2 =RZ(MK+1)-RZ(K)
      SH1 =RZ(MK+1)-RZ(K+1)
      DDD =PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      WVFFT(I,K,II,JJ)=DDD/((SH2-SH1)*(SV2-SV1))
      WVFTF(II,JJ,I,K)=DDD/((GH2-GH1)*(GV2-GV1))
      SWVFF(I,K)  =SWVFF(I,K)  +WVFFT(I,K,II,JJ)
      SWVFT(II,JJ)=SWVFT(II,JJ)+WVFTF(II,JJ,I,K)
  513 CONTINUE
C
      WRITE(6,47)
   47 FORMAT(2X,' I, K,SWVFF ( I, K) ** II,JJ,WVFFT (I,K,II,JJ),',
     & 'WVFTF (II,JJ,I,K), SWVFT (II,JJ)',/)
      DO 48 I=1,MI
      DO 48 K=1,MK
      WRITE(6,99)  I, K,SWVFF ( I, K)
   99 FORMAT(2X,' I=',I3,'  K=',I3,' SWVFF =',1PE10.2,/)
      WRITE(6,54) ((II,JJ,WVFFT ( I, K,II,JJ),WVFTF (II,JJ, I, K),
     & SWVFT (II,JJ),JJ=1,MJ),II=1,MI)
   48 CONTINUE
C
      RETURN
      END
      SUBROUTINE HSTWAL(NN,KSS,IP,JP,KP)
C**************************************************
C
      COMMON /BL3/ VFMXR(67,67),SMXVFW(67),SMXVFH(67)
      COMMON /BL4/ WVFLR(3,3,3,3),WVFLRE(3,3,4,3),WVFLF(3,3,4,3),
     & WVFLT(3,3,4,3),WVFRRE(3,3,4,3),WVFRF(3,3,4,3),WVFRB(3,3,4,3),
     & WVFRT(3,3,4,3),WVFRL (3,3,3,3),WVFFL(4,3,3,3),WVFFB(4,3,4,3),
     & WVFFT(4,3,4,3),WVFFRE(4,3,4,3),WVFFR(4,3,3,3),WVFBT(4,3,4,3),
     & WVFBL(4,3,3,3),WVFBRE(4,3,4,3),WVFBF(4,3,4,3),WVFBR(4,3,3,3),
     & WVFTL(4,3,3,3),WVFTRE(4,3,4,3),WVFTF(4,3,4,3),WVFTR(4,3,3,3),
     & WVFRET(4,3,4,3),WVFREF(4,3,4,3),WVFRER(4,3,3,3),WVFTB(4,3,4,3),
     & WVFREL(4,3,3,3),WVFREB(4,3,4,3),WVFLB(3,3,4,3)
C
      COMMON /BL5/
     & VFHSR(3,3),VFHSF(4,3),VFHSRE(4,3),VFHST(4,3),VFHSB(4,3),
     & VFRHS(3,3),VFFHS(4,3),VFREHS(4,3),VFTHS(4,3),VFBHS(4,3),
     & VFHSL(3,3),VFLHS(3,3)
C
      COMMON /BL6/ VFLHT(3,3),VFRHT(3,3),VFFHT(4,3),VFREHT(4,3),
     & VFFHR(3,3),VFRHR(3,3),VFREHR(4,3),VFTHR(4,3),VFBHR(4,3),
     & VFLHL(3,3),VFFHL(4,3),VFREHL(4,3),VFTHL(4,3),VFBHL(4,3),
     & VFLHRE(3,3),VFRHRE(3,3),VREHRE(4,3),VFTHRE(4,3),VFBHRE(4,3),
     & VFLHF(3,3),VFRHF(3,3),VFFHF(3,3),VFTHF(4,3),VFBHF(4,3),
     & VFLHB(3,3),VFRHB(3,3),VFFHB(4,3),VFREHB(4,3),VFBHB(4,3),
     & VFTHT(4,3)
C
      COMMON /BL7/ VFHTL(3,3),VFHTR(3,3),VFHTF(4,3),VFHTRE(4,3),
     & VFHRF(3,3),VFHRR(3,3),VFHRRE(4,3),VFHRT(4,3),VFHRB(4,3),
     & VFHLL(3,3),VFHLF(4,3),VFHLRE(4,3),VFHLT(4,3),VFHLB(4,3),
     & VFHREL(3,3),VFHRER(3,3),VHRERE(4,3),VFHRET(4,3),VFHREB(4,3),
     & VFHFL(3,3),VFHFR(3,3),VFHFF(3,3),VFHFT(4,3),VFHFB(4,3),
     & VFHBL(3,3),VFHBR(3,3),VFHBF(4,3),VFHBRE(4,3),VFHBB(4,3),
     & VFHTT(4,3)
C
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      COMMON /BL8/ X(22),Y(18),Z(18),NOD(22,18,18),
     &     RX(5),RY(4),RZ(4),AREA(67),ZX(5),ZY(4),ZZ(4)
C
      COMMON /BL9/ SWVFRE(4,3),SWVFL(3,3),SWVFR(3,3),SWVFF(4,3),
     &             SWVFT(4,3),SWVFB(4,3)
      COMMON /BL10/ NZ,DX,DY,DZ,DXY,DYZ,DZX,WC,DC,HC
C
      COMMON /BL1/ NI,NJ,NK,NIM1,NJM1,NKM1,NIM2,NJM2,NKM2,
     &  MI,MJ,MK,MII,MJJ,MKK,MIM,MIP,MJM,MJP,MKM,MKP,
     &  MIIM,MIIP,MJJM,MJJP,MKKM,MKKP,
     &  IREGN1,IREGN2,IREGN3,IREGN4,IREGN5,IREGN6,IREGN7,
     &  MREGN1,MREGN2,MREGN3,MREGN4,MREGN5,MREGN6,MREGN7
C
      COMMON /BL2/ IB,IE,IBM1,IBP1,IEM1,IEP1,
     &             JB,JE,JBM1,JBP1,JEM1,JEP1,
     &             KB,KE,KBM1,KBP1,KEM1,KEP1
      COMMON/BL11/ MIIZ(9),MJJZ(9),MKKZ(9),IS(6),LTYPE(9,6),
     &             LI(9),LJ(9),LK(9),AYZ(9),AXY(9),AZX(9),
     &             NHSZ,ITHIN(9),JTHIN(9),KTHIN(9),
     &             IHSB(9),NHSW(9),JHSB(9),NHSD(9),KHSB(9),NHSH(9)
      DIMENSION NN(6)
C
C **************************************************************
C
C *** THE VIEW FACTOR BETWEEN HEAT SOURCE AND WALL SURFACE ****
C
C **************************************************************
C
C *** THERE ARE 6 TYPES OF SURFACES CAN BE CONSIDERED INSIDE THE
C     THE ENCLOSURE
C *** 1ST TYPE : LEFT   SIDE OF THE HEAT SOURCE, IT SEES ONLY THE
C                -X DIRECTION.
C     2ND TYPE : RIGHT  SIDE OF THE HEAT SOURCE, IT SEES ONLY THE
C                +X DIRECTION.
C     3RD TYPE : REAR   SIDE OF THE HEAT SOURCE, IT SEES ONLY THE
C                -Y DIRECTION.
C     4TH TYPE : FRONT  SIDE OF THE HEAT SOURCE, IT SEES ONLY THE
C                +Y DIRECTION.
C     5TH TYPE : BOTTOM SIDE OF THE HEAT SOURCE, IT SEES ONLY THE
C                -Z DIRECTION.
C     6TH TYPE : TOP    SIDE OF THE HEAT SOURCE, IT SEES ONLY THE
C                +Z DIRECTION.
C
C     FIRST, CALCULATE THE VIEW FACTOR BETWEEN EACH SIDE OF HEAT
C     SOURCE AND WALL SURFACE
C
C *** THE 1ST TYPE OF SURFACE
C
      IF(NN(1).EQ.0) GO TO 101
      MIIQ=MIIP
C
C ========================================================
C ** (A) LEFT SIDE OF THE HEAT SOURCE (HL) VS WALL SURFACE
C ========================================================
C
C       1.  HL  VS  L
C       2.  HL  VS  B
C       3.  HL  VS  T
C       4.  HL  VS  RE
C       5.  HL  VS  F
C * 1.  L  TO  HL
C
      GHZ=RX(MII)
      SH1=RY(MJJ)
      SH2=RY(MJJP)
      SV1=RZ(MKK)
      SV2=RZ(MKKP)
      DO 5 J=1,MJ
      DO 5 K=1,MK
```

```
      GH1 =RY(J)
      GH2 =RY(J+1)
      GV1 =RZ(K)
      GV2 =RZ(K+1)
      DDD =PARLEL(SH1,SH2,SV1,SV2,GV1,GV2,GH1,
     &     GH2,GHZ)*GHZ*GHZ
      VFLHL(J,K)=DDD /((GV2-GV1)*(GH2-GH1))
      VFHLL(J,K)=DDD /((SV2-SV1)*(SH2-SH1))
    5 CONTINUE
C
      WRITE(6,621)
  621 FORMAT(/,5X,'VFLHL(J,K),VFHLL,K=1,MK, J=    1,  MJ)',/)
      WRITE(6,602) (( J, K,VFLHL(J,K),VFHLL(J,K),K=1,MK),J=1,MJ)
  602 FORMAT(2I3,2E12.4)
C
C * 2.  B  TO  HL
C
      SH1=RZ(MKK)
      SH2=RZ(MKKP)
      SV1=RY(MJJ)
      SV2=RY(MJJP)
      DO 19 I=1,MIIM
      GH1=RX(MII)-RX(I+1)
      GH2=RX(MII)-RX(I)
      DO 19 J=1,MJ
      GV1=RY(J)
      GV2=RY(J+1)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFBHL(I,J)=DDD /((GV2-GV1)*(GH2-GH1))
      VFHLB(I,J)=DDD /((SV2-SV1)*(SH2-SH1))
   19 CONTINUE
C
      WRITE(6,623)
  623 FORMAT(/,5X,'VFBHL(I,J),VFHLB,J=1,  MJ, I=1,MIIM)',/)
      WRITE(6,602) (( I, J,VFBHL(I,J),VFHLB(I,J),J=1,MJ),I=1,MIIM)
C
C * 3.  T  TO  HL
C
      SH1=RZ(MKP)-RZ(MKKP)
      SH2=RZ(MKP)-RZ(MKK)
      SV1=RY(MJJ)
      SV2=RY(MJJP)
      DO 21 I=1,MIIM
      GH1=RX(MII)-RX(I+1)
      GH2=RX(MII)-RX(I)
      DO 21 J=1,MJ
      GV1=RY(J)
      GV2=RY(J+1)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFTHL(I,J)=DDD /((GV2-GV1)*(GH2-GH1))
      VFHLT(I,J)=DDD /((SV2-SV1)*(SH2-SH1))
   21 CONTINUE
C
      WRITE(6,625)
  625 FORMAT(/,5X,'VFTHL(I,J),VFHLT,J=1,MJ, I=1,MIIM)',/)
      WRITE(6,602) (( I, J,VFTHL(I,J),VFHLT(I,J),J=1,MJ),I=1,MIIM)
C
C * 4. RE  TO HL
C
      SH1=RY(MJJ)
      SH2=RY(MJJP)
      SV1=RZ(MKK)
      SV2=RZ(MKKP)
      DO 18 I=1,MIIM
      GH1=RX(MII)-RX(I+1)
      GH2=RX(MII)-RX(I)
      DO 18 K=1,MK
      GV1=RZ(K)
      GV2=RZ(K+1)
```

```
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFREHL(I,K)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHLRE(I,K)=DDD/((SV2-SV1)*(SH2-SH1))
   18 CONTINUE
C
      WRITE(6,627)
  627 FORMAT(/,5X,'VFREHL(I,K),K=1,MK, I=1,MIIM)',/)
      WRITE(6,602) (( I, K,VFREHL(I,K),VFHLRE(I,K),K=1,MK),I=1,MIIM)
C
C * 5. F TO HL
C
      SH1=RY(MJP)-RY(MJJP)
      SH2=RY(MJP)-RY(MJJ)
      SV1=RZ(MKK)
      SV2=RZ(MKKP)
      DO 22 I=1,MIIM
      GH1=RX(MII)-RX(I+1)
      GH2=RX(MII)-RX(I)
      DO 22 K=1,MK
      GV1=RZ(K)
      GV2=RZ(K+1)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFFHL(I,K)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHLF(I,K)=DDD/((SV2-SV1)*(SH2-SH1))
   22 CONTINUE
C
      WRITE(6,629)
  629 FORMAT(/,5X,'VFREHL(I,K),VFHLRE,K=1,MK, I=1,MIIM)',/)
      WRITE(6,602) (( I, K,VFREHL(I,K),VFHLRE(I,K),K=1,MK),I=1,MIIM)
C
C *** THE 2ND TYPE OF SURFACE
C
  101 CONTINUE
      IF(NN(2).EQ.0) GO TO 102
      MIIQ=MII+IP
C
C ==============================================================
C ** (B) RIGHT SIDE OF THE HEAT SOURCE (HR) VS WALL SURFACE
C ==============================================================
C
C        1.  HR  VS  RE
C        2.  HR  VS  B
C        3.  HR  VS  T
C        4.  HR  VS  F
C        5.  HR  VS  R
C * 1. RE TO HR
C
      SH1=RY(MJJ)
      SH2=RY(MJJP)
      SV1=RZ(MKK)
      SV2=RZ(MKKP)
      DO 24 I=MIIQ,MI
      GH1=RX(I)-RX(MIIQ)
      GH2=RX(I+1)-RX(MIIQ)
      DO 24 K=1,MK
      GV1=RZ(K)
      GV2=RZ(K+1)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFREHR(I,K)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHRRE(I,K)=DDD/((SV2-SV1)*(SH2-SH1))
   24 CONTINUE
C
      WRITE(6,631)
  631 FORMAT(/,5X,'VFREHR(I,K),VFHRRE,K=1,MK,I=MIIP,MI)',/)
      WRITE(6,602) (( I, K,VFREHR(I,K),VFHRRE(I,K),K=1,MK),I=MIIQ,MI)
C
C * 2. B TO HR
C
      SH1=RZ(MKK)
```

```
      SH2=RZ(MKKP)
      SV1=RY(MJJ)
      SV2=RY(MJJP)
      DO 20 I=MIIQ,MI
      GH1=RX(I)-RX(MIIQ)
      GH2=RX(I+1)-RX(MIIQ)
      DO 20 J=1,MJ
      GV1=RY(J)
      GV2=RY(J+1)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFBHR(I,J)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHRB(I,J)=DDD/((SV2-SV1)*(SH2-SH1))
   20 CONTINUE
C
      WRITE(6,633)
  633 FORMAT(/,5X,'VFBHR(I,J),VFHRB,J=1,MJ,I=MIIP,MI)',/)
      WRITE(6,602) (( I, J,VFBHR(I,J),VFHRB(I,J),J=1,MJ),I=MIIQ,MI)
C
C * 3. T TO HR
C
      SH1=RZ(MKP)-RZ(MKKP)
      SH2=RZ(MKP)-RZ(MKK)
      SV1=RY(MJJ)
      SV2=RY(MJJP)
      DO 23 I=MIIQ,MI
      GH1=RX(I)-RX(MIIQ)
      GH2=RX(I+1)-RX(MIIQ)
      DO 23 J=1,MJ
      GV1=RY(J)
      GV2=RY(J+1)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFTHR(I,J)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHRT(I,J)=DDD/((SV2-SV1)*(SH2-SH1))
   23 CONTINUE
C
      WRITE(6,635)
  635 FORMAT(/,5X,'VFTHR(I,J),VFHRT,J=1,MJ,I=MIIP,MI)',/)
      WRITE(6,602) (( I, J,VFTHR(I,J),VFHRT(I,J),J=1,MJ),I=MIIQ,MI)
C
C * 4. F TO HR
C
      SH1=RY(MJP)-RY(MJJP)
      SH2=RY(MJP)-RY(MJJ)
      SV1=RZ(MKK)
      SV2=RZ(MKKP)
      DO 25 I=MIIQ,MI
      GH1=RX(I)-RX(MIIQ)
      GH2=RX(I+1)-RX(MIIQ)
      DO 25 K=1,MK
      GV1=RZ(K)
      GV2=RZ(K+1)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFFHR(I,K)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHRF(I,K)=DDD/((SV2-SV1)*(SH2-SH1))
   25 CONTINUE
C
      WRITE(6,637)
  637 FORMAT(/,5X,'VFFHR(I,K),VFHRF,K=1,MK,I=MIIP,MI)',/)
      WRITE(6,602) (( I, K,VFFHR(I,K),VFHRF(I,K),K=1,MK),I=MIIQ,MI)
C
C * 5. R TO HR
C
      GHZ=RX(MIP)-RX(MIIQ)
      SH1=RY(MJJ)
      SH2=RY(MJJP)
      SV1=RZ(MKK)
      SV2=RZ(MKKP)
      DO 6 J=1,MJ
      DO 6 K=1,MK
```

```
      GH1 =RY(J)
      GH2 =RY(J+1)
      GV1 =RZ(K)
      GV2 =RZ(K+1)
      DDD=PARLEL(SH1,SH2,SV1,SV2,GV1,GV2,GH1,
     &    GH2,GHZ)*GHZ*GHZ
      VFRHR(J,K)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHRR(J,K)=DDD/((SV2-SV1)*(SH2-SH1))
    6 CONTINUE
C
      WRITE(6,639)
  639 FORMAT(/,5X,'VFRHR(J,K),VFHRR,K=1,MK,J=1,  MJ)',/)
      WRITE(6,602) (( J, K,VFRHR(J,K),VFHRR(J,K),K=1,MK),J=1,MJ)
C
C *** THE 3RD TYPE SURFACE
C
  102 CONTINUE
      IF(NN(3).EQ.0) GO TO 103
      MJJQ=MJJP
C
C ==============================================================
C ** (C) REAR SIDE OF THE HEAT SOURCE (HRE) VS WALL SURFACE
C ==============================================================
C
C         1. HRE VS  RE
C         2. HRE VS  L
C         3. HRE VS  R
C         4. HRE VS  B
C         4. HRE VS  T
C * 1. RE TO HRE
C
      GHZ=RY(MJJ)
      SH1=RZ(MKK)
      SH2=RZ(MKKP)
      SV1=RX(MII)
      SV2=RX(MIIP)
      DO 7 I=1,MI
      DO 7 K=1,MK
      GV1 =RX(I)
      GV2 =RX(I+1)
      GH1 =RZ(K)
      GH2 =RZ(K+1)
      DDD=PARLEL(SH1,SH2,SV1,SV2,GV1,GV2,GH1,
     &     GH2,GHZ)*GHZ*GHZ
      VREHRE(I,K)=DDD/((GV2-GV1)*(GH2-GH1))
      VHRERE(I,K)=DDD/((SV2-SV1)*(SH2-SH1))
    7 CONTINUE
C
      WRITE(6,641)
  641 FORMAT(/,5X,'VREHRE(I,K),VHRERE,K=1,MK,I= 1,MI)',/)
      WRITE(6,602) (( I, K,VREHRE(I,K),VHRERE(I,K),K=1,MK),I=1,MI)
C
C * 2. L TO HRE
C
      SH1=RX(MII)
      SH2=RX(MIIP)
      SV1=RZ(MKK)
      SV2=RZ(MKKP)
      DO 26 J=1,MJJM
      GH1=RY(MJJ)-RY(J+1)
      GH2=RY(MJJ)-RY(J)
      DO 26 K=1,MK
      GV1=RZ(K)
      GV2=RZ(K+1)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFLHRE(J,K)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHREL(J,K)=DDD/((SV2-SV1)*(SH2-SH1))
   26 CONTINUE
C
```

```
      WRITE(6,643)
  643 FORMAT(/,5X,'VFLHRE( J, K),VFHREL,K=1,MK,J=1,MJJM)',/)
      WRITE(6,602) (( J, K,VFLHRE(J,K),VFHREL(J,K),K=1,MK),J=1,MJJM)
C
C * 3. R TO HRE
C
      SH1=RX(MIP)-RX(MIIP)
      SH2=RX(MIP)-RX(MII)
      SV1=RZ(MKK)
      SV2=RZ(MKKP)
      DO 27 J=1,MJJM
      GH1=RY(MJJ)-RY(J+1)
      GH2=RY(MJJ)-RY(J)
      DO 27 K=1,MK
      GV1=RZ(K)
      GV2=RZ(K+1)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFRHRE(J,K)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHRER(J,K)=DDD/((SV2-SV1)*(SH2-SH1))
   27 CONTINUE
C
      WRITE(6,645)
  645 FORMAT(/,5X,'VFRHRE(J,K),VFHRER,K=1,MK,J=1,MJJM)',/)
      WRITE(6,602) (( J, K,VFRHRE(J,K),VFHRER(J,K),K=1,MK),J=1,MJJM)
C
C * 4. B TO HRE
C
      SH1=RZ(MKK)
      SH2=RZ(MKKP)
      SV1=RX(MII)
      SV2=RX(MIIP)
      DO 28 J=1,MJJM
      GH1=RY(MJJ)-RY(J+1)
      GH2=RY(MJJ)-RY(J)
      DO 28 I=1,MI
      GV1=RX(I)
      GV2=RX(I+1)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFBHRE(I,J)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHREB(I,J)=DDD/((SV2-SV1)*(SH2-SH1))
   28 CONTINUE
C
      WRITE(6,647)
  647 FORMAT(/,5X,'VFBHRE(I,J),VFHREB,J=1,MJJM,I=1,MI)',/)
      WRITE(6,602) (( I, J,VFBHRE(I,J),VFHREB(I,J),J=1,MJJM),I=1,MI)
C
C * 5. T TO HRE
C
      SH1=RZ(MKP)-RZ(MKKP)
      SH2=RZ(MKP)-RZ(MKK)
      SV1=RX(MII)
      SV2=RX(MIIP)
      DO 29 J=1,MJJM
      GH1=RY(MJJ)-RY(J+1)
      GH2=RY(MJJ)-RY(J)
      DO 29 I=1,MI
      GV1=RX(I)
      GV2=RX(I+1)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFTHRE(I,J)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHRET(I,J)=DDD/((SV2-SV1)*(SH2-SH1))
   29 CONTINUE
C
      WRITE(6,649)
  649 FORMAT(/,5X,'VFTHRE(I,J),VFHRET,J=1,MJJM,I=1,MI)',/)
      WRITE(6,602) (( I, J,VFTHRE(I,J),VFHRET(I,J),J=1,MJJM),I=1,MI)
C
C *** THE 4TH TYPE SURFACE
C
```

```
  103 CONTINUE
      IF(NN(4).EQ.0) GO TO 104
      MJJQ=MJJ+JP
C
C ========================================================
C ** (D) FRONT SIDE OF THE HEAT SOURCE (HF) VS WALL SURFACE
C ========================================================
C
C       1.  HF  VS  F
C       2.  HF  VS  L
C       3.  HF  VS  R
C       4.  HF  VS  B
C       5.  HF  VS  T
C * 1. F TO HF
C
      GHZ=RY(MJP)-RY(MJJQ)
      SH1=RZ(MKK)
      SH2=RZ(MKKP)
      SV1=RX(MII)
      SV2=RX(MIIP)
      DO 8 I=1,MI
      DO 8 K=1,MK
      GH1 =RZ(K)
      GH2 =RZ(K+1)
      GV1 =RX(I)
      GV2 =RX(I+1)
      DDD=PARLEL(SH1,SH2,SV1,SV2,GV1,GV2,GH1,
     &    GH2,GHZ)*GHZ*GHZ
      VFFHF(I,K)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHFF(I,K)=DDD/((GV2-GV1)*(GH2-GH1))
    8 CONTINUE
C
      WRITE(6,651)
  651 FORMAT(/,5X,'VFFHF(I,K),VFHFF,K=1,MK,I=1,MI)',/)
      WRITE(6,602) (( I, K,VFFHF(I,K),VFHFF(I,K),K=1,MK),I=1,MI)
C
C * 2. L TO HF
C
      SH1=RX(MII)
      SH2=RX(MIIP)
      SV1=RZ(MKK)
      SV2=RZ(MKKP)
      DO 30 J=MJJQ,MJ
      GH1=RY(J)-RY(MJJQ)
      GH2=RY(J+1)-RY(MJJQ)
      DO 30 K=1,MK
      GV1=RZ(K)
      GV2=RZ(K+1)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFLHF(J,K)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHFL(J,K)=DDD/((SV2-SV1)*(SH2-SH1))
   30 CONTINUE
C
      WRITE(6,653)
  653 FORMAT(/,5X,'VFLHF(J,K),VFHFL,K=1,MK,J=MJJP,MJ)',/)
      WRITE(6,602) (( J, K,VFLHF(J,K),VFHFL(J,K),K=1,MK),J=MJJQ,MJ)
C
C * 3. R TO HF
C
      SH1=RX(MIP)-RX(MIIP)
      SH2=RX(MIP)-RX(MII)
      SV1=RZ(MKK)
      SV2=RZ(MKKP)
      DO 31 J=MJJQ,MJ
      GH1=RY(J)-RY(MJJQ)
      GH2=RY(J+1)-RY(MJJQ)
      DO 31 K=1,MK
      GV1=RZ(K)
      GV2=RZ(K+1)
```

```
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFRHF(J,K)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHFR(J,K)=DDD/((SV2-SV1)*(SH2-SH1))
   31 CONTINUE
C
      WRITE(6,655)
  655 FORMAT(/,5X,'VFRHF(J,K),VFHFR,K=1,MK,J=MJJP,MJ)',/)
      WRITE(6,602) (( J, K,VFRHF(J,K),VFHFR(J,K),K=1,MK),J=MJJQ,MJ)
C
C * 4. B TO HF
C
      SH1=RZ(MKK)
      SH2=RZ(MKKP)
      SV1=RX(MII)
      SV2=RX(MIIP)
      DO 32 J=MJJQ,MJ
      GH1=RY(J)-RY(MJJQ)
      GH2=RY(J+1)-RY(MJJQ)
      DO 32 I=1,MI
      GV1=RX(I)
      GV2=RX(I+1)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFBHF(I,J)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHFB(I,J)=DDD/((SV2-SV1)*(SH2-SH1))
   32 CONTINUE
C
      WRITE(6,657)
  657 FORMAT(/,5X,'VFBHF(I,J),VFHFB,J=MJJP,MJ,I=1,MI)',/)
      WRITE(6,602) (( I, J,VFBHF(I,J),VFHFB(I,J),J=MJJQ,MJ),I=1,MI)
C
C * 5. T TO HF
C
      SH1=RZ(MKP)-RZ(MKKP)
      SH2=RZ(MKP)-RZ(MKK)
      SV1=RX(MII)
      SV2=RX(MIIP)
      DO 33 J=MJJQ,MJ
      GH1=RY(J)-RY(MJJQ)
      GH2=RY(J+1)-RY(MJJQ)
      DO 33 I=1,MI
      GV1=RX(I)
      GV2=RX(I+1)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFTHF(I,J)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHFT(I,J)=DDD/((SV2-SV1)*(SH2-SH1))
   33 CONTINUE
C
      WRITE(6,659)
  659 FORMAT(/,5X,'VFTHF(I,J),VFHFT,J=MJJP,MJ,I=1,  MI)',/)
      WRITE(6,602) (( I, J,VFTHF(I,J),VFHFT(I,J),J=MJJQ,MJ),I=1,MI)
C
C *** THE 5TH TYPE SURFACE
C
  104 CONTINUE
      IF(NN(5).EQ.0) GO TO 105
      MKKQ=MKKP
C
C =========================================================
C * (E) BOTTOM SIDE OF THE HEAT SOURCE (HB) VS WALL SURFACE
C =========================================================
C       1.  HB  VS  RE
C       2.  HB  VS  F
C       3.  HB  VS  R
C       4.  HB  VS  L
C       5.  HB  VS  B
C * 1. RE TO HB
C
      SH1=RY(MJJ)
      SH2=RY(MJJP)
```

```
      SV1=RX(MII)
      SV2=RX(MIIP)
      DO 17 I=1,MI
      DO 17 K=1,MKKM
      GV1 =RX(I)
      GV2 =RX(I+1)
      GH1=RZ(MKK)-RZ(K+1)
      GH2=RZ(MKK)-RZ(K)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFREHB(I,K)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHBRE(I,K)=DDD/((SV2-SV1)*(SH2-SH1))
   17 CONTINUE
C
      WRITE(6,611)
  611 FORMAT(/,5X,'VFREHB(I,K),VFHBRE,K=1,MKKM,I=    1,  MI)',/)
      WRITE(6,602) (( I, K,VFREHB(I,K),VFHBRE(I,K),K=1,MKKM),I=1,MI)
C
C * 2. F TO HB
C
      SH1=RY(MJP)-RY(MJJP)
      SH2=RY(MJP)-RY(MJJ)
      SV1=RX(MII)
      SV2=RX(MIIP)
      DO 15 I=1,MI
      DO 15 K=1,MKKM
      GV1=RX(I)
      GV2=RX(I+1)
      GH1=RZ(MKK)-RZ(K+1)
      GH2=RZ(MKK)-RZ(K)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFFHB(I,K)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHBF(I,K)=DDD/((SV2-SV1)*(SH2-SH1))
   15 CONTINUE
C
      WRITE(6,613)
  613 FORMAT(/,5X,'VFFHB ( I, K),VFHBF, K=1,MKKM,I=1,MI)',/)
      WRITE(6,602) (( I, K,VFFHB(I,K),VFHBF(I,K),K=1,MKKM),I=1,MI)
C
C *  3.  R TO HB
C
      SH1=RX(MIP)-RX(MIIP)
      SH2=RX(MIP)-RX(MII)
      SV1=RY(MJJ)
      SV2=RY(MJJP)
      DO 13 J=1,MJ
      DO 13 K=1,MKKM
      GV1 =RY(J)
      GV2 =RY(J+1)
      GH1=RZ(MKK)-RZ(K+1)
      GH2=RZ(MKK)-RZ(K)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFRHB(J,K)=DDD /((GV2-GV1)*(GH2-GH1))
      VFHBR(J,K)=DDD /((SV2-SV1)*(SH2-SH1))
   13 CONTINUE
C
      WRITE(6,615)
  615 FORMAT(/,5X,'VFRHB(J,K),VFHBR,K=1,MKKM,J=1,  MJ)',/)
      WRITE(6,602) (( J, K,VFRHB(J,K),VFHBR(J,K),K=1,MKKM),J=1,MJ)
C
C * 4.  L  TO  HB
C
      SH1=RX(MII)
      SH2=RX(MIIP)
      SV1=RY(MJJ)
      SV2=RY(MJJP)
      DO 11 J=1,MJ
      DO 11 K=1,MKKM
      GV1=RY(J)
      GV2=RY(J+1)
```

```
      GH1=RZ(MKK)-RZ(K+1)
      GH2=RZ(MKK)-RZ(K)
      DDD=PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFLHB(J,K)=DDD /((GV2-GV1)*(GH2-GH1))
      VFHBL(J,K)=DDD /((SV2-SV1)*(SH2-SH1))
   11 CONTINUE
C
      WRITE(6,617)
  617 FORMAT(/,5X,'VFLHB(J,K),VFHBL,K=1,MKKM, J=   1,  MJ)',/)
      WRITE(6,602) (( J, K,VFLHB(J,K),VFHBL(J,K),K=1,MKKM),J=1,MJ)
C
C * 5.  B  TO  HB
C
      GHZ=RZ(MKK)
      SH1=RX(MII)
      SH2=RX(MIIP)
      SV1=RY(MJJ)
      SV2=RY(MJJP)
      DO 9 I=1,MI
      DO 9 J=1,MJ
      GH1 =RX(I)
      GH2 =RX(I+1)
      GV1 =RY(J)
      GV2 =RY(J+1)
      DDD =PARLEL(SH1,SH2,SV1,SV2,GV1,GV2,GH1,
     &     GH2,GHZ)*GHZ*GHZ
      VFBHB(I,J)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHBB(I,J)=DDD/((SV2-SV1)*(SH2-SH1))
    9 CONTINUE
C
      WRITE(6,619)
  619 FORMAT(/,5X,'VFBHB(I,J),VFHBB,J=1,MJ, I=   1,  MI)',/)
      WRITE(6,602) (( I, J,VFBHB(I,J),VFHBB(I,J),J=1,MJ),I=1,MI)
C
C *** THE 6TH TYPE OF SURFACE
C
  105 CONTINUE
      IF(NN(6).EQ.0) GO TO 106
      MKKQ=MKK+KP
C
C ==========================================================
C *** (F) TOP SIDE OF HEAT SOURCE (HT) VS WALL SURFACE
C ==========================================================
C         1.  HT  VS  L
C         2.  HT  VS  R
C         3.  HT  VS  F
C         4.  HT  VS  RE
C         5.  HT  VS  T
C * 1.  L TO HT
C
      SH1=RX(MII)
      SH2=RX(MIIP)
      SV1=RY(MJJ)
      SV2=RY(MJJP)
      DO 4 J=1,MJ
      DO 4 K=MKKQ,MK
      GV1 =RY(J)
      GV2 =RY(J+1)
      GH1 =RZ(K)-RZ(MKKQ)
      GH2 =RZ(K+1)-RZ(MKKQ)
      DDD =PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFLHT(J,K)=DDD /((GV2-GV1)*(GH2-GH1))
      VFHTL(J,K)=DDD /((SV2-SV1)*(SH2-SH1))
    4 CONTINUE
C
      WRITE(6,601)
  601 FORMAT(/,5X,'VFLHT ( J, K),VFHTL, K=MKKP,  MK, J=   1,  MJ)',/)
      WRITE(6,602) (( J, K,VFLHT(J,K),VFHTL(J,K),K=MKKQ,MK), J= 1,MJ)
C
```

```
C * 2. R TO HT
C
      SH1=RX(MIP)-RX(MIIP)
      SH2=RX(MIP)-RX(MII)
      SV1=RY(MJJ)
      SV2=RY(MJJP)
      DO 12 J=1,MJ
      DO 12 K=MKKQ,MK
      GV1 =RY(J)
      GV2 =RY(J+1)
      GH1 =RZ(K)-RZ(MKKQ)
      GH2 =RZ(K+1)-RZ(MKKQ)
      DDD =PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFRHT(J,K)=DDD /((GV2-GV1)*(GH2-GH1))
      VFHTR(J,K)=DDD /((SV2-SV1)*(SH2-SH1))
   12 CONTINUE
C
      WRITE(6,603)
  603 FORMAT(/,5X,'VFRHT ( J, K),VFHTR, K=MKKP,  MK, J=   1,  MJ)',/)
      WRITE(6,602) (( J, K,VFRHT(J,K),VFHTR(J,K),K=MKKQ,MK), J=1,MJ)
C
C * 3. F TO HT
C
      SH1=RY(MJP)-RY(MJJP)
      SH2=RY(MJP)-RY(MJJ)
      SV1=RX(MII)
      SV2=RX(MIIP)
      DO 14 I=1,MI
      DO 14 K=MKKQ,MK
      GV1 =RX(I)
      GV2 =RX(I+1)
      GH1 =RZ(K)-RZ(MKKQ)
      GH2 =RZ(K+1)-RZ(MKKQ)
      DDD =PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFFHT(I,K)=DDD /((GV2-GV1)*(GH2-GH1))
      VFHTF(I,K)=DDD /((SV2-SV1)*(SH2-SH1))
   14 CONTINUE
C
      WRITE(6,605)
  605 FORMAT(/,5X,'VFFHT(I,K),VFHTF,K=MKKP,MK, I=   1, .MI)',/)
      WRITE(6,602) (( I, K,VFFHT(I,K),VFHTF(I,K),K=MKKQ,MK), I=1,MI)
C
C * 4. RE TO HT
C
      SH1=RY(MJJ)
      SH2=RY(MJJP)
      SV1=RX(MII)
      SV2=RX(MIIP)
      DO 16 I=1,MI
      DO 16 K=MKKQ,MK
      GV1 =RX(I)
      GV2 =RX(I+1)
      GH1 =RZ(K)-RZ(MKKQ)
      GH2 =RZ(K+1)-RZ(MKKQ)
      DDD =PERPND(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2)
      VFREHT(I,K)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHTRE(I,K)=DDD/((SV2-SV1)*(SH2-SH1))
   16 CONTINUE
C
      WRITE(6,607)
  607 FORMAT(/,5X,'VFREHT(I,K),VFHTRE,K=MKKP,MK,I=1,  MI)',/)
      WRITE(6,602) (( I, K,VFREHT(I,K),VFHTRE(I,K),K=MKKQ,MK),I=1,MI)
C
C * 5. T TO HT
C
      GHZ=RZ(MKP)-RZ(MKKQ)
      SH1=RX(MII)
      SH2=RX(MIIP)
      SV1=RY(MJJ)
```

```
      SV2=RY(MJJP)
      DO 10 I=1,MI
      DO 10 J=1,MJ
      GH1 =RX(I)
      GH2 =RX(I+1)
      GV1 =RY(J)
      GV2 =RY(J+1)
      DDD =PARLEL(SH1,SH2,SV1,SV2,GV1,GV2,GH1,GH2,GHZ)
     &     *GHZ*GHZ
      VFTHT(I,J)=DDD/((GV2-GV1)*(GH2-GH1))
      VFHTT(I,J)=DDD/((SV2-SV1)*(SH2-SH1))
   10 CONTINUE
C
      WRITE(6,609)
  609 FORMAT(/,5X,'VFTHT(I,J),VFHTT,J=1,  MJ, I=  1,  MI)',/)
      WRITE(6,602) (( I, J,VFTHT(I,J),VFHTT(I,J),J=1,MJ),I=1,MI)
  106 CONTINUE
C
C
C ****************************************************************
C *** THE SECOND STEP IS TO TREAT ALL THE HEAT SOURCE SURFACE TO BE
C     ONE RADIATION EXCHANGE WALL ZONE
C *****************************************************************
C
C *** SUM THEM UP TO GET THE REAL VIEW FACTORS BETWEEN THE HEAT SOURCE
C     AND THE WALL ZONES
C
C ** SVFHSW: SUMMATION OF VIEW FACTOR FROM HEAT SOURCE TO ALL WALL ZONES
C ** SVFWHS: SUMMATION OF VIEW FACTOR FROM ALL WALL ZONES TO HEAT SOURCE
C
      SVFWHS=0.
      SVFHSW=0.
C
      DO 201 J=1,MJ
      DO 201 K=1,MK
C ** 2 VERTICAL WALLS TO HEAT SOURCE
      VFRHS(J,K)=VFRHF(J,K)+VFRHRE(J,K)+VFRHR(J,K)+VFRHT(J,K)+VFRHB(J,K)
      VFLHS(J,K)=VFLHF(J,K)+VFLHRE(J,K)+VFLHL(J,K)+VFLHT(J,K)+VFLHB(J,K)
      SVFWHS    =SVFWHS+VFRHS(J,K)+VFLHS(J,K)
C ** HEAT SOURCE TO 2 VERTICAL TANK WALLS
      VFHSR(J,K)=VFHFR(J,K)+VFHRER(J,K)
     &     +VFHRR(J,K)+VFHTR (J,K)+VFHBR(J,K)
      VFHSL(J,K)=VFHFL(J,K)+VFHREL(J,K)
     &     +VFHLL(J,K)+VFHTL (J,K)+VFHBL(J,K)
      SVFHSW    =SVFHSW+VFHSR(J,K)+VFHSL(J,K)
  201 CONTINUE
      DO 203 I=1,MI
      DO 203 K=1,MK
C ** 2 VERTICAL WALLS TO HEAT SOURCE
      VFREHS(I,K)=VFREHL(I,K)+VREHRE(I,K)+VFREHR(I,K)+VFREHT(I,K)
     &            +VFREHB(I,K)
      VFFHS(I,K) =VFFHF(I,K)+VFFHL(I,K)+VFFHR(I,K)+VFFHT(I,K)+VFFHB(I,K)
      SVFWHS     =SVFWHS+VFREHS(I,K)+VFFHS(I,K)
C ** HEAT SOURCE TO 2 VERTICAL TANK WALLS
      VFHSRE(I,K)=VFHLRE(I,K)+VHRERE(I,K)
     &      +VFHRRE(I,K)+VFHTRE(I,K)+VFHBRE(I,K)
      VFHSF(I,K) =VFHFF(I,K)+VFHLF(I,K)
     &      +VFHRF(I,K)+VFHTF(I,K)+VFHBF(I,K)
      SVFHSW     =SVFHSW+VFHSRE(I,K)+VFHSF(I,K)
  203 CONTINUE
C
      DO 202 I=1,MI
      DO 202 J=1,MJ
C ** 2 HORIZONTAL WALLS TO HEAT SOURCE
      VFTHS(I,J)=VFTHF(I,J)+VFTHT(I,J)+VFTHL(I,J)+VFTHRE(I,J)+VFTHR(I,J)
      VFBHS(I,J)=VFBHB(I,J)+VFBHRE(I,J)+VFBHF(I,J)+VFBHL(I,J)+VFBHR(I,J)
      SVFWHS    =SVFWHS+VFTHS(I,J)+VFBHS(I,J)
C ** HEAT SOURCE TO 2 HORIZONTAL WALLS
      VFHST(I,J)=VFHFT(I,J)+VFHTT(I,J)
```

```
     &      +VFHLT(I,J)+VFHRET(I,J)+VFHRT(I,J)
      VFHSB(I,J)=VFHBB(I,J)+VFHREB(I,J)
     &      +VFHFB(I,J)+VFHLB(I,J)+VFHRB(I,J)
      SVFHSW    =SVFHSW+VFHSB(I,J)+VFHST(I,J)
 202 CONTINUE
C
C *** PRINT OUT THE VIEW FACTORS
C
      WRITE(6,554) SVFHSW,SVFWHS
 554 FORMAT(/,'  SUMMATION OF VIEW FACTORS FROM  ALL HEAT SOURCE',
     & ' SURFACES TO ALL INTERIOR WALLS, SVFHSW =',E11.4,/,
     &         '  SUMMATION OF VIEW FACTORS FROM  ALL INTERIOR WALLS',
     & ' TO ALL HEAT SOURCE SURFACES    , SVFWHS =',E11.4,/)
C
      DO 34 J=1,MJ
      WRITE(6,35) J
  35 FORMAT(/,2X,'J=',I2,3X,'VFHSL ',5X,'VFHSR ',5X,
     & 'VFLHS ',5X,'VFRHS ',/)
      DO 34 K=1,MK
      WRITE(6,36)K,VFHSL(J,K),VFHSR(J,K),VFLHS(J,K),VFRHS(J,K)
  36 FORMAT(2X,'K=',I2, 4(1X,E10.4))
  34 CONTINUE
      DO 37 I=1,MI
      WRITE(6,38) I
  38 FORMAT(/,2X,'I=',I2,3X,'VFHSF ',5X,
     & 'VFHSRE',5X,'VFFHS ',5X,'VFREHS',/)
      DO 37 K=1,MK
      WRITE(6,39)K,VFHSF(I,K),VFHSRE(I,K),VFFHS(I,K),VFREHS(I,K)
  39 FORMAT(2X,'K=',I2, 4(1X,E10.4))
  37 CONTINUE
C
      DO 40 I=1,MI
      WRITE(6,42) I
  42 FORMAT(/,2X,'I=',I2,3X,'VFHST ',5X,'VFHSB ',5X,'VFTHS ',5X,
     &   'VFBHS',/)
      DO 40 J=1,MJ
      WRITE(6,41)J,VFHST(I,J),VFHSB(I,J),VFTHS(I,J),VFBHS(I,J)
  41 FORMAT(2X,'J=',I2,4(1X,E10.4))
  40 CONTINUE
C
      RETURN
      END
C
C ********************************************************************
C
      FUNCTION PERPND(GX1,GX2,GY1,GY2,GV1,GV2,GH1,GH2)
C     IMPLICIT REAL*8(A-H,O-Z)
C
      DIMENSION GX(2),GY(2),GV(2),GH(2)
C
C *** THIS FUNCTION IS USED TO CALCULATE THE VIEW FACTOR BETWEEN
C     TWO PERPENDICULAR RECTANGULAR SURFACES
C
      PERPND =0.
      IF(GX1.LT.1.E-10.AND. GH1.LT.1.E-10 .AND. GY1.EQ.GV1) GO TO 11
C
      GX(1)=GX1
      GX(2)=GX2
      GY(1)=GY1
      GY(2)=GY2
      GV(1)=GV1
      GV(2)=GV2
      GH(1)=GH1
      GH(2)=GH2
      DO 4 L=1,2
      DO 4 I=1,2
      DO 4 J=1,2
      DO 4 K=1,2
      BJK=GY(J)-GV(K)
```

```
      BJK2=BJK*BJK
      ALI=SQRT(GH(L)*GH(L)+GX(I)*GX(I))
      ALI2=ALI*ALI
      ABSQ=SQRT(ALI2+BJK2)
      IF(ABSQ.EQ.0.)GO TO 10
      CCC=ALOG(ABSQ)
      GO TO 18
   10 CCC=0.
   18 CONTINUE
      ICOEF=I+J+K+L
      IF(ALI.EQ.0.)GO TO 7
      DDD= ALI2*ALOG(ALI)
      BBB=ALI*ATAN(BJK/ALI)
      GO TO 8
    7 DDD=0.
      BBB=0.
    8 CONTINUE
      PERPND =PERPND +((-1.)**ICOEF)*(BJK*BBB-.5*(ALI2-
     &  BJK2)*CCC  +.5* DDD)/6.283
    4 CONTINUE
      GO TO 12
   11 CONTINUE
C
      W=GX2-GX1
      DL=GY2-GY1
      H=GH2-GH1
      W=W/DL
      H=H/DL
      W2=W*W
      H2=H*H
      W2P1=1.+W2
      H2P1=1.+H2
      W2H2=W2+H2
      W2H2P1=1.+W2+H2
      XXX=(W2*W2H2P1/(W2P1*W2H2))**W2
      YYY=(H2*W2H2P1/(H2P1*W2H2))**H2
      PERPND=(W*ATAN(1./W)+H*ATAN(1./H)-SQRT(W2H2)*
     &       ATAN(1./SQRT(W2H2))+.25*ALOG(W2P1*H2P1/W2H2P1*XXX*YYY))
     &       *DL*DL/3.14159
 12   CONTINUE
C
      RETURN
      END
C ********************************************************************
C
      FUNCTION PARLEL(XH1,XH2,YV1,YV2,GV1,GV2,GH1,GH2,GHZ)
C     IMPLICIT REAL*8(A-H,O-Z)
C
      DIMENSION GX(2),GY(2),GV(2),GH(2)
C
C *** THIS FUNCTION IS USED TO CALCULATE THE VIEW FACTOR BETWEEN
C     TWO PARALLEL RECTANGVE SURFACES
C
      PARLEL=0.
      IF(XH1.EQ.GV1 .AND. YV1.EQ.GH1) GO TO 11
C
      GX(1)=XH1/GHZ
      GX(2)=XH2/GHZ
      GY(1)=YV1/GHZ
      GY(2)=YV2/GHZ
      GV(1)=GV1/GHZ
      GV(2)=GV2/GHZ
      GH(1)=GH1/GHZ
      GH(2)=GH2/GHZ
      DO 1 L=1,2
      DO 1 K=1,2
      DO 1 J=1,2
      DO 1 I=1,2
      ALI=GH(L)-GX(I)
```

```
      BKJ=GV(K)-GY(J)
      ALI2=ALI*ALI
      BKJ2=BKJ*BKJ
      SBKJ=SQRT(1.+BKJ2)
      SALI=SQRT(1.+ALI2)
      ALAB2=0.5*ALOG(1.+ALI2+BKJ2)
      AAA=ALOG(SALI)
      ICOEF=I+J+K+L
      PARLEL=PARLEL+((-1.)**ICOEF)*(ALI*SBKJ*ATAN(ALI/SBKJ)
     &       -BKJ*ATAN(BKJ)+SALI*BKJ*ATAN(BKJ/SALI)
     &       -ALI*ATAN(ALI)+AAA+ALOG(SBKJ)-ALAB2)/6.28
    1 CONTINUE
      GO TO 12
C
 11   CONTINUE
      X=(XH2-XH1)/GHZ
      Y=(YV2-YV1)/GHZ
      X2=X*X
      Y2=Y*Y
      X2P1=1.+X2
      Y2P1=1.+Y2
      X2Y2=X2+Y2
      X2Y2P1=1.+X2Y2
      PARLEL=(ALOG(SQRT(X2P1*Y2P1/X2Y2P1))+X*SQRT(Y2P1)
     &       *ATAN(X/SQRT(Y2P1))+Y*SQRT(X2P1)*ATAN(Y/SQRT(X2P1))
     &       -X*ATAN(X)-Y*ATAN(Y))*2./3.14159
   12 CONTINUE
C
      RETURN
      END
      BLOCK DATA
C ****************************************************************
C
      COMMON/BL11/ MIIZ(9),MJJZ(9),MKKZ(9),IS(6),LTYPE(9,6),
     &             LI(9),LJ(9),LK(9),AYZ(9),AXY(9),AZX(9),
     &             NHSZ,ITHIN(9),JTHIN(9),KTHIN(9),
     &             IHSB(9),NHSW(9),JHSB(9),NHSD(9),KHSB(9),NHSH(9)
C
      DATA MIIZ/9*0/, MJJZ/9*0/, MKKZ/9*0/, IS/6*0/, LTYPE/54*0/
      DATA ITHIN/9*1/, JTHIN/9*1/, KTHIN/9*1/, NHSZ/9/
C
      END
```

APPENDIX C

FORTRAN LISTING OF THE RECTANGULAR NUMERICAL MODEL OF FIRE I

```
C     ****************************************************************
C     **                                                            **
C     **      THREE-DIMENSIONAL NUMERICAL SIMULATION                **
C     **     OF A FIRE SPREAD INSIDE A NAVY STORAGE TANK            **
C     **                                                            **
C     **                   DEVELOPED BY :                           **
C     **          K.V. LIU, K.T. YANG, G.F. NIES                    **
C     **                                                            **
C     **    DEPARTMENT OF AEROSPACE & MECHANICAL ENGINEERING        **
C     **              UNIVERSITY OF NOTRE DAME                      **
C     **             NOTRE DAME, INDIANA, 46556                     **
C     **                                                            **
C     **                        AND                                 **
C     **                                                            **
C     **        DEPARTMENT OF MECHANICAL ENGINEERING                **
C     **            U.S. naval postgraduate school                  **
C     **             Monterey, california 93940                     **
C     **                                                            **
C     **                                                            **
C     **                   DEC. 1986                                **
C     **                                                            **
C     ****************************************************************
C
      COMMON /BL1/BUOY,VISL,VOL,VOLDT,KBOUND,DTIME,NTREAL,SORSUM,NWRITE
      COMMON /BL2/ DX,DY,DZ,DXY,DYZ,DZX,XYOZ,YZOX,ZXOY,XYPZ,YZPX,ZXPY
      COMMON /BL3/ NI,NJ,NK,NIM1,NJM1,NKM1,NIM2,NJM2,NKM2
      COMMON/CONS/XTIME,NT,U0,PRT,TA,
     &          NTMAX0,RA,CPAIR,SIGMA
      COMMON/NE/   U(22,18,18),V(22,18,18),T(22,18,18),R(22,18,18),
C    &         P(22,18,18),W(22,18,18),WOD(22,18,18),NOD(22,18,18)
     &          P(22,18,18),W(22,18,18),WOD(22,18,18)
      COMMON/OD/UOD(22,18,18),VOD(22,18,18),TOD(22,18,18),ROD(22,18,18)
      COMMON/BL31/TPD(22,18,18),RPD(22,18,18),UPD(22,18,18),
     &  VPD(22,18,18),WPD(22,18,18),PPD(22,18,18),RESORM(20),ITER
        COMMON/CO/AP(22,18,18),AE(22,18,18),AW(22,18,18),AN(22,18,18),
     & AS(22,18,18),SU(22,18,18),SP(22,18,18),AF(22,18,18),AB(22,18,18)
      COMMON/PP/DU(22,18,18),DV(22,18,18),DW(22,18,18),PP(22,18,18)
      COMMON/BL10/ Z(30),REQ(30),VIS(22,18,18),RRES(3)
      COMMON/BL12/ DYZO2,DZXO2,DXYO2,XYPZ2,YZPX2,ZXPY2,DX4,DY4,DZ4
     &          ,XYOZ2,YZOX2,ZXOY2,DYZO4,DZXO4,DXYO4
      COMMON /BL4/ QCONW  ,
     &    QRADF ,QRADW ,ARFP,ARFS,QRADB,QCONB,QRADL,QCONL,QRADR,QCONR,
     &    QRADT,QCONT,QRADRE,QCONRE
      COMMON/WCAP/TWF (21,2,17),TWRE(21,2,17),TWR (2,17,17),
     &           TWL (2,17,17),TWB (21,17,2),TWT (21,17,2),
     &           CPF (21,3,17),CPRE(21,3,17),CPR (3,17,17),
     &           CPL (3,17,17),CPB (21,17,3),CPT (21,17,3)
     &          ,DXW,DYW,DZW,VOLW,ALFAW,BETAW,HCOEF,TINF,
     &           CCOWL,CCOWR,CCOWRE,CCOWF,CCOWB,CCOWT
      COMMON/RAD/RLW(17,17),RRW(17,17),RREW(21,17),RFW(21,17),RBW(21,17)
     &         ,RTW(21,17),RADHS
C
      COMMON/VF/VFMXC(67,67),T4ZON(67),TZON(67),RZON(67),AR(67)
     &        ,AREA(67),VIEW(67,67),CONSRA
      COMMON/BL80/BTURB,ABTURB,CNT,DX2,DY2,DZ2,VISMAX
     &          ,SMPP(22,18,18),RI(22,18,18)
C
      COMMON /VIEW1/ MI,MJ,MK,MII,MJJ,MKK,MIM,MIP,MJM,MJP,MKM,MKP,
     &             MIIM,MIIP,MJJM,MJJP,MKKM,MKKP,NHSZ,LZ,NZ,MZ,
     &             IREGN1,IREGN2,IREGN3,IREGN4,IREGN5,IREGN6,IREGN7,
```

```
     &               MREGN1,MREGN2,MREGN3,MREGN4,MREGN5,MREGN6,MREGN7
C
      COMMON /VIEW2/ MIIZ(9),MJJZ(9),MKKZ(9),LI(9),LJ(9),LK(9),
     &               ITHIN(9),JTHIN(9),KTHIN(9),AXY(9),AYZ(9),AZX(9),
     &               IHSB(9),JHSB(9),KHSB(9),NHSW(9),NHSD(9),NHSH(9),
     &               LTYPE(9,6)
C
      DIMENSION DUMMY(22,22),QDOT(9),QF1(9),SVIEW(67)
      DIMENSION TCELSI(22,18,18),POD(22,18,18)
C
      CHARACTER STAR
      DATA STAR/'*'/,ITLEFT/10000/
      DATA SORMAX,ITMAX/0.10,10/
      DATA TIME,RHEAT,CPHEAT/0.,82.3,.138/
      DATA RWALL/488.0/
      DATA QCORRT,PCURM1,PM1/1.0,1.0,1.0/
C
C ***********************************************************************
C
C
C
C ********  PAY SPECIAL ATTENTION TO LINES COVERED BY
C           $$$$$$$$$$$$$$$$$$ LINES $$$$$$$$$$$$$$$$
C
C
C
C *** U0     : REFERENCE VELOCITY (FT/SEC)
C *** RA     : REFERENCE AIR DENSITY (LBM/FT**3)
C *** H      : REFERENCE LENGTH (FT)
C *** TA     : REFERENCE TEMPERATURE (R)
C *** TINIT  : INITIAL TEMPERATURE (0)
C *** GC     : GRAVITATIONAL CONSTANT
C *** RAITR  : GAS CONSTANT; 53.34
C *** CONST1 : RA*U0**2/GC
C *** CONST4 : REFERENCE LENGTH (CM)
C *** CONST6 : REFERENCE VELOCITY (CM/S)
C *** CONSRA : TA**3/(RA*CP*U0*H*H)
C *** NPRNT  : USED IN T,R,U,V,P,.... PRINTOUT ROUTINE
C              NO. OF GRIDS BETWEEN TWO CONSECTIVE PRINTOUTS
C *** NTRWR  : NTREAL/NWRITE*NWRITE
C *** NTRWA  : NTREAL/NWALT*NWALT
C *** QD     : MAXIMUM HEAT INPUT,(WATTS)
C *** TIME1  : HEAT FLUX INCREASES LINEARLY TO IT FULL STRENGTH, QD,
C              AT TIME=TIME1, (SEC.)
C *** TIME2  : THEN THE HEAT INPUT GRADUALLY REDUCES TO ZERO, (SEC.)
C
C *** WTHICK ; INTERIOR THICKNESS (IN)
C     TWF (), TWRE(), TWL (), TWR (), TWB (), TWT () : TEMPERATURE
C          INSIDE THE TANK WALL, 2 CELLS DEEP.
C     QCONF (), QCONRE(), QCONR (), QCONL (), QCONB (), QCONT () :
C          THERMAL CONDUCTION ON TANK WALLS, CALCULATED IN #CALT#
C *** CPF (), CPRE(), CPR (), CPL(), CPB (), CPT () ; THERMAL WALL
C          WALL CAPACITANCES, IT IS A FUNCTION OF TEMPERATURE
C     CP__()=ALFA_+BETA_*TEMPERATURE
C *** RWALL, CCOWL,CCOWR,CCOWRE,CCOWF,CCOWB,CCOWT, CELLL,CELLR,
C     CELLRE,CELLF,CELLB,CELLT ; VARIABLES USED IN #MAIN# AND
C     #CALT# FOR WALL CAPACITY CALCULATION
C *** CPWALL,CONDET,CONDEB,CONDEW,CONDEF,  ACOWW,BCOWW,ACOWT,BCOWT,
C     ACOWB,BCOWB,ACOWF,BCOWF ; USED TO CALCULATE WALL THERMAL
C     CAPACITY
C *** AREA() : NUMBER OF CELLS IN A SURFACE ZONE
C     AR()   : AREA (FT**2) OF A SURFACE ZONE
C *** RRW (),RLW(),RREW(),RFW(),RBW(),RTW(); SURFACE RADIATIVE HEAT
C     FLUX ON EACH CELL. CALCULATED IN #SURRAD# AND USED IN #CALT#
C     FOR TANK WALL TEMPERATURE CALCULATION
C
C *** WC   : WIDTH  OF THE TANK, IN X-DIRECTION
C     DC   : DEPTH  OF THE TANK, IN Y-DIRECTION
C     HC   : HEIGTH OF THE TANK, IN Z-DIRECTION
```

```
C *** NI    : TOTAL NUMBER CELLS  IN X-DIRECTION
C     NJ    :                          Y-DIRECTION
C     NK    :                          Z-DIRECTION
C *** LTYPE() : TYPE OF HEAT SOURCE SURFACE;
C              0; NO RADIATION EXCHANGE OCCURS
C              1;    RADIATION EXCHANGE OCCURS
C *** MI    : NUMBER OF ZONES IN X-DIRECTION
C     MJ    :                    Y-DIRECTION
C     MK    :                    Z-DIRECTION
C *** NZ    : TOTAL NUMBER OF RADIATION ZONES IN SYSTEM
C *** MZ    : TOTAL NUMBER OF RADIATION ZONES ON TANK WALL
C *** MIIZ(), MII : LOCATION OF THE HEAT SOURCE, ZONE # IN X-DIRECTION
C     MJJZ(), MJJ :                                        Y-DIRECTION
C     MKKZ(), MKK :                                        Z-DIRECTION
C *** LI() : NUMBER OF CELLS FOR EACH ZONE IN X-DIRECTION
C     LJ() :                                  Y-DIRECTION
C     LK() :                                  Z-DIRECTION
C *** IHSB() : STARTING CELL NUMBER FOR EACH HEAT SOURCE IN X-DIRECTION
C     JHSB() :                                              Y-DIRECTION
C     KHSB() :                                              Z-DIRECTION
C *** NHSW() : NUMBER OF CELLS FOR EACH HEAT SOURCE, IN X-DIRECTION
C     NHSD() :                                          Y-DIRECTION
C     NHSH() :                                          Z-DIRECTION
C *** ITHIN() : 0 OR 1; ZERO OR ONE ZONE SPACE BETWEEN TWO OPPOSITE
C     JTHIN() :         SIDES OF A HEAT SOURCE IN X;(I), Y;(J) AND
C     KTHIN() :         Z;(K) DIRECTIONS
C              IF ITHIN=JTHIN=KTHIN=1 MEANS A RECTANGULAR SHAPE HEAT
C              SOURCE WITH ONE ZONE SPACE IN EACH DIRECTION
C              IF ITHIN=JTHIN=KTHIN=0 MEANS AN INFINITE THIN SHEET OF
C              HEAT SOURCE IN ALL 3 DIMENSIONS
C **********************************************************************
C
C     ***********************
C     >>  READ INPUT DATA  <<
C     ***********************
C
      KCASE=1
      KRUN=0
      KBOUND=1
      DTIME=.001
      TWRITE=1.
      TWALT=1.
      TMAX=5.
      NHSZ=1
      NPRNT=5
      NRAD=2
      QD=3.223E05
      TIME1=30.
      TIME2=60.
      NI=22
      NJ=18
      NK=18
C
      WC=40.2
      DC=17.
      HC=17.
C
C *** READ INPUT DATA
C
C *** READ # 1
C ==============
C
C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      READ(5,*) KRUN,KBOUND,DTIME,TWRITE,TWALT,NRAD,TMAX
C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
      WRITE(6,802) KRUN,KBOUND,DTIME,TWRITE,TWALT,NRAD,TMAX
  802 FORMAT(5X,'KRUN =',I3,2X,'KBOUND =',I3,2X,'DTIME =',E11.4,
     & 2X,'TWRITE =',E11.4,/,5X,'TWALT =',E11.4,2X,'NRAD =',
```

```
     & I4,2X,'TMAX =',E11.4,/)
C
C *** READ # 2
C =============
C
      READ(5,*) QD,TIME1,TIME2
C
CC    WRITE(6,801) QD,TIME1,TIME2
CC801 FORMAT(/,5X,'QD    =',E11.4,' WATTS',3X,'TIME1 =',E11.4,
CC   &          ' SEC.',3X,'TIME2 =',E11.4,' SEC.',//)
C
C *** WHEN KBOUND = 3 OR 4
C
C     MOST OF THE INPUT INFORMATION CAN BE OBTAINED FROM VIEW FACTOR
C     PROGRAM WHICH IS A SEPARATED FORTRAN PROGRAM CALCULATING
C     VIEW FACTOR BETWEEN ANY TWO TANK WALL ZONES AS WELL AS BETWEEN
C     HEAT SOURCE AND TANK WALL ZONE.
C     ONCE THE VIEW FACTOR, A MAXTRIX FORM, IS CALCULATED, ALL VARIABLES
C     ARE STORED INTO A FILE, SAY VIEW.DATA, EITHER ON DISK OR TAPE
C *** IF KBOUND IS NOT 3 OR 4, THEN ALL INPUT CARDS WILL BE READ
C
C *******************************************************************
      IF(KBOUND.EQ.4. OR.KBOUND.EQ.3) GO TO 7234
C *******************************************************************
C
C *** READ # 3
C =============
C
      READ(5,*) WC,DC,HC,NI,NJ,NK
C
C *** READ # 4
C =============
C
      READ(5,*) NHSZ
C
C ***
C ****** IF NHSZ > 1, THEN READ NHSZ SET OF CARDS FOR READ GROUP 2 TO 4
C ***
      DO 11 I=1,NHSZ
C
C *** READ # 5
C =============
C
      READ(5,*) LTYPE(I,1),LTYPE(I,2),LTYPE(I,3),LTYPE(I,4),LTYPE(I,5),
     &          LTYPE(I,6)
C
C *** READ # 6
C =============
C
C *** READ POSITION AND SIZD DATA FOR HEAT SOURCE
C
      READ(5,*) IHSB(I),NHSW(I),JHSB(I),NHSD(I),KHSB(I),NHSH(I)
C
C *** READ # 7
C =============
C
      READ(5,*) MIIZ(I),MJJZ(I),MKKZ(I)
C
C *** READ # 8
C =============
C
      READ(5,*) ITHIN(I),JTHIN(I),KTHIN(I)
C
   11 CONTINUE
C
C *** READ # 9
C =============
C
      READ(5,*) MI,MJ,MK
```

```
      READ(5,*) (LI(I),I=1,MI)
      READ(5,*) (LJ(I),I=1,MJ)
      READ(5,*) (LK(I),I=1,MK)
C
      GO TO 7235
C
 7234 CONTINUE
C
C *** READ VIEW FACTORS MATRIX AND ZONE CELL NUMBER
C
C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
      READ(15)
     &   IREGN1,IREGN2,IREGN3,IREGN4,IREGN5,IREGN6,IREGN7,
     &   MREGN1,MREGN2,MREGN3,MREGN4,MREGN5,MREGN6,MREGN7,
     &   WC,DC,HC,NI,NJ,NK,AXY,AYZ,AZX,
     &   MIIZ,MJJZ,MKKZ,MI,MJ,MK,LTYPE,MZ,NHSZ,NZ,LI,LJ,LK,
     &   ITHIN,JTHIN,KTHIN,IHSB,JHSB,KHSB,NHSW,NHSD,NHSH,VIEW,AREA
C
C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
      WRITE(6,667)
     &   IREGN1,IREGN2,IREGN3,IREGN4,IREGN5,IREGN6,IREGN7,
     &   MREGN1,MREGN2,MREGN3,MREGN4,MREGN5,MREGN6,MREGN7,
     &   WC,DC,HC,NI,NJ,NK,
     &   MI,MJ,MK,MZ,NZ,NHSZ
C
  667 FORMAT( 5X,' READ DATA FROM FILE 15, CALCULATED FROM VIEW ',
     & 'FACTOR PROGRAM'//,5X,'IREGN1 =',I3,2X,'IREGN2 =',I3,2X,
     & 'IREGN3 =',I3,2X,'IREGN4 =',I3,2X,'IREGN5 =',I3,2X,'IRENG6 =',
     & I3,2X,'IREGN7 =',I3,/,5X,'MREGN1 =',I3,2X,'MREGN2 =',I3,2X,
     & 'MREGN3 =',I3,2X,'MREGN4 =',I3,2X,'MREGN5 =',I3,2X,'MREGN6 =',
     & I3,2X,'MREGN7 =',I3,//,
     & 5X,'WC =',E11.4,' FT',3X,'DC =',E11.4,' FT',3X,'HC =',E11.4,
     & ' FT',/,5X,'NI =',I3,3X,'NJ =',I3,3X,'NK =',I3,//,
     & 5X,'MI =',I3,3X,'MJ =',I3,3X,'MK =',I3,3X,'MZ =',I3,3X,
     & 'NZ =',I3,//,5X,'NO. OF HEAT SOURCES =',I3,//)
C
 7235 CONTINUE
C
      WRITE(6,21) WC,DC,HC,NI,NJ,NK
   21 FORMAT(5X,'WC =',E11.4,' FT',3X,'DC =',E11.4,' FT',3X,
     &    'HC =',E11.4,' FT',/,
     & 5X,'NI =',I3,6X,'NJ =',I3,6X,'NK =',I3,//)
C
      WRITE(6,31) NHSZ
   31 FORMAT(5X,'TOTAL NUMBER OF HEAT SOURCES, NHSZ :',I2,//)
C
      DO 91 I=1,NHSZ
      WRITE(6,12) I,LTYPE(I,1),LTYPE(I,2),LTYPE(I,3),LTYPE(I,4),
     &          LTYPE(I,5),LTYPE(I,6),IHSB(I),JHSB(I),KHSB(I),
     &          NHSW(I),NHSD(I),NHSH(I),MIIZ(I),MJJZ(I),MKKZ(I),
     &          ITHIN(I),JTHIN(I),KTHIN(I)
  12  FORMAT(5X,'HEAT SOURCE NUMBER :',I2,//,
     & 10X,'ITS 6 SURFACE TYPES ARE : LTYPE(I) =',6I2,//,
     &  8X,'LOCATION OF THIS HEAT SOURCE .......',//,
     & 10X,'STARTING CELL NUMBER IN X-DIRECTION : IHSB = ',I2,/,
     & 10X,'                        Y-DIRECTION : JHSB = ',I2,/,
     & 10X,'                        Z-DIRECTION : KHSB = ',I2,//,
     & 10X,'        AND THE CELLS IN X-DIRECTION : NHSW = ',I2,//,
     & 10X,'                        Y-DIRECTION : NHSD = ',I2,//,
     & 10X,'                        Z-DIRECTION : NHSH = ',I2,//,
     & 10X,'LOCATION OF THIS HEAT SOURCE RADIATION EXCHANGE ZONE',/,
     & 20X,'ZONE NUMBER IN X-DIRECTION : MIIZ(I) = MII = ',I2,/,
     & 20X,'               Y-DIRECTION : MJJZ(I) = MJJ = ',I2,/,
     & 20X,'               Z-DIRECTION : MKKZ(I) = MKK = ',I2,//,
     & 10X,'THIS HEAT SOURCE ZONE HAS ',//,
     & 20X,'ITHIN(I) =',I2,' ZONE THICKNESS IN X-DIRECTION',/,
     & 20X,'JTHIN(I) =',I2,' ZONE THICKNESS IN Y-DIRECTION',/,
```

```
     & 20X,'KTHIN(I) =',I2,' ZONE THICKNESS IN Z-DIRECTION',//)
   91 CONTINUE
C
      WRITE(6,18) MI,(LI(I),I=1,MI)
   18 FORMAT(10X,'THERE IS ; MI =',I2,' ZONES IN X-DIRECTION',//,
     &   20X,'THE NUMBER OF CELLS IN EACH ZONE IS ; LI(I) =',10I3,/)
      WRITE(6,19) MJ,(LJ(J),J=1,MJ)
   19 FORMAT(10X,'THERE IS ; MJ =',I2,' ZONES IN Y-DIRECTION',//,
     &   20X,'THE NUMBER OF CELLS IN EACH ZONE IS ; LJ(I) =',10I3,/)
      WRITE(6,20) MK,(LK(K),K=1,MK)
   20 FORMAT(10X,'THERE IS ; MK =',I2,' ZONES IN Z-DIRECTION',//,
     &   20X,'THE NUMBER OF CELLS IN EACH ZONE IS ; LK(I) =',10I3,/)
C
      MZ=2*(MI*MJ+MJ*MK+MK*MI)
C
      WRITE(6,308) MZ
  308 FORMAT(5X,'TOTAL NUMBER OF ZONES ON TANK WALL =',I3,/)
C
      DO 668 L=1,NHSZ
      WRITE(6,669) L,LTYPE(L,1),LTYPE(L,2),LTYPE(L,3),LTYPE(L,4),
     & LTYPE(L,5),LTYPE(L,6),MIIZ(L),MJJZ(L),MKKZ(L),
     & IHSB(L),JHSB(L),KHSB(L),NHSW(L),NHSD(L),NHSH(L),
     & ITHIN(L),JTHIN(L),KTHIN(L),AXY(L),AYZ(L),AZX(L)
  669 FORMAT(5X,'HEAT SOURCE NUMBER ',I2,//,
     & 5X,'LTYPE =',6I3,/,5X,'MII  =',I3,2X,'MJJ  =',I3,
     & 2X,'MKK  =',I3,//,
     & 5X,'IHSB(L) =',I2,2X,'JHSB(L) =',I2,2X,'KHSB(L) =',I2,/,
     & 5X,'NHSW(L) =',I2,2X,'NHSD(L) =',I2,2X,'NHSH(L) =',I2,//,
     & 5X,'ITHIN(L)=',I2,2X,'JTHIN(L)=',I2,2X,'KTHIN(L)=',I2,//,
     & 5X,'AXY(L)  =',E11.4,' FT**2',2X,'AYZ(L)  =',E11.4,' FT**2',
     & 2X,'AZX(L)  =',E11.4,' FT**2',//)
  668 CONTINUE
C
      DO 766 L=1,NHSZ
      MII=MIIZ(L)
      MJJ=MJJZ(L)
      MKK=MKKZ(L)
      WRITE(6,767) L,MII,MJJ,MKK
  767 FORMAT(/,5X,'HEAT SOURCE NO. ',I2,2X,'MII =',I3,2X,'MJJ =',I3,
     &   2X,'MKK =',I3,/)
  766 CONTINUE
C
      WTHICK=2./12.
C
      NIM1=NI-1
      NJM1=NJ-1
      NKM1=NK-1
      NIM2=NI-2
      NJM2=NJ-2
      NKM2=NK-2
C
      H=HC
      DZ=HC/(NKM2)/H
      DX=WC/(NIM2)/H
      DY=DC/(NJM2)/H
      XDX=WC/(NIM2)
      YDY=DC/(NJM2)
      ZDZ=HC/(NKM2)
C
      DO 821 N=1,NHSZ
      XIHSB=IHSB(N)*DX*H
      YJHSB=JHSB(N)*DY*H
      ZKHSB=KHSB(N)*DZ*H
      XNHSW=NHSW(N)*DX*H
      YNHSD=NHSD(N)*DY*H
      ZNHSH=NHSH(N)*DZ*H
      WRITE(6,822) N, XIHSB,YJHSB,ZKHSB,XNHSW,YNHSD,ZNHSH
  822 FORMAT(/,5X,'HEAT SOURCE NO. ',I2,/,
     &  10X,'ITS LOCATION IS ',E11.4,' FT FROM X=0',/,
```

```
     &  10X,'                      ',E11.4,' FT FROM Y=0',/,
     &  10X,'                      ',E11.4,' FT FROM Z=0',//,
     &  10X,'ITS THICKNESS IS ',E11.4,' FT IN X-DIRECTION',/,
     &  10X,'                        ',E11.4,' FT IN Y-DIRECTION',/,
     &  10X,'                        ',E11.4,' FT IN Z-DIRECTION',//)
  821 CONTINUE
C
      U0=1.0
      XTIMEI=0.
C NFIRE IS AN UNNEEDED VARIABLE LEFT OVER FROM ALTERATIONS.
C TO GET RID OF IT SEVERAL PRINT STATEMENTS MUST BE ALTERED.
      NFIRE=1
C
C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
      NWALT = 10
      NWRITE = 10
C
C     NWALT=TWALT  *U0/(DTIME*H)
C     NWRITE=TWRITE*U0/(DTIME*H)
C
C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
C *** PRINT OUT INPUT INFORMATION
C
      WRITE(6,1)(STAR,I=1,100),KCASE,KRUN,TWRITE,TWALT,DTIME
     & ,HC,WC,DC,XDX,YDY,ZDZ,
     & QD,TQD,NWRITE,NFIRE,TMAX
    1 FORMAT(///,100A1,///,1X,'***  THREE-DIMENSIONAL NUMERICAL ',
     & 'SIMULATION OF THE NAVY STORAGE TANK:',/,4X,
     & '< CASE NO. = ',I2,' >',//,4X,'# KRUN   =',I2,/,4X,
     & '# TWRITE =',F6.1,/,4X, '# TWALT  =',F6.1,
     &/,4X,'# DTIME  =',F6.3,//,4X,'# THE ENCLOSURE : HEIGHT =',F6.1,
     &' FEET',2X,'WIDTH =',F6.1,' FEET',2X,'DEPTH =',F6.1,' FEET',//,
     & '# THE GRID CELL SIZE : DX =',F6.1,
     & ' FEET',2X,' DY   =',F6.1,' FEET',2X,' DZ   =',F6.1,' FEET',//,
     &5X,'TOTAL HEAT INPUT ; QD =', E11.4,' WATTS =',E11.4,' BTU/HR',/,
     & 5X,'NWRITE =',I4,5X,'NFIRE =',I4,/,
     & 5X,'TMAX =',F8.2,' SEC.',//)
C
      GO TO (1132,1133,1134,1135),KBOUND
 1132 WRITE(6,1136)KBOUND
      GO TO 1141
 1133 WRITE(6,1137)KBOUND
      GO TO 1141
 1134 WRITE(6,1138)KBOUND,NRAD
      GO TO 1141
 1135 WRITE(6,1139)KBOUND,NRAD
 1141 CONTINUE
C
 1136 FORMAT(4X,'< KBOUND =',I3,'  >',/,6X,'PURE CONVECTION WITH ',
     & 'INSULATED WALL IS CONSIDERED IN THIS CASE.',//)
 1137 FORMAT(4X,'< KBOUND =',I3,'  >',/,6X,'PURE CONVECTION WITH ',
     & 'WALL CAPACITANCE IS CONSIDERED IN THIS CASE.',//)
 1138 FORMAT(4X,'< KBOUND =',I3,'  >',/,6X,'BOTH CONVECTION AND ',
     & 'SURFACE RADIATION ARE INCLUDED IN THIS CASE WITH WALL ',
     & 'CAPACITANCE.',/,4X,'# NRAD =',I3,' TIME STEPS TO UPDATE THE ',
     & 'RADIATIVE HEAT FLUX.',//)
 1139 FORMAT(4X,'< KBOUND =',I3,'  >',/,6X,'BOTH CONVECTION AND ',
     & 'SURFACE RADIATION ARE INCLUDED IN THIS CASE WITH INSULATED',
     & ' WALL.',/,4X,'# NRAD =',I3,' TIME STEPS TO UPDATE THE',
     & 'RADIATIVE HEAT FLUX. *** NOT AVAILABLE RIGHT NOW',//)
C
C *********************************************************************
C

C *** DEFINE THE CONSTANT VARIABLES IN THE CALCULATION PROCESSES
C
      DXY=DX*DY
```

```
      DYZ=DY*DZ
      DZX=DZ*DX
      DX4=DX*4.
      DY4=DY*4.
      DZ4=DZ*4.
      DX2=DX*2.
      DY2=DY*2.
      DZ2=DZ*2.
C
      VOL=DX*DY*DZ
      UH=H/U0
      GC=32.17
      RAITR=53.34
C
      VOLDT=VOL/DTIME
      BUOY=GC*H/(U0*U0)
      UGRT=U0*U0/(GC*RAITR*TA)
      WRITE(6,374) BUOY,UGRT
  374 FORMAT(/,5X,'1/F = BUOY = ',E11.4,5X,'C = UGRT = ',E11.4,/)
C
      XYOZ=DXY/DZ
      YZOX=DYZ/DX
      ZXOY=DZX/DY
      PRT=1.
      XYPZ=XYOZ/PRT
      YZPX=YZOX/PRT
      ZXPY=ZXOY/PRT
      VISL=(1.56E-4)/(H*U0)
      VISMAX=VISL*400.
C
      DZXO2=DZX*.5
      DYZO2=DYZ*.5
      DXYO2=DXY*.5
      DZXO4=DZX*.25
      DYZO4=DYZ*.25
      DXYO4=DXY*.25
      XYPZ2=XYPZ*2.
      YZPX2=YZPX*2.
      ZXPY2=ZXPY*2.
      XYOZ2=XYOZ*2.
      YZOX2=YZOX*2.
      ZXOY2=ZXOY*2.
C
      CONST4=H*30.48
      CONST6=U0*30.48
      CONST1=RA*U0*U0/(GC*14.696*144.)
      TINIT=1.
C
C *** FOR WALL CAPACITY
C
      CELLB =FLOAT(NIM2*NJM2)
      CELLT =CELLB
      CELLRE=FLOAT(NIM2*NKM2)
      CELLF =CELLRE
      CELLL =FLOAT(NJM2*NKM2)
      CELLR =CELLL
C
C *** CONSTANTS FOR RADIATION CALCULATION
C
      CONSRA = TA*TA*TA/(RA*CPAIR*U0*3600.*H*H)
C
C *** CONSTANTS FOR WALL CAPACITANCE
C
C *** WTHICK IS THE TOTAL WALL THICKNESS, NOT THE CELL THICKNESS
      WTHICK=3./8./12.
      DXW=WTHICK/2.0/H
      DYW=DXW
      DZW=DXW
      VOLW=DXW*DX*DY
```

```
      CPWALL=0.104
      CONSTA=CPAIR*60.*RA*U0*H
C
C *** ALFAW AND BETAW ARE USED FOR WALL THERMAL CAPACITY CALCULATION
C
      CONDEW=35.0
CC    ALFAW=.000208/CONSTA*CONDEW
CC    BETAW=.000000731*TA*2./CONSTA *CONDEW
C *** THE NEW ALFAW BELOW IS IN UNITS OF BTU/SEC/FT/DEGREE F
      ALFAW=35.0/3600.0
      BETAW=0.0
C
C *** HCOEF, CCOWL,CCOWR,CCOWRE,CCOWF, CCOWB, AND CCOWT ARE USED
C     IN #CALT# FOR WALL TEMPERATURE CALCULATION
C
      HCONV=7.5
      HCOEF=HCONV*4./(3600.*CPAIR*RA*U0)
      CCOWL =CELLL *RWALL*VOLW *CPWALL/(CPAIR*DTIME*RA)/2.0
      CCOWR =CELLR *RWALL*VOLW *CPWALL/(CPAIR*DTIME*RA)/2.0
      CCOWRE=CELLRE*RWALL*VOLW *CPWALL/(CPAIR*DTIME*RA)/2.0
      CCOWF =CELLF *RWALL*VOLW *CPWALL/(CPAIR*DTIME*RA)/2.0
      CCOWB =CELLB *RWALL*VOLW *CPWALL/(CPAIR*DTIME*RA)/2.0
      CCOWT =CELLT *RWALL*VOLW *CPWALL/(CPAIR*DTIME*RA)/2.0
      TINF=1.
C
      WRITE(6,2334) HCONV,CCOWL,CCOWR,CCOWRE,CCOWF,CCOWB,CCOWT,
     & ALFAW,BETAW
 2334 FORMAT(2X,'***   THE CONVECTION COEFFICIENTS ARE ',
     & 'MULTIPLIED BY A FACTOR AT THE WALL = ',F10.4,//,
     & 5X,'CCOWL  =',E11.4,2X,'CCOWR  =',E11.4,2X,'CCOWRE =',E11.4,
     & 2X,'CCOWF  =',E11.4,2X,'CCOWB  =',E11.4,2X,'CCOWT  =',E11.4,/,
     & 5X,'ALFAW  =',E11.4,2X,'BETAW  =',E11.4,/)
C
C *****************************************************************
C
C ***    INITIALIZE THE CONDUCTIVITY FOR THE WALLS,
C ***    ONLY IN THE CASE: KBOUND = 3 AND THE FIRST RUN.
C
      IF(KBOUND.NE.3.AND.KBOUND.NE.2)GO TO 726
      IF(KRUN.EQ.1)GO TO 726
C
C     WRITE(10,1335)KCASE
C     WRITE(13,1335)KCASE
C     WRITE(14,1335)KCASE
C1335 FORMAT(2X,' *** THIS IS CASE ',I2,' ***')
      DO 728 I=2,NIM1
      DO 728 K=2,NKM1
      DO 728 J=1,2
      TWF (I,J,K)=1.
      TWRE(I,J,K)=1.
  728 CONTINUE
      DO 731 J=2,NJM1
      DO 731 K=2,NKM1
      DO 731 I=1,2
      TWR (I,J,K)=1.
      TWL (I,J,K)=1.
  731 CONTINUE
      DO 729 I=2,NIM1
      DO 729 J=2,NJM1
      DO 729 K=1,2
      TWT (I,J,K)=1.
      TWB (I,J,K)=1.
  729 CONTINUE
  726 CONTINUE
C
C *** DEFINE VERTICAL NODE POINTS AND COMPUTE HYDROSTATIC
C     EQUILIBRIUM DENSITY
C
      Z(1)=-.5*DZ
```

```
      Z(2)=0.5*DZ
      DO 93 K=3,NK
      Z(K)=Z(K-1)+DZ
   93 CONTINUE
      AAAA=-1.*BUOY*UGRT*Z(1)
      REQ(1)=EXP(AAAA)
      DO 13 K=1,NK
      AAAA=Z(K)*BUOY*UGRT
      REQ(K)=1./EXP(AAAA)
   13 CONTINUE
C
C *** DEFINE THE INITIAL VALUES
C
      TOTMS=0.
C
      DO 220 K=1,NKM1
      DO 220 J=1,NJM1
      DO 220 I=1,NIM1
      RI(I,J,K)=0.
      AE(I,J,K)=0.
      AW(I,J,K)=0.
      AN(I,J,K)=0.
      AS(I,J,K)=0.
      AF(I,J,K)=0.
      AB(I,J,K)=0.
      AP(I,J,K)=0.
      SP(I,J,K)=0.
      SU(I,J,K)=0.
      PP(I,J,K)=0.
      DU(I,J,K)=0.
      DV(I,J,K)=0.
      DW(I,J,K)=0.
      TOTMS=TOTMS+REQ(K)
C
  220 CONTINUE
      TOTMS=TOTMS*VOL*H*H*H*RA
      WRITE(6,376) TOTMS
  376 FORMAT(5X,'INITIAL TOTAL MASS = ',E11.4,' LBM',/)
      IF(KRUN.EQ.1)GO TO 2226
      DO 2222 K=1,NK
      DO 2222 J=1,NJ
      DO 2222 I=1,NI
      VIS(I,J,K)=VISL
      UOD(I,J,K)=0.
      VOD(I,J,K)=0.
      WOD(I,J,K)=0.
      TOD(I,J,K)=1.
      ROD(I,J,K)=REQ(K)
      P(I,J,K)=0.
C     NOD(I,J,K)=0
 2222 CONTINUE
      DO 2223 K=1,NKM1
      DO 2223 J=1,NJM1
      RLW(J,K)=0.
      RRW(J,K)=0.
 2223 CONTINUE
      DO 2225 I=1,NIM1
      DO 2225 J=1,NJM1
      RBW(I,J)=0.
      RTW(I,J)=0.
 2225 CONTINUE
      DO 2227 I=1,NIM1
      DO 2227 K=1,NKM1
      RFW(I,J)=0.
      RREW(I,J)=0.
 2227 CONTINUE
C
C *** QSIN, QSWAL AND QSAIR FOR HEAT GENERATION AND LOSS THROUGH
C     AIR AND WALL.
```

```
C *** RADHS : RADIATIVE HEAT FLUX FROM HEAT SOURCE
C
      RADHS=0.
      QSIN=0.
      QSWAL=0.
 2226 CONTINUE
C
C
      IF(KRUN.NE.1) GO TO 9999
C
C *** READ THE DATASET OF LAST JOB FROM THE TAPE OR THE DISK
C
C ***********************************************************************
 9997 READ(8,END=151)
     & TIME,NTMAXO,TOD,ROD,UOD,VOD,WOD,P,VIS,XTIMEI
     &,QSIN,QSWAL,QSAIR,PCURM1,PM1,QCORRT
     &,TWF ,TWRE,TWR ,TWL ,TWB ,TWT  ,RLW,RRW,RREW,RFW,RBW,RTW
     &,RADHS,QRADF,QRADW ,QRADB,QRADL,QRADR,QRADT,QRADRE
C **********************************************************************
      GO TO 9997
  151 BACKSPACE 8
CC    NTMAXO=TIME/DTIME
 9999 CONTINUE
      IF(XTIME.GT.TMAX)GO TO 9303
C
      DO 221 K=1,NK
      DO 221 J=1,NJ
      DO 221 I=1,NI
      U(I,J,K)=UOD(I,J,K)
      V(I,J,K)=VOD(I,J,K)
      W(I,J,K)=WOD(I,J,K)
      T(I,J,K)=TOD(I,J,K)
      R(I,J,K)=ROD(I,J,K)
      P(I,J,K)=P(I,J,K)
  221 CONTINUE
C
C ***********************************************************************
C
C *** THE FOLLOWING SECTION CAN BE SKIPPED
C     WHEN RADIATION IS NOT CONSIDERED.
C
      IF(KBOUND.NE.4.AND.KBOUND.NE.3) GO TO 1234
C
C *** CALCULATE THE # OF CELLS IN EACH WALL-ZONE
C
      DO 5 L=1,MREGN3
      AR(L)=AREA(L)
      AREA(L)=AREA(L)/DYZ/H/H
    5 CONTINUE
      DO 6 L=MREGN3+1,MREGN5
      AR(L)=AREA(L)
      AREA(L)=AREA(L)/DZX/H/H
    6 CONTINUE
      DO 7 L=MREGN5+1,MREGN7
      AR(L)=AREA(L)
      AREA(L)=AREA(L)/DXY/H/H
    7 CONTINUE
      DO 670 L=MREGN7+1,NZ
      AR(L)=AREA(L)
      AREA(L)=1.
  670 CONTINUE
C
C *** ADJUST THE VIEW FACTORS FOR ALL ZONES SUCH THAT THE SUMMATION
C     OF ANY ZONE TO ALL OTHER WALL ZONES TO ONE
C
  763 CONTINUE
      DO 768 I=1,NZ
      SVIEW(I)=0.
      DO 760 J=1,NZ
```

```
      SVIEW(I)= SVIEW(I)+VIEW(I,J)
  760 CONTINUE
C     WRITE(6,769) I,SVIEW(I)
C 769 FORMAT(5X,'I =',I3,3X,'S VIEW =',E11.4)
  768 CONTINUE
      SMX= SVIEW(1)
      IMX=1
      DO 761 I=2,NZ
      IF(SVIEW(I).LT.SMX)GO TO 761
      SMX=SVIEW(I)
      IMX=I
  761 CONTINUE
CV    WRITE(6,770) IMX,SMX
CV770 FORMAT(5X,'IMX =',I3,3X,'SMX =',E11.4)
      DO 762 I=1,NZ
      VIEW(IMX,I)=VIEW(IMX,I)/SVIEW(IMX)
      VIEW(I,IMX)=VIEW(I,IMX)/SVIEW(IMX)
C     WRITE(6,771) I,VIEW(IMX,I),VIEW(I,IMX)
C 771 FORMAT(5X,'I =',I3,2X,'VIEW(IMX,I) =',E11.4,2X,'VIEW(I,IMX) =',
C    & E11.4)
  762 CONTINUE
C
      IF(SMX.GT.1.) GO TO 763
      DO 765 I=1,NZ
      VIEW(I,I)=1.-SVIEW(I)
  765 CONTINUE
C
CV    WRITE(6,161)
CV161 FORMAT(5X,'((VIEW(I,J),J=1,NZ),I=1,NZ)',/)
C
CV    CALL WRITE2(VIEW,NZ,1,NZ,1,NZ)
C
C *** CALCULATE RADIATIVE COEFICIENT MATRIX
C
C ***************************
      CALL VIEWMX
C ***************************
C
      WRITE(6,2331) AR(LZ)
 2331 FORMAT(/,4X,' THE REAL AREAS USED IN RADIATION CALCULATION ARE',
     & /, 4X,'# HEAT SOURCE = ',F10.4,' FT**2',//,5X,'AR() FOR ',
     & 'INTERIOR WALL IN EACH WALL ZONE (FT**2), I=1,MZ',//)
C     WRITE(6,*)(AREA(I),I=1,MZ)
C
      CALL WRITE1(AR,1,NZ)
      WRITE(6,101)
  101 FORMAT(5X,' AREA(); # OF CELLS IN THIS ZONE',/)
      CALL WRITE1(AREA,1,NZ)
C
 1234 CONTINUE
C
      WRITE(6,2333) (STAR,I=1,100)
 2333 FORMAT(100A1,//)
C
C
C **********************************************************************
C                 >>> RETURN HERE EVERY TIME <<<
C **********************************************************************
C
  300 CONTINUE
C
      WRITE(6,3900)
 3900 FORMAT(6X,'NTREAL',5X,'TIME(SEC)',9X,'KTGP',5X,'PCORR(TOT)',
     & 5X,'%PF/PI',7X,'ITER',9X,'RESORM=',8X,'SORSUM=',//)
C
      NT=NT+1
      ITER=0
      NTREAL=NT+NTMAX0
      TIME=TIME+DTIME
```

```
      XTIME=TIME*H/U0
C
C *** THE TRANSIENT HEAT INPUT
C
CC    TIME1=DTIME*10.0*H/U0
      TIME2=85.71
      TIME3=120.0
      TIME4=240.0
CC    IF(XTIME.GT.TIME1) GO TO 60
CC    PCURVE=(.9167491E-5*XTIME*XTIME)+(.3306313E-3*XTIME)+(1.0)
CC    DPDT1=(1.8334982E-5*XTIME)+(.3306313E-3)
CC    QQ=8.316E7*DPDT1/TIME1*XTIME*2.0876
CC    GO TO 61
   60 IF(XTIME.GT.TIME2) GO TO 62
      PCURVE=(.9167491E-5*XTIME*XTIME)+(.3306313E-3*XTIME)+(1.0)
      DPDT1=(1.8334982E-5*XTIME)+(.3306313E-3)
      QQ=8.316E7*DPDT1*2.0876
C
C *** IN MANY OF THE FOLLOWING LINES A TEMPORARY CORRECTION FOR
C  *      ADJUSTING QQ TO AGREE WITH THE PRESSURE HAS BEEN APPLIED.
C *** OLDER CODE IS IDENTIFIED BY CC.
C
      GO TO 61
   62 IF(XTIME.GT.TIME3) GO TO 63
      PCURVE=(-.2138189E-20*XTIME**6)-(.2435482E-12*XTIME**5)+
     &   (.3501095E-9*XTIME**4)-(.1782647E-6*XTIME**3)+
     &   (.3518094E-4*XTIME*XTIME)-(.7541231E-3*XTIME)+1.0031876
      DPDT2=(-1.2829134E-20*XTIME*XTIME*XTIME*XTIME*XTIME)-
     &     (1.217741E-12*XTIME*XTIME*XTIME*XTIME)+
     &     (1.400438E-9*XTIME*XTIME*XTIME)-(5.347941E-7*XTIME*XTIME)+
     &     (7.036168E-5*XTIME)-(7.541231E-4)
      QQ=8.316E7*DPDT2*2.0876
      GO TO 61
   63 IF(XTIME.GT.TIME4) GO TO 64
      PCURVE=(-.2138189E-20*XTIME**6)-(.2435482E-12*XTIME**5)+
     &   (.3501095E-9*XTIME**4)-(.1782647E-6*XTIME**3)+
     &   (.3518094E-4*XTIME*XTIME)-(.7541231E-3*XTIME)+1.0031876
      DPDT3=(-239.0/3.0E7*XTIME)+(3.112E-3)
      QQ=8.316E7*DPDT3*2.0876
      GO TO 61
   64 PCURVE=(-.2138189E-20*XTIME**6)-(.2435482E-12*XTIME**5)+
     &   (.3501095E-9*XTIME**4)-(.1782647E-6*XTIME**3)+
     &   (.3518094E-4*XTIME*XTIME)-(.7541231E-3*XTIME)+1.0031876
      DPDT4=(-1.430E-10*(XTIME-420.0)*(XTIME-420.0)*(XTIME-420.0))+
             (-1.648E-8*(XTIME-420.0)*(XTIME-420.0))+(.0009)
      QQ=8.316E7*DPDT4*2.0876
   61 CONTINUE
      Q=QQ*3.4134/60./60.
   65 CONTINUE
      Q=Q*QCORRT
      WRITE(12) XTIME,Q
C
C *** THIS ENDS THE TEMPORARY PRESSURE CORRECTION IN THIS PROGRAM AREA
C
      DO 824 N=1,NHSZ
      QDOT(N)=Q/H**3/NHSW(N)/NHSD(N)/NHSH(N)/DX/DY/DZ
  824 CONTINUE
C
C  *** TIME DURATION BETWEEN PRINTOUTS
C
      NTRWR=NTREAL/NWRITE*NWRITE
      NTRWA=NTREAL/NWALT *NWALT
C
C
C *** WALL CAPACITANCES ARE THE FUNCTION OF TEMPERATURE.
C
      IF(KBOUND.NE.2.AND.KBOUND.NE.3)GO TO 722
C
      DO 725 I=2,NIM1
```

```
      DO 725 K=2,NKM1
      CPF (I,3,K)=ALFAW+BETAW*T(I,NJ,K)
      CPRE(I,3,K)=ALFAW+BETAW*T(I,1 ,K)
      DO 725 J=1,2
      CPF (I,J,K)=ALFAW+BETAW*TWF (I,J,K)
      CPRE(I,J,K)=ALFAW+BETAW*TWRE(I,J,K)
  725 CONTINUE
C
      DO 724 J=2,NJM1
      DO 724 K=2,NKM1
      CPR (3,J,K)=ALFAW+BETAW*T(NI,J,K)
      CPL (3,J,K)=ALFAW+BETAW*T(1, J,K)
      DO 724 I=1,2
      CPR (I,J,K)=ALFAW+BETAW*TWR (I,J,K)
      CPL (I,J,K)=ALFAW+BETAW*TWL (I,J,K)
  724 CONTINUE
C
      DO 723 I=2,NIM1
      DO 723 J=2,NJM1
      CPT (I,J,3)=ALFAW+BETAW*T(I,J,NK)
      CPB (I,J,3)=ALFAW+BETAW*T(I,J,1 )
      DO 723 K=1,2
      CPT (I,J,K)=ALFAW+BETAW*TWT (I,J,K)
      CPB (I,J,K)=ALFAW+BETAW*TWB (I,J,K)
  723 CONTINUE
  722 CONTINUE
C
C *** CALL CALVIS TO CALCULATE TURBULENT VISCOSITY
C
C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      IF(NTREAL.LE.51)GO TO 4020
C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
C    ****************************
C
      CALL CALVIS
C
C    ******************************
C
 4020 CONTINUE
C
C *** CALL SURRAD SUBROUNTINE TO CALCULATE RADIATIVE FLUX EVERY
C     "NRAD" TIME STEPS
C
      IF(KBOUND.NE.3.AND.KBOUND.NE.4)GO TO 1237
C
C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C     IF(XTIME.LE.2.)GO TO 1237
C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
      IF(NTREAL.NE.NTREAL/NRAD*NRAD)GO TO 1237
C
      DO 8 N=1,NHSZ
      LZ=MZ+N
      IB=IHSB(N)
      IE=IB+NHSW(N)-1
      JB=JHSB(N)
      JE=JB+NHSD(N)-1
      KB=KHSB(N)
      KE=KB+NHSH(N)-1
      D=0.
      SUM=0.
      DO 680 I=IB,IE
      DO 680 J=JB,JE
      DO 680 K=KB,KE
      SUM=SUM+T(I,J,K)*T(I,J,K)*T(I,J,K)*T(I,J,K)
      D=D+1.
  680 CONTINUE
      T4ZON(LZ)=SUM/D
```

```
      WRITE(6,9) N,T4ZON(LZ)
    9 FORMAT(/,5X,'HEAT SOURCE NUMBER :',I2,
     &         E11.4,3X,'AVERAGE TEMP. **4 =',E11.4,/)
    8 CONTINUE
C
C *********************************************
C
      CALL SURRAD
C
C *********************************************
C
      WRITE(6,1238)  RADHS
 1238 FORMAT(70X,'*** RADIOSITY FROM ALL HEAT SOURCE; RADHS=',E10.4)
 1237 CONTINUE
C
C ****************************
C    HEAT INPUT FOR FIRE
C    DEFINE THE HEAT SOURCE
C
      DO 826 N=1,NHSZ
      QF1(N)=QDOT(N)*H/(RA*TA*U0*CPAIR)
  826 CONTINUE
  310 CONTINUE
C
C ***********************************
C
C *** CALCULATE THE WALTAGE INPUTS AND THE TEMPERATURES OF HEAT ELEMENTS
C
C *** START CALCULATION
C
      ITERT=1
      KTGP=1
  375 CONTINUE
      ITER=0
      JTERM=0
      JJTERM=0
C
C *** DEFINE THE UPDATED TPD(I,J,K),R(I,J,K),U,V,W AND P
C
      DO 48 K=1,NK
      DO 48 J=1,NJ
      DO 48 I=1,NI
      TPD(I,J,K)=T(I,J,K)
      RPD(I,J,K)=R(I,J,K)
      UPD(I,J,K)=U(I,J,K)
      VPD(I,J,K)=V(I,J,K)
      WPD(I,J,K)=W(I,J,K)
      PPD(I,J,K)=P(I,J,K)
   48 CONTINUE
C 289 CONTINUE
   29 CONTINUE
      JTERM=JTERM+1
C
C *** ************************************************************
C
      CALL CALT(QDOT,QF1)
C
C *** ************************************************************
      IF(NTREAL.GT.100) GO TO 372
      DO 373 I=1,NI
      DO 373 J=1,NJ
      DO 373 K=1,NK
      IF(T(I,J,K).LT.1.) T(I,J,K)=1.
  373 CONTINUE
  372 CONTINUE
C
C     AAAA=-1.*BUOY*UGRT*Z(1)
C     DO 2010 J=1,NJ
C     DO 2010 I=1,NI
```

```
C     R(I,J,1)=EXP(AAAA)/T(I,J,1)
C2010 CONTINUE
C
C
C ******************************************************************
C *** GLOBLE PRESSURE CORRECTION FOR ENCLOSED TANK AIR
C
       SUMT=0.
       SUMPT=0.
       SUMPET=0.
       DO 370 I=2,NIM1
       DO 370 J=2,NJM1
       DO 370 K=2,NKM1
       SUMT=SUMT+1./T(I,J,K)
       SUMPT=SUMPT+P(I,J,K)/T(I,J,K)
       SUMPET=SUMPET+REQ(K)*(1./TINIT-1./T(I,J,K))
  370 CONTINUE
       SUMPET=SUMPET/UGRT
       PCORR=(SUMPET-SUMPT)/SUMT
       PCORRP=PCORR
       PCORRN=PCORR
       WRITE(6,289) PCORR
 289  FORMAT(5X,'PCORR =',1PE11.4/)
C
       DO 371 I=2,NIM1
       DO 371 J=2,NJM1
       DO 371 K=2,NKM1
       P(I,J,K)=P(I,J,K)+PCORRN
  371 CONTINUE
       PCORRT=PCORRP+PCORR
C
C *** END OF GLOBLE PRESSURE CORRECTION
C
C *******************************************************************
C
       TOTM=0.
C
       DO 2000 K=2,NKM1
       AAAA=BUOY*UGRT*Z(K)
       DO 2000 I=1,NIM1
       DO 2000 J=1,NJM1
       IF(T(I,J,K).LT.1.)  T(I,J,K)=1.
       R(I,J,K)=(UGRT*P(I,J,K)+(1./EXP(AAAA)))/T(I,J,K)
       TOTM=TOTM+R(I,J,K)
 2000 CONTINUE
       TOTM=TOTM*VOL*H*H*H*RA
       ERR1=(TOTMS-TOTM)/TOTMS*100.
C  *** ERROR IN TOTAL MASS DURING THIS TIME STEP
C
  301 ITER=ITER+1
C *** ***********************************************************
       CALL CALUV
       CALL CALW
       CALL CALP
C *** ***********************************************************
C     IF(RESORM.LE.0.05) GO TO 304
C     WRITE(6,3) ITER,RESORM,RSMP
C     IF(RESORM.LE.0.5) GO TO 304
    3 FORMAT(50X,'ITER=',I2,2X,'RESORM=',F8.5,1X,'SORSUM=',F8.5,
      & 2X,'ERRM =',E11.4,'%')
C     IF(ITER.GT.4)GO TO 304
C     IF(ITER.GE.2)GO TO 306
C     IF(ITER.EQ.3) GO TO 307
C     IF(ITER.GE.2) GO TO 306
C
C     RES1=RESORM
C     GO TO 301
C 306 IF(RESORM.GT.RES1)GO TO 307
C     GO TO 301
```

```
C 304 CONTINUE
      IF(RESORM(ITER).LE.SORMAX) GO TO 49
      IF(ITER.EQ.1) GO TO 302
      ITERM1=ITER-1
      IF(RESORM(ITER).LE.RESORM(ITERM1)) GO TO 302
      GO TO 304
  302 IF(JTERM.GE.2) GO TO 37
      SOURCE=RESORM(ITER)
      GO TO 39
   37 IF(RESORM(ITER).LE.SOURCE) GO TO 38
      GO TO 304
   38 SOURCE=RESORM(ITER)
   39 CONTINUE
      DO 23 K=1,NK
      DO 23 J=1,NJ
      DO 23 I=1,NI
      TPD(I,J,K)=T(I,J,K)
      RPD(I,J,K)=R(I,J,K)
      UPD(I,J,K)=U(I,J,K)
      VPD(I,J,K)=V(I,J,K)
      WPD(I,J,K)=W(I,J,K)
      PPD(I,J,K)=P(I,J,K)
   23 CONTINUE
      JJTERM=0
      IF(ITER.EQ.ITMAX) GO TO 49
      IF(JTERM.EQ.2) GO TO 35
      IF(ITER.EQ.4) GO TO 29
   35 CONTINUE
      IF(JTERM.EQ.3) GO TO 58
      IF(ITER.EQ.7) GO TO 29
   58 CONTINUE
      JJTERM=0
      WRITE(6,3) ITER,RESORM(ITER),SORSUM,ERR1
      GO TO 301
  304 CONTINUE
      JJTERM=JJTERM+1
      IF(JTERM.EQ.1) GO TO 41
      IF(JTERM.EQ.2.AND.JJTERM.EQ.1.AND.ITER.NE.5) GO TO 41
      GO TO 82
  41  CONTINUE
      IF(ITER.EQ.ITMAX) GO TO 49
      GO TO 49
   82 CONTINUE
      DO 43 K=1,NK
      DO 43 J=1,NJ
      DO 43 I=1,NI
      T(I,J,K)=TPD(I,J,K)
      R(I,J,K)=RPD(I,J,K)
      U(I,J,K)=UPD(I,J,K)
      V(I,J,K)=VPD(I,J,K)
      P(I,J,K)=PPD(I,J,K)
      W(I,J,K)=WPD(I,J,K)
   43 CONTINUE
      IF(ITER.EQ.ITMAX) GO TO 49
      IF((JTERM.EQ.3.AND.ITER.NE.8) .OR. JJTERM.EQ.2) GO TO 49
      GO TO 301
   49 CONTINUE
C
      IF(ITER.NE.ITMAX) GO TO 2435
      WRITE(6,222)
  222 FORMAT(//,1X,'ITER=ITMAX',/)
 2435 CONTINUE
CC
CC ** THE FOLLOWING PRESSURE TEST IS A TEMPORARY MEASURE TO MODIFY THE
CC    HEAT INPUT TO FORCE THE CALCULATED PRESSURE TO AGREE WITH THE
CC    EXPERIMENTAL PRESSURE.  IT WILL BE USED UNTIL ACCURATE HEAT INPUT
CC ** IS RECEIVED.
CC
      PSOUTH=P(20,9,16)*CONST1+REQ(16)
```

```
      PERROR=(PCURVE-PSOUTH)/PCURVE
      QCORR=1.0+PERROR-(PSOUTH-PM1)/PCURVE
CC    QCORR=1.0+PERROR-(PSOUTH-PM1)/PCURVE+(PSOUTH-PM1)/(PCURVE-PCURM1)*
CC   &    (PCURVE-PM1)/PCURVE
      QCORRT=QCORRT*QCORR
      PCURM1=PCURVE
      PM1=PSOUTH
      PRINT *
      PRINT *, '  PCURVE               PSOUTH               PERROR             QCOR
     &R             QCORRT             Q'
      PRINT *, PCURVE,PSOUTH,PERROR,QCORR,QCORRT,Q
      PRINT *
C
C *** SORSUM IS THE SUM OF ERROR SOURCE  FROM ALL OF THE CELLS
C     IN THE ENCLOSURE.
C
      WRITE(6,45) XTIME,NTREAL,TIME,ITER,RESORM(ITER),SORSUM,QF1(1),
     &    ERR1
C     WRITE(6,45)XTIME,NTREAL,TIME,ITER,RESORM,RSMP,QF1,ERR1
   45 FORMAT(1X, 'TIME=',F9.3,' SECS',1X,'NTREAL=',I5,1X,'TIME=',
     & F7.3, 1X,'ITER=',I2,1X,'RESORM=',F8.5,1X,'RSMP=',F6.4,2X,
     & 1X,'QF1=',F6.3,1X,'ERRM=',E11.4,'%',/)
C ***********************************************************************
C
C *** TO PRINT OUT THE FOLLOWING INFORMATION IS OPTIONAL
C
C     IF(NTREAL.NE.NTRWR)GO TO 661
C
C *** CALCULATE THE MAXIMUM PECLET NUMBER
      PEMAX=0.
      DO 6625 I=2,NIM1
      DO 6625 J=2,NJM1
      DO 6625 K=2,NKM1
      PENU=SQRT(U(I,J,K)*U(I,J,K)+V(I,J,K)*V(I,J,K)+
     &     W(I,J,K)*W(I,J,K))*U0*DX*H*R(I,J,K)*RA*H*U0/(30.43*VISL)
      IF(PENU.GE.PEMAX)GO TO 6623
      GO TO 6625
 6623 PEMAX=PENU
      IPMAX=I
      JPMAX=J
      KPMAX=K
 6625 CONTINUE
      WRITE(6,6624)IPMAX,JPMAX,KPMAX,PEMAX
 6624 FORMAT(/,2X,'AT I =',I3,' J =',I3,' K =',I3,
     & '  MAXIMUM PECLET NUMBER =',F10.3/)
      WRITE(6,*) 'THE VELOCITIES AT THE LOCATION OF THE MAXIMUM PECLET N
     &UMBER ARE:'
      WRITE(6,6626) U(IPMAX,JPMAX,KPMAX),V(IPMAX,JPMAX,KPMAX),
     &    W(IPMAX,JPMAX,KPMAX)
 6626 FORMAT(5X,'U=',F8.4,5X,'V=',F8.4,5X,'W=',F8.4,/)
 6666 CONTINUE
C
C *** PRINT OUT THE VELOCITY AND TEMPERATURE FIELD IN THE TANK
C
      IF(NTREAL .NE. NTREAL/NWRITE*NWRITE) GO TO 16
      WRITE(6,'(//1X,A76)') 'TEMPERATURES AT THE LEFT TC COLUMN, THE FIR
     &E COLUMN, AND THE RIGHT TC COLUMN'
      WRITE(6,'(/9X,A10,8X,A10,8X,A10/)') 'I= 3, J= 9','I=11, J= 9',
     &    'I=20, J= 9'
      DO 501 K=2,NKM1
          TCELSI(3,9,K)=TA/1.8*T(3,9,K)-273.15
          TCELSI(11,9,K)=TA/1.8*T(11,9,K)-273.15
          TCELSI(20,9,K)=TA/1.8*T(20,9,K)-273.15
          WRITE(6,'(1X,A2,I2,F12.1,F18.1,F18.1)') 'K=',K,TCELSI(3,9,K),
     &        TCELSI(11,9,K),TCELSI(20,9,K)
  501 CONTINUE
      XPN=P(3,9,16)*CONST1+REQ(16)
      XPS=P(20,9,16)*CONST1+REQ(16)
      WRITE (6,'(//1X,A15,F7.4,5X,A15,F7.4/)') 'NORTH PRESSURE=',XPN,
```

```
      &    'SOUTH PRESSURE=',XPS
   16 CONTINUE
C 661 CONTINUE
C
C ***********************************************************************
C
C *** CALCULATE THE ENERGY LOST THROUGH(OR CONSUMED BY)
C     1. THE TANK  WALLS.         2. TANK  AIR.
C
C    *****************************************************
C
       IF(KBOUND.NE.2.AND.KBOUND.NE.3)GO TO 22
       WWAL=QCONW +QRADW
   22 CONTINUE
C
C *** TANK  AIR
C
       WAIR=0.
       DO 25 I=2,NIM1
       DO 25 J=2,NJM1
       DO 25 K=2,NKM1
C     IF(NOD(I,J,K).GE.11)GO TO 25
       WAIR=WAIR+(T(I,J,K)-TOD(I,J,K))*R(I,J,K)*VOLDT
   25 CONTINUE
C
C *** SUM UP THE TOTAL WALT AT THAT TIME STEP
C
       WINS=0.
       DO 827 N=1,NHSZ
       WINS=WINS+QDOT(N)
  827 CONTINUE
C
C    *******************************************************
C *** THE ENERGY CALCULATION
C
       QSIN=QSIN+WINS*DTIME
       QSWAL=QSWAL-WWAL*DTIME
       QSAIR=QSAIR+WAIR*DTIME
C
C *** CALCULATE THE PERCENTAGE AND PRINT OUT THE RESULTS
C
       IF((NTREAL.NE.NTRWA).AND.(NTREAL.NE.NTRWR)) GO TO 1083
C
C *** WALT PERCENTAGE
C
       PAIR=WAIR/WINS*100.
       PWALL=-WWAL/WINS*100.
C
C *** ENERGY PERCENTAGE
C
       PSAIR=QSAIR/QSIN*100.
       PSWAL=QSWAL/QSIN*100.
C
C ***
C
       IF(NTREAL .NE. NWRITE) GO TO 17
       WRITE(6,1084)XTIME,WINS,WAIR
      & ,WWAL,QCONW ,QRADW
 1084 FORMAT(6X,'*** AT TIME = ',F9.4,' ***',/,
      & 9X,'THE WALTAGE INPUT; WINS = ',E10.4,/,
      & 9X,'WALTAGE INTO AIR; WAIR =',E10.4,/,
      &9X,'INTO THE WALL; WWAL =',E10.4,2X,'BY CONDUCTION; QCONW=',E10.4,
      & 2X,'BY RADIATION; QRADW  =',E10.4,//)
C
       WRITE(6,2728) QRADL ,QCONL ,QRADR,QCONR,QRADRE,QCONRE,
      &              QRADF ,QCONF ,QRADB,QCONB,QRADT ,QCONT
 2728 FORMAT(9X,'QRADL : INTO LEFT WALL BY RADIATION= ',E10.4,
      & 9X,'QCONL : BY CONDUCTION =',E10.4,/,
      & 9X,'QRADR : INTO RIGHT WALL BY RADIATION= ',E10.4,/,
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     & 9X,'QCONR : BY CONDUCTION = ',E10.4,/,
     & 9X,'QREARE: INTO REAR WALL BY RADIATION= ',E10.4,
     & 9X,'QCONRE: BY CONDUCTION = ',E10.4,/,
     & 9X,'QRADF : INTO FRONT WALL BY RADIATION= ',E10.4,
     & 9X,'QCONF : BY CONDUCTION = ',E10.4,/,
     & 9X,'QRADB : INTO FLOOR BY RADIATION= ',E10.4,
     & 9X,'QCONB : BY CONDUCTION = ',E10.4,/,
     & 9X,'QRADT : INTO TOP  BY RADIATION= ',E10.4,
     & 9X,'QCONT : BY CONDUCTION = ',E10.4,//)
C
      WRITE(6,1091)QSIN,QSAIR,QSWAL
 1091 FORMAT(9X,'QSIN : TOTAL ENERGY INPUT=',E10.4,/,
     & 9X,'QSAIR : TOTAL ENERGY INTO CAVITY AIR=',E10.4,/,
     & 9X,'QSWAL : TOTAL ENERGY INTO WALLS=',E10.4,2X,//)
C
      WRITE(6,1088) PAIR,PWALL,PSAIR,PSWAL
 1088 FORMAT(9X,'PAIR : LOSS INTO CAVITY AIR=',F8.3,' %',/,
     &       9X,'PWALL: LOSS INTO THE WALLS =',F8.3,' %',/,
     &       9X,'PSAIR: TOTAL INTO CAVITY AIR =',F8.3,' %',/,
     &       9X,'PSWAL: TOTAL INTO THE WALLS=',F8.3,' %',//)
C
   17 CONTINUE
C
C *** THE TOTAL ENERGY DISTRIBUTION.
C
      QQ=WINS
      PQAIR=QSAIR/QQ*100.
      PQWAL=QSWAL/QQ*100.
      WRITE(6,1093)XTIME,PQAIR,PQWAL,QQ
 1093 FORMAT(6X,'** AT TIME =',F9.3,' PERCENTAGE OF TEST ENERGY INPUT ',
     & /,9X,'PWAIR : INTO CAVITY AIR =',F8.3,' %',/,
     & 9X,'PQWAL : INTO THE WALLS=',F8.3,' %',/,
     & 9X,'QQ    : TOTAL ENERGY INPUT = ',E10.4,//)
C
 1083 CONTINUE
C
C *** CALCULATE THE AVERAGE TEMPERATURES OF THE WALLS AND PRINT THEM OUT
C
      IF((NTREAL.NE.NTRWA).AND.(NTREAL.NE. NTRWR)) GO TO 662
      STT =0.
      STB =0.
      STRE=0.
      STF =0.
      STR =0.
      STL =0.
      DO 663 I=2,NIM1
      DO 663 J=2,NJM1
      STB =STB +T(I,J,1)
C     IF(NOD(I,J,NKM1).EQ.2)GO TO 663
      STT =STT +T(I,J,NK)
  663 CONTINUE
      DO 664 I=2,NIM1
      DO 664 K=2,NKM1
      STRE=STRE+T(I,1,K)
C     IF(NOD(I,NJM1,K).EQ.2)GO TO 664
      STF =STF +T(I,NJ,K)
  664 CONTINUE
      DO 665 J=2,NJM1
      DO 665 K=2,NKM1
      STR =STR +T(NI,J,K)
      STL =STL +T(1,J,K)
  665 CONTINUE
      AVT =STT /CELLT *TA-460.
      AVB =STB /CELLB *TA-460.
      AVRE=STRE/CELLRE*TA-460.
      AVF =STF /CELLF *TA-460.
      AVR =STR /CELLR *TA-460.
      AVL =STL /CELLL *TA-460.
C
```

```
      WRITE(6,666)XTIME,AVT,AVB,AVRE,AVF,AVR,AVL
  666 FORMAT(/,3X,'*** AT TIME = ',F9.4,' ***',/,2X,'* THE AVERAGE ',
     &  'TEMPEATURE OF *',/,6X,'TOP  WALL =',F10.5,2X,'BOTTOM WALL=',
     & F10.5,/,6X,'REAR WALL =',F10.5,2X,'FRONT WALL =',F10.5,
     &  /,6X,'RIGHT WALL=',F10.5,2X,'LEFT  WALL =',F10.5,//)
  662 CONTINUE
C *********************************************************************
C
C *** RESET THE OLD VALUES
C
C  **** ALSO USED IN T4ZON(LZ)
C
      DO 305 K=1,NK
      DO 305 J=1,NJ
      DO 305 I=1,NI
      UOD(I,J,K)=U(I,J,K)
      VOD(I,J,K)=V(I,J,K)
      WOD(I,J,K)=W(I,J,K)
      TOD(I,J,K)=T(I,J,K)
      ROD(I,J,K)=R(I,J,K)
      P(I,J,K)=P(I,J,K)
  305 CONTINUE
C
C *** SAVE VALUES FOR PLOTTING
C
      IF (XTIMEI .LT. 10.) GO TO 306
          XTIMEI=0.
          WRITE(10)
     &         XTIME,TOD,ROD,UOD,VOD,WOD,P,VIS
  306 CONTINUE
      XTIMEI=XTIMEI+DTIME*H/U0
C *********************************************************************
CC    CALL TLEFT(IT)
CC    IF(IT.LE.ITLEFT) GO TO 303
      IF(TIMREM(0.) .LE. 40.) GO TO 303
      IF(XTIME.LT.TMAX)GO TO 300
C
  303 CONTINUE
C
      WRITE(9)
     & TIME,NTREAL,TOD,ROD,UOD,VOD,WOD,P,VIS,XTIMEI
     &,QSIN,QSWAL,QSAIR,PCURM1,PM1,QCORRT
     &,TWF ,TWRE,TWR ,TWL ,TWB ,TWT  ,RLW,RRW,RREW,RFW,RBW,RTW
     &,RADHS,QRADF ,QRADW ,QRADB,QRADL,QRADR,QRADT,QRADRE
      WRITE(11)
     & TIME,NTREAL,TOD,ROD,UOD,VOD,WOD,P,VIS,XTIMEI
     &,QSIN,QSWAL,QSAIR,PCURM1,PM1,QCORRT
     &,TWF ,TWRE,TWR ,TWL ,TWB ,TWT  ,RLW,RRW,RREW,RFW,RBW,RTW
     &,RADHS,QRADF ,QRADW ,QRADB,QRADL,QRADR,QRADT,QRADRE
 9303 CONTINUE
C
      STOP
      END
      SUBROUTINE CALT(QDOT,QF1)
C **********************************************************************
C
      COMMON /BL1/BUOY,VISL,VOL,VOLDT,KBOUND,DTIME,NTREAL,SORSUM,NWRITE
      COMMON /BL2/ DX,DY,DZ,DXY,DYZ,DZX,XYOZ,YZOX,ZXOY,XYPZ,YZPX,ZXPY
      COMMON /BL3/ NI,NJ,NK,NIM1,NJM1,NKM1,NIM2,NJM2,NKM2
      COMMON/CONS/XTIME,NT,U0,PRT,TA,
     &           NTMAX0,RA,CPAIR,SIGMA
      COMMON/NE/   U(22,18,18),V(22,18,18),T(22,18,18),R(22,18,18),
     &          P(22,18,18),W(22,18,18),WOD(22,18,18)
C    &          P(22,18,18),W(22,18,18),WOD(22,18,18),NOD(22,18,18)
      COMMON/OD/UOD(22,18,18),VOD(22,18,18),TOD(22,18,18),ROD(22,18,18)
      COMMON/BL31/TPD(22,18,18),RPD(22,18,18),UPD(22,18,18),
     &  VPD(22,18,18),WPD(22,18,18),PPD(22,18,18),RESORM(20),ITER
      COMMON/CO/AP(22,18,18),AE(22,18,18),AW(22,18,18),AN(22,18,18),
     & AS(22,18,18),SU(22,18,18),SP(22,18,18),AF(22,18,18),AB(22,18,18)
```

```
      COMMON/PP/DU(22,18,18),DV(22,18,18),DW(22,18,18),PP(22,18,18)
      COMMON/BL10/ Z(30),REQ(30),VIS(22,18,18),RRES(3)
      COMMON/BL12/ DYZO2,DZXO2,DXYO2,XYPZ2,YZPX2,ZXPY2,DX4,DY4,DZ4
     &         ,XYOZ2,YZOX2,ZXOY2,DYZO4,DZXO4,DXYO4
      COMMON /BL4/ QCONW ,
     &    QRADF ,QRADW ,ARFP,ARFS,QRADB,QCONB,QRADL,QCONL,QRADR,QCONR,
     &    QRADT,QCONT,QRADRE,QCONRE
      COMMON/WCAP/TWF (21,2,17),TWRE(21,2,17),TWR (2,17,17),
     &             TWL (2,17,17),TWB (21,17,2),TWT (21,17,2),
     &             CPF (21,3,17),CPRE(21,3,17),CPR (3,17,17),
     &             CPL (3,17,17),CPB (21,17,3),CPT (21,17,3)
     &            ,DXW,DYW,DZW,VOLW,ALFAW,BETAW,HCOEF,TINF,
     &             CCOWL,CCOWR,CCOWRE,CCOWF,CCOWB,CCOWT
      COMMON/RAD/RLW(17,17),RRW(17,17),RREW(21,17),RFW(21,17),RBW(21,17)
     &           ,RTW(21,17),RADHS
C
      COMMON /VIEW1/ MI,MJ,MK,MII,MJJ,MKK,MIM,MIP,MJM,MJP,MKM,MKP,
     &               MIIM,MIIP,MJJM,MJJP,MKKM,MKKP,NHSZ,LZ,NZ,MZ,
     &               IREGN1,IREGN2,IREGN3,IREGN4,IREGN5,IREGN6,IREGN7,
     &               MREGN1,MREGN2,MREGN3,MREGN4,MREGN5,MREGN6,MREGN7
      COMMON /VIEW2/ MIIZ(9),MJJZ(9),MKKZ(9),LI(9),LJ(9),LK(9),
     &                ITHIN(9),JTHIN(9),KTHIN(9),AXY(9),AYZ(9),AZX(9),
     &                IHSB(9),JHSB(9),KHSB(9),NHSW(9),NHSD(9),NHSH(9),
     &                LTYPE(9,6)
C
      DIMENSION QDOT(1),QF1(1)
C
      DO 100 I=2,NIM1
      IP1=I+1
      IM1=I-1
      DO 100 J=2,NJM1
      JP1=J+1
      JM1=J-1
      DO 100 K=2,NKM1
      KP1=K+1
      KM1=K-1
C
C     IF(NOD(I,J,K).GE.11)GO TO 100
C
      CE=(R(I,J,K)+R(IP1,J,K))*U(IP1,J,K)*DYZO2
      CW=(R(I,J,K)+R(IM1,J,K))*U(I  ,J,K)*DYZO2
      CN=(R(I,J,K)+R(I,JP1,K))*V(I,JP1,K)*DZXO2
      CS=(R(I,J,K)+R(I,JM1,K))*V(I,J  ,K)*DZXO2
      CF=(R(I,J,K)+R(I,J,KP1))*W(I,J,KP1)*DXYO2
      CB=(R(I,J,K)+R(I,J,KM1))*W(I,J,K  )*DXYO2
C
      VISCE=VIS(IP1,J,K)
      VISCW=VIS(IM1,J,K)
      VISCS=VIS(I,JM1,K)
      VISCN=VIS(I,JP1,K)
      VISCB=VIS(I,J,KM1)
      VISCF=VIS(I,J,KP1)
      AE(I,J,K)=0.5*( ABS(CE)-CE)+YZPX*VISCE
      AW(I,J,K)=0.5*( ABS(CW)+CW)+YZPX*VISCW
      AN(I,J,K)=0.5*( ABS(CN)-CN)+ZXPY*VISCN
      AS(I,J,K)=0.5*( ABS(CS)+CS)+ZXPY*VISCS
      AF(I,J,K)=0.5*( ABS(CF)-CF)+XYPZ*VISCF
      AB(I,J,K)=0.5*( ABS(CB)+CB)+XYPZ*VISCB
C
      SP(I,J,K)=-ROD(I,J,K)*VOLDT
      SU(I,J,K)= ROD(I,J,K)*VOLDT*TOD(I,J,K)
  100 CONTINUE
C
C *** CONSIDER THE SOLID BOUNDARIES AND FREE BOUNDARIES.
C     FOUR DIFFERENT CASES ARE AVAILABLE
C
C *** TOP AND BOTTOM
C
      DO 111 I=2,NIM1
```

```
      DO 111 J=2,NJM1
      AF(I,J,NKM1)=0.
C     IF(NOD(I,J,NKM1).NE. 2) GO TO 116
      CF=(R(I,J,NKM1)+R(I,J,NK))*W(I,J,NK)*DXYO2
      IF(CF.GE.0.) GO TO 116
      VISF=VISL
      SU(I,J,NKM1)=SU(I,J,NKM1)+(0.5*(ABS(CF)-CF)+XYPZ*VISF)*TOD(I,J,NK)
      SP(I,J,NKM1)=SP(I,J,NKM1)- 0.5*(ABS(CF)-CF)-XYPZ*VISF
  116 AB(I,J,2)=0.
  111 CONTINUE
      IF(KBOUND.NE.2.AND.KBOUND.NE.3) GO TO 301
      DO 304 I=2,NIM1
      DO 304 J=2,NJM1
      SU(I,J,2   )=SU(I,J,2   )+XYPZ2*VIS(I,J,2     )*TOD(I,J,1    )
      SP(I,J,2   )=SP(I,J,2   )-XYPZ2*VIS(I,J,2     )
C     IF(NOD(I,J,NKM1).EQ. 2) GO TO 304
      SU(I,J,NKM1)=SU(I,J,NKM1)+XYPZ2*VIS(I,J,NKM1)*TOD(I,J,NK     )
      SP(I,J,NKM1)=SP(I,J,NKM1)-XYPZ2*VIS(I,J,NKM1)
  304 CONTINUE
  301 CONTINUE
C
C *** RIGHT WALL AND LEFT WALL
C
      DO 212 J=2,NJM1
      DO 212 K=2,NKM1
      AE(NIM1,J,K)=0.
      AW(2,J,K)=0.
  212 CONTINUE
      IF(KBOUND.NE.3.AND.KBOUND.NE.2)GO TO 117
      DO 302 J=2,NJM1
      DO 302 K=2,NKM1
      SU(NIM1,J,K)=SU(NIM1,J,K)+YZPX2*VIS(NIM1,J,K)*TOD(NI,J,K      )
      SP(NIM1,J,K)=SP(NIM1,J,K)-YZPX2*VIS(NIM1,J,K)
      SU(2,J,K    )=SU(2,J,K    )+YZPX2*VIS(2,J,K      )*TOD(1,J,K    )
      SP(2,J,K    )=SP(2,J,K    )-YZPX2*VIS(2,J,K      )
  302 CONTINUE
  117 CONTINUE
C
C *** FRONT DOOR WALL AND REAR WALL
C
      DO 103 K=2,NKM1
      DO 103 I=2,NIM1
      AN(I,NJM1,K)=0.
C     IF(NOD(I,NJM1,K ).NE. 2) GO TO 119
      CN=(R(I,NJM1,K )+R(I,NJ,K))*V(I,NJ,K)*DXYO2
      IF(CN.GE.0.) GO TO 119
      VISN=VISL
      SU(I,NJM1,K)=SU(I,NJM1,K)+(0.5*(ABS(CN)-CN)+ZXPY*VISN)*TOD(I,NJ,K)
      SP(I,NJM1,K )=SP(I,NJM1,K)- 0.5*(ABS(CN)-CN)-ZXPY*VISN
  119 AS(I,2,K)=0.
  103 CONTINUE
      IF(KBOUND.NE.3.AND.KBOUND.NE.2)GO TO 118
      DO 305 K=2,NKM1
      DO 305 I=2,NIM1
      SU(I,2,K  )=SU(I,2,K  )+ZXPY2*VIS(I,2,K     )*TOD(I,1, K  )
      SP(I,2,K  )=SP(I,2,K  )-ZXPY2*VIS(I,2,K     )
C     IF(NOD(I,NJM1,K ).EQ. 2) GO TO 305
      SU(I,NJM1,K)=SU(I,NJM1,K)+ZXPY2*VIS(I,NJM1,K)*TOD(I,NJ,K      )
      SP(I,NJM1,K)=SP(I,NJM1,K)-ZXPY2*VIS(I,NJM1,K)
  305 CONTINUE
  118 CONTINUE
C
C *** VOLUMETRICAL HEAT SOURCE INPUT
C
      DO 102 N=1,NHSZ
      IB=IHSB(N)
      IE=IB+NHSW(N)-1
      JB=JHSB(N)
      JE=JB+NHSD(N)-1
```

```
      KB=KHSB(N)
      KE=KB+NHSH(N)-1
      DO 101 I=IB,IE
      DO 101 J=JB,JE
      DO 101 K=KB,KE
      SU(I,J,K)=SU(I,J,K)+QF1(N)*VOL
  101 CONTINUE
  102 CONTINUE
C
C *** THE TEST BLOCK
C
C
C *** THE CELLS INSIDE THE TEST BLOCK AND HEAT ELEMENTS WILL NOT
C     BE CALCULATED. THE VALUES OF AP AND SU ARE GIVEN IN MAIN PROGRAM.
C
C *** ASSEMBLE THE COEFICIENTS AND SOLVE THE EQUATIONS
C
      DO 300 I=2,NIM1
      DO 300 J=2,NJM1
      DO 300 K=2,NKM1
C     IF(NOD(I,J,K).GE.11)GO TO 300
      AP(I,J,K)=AE(I,J,K)+AW(I,J,K)+AN(I,J,K)+AS(I,J,K)+AF(I,J,K)+
     &          AB(I,J,K)-SP(I,J,K)
  300 CONTINUE
C
      IF(NTREAL.NE.0.AND.NTREAL.NE.0 )GO TO 3321
      DO 3322 I=2,NIM1
      WRITE(6,3323)I
 3323 FORMAT(/,2X,'I =',I2,2X,'TEMP')
      DO 3322 J=2,NJM1
      WRITE(6,3324)J
 3324 FORMAT(/,2X,'J =',I2,5X,'AE',9X,'AS',9X,'AW',9X,'AN',
     & 9X,'AF',9X,'AB',9X,'AP',9X,'SU')
      DO 3322 K=2,NK
      WRITE(6,3325)K,AE(I,J,K),AS(I,J,K),AW(I,J,K),AN(I,J,K),
     &               AF(I,J,K),AB(I,J,K),AP(I,J,K),SU(I,J,K)
 3325 FORMAT(2X,'K=',I2,1X,8(E11.5,1X))
 3322 CONTINUE
 3321 CONTINUE
C
      CALL TRID(2,2,2,NIM1,NJM1,NKM1,T)
C
C ***********************************************************************
C *      CALCULATE THE TEMPERATURES AT SOLID BOUNDARIES.                *
C ***********************************************************************
C
      GO TO (70,71,71,72),KBOUND
C
C ***    FOR THE CASE OF WALL CAPACITANCE CONSIDERED WITH RADIATION
C
   71  CONTINUE
      QCONF =0.
      QCONRE=0.
      QCONL =0.
      QCONR =0.
      QCONT =0.
      QCONB =0.
      QCONW =0.
C
      DO 271 I=2,NIM1
      DO 271 K=2,NKM1
      WWF =VIS(I,NJM1,K)*(TOD(I,NJ,K)-T(I,NJM1,K))*ZXPY2
      T(I,NJ,K)=TOD(I,NJ,K)-(WWF +RFW(I,K))/CCOWF
      TWF (I,2,K)=TWF (I,2,K)+(DZXO2*(CPF (I,2,K)+CPF (I,1,K))/DYW*
     & (TWF (I,1,K)-TWF (I,2,K))+DZXO2*(CPF (I,2,K)+CPF (I,3,K))/DYW*
     & (TOD(I,NJ,K)-TWF (I,2,K)))/CCOWF
      TWF (I,1,K)=TWF (I,1,K)+2.*(DZXO2*(CPF (I,2,K)+CPF (I,1,K))/DYW*
     & (TWF (I,2,K)-TWF (I,1,K))-DZX*(TWF (I,1,K)-TINF)*HCOEF)/CCOWF
      QCONF =QCONF +WWF
```

```
C
      WWRE=VIS(I,2,K)*(TOD(I,1 ,K)-T(I,2,K))*ZXPY2
      T(I,1 ,K)=TOD(I,1 ,K)+(DZXO2*(TWRE(I,2,K)-TOD(I, 1,K))
     & *(CPRE(I,2,K)+CPRE(I,3,K))/DXW-WWRE-RREW(I,K))/CCOWRE
      TWRE(I,2,K)=TWRE(I,2,K)+(DZXO2*(CPRE(I,2,K)+CPRE(I,1,K))/DXW*
     &  (TWRE(I,1,K)-TWRE(I,2,K))+DZXO2*(CPRE(I,2,K)+CPRE(I,3,K))/DXW*
     &  (TOD(I,1 ,K)-TWRE(I,2,K)))/CCOWRE
      TWRE(I,1,K)=TWRE(I,1,K)+2.*(DZXO2*(CPRE(I,2,K)+CPRE(I,1,K))/DXW*
     &  (TWRE(I,2,K)-TWRE(I,1,K))-DZX*(TWRE(I,1,K)-TINF)*HCOEF)/CCOWRE
      QCONRE=QCONRE+WWRE
 271  CONTINUE
      DO 273 J=2,NJM1
      DO 273 K=2   ,NKM1
      WWL =VIS(2,J,K)*(TOD(1,J ,K)-T(2,J,K))*YZPX2
      T(1,J ,K)=TOD(1,J ,K)+(DYZO2*(CPL (3,J,K)+CPL (2,J,K))
     &  /DXW*(TWL (2,J,K)-TOD(1,J,K))-WWL -RLW(J,K))/CCOWL
      TWL (2,J,K)=TWL (2,J,K)+(DYZO2*(CPL (2,J,K)+CPL (1,J,K))/DXW*
     &  (TWL (1,J,K)-TWL (2,J,K))+DYZO2*(CPL (2,J,K)+CPL (3,J,K))/DXW*
     &  (TOD(1,J ,K)-TWL (2,J,K)))/CCOWL
      TWL (1,J,K)=TWL (1,J,K)+2.*(DYZO2*(CPL (2,J,K)+CPL (1,J,K))/DXW*
     &  (TWL (2,J,K)-TWL (1,J,K))-DYZ*(TWL (1,J,K)-TINF)*HCOEF)/CCOWL
C
      WWR =VIS(NIM1,J,K)*(TOD(NI,J ,K)-T(NIM1,J,K))*YZPX2
      T(NI,J,K)=TOD(NI,J,K)+(DYZO2*(CPR (3,J,K)+CPR (2,J,K))
     &  /DXW*(TWR (2,J,K)-TOD(NI,J,K))-WWR -RRW(J,K))/CCOWR
      TWR (2,J,K)=TWR (2,J,K)+(DYZO2*(CPR (2,J,K)+CPR (1,J,K))/DXW*
     &  (TWR (1,J,K)-TWR (2,J,K))+DYZO2*(CPR (2,J,K)+CPR (3,J,K))/DXW*
     &  (TOD(NI,J,K)-TWR (2,J,K)))/CCOWR
      TWR (1,J,K)=TWR (1,J,K)+2.*(DYZO2*(CPR (2,J,K)+CPR (1,J,K))/DXW*
     &  (TWR (2,J,K)-TWR (1,J,K))-DYZ*(TWR (1,J,K)-TINF)*HCOEF)/CCOWR
      QCONR =QCONR +WWR
      QCONL =QCONL +WWL
 273  CONTINUE
      DO 274 J=2,NJM1
      DO 274 I=2   ,NIM1
      WWT =VIS(I,J,NKM1)*(TOD(I,J,NK)-T(I,J,NKM1))*XYPZ2
      T(I,J,NK)=TOD(I,J,NK)+(DXYO2*(CPT (I,J,3)+CPT (I,J,2))
     &  /DZW*(TWT (I,J,2)-TOD(I,J,NK))-WWT -RTW(I,J))/CCOWT
      TWT (I,J,2)=TWT (I,J,2)+(DXYO2*(CPT (I,J,2)+CPT (I,J,1))/DZW*
     &  (TWT (I,J,1)-TWT (I,J,2))+DZXO2*(CPT (I,J,2)+CPT (I,J,3))/DZW*
     &  (TOD(I,J,NK)-TWT (I,J,2)))/CCOWT
      TWT (I,J,1)=TWT (I,J,1)+2.*(DXYO2*(CPT (I,J,2)+CPT (I,J,1))/DZW*
     &  (TWT (I,J,2)-TWT (I,J,1))-DXY*(TWT (I,J,1)-TINF)*HCOEF)/CCOWT
      QCONT =QCONT +WWT
C
      WWB =VIS(I,J,2)*(TOD(I,J,1)-T(I,J, 2))*XYPZ2
      T(I,J,1 )=TOD(I,J,1 )+(DXYO2*(CPB (I,J,3)+CPB (I,J,2))
     &  /DZW*(TWB (I,J,2)-TOD(I,J,1 ))-WWB -RBW(I,J))/CCOWB
      TWB (I,J,2)=TWB (I,J,2)+(DXYO2*(CPB (I,J,2)+CPB (I,J,1))/DZW*
     &  (TWB (I,J,1)-TWB (I,J,2))+DXYO2*(CPB (I,J,2)+CPB (I,J,3))/DZW*
     &  (T(I,J ,1)-TWB (I,J,2)))/CCOWB
      TWB (I,J,1)=TWB (I,J,1)+2.*(DXYO2*(CPB (I,J,2)+CPB (I,J,1))/DZW*
     &  (TWB (I,J,2)-TWB (I,J,1))-DXY*(TWB(I,J,1)-TINF)*HCOEF)/CCOWB
      QCONB =QCONB +WWB
 274  CONTINUE
      QCONW =QCONB+QCONR+QCONT+QCONL+QCONRE+QCONF
      GO TO 73
C
C *** FOR THE CASE OF INSULATED WALLS
C
   70 CONTINUE
      DO 74 I=2,NIM1
      DO 74 J=2,NJM1
      T(I,J,1)=T(I,J,2)
C     IF(NOD(I,J,NKM1).EQ. 2) GO TO 74
      T(I,J,NK)=T(I,J,NKM1)
   74 CONTINUE
      DO 80 J=2,NJM1
      DO 80 K=2,NKM1
```

```
      T(1,J,K)=T(2,J,K)
      T(NI,J,K)=T(NIM1,J,K)
   80 CONTINUE
      DO 76 K=2,NKM1
      DO 76 I=2,NIM1
      T(I,1,K)=T(I,2,K)
C     IF(NOD(I,NJM1,K).EQ. 2) GO TO 76
      T(I,NJ,K)=T(I,NJM1,K)
   76 CONTINUE
      GO TO 73
C
C *** FOR THE CASE OF THE RADIATION WITH THE INSULATED WALLS,
C     NOT AVAILABEL YET.
C
   72 CONTINUE
C
C *** FOR THE FREE BOUNDARY
C
   73 CONTINUE
C
      RETURN
      END
      SUBROUTINE SURRAD
C *********************************************************************
C
      COMMON /BL1/BUOY,VISL,VOL,VOLDT,KBOUND,DTIME,NTREAL,SORSUM,NWRITE
      COMMON /BL2/ DX,DY,DZ,DXY,DYZ,DZX,XYOZ,YZOX,ZXOY,XYPZ,YZPX,ZXPY
      COMMON /BL3/ NI,NJ,NK,NIM1,NJM1,NKM1,NIM2,NJM2,NKM2
      COMMON /BL4/ QCONW ,
     &    QRADF ,QRADW ,ARFP,ARFS,QRADB,QCONB,QRADL,QCONL,QRADR,QCONR,
     &    QRADT,QCONT,QRADRE,QCONRE
      COMMON/NE/   U(22,18,18),V(22,18,18),T(22,18,18),R(22,18,18),
     &          P(22,18,18),W(22,18,18),WOD(22,18,18)
C    &         P(22,18,18),W(22,18,18),WOD(22,18,18),NOD(22,18,18)
      COMMON/RAD/RLW(17,17),RRW(17,17),RREW(21,17),RFW(21,17),RBW(21,17)
     &          ,RTW(21,17),RADHS
      COMMON/VF/VFMXC(67,67),T4ZON(67),TZON(67),RZON(67),AR(67)
     &         ,AREA(67),VIEW(67,67),CONSRA
      COMMON /VIEW1/ MI,MJ,MK,MII,MJJ,MKK,MIM,MIP,MJM,MJP,MKM,MKP,
     &              MIIM,MIIP,MJJM,MJJP,MKKM,MKKP,NHSZ,LZ,NZ,MZ,
     &              IREGN1,IREGN2,IREGN3,IREGN4,IREGN5,IREGN6,IREGN7,
     &              MREGN1,MREGN2,MREGN3,MREGN4,MREGN5,MREGN6,MREGN7
      COMMON /VIEW2/ MIIZ(9),MJJZ(9),MKKZ(9),LI(9),LJ(9),LK(9),
     &               ITHIN(9),JTHIN(9),KTHIN(9),AXY(9),AYZ(9),AZX(9),
     &               IHSB(9),JHSB(9),KHSB(9),NHSW(9),NHSD(9),NHSH(9),
     &               LTYPE(9,6)
C
C *** AREA() ; # OF CELL IN EACH OF THE SURFACE ZONE
C *** AR()   ; PHYSICAL AREA OF EACH SURFACE ZONE * H*H
C *** TZON() ; AVERAGE TEMPERATURE OF THE SURFACE ZONE
C *** T4ZON(); AVERAGE TEMPERATURE**4 OF THE SURFACE ZONE
C *** RZON() ; SIGMA OF VIEW FACTOR MATRIX COEFF. * T**4
C *** RLW , RRW,
C     RREW, RFW,
C     RBW , RTW ; RZON() FOR EACH CELL WITHIN ITS SURFACE ZONE
C *** RADHS  ; RADIOSITY OF EACH HEAT SOURCE
C *** QRADW  ; TOTAL RADIATIVE HEAT FROM ALL INTERIOR WALLS
C
C *** SURFACE RADIATION CONSTANTS, WHICH WILL BE INCLUDED INTO VIEW
C     FACTOR CALCULATION IN ORDER TO SAVE CPU TIME
C
C
C
      DO 401 I=1,NZ
      RZON (I)=0.
  401 CONTINUE
      RADHS=0.
C
C ************************
```

```
C *** LEFT AND RIGHT WALLS
C *************************
C
      N1=MREGN1+1
      N2=MREGN2+1
      JJJ=1
      DO 131 JJ=1,MJ
      J1=JJJ+1
      J2=JJJ+LJ(JJ)
      KKK=1
      DO 121 KK=1,MK
      SUM1=0.
      SUM2=0.
      K1=KKK+1
      K2=KKK+LK(KK)
      DO 132 J=J1,J2
      DO 132 K=K1,K2
      SUM1=SUM1+T( 1,J,K)*T( 1,J,K)*T( 1,J,K)*T( 1,J,K)
      SUM2=SUM2+T(NI,J,K)*T(NI,J,K)*T(NI,J,K)*T(NI,J,K)
  132 CONTINUE
      T4ZON(N1)=SUM1/AREA(N1)
      T4ZON(N2)=SUM2/AREA(N2)
      KKK=K2
      N1=N1+1
      N2=N2+1
  121 CONTINUE
      JJJ=J2
  131 CONTINUE
C
C
C *************************
C *** REAR AND FRONT WALLS
C *************************
C
      N3=MREGN3+1
      N4=MREGN4+1
      III=1
      DO 133 II=1,MI
      I1=III+1
      I2=III+LI(II)
      KKK=1
      DO 123 KK=1,MK
      SUM1=0.
      SUM2=0.
      K1=KKK+1
      K2=KKK+LK(KK)
      DO 134 I=I1,I2
      DO 134 K=K1,K2
      SUM1=SUM1+T(I, 1,K)*T(I, 1,K)*T(I, 1,K)*T(I, 1,K)
      SUM2=SUM2+T(I,NJ,K)*T(I,NJ,K)*T(I,NJ,K)*T(I,NJ,K)
  134 CONTINUE
      T4ZON(N3)=SUM1/AREA(N3)
      T4ZON(N4)=SUM2/AREA(N4)
      KKK=K2
      N3=N3+1
      N4=N4+1
  123 CONTINUE
      III=I2
  133 CONTINUE
C
C
C *************************
C *** BOTTOM AND TOP WALLS
C *************************
C
      N5=MREGN5+1
      N6=MREGN6+1
      III=1
      DO 135 II=1,MI
```

```
      I1=III+1
      I2=III+LI(II)
      JJJ=1
      DO 125 JJ=1,MJ
      SUM1=0.
      SUM2=0.
      J1=JJJ+1
      J2=JJJ+LJ(JJ)
      DO 136 I=I1,I2
      DO 136 J=J1,J2
      SUM1=SUM1+T(I,J, 1)*T(I,J, 1)*T(I,J, 1)*T(I,J, 1)
      SUM2=SUM2+T(I,J,NK)*T(I,J,NK)*T(I,J,NK)*T(I,J,NK)
  136 CONTINUE
      T4ZON(N5)=SUM1/AREA(N5)
      T4ZON(N6)=SUM2/AREA(N6)
      JJJ=J2
      N5=N5+1
      N6=N6+1
  125 CONTINUE
      III=I2
  135 CONTINUE
C
C
C ****************************************************************
C
      DO 85 I=1,MZ
   85 CONTINUE
C
      SRZON=0.
      DO 88 I=1,NZ
      DO 88 J=1,NZ
      RZON(I)=RZON(I)+ T4ZON(J)*VFMXC(I,J)
   88 CONTINUE
      DO 86 I=1,NZ
      SRZON=SRZON+RZON(I)
   86 CONTINUE
C
      QRADB=0.
      QRADRE=0.
      QRADF =0.
      QRADR =0.
      QRADL =0.
      QRADT =0.
      DO 111 I=1,MREGN2
      QRADL=QRADL+RZON(I)
  111 CONTINUE
      DO 112 I=MREGN2+1,MREGN3
      QRADR=QRADR+RZON(I)
  112 CONTINUE
      DO 113 I=MREGN3+1,MREGN4
      QRADRE=QRADRE+RZON(I)
  113 CONTINUE
      DO 114 I=MREGN4+1,MREGN5
      QRADF =QRADF +RZON(I)
  114 CONTINUE
      DO 115 I=MREGN5+1,MREGN6
      QRADB =QRADB +RZON(I)
  115 CONTINUE
      DO 116 I=MREGN6+1,MREGN7
      QRADT =QRADT +RZON(I)
  116 CONTINUE
      QRADW =QRADB+QRADT+QRADRE+QRADL+QRADR+QRADF
C
C ******************************
      DO 786 I=1,MZ
      RZON(I)=RZON(I)/AREA(I)
  786 CONTINUE
C ******************************
C
```

```
CC    WRITE(6,143) N1,N2,N3,N4,N5,N6
CC143 FORMAT(5X,'N1 =',I3,3X,'N2 =',I3,3X,'N3 =',I3,3X,'N4 =',I3,3X,
CC   & 'N5 =',I3,3X,'N6 =',I3,//,5X,'TZON(I),I=1,NZ',/)
C
CC    CALL WRITE1(TZON,1,NZ)
C
CC    WRITE(6,144) SRZON
CC144 FORMAT(5X,'SRZON =',E10.2,//,5X,'RZON(I),I=1,NZ',/)
C
CC    CALL WRITE1(RZON,1,NZ)
C
      WRITE(6,145) QRADL,QRADR,QRADRE,QRADF,QRADB,QRADT,QRADW
  145 FORMAT(5X,'QRADL =',E11.4,/,5X,'QRADR =',E11.4,/,
     & 5X,'QRADRE=',E11.4,/,5X,'QRADF =',E11.4,/,
     & 5X,'QRADB =',E11.4,/,5X,'QRADT =',E11.4,/,
     & 5X,'QRADW =',E11.4,//)
C
C ***************************
C *** LEFT AND RIGHT WALLS
C ***************************
C
      N1=MREGN1+1
      N2=MREGN2+1
      JJJ=1
      DO 137 JJ=1,MJ
      J1=JJJ+1
      J2=JJJ+LJ(JJ)
      KKK=1
      DO 127 KK=1,MK
      K1=KKK
      K2=KKK+LK(KK)
      DO 138 J=J1,J2
      DO 138 K=K1,K2
      RLW(J,K)=RZON(N1)
      RRW(J,K)=RZON(N2)
  138 CONTINUE
      N1=N1+1
      N2=N2+1
      KKK=K2
  127 CONTINUE
      JJJ=J2
  137 CONTINUE
C
C
C **************************
C *** REAR AND FRONT WALLS
C **************************
C
      N3=MREGN3+1
      N4=MREGN4+1
      III=1
      DO 139 II=1,MI
      I1=III+1
      I2=III+LI(II)
      KKK=1
      DO 129 KK=1,MK
      K1=KKK+1
      K2=KKK+LK(KK)
      DO 140 I=I1,I2
      DO 140 K=K1,K2
      RREW(I,K)=RZON(N3)
      RFW (I,K)=RZON(N4)
  140 CONTINUE
      KKK=K2
      N3=N3+1
      N4=N4+1
  129 CONTINUE
      III=I2
  139 CONTINUE
```

```
C
C
C ***************************
C *** BOTTOM AND TOP WALLS
C ***************************
C
      N5=MREGN5+1
      N6=MREGN6+1
      III=1
      DO 141 II=1,MI
      I1=III+1
      I2=III+LI(II)
      JJJ=1
      DO 128 JJ=1,MJ
      J1=JJJ+1
      J2=JJJ+LJ(JJ)
      DO 142 I=I1,I2
      DO 142 J=J1,J2
      RBW(I,J)=RZON(N5)
      RTW(I,J)=RZON(N6)
  142 CONTINUE
      JJJ=J2
      N5=N5+1
      N6=N6+1
  128 CONTINUE
      III=I2
  141 CONTINUE
C
C
      RADHS=0.
      DO 23 N=1,NHSZ
      LZ=MZ+N
      WRITE(6,24) N, RZON(LZ)
   24 FORMAT(/,5X,'HEAT SOURCE NUMBER :',I2,5X,'RZON(LZ) =',E11.4,/)
      RADHS=RADHS+RZON(LZ)
   23 CONTINUE
C
      WRITE(6,99) RADHS,SRZON
   99 FORMAT(2X,'RADHS; TOTAL RADIOSITY =',E11.4,2X,'SRZON =',E11.4,/)
C
C *** PRINT OUT WALL ZONE RADIATIVE FLUX
C
CC    IF(NTREAL.NE.NWRITE) GO TO 11
CC    WRITE(6,151)
CC151 FORMAT(5X,'((RLW(J,K),K=1,NK),J=1,NJ)',//)
CC    CALL WRITE2(RLW,NI,1,NJ,1,NK)
C
CC    WRITE(6,152)
CC152 FORMAT(5X,'((RRW(J,K),K=1,NK),J=1,NJ)',//)
CC    CALL WRITE2(RRW,NI,1,NJ,1,NK)
C
CC    WRITE(6,153)
CC153 FORMAT(5X,'((RREW(I,K),K=1,NK),I=1,NI)',//)
CC    CALL WRITE2(RREW,NI,1,NI,1,NK)
C
CC    WRITE(6,154)
CC154 FORMAT(5X,'((RFW(I,K),K=1,NK),I=1,NI)',//)
CC    CALL WRITE2(RFW,NI,1,NI,1,NJ)
C
CC    WRITE(6,155)
CC155 FORMAT(5X,'((RBW(I,J),J=1,NJ),I=1,NI)',//)
CC    CALL WRITE2(RBW,NI,1,NI,1,NJ)
C
CC    WRITE(6,156)
CC156 FORMAT(5X,'((RTW(I,J),J=1,NJ),I=1,NI)',//)
CC    CALL WRITE2(RTW,NI,1,NI,1,NJ)
C
CC 11 CONTINUE
C
```

```
      RETURN
      END
      SUBROUTINE WRITE1(ARRAY,I1,I2)
C ********************************************************************
C
      DIMENSION ARRAY(1)
C
      M=I1
      N=1
    2 CONTINUE
      IF(N.GT.I2/10) GO TO 3
      WRITE(6,1) (I,ARRAY(I),I=M,M+9)
    1 FORMAT(1X,10(I2,1PE9.2,', '))
      M=M+10
      N=N+1
      GO TO 2
    3 CONTINUE
      WRITE(6,1) (I,ARRAY(I),I=M,I2)
      RETURN
      END
      SUBROUTINE WRITE2(DUMMY,MN,I1,I2,J1,J2)
C ********************************************************************
C
      DIMENSION DUMMY(MN,1)
C
      M=1
      K=J1
      MK=J2/10
      DO 1 I=I1,I2
      WRITE(6,2) I
    2 FORMAT(5X,'I =',I2,2X,'J =',/)
    4 CONTINUE
      IF(M.GT.MK) GO TO 5
      WRITE(6,3) (J,DUMMY(I,J),J=K,K+9)
    3 FORMAT(1X,10(I2,1PE9.2,', '))
      K=K+10
      M=M+1
      GO TO 4
    5 CONTINUE
      WRITE(6,3) (J,DUMMY(I,J),J=K,J2)
      M=1
      K=J1
    1 CONTINUE
      RETURN
      END
      SUBROUTINE VIEWMX
C ********************************************************************
C
      COMMON /BL1/BUOY,VISL,VOL,VOLDT,KBOUND,DTIME,NTREAL,SORSUM,NWRITE
      COMMON /BL2/ DX,DY,DZ,DXY,DYZ,DZX,XYOZ,YZOX,ZXOY,XYPZ,YZPX,ZXPY
      COMMON/CONS/XTIME,NT,U0,PRT,TA,
     &            NTMAX0,RA,CPAIR,SIGMA
C
      COMMON/VF/VFMXC(67,67),EM(67),TZON(67),RZON(67),AR(67)
     &         ,AREA(67),VIEW(67,67),CONSRA
      COMMON /VIEW1/ MI,MJ,MK,MII,MJJ,MKK,MIM,MIP,MJM,MJP,MKM,MKP,
     &               MIIM,MIIP,MJJM,MJJP,MKKM,MKKP,NHSZ,LZ,NZ,MZ,
     &               IREGN1,IREGN2,IREGN3,IREGN4,IREGN5,IREGN6,IREGN7,
     &               MREGN1,MREGN2,MREGN3,MREGN4,MREGN5,MREGN6,MREGN7
      COMMON /VIEW2/ MIIZ(9),MJJZ(9),MKKZ(9),LI(9),LJ(9),LK(9),
     &                ITHIN(9),JTHIN(9),KTHIN(9),AXY(9),AYZ(9),AZX(9),
     &                IHSB(9),JHSB(9),KHSB(9),NHSW(9),NHSD(9),NHSH(9),
     &                LTYPE(9,6)
C
      DIMENSION VFMXL(67,67),VFMXR(67,67),VFMXIN(67,67),WKAREA(134)
C
C *** THE CALCULATION OF VIEW FACTORS IS DONE IN SEPERATE COMPUTER CODE.
C     THE DATA IS READ IN THE BEGINNING OF THIS CODE FROM THE TAPE OR
C     DISK. HERE THE SURFACE RADIATION MATRIXES ARE SET UP.
```

```
C
C *** EMISSIVITY FOR THE SURFACES
C
C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      DO 10 N=1,NHSZ
      LZ=MZ+N
      EM(LZ)=0.81
   10 CONTINUE
      DO 3 I=1,MZ
      EM(I)=0.84
    3 CONTINUE
C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
C *** CALCULATE THE COEFICIENTS OF THE MATRIX FOR THE SYSTEM OF SURFACE
C     RADIATIVE FLUX EQUATIONS
C     THE STRUCTURE OF MATRIX IS
C    J=LW,RW,REW,FW,BW,TW,TB     TOTAL IS NZ TERM
C  I=LW
C    RW          THE ARRAY IS LAID OUT AS FOLLOWS
C    REW         LW(1,1)(1,2),..(1,5),(2,1)(2,2)..(2,5),(3,1)..(3,5)
C    FW
C    BW
C    TW
C    HS
C
      DO 2 I=1,NZ
      DO 2 J=1,NZ
      VFMXL(I,J)=(EM(J)-1.)*VIEW(I,J)/EM(J)/AR(J)
      VFMXR(I,J)=-VIEW(I,J)*SIGMA
    2 CONTINUE
      DO 1 I=1,NZ
      VFMXL(I,I)=(1.-VIEW(I,I)*(1.-EM(I)))/(AR(I)*EM(I))
      VFMXR(I,I)=SIGMA*(1.-VIEW(I,I))
    1 CONTINUE
      NN=NZ
      MM=NZ
      IA=NZ
      IAIN=NZ
      IDGT=3
C
C *****************************************************
      CALL LINV1F(VFMXL,IA,NN,VFMXIN,IDGT,WKAREA,IER)
C *****************************************************
C
      DO 3011 I=1,NZ
      DO 3011 J=1,NZ
      VFMXC(I,J)=0.
      DO 3011 K=1,NZ
      VFMXC(I,J)=VFMXC(I,J)+VFMXIN(I,K)*VFMXR(K,J)
 3011 CONTINUE
C
C *** NONDIMENSIONIZE THE RADIATIVE MATRIX COEFICIENTS
C
      DO 1233 I=1,NZ
      DO 1233 J=1,NZ
      VFMXC(I,J)=VFMXC(I,J)*CONSRA
 1233 CONTINUE
C
C *** PRINT OUT VIEW FACTOR MATRIX COEEFICIENTS
C
      IF(NTREAL.NE.NWRITE) GO TO 12
      WRITE(6,11)
   11 FORMAT(/,5X,'(VFMXC(I,J),J=1,NZ),I=1,NZ)',/)
      CALL WRITE2(VFMXC,NZ,1,NZ,1,NZ)
C
   12 CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE CALVIS
C     ****************************************************************
C
      COMMON /BL1/BUOY,VISL,VOL,VOLDT,KBOUND,DTIME,NTREAL,SORSUM,NWRITE
      COMMON /BL2/ DX,DY,DZ,DXY,DYZ,DZX,XYOZ,YZOX,ZXOY,XYPZ,YZPX,ZXPY
      COMMON /BL3/ NI,NJ,NK,NIM1,NJM1,NKM1,NIM2,NJM2,NKM2
      COMMON/CONS/XTIME,NT,U0,PRT,TA,
     &            NTMAX0,RA,CPAIR,SIGMA
      COMMON/NE/    U(22,18,18),V(22,18,18),T(22,18,18),R(22,18,18),
     &          P(22,18,18),W(22,18,18),WOD(22,18,18)
C    &          P(22,18,18),W(22,18,18),WOD(22,18,18),NOD(22,18,18)
      COMMON/BL12/ DYZO2,DZXO2,DXYO2,XYPZ2,YZPX2,ZXPY2,DX4,DY4,DZ4
     &           ,XYOZ2,YZOX2,ZXOY2,DYZO4,DZXO4,DXYO4
      COMMON/BL10/ Z(30),REQ(30),VIS(22,18,18),RRES(3)
      COMMON/BL80/BTURB,ABTURB,CNT,DX2,DY2,DZ2,VISMAX
     &           ,SMPP(22,18,18),RI(22,18,18)
C
      COMMON /VIEW2/ MIIZ(9),MJJZ(9),MKKZ(9),LI(9),LJ(9),LK(9),
     &               ITHIN(9),JTHIN(9),KTHIN(9),AXY(9),AYZ(9),AZX(9),
     &               IHSB(9),JHSB(9),KHSB(9),NHSW(9),NHSD(9),NHSH(9),
     &            .  LTYPE(9,6)
C
C ***   CALCULATE LOCAL SHEAR AND VISCOSITY VIS(I,J,K)
C
C ***   SPECIFY LOCAL TURBULENT LENGTH SCALES  SMPP(I,J,K)
C
      DO 611 I=2,NIM1
      IP1=I+1
      IM1=I-1
C
      DO 611 J=2,NJM1
C
C ***   CACULATE DV/DX,D2V/DX2,DU/DX,D2U/DX2,DW/DX AND D2W/DX2
C
      JM1=J-1
      JP1=J+1
      DO 611 K=2,NKM1
      KM1=K-1
      KP1=K+1
C
C     IF(NOD(I,J,K).GE.11)GO TO 611
C
      DVDX=(V(IP1,JP1,K)+V(IP1,J,K)-V(IM1,J,K)-V(IM1,JP1,K))/DX4
      D2VDX2=((V(IP1,JP1,K)+V(IP1,J,K))-2.*(V(I,JP1,K)+V(I,J,K))
     &      +(V(IM1,JP1,K)+V(IM1,J,K)))/DX2
      DUDX=(U(IP1,J,K)-U(I,J,K))/DX
      D2UDX2=((U(I+2,J,K)-U(I,J,K))-(U(IP1,J,K)-U(IM1,J,K)))/DX2
      DWDX=(W(IP1,J,KP1)+W(IP1,J,K)-W(IM1,J,K)-W(IM1,J,KP1))/DX4
      D2WDX2=((W(IP1,J,KP1)+W(IP1,J,K))-2.*(W(I,J,KP1)+W(I,J,K))
     &      +(W(IM1,JP1,K)+W(IM1,J,K)))/DX2
  602 CONTINUE
C
C ***   CALCULATE DU/DY,D2U/DY2,DV/DY,D2V/DY2,DW/DY AND D2W/DY2
C
      DUDY=(U(I,JP1,K)+U(IP1,JP1,K)-U(IP1,JM1,K)-U(I,JM1,K))/DY4
      D2UDY2=((U(I,JP1,K)+U(IP1,JP1,K))-2.*(U(I,J,K)+U(IP1,J,K))
     &      +(U(I,JM1,K)+U(IP1,JM1,K)))/DY2
      DWDY=(W(I,JP1,K)+W(IP1,JP1,K)-W(IP1,JM1,K)-W(I,JM1,K))/DY4
      D2WDY2=((W(I,JP1,K)+W(I,JP1,KP1))-2.*(W(I,J,K)+W(I,J,KP1))
     &      +(W(I,JM1,K)+W(I,JM1,KP1)))/DY2
C     DRDY=(R(I,JP1,K)-REQ(KP1)-R(I,JM1,K)+REQ(KM1))/DY*.5
      DVDY=(V(I,JP1,K)-V(I,J,K))/DY
      D2VDY2=((V(I,J+2,K)-V(I,JP1,K))-(V(I,J,K)-V(I,JM1,K)))/DY2
  606 CONTINUE
C
C ***   CALCULATE DU/DZ,D2U/DZ2,DV/DZ,D2V/DZ2,DW/DZ AND D2W/DZ2
C
      DUDZ=(U(I,JP1,K)+U(IP1,JP1,K)-U(IP1,JM1,K)-U(I,JM1,K))/DZ4
      D2UDZ2=((U(I,JP1,K)+U(IP1,JP1,K))-2.*(U(I,J,K)+U(IP1,J,K))
```

```
     &      +(U(I,JM1,K)+U(IP1,JM1,K)))/DZ2
      DVDZ=(V(I,JP1,K)+V(I,JP1,KP1)-V(I,JM1,KP1)-V(I,JM1,K))/DZ4
      D2VDZ2=((V(I,JP1,K)+V(I,JP1,KP1))-2.*(V(I,J,K)+V(I,J,KP1))
     &      +(V(I,JM1,K)+V(I,JM1,KP1)))/DZ2
      DRDZ=(R(I,J,KP1)-REQ(KP1)-R(I,J,KM1)+REQ(KM1))/DZ2
      DWDZ=(W(I,J,KP1)-W(I,J,K))/DZ
      D2WDZ2=((W(I,J,K+2)-W(I,J,KP1))-(W(I,J,K)-W(I,J,KM1)))/DZ2
C
C ***   CALCULATE RICHARDSON NUMBER
C
      STRAIN=DUDY**2+DVDX**2+DWDX**2+DVDZ**2+DWDY**2+DUDZ**2
      DDO2 = SQRT(DUDY*DUDY+DUDX*DUDX+DUDZ*DUDZ+DVDY*DVDY+DVDX*DVDX+
     & DVDZ*DVDZ+DWDX*DWDX+DWDY*DWDY+DWDZ*DWDZ)
      IF(DDO2.EQ.0.)GO TO 600
C ***   CALCULATE TURBULENT LENGTH SCALE SMPP(I,J)
C
      SMP123=SQRT(U(I,J,K)*U(I,J,K)+V(I,J,K)*V(I,J,K)+W(I,J,K)*W(I,J,K))
     & /DDO2
      SMPP12=DDO2 /SQRT(D2UDX2*D2UDX2+D2UDY2*D2UDY2
     & +D2UDZ2*D2UDZ2+D2VDX2*D2VDX2+D2VDY2*D2VDY2+D2VDZ2*D2VDZ2+
     & D2WDZ2*D2WDZ2+D2WDX2*D2WDX2+D2WDY2*D2WDY2)
      SMPP(I,J,K)=CNT*(SMP123+SMPP12)*.5
      RI(I,J,K)=-BUOY*DRDZ/(R(I,J,K)*STRAIN)
      ABRIPR=ABTURB+RI(I,J,K)/PRT
      IF(ABRIPR .LT. 0.) GO TO 600
      IF(ABRIPR .EQ. 0.) GO TO 613
      GO TO 610
  600 VIS(I,J,K)=VISL
      GO TO 611
  613 VIS(I,J,K)=VISMAX
      GO TO 611
  610 VIS(I,J,K)=VISL+R(I,J,K)*SMPP(I,J,K)*SMPP(I,J,K)*SQRT(STRAIN)/
     &          (BTURB*ABRIPR)
      IF(VIS(I,J,K) .GT. VISMAX) VIS(I,J,K)=VISMAX
  611 CONTINUE
CC    DO 41 I=IVW,IVE
CC    DO 41 J=JVS,JVN
CC    VIS(I,J,NK)=VIS(I,J,NKM1)
CC 41 CONTINUE
CC    DO 42 I=IDW,IDE
CC    DO 42 K=2,KD1
CC    VIS(I,NJ,K)=VIS(I,NJM1,K)
CC 42 CONTINUE
      RETURN
      END
      SUBROUTINE CALUV
C ***********************************************************************
C
      COMMON /BL1/BUOY,VISL,VOL,VOLDT,KBOUND,DTIME,NTREAL,SORSUM,NWRITE
      COMMON /BL2/ DX,DY,DZ,DXY,DYZ,DZX,XYOZ,YZOX,ZXOY,XYPZ,YZPX,ZXPY
      COMMON /BL3/ NI,NJ,NK,NIM1,NJM1,NKM1,NIM2,NJM2,NKM2
      COMMON/CONS/XTIME,NT,U0,PRT,TA,
     &          NTMAX0,RA,CPAIR,SIGMA
      COMMON/NE/   U(22,18,18),V(22,18,18),T(22,18,18),R(22,18,18),
     &          P(22,18,18),W(22,18,18),WOD(22,18,18)
C    &          P(22,18,18),W(22,18,18),WOD(22,18,18),NOD(22,18,18)
      COMMON/OD/UOD(22,18,18),VOD(22,18,18),TOD(22,18,18),ROD(22,18,18)
      COMMON/BL31/TPD(22,18,18),RPD(22,18,18),UPD(22,18,18),
     & VPD(22,18,18),WPD(22,18,18),PPD(22,18,18),RESORM(20),ITER
      COMMON/CO/AP(22,18,18),AE(22,18,18),AW(22,18,18),AN(22,18,18),
     & AS(22,18,18),SU(22,18,18),SP(22,18,18),AF(22,18,18),AB(22,18,18)
      COMMON/PP/DU(22,18,18),DV(22,18,18),DW(22,18,18),PP(22,18,18)
      COMMON/BL10/ Z(30),REQ(30),VIS(22,18,18),RRES(3)
      COMMON/BL12/ DYZO2,DZXO2,DXYO2,XYPZ2,YZPX2,ZXPY2,DX4,DY4,DZ4
     &          ,XYOZ2,YZOX2,ZXOY2,DYZO4,DZXO4,DXYO4
      COMMON /VIEW2/ MIIZ(9),MJJZ(9),MKKZ(9),LI(9),LJ(9),LK(9),
     &              ITHIN(9),JTHIN(9),KTHIN(9),AXY(9),AYZ(9),AZX(9),
     &              IHSB(9),JHSB(9),KHSB(9),NHSW(9),NHSD(9),NHSH(9),
     &              LTYPE(9,6)
```

```
C
      DO 100 I=3,NIM1
      IP1=I+1
      IM1=I-1
      DO 100 J=2,NJM1
      JP1=J+1
      JM1=J-1
      DO 100 K=2,NKM1
      KP1=K+1
      KM1=K-1
C     IF(NOD(I,J,K).GE.11)GO TO 100
C     IF(NOD(I,J,K).EQ.3)GO TO 1000
C
      CE=DXYO2*R(I,J,K)*(U(I,J,K)+U(IP1,J,K))
      CW=DYZO2*R(IM1,J,K)*(U(I,J,K)+U(IM1,J,K))
      CN=DZXO4*((R(I,J,K)+R(I,JP1,K))     *V(I   ,JP1,K)
     &          +(R(IM1,J,K)+R(IM1,JP1,K))*V(IM1,JP1,K))
      CS=DZXO4*((R(I,J,K)+R(I,JM1,K))     *V(I   ,J,K)
     &          +(R(IM1,J,K)+R(IM1,JM1,K))*V(IM1,J,K))
      CF=DXYO4*((R(I,J,K)+R(I,J,KP1))     *W(I,J,KP1)
     &          +(R(IM1,J,K)+R(IM1,J,KP1))*W(IM1,J,KP1))
      CB=DXYO4*((R(I,J,K)+R(I,J,KM1))     *W(I,J,K)
     &          +(R(IM1,J,K)+R(IM1,J,KM1))*W(IM1,J,K))
C
      VISCE=VIS(IP1,J,K)
      VISCW=VIS(IM1,J,K)
      VISCS=VIS(I,JM1,K)
      VISCN=VIS(I,JP1,K)
      VISCB=VIS(I,J,KM1)
      VISCF=VIS(I,J,KP1)
      AE(I,J,K)=0.5*( ABS(CE)-CE)+YZOX*VISCE
      AW(I,J,K)=0.5*( ABS(CW)+CW)+YZOX*VISCW
      AN(I,J,K)=0.5*( ABS(CN)-CN)+ZXOY*VISCN
      AS(I,J,K)=0.5*( ABS(CS)+CS)+ZXOY*VISCS
      AF(I,J,K)=0.5*( ABS(CF)-CF)+XYOZ*VISCF
      AB(I,J,K)=0.5*( ABS(CB)+CB)+XYOZ*VISCB
C
      SP(I,J,K)=-0.5*(ROD(I,J,K)+ROD(IM1,J,K))*VOLDT
      PX=(P(IM1,J,K)-P(I,J,K))*DYZ
      RU=0.5*(ROD(IM1,J,K)+ROD(I,J,K))*UOD(I,J,K)*VOLDT
      RE=(UOD(IP1,J,K)-UOD(I,J,K))*VISCE*YZOX
      RW=(UOD(I,J,K)-UOD(IM1,J,K))*VISCW*YZOX
      RN=(VOD(I,JP1,K)-VOD(IM1,JP1,K))*VISCN*DZ
      RS=(VOD(I,J   ,K)-VOD(IM1,J   ,K))*VISCS*DZ
      RF=(WOD(I,J,KP1)-WOD(IM1,J,KP1))*VISCF*DY
      RB=(WOD(I,J,K   )-WOD(IM1,J,K   ))*VISCB*DY
      SU(I,J,K)=PX+RU+RE-RW+RN-RS+RF-RB
C     GO TO 100
C1000 SU(I,J,K)=0.
C     AP(I,J,K)=1.E20
  100 CONTINUE
C
C *** LEFT AND RIGHT WALLS
C
      DO 101 J=2,NJM1
      DO 101 K=2,NKM1
      AW(3,J,K)=0.
      CW=(R(2,J,K)+R(3,J,K))*U(3,J,K)*DYZO4
      VISW=VIS(2,J,K)
      SP(3,J,K)=SP(3,J,K)-0.5*( ABS(CW)+CW)-YZOX*VISW
      AE(NIM1,J,K)=0.
      CE=(R(NIM1,J,K)+R(NIM2,J,K))*U(NIM1,J,K)*DYZO4
      VISE=VIS(NIM1,J,K)
      SP(NIM1,J,K)=SP(NIM1,J,K)-0.5*( ABS(CE)-CE)-YZOX*VISE
  101 CONTINUE
C
      DO 102 I=3,NIM1
      IM1=I-1
C
```

```
C *** REAR AND FRONT WALLS
C
       DO 107 K=2,NKM1
       AS(I,2,K)=0.
       VISS=0.25*(2.*VISL+VIS(I,2,K)+VIS(IM1,2,K))
       SP(I,2,K)=SP(I,2,K)-ZXOY2*VISS
       AN(I,NJM1,K)=0.
C     IF(NOD(I,NJM1,K).EQ.2)GO TO 107
       VISN=0.25*(2.*VISL+VIS(I,NJM1,K)+VIS(IM1,NJM1,K))
       SP(I,NJM1,K)=SP(I,NJM1,K)-ZXOY2*VISN
  107 CONTINUE
C
C *** TOP AND BOTTOM WALLS
C
       DO 103 J=2,NJM1
       AB(I,J,2)=0.
       VISB=0.25*(2.*VISL+VIS(I,J,2)+VIS(IM1,J,2))
       SP(I,J,2)=SP(I,J,2)-XYOZ2*VISB
       AF(I,J,NKM1)=0.
C     IF(NOD(I,J,NKM1).EQ.2) GO TO 103
       VISF=0.25*(2.*VISL+VIS(I,J,NKM1)+VIS(IM1,J,NKM1))
       SP(I,J,NKM1)=SP(I,J,NKM1)-XYOZ2*VISF
  103 CONTINUE
  102 CONTINUE
C
C *** THE TEST BLOCK
C
C
C *** THE CELLS WITH NOD(I,J,K) = 3
C     THE VALUES OF SU AND AP ARE GIVEN IN DO LOOP 100
C
C *** ASSEMBLY THE COEFICIENTS
C
       DO 300 K=2,NKM1
       DO 300 J=2,NJM1
       DO 300 I=3,NIM1
C     IF(NOD(I,J,K).GE.11.OR.NOD(I,J,K).EQ.3)GO TO 300
       AP(I,J,K)=AE(I,J,K)+AW(I,J,K)+AN(I,J,K)+AS(I,J,K)+AF(I,J,K)+
      &          AB(I,J,K)-SP(I,J,K)
       DU(I,J,K)=DYZ/AP(I,J,K)
  300 CONTINUE
C
       CALL TRID(3,2,2,NIM1,NJM1,NKM1,U)
C
C *** GIVE THE U-VELOCITY IN THE VENT AND DOOR GAP
C
C
C ***********************************************************************
CCC   SUBROUTINE CALV
C ***********************************************************************
C
       DO 150 I=2,NIM1
       IM1=I-1
       IP1=I+1
       DO 150 J=3,NJM1
       JM1=J-1
       JP1=J+1
       DO 150 K=2,NKM1
       KM1=K-1
       KP1=K+1
C     IF(J.EQ.NJ.AND.NOD(I,NJM1,K).NE.2)GO TO 1050
C     IF(NOD(I,J,K).GE.11)GO TO 150
C     IF(NOD(I,J,K).EQ.4)GO TO 1050
C
       CE=((R(I,J,K)+R(IP1,J,K))*U(IP1,J,K)
      &        +(R(I,JM1,K)+R(IP1,JM1,K))*U(IP1,JM1,K))*DYZO4
       CW=((R(I,J,K)+R(IM1,J,K))*U(I,J,K)
      &        +(R(I,JM1,K)+R(IM1,JM1,K))*U(I   ,JM1,K))*DYZO4
       IF(J.EQ.NJ)GO TO 1060
```

```
      CN=R(I,J,K)*(V(I,J,K)+V(I,JP1,K))  *DZXO2
      GO TO 1070
 1060 CN=R(I,J,K)*V(I,J,K)*DZX
 1070 CONTINUE
      CS=R(I,JM1,K)*(V(I,J,K)+V(I,JM1,K))*DZXO2
      CF=((R(I,J,K)+R(I,J,KP1))*W(I,J,KP1)
     &         +(R(I,JM1,K)+R(I,JM1,KP1))*W(I,JM1,KP1))*DXYO4
      CB=((R(I,J,K)+R(I,J,KM1))*W(I,J,K)
     &         +(R(I,JM1,K)+R(I,JM1,KM1))*W(I,JM1,K  ))*DXYO4
C
      VISCE=VIS(IP1,J,K)
      VISCW=VIS(IM1,J,K)
      VISCS=VIS(I,JM1,K)
      VISCN=VIS(I,JP1,K)
      VISCB=VIS(I,J,KM1)
      VISCF=VIS(I,J,KP1)
      AE(I,J,K)=0.5*( ABS(CE)-CE)+YZOX*VISCE
      AW(I,J,K)=0.5*( ABS(CW)+CW)+YZOX*VISCW
      AN(I,J,K)=0.5*( ABS(CN)-CN)+ZXOY*VISCN
      AS(I,J,K)=0.5*( ABS(CS)+CS)+ZXOY*VISCS
      AF(I,J,K)=0.5*( ABS(CF)-CF)+XYOZ*VISCF
      AB(I,J,K)=0.5*( ABS(CB)+CB)+XYOZ*VISCB
C
      SP(I,J,K)=-0.5*(ROD(I,J,K)+ROD(I,JM1,K))*VOLDT
      PY=(P(I,JM1,K)-P(I,J,K))*DZX
      RU=0.5*(ROD(I,J,K)+ROD(I,JM1,K))*VOD(I,J,K)*VOLDT
      RE=(UOD(IP1,J,K)-UOD(IP1,JM1,K))*VISCE*DZ
      RW=(UOD(I   ,J,K)-UOD(I   ,JM1,K))*VISCW*DZ
      IF(J.EQ.NJ)GO TO 1080
      RN=(VOD(I,JP1,K)-VOD(I,J,K))*VISCN*ZXOY
      GO TO 1090
 1080 RN=0.
 1090 CONTINUE
      RS=(VOD(I,J,K)-VOD(I,JM1,K))*VISCS*ZXOY
      RF=(WOD(I,J,K+1)-WOD(I,JM1,K+1))*VISCF*DX
      RB=(WOD(I,J,K  )-WOD(I,JM1,K  ))*VISCB*DX
      SU(I,J,K)=PY+RU+RE-RW+RN-RS+RF-RB
C     GO TO 150
C1050 SU(I,J,K)=0.
C     AP(I,J,K)= 1.E30
  150 CONTINUE
C
C *** RIGHT AND LEFT WALLS
C
      DO 151 J=3,NJM1
      JM1=J-1
      DO 151 K=2,NKM1
      AW(2,J,K)=0.
      VISW=0.25*(2.*VISL+VIS(2,J,K)+VIS(2,JM1,K))
      SP(2,J,K)=SP(2,J,K)-YZOX2*VISW
      AE(NIM1,J,K)=0.
      VISE=0.25*(2.*VISL+VIS(NIM1,J,K)+VIS(NIM1,JM1,K))
      SP(NIM1,J,K)=SP(NIM1,J,K)-YZOX2*VISE
  151 CONTINUE
C
C *** THE REAR AND FRONT WALLS
C
      DO 152 I=2,NIM1
      DO 152 K=2,NKM1
      AS(I,3,K)=0.
      CS=R(I,2,K)*V(I,3,K)*DZXO2
      VISS=VIS(I,2,K)
      SP(I,3,K)=SP(I,3,K)-0.5*( ABS(CS)+CS)-ZXOY*VISS
C     IF(NOD(I,NJM1,K).EQ.2)GO TO 170
      AN(I,NJM1,K)=0.
      CN=R(I,NJM1,K)*V(I,NJM1,K)*DZXO2
      VISN=VIS(I,NJM1,K)
      SP(I,NJM1,K)=SP(I,NJM1,K)-0.5*( ABS(CN)-CN)-ZXOY*VISN
C     GO TO 152
```

```
C 170 AN(I,NJ,K)=0.
  152 CONTINUE
C
C *** THE TOP AND BOTTOM WALLS
C
      DO 153 I=2,NIM1
      DO 153 J=3,NJM1
      JM1=J-1
      AB(I,J,2)=0.
      VISB=0.25*(2.*VISL+VIS(I,J,2)+VIS(I,JM1,2))
      AP(I,J,2)=AP(I,J,2)-XYOZ2*VISB
      AF(I,J,NKM1)=0.
C     IF(NOD(I,J,NKM1).EQ.2)GO TO 171
      VISF=0.25*(2.*VISL+VIS(I,J,NKM1)+VIS(I,JM1,NKM1))
      SP(I,J,NKM1)=SP(I,J,NKM1)-XYOZ2*VISF
C     GO TO 153
C 171 AF(I,J,NK)=0.
  153 CONTINUE
C
C *** FOR THE TEST BLOCK
C
C
C *** THE CELLS WITH NOD(I,J,K) = 4
C     THE VALUES OF SU AND AP ARE GIVEN IN DO LOOP 105
C *** THE CELLS INSIDE THE DOOR WALL
C     THE VALUES OF SU AND AP ARE GIVEN IN DO LOOP 105
C *** ASSEMBLY THE COEFICIENTS
C
      DO 350 K=2,NKM1
      DO 350 J=3,NJM1
      DO 350 I=2,NIM1
C     IF(NOD(I,J,K).GE.11.OR.NOD(I,J,K).EQ.4)GO TO 350
      AP(I,J,K)=AE(I,J,K)+AW(I,J,K)+AN(I,J,K)+AS(I,J,K)+AF(I,J,K)+
     &         AB(I,J,K)-SP(I,J,K)
      DV(I,J,K)=DZX/AP(I,J,K)
  350 CONTINUE
C
      CALL TRID(2,3,2,NIM1,NJM1,NKM1,V)
C
C *** GIVE V-VELOCITY IN THE VENT AND DOOR GAP
C
      RETURN
      END
      SUBROUTINE CALW
C ***********************************************************************
C
      COMMON /BL1/BUOY,VISL,VOL,VOLDT,KBOUND,DTIME,NTREAL,SORSUM,NWRITE
      COMMON /BL2/ DX,DY,DZ,DXY,DYZ,DZX,XYOZ,YZOX,ZXOY,XYPZ,YZPX,ZXPY
      COMMON /BL3/ NI,NJ,NK,NIM1,NJM1,NKM1,NIM2,NJM2,NKM2
      COMMON/CONS/XTIME,NT,U0,PRT,TA,
     &            NTMAX0,RA,CPAIR,SIGMA
      COMMON/BL10/ Z(30),REQ(30),VIS(22,18,18),RRES(3)
      COMMON/NE/   U(22,18,18),V(22,18,18),T(22,18,18),R(22,18,18),
     &           P(22,18,18),W(22,18,18),WOD(22,18,18)
C    &           P(22,18,18),W(22,18,18),WOD(22,18,18),NOD(22,18,18)
      COMMON/OD/UOD(22,18,18),VOD(22,18,18),TOD(22,18,18),ROD(22,18,18)
      COMMON/BL31/TPD(22,18,18),RPD(22,18,18),UPD(22,18,18),
     &  VPD(22,18,18),WPD(22,18,18),PPD(22,18,18),RESORM(20),ITER
      COMMON/CO/AP(22,18,18),AE(22,18,18),AW(22,18,18),AN(22,18,18),
     & AS(22,18,18),SU(22,18,18),SP(22,18,18),AF(22,18,18),AB(22,18,18)
      COMMON/PP/DU(22,18,18),DV(22,18,18),DW(22,18,18),PP(22,18,18)
      COMMON/BL12/ DYZO2,DZXO2,DXYO2,XYPZ2,YZPX2,ZXPY2,DX4,DY4,DZ4
     &            ,XYOZ2,YZOX2,ZXOY2,DYZO4,DZXO4,DXYO4
      COMMON /VIEW2/ MIIZ(9),MJJZ(9),MKKZ(9),LI(9),LJ(9),LK(9),
     &              ITHIN(9),JTHIN(9),KTHIN(9),AXY(9),AYZ(9),AZX(9),
     &              IHSB(9),JHSB(9),KHSB(9),NHSW(9),NHSD(9),NHSH(9),
     &              LTYPE(9,6)
C
      DO 100 I=2,NIM1
```

```
      IM1=I-1
      IP1=I+1
      DO 100 J=2,NJM1
      JM1=J-1
      JP1=J+1
      DO 100 K=3,NKM1
      KM1=K-1
      KP1=K+1
C     IF(NOD(I,J,K).GE.11)GO TO 100
C     IF(K.EQ.NK.AND.NOD(I,J,NKM1).NE.2)GO TO 1000
C     IF(NOD(I,J,K).EQ.5)GO TO 1000
C
      CE=DYZO4*((R(I,J,K)+R(IP1,J,K))      *U(IP1,J,K)
     &       +(R(I,J,KM1)+R(IP1,J,KM1))*U(IP1,J,KM1))
      CW=DYZO4*((R(I,J,K)+R(IM1,J,K))      *U(I,J,K)
     &       +(R(I,J,KM1)+R(IM1,J,KM1))*U(I,J,KM1))
      CN=DZXO4*((R(I,J,K)+R(I,JP1,K))      *V(I   ,JP1,K)
     &       +(R(I,J,KM1)+R(I,JP1,KM1))*V(I,JP1,KM1))
      CS=DZXO4*((R(I,J,K)+R(I,JM1,K))      *V(I   ,J,K)
     &       +(R(I,J,KM1)+R(I,JM1,KM1))*V(I,J,KM1))
      IF(K.EQ.NK)GO TO 130
      CF=DXYO2*R(I,J,K  )*(W(I,J,K)+W(I,J,KP1))
      GO TO 131
  130 CF=DXY*R(I,J,K)*W(I,J,K)
  131 CONTINUE
      CB=DXYO2*R(I,J,KM1)*(W(I,J,K)+W(I,J,KM1))
C
      VISCE=VIS(IP1,J,K)
      VISCW=VIS(IM1,J,K)
      VISCS=VIS(I,JM1,K)
      VISCN=VIS(I,JP1,K)
      VISCB=VIS(I,J,KM1)
      VISCF=VIS(I,J,KP1)
      AE(I,J,K)=0.5*( ABS(CE)-CE)+YZOX*VISCE
      AW(I,J,K)=0.5*( ABS(CW)+CW)+YZOX*VISCW
      AN(I,J,K)=0.5*( ABS(CN)-CN)+ZXOY*VISCN
      AS(I,J,K)=0.5*( ABS(CS)+CS)+ZXOY*VISCS
      AF(I,J,K)=0.5*( ABS(CF)-CF)+XYOZ*VISCF
      AB(I,J,K)=0.5*( ABS(CB)+CB)+XYOZ*VISCB
C
      SP(I,J,K)=-0.5*(ROD(I,J,K)+ROD(I,J,KM1))*VOLDT
C
      BURQ=-BUOY*0.5*(R(I,J,K)-REQ(K)+R(I,J,KM1)-REQ(KM1))*VOL
      PZ=(P(I,J,KM1)-P(I,J,K))*DXY
      RU=0.5*(ROD(I,J,KM1)+ROD(I,J,K))*WOD(I,J,K)*VOLDT
      RE=(UOD(IP1,J,K)-UOD(IP1,J,KM1))*VISCE*DZ
      RW=(UOD(I  ,J,K)-UOD(I  ,J,KM1))*VISCW*DZ
      RN=(VOD(I,JP1,K)-VOD(I,JP1,KM1))*VISCN*DX
      RS=(VOD(I,J  ,K)-VOD(I,J  ,KM1))*VISCS*DX
      IF(K.EQ.NK)GO TO 133
      RF=(WOD(I,J,KP1)-WOD(I,J,K))*VISCF*XYOZ
      GO TO 134
  133 RF=XYOZ*WOD(I,J,K)*VISCF
  134 CONTINUE
      RB=(WOD(I,J,K)-WOD(I,J,KM1))*VISCB*XYOZ
      SU(I,J,K)=BURQ+PZ+RU+RE-RW+RN-RS+RF-RB
C     GO TO 100
C1000 SU(I,J,K)=0.
C     AP(I,J,K)= 1.E20
  100 CONTINUE
C
C *** THE TOP AND BOTTOM WALLS
C
      DO 101 I=2,NIM1
      DO 101 J=2,NJM1
      AB(I,J,3)=0.
      CB=R(I,J,2)*W(I,J,3)*DXYO2
      VISB=VIS(I,J,2)
      SP(I,J,3)=SP(I,J,3)-0.5*( ABS(CB)+CB)-XYOZ*VISB
```

```
C     IF(NOD(I,J,NKM1).EQ.2)GO TO 132
       AF(I,J,NKM1)=0.
       CF=R(I,J,NKM1)*W(I,J,NKM1)*DXYO2
       VISF=VIS(I,J,NKM1)
       SP(I,J,NKM1)=SP(I,J,NKM1)-0.5*( ABS(CF)-CF)-XYOZ*VISF
C     GO TO 101
C 132 AF(I,J,NK)=0.
  101 CONTINUE
C
C *** THE REAR AND FRONT WALLS
C
       DO 102 I=2,NIM1
       DO 102 K=2,NKM1
       KM1=K-1
       AS(I,2,K)=0.
       VISS=0.25*(2.*VISL+VIS(I,2,K)+VIS(I,2,KM1))
       SP(I,2,K)=SP(I,2,K)-ZXOY2*VISS
       AN(I,NJM1,K)=0.
C     IF(NOD(I,NJM1,K).EQ.2)GO TO 102
       VISN=0.25*(2.*VISL+VIS(I,NJM1,K)+VIS(I,NJM1,KM1))
       SP(I,NJM1,K)=SP(I,NJM1,K)-ZXOY2*VISN
  102 CONTINUE
C
C *** THE RIGHT AND LEFT WALLS
C
       DO 103 J=2,NJM1
       DO 103 K=2,NKM1
       KM1=K-1
       AW(2,J,K)=0.
       VISW=0.25*(2.*VISL+VIS(2,J,K)+VIS(2,J,KM1))
       SP(2,J,K)=SP(2,J,K)-YZOX2*VISW
       AE(NIM1,J,K)=0.
       VISE=0.25*(2.*VISL+VIS(NIM1,J,K)+VIS(NIM1,J,KM1))
       SP(NIM1,J,K)=SP(NIM1,J,K)-YZOX2*VISE
  103 CONTINUE
C
C *** THE TEST BLOCK
C *** THE CELLS WITH NOD(I,J,K) = 5
C     THE VALUES OF SU AND AP ARE GIVEN IN DO LOOP 100
C *** THE CELLS INSIDE THE TOP WALL
C     THE VALUES OF SU AND AP ARE GIVEN IN DO LOOP 100
C
C *** ASSEMBLY THE COEFICIENTS
C
       DO 300 I=2,NIM1
       DO 300 J=2,NJM1
       DO 300 K=3,NKM1
C     IF(NOD(I,J,K).GE.11.OR.NOD(I,J,K).EQ.5)GO TO 300
C     IF(NOD(I,J,NKM1).EQ.2.AND.K.EQ.NK)GO TO 300
       AP(I,J,K)=AE(I,J,K)+AW(I,J,K)+AN(I,J,K)+AS(I,J,K)+AF(I,J,K)+
      &          AB(I,J,K)-SP(I,J,K)
       DW(I,J,K)=DXY/AP(I,J,K)
  300 CONTINUE
C
C
       CALL TRID(2,2,3,NIM1,NJM1,NKM1,W)
C
       RETURN
       END
       SUBROUTINE CALP
C ***********************************************************************
C
       COMMON /BL1/BUOY,VISL,VOL,VOLDT,KBOUND,DTIME,NTREAL,SORSUM,NWRITE
       COMMON /BL2/ DX,DY,DZ,DXY,DYZ,DZX,XYOZ,YZOX,ZXOY,XYPZ,YZPX,ZXPY
       COMMON /BL3/ NI,NJ,NK,NIM1,NJM1,NKM1,NIM2,NJM2,NKM2
       COMMON/CONS/XTIME,NT,U0,PRT,TA,
      &         NTMAX0,RA,CPAIR,SIGMA
       COMMON/BL10/ Z(30),REQ(30),VIS(22,18,18),RRES(3)
       COMMON/NE/   U(22,18,18),V(22,18,18),T(22,18,18),R(22,18,18),
```

```
     &          P(22,18,18),W(22,18,18),WOD(22,18,18)
C    &         P(22,18,18),W(22,18,18),WOD(22,18,18),NOD(22,18,18)
      COMMON/OD/UOD(22,18,18),VOD(22,18,18),TOD(22,18,18),ROD(22,18,18)
      COMMON/BL31/TPD(22,18,18),RPD(22,18,18),UPD(22,18,18),
     &  VPD(22,18,18),WPD(22,18,18),PPD(22,18,18),RESORM(20),ITER
      COMMON/CO/AP(22,18,18),AE(22,18,18),AW(22,18,18),AN(22,18,18),
     & AS(22,18,18),SU(22,18,18),SP(22,18,18),AF(22,18,18),AB(22,18,18)
      COMMON/PP/DU(22,18,18),DV(22,18,18),DW(22,18,18),PP(22,18,18)
      COMMON/BL12/ DYZO2,DZXO2,DXYO2,XYPZ2,YZPX2,ZXPY2,DX4,DY4,DZ4
     &          ,XYOZ2,YZOX2,ZXOY2,DYZO4,DZXO4,DXYO4
      COMMON /VIEW2/ MIIZ(9),MJJZ(9),MKKZ(9),LI(9),LJ(9),LK(9),
     &              ITHIN(9),JTHIN(9),KTHIN(9),AXY(9),AYZ(9),AZX(9),
     &              IHSB(9),JHSB(9),KHSB(9),NHSW(9),NHSD(9),NHSH(9),
     &              LTYPE(9,6)
C
      DO 100 I=2,NIM1
      IM1=I-1
      IP1=I+1
      DO 100 J=2,NJM1
      JP1=J+1
      JM1=J-1
      DO 100 K=2,NKM1
      KP1=K+1
      KM1=K-1
C     IF(NOD(I,J,K).GE.11)GO TO 100
      IF(I.NE.NIM1)GO TO 301
      AE(NIM1,J,K)=0.
      CE=0.
      GO TO 302
  301 CONTINUE
      AE(I,J,K)=(R(I,J,K)+R(IP1,J,K))*DYZO2*DU(IP1,J,K)
      CE=(R(I,J,K)+R(IP1,J,K))*U(IP1,J,K)*DYZO2
  302 CONTINUE
      IF(I.NE.2   )GO TO 303
      AW(2   ,J,K)=0.
      CW=0.
      GO TO 304
  303 CONTINUE
      AW(I,J,K)=(R(I,J,K)+R(IM1,J,K))*DYZO2*DU(I   ,J,K)
      CW=(R(I,J,K)+R(IM1,J,K))*U(I   ,J,K)*DYZO2
  304 CONTINUE
      AN(I,J,K)=(R(I,J,K)+R(I,JP1,K))*DZXO2*DV(I,JP1,K)
      CN=(R(I,J,K)+R(I,JP1,K))*V(I,JP1,K)*DZXO2
      AS(I,J,K)=(R(I,J,K)+R(I,JM1,K))*DZXO2*DV(I,J   ,K)
      CS=(R(I,J,K)+R(I,JM1,K))*V(I,J   ,K)*DZXO2
      AF(I,J,K)=(R(I,J,K)+R(I,J,KP1))*DXYO2*DW(I,J,KP1)
      CF=(R(I,J,K)+R(I,J,KP1))*W(I,J,KP1)*DXYO2
      AB(I,J,K)=(R(I,J,K)+R(I,J,KM1))*DXYO2*DW(I,J,K   )
      CB=(R(I,J,K)+R(I,J,KM1))*W(I,J,K   )*DXYO2
C
      SP(I,J,K)=0.
C
      SU(I,J,K)=(ROD(I,J,K)-R(I,J,K))*VOLDT-CE+CW-CN+CS-CF+CB
  100 CONTINUE
C
C *** THE TOP AND BOTTOM WALLS
C
      DO 101 I=2,NIM1
      DO 101 J=2,NJM1
      AB(I,J,2)=0.
      AF(I,J,NKM1)=0.
C     IF(NOD(I,J,NKM1).EQ.2)
C    &SP(I,J,NKM1)=-0.5*(R(I,J,NKM1)+R(I,J,NK))*DW(I,J,NKM1)*DXY
  101 CONTINUE
C
C *** THE REAR AND FRONT WALLS
C
      DO 102 I=2,NIM1
      DO 102 K=2,NKM1
```

```
        AS(I,2,K)=0.
        AN(I,NJM1,K)=0.
C      IF(NOD(I,NJM1,K).EQ.2)
C     &SP(I,NJM1,K)=-0.5*(R(I,NJM1,K)+R(I,NJ,K))*DV(I,NJM1, K)*DYZ
  102 CONTINUE
C
C *** THE RIGHT AND LEFT WALLS
C      GIVEN IN DO LOOP 100
C
C *** THE TEST BLOCK
C7712 CONTINUE
C
C *** ASSEMBLY THE COEFICIENTS
C
        DO 150 I=2,NIM1
        DO 150 J=2,NJM1
C      DO 150 K=2,NKM1
C      IF(NOD(I,J,K).GE.11)GO TO 150
        AP(I,J,K)=AE(I,J,K)+AW(I,J,K)+AN(I,J,K)+AS(I,J,K)+AF(I,J,K)+
       &             AB(I,J,K)-SP(I,J,K)
  150 CONTINUE
C
        CALL TRID(2,2,2,NIM1,NJM1,NKM1,PP)
C
        DO 600 I=3,NIM1
        DO 600 J=2,NJM1
        DO 600 K=2,NKM1
C      IF(NOD(I,J,K).GE.11)GO TO 600
        U(I,J,K)=U(I,J,K)+DU(I,J,K)*(PP(I-1,J,K)-PP(I,J,K))
  600 CONTINUE
        DO 601 I=2,NIM1
        DO 601 J=3,NJM1
        DO 601 K=2,NKM1
C      IF(NOD(I,J,K).GE.11)GO TO 601
        V(I,J,K)=V(I,J,K)+DV(I,J,K)*(PP(I,J-1,K)-PP(I,J,K))
  601 CONTINUE
        DO 602 I=2,NIM1
        DO 602 J=2,NJM1
        DO 602 K=3,NKM1
C      IF(NOD(I,J,K).GE.11)GO TO 602
        W(I,J,K)=W(I,J,K)+DW(I,J,K)*(PP(I,J,K-1)-PP(I,J,K))
  602 CONTINUE
        DO 220 I=2,NIM1
        DO 220 J=2,NJM1
        DO 220 K=2,NKM1
C      IF(NOD(I,J,K).GE.11)GO TO 220
        P(I,J,K)=P(I,J,K)+PP(I,J,K)
        PP(I,J,K)=0.
C      WRITE(6,221)I,J,K,P(I,J,K)
C221   FORMAT(5X,'I',I4,'J',I4,'K',I4,'P',E11.4)
  220 CONTINUE
C
C *** RESET THE VELOCITY IN  THE FREE BOUNDARY
C
        SORSUM=0.
        RESORM(ITER)=0.
        DO 240 I=2,NIM1
        DO 240 J=2,NJM1
        DO 240 K=2,NKM1
C      IF(NOD(I,J,K).GE.11)GO TO 240
        IF(I.EQ.NIM1)GO TO 241
        CE=(R(I,J,K)+R(I+1,J,K))*U(I+1,J,K)*DYZO2
        GO TO 242
  241 CONTINUE
        CE=0.
  242 CONTINUE
        CW=(R(I,J,K)+R(I-1,J,K))*U(I  ,J,K)*DYZO2
        CN=(R(I,J,K)+R(I,J+1,K))*V(I,J+1,K)*DZXO2
        CS=(R(I,J,K)+R(I,J-1,K))*V(I,J  ,K)*DZXO2
```

```
      CF=(R(I,J,K)+R(I,J,K+1))*W(I,J,K+1)*DXYO2
      CB=(R(I,J,K)+R(I,J,K-1))*W(I,J,K  )*DXYO2
      RESIDU=(ROD(I,J,K)-R(I,J,K))*VOLDT-CE+CW-CN+CS-CF+CB
      SORSUM=SORSUM+RESIDU
      RESORM(ITER)=RESORM(ITER)+ABS(RESIDU)
  240 CONTINUE
      RETURN
      END
      SUBROUTINE TRID(IST,JST,KST,ISP,JSP,KSP,PHI)
C ***********************************************************************
C
      COMMON /BL3/ NI,NJ,NK,NIM1,NJM1,NKM1,NIM2,NJM2,NKM2
      COMMON/BL31/TPD(22,18,18),RPD(22,18,18),UPD(22,18,18),
     &  VPD(22,18,18),WPD(22,18,18),PPD(22,18,18),RESORM(20),ITER
      COMMON/CO/AP(22,18,18),AE(22,18,18),AW(22,18,18),AN(22,18,18),
     & AS(22,18,18),SU(22,18,18),SP(22,18,18),AF(22,18,18),AB(22,18,18)
      DIMENSION A(25),B(25),C(25),PHI(22,18,18)
C
      ISTM1=IST-1
      A(ISTM1)=0.
      C(ISTM1)=0.
      DO 100 J=JST,JSP
      DO 100 K=KST,KSP
      DO 101 I=IST,ISP
      IF(JSP.EQ.NJ)PHI(I,NJ+1,K)=PHI(I,NJ,K)
      IF(KSP.EQ.NK)PHI(I,J,NK+1)=PHI(I,J,NK)
      A(I)=AE(I,J,K)
      B(I)=AW(I,J,K)
      C(I)=AN(I,J,K)*PHI(I,J+1,K)+AS(I,J,K)*PHI(I,J-1,K)
     &    +AF(I,J,K)*PHI(I,J,K+1)+AB(I,J,K)*PHI(I,J,K-1)+SU(I,J,K)
      TERM=1./(AP(I,J,K)-B(I)*A(I-1))
      A(I)=A(I)*TERM
      C(I)=(C(I)+B(I)*C(I-1))*TERM
  101 CONTINUE
      PHI(ISP,J,K)=C(ISP)
      ISTA=IST+1
      DO 102 II=ISTA,ISP
      I=IST+ISP-II
      IP1=I+1
      PHI(I,J,K)=A(I)*PHI(IP1,J,K)+C(I)
  102 CONTINUE
  100 CONTINUE
C
      JSTM1=JST-1
      A(JSTM1)=0.
      C(JSTM1)=0.
      DO 200 K=KST,KSP
      DO 200 I=IST,ISP
      DO 201 J=JST,JSP
      A(J)=AN(I,J,K)
      B(J)=AS(I,J,K)
      C(J)=AE(I,J,K)*PHI(I+1,J,K)+AW(I,J,K)*PHI(I-1,J,K)
     &    +AF(I,J,K)*PHI(I,J,K+1)+AB(I,J,K)*PHI(I,J,K-1)+SU(I,J,K)
      TERM=1./(AP(I,J,K)-B(J)*A(J-1))
      A(J)=A(J)*TERM
      C(J)=(C(J)+B(J)*C(J-1))*TERM
  201 CONTINUE
      PHI(I,JSP,K)=C(JSP)
      JSTA=JST+1
      DO 202 JJ=JSTA,JSP
      J=JST+JSP-JJ
      JP1=J+1
      PHI(I,J,K)=A(J)*PHI(I,JP1,K)+C(J)
  202 CONTINUE
  200 CONTINUE
C
      KSTM1=KST-1
      A(KSTM1)=0.
      C(KSTM1)=0.
```

```
      DO 300 I=IST,ISP
      DO 300 J=JST,JSP
      DO 301 K=KST,KSP
      A(K)=AF(I,J,K)
      B(K)=AB(I,J,K)
      C(K)=AE(I,J,K)*PHI(I+1,J,K)+AW(I,J,K)*PHI(I-1,J,K)
     &    +AN(I,J,K)*PHI(I,J+1,K)+AS(I,J,K)*PHI(I,J-1,K)+SU(I,J,K)
      TERM=1./(AP(I,J,K)-B(K)*A(K-1))
      A(K)=A(K)*TERM
      C(K)=(C(K)+B(K)*C(K-1))*TERM
  301 CONTINUE
      PHI(I,J,KSP)=C(KSP)
      KSTA=KST+1
      DO 302 KK=KSTA,KSP
      K=KST+KSP-KK
      KP1=K+1
      PHI(I,J,K)=A(K)*PHI(I,J,KP1)+C(K)
  302 CONTINUE
  300 CONTINUE
C
C     GO TO 700
C ****************
      IF(IST.LT.0) GO TO 700
C **************************
C
      ISP1=ISP+1
      B(ISP1)=0.
      C(ISP1)=0.
      DO 400 J=JST,JSP
      DO 400 K=KST,KSP
      DO 401 II=IST,ISP
      I=ISP+IST-II
      IP1=I+1
      A(I)=AE(I,J,K)
      B(I)=AW(I,J,K)
      C(I)=AN(I,J,K)*PHI(I,J+1,K)+AS(I,J,K)*PHI(I,J-1,K)+AF(I,J,K)*
     &     PHI(I,J,K+1)+AB(I,J,K)*PHI(I,J,K-1)+SU(I,J,K)
      TERM=1./(AP(I,J,K)-A(I)*B(I+1))
      B(I)=B(I)*TERM
      C(I)=(C(I)+A(I)*C(I+1))*TERM
 401  CONTINUE
      PHI(IST,J,K)=C(IST)
      ISTP1=IST+1
      DO 402 I=ISTP1,ISP
      PHI(I,J,K)=B(I)*PHI(I-1,J,K)+C(I)
  402 CONTINUE
  400 CONTINUE
C
      JSP1=JSP+1
      B(JSP1)=0.
      C(JSP1)=0.
      DO 500 K=KST,KSP
      DO 500 I=IST,ISP
      DO 501 JJ=JST,JSP
      J=JSP+JST-JJ
      JP1=J+1
      A(J)=AN(I,J,K)
      B(J)=AS(I,J,K)
      C(J)=AE(I,J,K)*PHI(I+1,J,K)+AW(I,J,K)*PHI(I-1,J,K)+AF(I,J,K)*
     &     PHI(I,J,K+1)+AB(I,J,K)*PHI(I,J,K-1)+SU(I,J,K)
      TERM=1./(AP(I,J,K)-A(J)*B(J+1))
      B(J)=B(J)*TERM
      C(J)=(C(J)+A(J)*C(J+1))*TERM
 501  CONTINUE
      PHI(I,JST,K)=C(JST)
      JSTP1=JST+1
      DO 502 J=JSTP1,JSP
      PHI(I,J,K)=B(J)*PHI(I,J-1,K)+C(J)
  502 CONTINUE
```

```
  500 CONTINUE
C
      KSP1=KSP+1
      B(KSP1)=0.
      C(KSP1)=0.
      DO 600 I=IST,ISP
      DO 600 J=JST,JSP
      DO 601 KK=KST,KSP
      K=KSP+KST-KK
      KP1=K+1
      A(K)=AF(I,J,K)
      B(K)=AB(I,J,K)
      C(K)=AE(I,J,K)*PHI(I+1,J,K)+AW(I,J,K)*PHI(I-1,J,K)+AN(I,J,K)*
     &     PHI(I,J+1,K)+AS(I,J,K)*PHI(I,J-1,K)+SU(I,J,K)
      TERM=1./(AP(I,J,K)-A(K)*B(K+1))
      B(K)=B(K)*TERM
      C(K)=(C(K)+A(K)*C(K+1))*TERM
 601  CONTINUE
      PHI(I,J,KST)=C(KST)
      KSTP1=KST+1
      DO 602 K=KSTP1,KSP
      PHI(I,J,K)=B(K)*PHI(I,J,K-1)+C(K)
  602 CONTINUE
  600 CONTINUE
  700 CONTINUE
      RETURN
      END
C
C ***************************
      BLOCK DATA
C ***************************
C
      COMMON/BL80/BTURB,ABTURB,CNT,DX2,DY2,DZ2,VISMAX
     &           ,SMPP(22,18,18),RI(22,18,18)
      COMMON/CONS/XTIME,NT,U0,PRT,TA,
     &            NTMAX0,RA,CPAIR,SIGMA
C
      DATA BTURB,ABTURB,CNT/1.,2.,.08/
C     DATA CONDB,KI/.03565,2/
C
      DATA XTIME,NT/0.,0/
      DATA RA,CPAIR,U0,PRT,TA,NTMAX0,SIGMA/
     &     .0714,.24,1.,1.,555.86,0,1.712E-9/
      END
```

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