Spring 5-31-1974

Effect of gas temperature gradients and radiant heat transmission on kinetic model behavior

Richard W. J. Robertson
New Jersey Institute of Technology

75-12,795

ROBERTSON, Richard Walter J., 1943-
EFFECT OF GAS TEMPERATURE GRADIENTS AND RADIANT HEAT TRANSMISSION ON KINETIC MODEL BEHAVIOR.

New Jersey Institute of Technology, D.Eng.Sc., 1974
Engineering, chemical

Xerox University Microfilms, Ann Arbor, Michigan 48106

EFFECT OF GAS TEMPERATURE GRADIENTS AND RADIANT HEAT TRANSMISSION ON KINETIC MODEL BEHAVIOR

by

RICHARD W. J. ROBERTSON

A DISSERTATION

PRESENTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE

OF

DOCTOR OF ENGINEERING SCIENCE IN CHEMICAL ENGINEERING

AT

NEWARK COLLEGE OF ENGINEERING

Newark, New Jersey

1974

APPROVAL OF DISSERTATION

EFFECT OF GAS TEMPERATURE GRADIENTS AND RADIANT HEAT TRANSMISSION OF KINETIC MODEL BEHAVIOR

BY

RICHARD W. J. ROBERTSON

FOR

DEPARTMENT OF CHEMICAL ENGINEERING

NEWARK COLLEGE OF ENGINEERING

BY

FACULTY COMMITTEE

APPROVED: ______________________________, CHAIRMAN

____

____

____

____

NEWARK, NEW JERSEY

MAY, 1974

ABSTRACT

EFFECT OF GAS TEMPERATURE GRADIENTS AND RADIANT HEAT TRANSMISSION ON KINETIC MODEL BEHAVIOR

by

Richard W. J. Robertson

Satisfactory methods to predict radiant heat transmission in enclosures containing a radiating gas at uniform temperature are available. These methods have been traditionally used in solutions of kinetic models.

Kinetic models are strongly temperature dependent with a difference of 10°K able to double the reaction rate. In the present investigation, calculation techniques which make allowance for the non-uniformity of gas temperatures in an en losure are applied to the kinetic models. The furnace problem considers only the radiation section with the assumption that detailed knowledge of combustion and fluid flow pattern within the enclosure is available.

If the gas space in the enclosure and the bounding walls are divided into zones, a zone being taken small enough so that it may be considered isothermal, then for steady-state operation one can write an energy balance on each zone. For any specific problem, every term in these equations with the

exception of the net wall fluxes may be written as a function of unknown temperatures only; furthermore the number of equations is exactly equal to the number of unknown temperatures and wall fluxes so that a solution is possible, though exceedingly difficult due to the existing non-linearities.

The net wall fluxes are calculated by the kinetic model, the flux at any point being a function of the overall heat transfer coefficient, the extent of reaction, and the temperature of the reacting gases, each of which in turn is a complex function of reaction gas composition and velocity.

The chief problem of this investigation was one of evaluating the emission from both a gas zone and a surface zone and the radiant interchange between all zones, making due allowance for absorption along every path from one zone to another.

The primary result of this dissertation has been the application of radiant dominant heat transmissions in enclosures (which make allowances for temperature non-uniformity in gas mass) to a pyrolysis reactor. The result of this reactor-furnace hybrid model is the ability to determine optimum tube placement, furnace size, and fuel consumption, while accounting for the effect of carbon deposition in the reactor.

The methods developed in this dissertation were instrumented on an IBM 370-15 computer. This machine made it possible to make parametoric studies which predict the effect of changing furnace and reactor variables.

The high severity steam cracking furnace results in the greatest production per pound of fuel consumed. A yield of 73% represents maximum fuel economy. However, the associated problems of coke formation and high tube metal temperature must first be overcome before these yields can be realized.

Acknowledgements

The author wishes to take this opportunity to express his gratitude to all the individuals whose cooperation enabled him to produce this dissertation.

He wants to thank his advisor, Dr. E. C. Roche for his contribution of advice, exhortation, time and effort on the author's behalf.

The author's thanks are also due to the staff of the N.C.E. Computer Center.

The author includes a special thanks to his wife, Linda, for her assistance throughout the period of the writing of this dissertation and for her many hours of typing! He also wishes to thank his sons, Donald and David, for their good behavior while the thesis was being written and typed.

Table of Contents

Title Page..i

Approval Page..ii

Abstract...iii

Acknowledgements..vi

Table of Contents...vii

List of Figures..xi

List of Tables..xii

Chapter I - Summary...1

Chapter II...13

1. The Furnace Model.......................................13

   A. Introduction...14

   B. Fundamental Laws Governing Surface and Gas Radiation.....14

      1. Radiation from Solid Surfaces.....................14

      2. Radiation from Gases..............................15

   C. Techniques Available for Predicting Radiant Heat Interchange in Furnace Enclosures.....16

      1. Interchange in Gray Enclosures Containing Non-Absorbing Media.....17

      2. Interchange in Gray Enclosures Containing a Gray Isothermal Gas Mas.....18

   D. Allowance for a Real Gas.............................19

   E. Limitations on the Calculational Techniques.....21

F. Methods Used to Solve Furnace Model..........26

2. The Reactor Model................................28

A. Introduction................................28

B. Pyrolysis of Ethane Process..................29

C. Carbon Deposition...........................30

D. Chemistry of Pyrolysis......................31

3. The Mapping Function..............................34

A. Temperature Variations Along Reactor Length..36

B. Mapping the "Plane" Into a Reactor Tube......38

C. Placement of the Reactor Tube................40

D. End Effects..................................42

Chapter III- Procedures Used In Solution of the

Zoned Furnace-Reactor Model.............46

1. The Furnace Model...........................46

A. Energy Balances on the System................47

B. Radiant Interchange in a Black Enclosure

Containing a Gray Gas.......................51

1. Emission from a Volume of Gas...........52

2. Emission from a Surface Area............53

3. Interchange Between Two Surfaces........54

4. Interchange Between a Volume of Gas 64

and a Bounding Surface.................64

5. Interchange Between Two Gas Volumes.....65

C. Calculation of Direct Energy Transfer......... 67
D. Allowance for Grayness of Walls............... 69
i. Original Emitter is a Gas Zone............ 72
ii. Original Emitter is a Surface Zone........76
E. Allowance for a Real Gas.......................77
F. Energy Balance of the Gas Volumes...............82
G. Energy Balance on Surface Area.................91
i. The Source Term............................92
ii. Radiant Energy Term........................92
iii. Convective Heat Transfer...................93
iv. Net Heat Absorbed by a Surface............94
2. The Kinetic Model..................................96
A. Description of Reactor........................96
B. The Material Balance..........................97
C. Calculation of Incremental Conversion.........98
D. Calculation of Pressure Profile...............100
E. Calculation of Temperature Profile............101
F. Calculation of Overall Heat Transfer Coefficient......................................102
3. The Mapping Models................................106
A. Furnace Model to Reactor Model................106
B. Reactor Model to Furnace Model................108
4. Calculation "Flow"..................................113
A. Introduction...................................113

B. The "Flow" 114

Chapter IV - Results and Conclusions 119

1. Verification of Results 120

2. Furnace Temperature Driving Force 122

3. Convected Heat Transfer in the Radiant Section of the Furnace 126

4. Optimization of the Furnace-Reactor as a Function of Fuel Rate 129

Chapter V - Recommendations 135

References 137

Appendix A A-1

Appendix B A-11

List of Figures

Figure 1. Temperature of Reactor Wall as "Viewed" From Furnace and "Used" by Kinetic Model........ 37

Figure 2. Front and Side View of a "Zoned" Furnace with Three Subsections.................................. 44

Figure 3. Top View of Furnace-Reactor Showing Isotherm Zone Placement.................................. 45

Figure 4. Results of Integrating F'(UK).................. 63

Figure 5. Mapping the Reactor Temperature Profile Into An Isotherm Surface Area....................... 111

Figure 6. Typical Temperature Driving Forces as "Viewed" by a Furnace Subsection....................... 123

Figure 7. Temperature Profile in Furnace Subsection..... 123

Figure 8. Effect of Wall to Wall Separation on Ethylene Yield (Radiant Effect Isolated - No Adjustment of Gas to Wall Heat Transfer Coefficient).................................. 128

Figure 9. Effect of Wall Separation on Ethylene Yield (Heat Transfer Adjusted)....................... 128

Figure 10. Ethylene Yield as a Function of Heat Availability.......131

Figure 11. Optimization of Furnace Based on Fuel Economy.......132

Figure 12. Effect of Ethylene Yield on Rate of Coke Buildup in Reactor Tube.......133

List of Tables

Table 1. Comparison of this Study with Shah and Nelson..120

Table 2 . Effect of Wall Separation on Reactor Yield Radiation Effects Isolated by Using Uncorrected Surface to Gas Heat Transfer Coefficient. 127

Table 3 . Effect of Wall Separation on Reactor Yield Using Corrected Surface to Gas Heat Transfer Coefficient.......................................12[illegible]

Table 4. Effect of Heat Availability on Reactor Yield for 10 Foot Wall - Wall Separation..................13[illegible]

Chapter I

SUMMARY

An increased understanding of the basic principles underlying heat transfer processes has forced a realization of the importance of radiation as the dominant mode of heat transfer in high-temperature industrial furnaces. It is, therefore, desirable to be able to predict rates of radiant dominant heat transmission with confidence for both design and performance calculations. Methods which predict the net interchange between a radiating gas at a uniform temperature (a one gas zone furnace) with the walls forming the enclosure are available in the literature.

For many industrial furnaces, however, it is not permissable to assign a uniform temperature to the radiating gas, particularly when the distribution of heat flux within the enlcoure as well as the over-all performance is desired. When endothermic fluid phase reactions take place within the process fluid of the reactor a detailed knowledge of the local temperature gradient on the tube wall becomes important in that it affects the extent of reaction. The relatively large deviation from the true temperature profile produced by assuming one zone furnace

results in solutions which, though valid, are poor in engineering application. In the present investigation, therefore, the work of applying calculational techniques for predicting radiant dominant transmission has been continued, with the specific aim of making allowance for the non-uniformity of gas temperature in a fixed reactor. It was decided to limit the scope of the project by focusing attention on the radiation section of the fired heater problem and assuming that a description of the other phenomena necessary to the formulation, namely fuel-air combustion and internal flow patterns are available for use.

If the gas space in the enclosure and the bounding walls are divided up into zones, a zone being taken small enough so that it may be considered isothermal, then for steady-state operation it is possible to write an energy balance for each zone. For a gas zone the sum of the radiant energy received from all zones in the system (both gas and surface) plus the net convection to it from adjacent gas or surface elements plus the net enthalpy flux (chemical and sensible) to it due to bulk flow must equal the radiant energy originating within the gas zone. Similarly, for a surface, the sum of the radiant energy received from all zones (gas and surface) plus the net convection to it must equal the emission from the surface plus the net flux through the surface. Every term in these equations with the exception of the net wall fluxes may be written as a function of unknown temperatures only and the number of equations is exactly equal to the number of unknown temperatures and wall fluxes. A solution of a set of these non-linear equations, once written for each zone in the enclosure, would yield the desired distribution of temperature and energy flux throughout the system.

One problem of this investigation, therefore, was one of evaluating the emission from either a gas zone or a surface zone and the radiant interchange between any two of these zones, making due allowance for absorption along every path from one zone to another and for partial diffuse reflection of every path at every surface ad infinitum. The furnace was subdivided into a set of isothermal zones. Each zone extended the entire length of the furnace and end effects were neglected. Sets of these furnaces can be set up one next to the other to produce a three-dimensional furnace of any degree of complexity. Some error will result due to the assumption that no interaction takes place between any furnace and its neighbor.

The results produced, however, are still an improvement over most computational techniques.

A computational technique developed by Cohen [18] is able to handle zoning along the length of the reactor as well as across and vertically. His methods, however, were principally graphic, and do not lend themselves to the digital computer.

The emission rate from a gas volume of Area A is given by the following equation:

$$E_g = 4(kL)\ (A)\ \cdot \phi \cdot \sigma T_g^4 \qquad (1\text{-}1)$$

where E_g is the rate of emission in energy per unit time, kL is the absorption coefficient of the gas times its path length, and ϕ is the fraction of the energy originating within the volume which leaves the boundaries of the volume. The escape factor, ϕ , is a function of kL only and has been obtained by multiple numerical integrations as described in a later Chapter.

The emission rate from a surface area of Area A is given by:

$$E_s = \mathcal{E}_s\ (A)\ \ \sigma T_s^4 \qquad (1\text{-}2)$$

where $\mathcal{E}_s$ is the emissivity of the surface.

The interchange between any two zones in the system is more complex, involving not only the direct radiant flux between the two zones, but also the sum of the infinite number of reflected beams within the enclosure due to energy originating at either of the zones under consideration with due allowance for multiple attenuation. It is profitable to consider first only the direct interchange between the two zones; i.e. the interchange in a black-walled system.

The one-way radiation flux - surface to surface, surface to gas, gas to surface, and gas to gas respectively may be written as:

$$q_{ss}/(\sigma T_s^4) = ss \qquad (1\text{-}3)$$

$$q_{sg}/(\sigma T_s^4) = sg \qquad (1\text{-}4)$$

$$q_{gs}/(\sigma T_g^4) = gs \qquad (1\text{-}5)$$

$$q_{gg}/(\sigma T_g^4 = gg \qquad (1\text{-}6)$$

where the terms ss, sg, gs, and gg, designated as direct interchange factors, also termed in the literature as interchange areas due to the dimensional units. These factors may be thought of as the product of a radiation factor f, having any of the subscript combinations indicated on the right-hand sides of equations (1-3) through (1-6) with the first subscript representing the source of the energy and the second the receiver, which represents the fraction of the energy originating in any zone in the enclosure which reaches and is absorbed by any other zone, and a radiating-ability factor, (area)·(emissivity) for a surface zone and 4 X (volume) X (absorption coefficient) for a gas zone. Values of these radiation factors have been evaluated. These factors are functions of the path length and k, where k is the absorption coefficient of the gas. It is to be noted that these factors have been evaluated assigning a uniform k to each characteristic gas, a characteristic gas being a mathematical representation of a gas, which, in conjunction with other characteristic gases predicts the properties of gases in the system. The details of this technique, involving evaluation of determinants of order equal to the number of surface zones and of volume zones in the system, are given in Chapter 3.

With all the interchange factors for the system evaluated, it is possible to return to the original energy balances and solve for the temperature and flux distribution in the "two-dimensional enclosure." It will be recalled that the details of the fuel-air combustion, convection, and internal flow patterns are assumed known so that all terms in the energy balances have been evaluated and only temperatures or net wall fluxes appear as unknowns. Unfortunately, the set of equations contains unknown temperature in mixed first and fourth powers. For obtaining numerical solutions, these equations were linearized in T^4 by forcing the convection and enthalpy flux terms into a fourth-power law; this technique necessitates an iterative solution since the coefficients on the convection and enthalpy flux terms are now strong functions of temperature. The sets of equations are solved iteratively until the assumed values are verified.

The use of the digital computer enables a parametoric study of furnace conditions and designs criterions. The results were an optimization of a pyrolysis reactor which maximizes the ratio of product to fuel consumption. The results are given in Chapter (4).

The over-all performance of the furnace (i.e., the total amount of energy transferred from the gas) as calculated by the method presented in this thesis was found to give good agreement with the performance as calculated by existing techniques in the literature.[49] The distribution of the heat flux within the enclosure, however, was found to be very different.

The technique developed in this dissertation is capable of giving far more detailed information as to the radiant interchange within the enclosure than has been possible up to the present time. Its chief weaknesses are:

1. Finite sized zones, assumed to be isothermal, have been chosen so as to facilitate numerical solutions.
2. It has been assumed that detailed knowledge of the combustion and mixing pattern is available. This is not actually the case for most enclosures.
3. It has been assumed that no interaction takes place between furnace subsections along the reactor length.
4. The furnace is assumed to be of infinite length. This assumption can be eliminated with moderate additional complexity.

The furnace model was used in connection with a reactor model. The reactor model is able to handle large numbers of interrelated chemical reactions. The model is set up to accept any set of reactions so long as the kinetic data of reactions and the physical properties of the components are known.

From this initial data, the heat of reaction, heat of formation and the equilibrium constants are defined as functions of temperature. These functions are later evaluated to give point conditions in the reaction fluids.

The reactor is sectioned off into increment sections. Simultaneous material, momentum, and energy balances are performed on each section.

The temperature, pressure and composition of reaction fluids at the inlet of an incremental section are known from previous calculation. The temperature of the outside of the reactor wall is supplied by the furnace model. A temperature, pressure and composition are assumed at the end of the increment. A better estimate is made by calculating the reaction rates at the two ends and averaging the result. This procedure is continued until agreement is reached between two successful estimates.

The increment of heat flow to the reactor is calculated by summing the sensible heat gain of the reaction mass and the heat of reaction of each competing reaction. This must equal the net heat flux through the walls. The increment heat flux is then summed over the length of each reactor section.

The reactor model also calculates the coke buildup as a function of reaction rates. The reaction rates are assumed to be invariant over the time span during which the carbon is deposited. New reactor conditions are then used during each additional time span of carbon deposition. The coke's chief effect on reactor conditions is a decrease in overall reaction rate due to the following effects:

1. A decrease in the net heat flux through the wall of the reactor due to the presence of a coke layer.
2. A reduction in reactor volume and hence, reactor mean residence time.
3. A larger pressure drop throughout the reactor length necessitating a higher inlet pressure, adversely affecting equilibrium.

The reactor model results in a new temperature profile for the reactor. The new profile is then mapped into three corresponding process temperature profiles which is then transferred into the furnace model.

The furnace model and the reactor model are solved repeatedly until good agreement is reached between assumed and calculated temperature profiles. The net heat flux through the wall is also forced to converge. The net heat flux into the reactor is solved by the relationship

$$Q = UA \Delta T \qquad (1\text{-}7)$$

The overall heat transfer coefficient (U_R) used by the reactor model, is a function of the thickness of the reactor wall, the thicknesss, if any, of the coke layer and the inside film coefficient (H_i). H_i is in turn a function of the reaction mixture velocity, thermal conductivity and composition.

The overall heat transfer coefficient used by the furnace model (U_F) to calculate the outside wall temperature from the known temperature of the process fluid must be mapped into the tube plane. The mapping is necessary due to the pseudo two dimensional nature of the furnace model. The mapping is done through a net heat flux balance on the reactor wall. The value of U_F is thus mapped by forcing agreement between the overall heat flux calculated by the furnace model and the heat flux calculated by the reactor model. U_F does not correspond with U_R calculated by the reactor model.

Since both the reactor and furnace models were set up in a computer program it was possible to make a parametoric study on the complete system. Thus the effect of tube placement, oil fired rate, furnace dimensions, reactor length, reactor composition can be correlated to design a furnace of optimum yield with minimum fuel consumption. One of the major contributions of this thesis is to correlate these quantities to predict optimum furnace and reactor design.

CHAPTER II

1. The Furnace Model

A. Introduction

This analysis depends on the development of two unrelated, but interdependent models. These two models are then coupled together and form an effective method to predict optimum furnace design.

One model, the furnace model, will be discussed is Chapter II-1. The other model, the kinetic model, will be discussed in Chapter II-2. The coupling model is then explained in Chapter II-3.

An increased understanding of the basic principles underlying heat transfer processes has forced a realization of the inportance of thermal radiation as the dominant mode of heat transfer in high temperature industrial furnaces. High installation and maintenance costs as well as the competitive market of today call for the design of furnaces or heaters which will perform efficiently and economically. Furthermore, because of variations in process conditions one would like to be able to predict the effect of such variations on furnace operation. To these ends, therefore, considerable effort has been extended to put the calculation and prediction of radiant heat interchange on a firm engineering basis.

The model makes use of work done by Cohen [18] and Roche [63] which allows for the non-uniformity of gas temperatures in an enclosure.

B. Fundamental Laws Governing Surface and Gas Radiation

1. Radiation from Solid Surfaces

All solids, at any temperature other than absolute zero, emit and absorb radiant energy. Both the magnitude of the emission and its quality (i.e., its spectral distribution) depend primarily on the temperature of the material, but also, to a lesser extent, on the particular nature of its surface. The rate of emission from a perfect radiator (defined as a black body) is given by the familiar Stefan-Boltzmann Law: the emitted flux (energy per unit time per unit area) is proportional to the fourth power of the absolute temperature. The spectral distribution of black-body radiation is a function of temperature only and is given by Planck's Law. Any real surface always emits less than black-body radiation, and if its spectral distribution is the same as the Planck distribution, the body is said to be gray. The ratio of the energy emitted by any gray body at a fixed temperature to black-body emission at the same temperature is termed the emissivity; by the very nature of its definition, numerical values of emissivity must always lie between zero and unity.

For a further review of surface emissivities and radiation from solids Jakob[36], McAdams[49] and Hottel and Sarofim[33] or other standard references on heat transfer may be consulted.

2. Radiation from Gases

In addition to surfaces, certain gases absorb and emit energy when heated. Of greatest interest to the furnace designer are water vapor and carbon dioxide, the primary products of combustion. Data on the radiating and absorbing characteristics exist for both carbon dioxide and water vapor. (32), (35), (49) Somewhat more limited data are available for carbon monoxide, sulfur dioxide and ammonia. (16), (26), (59), (88)

Gas radiation differs from surface radiation in one important respect. Gas radiation is by no means gray, rather these gases exhibit very strong emission and absorption bands in certain spectral regions and are practically transparent in others. This non-grayness of real gases leads to enormous complications in furnace design calculations if it is to be allowed for rigorously. Fortunately, approximation techniques exist for handling the real-gas case; they will be discussed in later sections of this chapter.

C. Techniques Available for Predicting Radiant Heat Interchange in Furnace Enclosures

The calculation of the radiant interchange in a furnace enclosure may be resolved into three different, though not completely separable, problems:

1. Allowance for the geometry of the system.
2. Emission of radiation from the gas and its absorption and/or reflection at the various surfaces.
3. Absorption by the gas of radiation emitted by or reflected at the different surfaces.

A little thought will show that a completely rigorous calculation of the interchange in an enclosure would be exceedingly complex, and, in fact, a perfectly rigorous solution appears to be almost impossible to attain. One of the most important reasons for this complexity is the fact that in a radiating system, what goes on at any point is influenced by every other point in the system. That is, one must write an integral equation to express the heat transfer rates everywhere, instead of a differential expression expressing the local rate dependent only upon local conditions, as is possible for convective and conductive heat transfer. For this reason certain simplifications have been made which have enormously decreased the complexity of the calculations but which nevertheless yield answers for certain cases of sufficient accuracy for engineering use. A brief review, without any derivations or elaborate explanations, of the methods presently available for calculating radiant heat transfer appears below.

A. Interchange in Gray Enclosures Containing Non-Absorbing Media

The radiant interchange in a gray furnace enclosure, of any degree of complexity so long as it does not contain any absorbing gas, is calculable by the method presented by Hottel[46]. The net transfer by radiation between any two surfaces such as A_1 and A_2 is given as:

$$q_{A_1 \to A_2} = A_1 \mathcal{F}_{12} \sigma (T_1^4 - T_2^4) \qquad (2\text{-}1)$$

(A portion of the enclosure may be grouped together as a surface, e.g., A_1, when it has a substantially uniform temperature and when all portions of it have substantially the same "view" of the remainder of the enclosure.) The term $A_1 \; _{12}$ is dependent upon the geometry of the entire system as well as the emissivities (equal to the absorptivities for a gray system) of all surfaces, but it is not a function of the temperatures of any surfaces so long as their emissivities are themselves independent of temperature.

B. Interchange in Gray Enclosures Containing a Gray Isothermal Gas Mass

If now, the enclosure is filled with a gray gas of uniform temperature, the interchange between the gas and any surface or between any two surfaces separated by gas, may be calculated by a slight nodification of the above method. Gas-surface interchange is defined by the following equation:

$$q_{G_1 \to A_1} = A_1 \mathcal{F}_{1G}\, \sigma (T_G^4 - T_1^4) \qquad (2\text{-}2)$$

The surface-to-surface heat transfer is exactly the same as given in equation (2-1) with the modification, however, that the interchange factor $A_1 \mathcal{F}_{12}$ has been adjusted so as to allow for the fact that on each pass from surface A_1 to surface A_2, directly or via any surface forming the enclosure, a portion of the energy is absorbed by the gas.

The interchange factors for this case, as before, are dependent upon the geometry of the entire system as well as the emissivities of all surfaces, and in addition are dependent upon the gas emissivity. For opaque surfaces, the emissivity is equal to the absorptivity and the complement of the reflectivity: that is $\varepsilon = \alpha = (1-\rho)$ They are not functions of any temperature in the system, so long as the emissivities of the system, both gas and surface, are independent of temperature.

D. Allowance for a Real Gas

Non-luminous gas radiation, particularly radiation from carbon dioxide and water vapor, which are of greatest importance to the furnace designer, is not gray. The transmissivity of such a gas is not only a function of the gas properties, but is also very markedly influenced by the spectral distribution of the energy which is being absorbed. For example, the absorption of very high-temperature radiation by carbon dioxide, with its strong absorption bands in the long wavelength region would be very low because the source of radiation would be predominantly of short wavelength; but the absorption of lower temperature gray radiation, with a consequent larger fraction of the incident energy in the same spectral region as the gas absorption bands, would be much higher. In the treatment of the gray gas system mentioned in subsection 2, it was assumed that the absorptivity of the gas for surface radiation was independent of the quality of that incident radiation, and for this reason the gray-gas formulation is in error if applied directly to a real system.

Hottel and Sarofim[(33)] have shown it is possible to approximate very closely real-gas radiation, without losing the mechanics of the gray-gas formulation. Since for the gray gas the transmittance of a gas beam of length x with a gas pressure P_G is given by:

$$\tau_x = e^{-k' P_G X} \qquad (2-3)$$

where k' is the absorption coefficient of the gas and is independent of wavelengths, the emissivity and absorptivity are equal and may be expressed as:

$$\varepsilon_x = a_x = 1 - \tau_x = 1 - e^{-k' P_G X} \qquad (2-4)$$

It is, of course, possible to fit the $\tau_x = f(P_G x)$ curve for a real gas to any degree of precision by a series of exponential type terms such as:

$$\varepsilon_x = a\, e^{-k_a' P_G X} + b\, e^{-k_b' P_G X} + c\, e^{-k_c' P_G X} \ldots \qquad (2-5)$$

This equation indicates that the transmissivity of a real gas may be thought of as a weighted sum of a number of gray-gas transmissivities, each applicable over a different spectral region. The sum of the weighting factors, a,b, c,....... must be unity, since the emissivity of a gray gas having no thickness (x=0) must be unity. The interchange in an enclosure, therefore, can be thought of as equivalent to the sum of the interchanges of a number of gray-gas systems each weighted in porportion to that fraction of the spectral region over which it acts. It is to be noted that the gray gas in each region has a different absorption coefficient and hence a different emissivity.

In the limit, as one considers an infinite number of spectral regions each obeying the gray-gas formulation, the answer of course, must be exact. For engineering calculations, however, this type of approach would be extraordinarily complex if one had to consider a large number of zones. Numerical analysis of typical problems has indicated, fortunately, that if the $e^{-k'X}$ curve is to be fitted anew for each numerical problem, it is in general sufficient to consider only two spectral regions, a and b, where the fraction "a" consists of a gray gas with a finite absorption coefficient k_a and the fraction "b" (the complement of "a") consists of a gas with a zero absorption coefficient (i.e., a clear gas which neither absorbs nor emits). Again, space limitations prohibit a more adequate discussion of this problem and, for details, the reader is referred to Hottel[49] and Hottel and Sarofim.[33]

E. Limitations on the Calculational Techniques

Recapitulating, it has been shown that one is able to handle satisfactorily an enclosure made up of any number of gray surfaces and filled with a real isothermal gas mass. In actual practice it may be difficult to obtain a numerical solution for a very complicated case; however, the principles governing the interchange in such enclosures and the technique for obtaining solutions have been formulated and are generally available. (4)

Perhaps the most servious limitation to the calculational methods outlined above is the fact that the gas temperature and composition have been assumed to be uniform throughout the enclosure. Obviously, this assumption is never completely true for any industrial furnace, and in a good many cases it may be very seriously in error. If the furnace chamber is roughly cubical in shape, and if turbulence and mixing are present to a high degree, then the gas temperature will be nearly uniform and equal to the temperature of the exit gas so that the above methods apply directly. Even if these conditions apply only approximately, that is, if the gas temperature and composition at the inlet and outlet of the furnace are not too different from each other, then some mean of the two temperatures ought to give a reasonably accurate answer. Unfortunately, few industrial furnaces fall in this category.

If, on the other hands, the furnace is very long compared to the dimensions of the cross-section normal to the direction of gas flow, and if combustion is rapid at the furnace entrance, the temperature of the gas falls continuously as it passes through the furnace. In the limiting case of a furnace with length infinitely great relative to the transverse dimensions, allowance for this drop in gas temperature can be made by calculating local heat transfer rates at several points and graphically integrating along the furnace length. Long furnaces have been handled adequately by this technique, which in effect ignores radiant flux in the direction of gas flow, as long as there is a definitive negative temperature gradient from the botton of the combustion chamber to the top. This tedious process, which applies only to one very special type of furnace, has been performed for a wide range of furnace variables, and a simplified method of predicting a mean gas temperature to give the answer in a single step is available.[17] [49]

In this thesis a furnace model of the infinite length relative to the transverse dimension is considered. However, the model incorporates radiant flux consideration in both transverse directions. Radiant flux along the infinite axis is also calculated, but ignores end conditions along the infinite axis. This makes it possible to section the model along the long axis and consider each section independently of the others. Some error is introduced in that the model can not show any net heat flux between adjacent sections despite the existence of temperature gradients between sections. The errors thus generated are minimal due to the relatively small difference of temperature and the low value of the heat transfer due to eddy diffusion.

While one is able to handle the two limiting cases of furnaces mentioned above quite simply, it is rather unfortunate that most industrial furnaces fall into a category somewhere in between them. At the present time, only the method developed by Cohen[18] allows one to take into account the fact that in actual furnaces, very substantial gas temperature gradients exist, both in the direction of gas flow and transverse to it. The method, however, is very tedious, and does not easily lend itself to computer calculations due to the graphical techniques or methodology employed.

Simply to illustrate the magnitude of the temperature gradients, a few numerical examples will be given.

1. Data obtained by Smith[73] and reported by Cohen[18] on a scaled-down model of a steel-reheating furnace, using premixed air and gaseous fuel, have indicated that a drop of about 300-400 Centigrade degrees between the

gas temperature near the refractory roof and the cool floor sink, a total distance of about one foot in his equipment, is not at all unusual.

2. The large-scale furnace (about 6 feet by 6 feet by 20 feet) used by the International Flame Radiation Research Committee, and fired with either gaseous or liquid fuel in a burner jet, has shown temperature drops between the hot combustion zone near the center of the flame and the refractory wall of as much as 600 Centigrade degrees in a distance of about three feet.[37]

These figures have been quoted merely for illustrative purposes. However, when one considers that gas emission is roughly proportional to the second or third power of absolute gas temperature, it seems likely that the consequences of these large gradients might be extremely important.

It is possible for one to handle rigorously the simplest possible case of allowing for temperature non-uniformity in the gas. This method has been presented by Hottel[49] for the case of energy reception by a black wall adjacent to a gas mass having a known one-dimensional temperature gradient.

F. Methods Used to Solve Furnace Model

There are, of course, two fundamentally different approaches that one might use in attacking this problem. The first is completely theoretical and involves the development of calculational techniques to enable the prediction of the effect of temperature gradients on radiant heat interchange. Since basically the processes occuring within a furnace are determined solely by the fundamental laws of heat transfer, fluid flow, and combustion kinetics, the problem reduces itself to one of expressing the interrelationships of the various mechanisms interacting with one another in such a way that it becomes possible to obtain a numerical solution. The second technique would be to determine experimentally heat transfer rates under a wide variety of conditions with the hope of obtaining some sort of correlation which would enable one to predict the operation of furnaces other than those studied.

The first method of attack was felt to be the more profitable one in this case, and accordingly a purely calculational approach was used. The advent of the high speed digital computer has allowed implementation of this approach to handle far more complex systems than heretofor have been attempted. The speed of computation also allows for solution of many furnace models with the ultimate objective of being able to simplify the result into some generalized empiricle relationship. The solution has been to set up in the most general terms possible, that is, in such a form that if one had specific knowledge of combustion and mixing, he would be able to incorporate such information directly into the recommended technique.

In all fairness to the reader, it must be pointed out that the combination of processes occuring in a furnace is extremely complex. The extent to which the method developed in this dissertation might be used by an engineer is dependent solely upon the amount of time which he is justified in spending on any particular problem. For one wishing only an approximate answer, it would be uneconomical to go through the costly and involved processes described later. On the other hand, if it is really important that one has the right answer, the author sees no alternative to following the methods recommended in this dissertation or their equivalent. Their use to prove the validity of engineering shortcuts is an interesting application, but not the subject of this dissertation. The use of the computer in handling the model will make it feasible for an investigator to find such simplified approaches.

2. The Reactor Model

A. Introduction

To perform an optimization one needs some sort of plant description to form an objective function such as production rate or profit margin which must be optimized in terms of the independent variables.

Historically, plant data were used in deriving mathematical models by regression analysis. Some plants had even been deliberately disturbed in order to obtain enough data to determine the independent variables into which the plant was being fitted.

This method has many drawbacks such as noise in the plant data causing unreliability in the reading and a limited range of conditions under which the data is collected. Conditions outside of the range of those specifically studied must be calculated by the relatively unreliable method of extrapolation.

An alternative method is to simulate the plant based on the physical and chemical conditions. This simulated model can then be perturbed to determine the effect on the function to be optimized.

In order to describe plant conditions as thoroughly and accurately as possible, a model should consider the entire plant, including recycle streams, separators and peripheral equipment as well as the reactor. This is not the intent of this study.

It was decided that the optimization of fuel consumption would be most meaningful and would give optimum conditions close to the optimum based on an overall profit objective function.

The purpose of this disseration is to develop an algorithm which successfully predicts the behavior of a reactor-furnace. In order to be able to verify the results a reaction system was chosen which has been extensively reported in the literature. The reaction system thus decided upon was the cracking of ethane to form ethylene.

B. Pyrolysis of Ethane Process

Ethylene is a basic raw material used in the manufacture of polyethylene and polyethylene copolymers and as an intermediate in the synthesis of many organic compounds, with plant sizes ranging between 50 to 250 million pounds per year. The pyrolysis of ethane is very profitable becuase the raw material, ethane, would have a minimum value as a fuel gas. Ethylene is produced by "cracking" of the feed stock in fired reactors at temperatures up to $1250^{o}K$.

Almost all larger petrochemical facilities have several furnaces which operate with different feed stocks, notably various proportions of ethane, propane, butane and "naphtha". The reactor pressure and temperature profiles and feed rates are also varied. The products from these different streams are generally combined into one stream after "quenching" to terminate the production of unwanted byproducts.

The reactor model is able to handle each set of feed stocks independently and perform separate optimizations for each furnace. In this study, the cases of pure ethane, propane, and combinations, each mixed with steam, were considered. The steam provides a chemical mechanism to minimize the rate of coke deposition. The model is also capable of optimizing the production of acetylene by increasing the residence time.

C. Carbon Deposition

Carbon is one of the byproducts of the pyrolysis reactions. Carbon is deposited on the wall of the reactor and results in a continuously decreasing reactor radius. This results in larger pressure drops occuring within the reactor tube. Eventually the pressure drop reaches a value which is too high to keep the system operating, and the reactor must be shut down for cleaning. Another effect of the carbon deposition is to reduce the overall heat

heat transfer coefficient making the fired heater less efficient.

An increase in reactor outlet temperature increases both the yield of ethylene and the rate of carbon deposition, hence causing an increase in the frequency of reactor shutdown for cleaning. As fuel consumption in the furnace increases, so does the reactor yield. The function of reactor yield divided by fuel consumption plotted against fuel consumption goes through a maximum which represents an optimum operating condition for any given set of furnace and reactor parameters, i.e.

$$\text{Yield/Fuel Consumption} = \text{f(reactor parameters, furnace parameters)/fuel consumption} \quad (2\text{-}4)$$

The reactor-furnace model developed in this dissertation is able to determine this ideal operating point for most existing furnaces. The model also lends itself to the determination of the optimum design of most new furnace-reactor systems.

D. Chemistry of Pyrolysis

The chief products from thermal cracking furnaces-reactors vary from feed to feed. For the feed considered in this study, the chief products were ethane, ethylene, acetylene, methane, propane, propene, hydrogen and coke. Small amounts of aromatics were also formed. As an approximation these were defined to have the properties of C4's and C6's alpha olefins.

The eight equations considered in this study are:[71]

	Order Forward	Order Reverse	
$C_2H_6 \rightleftharpoons C_2H_4 + H_2$	1	1-1	(2-5)
$C_2H_6 \rightleftharpoons CH_4 + \frac{1}{2}C_2H_4$	1	1-1	(2-6)
$C_2H_4 \rightleftharpoons C_2H_2 + H_2$	1	1-1	(2-7)
$C_2H_2 \rightleftharpoons 2C + H_2$	2	1-1	(2-8)
$2C_2H_2 \rightleftharpoons C_4H_4$ (i.e.) C4's	1	1	(2-9)
$C + H_2O \rightleftharpoons CO + H_2$	1-0	1-1	(2-10)
$C_3H_8 \rightleftharpoons C_3H_6 + H_2$	1	1-1	(2-11)
$C_3H_8 \rightleftharpoons C_3H_4 + CH_4$	1	1-1	(2-12)

A detailed explanation of the kinetic reactor model can be found in the M.S. Thesis of Robertson.[62] It was necessary to modify Robertson's model in order to incorporate the calculation of the net heat flux through the wall of the reactor when the details of the pointwise temperature distribution are known.

Further detail may be found in the following references:

1. Use of computers in pyrolysis - see Reference Numbers (3, 9, 12, 23, 25, 44, 45, 53, 60, 62, 65, 68, 69, 70, 86, 95)
2. Chemistry of Pyrolysis (2, 38)
3. Reaction Rate (80, 81)
4. Equilibrium Rate (40)
5. Heat of Reaction (77)
6. Heat Transfer (13, 76)
7. Carbon Deposition (10, 14, 20, 28, 55, 57, 82)
8. Furnace Construction (15, 37, 48, 67, 74, 78)
9. Supersonic Oxidative Pyrolysis (90)
10. Sub-sonic Oxidative Pyrolysis (89)
11. Pyrolysis of Heavy Feed Stock (79, 86)

3. The Mapping Function

The development of the kinetic model and the furnace model are independent of each other. In order to make the two models interdependent it was necessary to develop a third model which could communicate between the first two models. This third or mapping model is the author's specific contribution in this dissertation. It was utilized to investigate the product yield, fuel consumption geometry and tube placement of the reactor-furnace. The firing patterns produced by different tips on the burners can also be studied with the idea of designing a firing tip which would yield an optimum firing pattern.

The mapping model has to take into account a number of inconsistencies which include:

1. The furnace model assumes that there is no variation in temperatures along its infinite axes. The kinetic model, however, shows a continuous increase in temperature as the reaction mass flows through the reactor tube, which has vertical as well as longitudinal variations in geometry.

2. The furnace model "views" the furnace wall as a continuous semi-porous plane, a pprtion of which

is a heat sink to the ambient (through the insulating walls of the furnace). The kinetic model considers itself a discreet section of tubing with a radial uniform outside surface temperature.

3. The furnace model was picked to have a height of 28' feet. The reactor model was 400 feet long. This made it necessary to fold the reactor tube into a series of "u" bends which run up and down along the wall of the furnace.

4. The furnace model considered itself infinitely long with no end effects due to the presence of walls at both ends of the furnace. The reactor model was clearly finite in length.

Methods used to handle each of these inconsistencies will be discussed later in this section.

In order to make the models compatable, both temperature and net heat flux profiles through the reactor wall had to be in agreement. As each of these quantities is calculated independently by both models, a trial and error type of solution was developed.

The temperature profile of the outer reactor wall was assumed. With this assumed profile, the kinetic calculations were completed. The kinetic calculations included a reactor fluid temperature profile and a net heat flux. The furnace calculations were then performed and yielded a new outer reactor wall temperature profile and a net heat flux to the reaction fluids.

This new outer wall temperature profile was then used to repeat the kinetic calculations. This process was then repeated until the maximum difference between old and new reactor fluid temperatures was less than 1.25°K and the net heat fluxes calculated by the two models were within 2% of each other.

A. Temperature Variations Along Reactor Length

The temperature of the reaction fluids increases continuously as the reactions take place. The net heat flux into the reactor results in two net effects:

1. An increase in the temperature of the reaction mass due to a sensible heat gain.
2. A change in reactor mass composition due to chemical change. (The principal reaction being endothermic).

In the initial stage of reaction the mixture has an insufficient temperature for any appreciable reaction to take place, hence, most of the heat flux results in a sensible heat gain.

In a second portion of the reactor the reaction mass is at reaction temperature with large quantities of unreacted species present. A majority of the heat flux goes to supplying the reaction mass with the necessary heat of reaction, with some sensible heat gain still occurring.

A final portion of the reactor consists of an ever declining portion of the net heat flux contributing to the heat of reaction;

It becomes possible to take advantage of these tendencies by splitting the furnace into three zones. In the first zone there is considerable increase in the temperature of the reaction mass. This in turn results in rapidly changing wall flux. However, since in this section of the reactor little reaction takes place, an averaging technique of the the temperature flux along the infinite axis for each isothermal wall zone will not seriously affect the kinetic model.

In the second zone the kinetic model predicts large extent of reaction but only mild increasing temperatures. Again an averaging technique for each isothermal wall zone along the inifinite axis lives temperature distributions which can be used by the kinetic model, since only relatively small temperature differences exist.

In the third zone both relatively extensive amounts of reaction and fairly large reactor fluid temperature changes take place. By minimizing the size of this section, the averaging technique is again applicable.

The reader should note that considerable flue gas temperature gradients exist between each isothermal zone in adjoining sections. This would suggest that a subdivision of each section into two or more sub-sections would result in still more precise results. However, the additional computational time required by the computer for such an undertaking would be prohibitively large.

B. Mapping the "Plane Into A Reactor Tube

The furnace model views the wall of the furnace as a continuous plane with isotherms running along the horizontal and discreet temperatures of radiation running along the vertical. The plane is porous in that it "views" the furnace wall and reactor tubing simultaneously, differentiating between them as the ratio of their respective areas. The furnace model does not distinguish individual sections of tube and wall, rather "considers" the two as the wall of the furnace.

The kinetic model "uses" the outer skin temperature of the reactor to calculate the net heat flux to the reaction mixture. In a furnace tube there would be some radial temperature distribution since the side of the tube facing the wall of the furnace would have a lower temperature than the side facing the bulk of the hot flue gases. The net temperature difference is not too great since the major resistance to heat flow is the result of the inside film heat transfer coefficient. (The resistance to heat flow through the coke layer would also be large, but this quantity is a variable, depending on the length of time the coke has been forming and the particular location in the reactor tube). The ratio of heat resistance in the tube metal to that caused by the inside film coefficient is an order of magnitude greater than 10 to 1, as was calculated by Robertson.[62]

In order to make some allowance for this effect, the net heat transfer coefficient calculated from reaction mixture to outer tube wall temperature used by the furnace was adjusted in such a fashion that the net heat flux as calculated from the furnace equation was equal to the net heat flux as calculated from the reactor equations.

The net heat transfer coefficient found by the reaction equation was calculated from considerations of physical properties of the reactor tube, the thickness of the coke layer and the chemical composition and physical properties of the reaction mass.[62]

C. Placement of Reactor Tube

The reactor being 400 feet of continuous tubing which is hung in the vertical direction (to avoid gradual bending of the tube near its center if the tube were placed in a horizontal position due to the excessive heat required for pyrolysis) would not fit into a furnace 20 feet in height. It was therefore placed in the furnace in a series of "U" bends running first from top to bottom and then bottom to top. A total of 14 such bends was required to accomodate the entire reactor length. A total of 14 such reactors can be placed in the 40 foot length of the furnace, seven on each side of the flame wall. The "U" bends provide mechanical support while allowing for thermal expansion.

Within the series of 14 "U" bends, the furnace was further subdivided into three distinct reactor zones discussed earlier in this Chapter. The mapping model had to be able to distinguish in which furnace zone the corresponding reactor segment lay. It is also necessary to know whether the tube was running up the furnace or down. The temperature profiles used by the furnace and the reactor are illustrated in Figure 1.

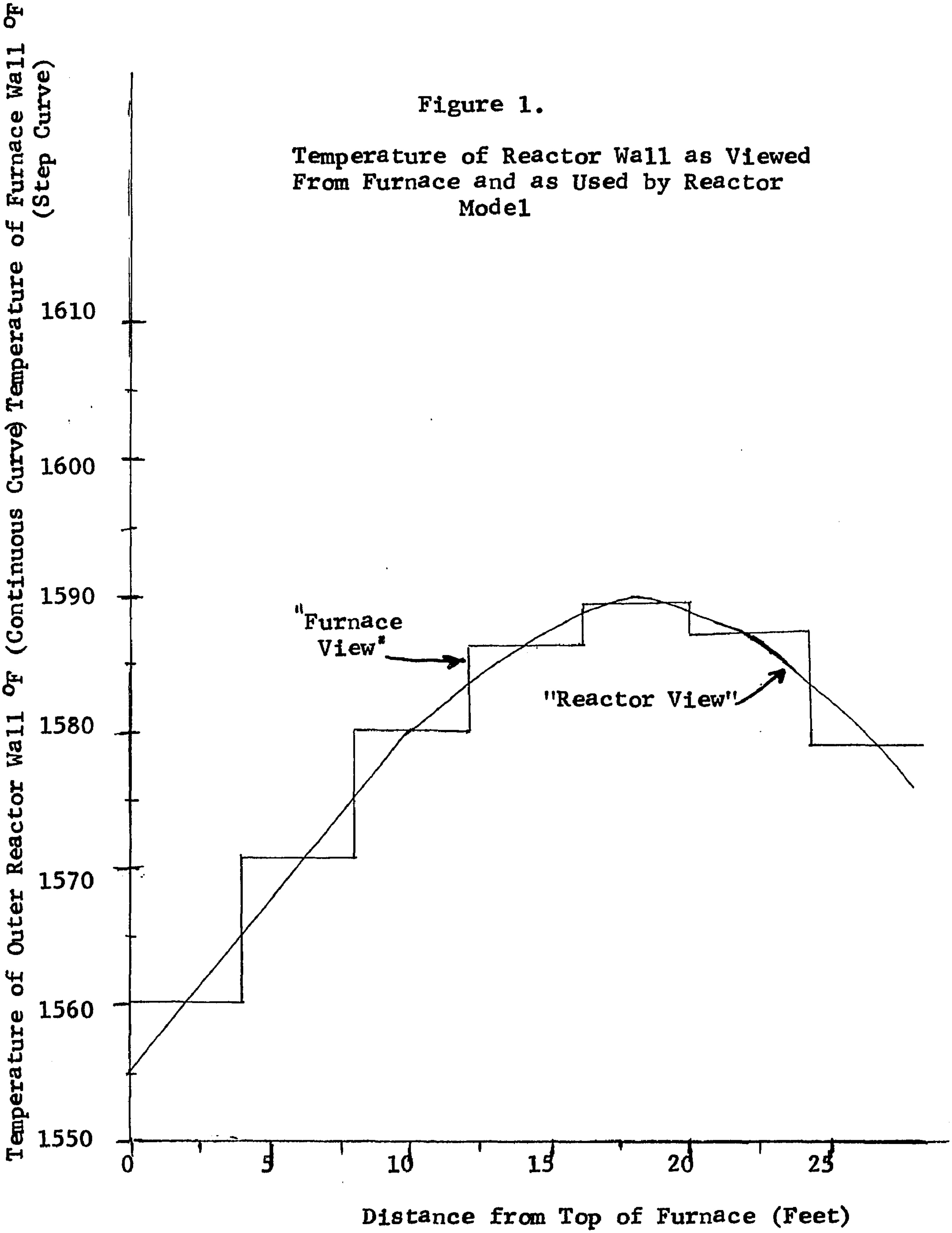


Figure 1.

Temperature of Reactor Wall as Viewed From Furnace and as Used by Reactor Model

The smooth curve shown in Figure 1 was calculated by fitting a fourth power polynomial of $T - f(Z) = a \pm bZ + cZ^2 + dZ^3 + eZ^4$ using the midpoint of each discreet furnace zone temperature as calculated by the furnace model. These discreet temperature zones were adjusted at the end of each furnace calculation and smooth curves were refitted for each of the three furnace zones recalculated.

Figures 2 and 3 show the actual location of the tubing in the furnace as well as the placement of the isothermal zones. The bridge wall extends on half the distance along the top of the furnace, the remaining half being the opening into the convection section and the stack.

D. End Effects

The furnace model studied in this thesis was considered to be infinitely long and end effects were ignored. As the dominant mode of heat transfer is radiation, an estimate of the distance necessary to completely absorb all incident radiation was made for the gray gases consisting of the flow gas. It was determined that for beam lengths of 65 feet, less than one part per million of the original radiation was still present in the beam. The clear gas contribution was somewhat higher.

The furnace model was further complicated by assuming subdivisions along the reactor length (See Figure 2). Each subdivision assumes that its unique properties exist unchanged through neighbor subdivisions in the horizontal plane. In the furnace model studied, which was 70 feet long, there occurred 21 subdivisions. There were, however, only three distinct furnace subdivisions which had to be calculated.

Figure 2
Front and Side View of a "Zoned" Furnace with 3 Subsections

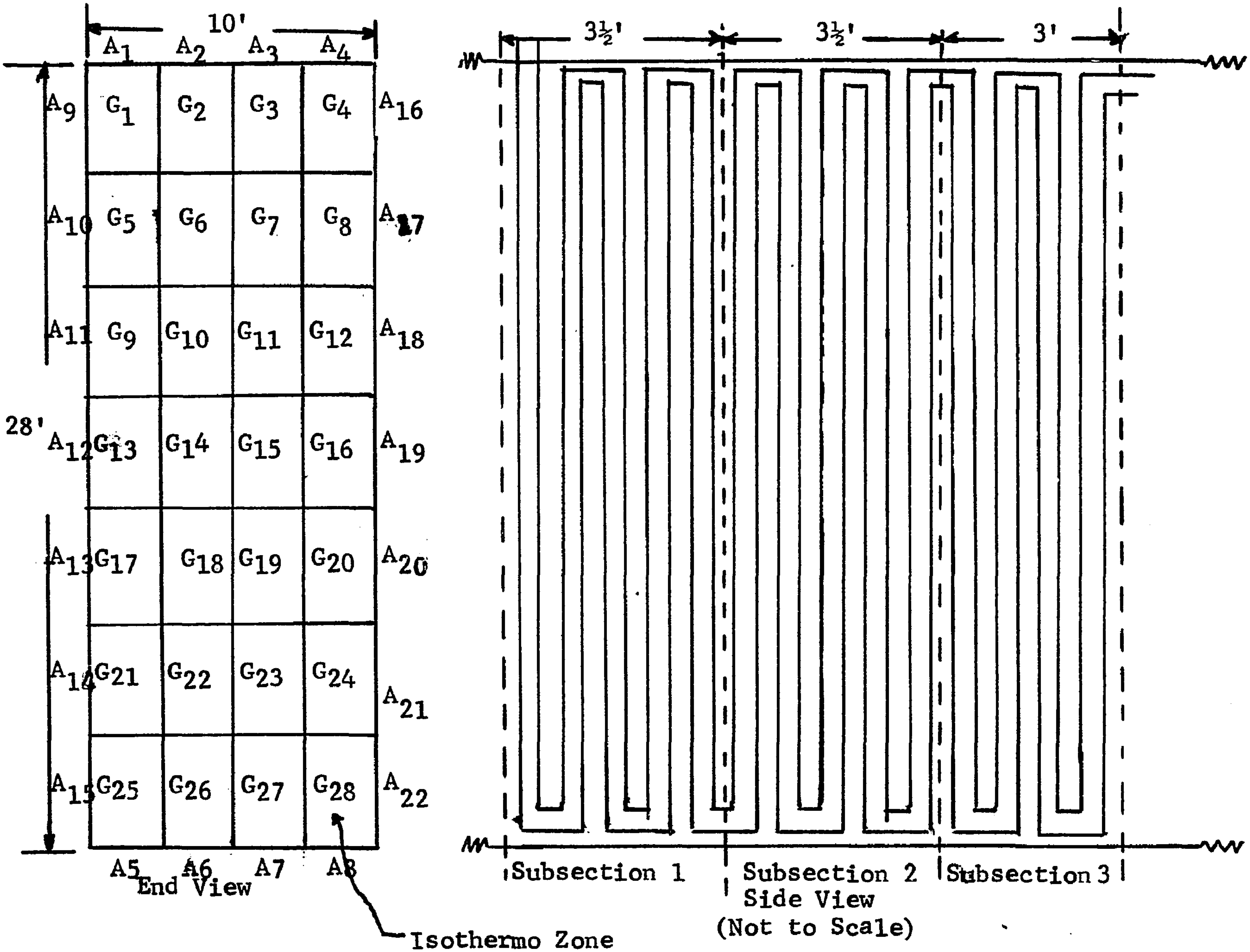
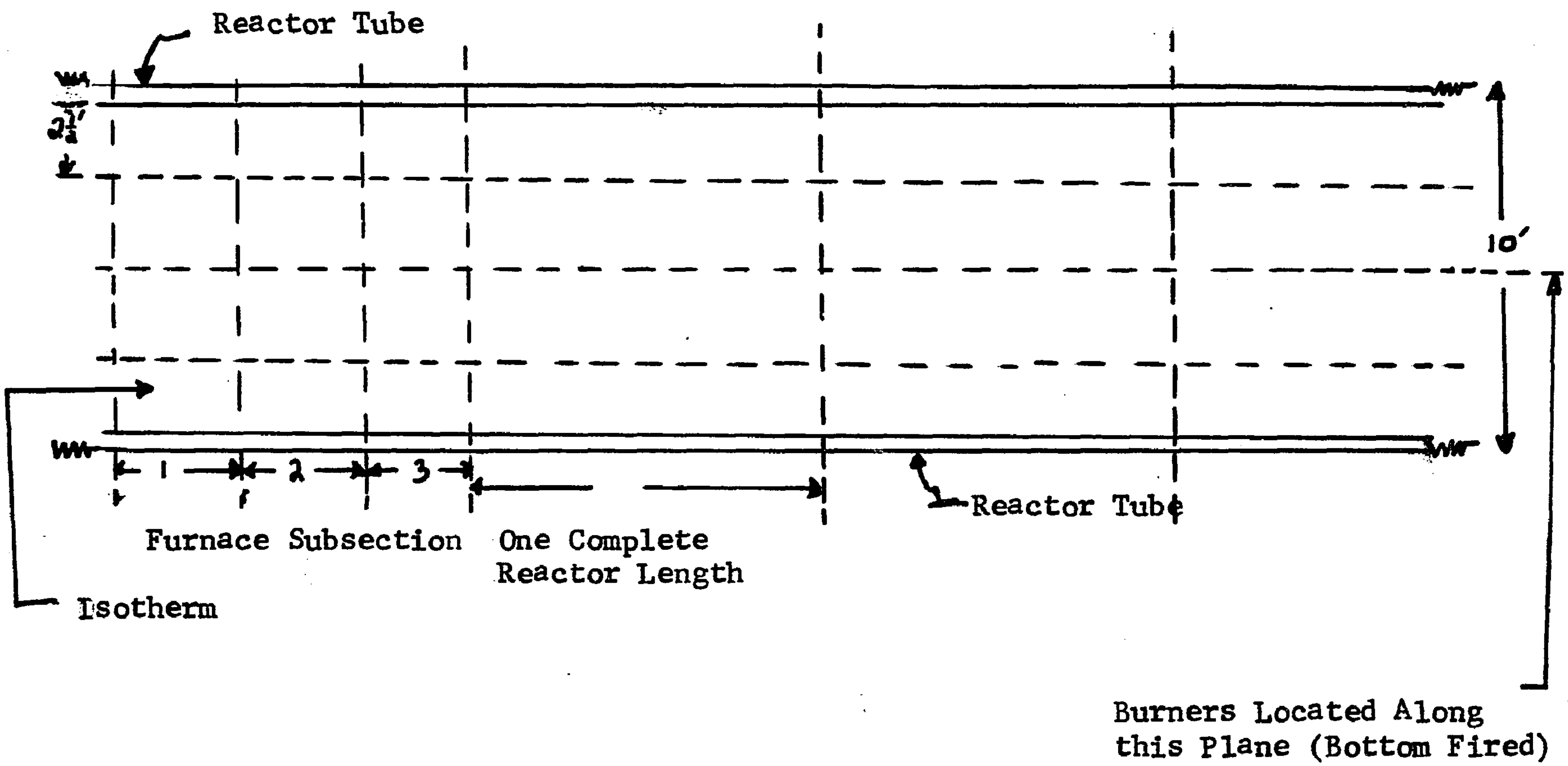


Figure 3

Top View of Furnace-Reactor Showing Isotherm

Zone Placement



Chapter III

Procedures Used in Solution of the Zoned Furnace-Reactor Model

1. The Furnace Model

This Chapter will discuss in detail the mechanism used in the solution of each of the problems handled in this study. The furnace model will be discussed in Chapter III-1, the kinetic model in Chapter III-2, and the mapping model in Chapter III-3. In addition, Chapter III-4 will show the computational procedure used in order to arrive at the solution which comprises this study. In the remainder of this dissertation, all discussion will be limited to steady-state conditions in an enclosure.

In this study the furnace was zoned into isothermal gas volumes and surfaces areas. The volumes run through the entire length of the furnace and are in fact treated as infinite in length; the height and width of each of these zones being finite. Likewise the surface areas are infinite in length and finite in width if in the horizontal plane, or in height if in the vertical plane. The model does not consider any plane or volume which is not either mutually parallel or perpendicular to the infinite axis (see Figures 2, 3, 4). These limitations should be kept in mind for all future references to surface area and gas volumes.

The furnace was further subdivided along the infinite axis in order to make allowance for the nonuniformity along that axis. However, for the calculation, each subdivision is treated as if those conditions in that subdivision existed along the entire length of the furnace. This precedure allows the handling of each subdivision as an independent calculation, greatly reducing the complexities of the calculation procedure.

The general approach to be used consists of dividing the space enclosed and the bounding surfaces into zones, each zone being taken small enough so that it may be considered isothermal.

An energy balance may be written for each zone in the system, and when this is done it will be found that the series of equations contains only gas temperatures, surface temperatures or wall fluxes as unknowns. Futhermore, the number of unknowns will be found to equal exactly the number of equations. In principle then, one can solve either for the temperature at any given point in the system or the flux through the wall.

A. Energy Balances on the System

Consider the enclosure to be made up of isothermal volumes of space containing a gray gas, and designated as

g_1, g_2, g_3 ..... and isothermal areas of bounding surface (either heat sinks or refractory) designated as s_1, s_2, s_3..... . The surface areas will coincide exactly with the gas volumes that touch them.

The conventions of naming the various surfaces and gas volumes used in this dissertation are as follows: (Refer to Figure 2, cross section view).

1. The gas volumes are numbered from left to right, starting in the upper left hand corner and working down as each row is completed. Hence the first gas volume in the upper left hand corner would be g_1.
2. The surface areas are numbered from left to right along the floor of the furnace. The sides of the furnace are then enumerated from top to bottom going down the right wall, then from top to bottom going down the left wall. Hence the last surface area, number 22, would be on the bottom of the right side of the vertical wall of the furnace and would be called s_{22}.

Since the temperature of the gas in any volume g (a volume defined as fixed in space) will remain unchanged once steady state has been reached, an energy balance on any volume such as g_1 may be written as follows:

Total outward radiation in all directions through the bounding walls of volume g_1	=	Radiation absorbed by g_1 from all volumes both direct and by multiple reflections at the walls	+	Radiation absorbed by volume g_1, from all surface elements, both direct and by multiple reflections
	+	Net energy to volume g_1 by bulk transport of the flowing gas stream	+	Net energy to volume g_1 by convection from adjacent gas volumes or surface elements

(3-1)

Rewriting in terms of symbole, where the various terms correspond directly:

$$E_{g_1} = \sum_i q_{g_i g_1} + \sum q_{s_j g_1} + q_{B_{g_1}} + q_{C_{g_1}} \qquad (3\text{-}2)$$

In the above and all subsequent equations a double set of subscripts such as gg, gs or ss indicates the direction of the energy transfer, the first subscript denoting the source of the energy and the second the receiver. Subscripts on the last 2 terms refer to bulk transport B or convection C, with an additional subscript to indicate which single gas or surface element is involved.

Similarly, writing an energy balance on any surface s_1:

Total outward radiation in all directions from surface s_1 = Radiation absorbed by s_1 from all volumes both direct and by multiple reflections at the walls. + Radiation absorbed by surface$_1$ from all surface elements both direct and by multiple reflections.

+ Net energy to surface s_1 by convection from adjacent gas cubes - Energy flux through wall s_1

(3-3)

Rewriting again in symbols:

$$E_{s_1} = \sum_i q_{g_i s_1} + \sum_j q_{s_j s_1} + q_{c_{s_1}} - q_{w_{s_1}} \qquad (3\text{-}4)$$

A little consideration of equations (3-2) and (3-4) will show that all the terms with the exception of wall-flux $q_{W_{s_1}}$ may be written as functions of temperatures, the coefficients on the temperature terms being functions of the geometry, heat capacities, flow rates and emissivities (and absorptivities) of the system. If it may be assumed that these temperature coefficients can all be evaluated at some mean temperature for the system, then there will result a total of g + s equations on g unknown gas temperatures and s unknown wall temperatures or wall fluxes.

It is to be noted at this point that, most unfortunately, the resulting series of simultaneous equations is neither linear in temperature nor in any power of temperature. If one is willing to assign to the temperature coefficients mean values for the system then the radiation terms will be proportional to the fourth power of temperature while the convection and bulk flow terms are proportional to the first power of temperature. In order to simplify the final solution of the equations, it is advisable to linearize them by forcing the convection and bulk flow terms into a fourth power law. It would also be possible to force the radiant terms into the first power law. However, this alternate procedure does not reflect the radiant dominant nature of the fired heater or furnace. Using the first method means that the coefficients on these terms are very strong functions of temperature and hence of the solution to the equations, necessitating an iterative procedure in solution. Details of this technique will be presented later in this section.

B. Radiant Interchange in a Black Enclosure Containing a Gray Gas

To simplify the problem of determining the radiant interchange factors in the most general case, it was decided to determine them first for this simple case: An enclosure containing black walls (and thus no multiple reflections) and filled with a gray gas. In the case of a single-temperature gas zone as was described in Chapter 2, it was found possible to build up the interchange factor which allows for multiple reflections from the much simpler one of direct interchange only; a similar situation is found in the multi-gas zone cases. Futhermore, the technique for allowance for a real gas as the weighted sums of a number of gray gases also applies. For these reasons, the direct interchange factors for the gray-gas case will be evaluated first; then the method of building up solutions to the more complex situation of gray walls and a real gas will be indicated.

1. Emission from a Volume of Gas

The rate of emission of energy from an isothermal gas volume, if there were no attenuation of radiation within the volume, would be equal to the gas emissivity per unit volume multiplied by the volume and by "black body" emission at the same temperature:

$$E_g^* = \mathcal{V} \cdot V_g \cdot \sigma T^4 \qquad (3\text{-}5)$$

where E_g^* is the rate of emission if no attenuation occurs

$\mathcal{V}$ is the gas emissivity on a volume base

V_g is the volume of the gas

σT^4 is the Stefan-Boltzmann Constant times the temperature to the fourth power

Since the gas volume is infinite in length, some distance (such as the actual length of the furnace) is used in calculating this volume.

It may readily be shown that the gas emissivity on a volume basis is equal to 4k, where k is the absorption coefficient for a characteristic gas such that the gas emissivity, g, is equal to $(1 - e^{-kx})$. [18] [33]

Since for any restricted volume of gas there will be attenuation of energy originating within the volume, the actual emission will be less than that given by equation (3-5).

2. <u>Emission from a Surface Area</u>

There is no problem involved in the formulation of the total rate of energy emission from a surface which is simply equal to the surface emissivity multiplied by black radiation at the temperature of the surface. The values of emissivity for a wide variety of materials encountered in industrial practice are available in the literature.[34, 45]

3. Interchange Between Two Surfaces

The one-way radiation from surface s_1 to surface s_2 is given by the following equation which may be considered a definition of the factor $f_{s_1 s_2}$:

$$q_{s_1 s_2} = f_{s_1 s_2} A_{s_1} \sigma T_{s_1}^4 \tag{3-6}$$

The factor $f_{s_1 s_2}$ plainly represents the fraction of the energy leaving surface s_1 that is intercepted by surface s_2 and is a function of the areas and geometrical configurations of the two surfaces as well as the absorption coefficient of the intervening gas mass. For evaluation of the factors of the type f_{ss} it will be assumed that the intervening gas has constant absorption properties, that is, a constant absorption coefficient k, no matter how far apart the surfaces are. This is in accordance with an earlier statement that it is desirable to evaluate the coefficients on the temperature terms in the energy balances, equations (3-2) and (3-4) at some mean temperature for each isothermic gas volume.

Consider two differential areas dA_1 and dA_2 separated by distances Δx, Δy and Δz measured on the three coordinate axes and therefore separated by a center-to-center distance r, where:

$$r = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2} \qquad (3\text{-}7)$$

The one-way radiation between the two differential areas is plainly proportional to the areas of each as viewed from the other, inversely proportional to the square of the separating distance, and must be diminished by the transmissivity of the intervening gas of absorption coefficient k and path length r. Expressing this methematically and putting in the proportionality constant $1/\pi$ which has been established elsewhere,[46] one obtains:

$$dq_{12} = \frac{dA_1 \cos\phi_1 \cdot dA_2 \cos\phi_2}{\pi r^2} \cdot e^{-kr} \sigma T_1^4 \qquad (3\text{-}8)$$

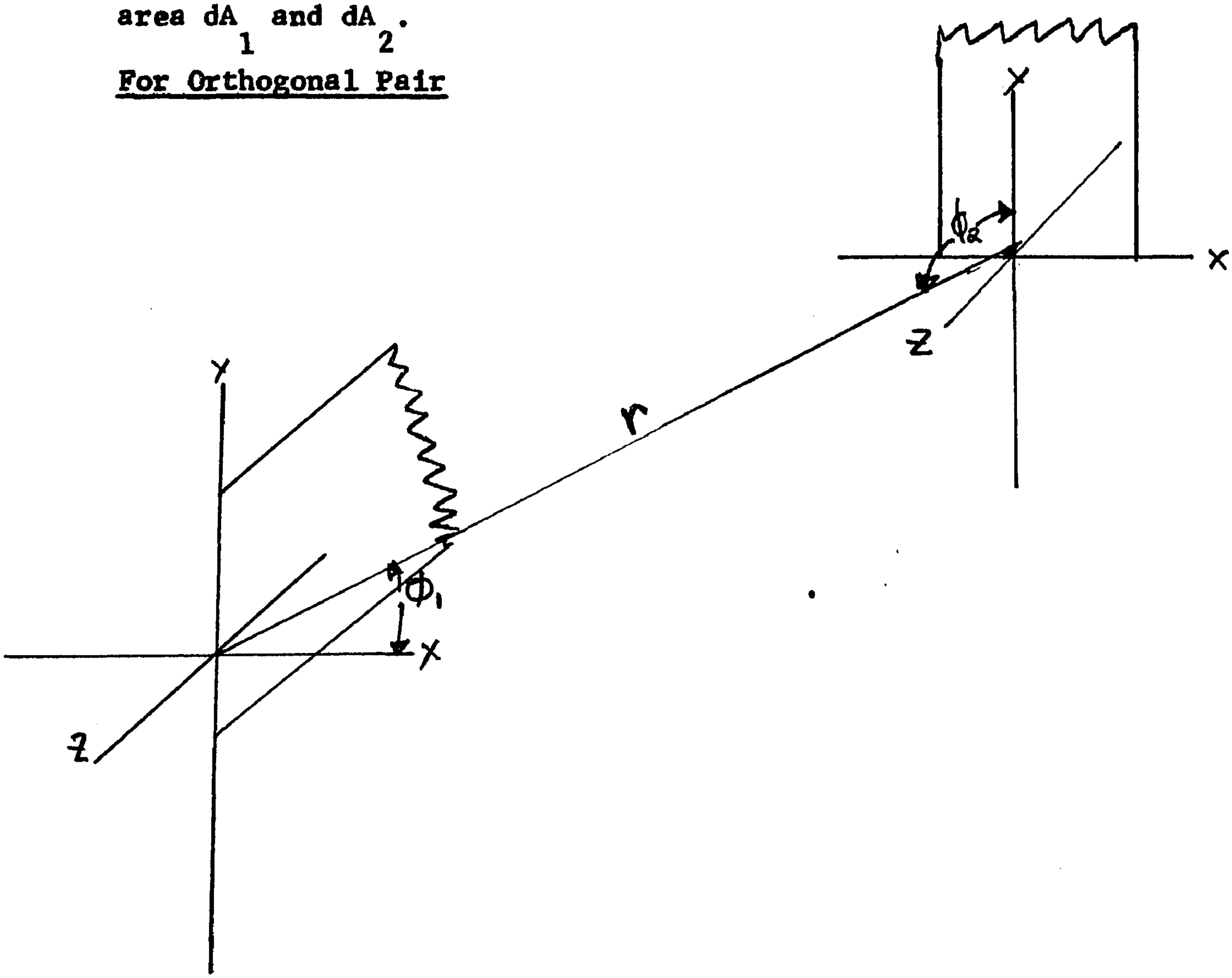
It is now necessary to integrate this expression over the two finite areas A_{s_1} and A_{s_2} to obtain the interchange, and combining this result with equation (3-6) one can evaluate the factors $f_{s_1 s_2}$. Due to the presence of both an exponential term and a polynomial it is not possible to integrate equation (3-8) analytically. At this point it is adequate to point out that two distinct cases of interchange between surfaces must be handled - surfaces in parallel planes and surfaces in perpendicular planes. Considering these two cases only for the parallel and orthogonal cases, one arrives at the two following expressions to be numerically integrated to obtain the F_{ss}:

$$F_{ss} = \frac{q_{s_1 \to s_2}}{\sigma T^4} = f_{ss} A_s$$

$$f_{ss} = \int_{A_1} \int_{A_2} \frac{e^{-Kr}}{\pi r^2} \cos\phi_1 \cos\phi_2 \, dA_1 \, dA_2 \quad (3\text{-}9)$$

where r is the distance separating the incremental area dA_1 and dA_2.

<u>For Orthogonal Pair</u>



$\cos\phi_1 = \frac{y}{r}$ $\cos\phi_2 = \frac{x}{r}$

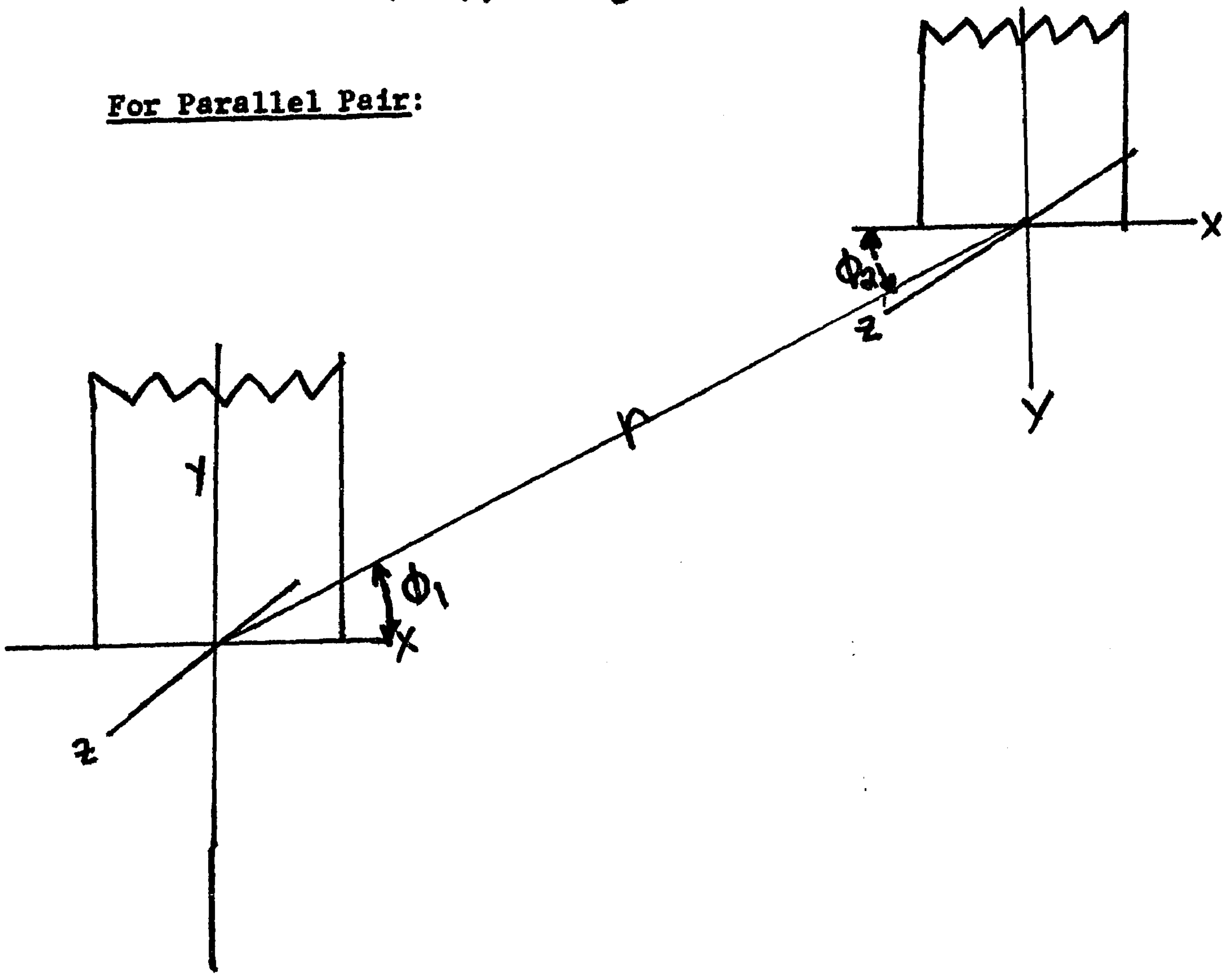
$dA_1 = dy\ dz$ $dA_2 = dx\ dz$

$$r = \sqrt{\Delta x_2^2 + \Delta y^2 + \Delta z^2}$$

$$f_{ss} = \int\int\int\int e^{-kr}/r^2 \cdot \frac{y}{r}\ \frac{x}{r}\ dz_R\, dy\, dx\, dz_E$$

$$= \int_0^L \int_{x_1}^{x_2} \int_{y_1}^{y_2} \int_{-\infty}^{+\infty} xy\, e^{-kr}/r^4\, dz_R\, dy\, dx\, dz_E$$

For Parallel Pair:



$\cos\phi_1 = y/r$ $\qquad\qquad$ $\cos\phi_2 = \quad /r$

$dA_1 = dy\ dz$ $\qquad\qquad$ $dA_2 = dx\ dz$

$$f_{ss} = \iiiint \frac{e^{-Kr}}{r^2} \frac{y_1}{r} \frac{y_2}{r} dz_R\, dy_1\, dy_2\, dz$$

or

(3-12)

$$f_{ss} = \int_0^L \int_{y_1'}^{y_1''} \int_{y_2'}^{y_2''} \int_{-\infty}^{\infty} \frac{e^{-Kr}}{r^4} y^2\, dz_R\, dy_1\, dy_2\, dz_E$$

(3-13)

Similar relationships exist for the other possible orientations, but will not be given here. It now becomes possible to perform numerical integration on equations (3-10) and (3-11) and any of the other required orientations.

The method of Gaussian quadratures was combined with Simpson's integration[1] to yield the numerical results.

All of the possible orientations were of the following form:

$$f_{ss} = \int_0^L \int_{\varphi_1'}^{\varphi_1''} \int_{\varphi_2'}^{\varphi_2''} f(x,y) \int_{-\infty}^{\infty} \frac{e^{-K\sqrt{U^2+z^2}}}{(U^2+z^2)^2} dz_R\, d\varphi_1\, d\varphi_2\, dz_E$$

Where

$$U = \sqrt{x^2 + y^2}$$

and f(x,y) takes into account the particular orientation being evaluated, the function can be brought outside of the two innter integrals because it is independent of z.

The limits of integration Q_1 and Q_2 are either both x, or both y, or x and y, again depending on the orientation of the surfaces under evaluation.

Evaluating the two indefinite integrals using Simpson's integration of the following form: (1)

$$\int_a^b f(x)dx = \frac{h}{3}\left[f(a) + 4f(a+h) + 2f(a+2h) + 4f(a+3h) + + 4f(a+(2m-1)h) + f(b)\right] \tag{3-15}$$

where $h = (b - a)/2m$

and m is the number of subdivisions used.

Considering the inner integral of (3-14) and allowing

$U^2 = \sqrt{x^2 + y^2}$ and $r = \sqrt{x^2 + y^2 + z^2}$ results in:

$$\int_{-\infty}^{\infty} e^{-Kr} \frac{dz}{r^4} = \int_{-\infty}^{\infty} \frac{e^{-KU\sqrt{1+z^2/u^2}}}{U^4(1+z^2/u^2)^2} dz \tag{3-16}$$

Letting $w = z/u$ or $dz = udw$ yields:

$$\int_{-\infty}^{\infty} \frac{e^{-KU\sqrt{1+w^2}}}{U^4(1+w^2)^2} U\,dw = \frac{1}{U^3}\int_{-\infty}^{\infty} \frac{e^{-KU\sqrt{1+w^2}}}{(1+w^2)^2} dw \tag{3-17}$$

Defining:

$$F(KU) = \int_{-\infty}^{\infty} \frac{e^{-KU\sqrt{1+w^2}}}{(1+w^2)^2} \, dW \tag{3-18}$$

Noting:

$$F(KU) = 2 \int_{0}^{\infty} \frac{e^{-KU\sqrt{1+w^2}}}{(1+w^2)^2} \, dW \tag{3-19}$$

$$\approx \int_{0}^{40} \frac{e^{-KU\sqrt{1+w^2}}}{(1+w^2)^2} \, dW$$

Equation (3-19) can now be evaluated from equation (3-15).

The replacement of the upper limit in equation (3-19) to a value of 40 was justified by evaluating (3-19) for a value of KU = 0, since when this substitution is made, equation (3-19) can be evaluated analytically yielding a value of $\pi/2$.

$$F(0) = 2\int_{0}^{\infty} \frac{dW}{(1+w^2)^2}$$

$$= 2\left[\frac{w}{2(1+w^2)} + \tfrac{1}{2}\,\mathrm{Tan}^{-1}(w)\right]_0^{\infty} = \pi/2. \tag{3-20}$$

The numerical evaluation of (3-19) using the upper limit of 40 and using h = .05 i.e. evaluating 800 terms in the Simpson integration) resulted in a value of F(0) = 1.570795 ($= \pi/2$).

It is important to note that KU will always be positive, so that the evaluation of (3-19) by Simpson's Rule will result in numerical values smaller than for K = 0 (a clear gas).

Settong KU = 0 to evaluated F(KU) results in the largest numerical deviation from the correct value of the function.

The value of F(KU) can now be evaluated separately for various values of KU. This procedure was carried out for values of KU varying between 0 and 20, as shown on Figure 4. Above 20 the contributions of the terms constituting the numerical equivalent of the integral made no significant contribution to the calculation of the view factor and thus was taken as 0. This would correspond to a beam length of approximately 60 feet. The value being discarded results in an error less than one part in a million. Previous to this, graphical integration techniques could only yield results that were accurate to one part in a hundred.[18]

The function of F(KU) versus log (KU) was then fitted to a 7th order polynomial. In order to get the best possible fit, the function was broken down into four ranges, a separate polynomial being used for each interval. The results of these curve fits can be found in Appendix B which gives the Fortran listing of the calculation procedure. The results are shown in Function W.[19]

Once the value of F(KU) is determined, it is necessary to evaluate the rest of the equation (3-14). This is done by using Gaussian quadratures,[1] the relationship is:

$$\int_{-1}^{1} f(x)\,dx = \sum_{i=1}^{N} w_i \cdot f(x_i) \qquad (3\text{-}21)$$

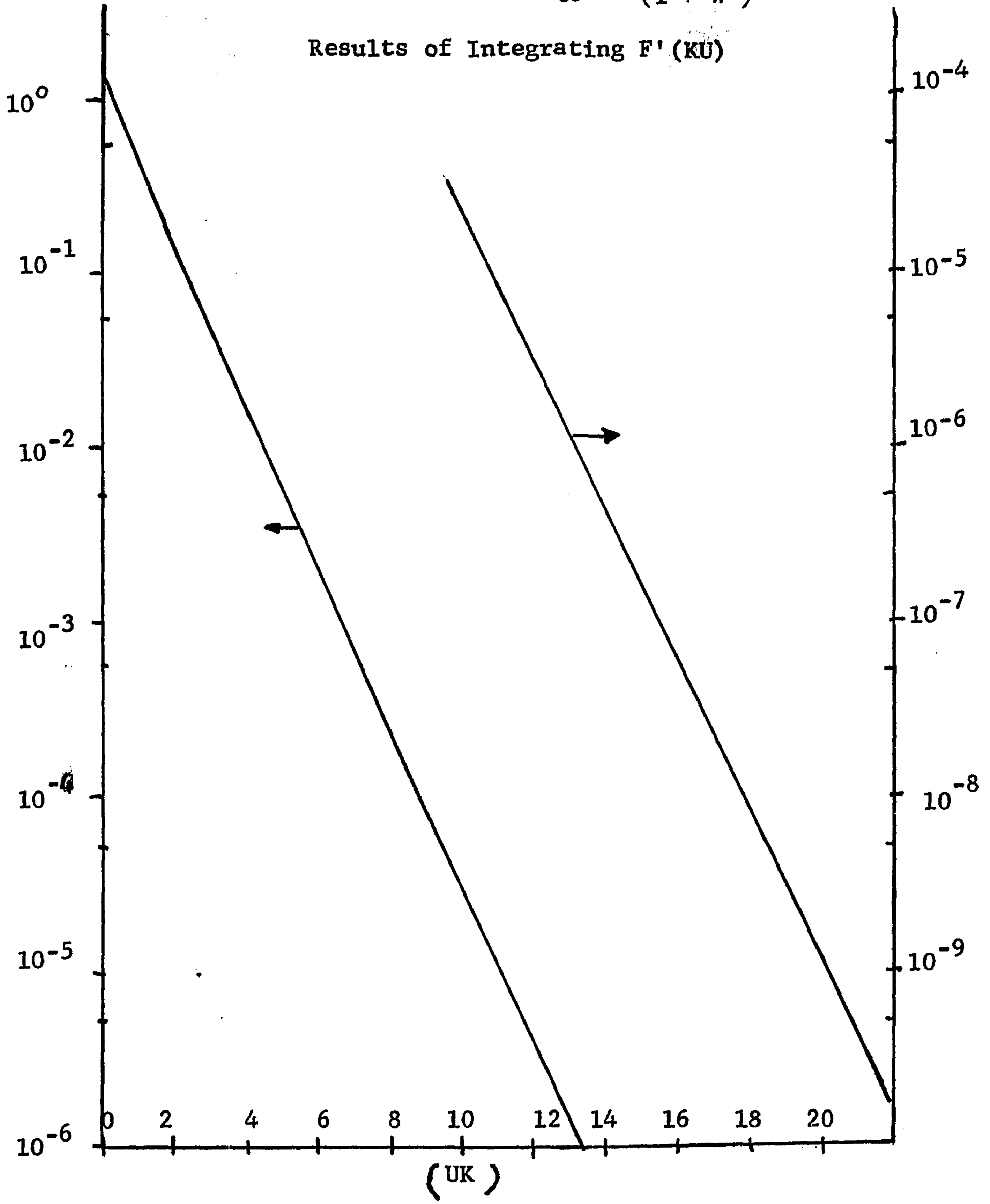
Where W_i is the weight factor different from W_i used by the Hermite integrations

X_i is the associated value of the independent variable

Figure 4.

$$F(UK) = \int_{-\infty}^{\infty} \frac{e^{-KU\sqrt{1 + W^2}}}{(1 + W^2)^2} \, dW$$

Results of Integrating F'(KU)



This relationship is applied twice to equation (3-14) to yield:

$$f_{ss} = \sum_{i}^{N} W_i \sum_{j}^{N} w_j \, f(x_i, y_i) \cdot F(UK) \tag{3-22}$$

In doing the calculation it was decided to use a value of 9 for N, resulting in 81 calculations for the determination of each F_{ss} term. The value of 9 for N was selected as a compromise between accuracy and time required to perform the calculation.

4. Interchange Between a Volume of Gas and a Bounding Surface

The defining equations for the one-way radiation, gas to surface or surface to gas, are as follows:

$$q_{sg} = A_s \cdot f_{sg} \cdot \sigma T_s^4 \tag{3-23}$$

$$q_{gs} = 4KV_g \cdot f_{gs} \, \sigma T_g^4 \tag{3-24}$$

As T_s approaches T_g, that is as the temperatures of the two elements approach each other, the values of q must likewise approach each other and it follows that:

$$A_s f_{sg} = 4KV_g \cdot f_{gs} \tag{3-25}$$

Formerly, when the values of F_{ss} were calculated by techniques with an estimated error in one part per hundred, the difference between the six values was small in comparison to the magnitude of the solution. By using the computer this problem has been eliminated, and the error reduced to approximately one part in a million.

In our two dimensional model the radiation entering and leaving the infinite areas can not be "viewed" by the surface. This means that only a total of four values of f_{ss} need to be calculated and summed together with the appropriate sign to yield the desired value of f_{sg}.

In instrumenting this procedure on the computer, great care must be taken in the determination of the correct orientation. Once this is accomplished, it becomes possible to use the already existing procedures for the calculations of the values of f_{ss}. The reader is referred to the Fortran listing of the calculation procedures and specifically to FUNCTION SG, on page 96 of Appendix B.

5. Interchange Between Two Gas Volumes

The defining equation for this final case of one-way radiation exchange, that is the energy transfer from one volume to another in the system may be written as:

$$q_{gg} = 4 K V_g f_{gg} \cdot \sigma T_g^4 \tag{3-26}$$

The meaning of this type of interchange areas, as before, is the fraction of the radiation originating in one element that reaches and is absorbed by any other in the system. If the two subscripts g refer to the same gas volume, q represents the radiation originating in the volume q_{gg} and absorbed by itself before reaching the boundary surface.

Once again the factor f_{gg} is function of the geometry of the system and the absorption coefficient of the gas. Just as it was possible to obtain f_{sg} by properly adding up six values of f_{ss} it is also possible to calculate f_{gg} by the appropriate addition of six values of f_{gs} in a system where the gas volumes have finite length. Plainly, f_{gg} must equal the sum of the f_{gs} values to the near faces of the second volume, minus the sum of the f_{gs} values seen dimly through the volume.

In the two dimensional model being developed in this study, only four values of f_{gs} need to be computed, the two edges at the end of the finite axis being unable to view each other.

The evaluation of f_{gs} again requires the evaluation of four f_{ss} terms. This means for each f_{gg} term calculated, a total of sixteen f_{ss} terms need to be evaluated. With the orientation determined, the evaluation of f_{gg} is accomplished by using FUNCTION SG which in turn uses FUNCTION SS.

C. Calculation of Direct Energy Transfer

It will be useful at this point to define a new type of interchange factor - one that when multiplied by σT^4 the black emissive power of a unit surface at the temperature of the radiating zone will yield directly the rate of energy absorption by any other zone in the system. Again the reacer is reminded that discussion is presently restricted to one in which all surfaces are perfect absorbers. These factors, in simplified nomenclature, will always be written as two letters - either ss, sg, gs or gg - where g and s stand for gas and surface respectively. Furthermore each of the letters will have a numerical subscript to identify which particular volume or surface is under consideration. For example the energy transferred from surface 2 to gas volume 4 is equal to $s_2g_4 \cdot W_{s2}$; similarly, the transfer from gas volume 4 to surface 2 is $g_4s_2 \cdot W_{g4}$, where W_{sn} is equal to the rate of emission from unit area of a black body at a temperature indicated by subscript (i.e. temperature of surface n). Since, as the temperature of the gas zone and the surface zone approach each other (i.e. as the values of W approach each other) the net transfer between the two zones must be zero; the only way that this can happen is for s_2g_4 to equal g_4s_2, and thus, in this type of formulation the order in which two zones are mentioned is immaterial. This same reasoning applies to both surface-surface and gas-gas radiation.

The use of four symbols to describe interchange areas - two to indicate the types of zones involved (gas or surface) and two to indicate the particular zones - is a necessary consequence of having more than one gas zone in the enclosure.

It is noted that the total of all the interchange areas from any one zone to all other zones in the enclosure including itself must add up to the energy originating from that same area per unit emissive power. Expressed mathematically:

$$s_1s_1 + s_1s_2 + s_1s_3 + + \cdots s_1g_1 + s_1g_2 + s_1g_3 + \cdots = A_{s1} \tag{3-27}$$

or

$$\sum_i s_1s_i + \sum s_1g_i = A_{s_1} \tag{3-28}$$

and $g_1 g_1 + g_1 g_2 + g_1 g_3 + \cdots g_1 s_1 + g_1 s_2 + g_1 s_3 + \cdots$

$$= 4KVg_1 \qquad (3\text{-}29)$$

or

$$\sum_i g_1 g_i + \sum g_1 s_i = 4KVg_1 \qquad (3\text{-}30)$$

D. Allowance for Grayness of Walls

The discussion which follows summarizes the work of Hottel[33 A] and Cohen [18]

All discussion up to this point has been concerned with a system in which all walls were perfect absorbers so that any energy which reached a wall surface was not reflected back into the system, hence total or perfect absorption took place. In general, however, the walls of a furnace are not black but are capable of reflecting some of the energy incident upon them. This reflected energy is distributed among all the gas and all the surfaces in accordance with the geometrical configuration of the various surfaces and the absorbing power of the gas; and that portion incident on the surface is again partially absorbed and partially reflected to repeat the process ad infinitum. The result is an extremely complex situation necessitating a condiseration of all possible beams of original energy and the results of an infinite number of reflections at the walls.

The technique for making allowance for this complicated problem to be given here is simply an extension of the one presented by Hottel[46] for the one-gas zone, multi-surfaced enclosure. As in Hottel's treatment where the direct interchange between two zones was equal to A_1F_{1G} or A_1F_{12} multiplied by the difference in emissive powers, so in the present case it is equal to a factor g_1g_2, s_2s_3, etc. Similarly, if one allows for the multiple reflections within the enclosure, defined as G_1G_2, G_1S_1 or S_1S_1, one can evaluate such factors as GS, GG, or SS from the direct factors gs, gg or ss. Note that the factors GG, GS, and SS like their lower-case counterparts all have the dimensions of area.

It is plain that the interchange area between any two zones in the enclosure cannot be a function of temperature as long as the physical properties of the system (emissivities and absorptivities) are independent of temperature. Therefore one is justified in evaluating the interchange areas at any convenient temperature and the results will be completely general. The problem of evaluating the interchange areas is very much simplified if one causes the temperature of every surface and gas zone except one to be maintained at absolute zero and as a consequence the emissive powers of every zone except one area are all zero. This necessitates some sort of energy withdrawal from all zones, including the gas zones, by means unspecified but not interfering with transmission. Furthermore, one can let the temperature of the one emitting zone be such that its black emissive power is unity; i.e. such that σT^4 is unity. As a result of maintaining the temperature at $\sigma T^4 = 1$ at the single surface or gas zone, there will be a radiant flux at and toward every surface in the system, and at and away from it as well due solely to original emission from the one zone and to the multiple reflections within the enclosure. In a black system this reflected flux would, of course, be equal to zero. The terminology to describe this outgoing flux density will be R with a presubscript designating the original source of the energy and a final subscript, the reflecting surface. Thus if gas zone g_1 were the only emitter in the system, the flux density at surfaces s_1, s_2,..... would be indicated by ${}_{g_1}R_{s_1}$, ${}_{g_1}R_{s_2}$,..... . Similarly if surface s_1 were the only original emitter the flux density at surfaces s_2, s_3,..... would be ${}_{s_1}R_{s_2}$, ${}_{s_1}R_{s_3}$, ... but the flux density at surface s_1 would be equal to ${}_{s_1}R_{s_1}$ due to reflections corrected for ϵ_{s_1} to allow for original emission from the surface.

i. Original Emitter is a Gas Zone

If, for example, gas zone g_1 is the sole original emitter then the total radiant flux at and away from any surface such as s_1 in the system is designated as ${}_{g_1}R_{s_1} \cdot A_{s_1} \cdot \sigma T^4$. Since this is the reflected flux, if one multiplies it by the ratio of the absorptivity (equal to emissivity) of the surface to the reflectivity of the surface (the complement of absorptivity) the result will be the absorbed energy at the surface, and since the value of σT^4 of the original emitter was made equal to unity, this must by definition be identical with the desired factor G_1S_1. Expressing this statement more generally by considering the i-th gas zone and the j-th surface zone:

$$G_i S_j = S_j G_i = {}_{g_i}R_{s_j} \cdot \frac{A_{s_j} \varepsilon_{s_j}}{\varphi_{s_j}} \qquad (3\text{-}31)$$

In order to determine the value of the reflected flux R at any surface one can write an energy balance on each surface. The total rate of energy impingement on surface s_1 is equal to the contributions from all the surfaces in the system including itself plus the energy it receives directly from the single gas zone which is the original emitter. If the sum of all these terms is then multiplied by the surface reflectivity, then the result which is the reflected flux must be equal to ${}_{g_i}R_{s_i} \cdot A_{s_i}$. This summation can be carried out for every surface in the system yielding a set of equations, one for each surface, as follows:

$$\left[s_1 s_1 \cdot {}_{g_i}R_{s_i} + s_1 s_2 \cdot {}_{g_i}R_{s_2} + \cdots {}_{g_i}s_1 \right] \varphi_{s_1} = A_{s_1} \cdot {}_{g_i}R_{s_1}$$

$$\left[s_1 s_2 \; {}_{g_i}R_{s_1} + s_2 s_2 \cdot {}_{g_i}R_{s_2} + \cdots {}_{g_i}s_2 \right] \varphi_{s_2} = A_{s_2} \cdot {}_{g_i}R_{s_2}$$

$$\left[s_1 s_3 \; {}_{g_i}R_{s_1} + s_3 s_2 \cdot {}_{g_i}R_{s_2} + \cdots {}_{g_i}s_3 \right] \varphi_{s_3} = A_{s_3} \cdot {}_{g_i}R_{s_3}$$

$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

(3-32)

It is apparent that the total number of equations in set (3-32) is exactly equal to the number of unknown reflected-flux densities R_s.

Expression (3-32) in matrix form:

$$|D| \cdot |{}_{g_i}R_{s_L}| = |-{}_{g_i}s_L| \qquad (3\text{-}33)$$

$$D = \begin{vmatrix} S_1 S_2 - A_{s_1}/\rho_{s_1} & S_1 S_2 & S_1 S_3 & \cdots \\ S_1 S_2 & S_2 S_2 - A_{s_2}/\rho_{s_2} & S_2 S_3 & \cdots \\ S_1 S_3 & & S_3 S_3 - A_{s_3}/\rho_{s_3} & \cdots \\ & S_2 S_3 & & \\ \bullet & \bullet & \bullet & \cdots \\ \bullet & \bullet & \bullet & \cdots \\ \bullet & \bullet & \bullet & \cdots \end{vmatrix} , \; g_i R_{s_L} \begin{vmatrix} g_i R_{s_1} \\ g_i R_{s_2} \\ g_i R_{s_3} \\ \\ \bullet \\ \bullet \\ \bullet \end{vmatrix} , \; -g_1 s_L = \begin{vmatrix} -g_i s_1 \\ g_i s_2 \\ g_i s_3 \\ \\ \bullet \\ \bullet \\ \bullet \end{vmatrix}$$

(3-33A)

Equation (3-33) can then be solved by taking the matrix inverse:

$$\left| {}_{g_i}R_{s_L} \right| = \left| D \right|^{-1} \cdot \left| -g_i s_L \right| \tag{3-34}$$

The reader is again referred to Apprendix B to SUBROUTINE INVERT page 104 to get the details of the inversion procedure. The invert algorithm takes advantage of the fact that D is a diagonally dominant matrix.

From the values of the reflected flux density at the various surfaces it is also possible to calculate the total interchange factor between any two gas cubes. If gas zone g_1 is the original emitter, then the total reception at any other gas zone g_2 is equal to the direct radiation from g_1 to g_2 (equal to g_1g_2) plus the sum of the products of the reflected flux at each surface in the system multiplied by the fraction of that flux which reaches and is absorbed by gas zone g_2. Again, since the black-body emission from zone g_1 has been set at unity this sum represents the desired factor G_1G_2. The general expression for this factor between any two gas zones m and n then becomes:

$$G_m G_n = g_m g_n + \sum_i \left({}_{g_m}R_{s_i} \right) \cdot \left(s_i g_n \right) \tag{3-35}$$

ii. Original Emission in a Surface Zone

In order to obtain the one remaining factor - interchange between two surfaces - it is necessary to let one of the surface zones be at such a temperature that its black body emission would be equal to unity and to let all other surfaces as well as all gas zones be at absolute zero. One can again write energy balances on each surface in the system, the only changes being that there will be no direct radiation from the gas and that the surface that is the original emitter will send out, in addition to the reflected flux term, an amount of energy per unit area equal to its emissivity. The set of resultant equations for this case where surface s_1 is the sole original emitter is:

$$\left[s_1 s_1 \left({}_{s_1}R_{s_1} + \varepsilon_{s_1}\right) + s_1 s_2 \cdot {}_{s_1}R_{s_2} + \cdots \right] \varphi_{s_1} = A_{s_1} \cdot {}_{s_1}R_{s_1}$$

$$\left[s_1 s_2 \left({}_{s_1}R_{s_1} + \varepsilon_{s_1}\right) + s_2 s_2 \cdot {}_{s_1}R_{s_2} + \cdots \right] \varphi_{s_2} = A_{s_2} \cdot {}_{s_1}R_{s_2}$$

$$\left[s_1 s_3 \left({}_{s_1}R_{s_1} + \varepsilon_{s_1}\right) + s_3 s_2 \cdot {}_{s_1}R_{s_2} + \cdots \right] \varphi_{s_3} = A_{s_3} \cdot {}_{s_1}R_{s_2}$$

$$\vdots \qquad\qquad \vdots \qquad\qquad \vdots$$

(3-36)

Just as before the total number of equations is equal to the total number of unknown reflected flux densities and the solution for any one of them may be written as:

$$\left| g_i R s_l \right| = \left| D \right|^{-1} \cdot \left| s_i s_l \right| \tag{3-37}$$

where D is exactly the same as the expression obtained earlier and given in equation (3-33).

Hottel(46) and Cohen(18) demonstrate that

$$s_i s_j = s_j s_i \tag{3-38}$$

E. Allowance for a Real Gas

It has already been shown in Chapter 2, that it is possible to approximate the behavior of a real gas in a system by considering it to be a weighted sum of gray gases and one clear gas, each weighted in proportion to the energy fraction of the spectrum that it occupies. Furthermore, since in most systems it is the first beam that is the important one all successive beams undergo double attenuation by the gas and the surface on each pass, an adequate approximation to the real gas is the simple sum of two characteristic gases - one having an absorption coefficient k and occupying the fraction "a" of the spectrum, the second being a clear gas (absorption coefficient equals zero) and occupying the fraction "1-a" of the spectrum.

One is cautioned that such an approximation would not be valid in a system where the K_1 is so low that the gas transmissivity is very high and where the walls are highly reflective. For the single-gray + clear-gas case the emissivity and absorptivity are then related to the path length x as follows:

$$\varepsilon_x = a\left(1 - e^{-Kx}\right) \qquad (3\text{-}39)$$

If one then fits the above exponential to the actual emissivity versus path length curve for a real gas, at a path length equal to the primary path length for the system, and at twice this value, mathematical manipulation leads to the following expression for "a", the fraction of the spectrum occupied by the gray portion:

$$a = \frac{\varepsilon_1^2}{2\varepsilon_1 - \varepsilon_2} \qquad (3\text{-}40)$$

The value of kL for this case is then equal to:

$$KL = LN\left(\frac{\varepsilon_1}{\varepsilon_2 - \varepsilon_1}\right) = LN\left(\frac{1}{1 - \varepsilon_1/a}\right) \tag{3-41}$$

In both the above expressions ε_1 refers to the gas emissivity evaluated at the characteristic path length for the system L, and ε_2 is the emissivity evaluated at twice that path length.

Since ε_x is a function of temperature, it is now possible to find a series of "ε" at different temperatures and calculate the corresponding values of "a". The resulting values of "a" can now be fitted to polynomials in temperature resulting in:

$$a = b_0 + b_1 T + b_2 T^2 + b_3 T^3 + b_4 T^4 + b_5 T^5 \tag{3-42}$$

The value of ε_x was calculated from a regression fit of the emissivity data reported by Hottel in McAdams Chapter 4.[49] The regressed data fit considers carbon dioxide, sulfur dioxide and water vapor. The calculation procedures are presented in the Fortran program in Appendix B FUNCTION EMISS. The regressed curve fit takes into consideration the partial pressure of the components, the total pressure of the system and the temperature of the gas system being determined.

Once the value of "a" has been determined as a function of temperature it can be applied to the following equation:

$$SS = a\,[SS]_{KL} + (1-a)[SS]_{KL=0} \tag{3-43}$$

The value of $[ss]_{kL = 0}$ represents the value of the interchange area evaluated for a clear gas.

$$GS = a\,[GS]_{KL} \tag{3-44}$$

$$GG = a\,[GG]_{KL} \tag{3-45}$$

It is to be noted that, as a result of this real-gas approximation, several important changes have been made:

1. In addition to the factos SS, SG and GG evaluated at kL by the methods of the previous sections, one must evaluate a new set of the SS-factors for the clear gas portion; i.e. at kL = 0.
2. As before, the sum of the total interchange factos from any surface to all surface and gas zones is

equal to the surface emissivity times the area. The sum of the factors from one gas zone to all zones, however, is now given by:

$$\sum_j G_i G_j + \sum_j G_i S_j = 4 K a V_{g_1} \qquad (3\text{-}46)$$

The values of the partial pressure of CO_2, SO_2 and H_2O are calculated via a flue gas analysis. No attempt was made to calculate the values of partial pressure within each isotherm, the flow patterns being assumed known throughout the system.

In evaluating the total interchange areas within a given zone, each in turn was considered to be the original emitter. This enabled the evaluation of the set of factors at the KU of the emitting zone. This means that G_1G_2 no longer is equal to G_2G_1, since each is now based on evaluations at different temperatures.

It was necessary first to estimate all the temperatures in the system and then, after the final solution to the problem, revise the estimates of temperature and repeat the computational procedure. This procedure was continued until the difference between the guessed values and the actual values was less than $.5^{o}$ Rankin.

This procedure, however, is not completely rigorous since one should allow for that fact that the kL of the gas is constantly changing with path length. It is conceivable that one could, for each individual problem, start at the beginning and repeat the numerical integrations, allowing for the fact that the absorption coefficient was changing as one moved along a path length. It should be stated that the computer time involved in such a technique would be absolutely prohibitive for engineering calculations.

F. Energy Balance of Gas Volumes

The energy balance on the gas volumes and the surface area have been decoupled . This procedure has two chief advantages:

1. It reduces the computational magnitude of the energy balances to more manageable size.
2. It takes advantage of wall temperature being relatively stable due to the presence of sinks (i.e. the reactor).

The disadvantage of the procedure is that the convergence procedure has to be repeated for the surface and volume energy balances.

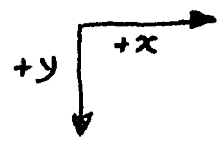
The term q_B in the energy balance on a gas zone in equation (3-2) represents the net energy transferred to the zones by the bulk flow of the gas stream. It is equal to the total enthalpy above any arbitrary base temperature of all entering streams minus the total enthalpy above the same base temperature of all leaving streams. In order to formulate this enthalpy flux vorrectly, one would need to know the details of the gas flow pattern within the enclosure. Unfortunately, for most enclosures one does not have a detailed description of the flow pattern.

Some studies have been carried out utilizing the use of metal filings being introduced into the flow stream. Stop action photography techniques are then employed to determine actual flow distribution. The results of one such study were reported by Yeich[93] and are used in this study. The details of this flow pattern are presented in Appendix A.

The flow patterns were defined for an infinite furnace, hence no flow is permissable along the infinite axis. The flow in the plane perpendicular to the infinite axis was resolved into the flow along the other two mutually perpendicular directions. Flow from the eighteen gas volumes would thus be represented as $(GM_{x_{18}}, GM_{y_{18}})$.

A computational check was performed to verify that the gas volume had neither a positive or a negative accumulation term. It should be noted that GM_{xj} is a vector quantity and is used in the same sense as are the gas volume orientations, as shown in Figure 2.

i.e. the coordinate system is:



It now becomes possible to write an energy balance on the gas volume:

Note the subscript I refers to inlet conditions

O refers to outlet conditions

$$\text{Heat In} - \text{Heat Out} + \text{Sources} = 0 \qquad (3\text{-}47)$$

$$\left[\text{Enthalpy}_I - \text{Enthalpy}_O\right]_{\text{Bulk Flow}} + \left[\text{Heat}_I - \text{Heat}_O\right]_{\text{Convection}}$$

$$+ \left[\text{Radiant Energy}_I - \text{Radiant Energy}_O\right] + \text{Heat Release}$$

$$\text{by Combustion} = 0 \qquad (3\text{-}48)$$

Equation (3-48) can now be rewritten for gas volume i

$$\left[GM_{x_I}\cdot H(T_{j_1}) - GM_{x_I} H(T_{j_2})\right] + \left[GM_{y_I}\cdot H(T_{j_3}) - GM_{y_0}\cdot H(T_{j_4})\right)$$
$$+ \left[h_{x_I} A_{x_I}({}_sT_{x_I} - T_i) - h_{x_0} A_{y_0}(T_i - {}_sT_{x_0})\right]$$
$$+ \left[h_{y_I} A_{y_I}({}_sT_{y_I} - T_i) - h_{y_0} A_{y_0}(T_i - {}_sT_{y_0})\right]$$
$$+\sigma\left[\sum_j G_j G_i \cdot T_j^4 + \sum_j S_j G_i \cdot T_j^4 - T_i^4\left(\sum_j G_i G_j \cdot \sum_j G_i \cdot S_j\right)\right.$$
$$+ E_T \cdot \phi(X_i\, Y_i) = 0 \qquad (3\text{-}49)$$

where

H(T) is the enthalpy of the flue gas and is calculated by integrating $C_p(T) = c_0 + c_1T + c_2T^2 + c_3T^3$ between absolute 0 and T

$$H(T) = c_0 T + \tfrac{1}{2} c_1 T^2 + \tfrac{1}{3} c_2 T^3 + \tfrac{1}{4} T^4 \qquad (3\text{-}50)$$

h_{X_I} is converted heat transfer coefficient between the gas and the gas surface with contact area A_{X_I} and ${}_sT_{S_I}$ is the surface temperature in contact with the volume.

$\phi\ (X_i\ Y_i)$ is the fraction of the total heat released within the isothermal gas volume by combustion

E_T is the total heat released within the furnace.

$$a_{ii}\,\sigma T_i^4 + \sum_j b_{ij} T_j^4 + \tfrac{1}{4}\frac{\alpha}{T_{x_I}^3} T_{x_I}^4 + \frac{1}{4}\frac{\beta}{T_{x_I}^3} T_{y_I}^4 + \frac{1}{4}\frac{\gamma'''}{T_{x_0}} T_{x_0}^4 + \frac{\delta'''}{T_{y_0}^3} T_{y_0}^4 = C_i \qquad (3\text{-}51)$$

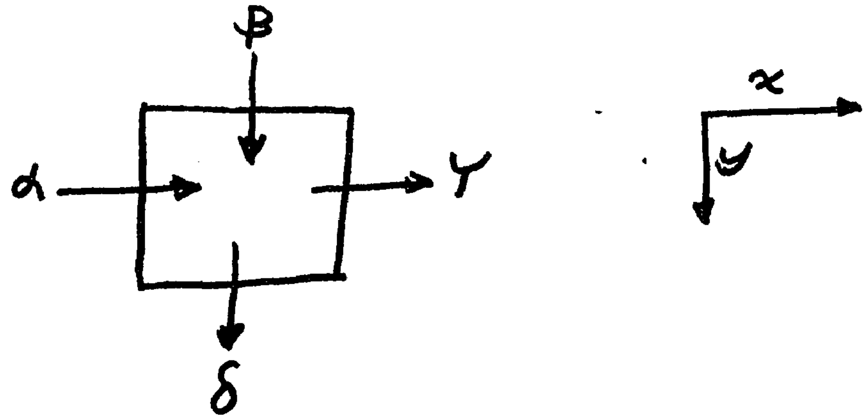
Where

$$a_{ii} = -\sigma\left[\sum_j G_i G_j + \sum_s G_j S_i\right] + \tfrac{1}{4}\left[h_{x_I} A_{x_I} - h_{y_I} A_{y_I} - h_{x_0} A_{x_0} - h_{y_0} A_{y_0}\right]\frac{1}{T_i^3} + \tfrac{1}{4}\left[\alpha'' + \beta'' + \gamma' + \delta'\right]\cdot\frac{1}{T_i^3}$$

$$b_{ij} = \sigma G_j G_i$$

$$C_i = \Big[-\sigma \sum_j G_i G_j \cdot T_j^4 + \left(-h_{x_I} A_{x_I}\, {}_sT_{x_I} - h_{y_I} A_{y_I}\, {}_sT_{y_I} - h_{y_0} A_{y_0}\, {}_sT_{x_0} - h_{y_0} A_{y_0}\, {}_sT_{y_0}\right) - E_T\,\phi(x,y) + \alpha''' + \beta''' + \gamma''' + \delta'''\Big] - \tfrac{3}{4}\left[\alpha' T_{x_I} + \alpha'' T_i + \beta' T_{y_I} + \beta'' T_i + \gamma' T_i + \gamma'' T_{x_0} + \delta' T_i + \delta'' T_{y_0}\right] + ~~HT_i~~$$

Where $\alpha, \beta, \gamma, \delta$ are the bulk flow terms from the four sides of the isotherm under consideration.



The single prime on the bulk flow term indicates that there is a sensible heat flow from the facing isotherm. The double prime on the bulk flow term indicates the sensible heat flow from within the isotherm. The triple prime of the bulk flow term indicates the enthalpy gain within the isotherm.

The bulk flow terms are evaluated as follows: (3-51a)

$$GM_{x_I} > 0$$

No Area Contact | **Area Contact**

$$\alpha' = GM_{x_I} \cdot c_p(T_{o_{x_I}}) \qquad \alpha' = 0.0$$

$$\alpha'' = 0.0 \qquad \alpha'' = 0.0$$

$$\alpha''' = -GM_{x_I}\left[H(T_{o_{x_I}}) - c_p(T_{o_{x_I}}) \cdot T_{o_{x_I}}\right] \qquad \alpha''' = -GM_{x_I} \cdot H(T_{Fe}$$

$$GM_{x_I} < 0.0 \qquad GM_{x_I} = 0.0$$

$$\alpha' = 0.0 \qquad \alpha' = 0.0$$

$$\alpha'' = GM_{x_I} \cdot c_p(T_{o_\alpha}) \qquad \alpha'' = 0.0$$

$$\alpha''' = -GM_{x_I}\left(-H(T_{o_\alpha}) - c_p(T_{o_\alpha}) \cdot T_{o_{x_I}}\right) \qquad \alpha''' = 0.0$$

$$\alpha = \alpha' + \alpha'' + \alpha'''$$

$$GMy_I > 0$$

No Area Contact

$$\beta' = GMy_I \cdot C_p(To_{y_I})$$

$$\beta'' = 0.0$$

$$\beta''' = -GMy_I\left[H(To_{y_I}) - C_p(To_{x_I}) \cdot To_{y_I}\right]$$

Area Contact

$$\beta' = 0.0$$

$$\beta'' = 0.0$$

$$\beta''' = -GMy \cdot H(T_{fk})$$

$$GMy_I < 0$$

$$\beta' = 0$$

$$\beta'' = GMy_I \cdot C_p(To_i)$$

$$\beta''' = -GMy_I \cdot \left[H(To_i) - C_p(To_i) \cdot To_i\right]$$

$$GMy_I = 0.0$$

$$\beta' = 0.0$$

$$\beta'' = 0.0$$

$$\beta''' = 0.0$$

$$\beta = \beta' + \beta'' + \beta'''$$

$$GMx_o > 0$$

$$\gamma' = 0$$

$$\gamma'' = GMy_I \cdot C_p(To_i)$$

$$\gamma''' = -GMy_I\left[H(To_i) - C_p(To_i) \cdot To_i\right]$$

$$GMx_o = 0$$

$$\gamma' = 0.0$$

$$\gamma'' = 0.0$$

$$\gamma''' = 0.0$$

$GM_{x_0} < 0$
No Area Contact

$$\gamma' = 0.0$$
$$\gamma'' = GM_{x_0} \cdot C_p(T_{o_{x_0}})$$
$$\gamma''' = GM_{x_0} \cdot [H(T_{o_{x_0}}) - C_p(T_{o_{x_0}})]$$

$GM_{x_0} < 0$
Area Contact

$$\gamma' = 0.0$$
$$\gamma'' = 0.0$$
$$\gamma''' = GM_{x_0}[H(T_{Fa})]$$

$$\gamma = \gamma' + \gamma'' + \gamma'''$$

$GM_{y_0} > 0$

$$\delta' = 0$$
$$\delta'' = -GM_{x_0} C_p(T_{o_{x_0}})$$
$$\delta''' = GM_{x_0} [H(T_{o_{x_0}}) \cdot T_{o_{x_0}}]$$

$GM_{y_0} < 0$
Area Contact

$$\delta' = 0.0$$
$$\delta'' = 0.0$$
$$\delta''' = -GM_{y_0} H(T_{Fa})$$

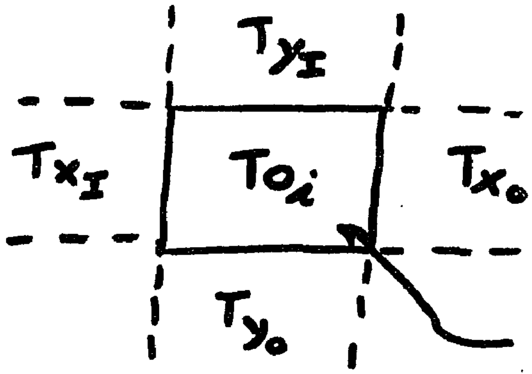
$GM_{y_0} < 0$
No Area Contact

$$\delta' = 0.0$$
$$\delta'' = -GM_{x_0} \cdot C_p(T_{o_{x_0}})$$
$$\delta''' = GM_{y_0} [H(T_{o_{y_0}}) - C_p(T_{o_{y_0}}) \cdot T_{o_{y_0}}]$$

$GM_{y_0} = 0$

$$\delta' = 0.0$$
$$\delta'' = 0.0$$
$$\delta''' = 0.0$$

$$\delta = \delta' + \delta'' + \delta'''$$



Isotherm Under Consideration

The relationship used in equation (3-51) can be changed by reference to the above figure. The gas volume i has a temperature T_{0_i}. The temperature for the isotherm to the left is T_{X_I}. The subscript I refers to inlet temperatures in reference to positve X axis. Similarly, the 0 in T_{X_O} refers to outlet temperature. The T_{Y_I} and T_{Y_O} have similar meanings in reference to the positive Y area. The temperature T_{FA} refers to the fuel-air temperature of the incoming fuel. The reader should note that all possible burner locations are accounted for by the four special cases of area contact. To illustrate this point, consider the case for and GM_X 0. If $GM_X = 0$, no fuel-air mixture could enter since no bulk flow term is present. If GM_X 0 the bulk flow would have to go in the direction of the furnace wall and since the gas volume is in contact with the wall, there could clearly be no flow. Consideration of the other three cases leads to similar results.

Temperature terms which have a presubscript s such as $_sT_{X_I}$ would refer to a surface temperature of the enclosing furnace wall. The subscript X_I would have the same meaning as previously discussed.

Equation (3-51) may now be written for every gas volume with the number of unknown gas volume temperatures equal to the number of equations. The matrix is again diagonally dominant and can be solved by the methods of Gauss-Jordan without double pivoting. The matrix contains surface area temperatures which are assumed constant in the solution of the gas volume temperature. In the next section the surface area temperature balance will be made assuming known gas volume temperature. This procedure allows for seperation of the surface energy balance from the gas volume energy balance.

The two energy balances are then solved repeatedly (adjusting the total interchange area for the newly calculated temperature) using the Newton-Raphson technique.

G. Energy Balance on Surface Area

The heat balance on the surface is expressed as:

$$\text{Heat In} - \text{Heat Out} = 0 \tag{3-52}$$

or

Heat release due to combustion + Radiant Energy In - Radiant Energy Out + Heat Transfer In - Heat Transfer Out by convection - Heat Loss to Ambient Surroundings = 0 (3-53)

The enthalpy consideration is zero as a result of considering heat transfer due to bulk flow to have occurred before flue gas has passed through the "porous membrane."

i. The Source Term

The source term accounts for burner heat release that is very near the furnace. It is assumed that the detailed information of such heat release is known. This term is presented as:

$$H_S = E_{Total} \, \psi(x, y) \qquad (3\text{-}54)$$

where ψ (X,Y) = fractions of total heat released at surface area.

ii. Radiant Energy Term

The radiant energy term accounts for all radiation in the system. Radiant energy from all the surface zones and all of the gas volumes over surface i may be expressed as

$$R = \left[\sum_j G_j G_i \sigma T_j^4 + \sum_j S_j S_i \sigma T_j^4 \right] + \left[- \sum_j S_i G_j \sigma T_i^4 - \sum_j S_i S_j \sigma T_i^4 \right] \quad (3\text{-}55)$$

iii. Convective Heat Transfer

Convective heat transfer can take place in the bounding wall aa well as internal heat transfer surface.

If the heat transfer takes place in the bounding wall, the net convected heat transfer becomes:

$$= h_c (T_G - T_i) A_i - h''_c (T_i - T_{sink}) A_i - h'_c (T_i - T_{proc}) A_i \quad (3\text{-}56)$$

where

T_G is the temperature of the adjoining gas volume

T_i is the temperature of Area A_i

T_{sink} is the temperature of ambient

T_{proc} is the temperature of the process fluid

h_c is the adjusted overall heat transfer coefficient between surface i and the flue gas

h'_c is the adjusted overall heat transfer coefficient between the area A_i and the process fluid

h_c'' is the adjusted overall heat transfer coefficient between the area A_i and the ambient temperature

The net convected heat transfer for internal surface becomes:

$$h_c(T_G - T_i)A_i\Big|_{Left} + h_c(T_G - T_i)A_i\Big|_{Right} - h_c'(T_i - T_{proc})A_i \quad (3\text{-}57)$$

Note internal surfaces always have a vertical orientation.

iv. Net Heat Absorbed by a Surface

The net heat absorbed by a surface can be expressed as:

$$[E_{Total} \cdot \psi(x,y)] + [h_c(T_G - T_i)A_i]$$
$$+ [\sum_j G_i G_j \sigma T_j^4 + \sum_j S_j S_i \sigma T_j^4 - \sigma T_i^4(\sum_j S_i G_j + \sum_j S_i S_j)] \quad (3\text{-}53)$$

The overall heat balance on surface zone $_i$

$$E_T \psi(x,y) + \sum_j G_j S_i \sigma T_j^4 + \sum_j S_j S_i \sigma T_j^4$$
$$- \sigma T_i^4 [\sum_j S_i G_j + \sum_j S_i S_j] + h_c(T_G - T_i)A_i$$
$$- h_c'(T_i - T_{proc})A_i - h_c''(T_i - T_{sink})A_i \quad (3\text{-}59)$$
$$= 0$$

It ia now possible to write (3-59) for each surface area and linearize it in terms of T^4. The resulting equation can be solved for T_i^4 by assuming the gas volume temperature as constant. The equation has the form:

$$A_{ii} T_i^4 + \sum_j b_{ij} T_j^4 = c_i \qquad (3\text{-}60)$$

where

$$A_{ii} = \sigma \left[\sum_j S_j S_i - \sum_j S_i G_j \right] - \left[(h_c + h_c' + h_c'') A_i \frac{1}{T_i^3} \right] \cdot 1/4$$

$$B_{ij} = \sigma S_j S_i$$

$$C_i = -\sigma \sum_j G_j S_i T_j^4 - (h_c T_G + h_c' T_{proc} + h_c'' T_{sink}) A_i - E_T \psi(\alpha, y) + \left[(h_c + h_c' + h_c'') A_i T_i \right] \cdot 3/4$$

The reader should note that T_i is treated as a constant and the equation is then solved. The solution is then used to resolve the equation. This procedure is repeated until the maximum difference between two successive T_i's is less than some abstract small quantity. 1° R was used as the criterion for convergence in this study.

2. The Kinetic Model

The complete description of the kinetic model is given by Robertson[62] and will not be repeated here.

A brief discussion, however, will be presented and the method of incorporating the pointwise temperature distribution of the reactor wall will be explained.

A. Description of Reactor

The reactor is a tube 400 feet long placed in a furnace in a series of U bends. The tube runs up and down in the reactor to prevent bending of the tube in the center which would occur if it was strung out in an elongated position.

The tube itself is 3.640 inches in inside radius and the walls are .226 inches thick (a nominal four inch tube). The tube is assumed to have scale both on its inner and outer walls that add to the resistance of heat flow. The reactor tube was considered to be free of coke deposit. All initial design considerations did not consider the effect of coke on overall performance. However, a coke profile was calculated and later used to determine its effect on reactor yield.

The reactor inlet pressure was adjusted to give an outlet pressure of two atmospheres. The initial reactor feed comsisted of steam, ethane and propane. It is possible to include other material as long as the various mechanisms of reaction are known. The user would have to input kinetic and thermo-dynamic data. These however, were not included as a part of this study.

B. The Material Balance

Considering any incremental length of reactor the material balance can be written as:

IN = OUT + Change By Reaction + Accumulation (3-61)

Since steady state is assumed, the only accumulation term involved in this study was the deposition of carbon on the reactor wall. When (3-61) is rewritten in syn

$$\sum_i N_i \Big|_{INLET} = \sum_i \left[N_i \Big|_{OUTLET} + \sum_j A_{ij} N_{ij} \Big|_{INLET} \cdot \Delta X \right.$$

$$\sum_i N_i \Big|_{INLET} = \sum_i \left[N_i \Big|_{OUTLET} + \sum_j A_{ij} N_{ij} \Big|_{INLET} \cdot \Delta X_j \right]$$

$$+ A_{cc} \qquad (3\text{-}62)$$

where

N_i = number of molar flow rate into incremental reactor

A_{ij} = stoichiometric coefficient of the i^{th} chemical component in the j^{th} reaction

N_{ij} = the molar flow rate of the j^{th} reaction of the i^{th} component

ΔX_j = the incremental conversion calculated within the incremental length

A_{cc} = accumulation term

Equation (3-62) can be written for the i^{th} component to yield a component balance.

C. Calculation of Incremental Conversion

For the plug flow reactor the space time is defined by

$$\tau = \frac{1}{s} = C_{A_0} \int_{x_1}^{x_2} dX_A / -r_A \tag{3-63}$$

where

τ = is the reactor space time =

dX_a = differential conversion of A component

$-r_A$ = rate of reaction

C_{A_0} = initial concentration of component A

V = reactor volume =

F_a = volumetric flow rate

s = space time

Considering finite differences in equation (3-63) and solving for $X_a = X_2 - X_1$ results in:

$$\Delta X_A = -r_A \Delta \Upsilon / C_{A_0} \tag{3-64}$$

Equation (3-64) can now be expressed in terms of flow rates:

$$\Delta X_A = \pi R^2 / F_{A_0} (-r_A) \Delta L \tag{3-65}$$

Where ΔL = the incremental reactor length under consideration.

Defining the reaction rate $(-r_A)$ in terms of the Arrhenius rate law:

$$(-r_A) = e^{-E_A^*/RT} \left[K_o \prod_j C_{A_i}^{N_{A_i}} - K \prod_j C_{A_i}^{N_{A_i}} \right] \tag{3-66}$$

Where

K_o = the Arrhenius frequency factor

E_A^* = the Arrhenius energy of reactivation

R = gas constant

T = absolute temperature

N_{A_i} = order of reaction j of the i^{th} component

K = equilibrium constant

C_{a_i} = concentration of component

The reader should note Π_j refers to the Pi product of the concentration terms. The concentration terms can be calculated from the ideal gas law:

$$C_a = P_a / R'T \qquad (3\text{-}67)$$

where

P_a = Pressure of component a

R' = Gas constant

D. Calculation of Pressure Profile

In order to calculate the pressure at the end of the incremental reactor section a momentum balance was performed using the Bernouli equation.[51]

$$\Delta P = \left[\frac{V_1 + V_2}{2} \Delta F \Delta L / R + V_2^2 - V_1^2 \right] / 2g \qquad (3\text{-}68)$$

where

P = Pressure drop

V_1, V_2 = Reactor gas velocity at inlet, outlet conditions

F = Friction factor

L/R = Incremental length of reactor radius ratio

g = Gravitational constant

E. Calculation of Temperature Profile

In order to calculate the temperature at the end of the reactor increment, a heat balance was performed on the incremental reactor segment.

Heat flux in = sensible heat gain + heat of reaction (3-69)

$$UA\Delta T_1 = \sum_j F_j C_{Pj} \Delta T_2 + \sum_i \Delta H_i F_{K(i)} \Delta X_i \quad (3-70)$$

where

U = to the overall heat transfer coefficient from reactor tube outer wall to reaction fluid

A = the area through which heat flux is transmitted = 2 R L

T_1 = The temperature between outside wall and reaction fluid

T_2 = Temperature difference between reaction fluid at start of increment and end of increment

H_i = Heat of reaction $_i$

$F_{K(i)}$ = Molar flow rate of key component K(i) of the ith reaction

X_i = Extent of ith reaction between the start and end of reactor increment

CP_j = Heat capacity of the jth component.

The reaction rate $(-r_A)$ was determined by calculating its value at both ends of the incremental portion of the reactor and averaging the results. The average value was then used to recalculate the reactor conditions at the far end of the increment. This procedure was repeated until good values were obtained between the assumed end conditions and the actual end conditions. Thus an implicit method of solving differential equations was combined with Euler's method.

The convergence of reaction rate $(-r_A)$ took place simultaneously with convergence of the pressure profile. The concentration profile and the temperature profile converged through repeated applications of momentum, component, overall material and energy balances.

F. Calculation of Overall Heat Transfer Coefficient

The previous discussion has been condensed; readers who are interested in more details are again referred to Robertson [62].

However, more detailed information will be given on the calculation of U the overall heat transfer coefficient, as the concept was not fully developed in Robertson's work. The overall heat transfer coefficient from outer wall to reaction mass can be defined as:

$$\frac{1}{UA} = \sum_{i} R_i = \frac{R_o}{A_o} + \frac{\Delta X_{ST}}{K_{ST} A_{ST}} + \frac{R_I}{A_I} + \frac{\Delta X_c}{K_c A_c} + \frac{1}{h_I A_I} \quad (3\text{-}71)$$

where

R_i = Resistance to heat flow

R_o, R_I = Scale resistance to heat flow on outside and inside of reactor tube = .001 $\frac{\text{hr. ft}^2\ ^\circ\text{F}}{\text{BTU}}$

.001 from Ludvig (44A)

X_{ST}, X_C = Thickness of heat resisting material

ST = steel reactor tube thickness

C = coke thickness

K_{ST}, K_C = Thermal conductivity, BTU/hr. ft^2($^\circ$F/ft.)

K_{ST} = 26., K_C = 2.90 (44-A)

A, A_C, A_I = Average area of heat transfer area

$A_{ST} = 2\ L\ (r_o - r_i) / \ln (r_o/r_I)$

$A_C = 2\ L\ (r_I - r_C) / \ln (r_I/r_C)$

$A_I = 2\ L\ r_C$

and where

r_o = radius of reactor tube (center to outer wall)

r_i = radius of reactor tube (center to inner wall)

r_c = radius of coke deposit (center of tube to coke surface)

h_I = heat transfer coefficient from coke surface to reaction fluid.

The value of h_I is a function of reaction fluid temperature, pressure, composition, velocity and temperature and can be calculated from the Seiden Tate equation since the clow is maintained in the turbulent re to minimize residence time and product degradation via carbon deposition.

$$\frac{h_o D_i}{K} = 0.023 (N_{Re})^{.8} (N_{Pr})^{1/3} \left(\frac{\mu}{\mu_1}\right)^{.14} \qquad (3\text{-}72)$$

$$h = 0.023 \frac{K}{2r_i} \left(\frac{2 r_i V \rho}{\mu}\right)^{.8} \left(\frac{C_p \mu}{K}\right)^{1/3} \left(\frac{\mu}{\mu_1}\right)^{.14} \qquad (3\text{-}73)$$

where

V = velocity of reaction fluid

P = density of reactor fluid

= viscosity of reaction fluid

μ_1 = viscosity of reaction fluid at wall temperature

C_p = heat capacity of reaction fluid

K = thermal conductivity of the fluid

N_{Re} = Reynold's number

N_{Pr} = Prandtl's number

D_i = Diameter of the reactor radius after i increments of coke deposition

The methods of calculating C_p, μ, V and P are discussed in Robertson's Thesis[62]. However, the calculation of the thermal conductivity has not been discussed.

The Mason equation was used:[11, 91]

$$K_{mix} = \sum_i \frac{x_i K_i}{\sum_j x_j \phi_{ij}} \tag{3-74}$$

where

$$\phi_{ij} = \frac{1}{\sqrt{8}} \left[\left(1 + \frac{M_i}{M_j} \right) \right]^{-1/2} \left[1 + \left(\frac{\mu_i}{\mu_j} \right)^{1/2} \left(\frac{M_j}{M_i} \right)^{1/4} \right]$$

M = molecular weight of the compoent

X = mole fraction of the component

The value of K_i was calculated from Eucken's[19-A] development of handling energy exchange in polyatomic gases and is given by

$$K_i = \left(c_{p_i} + 5/4 \frac{R'}{M_i} \right) \mu_i \tag{3-75}$$

The method used to calculate the viscosity utilizes the Lennard Jones equation.[11]

$$\mu_i = 2.6693 * 10^{-5} \sqrt{M_i T} / \sigma_i \Omega_\mu \tag{3-76}$$

where

σ_i is the characteristic of collision diameter of the molecule

Ω_μ is a slowly varying function of the dimensionless temperature KT/ϵ

σ_i and K/ϵ are commonly known as the Lennard Jones constants. The reader is referred to Robertson's Thesis[62] for the details of the evaluation of Ω_μ .

The reactor model now is able to calculate an increment of conversion but requires the outer tube metal temperature. This calculation procedure is repeated for the entire length of the reactor.

3. The Mapping Models

A. Furnace Model to Reactor Model

The furnace model supplies the furnace plane wall temperature. This plane wall temperature is split into m isothermal temperature areas. In addition there were n sets of these isothermal zones, one for each subdivision of the furnace-reactor model.

It would be possible to use these discreet isothermal zones as the tube metal temperature used by the reactor. However, it was felt that a better approximation of the net heat flux could be obtained by considering the m isothermal temperatures as m points in a continuous curve. The location of each point would be the mid point of the isothermal zone. These points are then fitted to a fourth order polynomial in Y (the furnace height). The fit is accomplished by a linear least square fit (function FITIT), which is given in Appendix B. An actual fit is illustrated in Figure 2 of Chapter I.

This procedure is repeated for the other n-1 furnace subsections. In order to determine what the reactor tube wall temperature is at any point, all that is required is to determine which subsection of the furnace the reactor tube is located in, and what height that location lies relative to the furnace wall. This can be determined by the following relationship:

$$y_i = z_i - \text{Integer}(z_i/L_i) * L_i \tag{3-76}$$

where L_i is twice the furnace height

Integer implies that the result of $Z_i/56$ is rounded off to the lower whole number. That is, the result of Integer (51.9971) 51

Z_i is the position of the reactor tube being evaluated for the tube metal temperatures.

If the value of Y is greater than $(L_i/2)$ Y is redefined in terms of the original Y by

$$y_i = L_i - y_{original} \tag{3-77}$$

The furnace subsection the tube is in is easily determined by knowing the length of each reactor subdivision.

The standard deviation of the temperature as function of wall height was approximately one half of a Farenheit degree.

By using the method described, it is possible to take into account the fluctuation of temperature with wall height. Variations along the long axes are handled as a set of three discontinuous isotherms.

One method would entail the determination of some continuous and smooth functions which would yield the temperature as a function Y and Z, which is:

$$T = f(Y, Z) \tag{3 78}$$

One such method would be to determine the best straight line, or the best second order polynomial through the three temperatures for the value of X and then determine the value for the particular location above the long or Z axis.

This procedure was not incorporated in this study, but it is recommended that consideration be given to it in any future refinement of this work.

B. <u>Reactor Model to Furnace Model</u>

It was necessary to map the reactor process fluid temperature into a set of (n X m) isothermals. This was accomplished by considering each one of the n subdivisions seperately. The temperature of the reactor process fluid was recorded at m furnace height for every up and down pass of the reactor tube in the furnace. It then became possible to sum the temperatures for any given furnace height and average the result. Thus:

$$\overline{T_{PF_i}} = \frac{\sum_i (T_{PF_i})}{\eta} \quad (3\text{-}79)$$

Where T_{PF_i} = average temperature of process fluid for isotherm at height Y

(T_{PF}) = successive temperatures of the process plane each time the tube passes through the height .

η = number of times the reactor tube passes through the height

Referring to Figure 5 for example, to calculate the temperature of isothermal zone being in isotherm 4, X_4 would result in:

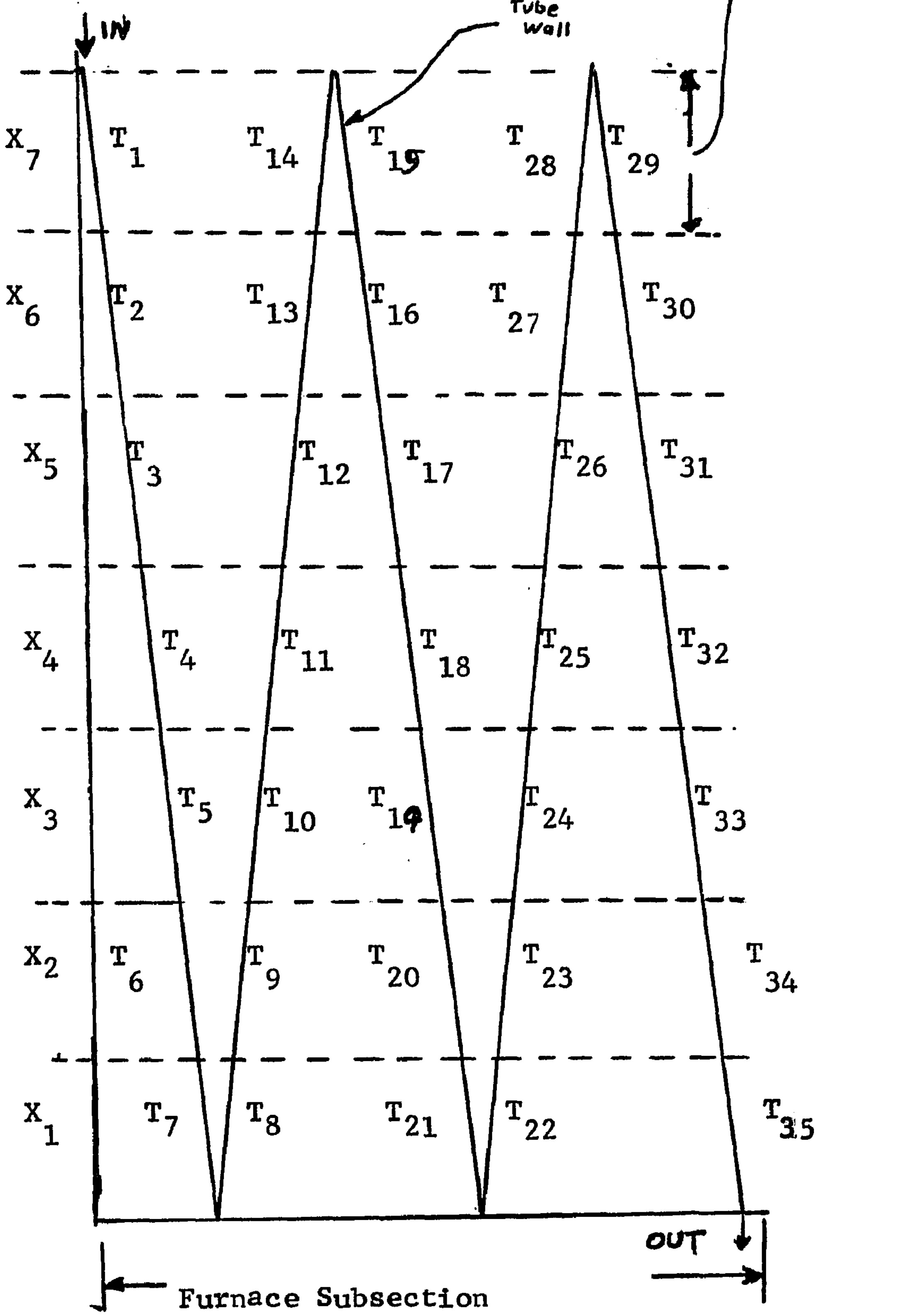
$$\overline{T_{I(J1,4)}} = \frac{\sum_{J1=1}^{5} (T_{J(J1,4)})}{5} = \frac{T_4 + T_{11} + T_{18} + T_{26} + T_{32}}{5} \quad (3\text{-}80)$$

In order to determine the value of $\overline{T_{J(J1,4)}}$ it was necessary to manually determine which temperature lay in which isotherm. This procedure was repeated for each of the furnace subsections under investigation. The temperature locations were then stored as a part of the computer program (Apprendix B).

Any further user who had a different set of furnace or reactor conditions or who desired to zone the furnace in a different way would have to redo these determinations and rewrite the main program. No changes in any subroutines or functions (with the exception of 'TEMP') would have to be performed.

Figure 5

Mapping the Reactor Temperature Profile Into An Isotherm Surface Area



The average process temperature can thus be calculated from any set of isotherms for any furnace subsection.

The overall heat transfer coefficient from tube plane to process fluid plane will not be the same coefficient calculated from outer tube wall to process fluid in the reactor model. This is due to the differences in geometry between the two models. It was decided to allow the models themselves to do the mapping between the two geometries.

This mapping was accomplished by calculating the net heat flux Q_R through the reactor tube via the method described in Chapter III-2 for each furnace subsection. The furnace model then uses a fuessed value for the overall heat transfer U_F to calculate the net heat flux Q_F to the process fluid.

At the next repeat of the furnace calculation the value of the overall heat transfer is adjusted according to:

$$U_F = U'_F (D + Q_R/Q_F)/(D+1.) \tag{3-81}$$

Where U'_F = former guessed value of the overall heat transfer coefficient

D = Damping factor

It was necessary to damp the change in the value of U_F as the undamped change i.e.:

$$U_F = U_F' \, q_R / q_F \qquad (3\text{-}82)$$

results in divergent oscillation of the solution around the solution. The value of U_F was calculated independently for each furnace subsection.

4. Calculation "Flow"

A. Introduction

This section is an attempt to give the reader a "feel" for the computational sequence. Thr reader is reminded that the calculations were carried out on a high speed computer so some references will be made to data "input" and "output".

It would be extremely complicated to give detailed calculations of each step. In order to avoid this difficulty, whole groups of calculations will be referred to by a few descriptibe words. It would also be difficult to give a "flow diagram" but reference will be made referring back to previous steps. This will be accomplished by numbering the various steps.

B. The "Flow"

STEP I. Input Furnace Data

1. Total heat release distribution
2. Fuel-excess air analysis
3. Geometry of furnace
4. Bulk flow pattern
5. Furface properties
   a. Transmissivity
   b. Emissivity
   c. Heat transfer coefficient
6. Surface boundary conditions

STEP II. Preliminary Furnace Calculations

1. Flue gas analysis
2. Specific heat enthalpy data
3. Initial temperature profile (if not inputted)
4. Characteristic flue gas by clear-gray gas combintation. (isolate temperature dependence)

STEP III. Calculate Direct Interchange Area

1. Surface to surface - ss (clear gas . gray gas(es))
2. Surface-gas/ gas-surface, sg, gs (gray gas(es))
3. Gas - gas gg (gray gas(es))

STEP IV. Account for Surface Reflectivity

1. Reflection with gas volume as the emitter.

   Solve for ${}_{g}R_{s}$ (gray gas(es))

2. Reflection with surface area as the emitter

   Solve for ${}_{s}R_{s}$ (gray gas(es)

STEP V. Calculate Total Interchange Area - for a Characteristic Gas (Temperature Independent)

1. Gas to gas $GG = gg + \sum {}_{g}R_{s}$ $\cdot$ g (Gray gas(es)
2. Gas to surface/surface to gas

   $GS = {}_{g}R_{s} \cdot \frac{A\varepsilon}{\varphi}$ (Gray gas(es))

3. Surface to Surface

   a. $SS_c = {}_{s}R_{s_c} \; A\varepsilon/\varphi$ (Clear Gas)

   b. $SS = {}_{s}R_{s_c} \; A\varepsilon/\varphi$ (Gray gas(es))

STEP VI. Input Reaction Data

1. Initial Tube Wall Temperature (Guessed)
2. Description of Reactions
3. Description of Reactor
4. Initial Reactant Concentration
5. Physical Data
   a. Heat Capacity
   b. Arrhenius Kinetic Data
   c. Enthalpy
   d. Entropy

e. Reaction Equilibrium

f. Lennard - Jones Constants

6. Miscellaneous Control Parameter

STEP VII. Calculate Parameter Needed for Reactor Calculation as a Function of Temperature

STEP VIII. Output the Reaction System and Generate Parameters

STEP IX. Calculate Reactor Pressure, Component, Temperature, Heat Flux and Carbon Deposition Profiles

1. Determine the Temperature Profiles for Each Furnace Subsection

2. Determine Rates for Beginning of Increment (All Conditions Known)

3. Guess or Update Temperature, Composition and Pressure at End of Increment and Determine Reaction Rates at End of Increment

4. Calculate Average Reaction Rates

5. Using Average Rates do:

A. Material Balance

i. Component Balance

ii. Pressure Drop Calculation

iii. Material Balance

B. Heat Balance

i. Sensible Heat Gain

ii. Heat Flux Calculation Using T=f(z)

6. Compare End Conditions. (if in agreement with set used (go to Step IX-7) otherwise (go to Step IX-3)

7. Calculate Next Reactor Increment Using End Conditions as Initial Conditions

   a. If Finished the Length of the Reactor, Go to Step X.

   b. Otherwise - Step IX-3

STEP X Using the Reactor Fluid Temperature Profile, Calculated in Step IV, Calculate Isothermal Area Temperature for Each Isotherm in each Furnace Subsection.

STEP XI Calculate New Surface and Gas Volume Temperatures Using the Isothermal Temperature Calculated in Step X or Step XI-3

1. Total interchange area for real gas (temperature dependent) 1 corrected for intermediate surface if any transmissivity

   a. Surface to Gas $SG=\left[\sum_n A_n \cdot SG_n\right]\tau$

   b. Surface to Surface $SS=\left[\sum_n a_n \cdot SS_n + (1-\sum_n a_n)SS_c\right.$

2. Total interchange area for real gas (temperature dependent) 2 Corrected for intermediate surface, if any transmissivity

a. Gas to Gas $GG = \left[\sum_n GG_n \right] \uparrow$

b. Gas to Surface $GS = \left[\sum_n \cdot GG_n \right] \uparrow$

3. Gas Volume Heat Balance

a. Surface area temperatures are assumed constant

b. Heat Balance

i. Bulk Flow

ii. Radiation

iii. Source

iv. Convection

c. Linear Heat Balance Equation Using Iterated Newton-Raphson

d. Solve for T

e. Update Gas Volume Temperature

f. Test the Size of the Max T

4. Surface Area Heat Balance

a. Gas Volume Temperatures are Assumed Constant

b. Heat Balance

i. Radiation

ii. Sources

iii. Convection

c. Linearize Heat Balance Equation Using Iterated Newton-Raphson (as in Step XI-3c)

Chapter IV

Results and Conclusions

The calculation procedures described in the first three chapters were used to make a parameter study of a typical large scale industrial furnace producing ethylene and propylene (as a secondary product).

The chief parameters which were adjusted were the fuel rate and the wall to wall separation. The results obtained were compared with plant observations. It should be realized that an exact matching of the two is difficult in view of the errors in plant measurements and the uncertainties in the value of kinetic data, emissivities, and other physical properties of furnace and reactor.

The values of yeilds obtained have good agreement with data obtained with adjusted of the Arrhenius frequency factor (A_i). As these adjustments were in the unimportant side reactions, it was decided to perform the optimization with the unadjusted constants.

Comparing the overall furnace performances was somewhat more difficult as these results are highly dependent on the physical pnoperties of the furnace being studied. The author was unable to locate any data from industrial furnaces with sufficient amount of detail to duplicate the calculations. However, excellent agreement was found with general operating conditions of industrial plants. The point of optimum operation determined in this study corresponds to actual operating conditions found in existing furnaces.

1. Verification of Results

The results from this study were compared with results reported by two other investigators, Shah[70] and Nelson.[54]

Shah had simulated a reactor system using the method of Lobo[46] to calculate the outer tube wall temperature. Shah then adjusted the Arrhenius rate constant to force agreement of his results with data he had available.

Nelson reported data from a variety of industrial furnaces. As a result, the individual furnace characteristics are not available.

Table I shows a comparison of Shah, Nelson and results from this study. It should be noted that good agreement exists between Shah's results and the results reported in this study. There is some disparity in the reported outlet temperature. The two cases reported in this table represent different rates of firing. The two rates bracket the firing rates found in some industrial furnaces is in excellent agreement.

The operating point of the industrial furnaces as reported by Nelson was in agreement with the optimum operating report as developed in this study.

TABLE I

COMPARISON OF RESULTS OF THIS STUDY WITH SHAH[70] AND NELSON [54]

	Shah's Results	Nelson Reports	Robertson Case 1	Robertson Case 2
Heat Availability 10^6 BTU/Hr.-Foot Furnace	-	-	2.86	3.22
Total Feed (lb/ moles/hr.)	171	-	280	280
Steam-Feed Ratio	.363	.3 - 1.1	.35	.35
Inlet Pressure (atm.)	4.43		6.6	6.6
Outlet Pressure (atm.)	?	1.2 - 3	2.0	2.2
Reactor Length (feet)	394	-	400	400
Tube Radius (inches)	?	-	4	4
Gas Inlet Temperature °F	1010°	-	1012°	1012°
Gas Outlet Temperature °F	1400°	1515-1525°	1544°	1560°
Mole % Ethylene Yield	47.6%	58 - 62%	52.48%	60.05%
Mole Ratio Methane/Ethane (+)	.0177	.025-.067	.0142	.0157
Mole Ratio Acetylene/Ethane(+)	.00053	.0014	.00101	.00145
Thermo Efficiency Ratio BTU to Reactor/ BTU Fired	-	-	.350	.315

2. Furnace Temperature Driving Force

Figure 6 shows a typical temperature driving force calculated by the procedure outlined in this study.

It should be noted that fluctuations ranging up to 790°F are found between adjoining gas zone isotherms. Differences of 1100°F exist between the highest and the lowest isothermal temperature zones.

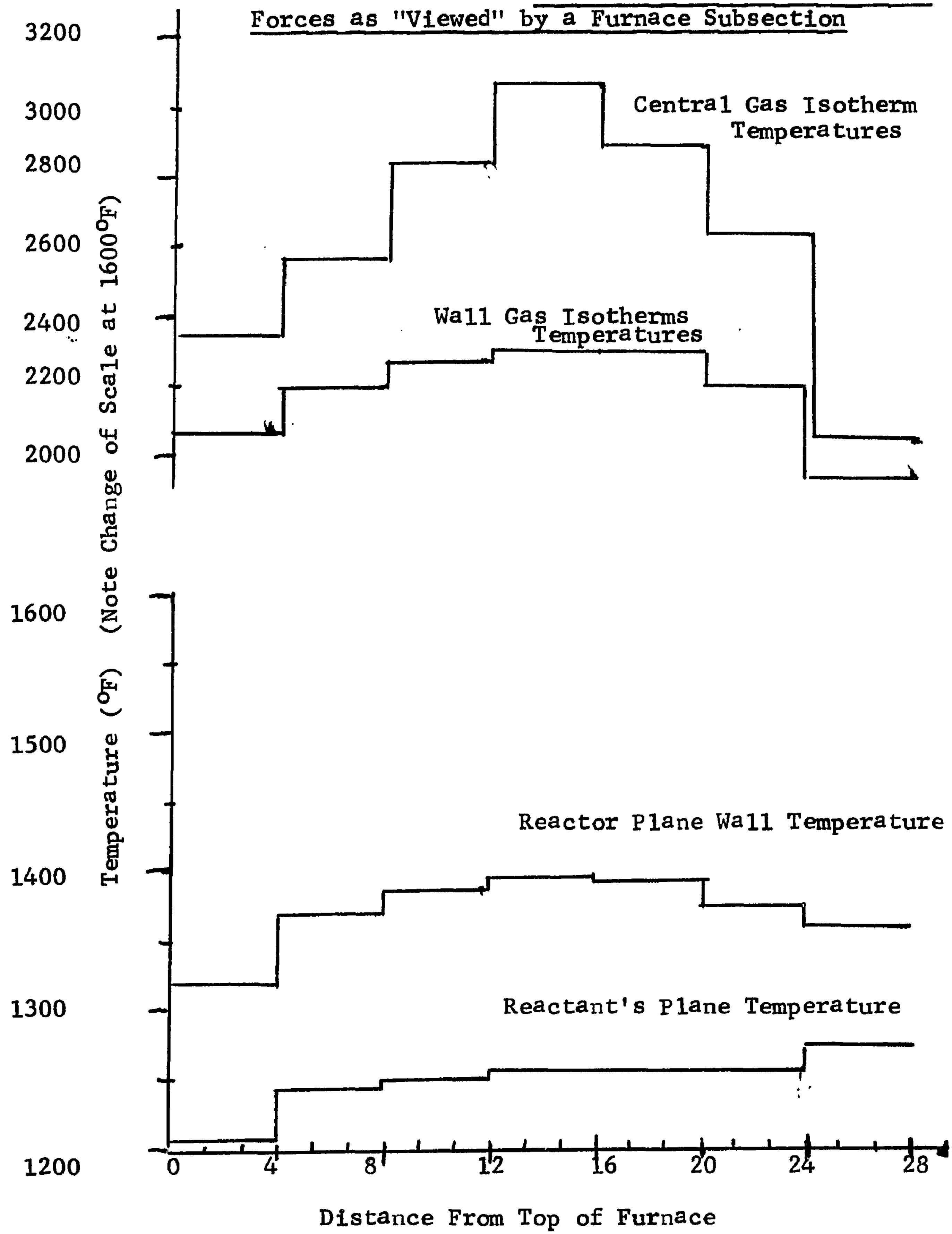
The large differences calculated are a strong justification for the use of this complex procedure, expecially when highly temperature dependent calculations are being used.

It is also interesting to note that the temperature driving force between the tube wall "plane" and the process "plane" is not constant, but is dependent on tube height.

Normally the process plane temperature would be nearly constant at the average temperature of the process fluid. However, in this example there is an increase near the bottom of the furnace due to an uneven number of tubes in this subsection.

Figure 7 is a numerical example of the temperature driving force in each of the three furnace subsections.

Figure 6. Typical Temperature Driving Forces as "Viewed" by a Furnace Subsection



Each subsection represents only half of the plane of the furnace subsection (the missing half would be symmetrical to that shown).

Several interesting observations may be drawn from this figure:

1. Once again, considerable temperature differences exist between adjoining isothermal zones in different furnace subsections.

2. The temperature of the central isothermal zone shows only relatively small variation from subsection to subsection.

3. Considerably larger temperature fluctuations exist in those isotherms abutting the furnace wall. This is important as these isotherms act as the chief driving force for convective heat transfer. It has been generally accepted that radiation is the dominant mode of heat transfer in the fire box. The results of this study suggest that convection also plays a significant role. It should be given consideration in the design of an "optimum furnace."

The use of a single gas isotherm for the entire furnace zone would do a poor job at estimating the importance of the convected heat transfer.

Figure 7

Temperature Profile in Furnace Subsection in (°F)

Note the furnace temperatures are symmetrical about the center line.

Furnace Subsection 1

Process Temperature	Plane Wall Temperature	Wall-Gas Temperature	Central Gas Temperature
1208	1321	2073	2352
1245	1370	2207	2570
1252	1386	2277	2849
1256	1395	2306	3082
1258	1392	2304	2893
1259	1376	2301	2636
1278	1361	1939	2044

Furnace Subsection 2 (Furnace Wall between the second and third columns)

Process Temperature	Plane Wall Temperature	Wall-Gas Temperature	Central Gas Temperature
1470	1568	2165	2418
1454	1573	2283	2621
1458	1581	2343	2885
1456	1583	2363	3110
1453	1575	2351	2913
1448	1553	2242	2649
1430	1508	1978	2051

Furnace Subsection 3

Process Temperature	Plane Wall Temperature	Wall-Gas Temperature	Central Gas Temperature
1565	1664	2220	2460
1569	1681	2332	2656
1571	1691	2388	2912
1572	1695	2404	3131
1571	1688	2387	2930
1570	1668	2274	2660
1569	1638	2013	2058

(℄ = center line at the right edge of each subsection)

3. Convected Heat Transfer in the Radiant Section of the Furnace

In order to dramatize the effect of convected heat transfer, a series of calculations were made which varied the wall to wall separation. During the first set of calculations, no correction was made to the gas to surface heat transfer coefficient. (Normally as the walls of the furnace get closer together retaining the same fuel consumption rate, the convected heat transfer coefficient would increase according to the .8 power of the bulk flow rates.)

The result (See Figure 8 and Table 2) was an increase in reactor yield with increasing wall separation. The result is a representation of an isolation of the radiative heat transfer rate which would increase as the surface area is able to view larger sections of the flame boundary at less oblique angles.

If the distance separating the wall continued to increase, the rate would ultimately drop off as the area would "view" a line source of radiation.

In the second set of calculations, the surface to gas volume heat transfer coefficient was corrected for bulk flow consideration. (See Figure 9 and Table 3 .) The results were reversed, with the closer the wall to wall separation, the higher the yield for the same amount of fuel fired.

Table 2-2

Effect of Wall Separation on Reactor Yield Radiation Effects Isolated by Using Uncorrected Surface to Gas Heat Transfer Coeﬁcient

Heat Availability $2.142*10^6$ BTU/hr.-foot(furnace)

Wall-Wall Separation Feet	% Yield Ethylene	Uncorrected Heat Transfer Coefficient Area Base BTU/hr °F/ft
6	32.27	3.14
8	32.52	3.14
10	33.20	3.14
50	37.16	3.14

Table 3

Effect of Wall Separation on Reactor Yield Using Corrected Surface to Gas Heat Transfer Coefficient

Heat Availability $2.142 * 10^6$ BTU/hr.- foot/furnace

Wall-Wall Separation Feet	% Yield Ethylene	Corrected Heat Transfer Coefficient (Area Bases) BTU/hr °F/ft
6	34.35	4.73
8	33.83	3.76
10	33.20	3.14
14	31.95	2.40
18	31.59	1.96

Figure 8.

Effect of Wall to Wall Separation on Ethylene Yield (Radiant Effect Isolated - No Adjustment of Gas to Wall Heat Transfer Coefficient)

Heat Available $2.142 * 10^6$ BTU/Hour - Foot Furnace

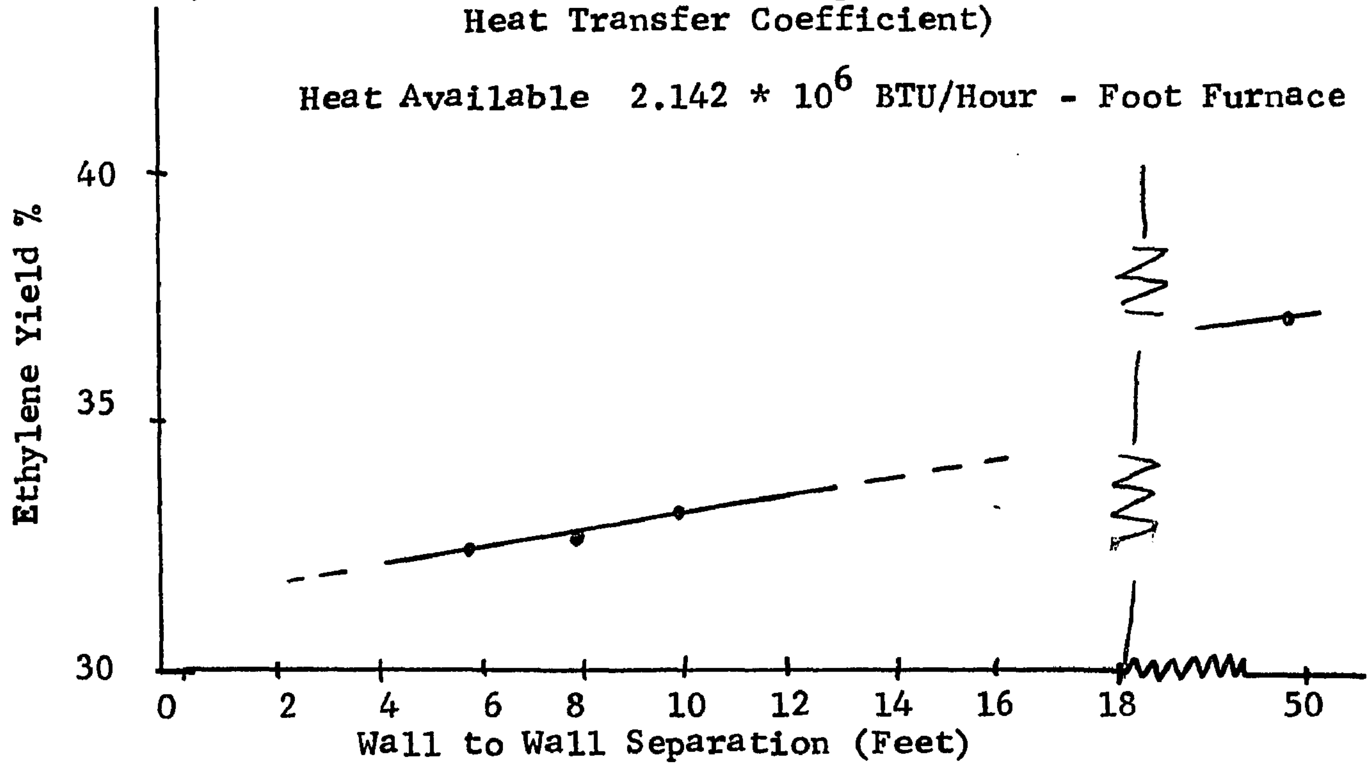
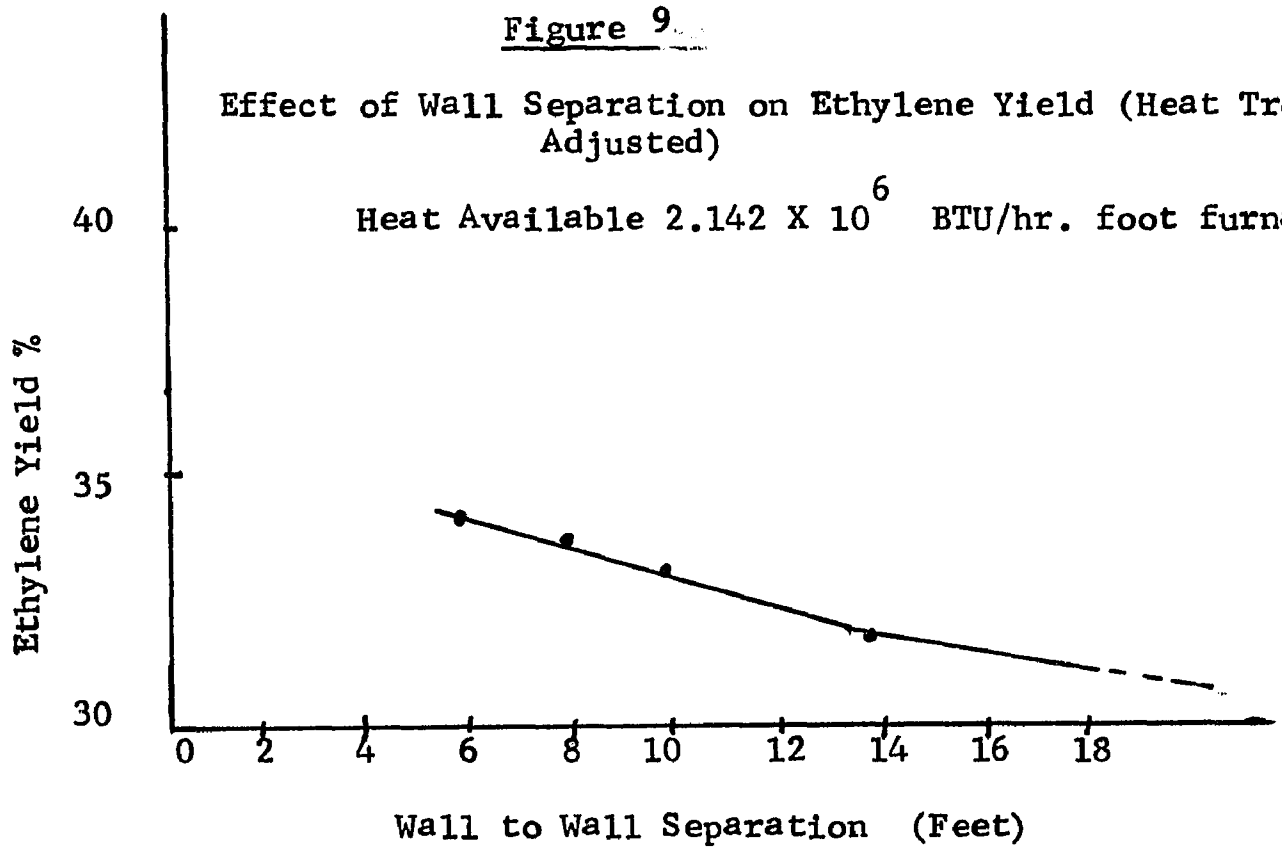


Figure 9

Effect of Wall Separation on Ethylene Yield (Heat Transfer Adjusted)

Heat Available 2.142×10^6 BTU/hr. foot furnace



This would suggest that optimum furnace construction should have the walls as close as possible while allowing sufficient volume for the complete combustion of the fuel.

The above discussion did not allow for the introduction of more isothermal zones as the wall separation was increased. It is likely that if such a procedure had been followed, the effects would have been less pronounced, but still valid.

4. Optimization of the Furnace-Reactor as a Function of Fuel Rate

Several sets of calculations were performed varying the net heat availability (E_t). The ethylene yield was then plotted as a function of net heat availability (Figure 9). The wall to wall separation was kept constant at 10 feet, 10 ft. separation being used as a basis for all variations.

Figure 10 and Table 4 predict the possibility of ethylene yields in excess of 70% per pass. There are, however, two main reasons why this yield is not practical.

The first reason is illustrated in Figure 10 which shows the rate of ethylene production in terms of pounds of ethylene produced/pound of fuel consumed versus net heat availability of the furnace. The plot goes through a

Table 4

Effect of Heat Availability on Reactor Yield for

10 Foot Wall - Wall Separation

Heat Availability BTU/hr. Foot Furnace X 10^6	% Ethylene Yield	Surface to Gas Heat Transfer Coefficient* Adjusted Area Bases BTU/hr. °F/ft.
1.79	23.18	2.72
2.14	33.20	3.14
2.50	43.42	3.55
2.86	52.48	3.95
3.22	60.05	4.35
3.57	66.67	4.73
3.93	72.14	5.10

*Adjustment takes into consideration increase in flue gas velocity due to increase in fuel fired.

Figure 10

Ethylene Yield as a Function of

Heat Availability

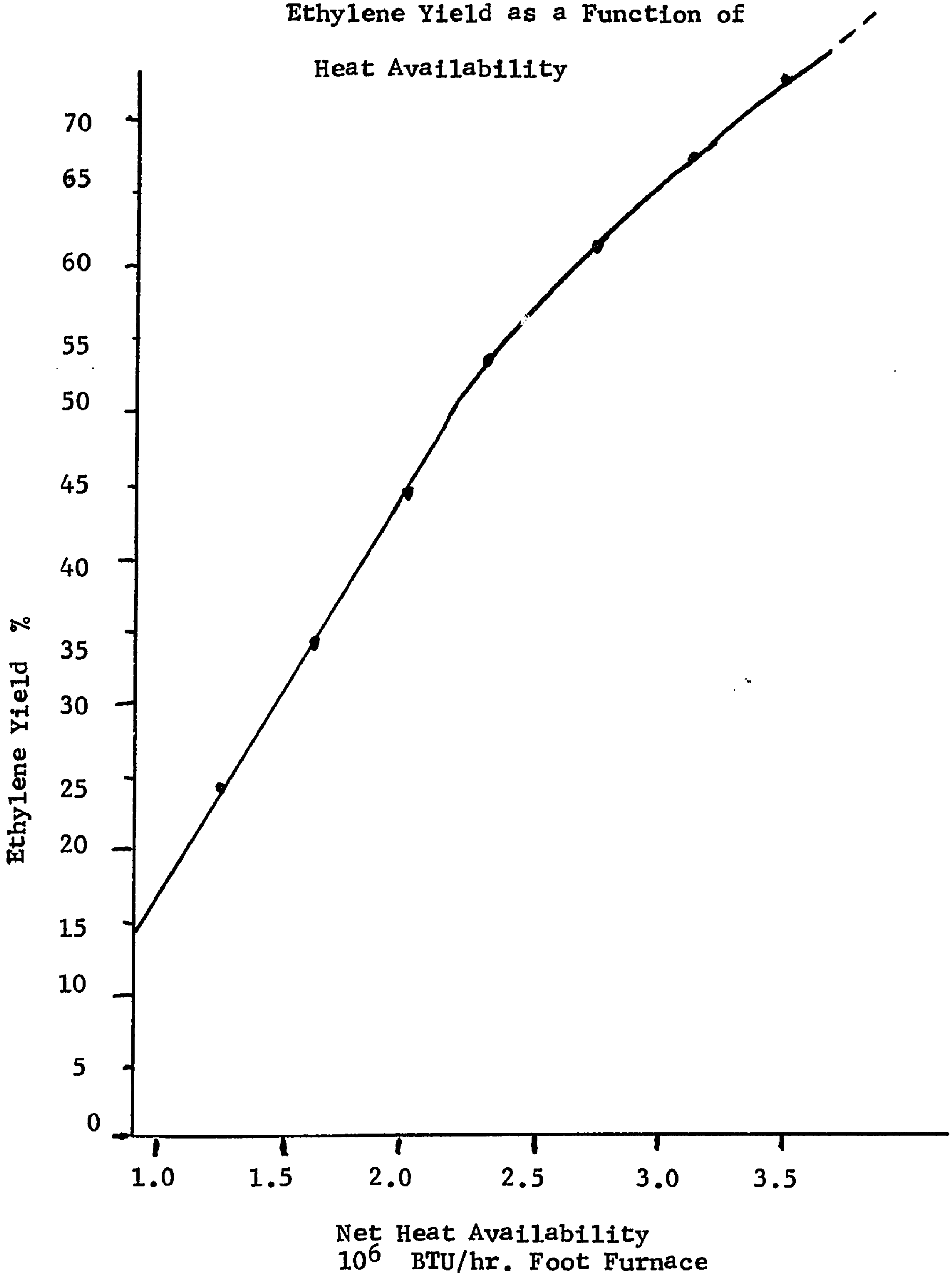


Figure 11

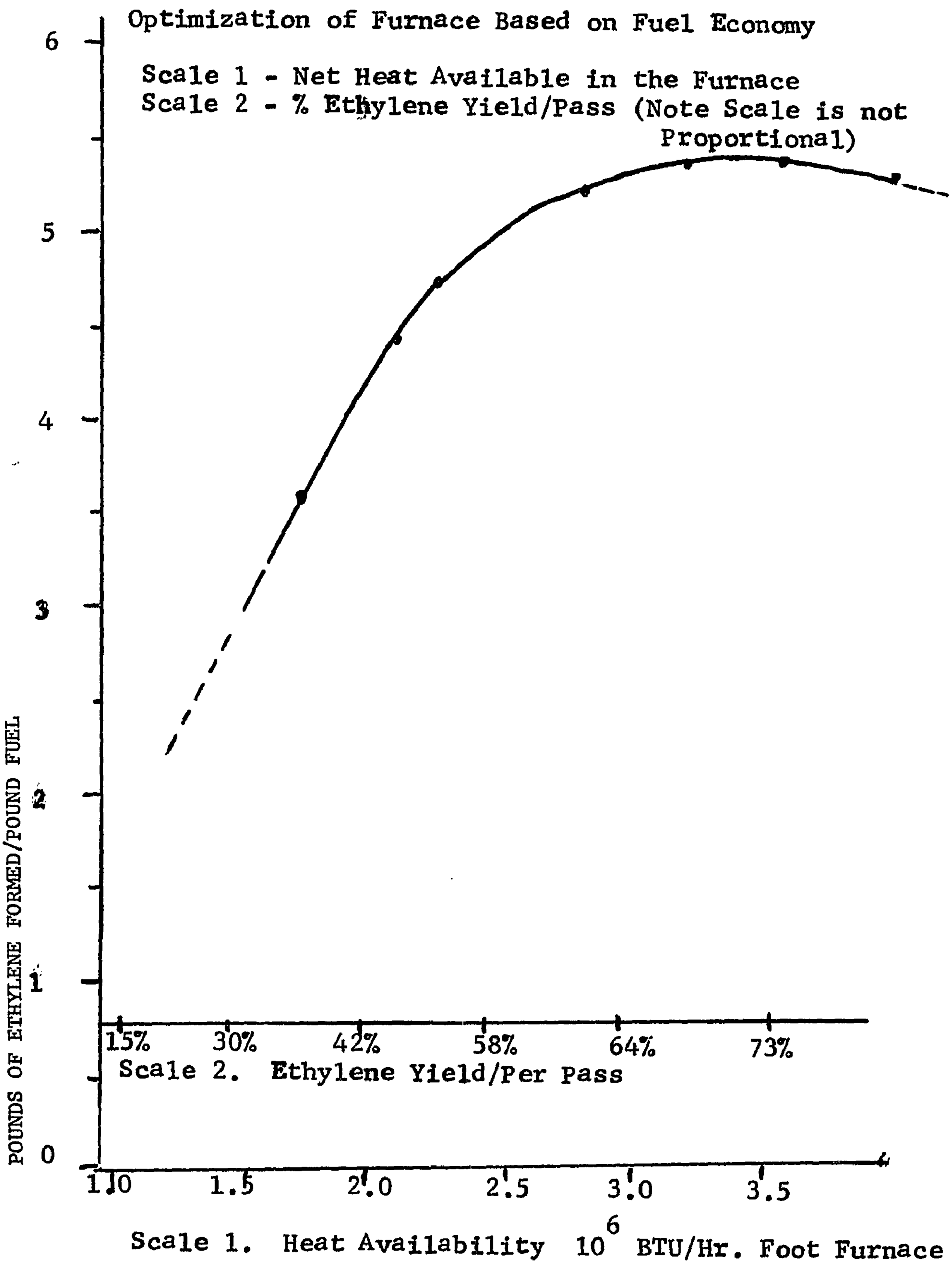
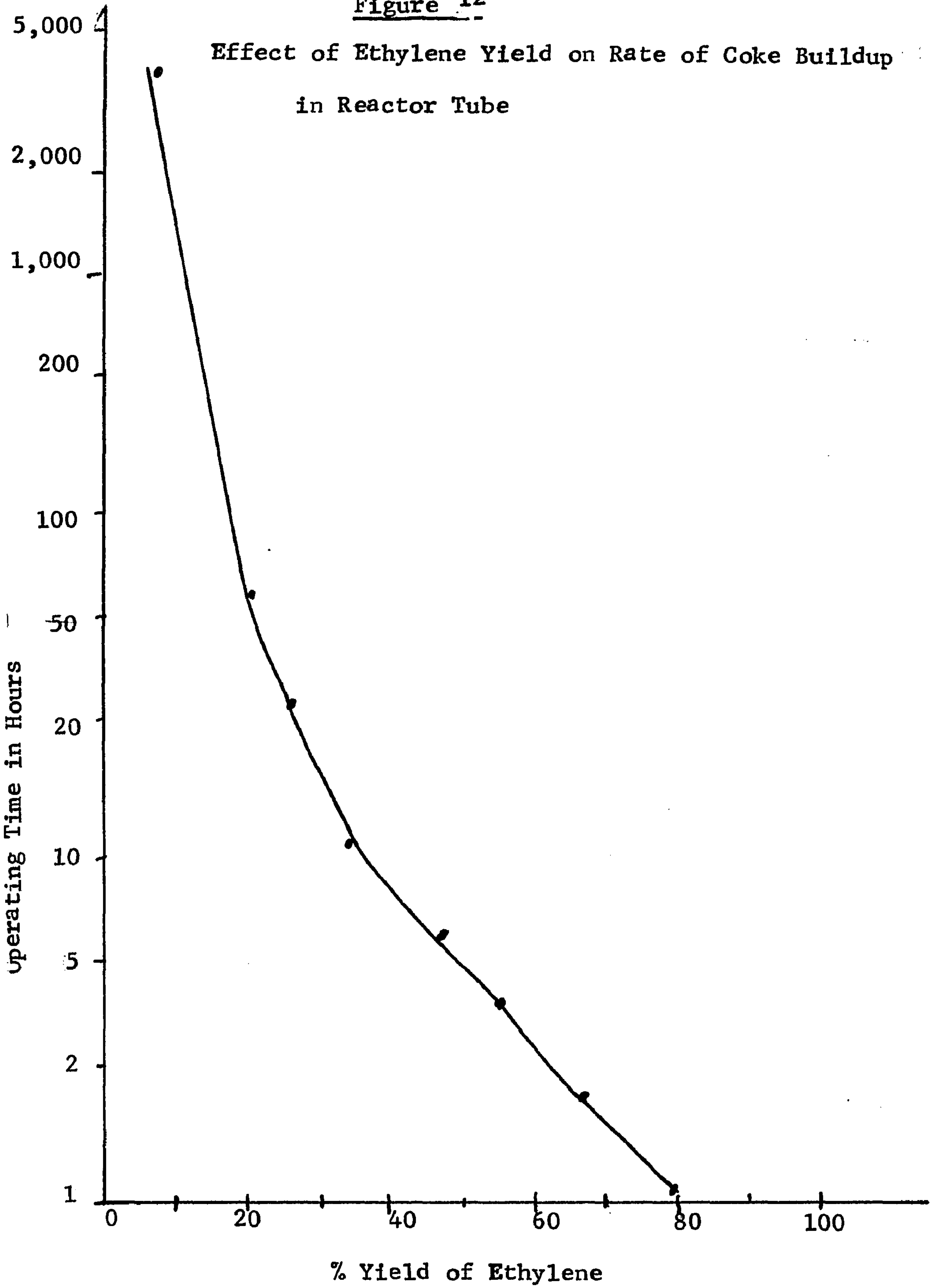

Optimization of Furnace Based on Fuel Economy
Scale 1 - Net Heat Available in the Furnace
Scale 2 - % Ethylene Yield/Pass (Note Scale is not Proportional)
POUNDS OF ETHYLENE FORMED/POUND FUEL
0
1
2
3
4
5
6
15%
30%
42%
58%
64%
73%
Scale 2. Ethylene Yield/Per Pass
1.0
1.5
2.0
2.5
3.0
3.5
Scale 1. Heat Availability 10^6 BTU/Hr. Foot Furnace

Figure 12

Effect of Ethylene Yield on Rate of Coke Buildup in Reactor Tube



maximum. The curve is flat near the top, however, and at first consideration it would be possible to assume yield of 65-70% would be possible. This would correspond with an optimum fuel economy of 5.4 pounds of ethylene/pound of fuel consumed.

Figure 12 however, shows that the rate of coke buildup in the pyrolysis tubes becomes very rapid when large yields of ethylene are desired. A yield of 65-70% would necessitate the cleaning of the reactor every 3-4 days. A 40% yield with a corresponding fuel economy of 4.1 pounds of ethylene/pound of fuel would result in a reactor requiring cleaning only every 18 - 20 days.

If a manufacturer wishes to obtain the higher fuel economy predicted in this study, clearly something would have to be done about the coke buildup. One possible solution lies in the supersonic oxidative pyrolysis of Vasil'ev [90] or his subsonic oxidative pyrolysis [89] which incorporated the introduction of oxygen into the reactant stream. This resulted in a blocking of the coke reaction and 58% yields of ethylene.

Chapter V

Recommendations

The computational procedures developed in this study are very extensive, enabling the handling of complex furnace-reactor design. The furnace design utilizes the complex method of Hottel and Cohen in handling zoned furnaces. It incorporates several suggestions of Cohen, notably the evaluation of the gas emissivities and absorption at individual zone temperatures instead of a system mean temperature.

There are, however, important limitations:

1. The furnace was assumed to be infinite in length, thus no end effects were taken into consideration. The subdivision of the furnace into furnace subsections enabled the handling of variable wall fluxes, but allowed no interreaction between subsections.

2. The zones in the system have been assumed to be isothermal. The solution could only become exact as the size of the zones are shrunk to infinitessimal size.

3. The reactor model calculates coke deposit as a function of reaction rate. No mechanism was supplied to to allow a portion of the coke to be carried out of the furnace. The exact mechanism of coke formation is not known. It has been considered to be catalytic in nature.

This depends on whether sufficient deposition takes place on the bare metal of the reactor or on other coke deposits.

4. The reactor increments were to have uniform average properties. The solution could only become exact as the increments are shrunk to infinitessimal size.

It is therefore recommended:

1. To take end effect into consideration in order to make a "true" three dimensional model.

2. To determine the exact nature of the coke formation.

3. To apply the calculation procedure to a large variety of furnaces with the objective of formulating a general correlation which would allow for rapid estimation of design criterion.

4. To apply the calculation procedure to the optimization of existing furnace-reactor structures.

5. To design optimum furnace configurations by repeated application of the calculation procedures.

References

[1]Abramowitz, M. and Stegun, I., Handbook of Mathematical Functions. Dover Publications Inc., New York, 1965.

[2]Amano, A. and Uchiyama, M., Journal of Physical Chemistry. Vol. 68, No. 5, 1964, pp. 1133-1137.

[3]Andrews, A. J. and Pollock, L. W., "Tube by Tube Design of Light Hydrocarbom and Cracking Furnaces Using the Digital Computer", Industrial and Engineering Chemistry. Vol. 51, No.2, Feb., 1959, pp. 125 - 128.

[4]Aris, R., Introduction to the Analysis of Chemical Reactors. Prentice-Hall, Inc., 1965, pp. 259 - 313.

[5]Bird, Steward and Lightfoot, Transport Phenomenon. John Wiley & Sons, 1960, p. 23.

[6]Bird, Steward and Lightfoot, Transport Phenomenon. John Wiley & Sons, 1960, p. 746.

[7]Bird, Steward and Lightfoot, Transport Phenomenon. John Wiley & Sons, 1960, p. 257.

[8]Bird, Steward and Lightfoot, Transport Phenomenon. John Wiley & Sons, 1960, pp. 744 - 745.

[9]Bonner and Honeycutt, "The Use of the Digital Computer in Petroleum Refining", Advanced Petroleum Chemical Refining. Vol. 5, 1962, pp. 83 - 114.

[10]Buckley, J. W. A., Edge, R. F. and Thompson, B. H., British Patent #1,122,426 (CL-B-01j), Aug. 7, 1968.

[11]Buddenbury, J. W. and Wilke, C. R. Industrial and Engineering Chemistry. Vol. 41, 1947, pp. 1345 - 1347.

[12]Burk, R. E., Laskowski, Lenoa and Lankelma, H. P., Journal of the American Chemical Society. Vol. 63, 1941, pp. 48 -50.

[13]Butovskii, V. A., Feigin, E. A., Girsanov, I. V. and Platonov, V. M., "Mathematical Model of the Pyrolysis Process in Funnaces", Khim. i Tekhnol. Topliv. i Masel 10 (10), 1965, pp. 1 - 5.

[14]Cahn, R. P., Kevlin, J. A. and Thurlow, D. K., U.S. Patent #3,365,387 (CL 208-48), Jan. 23, 1968.

[15]Chukenov, Z. F. and Kobzev, Y. N., High Speed Thermo Decomposition of Gaseous and Vaporous Hydrocarbons. U.S.S.R. #197,064 (CL.C10g) May 31, 1967.

[16]Coblentz, W. H. "Investigation of Infra-Red Spectra," Carnegie Institute, Washington, D.C., 1905.

[17]Cohen, E. S., S. M. Thesis in Chemical Engineering, M.I.T., 1951.

[18]Cohen, E. S., Sc.D. Thesis in Chemical Engineering, M.I.T., 1955, "Effect of Gas Temperature Gradients on Radiant Heat Transmission,"

[19]Crout, P. D., Trans. A.I.E.E., 60, 1235 (1941).

[20]Esso Research and Engineering, Unsaturated Hydrocarbon Furnaces. U.S. Patent #1,497,055 (CL.C07) Oct. 6, 1967.

[21]Eucken, A. Physik Z, 1913.

[22]Faust, et al., Principães of Unit Operations. Corrected Second Edition. Hohn Wiley & Sons, pp. 157, 158.

[23]Faigin, E. A. et al., "Method for the Optimum Design of the Coil in the Pyrolysis Furnace", Khim. Prom. Vol. 5, July, 1963, pp. 19-26.

[24]Forstall, W., Jr., and Shapiro, A. H., "Momentum and Mass Transfer in Coaxial Gas Jets", Project Meteor Report No. 39, M.I.T., July, 1949.

[25]Frey, F. E. and Hepp, H. J., The Science of Petroleum. Oxford University Press, 1964, p. 1994.

[26]Guerrieri, S. A. Report on Research at Massachusetts Institute of Technology, 1933.

[27]Guy, A. G., Elements of Physical Metallurgy. Second Edition. Addison & Wesley, 1960, p. 386.

[28]Heicklen, J., Hudson, J. L. and Arma, L., "Theory of Carbon Formation in Vapor Phase Phyrolysis - Variable Concentration of Active Species", Carbon Vol. 7 No. 3, 1969, pp. 365 - 372.

29. Hennig, H., U. S. Patent #2,885,455, May, 5, 1959.

30. Himmelblau, Basic Principles and Calculations of Chemical Engineering. Prentice-Hall.

31. Homogenous Reactional Kinetics Pyrolysis of Aliphatic Hydrocarbons. National Bureau of Standards, National Research Council, pp. 507-517.

32. Hottel, H. C., and Egbert, R. B., Trans. A.S.M.E., 63, 297 - 307 (1941).

33. Hottel, H. C., and Sarofim, Radiative Transfer McGraw-Hill.

34. Hottel, H. C., Williams, G. C. and Satterfield, C. N., "Thermodynamic Charts for Combustion Processes", John Wiley & Sons, 1949.

35. Hottel, H. C., Mangelsdorf, H. C., Trans. I.I.Ch.E., 31 517-549.

36. Jakob, M. "Heat Transfer", Vol. 1. John Wiley & Sons, 1949. Chapters 4 and 7.

37. International Flame Radiation Research I. Jmuiden (Netherlands), Unpublished Date, 1954.

38. Kevorkian, V., "High Temperature Chemistry of Light Hydrocarbons", Advanced Petroleum Chemical Refining. Vol. 5, 1962 pp. 368 - 438.

39. Lapple, C. E., Fluid and Particle Mechanics. University of Delaware, March, 1966, pp. 51 - 58.

40. Lavrov, N. V, and Baklistskii, E. P., "Calculation of the Composition of the Equilibrium Mixture Obtained by the Oxidation Pyrolysis of Hydrocarbons", Dokl. Akad. Nank U.S.S.R. 20 (C), 1963, pp. 16 - 20.

41. Levenspiel, Chemical Reaction Engineering. John Wiley & Sons, P. 116.

42. Levenspiel, Chemical Reaction Engineering. John Wiley & Sons, p. 113.

43. Lichenstein, I., "Design Cracking Furnace by Computer", Chemical Engineering Progress. Vol. 60, No 12, Dec., 1964. pp. 64 - 68.

44 Lindahl, A., "Improved Operation with Process Simulation", Chemical Engineering Progress. Vol. 61, No. 4, 1965. pp. 77 - 81.

45 Lindsay, H. F. and Wulzen, R., "Refinery Studies by Digital Computer", World Petroleum Congress, Proc. 5th N.Y. 1959 #3,251-60, 1960.

46 Lobo, W. W. et al. Transactions of the A.I.Ch.E., Vol. 31, 1939, p. 743.

47 Ludwig, E. E., "Applied Process Design for Chemical and Petrochemical Plants," Gulf Publishing Co.

48 Mamedov, A. M., Pogorelskii, A, N, and Alizade, N. A., Tubular Furnace. U.S.S.R. Patent #190,867 (CL.BOLj) Jan. 14, 1967.

49 McAdams, W. H., "Heat Transmission", 3rd ed. McGraw-Hill, 1954. Chapter 4, "Radiant Heat Transmission" by H. C. Hottel.

50 McBird, Hermel, Ehlers, Gordon, "Thermodynamic Properties to 6000°K for 210 Substances Involving the First 18 Elements," N.A.S.A. SP-3001 1963.

51 McCabe and Smith, Unit Operations of Chemical Engineering. Second Edition, McGraw-Hill, p. 77.

52 Michaud, M., Sc.D., University of Paris, 1951.

53 Myers, P.S. and Watson, K.M., Principles of Reactor Design. Article No. 2 "Pyrolysis of Propane, National Petroleum News" Vol. 38, No. 18, May 1, 1946, pp. 9388-9442.

54 Nelson, Petroleum Refining Engineering, McGraw-Hill, Fourth Edition, 1958.

55 Noguchi, T., Suzuki, J. and Seki, M. Computer Control of Petroleum Refining. Sekiyu Gakkai, Shi 1969 12(2) Japan, pp. 107 - 112.

56 Oliver, G. D. Removal of Coke from a Thermal Cracker by Intermittent Switch to Ethane Feed. U.S. 3,433,731 (LL 208-48;CIOg) March 18, 1969.

57 Palmer, H.B., "Kinetics and Mechanism of Carbon Deposition During Gaseous Pyrolysis", Fuel Society Journal 1962 pp. 13, 7 - 18.

58 Perry, J. H. (Editor). "Chemical Engineers' Handbook", 3rd ed. McGraw-Hill, 1950.

59 Port, F. J., Sc.D. Thesis in Chem. Engineering, M.I.T., 1939.

60 "Pyrolysis of Ethane in a Tubular Reactor", Example Problem No. 116, Symposium University of Wisconsin, Katz, Editor. Use of Computers in Chemical Engineering. pp. 140 - 144.

61 Riviere, M., Journee Etudes Falmmes, June 1953.

62 Robertson, Richard W., "A Study of the Optimization of Ethylene Production in a Tubular Reactor". M.S. Thesis, Newark College of Engineering, 1962.

63 Roche, Edward C. Unpublished Work.

64 Rosendahl, Fritz. Chim and Ind. Paris, 1960 No. 84, pp. 357-374.

65 Rosier, G. O. and Watson, K. M. National Petroleum News. Technical Section, No. 38, April 3, 1946, p. 260.

66 Selected Values of Chemical Thermodynamic Properties. National Bureau of Standards, June 30, 1946.

67 Selected Values of Chemical Thermodynamic Properties. National Bureau of Standards, March 31, 1947, Series III Table 23.

68 Schneider, U. and Frolich, P. K., Industrial and Engineering Chemistry, No. 23, 1931, p. 1405.

69 Shah, J. Manesh. "Computer Control of Ethylene Production," Industrial and Engineering Chemistry, Vol. 59, No. 5, 1967, p. 74,

70 Shah, J. Manesh, "Computer Control of Ethylene Production," Industrial and Engineering Chemistry, Vol. 59, No. 5, 1967, p. 74.

71 Shah, J. Manesh, "An Approach to Model Simplification in Process of Optimization and Control" American Institute of Chemical Engineering - I Chemical Engineering Symposium No. 4, 1965, pp. 4:47-4:52.

72 Smith and Van Ness, Introduction to Chemical Engineering and Thermodynamics. McGraw-Hill, pp. 410-412.

73
Smith, D., University of Sheffield (England), Personal Communications 1953-55. (between E. S. Cohen and Smith)

74
Smolen, H., "Heating High Severity Pyrolysis Furnaces and Steam Reformers with Gas or Heavy Oil" Erdoel, Kohle, Erdgas, Petrochem 1969, 22(9) (Ger.) pp. 557-561.

75
Spectra 70 Fortran IV Reference Manual. Radio Corporation of America, No., 1967.

76
Stepanov, A., "Heat Tranfer in a Tubular Pyrolysis Reactor", Konvektivryi - Teploobmen 1968 pp. 133 - 138.

77
Stepanov, A.A., Stepanova, A. V. and Kostyuk, "Pyrolysis and Gas Compression in a High Pressure Reactor," Neft. i Gaz. Prom. Inform Mauchm-Tekkn. Sb. 1964 (3) Russian, pp. 56 - 58.

78
Stepanova, A. V. and Stepanov, A. A., "J-T Diagrams of the Pyrolysis of Ethane and Propane", Khim. i Tekhnol. Topliv i Masel 9 (6), 1964, pp. 10 - 14.

79
Steacie, E. W. R. et al., Canadian Journal of Research, Vol. 16B 1939, pp. 176, 360, 303, 411.

80
Swinbourne, E. S., Journal of the Chemical Society, 1960, pp. 231, 232.

81
Szepesy, F. S. and Simon, F., "The Use of Gas Chromatography in Gas Analysis", Magyar-Kim Folyrat 67, 1961 pp. 27-33.

82
Tamai, Y., Nishiyama, Y. and Takahashi,"Effects of Solid Substances on the Thermo Decomposition of Hydrocarbons - Effects of Wall on the Carbon Deposition from Methane" Kogyo-Kagaku Zassni 70 (6) 1967, Japan, pp. 889-891.

83
Tayyabkhan, M. T., "Competitive Development in Computer Applications," Petro/Chem Engineering 38(10) Vol. 58, 1966 pp. 54-56.

84
Tmenov, D. N. and Mamedov, K. T., "Contract Pyrolysis of a Middle Straight Run Fraction of Petroleum in a Reactor with Rising Flow of Heat Carrier." Izv. Vyash. Ucheb. Zayed., Neft Gaz 15(5), 1969, (Russian) pp. 49-53.

85
Towle, W. L., Sc.D. Thesis in Cehmical Engineering, M.I.T., 1937.

[86] Towell, D. Gordon and Martin, J. Joseph, "Kinetic Data from Nonisothermal Experiments: Thermal Decomposition of Ethane, Ethylene and Acetylene," A. I. Ch. E. Journal, Vol. 7, No.4, Dec. 1961, pp. 693-698.

[87] Tucker, W., "Conical Joint Between Hydrocarbon Cracking Zone Outlet and Heat Exchange to Minimize Coking," Fr. 1,522.833 (Cl.C10g) April 26, 1968.

[88] Ulrich, W., Sc.D. Thesis in Chemical Engineering, M.I.T., 1935.

[89] Vasil'ev, S. F. and Lapides, N.A., "The Oxidative Pyrolysis of N-Butane in Industrial Conditions," Khim i Tekhnol. Smol Tern, Erzbotki Tuerd. Topliv, Akad. Nauk S.S.S.R., Inst. Goryuch. Iskop, 1965 (Russian) pp. 36 - 56.

[90] Vasil'ev, S. F., Lapides, N.A. and Mosiv, A. N., "Oxidative Pyrolysis," Sintez i Sovistvs, Monomerov Akad. Nauk, S.S.S.R. Inst. Neftekhim Sinteza, Sb. Rabot 120i (Dvenadtsatoi) Konf, Po. Vystokomolikuul Soldin, 1962 (Pub. 1964) (Russ.) pp. 12, 13.

[91] Walker, H. M., "Advances in Heavy Liquid Cracking," Chemical Engineering Progress, 1969, 65(8), pp. 53 - 58.

[92] Wilke, C. R., Journal of Chemical Physics, Volume 18, 1950, pp. 517 - 554.

[93] Yeich, William Personal Communications to Roche. See Ref. 58.

APPENDIX A

TABLE OF NOMENCLATURE

Area of a surface, square feet; A_1, A_2 area of a source-sink surface; A_{s_1}, A_{s_2}, ... area of surface zones s_1, s_2, ...

AMWT Average molecular weight of reacting system

B Normal distance between differential radiating volume elements and a plane, feet

B(I,K) Coefficient of component in K^{th} position I^{th} reaction

BB(I,K) Order of reaction of component in I^{th} position K^{th} reaction

C Convective-flux coefficient, square feet, C_g evaluated at T_g, C_s evaluated at T_s

c Exponent on temperature ratio in obtaining ${}_G$ from ${}_{G'}$ dimensionless

c Heat capacity, B.t.u./lb. °F.

C(J) Concentration of J^{th} component (lb. moles/ft.^{3})

CF Temporary constant used in calculating the product of concentration raised to order of reaction components in the forward direction

CLJ(J,1) Constant of Lennard and Jones - collision diameter (Å) J^{th} component

CLJ(J,2) Constant of Lennard and Jones - /K-(°K)J^{th} component

CP(J,1-4) Heat capacity data for J^{th} component C_p=CP(J,1) + CP(J,2)*T+CP(J,3)*T^2+CP(J,4)*T^3 (BTU/lb. mole °F)

CR Temporary constant used in calculating the products of concentration raised to the order of reaction of each reaction component in the reverse direction

CT = C(J) (lb. moles/ft.^{3})

D =MAX(ABS(DXA(I))) i.e. the max of the absolute incremental change of reaction

D Basic determinant for the system of simultaneous equations used to obtain total interchange factors

$g_i D_{s_j}$ Determinant formed by replacing the s_j-column of D by a column of g_i-functions

d $\ln_G$ / ln PL, dimensionless

$$DCP(I,1\text{-}4) = \sum_{K=SF(I)+1}^{SR(I)} \frac{B(I,K)}{B(I,1)} CP(I,1\text{-}4) - \sum_{K=1}^{SF(1)} \frac{B(I,K)}{B(I,I)} CP(I,1\text{-}4) \quad \text{(BTU/lb. mole °F)} \qquad (1)$$

(i.e.) Summation of heat capacity of products - heat capacity of reactants

DF(I) Summation of free energy of products - free energy of reactants I^{th} reaction (BTU/lb. mole)

DH(I) Summation of heat of formation of products - heat of formation of reactants (BTU/lb. mole)

DS(I) Summation of entropy of products - entropy of reactants (BTU/lb. mole)

EA(I) Arrhenius frequency factor of I^{th} reaction

EE(I) Arrhenius activation energy of I^{th} reaction (cal/m)

E Radiation-emission rate, energy per unit time; E_{g_1}, E_{g_2}, ... from surface zone s_1, s_2, ...

E Eddy diffusivity, square feet per hour

F View Factor = Fraction of radiation from one surface zone intercepted by another surface zone in the presence of a non-absorbing medium, dimensionless; $F_{s_1 s_2}$ from surface s_1 to s_2

$\underline{F}$ Fraction of energy from a point radiating source absorbed by a sphere of gas, dimensionless; F_1 intercepted by a portion of spherical surface F_2 absorbed by a portion of a spherical shell

f Fraction of radiation originating in one zone which reaches and is absorbed by another zone in a black-walled enclosure, dimensionless; f_{ss} between two

	surface zones; f_{gg} between two gas zones, f_{sg} from a surface zone to a gas zone; f_{gs} from a gas zone to a surface zone
F(J)	Factor by which the Arrhenius frequency factor is changed - assumed to be one
FI(I)	Constant of integration used in calculating the equilibrium constant
GC	Gas constant = 1.341 At/lb mole ^{o}K
G_m	Molal flow rate per unit area mols/hr. sq. ft.
GG	Total interchange factor between any two gas zones including reflections at all surfaces, square ft.; G_1G_2 (G_2G_1) is equal to $q_{g_1g_2}/W_{g_1}$ or $q_{g_2g_1}/W_{g_2}$
GS	Total interchange factor between any gas and surface zone including reflections at all suraces, square feet; G_1S_1 (S_1G_1) is equal to $q_{g_1s_1}/W_{g_1}$ or $q_{g_2g_1}/W_{s_1}$
g	Gas zone with a numerical subscript to designate the particular zone under consideration
gg	Direct interchange factor between any two gas zones, square feet; g_1g_2 (g_2g_1) is equal to $(q_{g_1g_2})$direct/W_{g_1} or $(q_{g_2g_1})$ direct/W_{g_2}

gs	Direct interchange factor between any gas and surface zone, square feet; $g_1 s_1$ ($s_1 g_1$) is equal to $(q_{g_1 s_1})$ direct/W_{g_1} or $(q_{s_1 g_1})$direct/W_{s_1}
H_{ex}	Total enthalpy of entering fuel and air per unit time, B.t.u./hr.
H_g	Enthalpy-flux coefficient evaluated at T_g, square ft.
h_c, h_c', h_c'', h_c'''	Convective coefficient of heat transfer, B.t.u./hr. sq. ft. ^oF
h	Enthalpy content, B.t.u./mol;h_s sensible enthalpy; h_{ch} chemical enthalpy
HR	Number of hours in which carbon has been accumulating
HT(J)	Heat of reaction of the (J) component (BTU/lb. mole)
I	Temporary storage to denote I^{th} reaction
IA(I,K)	Used to identify J in the reaction species in the I^{th} reaction the K^{th} position (i.e. J=IA(J,K)
IB	Number of increments the reactor will calculate before it is forced off
K,K'	Correction factors by which to multiply $T_{avg.}$, dimensionless.
k	Absorption coefficient of a gas, $ft.^{-1}$
L	Mean beam length for gas radiation, feet.
P	Pressure, atmospheres; P_w partial pressure of water vapor; P_c partial pressure of carbon dioxide; P_G gas pressure

P	Dimensionless ratio r/β for evaluating f_P
P(J)	Pressure of J component (at.)
PD	Pressure drop increment (in at.)
PDIP	Initial incremental pressure change used in convergence (at.)
PI	Pressure into reactor (at.)
P OUT	Pressure out of reactor (at.)
PPI(J)	Initial pressure of J^{th} component (at.)
Pr	Prandtl Number /k, dimensionless
	Heat transfer rate, B.t.u. per hour; $q_{1\ 2}$ net between surfaces 1 and 2; $q_{1\ G}$ net between surface 1 and the gas; $q_{g_i g_1}$ one-way from g_i to g_1; $q_{s_j g_1}$ one-way from g_i to s_1; $q_{B_{g_1}}$ net to g_1 by bulk transport; $q_{C_{g_1}}$ net to g_1 by convection; $q_{C_{s_1}}$ net to s_1 by convection; $q_{w_{s_1}}$ net through surface s_1.
R	Relative flux density, dimensionless; ${}_{s_1}R_{s_2}$, flux density away from s_2, due solely to radiation originating at s_1, and expressed as a ratio to W_{s_1}; ${}_{g_1}R_{s_2}$, same, but due to radiation originating in gas zone g_1.
R	Gas constant 1.987 cal/gram mole ^{o}K
r	Linear distance between two elements (feet)
RA	Rate of reaction
RAD	Radius of the reactor (feet)

RADD(I)	Radius of reactor at I% temporary storage
RADF(I)	Radius of reactor at I% previously calculated
RADI(I)	Radius of reactor at I% presently being calculated
RADU	Original radius of clean reactor (feet)
RAF	Original radius of clean reactor (feet)
RATE	Total rate of reaction
Re	Reynolds Number DG/ , dimensionless
SS	Total interchange factor between any two surface zones including reflections at all surfaces, sq. ft. S_1G_1 (G_1 S_1) is equal to $q_{s_1g_1}/W_{s_1}$ or $q_{g_1s_1}/W_{g_1}$
s	Surface zone with a numerical subscript to designate the particular zone under consideration
sg	Direct interchange factor between any surface and gas zone, sq. ft; s_1g_1 (g_1s_1) is equal to $(q_{s_1g_1})$ direct/W_{s_1} or $(q_{g_1s_1})$ direct/W_{g_1}
ss	Direct interchange factor between any two surfaces, sq. ft.; s_1s_2 (s_2s_1) is equal to $(q_{s_1s_2})$ direct W_{s_1} or $(q_{s_2s_1})$ direct W_{s_2}

SR(I) (Integer) number of components in I^{th} reverse reaction

T Temperature, ^oR; T_{g_1}, T_{g_2}, of gas zone g_1, g_2, ... ; T_{s_1}, T_{s_2}, ... of surface zone s_1, s_2, ...; T_G and T_S of gas and surface respectively; T_1 and T_2 of surfaces 1 and 2

T Temperature of reactor (any point) (^oF)

TIN Temperature of inlet conditions (^oF)

TMPH Total moles per hour (lb moles/hour)

TMPHI Initial molar flow rate (lb. moles/hour)

U Over-all coefficient of heat transfer through a wall, based on inside surface and outside air temperatures, B.t.u./hr. sq. ft.^oF

V Gas volume cubic feet

VELI Velocity of gas at any point in reactor (ft/sec)

VC(J,L) Concentration of component J at L% into reactor

W Rate of emission from a unit area of a black-body at the temperature indicated by a subscript (W_{g_1} at the temperature of g_1); B.t.u./hr. sq. ft.

WDZA(I,L) Rate of reaction I at distance L% into reactor

WPJ(L) Pressure L% into reactor (At)

WT(L) Temperature L% into reactor (^oF)

WTM(J,L) Total mole/hour of component J, L% into reactor

WTMPH(L)	Total mole/hour L% into reactor
WVELI(L)	Velocity ft/sec L% into reactor
WZIC(L)	Length ft L% into reactor
X	Used as temporary in calculating heat of reaction, heat capacity
XN	Used to calculate temperature profile in reactor
x_1, x_2	Thickness of gas layers, feet.
x,y,z	Linear dimensions along the three coordinate axes, ft
α	Absorptivity, dimensionless, $_{GS}$ of a gas for surface radiation; $_x$ of a gas of path length x, $_s$ of a surface.
$\alpha, \beta, \delta, \gamma$	Positional parameter indicating the magnitude and direction of bulk flow heat exchange between gas volumes
γ	Factor by which to multiply center-to-center distance between two zones to obtain correct mean beam length between them for radiation, dimensionless.
γ	Emission coefficient, sq. ft. $\gamma_g = 4kaV_g$; $\gamma_s = \epsilon_s A_s$
Δ	Denotes a difference
$\mathcal{D}$	Determinant formulation of energy balances
ϵ	Emissivity, dimensionless; ϵ_s of a surface; ϵ_G or ϵ_g of a gas; $\epsilon_{T_{avg}}$ evaluated at the arithmetic mean of the gas and surface temperatures; ϵ_x of path

	length x; ϵ_1, ϵ_2, ... of a gas at PL_1, PL_2, ...
$\mathcal{F}$	Overall interchange factor, dimensionless; $\mathcal{F}_{1G}$ = radiation reaching gas and $\mathcal{F}_{12}$ radiation reaching surface A_2, due to original emission from A_1 only, but including assistance given by reflection at all surfaces, expressed as a ratio to σT^4
ϕ	Angle between line joining centers of two zones and the normal to a surface, radians.
ϕ_1, ϕ_2	Angles used in evaluation of f_p, radians
μ	Viscosity, lb/ft. hr.
ν	Emissivity of a gas on a volume basis, $ft.^{-1}$
ρ	Density, lb/cu. ft.
ρ_s	Reflectivity of a surface, dimensionless
σ	Stefan-Boltzmann constant = 0.1713×10^{-8} B.t.u./hr. sq. ft. $^{\circ}R^4$
τ	Gas transmissivity, dimensionless; $_x$ of path length x
ψ	Escape factor for radiation from a cube of gas (ratio of energy leaving boundaries to energy originating within volume), dimensionless
θ_1, θ_2	Angles between radiant beam and normals to a surface, radians
ω	Solid angle, steradians

Appendix B

Computer Program

```
      PROGRAM MAIN
      COMMON/ZREAD/ID
      COMMON/TUBE2/IND,TX(100),QT(4),QFF
      COMMON/ANDY1/TP1(60),TP2(60),TP3(60),T1(60),T2(60),T3(60)
     1 ,H1(60),H2(60),H3(60)
      COMMON//DUMMY(400),NPRNT
      DIMENSION ID(105),TXF(85),TXFOLD(85),TXOLD(85),QF(4)
      DEFINE FILE 20(2400,61,U,ID),21(480,61,U,ID),22(480,61,U,ID),
     1 23(8,401,U,ID),24(2400,61,U,ID),25(480,61,U,ID)
      DATA ID      /1,13,25,100,100,2,12,14,24,26,3,11,15,23,27,4,10,16,
     1            22,28,5,9,17,21,29,6,8,18,20,30,7,19,31,100,100,
     2            37,49,61,100,100,36,38,48,50,60,35,39,47,51,59,34,40,
     3         46,52,58,33,41,45,53,57,32,42,44,54,56,31,43,55,100,100,
     4            61,73,85,100,100,62,72,74,84,100,63,71,75,83,100,64,70
     5,           76,82,100,65,69,77,81,100,66,68,78,80,100,67,79,100,100
     6,100/
C     CALL ERRSET(209,,1,0,0,0)
       CALL EEAD(4,'START',DUMMY(1),400)
      CALL PZERO(TP1(1),540)
      READ(5,904)(T1(I),I=1,22),(T2(I),I=1,22),(T3(I),I=1,22)
C   T1 TI T3 ARE THE THREE ASSUMED OUTER WALL REACTOR TEMPERATURE PROFIL
      P2=3.1415926/2.
      READ(5,904)DTREC
C   DTREC IS THE CONVERGENCE CRITERAM FOR THE REACTOR IN KELVIN DEGREES
      CALL FURN
      IND=1
      NPRNT=1
      NSURF=22
      CALL WRITE(3,'TEM1',T1(1),60)
      CALL WRITE(3,'TEM2',T2(1),60)
      CALL WRITE(3,'TEM3',T3(1),60)
      CALL PYRO
      CALL READ(2,'HCP ',H1(1),60)
      CALL READ(2,'HCP ',H2(1),60)
      CALL READ(2,'HCP ',H3(1),60)
      DO 1000 1000=1,10
      IJ=1
      DO 10 I=1,85
      TXOLD(I)=TX(I)
   10 TXF(I)=TX(I)*1.3
      WRITE(6,901)TXF
      TX(100)=0.0
      J1=0
      DO 2 J=9,15
      X1=0.
      X2=0.
      X3=0.
      DO 1 K=1,5
      J1=J1+1
      I1=ID(J1)
```

```
      I2=ID(J1+35)
      I3=ID(J1+70)
      IF(I1.NE.100)X1=X1+1.
      IF(I2.NE.100)X2=X2+1.
      IF(I3.NE.100)X3=X3+1.
      TP1(J)=TP1(J)+TX(I1)
      TP2(J)=TP2(J)+TX(I2)
1     TP3(J)=TP3(J)+TX(I3)
      TP1(J)=TP1(J)/X1*1.8
      TP1(J+7)=TP1(J)
      TP2(J)=TP2(J)/X2*1.8
      TP2(J+7)=TP2(J)
      TP3(J)=TP3(J)/X3*1.8
2     TP3(J+7)=TP3(J)
      CALL WRITE(2,'TEMP',TP1(1),60)
      CALL WRITE(2,'HCP ',H1(1),60)
      CALL FURN1
      QF(IJ)=QFF
      CALL READ(2,'TEMS',T1(1),60)
      DO 11 I=1,60
11    T1(I)=T1(I)/1.8
      WRITE(6,900)IJ,(T1(I),I=1,NSURF)
      CALL WRITE(3,'TEM1',T1(1),60)
      CALL WRITE(2,'HCP ',H2(1),60)
      CALL WRITE(2,'TEMP',TP2(1),60)
      IJ=IJ+1
      WRITE(6,902)IJ,(TP2(I),I=1,NSURF)
      CALL FURN1
      QF(IJ)=QFF
      CALL READ(2,'TEMS',T2(1),60)
      DO 12 I=1,60
12    T2(I)=T2(I)/1.8
      WRITE(6,900)IJ,(T2(I),I=1,NSURF)
      CALL WRITE(3,'TEM2',T2(1),60)
      CALL WRITE(2,'TEMP',TP3(1),60)
      CALL WRITE(2,'HCP ',H3(1),60)
      IJ=IJ+1
      WRITE(6,902)IJ,(TP3(I),I=1,NSURF)
      CALL FURN1
      QF(IJ)=QFF
      CALL READ(2,'TEMS',T3(1),60)
      DO 13 I=1,60
13    T3(I)=T3(I)/1.8
      WRITE(6,900)IJ,(T3(I),I=1,NSURF)
      CALL WRITE(3,'TEM3',T3(1),60)
      IND=1
      CALL PYRO1
      DO 101 I=1,22
      T1(I)=T1(I)/1.8
      T2(I)=T2(I)/1.8
```

```
101     T3(I)=T3(I)/1.8                                                MAIN 101
        A=400./84.                                                     MAIN 102
        IND=2                                                          MAIN 103
        DO 4 I=1,85                                                    MAIN 104
        ZIC=A*FLOAT(I)-A                                               MAIN 105
4        CALL TEMPT(TXF(I),ZIC,IND)                                    MAIN 106
        WRITE(6,903)TXF                                                MAIN 107
        DO 3 IJ=1,3                                                    MAIN 108
        N1=(IJ-1)*60+1                                                 MAIN 109
        N2=N1+NSURF-1                                                  MAIN 110
3       WRITE(6,902)IJ,(TP1(I),I=N1,N2)                                MAIN 111
        DT=0.0                                                         MAIN 112
        DO 5 IJ=1,85                                                   MAIN 113
        DT=AMAX1(DT,ABS(TX(IJ)-TXOLD(IJ)))                             MAIN 114
5        TXOLD(IJ)=TX(IJ)                                              MAIN 115
        IF(DT.LT.DTREC)GO TO 6                                         MAIN 116
        IF(DT.LT.1.0)GO TO 6                                           MAIN 117
        CALL PZERO(TP1(1),360)                                         MAIN 118
        WRITE(6,907)DT,I000                                            MAIN 119
        DO 100 IJ=1,NSURF                                              MAIN 120
        H1(IJ)=H1(IJ)*QT(1)/(QF(1)*5./3.)                              MAIN 121
        H2(IJ)=H2(IJ)*QT(2)/(QF(2)*5./3.)                              MAIN 122
        H3(IJ)=H3(IJ)*QT(3)/(QF(3)*5./3.)                              MAIN 123
100     CONTINUE                                                       MAIN 124
        WRITE(6,908)H1(9),H2(9),H3(9)                                  MAIN 125
1000    CONTINUE                                                       MAIN 126
        WRITE(6,905)DT                                                 MAIN 127
        GO TO 7                                                        MAIN 128
6        WRITE(6,906)I000,DT                                           MAIN 129
900     FORMAT(///'1',20X,'SURFACE TEMPERATURE PROFILE FOR FURNACE SEGMENTMAIN 130
       1',I10,'  DEG K',/20X,60('-'),//(25X,6F15.1))                   MAIN 131
901     FORMAT(//'1',20X,'REACTOR  PROCESS  TEMPERATURE PROFILE'/20X,35('-MAIN 132
       1'),20X,'DEG K',///(25X,6F15.1))                                MAIN 133
902     FORMAT(//20X,'PROCESS TEMPERATURE PROFILE FOR FURNACE SEGMENT',I10MAIN 134
       1,'  DEG K',/20X,60('-'),//(25X,6F15.1))                        MAIN 135
903     FORMAT(//'1',20X,'REACTOR  OUT WALL TEMPERATURE PROFILE'/20X,35('-MAIN 136
       1'),20X,'DEG K',///(25X,6F15.1))                                MAIN 137
904     FORMAT(2(3(7F10.0/),F10.0/),3(7F10.0/),F10.0)                  MAIN 138
905     FORMAT('  INSIDE TEMPERATURE PROFILE DID NOT CONVERGE AFTER 10 TRAMAIN 139
       1ILS MAX TEMPERATURE= ',F10.3,' DEG K'/' ',90('-'))             MAIN 140
906     FORMAT(' INSIDE  TEMPERATURE PROFILE CONVERGED AFTER',I3,'TRAILS MMAIN 141
       1AX TEMPERATURE DIFERENCE= ',E10.3,' DEG K'/' ',95('-'))        MAIN 142
907     FORMAT(20X,'MAXIUM TEMPRATURE DIFERENCE CALCULATED= ',F16.3,'  AFTMAIN 143
       1ER',I5,2X,'TRAILS')                                            MAIN 144
908     FORMAT('0ADJUSTED HEAT TRANSFER COEFICIENT PROCESS FLUID TO OUTSIDMAIN 145
       1E TUBE WALL BTU/(HR FOOT OF FURNACE LENGTH',//' ',20X,3F20.3)  MAIN 146
7       CALL WRITE(4,'STAR',DUMMY(1),400)                              MAIN 147
        STOP                                                           MAIN 148
        END                                                            MAIN 149
```

```
      SUBROUTINE PYRO                                                   PYRO 150
      COMMON/TUBE1/IR,IS,KE(25),KR(25),B(25,10),BB(25,10),DL,IA(25,10)  PYRO 151
     1,EA(25),EE(25),RAD,AU                                             PYRO 152
      COMMON/TUBE2/INO,TX(100)                                          PYRO 153
      COMMON/PYRO3/Z(11),ZTT,C(25),CP(25,4)                             PYRO 154
     1,DH(25),DS(25),DF(25)                                             PYRO 155
C                                                                       PYRO 156
      COMMON/FE/DCP(25,4),HT(25),ST(25),FT(25),FI(25),HD(25)            PYRO 157
      COMMON/PO/P(25),DN,SMWT(25),CLJ(25,2),VI(25),AMWT,VEL1,HI         PYRO 158
      COMMON/PT2/TI,RN1,RN2,VIS                                         PYRO 159
      COMMON/TM/TMPH,RADI(100),DE(25),ZIC                               PYRO 160
      COMMON/SET/MY,MB,IB,IPLOT,DLS                                     PYRO 161
      DIMENSION DXA(25),TM(25),PPI(25),RADF(100),CARD(80)               PYRO 162
      COMMON/W/ WZIC(50),WT(50),WTMPH(50),WPT(50),WVEL1(50),WC(25,50),WTPYRO 163
     1M(25,50),WDXA(25,50),RADD(100,50)                                 PYRO 164
      DIMENSION  RA(25),F(25),INAME(500),IDATB(240)                     PYRO 165
      DATA DXA/25*0./,F/25*1./                                          PYRO 166
      INTEGER IDATA(43)/'A','B','C','D','E','F','G','H','I','J','K','L'PYRO 167
     1,'M','N','O','P','Q','R','S','T','U','V','W','X','Y','Z','->','+' PYRO 168
     2,' ','1','2','3','4','5','6','7','8','9','0','(',')','=','*'/     PYRO 169
      INTEGER IDATP(9)/'1N','2N','3N','4N','5N','6N','7N','8N','9N'/    PYRO 170
      INTEGER IDATU(50)/' H',' H','RN','EN','AN','CN','TN','ON','RN',   PYRO 171
     1' N','PN','ON','SN','IN','TN','IN','ON','NN',' N','FN','EN','EN','PYRO 172
     2TN',' N',' N',25*' N'/                                            PYRO 173
      IDATP(1)=IDATP(1)                                                 PYRO 174
      REAL*4 LOG                                                        PYRO 175
      IB=1                                                              PYRO 176
      IGOTO=1                                                           PYRO 177
C     F(ID)=CHANGE IN ARRHENIUS FREQUENCY FACTOR FROM                   PYRO 178
C     PUBLISHED DATA .CHANGE IS MADE FOR CHEMICAL SPECIES REACTION ID   PYRO 179
  107 READ(5,953) ID,FFF                                                PYRO 180
      F(ID)=FFF                                                         PYRO 181
      IF(ID.EQ.25)GO TO 100                                             PYRO 182
      GO TO 107                                                         PYRO 183
C      IR  IS TOTAL NUMBER OF REACTIONS                                 PYRO 184
C     IS IS TOTAL NUMBER OF CHEMICAL SPECIES INCLUDING INERTS           PYRO 185
  100 READ(5,900,END=99)IR,IS                                           PYRO 186
C IR=TOTAL NUMBER OF REACTIONS,IS=TOTAL NUMBER OF CHEMICAL SPECIES      PYRO 187
C     IGOW 1READ IN NEW.DATA SET                                        PYRO 188
C           2RETAIN PRESENT DATA SET READ IN NEW TEMPERATURE PROFILE    PYRO 189
C           3NO NEW CASES OR TEMPERATURES TO FOLLOW COMPUTER  STOPS     PYRO 190
C                                                                       PYRO 191
C     Z(II) TEMPERATURE PROFILE IN 10% INCREMENTS INCLUDING 0 AND 100   PYRO 192
      READ(5,943)IGOW,(Z(II),II=1,11)                                   PYRO 193
C     CARD CONTAINS UP TO 80 ALPHANUMERIC IDENTIFATION OF SYSTEM BEING  PYRO 194
C     CALCULATED                                                        PYRO 195
      READ(5,950)CARD                                                   PYRO 196
C     IB TIME INCREMENTS USED TO CALCULATE CARBON DEPOSITION            PYRO 197
C     IZZ MAX ALLAWABLE TRIALS FOR CONVERGENCE                          PYRO 198
C     IPLOT                                                             PYRO 199
```

```
C        1        PLOT RESULTS      DO NOT WRITE DETAILED CALCULATIONS       PYRO 200
C        2        PLOT RESULTS      WRITE OUT DETAILED CALCULATIONS          PYRO 201
C        3        PLOT NOT DONE     WRITE OUT DETAILED CALCULATIONS          PYRO 202
C        4        PLOT NOT DONE     DO NOT WRITE DETAILED CALCULATIONS       PYRO 203
      READ(5,958)IB,IZZ,IPLOT                                                PYRO 204
C     T IS TEMPERATURE AT INLET Z(1)                                         PYRO 205
C     PT IS INITIAL PRESSURE AT STARTUP                                      PYRO 206
C     PRESS IS MAX ALLOWABLE PRESSURE AT INLET                               PYRO 207
C     POUT IS DESIRED PRESSURE AT OUTLET                                     PYRO 208
C     ALL PRESSURES IN ATMOSPHESES                                           PYRO 209
C      ZT IS TOTAL REACTOR LENGTH FEET                                       PYRO 210
C     DL IS INCREMENT OF LENTH USED TO CALCULATE REACTOR CONDICITIONS        PYRO 211
      READ(5,919)T,PT,PRES,ZT,DL,POUT                                        PYRO 212
      DLS=DL                                                                 PYRO 213
      TIN=T                                                                  PYRO 214
C IA(I,M)=IDENTITY OF CHEMICAL SPECIES IN CHEMICAL REACTION POSITION M       PYRO 215
      GC=1.3143                                                              PYRO 216
C     KE(I) IS NUMBER OF REACTANTS IN REACTION I                             PYRO 217
C     KR(I) IS NUMBER OF PRODUCTS IN REACTION I                              PYRO 218
      READ(5,901)(KE(I),KR(I),I=1,IR)                                        PYRO 219
      DO 1 I=1,IR                                                            PYRO 220
      IT=KE(I)+KR(I)                                                         PYRO 221
C     IA(I,M) REPRESENTS THE CHEMICAL SPECIES IA IN REACTION I               PYRO 222
C             POSITION M                                                     PYRO 223
      READ(5,901)ID,(IA(I,M),M=1,IT)                                         PYRO 224
      IF (ID.NE.I)GO TO 101                                                  PYRO 225
 1    CONTINUE                                                               PYRO 226
C B(I,M)COEFFICIENT OF M CHEMICAL SPECIES IN REACTION I                      PYRO 227
      DO 2 I=1,IR                                                            PYRO 228
      IT=KE(I)+KR(I)                                                         PYRO 229
C     B(I,M) IS THE STOCIMETRIC COEFFICIENT REACTION I                       PYRO 230
C           POSITION M                                                       PYRO 231
C     BB(I,M) IS THE PSEUDO  ORDER OF REACTION REACTION I                    PYRO 232
C          POSITION M                                                        PYRO 233
      READ(5,903)ID,(B(I,M),M=1,IT),(BB(I,M),M=1,IT)                         PYRO 234
      IF(ID.NE.I)GO TO  102                                                  PYRO 235
 2    CONTINUE                                                               PYRO 236
C C(J) IS THE INITIAL CONCENTRATION OF THE J CHEMICAL SPECIES (8 PER CARPYRO 237
      READ(5,904)(P(J),J=1,IS)                                               PYRO 238
      PTT=0.0                                                                PYRO 239
      DO 220 I=1,IS                                                          PYRO 240
 220  PTT=PTT+P(I)                                                           PYRO 241
      DO 18 I=1,IS                                                           PYRO 242
      PPI(I)=P(I)*PT/PTT                                                     PYRO 243
      P(I)=PPI(I)                                                            PYRO 244
 18   C(I)=P(I)/GC/T                                                         PYRO 245
C INAME(I)IS THE NAME OF EACH CHEMICAL SPECIES (MAX 20 LETTERS) 4 PER CAPYRO 246
      IT=IS*20                                                               PYRO 247
C     INAME(J) IS THE ALPANUMERIC IDENTIFCATION OF CHEMICAL                  PYRO 248
C     SPECIES J                                                              PYRO 249
```

```
          READ(5,905)(INAME(J),J=1,IT)                                 PYRO 250
          DO 3 J=1,IS                                                  PYRO 251
    C     CP(J,M) IS THE HEAT CAPACITY OF CHEMICAL SPECIES J           PYRO 252
    C               EXPRESSED AS A 3-RD POWER POLYMONAL IN TEMPERATURE PYRO 253
          READ(5,906) (CP(J,M),M=1,4),ID                               PYRO 254
          IF(ID.NE.J)GO TO 103                                         PYRO 255
    3     CONTINUE                                                     PYRO 256
          DO 4 I=1,IR                                                  PYRO 257
    C     EA(I) IS ARRHENIUS FREQUENCY FACTOR OF REACTION I            PYRO 258
    C     EE(I) IS THE ARRHENIUS ACTIVATION ENERGY OF REACTION I       PYRO 259
    C          CAL/MOLE OK                                             PYRO 260
          READ(5,907)ID,EA(I),EE(I)                                    PYRO 261
          EA(I)=EA(I)*F(I)                                             PYRO 262
          IF (ID.NE.I)GO TO 104                                        PYRO 263
    4     CONTINUE                                                     PYRO 264
          DO5 J=1,IS                                                   PYRO 265
    C     DS(J) IS THE ENTOPY OF CHEMICAL SPECIES J 25 C               PYRO 266
    C     DH(J) IS THE ENTHALPY OF CHEMICAL SPECIES J 25 C             PYRO 267
    C     DF(J) IS GIBBS FREE ENERGY OF CHEMICAL SPECIES J 25 C        PYRO 268
           READ(5,908) ID,DS(J),DH(J),DF(J)                            PYRO 269
          IF(ID.NE.J) GO TO 105                                        PYRO 270
    5     CONTINUE                                                     PYRO 271
          DO 21 J=1,IS                                                 PYRO 272
    C     CLJ(J,M) ARE THE CONSTANTS OF LENNARD & JONES                PYRO 273
    C     M                                                            PYRO 274
    C     1 COLLISION PARAMETER                                        PYRO 275
    C     2 E/K                                                        PYRO 276
    C     SMWT(J) IS THE MOLECULAR WEIGHT OF THE JTH CHEMICAL SPECIES  PYRO 277
    C     DE(J) IS THE DENSITY OF SOLID CHEMICAL SPECIES J             PYRO 278
          READ(5,911) ID,(CLJ(J,M),M=1,2),SMWT(J)                      PYRO 279
          IF(CLJ(J,2).EQ.0.)READ(5,940)DE(J)                           PYRO 280
          IF(ID.NE.J)GO TO 106                                         PYRO 281
    21    CONTINUE                                                     PYRO 282
          DO 6 I=1,IR                                                  PYRO 283
          DO 7 L=1,4                                                   PYRO 284
    7     DCP(I,L)=0.                                                  PYRO 285
          I1=KF(I)+1                                                   PYRO 286
          I2=KR(I)+KF(I)                                               PYRO 287
          DO 8 M=I1,I2                                                 PYRO 288
          J=IA(I,M)                                                    PYRO 289
          DO 8 L=1,4                                                   PYRO 290
    8     DCP(I,L)=DCP(I,L)+B(I,M)*CP(J,L)/B(I,1)                      PYRO 291
          I2=KF(I)                                                     PYRO 292
          DO 6 M =1,I2                                                 PYRO 293
          J=IA(I,M)                                                    PYRO 294
          DO 6 L=1,4                                                   PYRO 295
    6     DCP(I,L)=DCP(I,L)-B(I,M)*CP(J,L)/B(I,1)                      PYRO 296
    C   TEMPERATURE                                                    PYRO 297
          R1=1.987                                                     PYRO 298
          DO 9 I=1,IR                                                  PYRO 299
```

```
      FT(I)=0.                                                          PYRO 300
       ST(I)=0                                                          PYRO 301
      HT(I)=0                                                           PYRO 302
      I1=KF(I)+1                                                        PYRO 303
      I2=KR(I)+KF(I)                                                    PYRO 304
      DO 10 M=I1,I2                                                     PYRO 305
      J=IA(I,M)                                                         PYRO 306
      ST(I)=ST(I) +B(I,M)*DS(J)/B(I,1)                                  PYRO 307
      FT(I)=FT(I)+B(I,M)*DF(J)/B(I,1)                                   PYRO 308
 10   HT(I)=HT(I)+B(I,M)*DH(J)/B(I,1)                                   PYRO 309
      I2=KF(I)                                                          PYRO 310
      DO 9 M=1,I2                                                       PYRO 311
      J=IA(I,M)                                                         PYRO 312
      FT(I)=FT(I)-B(I,M)*DF(J)/B(I,1)                                   PYRO 313
      ST(I)=ST(I)-B(I,M)*DS(J)/B(I,1)                                   PYRO 314
 9    HT(I)=HT(I)-B(I,M)*DH(J)/B(I,1)                                   PYRO 315
      TO=298.15                                                         PYRO 316
      DO19  I=1,IR                                                      PYRO 317
      READ(5,908)IJ,TT,FI(I)                                            PYRO 318
      HO(I)=HT(I)                                                       PYRO 319
      DO 29 M=1,4                                                       PYRO 320
      X=M                                                               PYRO 321
 29   HO(I)=HO(I)-DCP(I,M)/X*TO**M                                      PYRO 322
      IF(FI(I).GT.0.)FI(I)=LOG(FI(I))                                   PYRO 323
      IF(FI(I).LE.0.0)FI(I)=-FT(I)/TO/R1                                PYRO 324
 19   FI(I)=HO(I)/R1/TT+FI(I)-DCP(I,1)/R1*LOG(TT)-DCP(I,2)/2./R1*T      PYRO 325
     1T-DCP(I,3)/6./R1*TT**2-DCP(I,4)/12./R1*TT**3                      PYRO 326
C  NOW WE HAVE THE REACTION SYSTEM, IT WILL BE PRINTED OUT.             PYRO 327
C CHEMICAL SPECIES IDENTIFICATION                                       PYRO 328
      WRITE(6,909)                                                      PYRO 329
      WRITE(6,910)                                                      PYRO 330
      DO 11 J=1,IS                                                      PYRO 331
      JJ1=1+20*(J-1)                                                    PYRO 332
       JJ2=20*J                                                         PYRO 333
 11   WRITE(6,912)(INAME(JJ),JJ=JJ1,JJ2),IDATA(J),J,(CP(J,M),M=1,4),DH(JPYRO 334
     1),DS(J),DF(J)                                                     PYRO 335
      IGOTO=1                                                           PYRO 336
      WRITE(6,920)                                                      PYRO 337
      DO 17 J=1,IS                                                      PYRO 338
      JJ1=1+20*(J-1)                                                    PYRO 339
       JJ2=20*J                                                         PYRO 340
 17   WRITE(6,917)(INAME(JJ),JJ=JJ1,JJ2),IDATA(J),J,(CLJ(J,M),M=1,2),SNWPYRO 341
     1T(J),C(J)                                                         PYRO 342
      WRITE(6,913)                                                      PYRO 343
      DO 12 I=1,IR                                                      PYRO 344
      II=2                                                              PYRO 345
      IF (EE(I).EQ.0.)II=1                                              PYRO 346
      I2=KF(I)                                                          PYRO 347
      DO 14 M=1,I2                                                      PYRO 348
      J=IA(I,M)                                                         PYRO 349
```

```
          MM=M*3-1                                                      PYRO 350
          IDATB(MM)=IDATA(J)                                            PYRO 351
          J=P(I,M)+29.01                                                PYRO 352
          MM=M*3-2                                                      PYRO 353
          IDATB(MM)=IDATA(J)                                            PYRO 354
          MM=M*3                                                        PYRO 355
     14   IDATB(MM)=IDATA(28)                                           PYRO 356
          MM=KF(I)*3                                                    PYRO 357
          KK=40                                                         PYRO 358
          GO TO (122,121),II                                            PYRO 359
    121   IDATB(MM)=IDATA(KK)                                           PYRO 360
          MM=MM+1                                                       PYRO 361
    122   KK=KK+1                                                       PYRO 362
          IDATB(MM)=IDATA(KK)                                           PYRO 363
          MM=MM+1                                                       PYRO 364
          KK=KK+1                                                       PYRO 365
          IDATB(MM)=IDATA(KK)                                           PYRO 366
          I1=KF(I)+1                                                    PYRO 367
          I2=KF(I)+KP(I)                                                PYRO 368
          DO 15 M=I1,I2                                                 PYRO 369
          J=IA(I,M)                                                     PYRO 370
          MM=M*3-1 +II                                                  PYRO 371
          IDATB(MM)=IDATA(J)                                            PYRO 372
          J=R(I,M)+29.01                                                PYRO 373
          MM=M*3-2+II                                                   PYRO 374
          IDATB(MM)=IDATA(J)                                            PYRO 375
          MM=M*3+II                                                     PYRO 376
     15   IDATB(MM)=IDATA(28)                                           PYRO 377
          DO 16 J=MM,44                                                 PYRO 378
     16   IDATB(J)=IDATA(29)                                            PYRO 379
     12   WRITE(6,915)I,(IDATB(M),M=1,40),EA(I),EE(I),(DCP(I,M),M=1,4)  PYRO 380
          WRITE(6,927)                                                  PYRO 381
          DO 28 J=1,IR                                                  PYRO 382
          I2=KF(J)+KR(J)                                                PYRO 383
          DO 32 I=1,I2                                                  PYRO 384
          I3=IA(J,I)                                                    PYRO 385
     32   IDATB(I)=IDATA(I3)                                            PYRO 386
     28   WRITE(6,926)J,FT(J),FI(J),(IDATB(I),BB(J,I),I=1,I2)           PYRO 387
C         RAD IS THE RADIUS OF THE INSIDE OF THE REACTOR TUBE           PYRO 388
C         AO IS THE RADIUS OF THE OUTSIDE OF THE REACTOR TUBE           PYRO 389
C         TMPH IS THE MOLAR FLOW RATE IN LB MOLES PRE HOUR              PYRO 390
C         KEYR IS THE KEY REACTANT                                      PYRO 391
C         KEYP IS THE KEY PRODUCT                                       PYRO 392
          READ(5,902) RAD,AO,TMPH                                       PYRO 393
          READ(5,900)KEYR,KEYP                                          PYRO 394
          TMPHI=TMPH                                                    PYRO 395
          RADU=RAD                                                      PYRO 396
          ZTT=ZT                                                        PYRO 397
          IGOTO=1                                                       PYRO 398
          PDP=.2                                                        PYRO 399
```

```
      PSAVE=PT                                                          PYRO 400
      IF(KEYR.EQ.0)GO TO 92                                             PYRO 401
      WRITE(6,918)                                                      PYRO 402
      DO 205 I=1,IR                                                     PYRO 403
      MM=0                                                              PYRO 404
      IFIN=1                                                            PYRO 405
      I1=1                                                              PYRO 406
      I2=KF(I)                                                          PYRO 407
      GO TO 206                                                         PYRO 408
  207 I1=KF(I)+1                                                        PYRO 409
      I2=KF(I)+KP(I)                                                    PYRO 410
      IFIN=2                                                            PYRO 411
  206 DO 214 M=I1,I2                                                    PYRO 412
      JJ1=1+20*(IA(I,M)-1)                                              PYRO 413
      JJ2=JJ1+19                                                        PYRO 414
      DO 208 I3=JJ1,JJ2                                                 PYRO 415
      IF(INAME(I3).EQ.INAME(20).AND.INAME(I3+1).EQ.INAME(20))GO TO 209  PYRO 416
  208 CONTINUE                                                          PYRO 417
      GO TO 210                                                         PYRO 418
  209 JJ2=I3                                                            PYRO 419
  210 J=B(I,M)+29.01                                                    PYRO 420
      MM=MM+1                                                           PYRO 421
      IDATB(MM)=IDATA(J)                                                PYRO 422
      MM=MM+1                                                           PYRO 423
      IDATB(MM)=IDATA(29)                                               PYRO 424
      DO 211 I3=JJ1,JJ2                                                 PYRO 425
      MM=MM+1                                                           PYRO 426
  211 IDATB(MM)=INAME(I3)                                               PYRO 427
      IF(M.EQ.I2)GO TO 214                                              PYRO 428
      MM=MM+1                                                           PYRO 429
      IDATB(MM)=IDATA(28)                                               PYRO 430
  214 CONTINUE                                                          PYRO 431
      IF(IFIN.EQ.2)GO TO 205                                            PYRO 432
      DO 212 I3=1,3                                                     PYRO 433
      MM=MM+1                                                           PYRO 434
      KK=39+I3                                                          PYRO 435
  212 IDATB(MM)=IDATA(KK)                                               PYRO 436
      GO TO 207                                                         PYRO 437
  205 WRITE(6,971)(IDATB(I3),I3=1,MM)                                   PYRO 438
      ENTRY PYRO1                                                       PYRO 439
  110 WRITE(6,916)                                                      PYRO 440
      HR=0.                                                             PYRO 441
      MAZE=1                                                            PYRO 442
      KK=1                                                              PYRO 443
C T=GAS TEMPERATURE AT ENTRANCE, PRES=PRESSURE OF GAS, ZT=LENGTH OF TUBEPYRO 444
      HR=0.                                                             PYRO 445
C DZ=INCREMENTAL CHANGE IN REACTOR,CI=CONCENTRATION OF INERTS, A=T=A(1) PYRO 446
C A(2)Z + A(3) Z**L + A(4)*Z**3                                         PYRO 447
  900 FORMAT(2I2)                                                       PYRO 448
  901 FORMAT(40I2)                                                      PYRO 449
```

```
902   FORMAT(3F10.5)                                                   PYRO 450
903   FORMAT(I2,25F3.2)                                                PYRO 451
904   FORMAT(12F6.5)                                                   PYRO 452
905   FORMAT(60A1)                                                     PYRO 453
906   FORMAT(4E16.8,I7)                                                PYRO 454
907   FORMAT(I2,F7.1,F10.4)                                            PYRO 455
908   FORMAT(I2,3F9.2)                                                 PYRO 456
909   FORMAT('1  PROGRAM PYRO',/,' PROGRAMMER RICHARD ROBERTSON',/,' ADVPYRO 457
     1ISORS',//,' DR ROCHE ',/,' DR HANESIAN',/,' AS PARITIAL FULFILMENT PYRO 458
     2OF PHD THESIS',/,' NEWARK COLLEGE OF ENGINEERING')               PYRO 459
910   FORMAT (1H1,T45,'IDENTIFICATION OF REACTION SYSTEM',///,T5,'CONPONPYRO 460
     1ENT',T22,'CO  NO.',T44,'HEAT CAPACITY DATA',T81,'DELTA-H',T98,'DELPYRO 461
     2TA-S',T116,'LOG(K) ',/,T33,'A',T44,'B',T56,'C',T68,'D')          PYRO 462
911   FORMAT(I2,3X,3F5.0)                                              PYRO 463
912   FORMAT(' ',20A1,1X,1A1,1X ,I2,4(2X,1PE10.3),3(3X,1PE15.8))       PYRO 464
913   FORMAT(1H1,T45,'REACTION SYSTEM',//,' EQUATION',T45,'ARRHENIUS  RAPYRO 465
     1TE CONTANT',T75,'DELTA HEAT CAPACITY  DATA FOR REACTION',/1H ,T71,PYRO 466
     2 'DELTA-A',T83,'DELTA B',T95,'DELTA C',T107,'DELTA D',T51,'K(O)',TPYRO 467
     361,'E')                                                          PYRO 468
915   FORMAT(1H ,I2,2X,40A1,6(1PE10.3,2X))                             PYRO 469
916   FORMAT(1H )                                                      PYRO 470
917   FORMAT(' ',21A1,I2,5X,F5.3,5X,F5.1,5X,F7.2,1PE12.4)              PYRO 471
918   FORMAT(1H1)                                                      PYRO 472
919   FORMAT(0E12.5)                                                   PYRO 473
920   FORMAT('0  COMPONENT',T22,'CO NO',T36,'LENNARD-JONES  MOL. WT.',T62PYRO 474
     1,'INITAL ',/,T36,'PARAMETERS',/,T58,'CONCENTRATION',/,T31,'(A)   PYRO 475
     2  (DEG-K)')                                                      PYRO 476
921   FORMAT('1COMPONENT    IDENTIFICATION',I2,' OUT OF PLACE',I5,' ID')PYRO 477
922   FORMAT('1COEFFICIENT  IDENTIFICATION',I2,' OUT OF PLACE',I5,' ID')PYRO 478
923   FORMAT('1CP(HEAT CAP) IDENTIFICATION',I2,' OUT OF PLACE',I6,' ID')PYRO 479
924   FORMAT('1ARRHENIUS    IDENTIFICATION',I2,' OUT OF PLACE',I5,' ID')PYRO 480
925   FORMAT('1ENTHALPHY    IDENTIFICATION',I2,' OUT OF PLACE',I5,' ID')PYRO 481
926   FORMAT(' ',I2,2(5X,1PE12.5),5X,6(5X,1A1,'**(',0PF3.1,')'))       PYRO 482
927   FORMAT('0EQ',T13,'LOG(K)',9X,'CONSTANT ',10X,   'ORDER OF REACTIOPYRO 483
     1N BY COMPONENT',/,T11,'REACTION',T29,'INTEGERATION')             PYRO 484
928   FORMAT(' ',I2,1PE14.4,E14.4,E14.4)                               PYRO 485
929   FORMAT(' ITERATION NUMBER-',I3,/,' NO CONCENTRATION     TMPH     PYRO 486
     1   DXA')                                                         PYRO 487
930   FORMAT('0 DL CHANGED  TO',1PE15.5,5X,'ZIC=',1PE14.5)             PYRO 488
931   FORMAT('1  ALL DXA= 0, SYSTEM MUST BE CHANGED TO ALLOW REACTION') PYRO 489
932   FORMAT (' I=',I2,2X,'RA=',1PE14.5,2X,'DXA(I)=',1PE14.5,2X,'CF,CR='PYRO 490
     1,2E14.5,2X,'REQC=',1PE14.5,/,5HORATE,'=',1PE14.5)                PYRO 491
933   FORMAT(' ', 25(1PE14.5,5X,I2/,' '))                              PYRO 492
934   FORMAT(' ',I2,1PE12.5)                                           PYRO 493
935   FORMAT('1',' LENNARD JONES CONSTANTS',I2,'CARD ID',I2,',INTERNAL')PYRO 494
936   FORMAT('0',3(5X,1PE16.7))                                        PYRO 495
937   FORMAT('1REACTOR IS ',F10.2,' FEET LONG AND ',F6.3,' FEET IN RADIUPYRO 496
     1S',/,' TOTAL MOLES  / HOUR ARE',F6.1,'POUND MOLES  AT PRESSURE',F8PYRO 497
     2.3,'A  VELOCITY OF ',1PE12.5,' AT TEMPERATURE',0PF8.1,'DEG K',/,' PYRO 498
     3INITIAL REACTOR INCREMENT(DL',1PE12.5,'FEET)')                   PYRO 499
```

```
 938    FORMAT(' ',I2,14X,1PE14.4)                                         PYRO 500
 939    FORMAT(' ',I2,1PE14.5,E14.5)                                       PYRO 501
 940    FORMAT(F10.0)                                                      PYRO 502
 942    FORMAT(' PRESSURE IS',1PE14.5,'     VELOCITY',1PE14.4,'FEET/SEC.') PYRO 503
 943    FORMAT(I3,11F7.2)                                                  PYRO 504
 944    FORMAT(' ',10E11.6)                                                PYRO 505
 945    FORMAT('1',T25,'REACTOR RADIUS PROFILE AFTER  ',F9.2,'  HOURS',//)PYRO 506
 946    FORMAT(' ',I2,'=',1A1,2X,20A1,1PE14.5,5X,E14.5)                    PYRO 507
 948    FORMAT(' ',I2,1PE14.4,E14.4)                                       PYRO 508
 949    FORMAT('1 UNSTABLE TEMPERATURE PROFILE NEW CASE')                  PYRO 509
 950    FORMAT(80A1)                                                       PYRO 510
 951    FORMAT(' ',80A1)                                                   PYRO 511
 952    FORMAT('0VELOCITY OF GAS GREATER THAN SOUND')                      PYRO 512
 953    FORMAT(I2,F8.2)                                                    PYRO 513
 954    FORMAT('0 REACTOR TUBE COMPLETELY BLOCKED WITH CARBON')            PYRO 514
 955    FORMAT(' REACTOR RADIUS PROFILE FROM START TO CLOSE DOWN')         PYRO 515
 956    FORMAT(T20,',TEMPERATURE  REACTANT  PRODUCT PROFILES')             PYRO 516
 958    FORMAT(3I3)                                                        PYRO 517
 960    FORMAT(T16,'0%',T36,'20%',T56,'40%',T76,'60%',T96,'80%',T116,'10  PYRO 518
       10%')                                                               PYRO 519
 961    FORMAT(' ',F4.0,'FT')                                              PYRO 520
 962    FORMAT(T16,'/',T26,'/',T36,'/',T46,'/',T56,'/',T66,'/',T76,'/',T10PYRO 521
       16,'/',T86,'/',T116,'/')                                            PYRO 522
 963    FORMAT(T20,'R=MOLE REACTANT/(INITIAL MOLE REACTANT)',T60,'E=MOLE PPYRO 523
       1RODUCT/(INITIAL MOLE REACTANT)*S.C.',/,T20,'T=TEMPERATURE/(T(I)- TPYRO 524
       2(F)',T56,'P=PRESSURE/(P(MAX)-P(MIN))',/,T20,',ELASPED REACTOR RUNPYRO 525
       3 TIME',F7.0,'HOURS')                                               PYRO 526
 964    FORMAT(' TROUBLE IN PRESSURE DROP')                                PYRO 527
 965    FORMAT('0CONVERSION OF ',20A1,'TO  ',20A1,'IS',F6.2,'%')           PYRO 528
 966    FORMAT('+  0. FT',T66,'/',/,T65,'CL')                              PYRO 529
 967    FORMAT(///,25X,80A1)                                               PYRO 530
 968    FORMAT('     ',F8.2,' FT',T65,'CL',/,T66,'/')                      PYRO 531
 969    FORMAT(' ',I4,3X,3(' ',1PE11.4,9E11.4,/))                          PYRO 532
 970    FORMAT('1TEMP       EQUILIBRUM CONSTANTS',/,'0',T30,',EQUATIONS  NUPYRO 533
       1MBER'/,5X,10(5X,I2,5X))                                            PYRO 534
 971    FORMAT(' ',3(120A1/,' '))                                          PYRO 535
 972    FORMAT('1TEMP      HEAT OF REACTION'/31X,'EQUATION NUMBER'/5X,10(5PYRO 536
       1X,I2,5X))                                                          PYRO 537
 973    FORMAT(' ',I5,4X,13(F7.3,2X))                                      PYRO 538
 974    FORMAT('+',7X,F5.1)                                                PYRO 539
 975    FORMAT('1TEMP      HEAT CAPACITY DATA'/31X,'COMPONENT NUMBER'/5X,5PYRO 540
       10(3X,I3,3X))                                                       PYRO 541
 9934   FORMAT(' REACTOR POSITION',1PE14.5,'FEET',/,' TEMPERTURE',0PF8.2,'PYRO 542
       1,DEGREE-K  MOLAR FLOW RATE',1PE14.5,'POUND MOLES PER HOUR')         PYRO 543
C       DENC= DENSITY OF CARBON AT UI 1200DEG, F                           PYRO 544
C TEMPERTURE ON OUTSIDE WALL OF REACTOR  WILL BE ASSUMED CONSTANT          PYRO 545
CC  RAD=RADIUS OFPIPE IN FEET                                              PYRO 546
        ISS=MAX0(IR,IS)                                                    PYRO 547
        IM=MIN0(IR,IS)                                                     PYRO 548
        IGO=1                                                              PYRO 549
```

```
          IF(IR.EQ.IS)IGO=3                                    PYRO 550
          IF(IR.LT.IS)IGO=2                                    PYRO 551
          RAD=RADO                                             PYRO 552
          DO 48 I=1,100                                        PYRO 553
          RADF(I)=RAD                                          PYRO 554
    48    RADI(I)=RAD                                          PYRO 555
          ITEST=1                                              PYRO 556
    58    MA=1                                                 PYRO 557
          TMPH=TMPHI                                           PYRO 558
          PT=0.                                                PYRO 559
          DO 57 I=1,IS                                         PYRO 560
    57    PT=PT+P(I)                                           PYRO 561
          DO 60 I=1,100                                        PYRO 562
    60    RADI(I)=RADF(I)                                      PYRO 563
          RAD=RADF(1)                                          PYRO 564
          T=TIN                                                PYRO 565
          PI=PT                                                PYRO 566
          VEL1=1.16209296000E-4*TMPH*T/PT/RAD**2               PYRO 567
          WRITE(6,937)ZT,RAD,TMPH,PT,VEL1,T,DL                 PYRO 568
          R=1.967                                              PYRO 569
          ZT=ZTT                                               PYRO 570
          ZIC=0.                                               PYRO 571
          MB=0                                                 PYRO 572
          MMM=1                                                PYRO 573
          MZ=0.                                                PYRO 574
          ZICI=0.                                              PYRO 575
          CALL TUBE(T,TMPH)                                    PYRO 576
          IF(MB.GE.1000)GO TO 200                              PYRO 577
          IWMZ=MB                                              PYRO 578
          DO 93 I=1,IS                                         PYRO 579
          TM(I)=WTM(I,MB)                                      PYRO 580
    93    C(I)=WC(I,MB)                                        PYRO 581
          IZZ=1                                                PYRO 582
          GO TO 65                                             PYRO 583
    200   MB=MB/1000                                           PYRO 584
          GO TO(201,201,202,202,203,300),MB                    PYRO 585
    201   WRITE(2,964)                                         PYRO 586
          GO TO 213                                            PYRO 587
    202   WRITE(2,952)                                         PYRO 588
    213   DL=DLS                                               PYRO 589
          GO TO 49                                             PYRO 590
    203   WRITE(2,954)                                         PYRO 591
    204   MB=20                                                PYRO 592
          STOP                                                 PYRO 593
    300   CONTINUE                                             PYRO 594
          MB=MB+1                                              PYRO 595
    25    CONTINUE                                             PYRO 596
          IF(MA.GT.9)GO TO 55                                  PYRO 597
          ZIC=ZIC+DL                                           PYRO 598
          IF(ZIC.GE.ZTT)GO TO 33                               PYRO 599
```

```
      XN=ZIC/ZTT*10.+1.                                              PYRD 600
      IIN=XN                                                         PYRD 601
      XXN=IIN                                                        PYRD 602
      TR=Z(IIN)+(Z(IIN+1)-Z(IIN))*(XN-XXN)                           PYRD 603
      RAF=RAD                                                        PYRD 604
      IJ=100.001-(ZTT-ZIC)/ZTT*99.                                   PYRD 605
      RIJ=IJ                                                         PYRD 606
      RJ=100.000-(ZTT-ZIC)/ZTT*99.                                   PYRD 607
      IF(IJ.LE.99)RAD=RADF(IJ)+(RADF(IJ+1)-RADF(IJ))*(RIJ-RJ)        PYRD 608
      IF(IJ.GE.100)RAD=RADF(100)                                     PYRD 609
      TT=T                                                           PYRD 610
      T=TR                                                           PYRD 611
      DO34 I=1,IR                                                    PYRD 612
      NO=0                                                           PYRD 613
      I1=1                                                           PYRD 614
      I2=KF(I)                                                       PYRD 615
      K=IA(I,1)                                                      PYRD 616
      CF=1.                                                          PYRD 617
      DO 35 M=I1,I2                                                  PYRD 618
      J=IA(I,M)                                                      PYRD 619
       IF(CLJ(J,2).EQ.0.)NO=I                                        PYRD 620
      IF(BB(I,M).NE.0.)CF=CF*C(J)**BB(I,M)                           PYRD 621
   35 CONTINUE                                                       PYRD 622
      CR=1                                                           PYRD 623
      I1=KF(I)+1                                                     PYRD 624
      I2=KR(I)+KF(I)                                                 PYRD 625
      DO 36 M=I1,I2                                                  PYRD 626
      J=IA(I,M)                                                      PYRD 627
       IF(CLJ(J,2).EQ.0.)NO=I                                        PYRD 628
      IF(BB(I,M).NE.0.)CR=CR*C(J)**BB(I,M)                           PYRD 629
   36 CONTINUE                                                       PYRD 630
      EA(I)=EA(I)*EXP(-EE(I)/R/T)*(CF-CR*REQC(T,I))                  PYRD 631
      IF(P(K).NE.0.)DXA(I)=1.130973355E4*DL*RA(I)*RAD**2/TMPH*PT/P(K) PYRD 632
      IF(P(K).EQ.0.)DXA(I)=0.                                        PYRD 633
      IF(NO.NE.0)GO TO 54                                            PYRD 634
      GO TO 68                                                       PYRD 635
   54 IF((ABS(DXA(I)).GE.1.E-2).AND.(F(I).LE.9.))GO TO 20            PYRD 636
   68 IF(DXA(NO).LE.0.)DXA(NO)=0.                                    PYRD 637
      IF(DXA(I).GE..1)DXA(I)=DXA(I)*.1                               PYRD 638
      IF(DXA(I).GE..1)GO TO 20                                       PYRD 639
   34 CONTINUE                                                       PYRD 640
      GO TO 23                                                       PYRD 641
   20 ZIC=ZIC-DL                                                     PYRD 642
      DL=ABS(DL*.005/DXA(I))                                         PYRD 643
      REQ=REQC(T,I)                                                  PYRD 644
      RATE=EA(I)*EXP(-EE(I)/R/T)                                     PYRD 645
      WRITE(6,930)DL,ZIC                                             PYRD 646
      WRITE(6,932)I,RA(I),DXA(I),CF,CR,REQ,RATE                      PYRD 647
      MA=MA+1                                                        PYRD 648
      GO TO 25                                                       PYRD 649
```

```
23    DN=0.                                              PYRO 650
      PT2=PRR(IS)                                        PYRO 651
      DO 39 I=1,IR                                       PYRO 652
      K=IA(I,1)                                          PYRO 653
      I1=1                                               PYRO 654
      I2=KF(I)                                           PYRO 655
      DO 38 M=I1,I2                                      PYRO 656
      J=IA(I,M)                                          PYRO 657
      DN=DN-B(I,M)/B(I,1)*C(K)*DXA(I)                    PYRO 658
38    P(J)=P(J)-B(I,M)/B(I,1)*P(K)*DXA(I)                PYRO 659
      I1=KF(I)+1                                         PYRO 660
      I2=KR(I)+KF(I)                                     PYRO 661
      DO 39 M=I1,I2                                      PYRO 662
      J=IA(I,M)                                          PYRO 663
      DN=DN+B(I,M)/B(I,1)*C(K)*DXA(I)                    PYRO 664
39    P(J)=P(J)+B(I,M)/B(I,1)*P(K)*DXA(I)                PYRO 665
      CT=0.                                              PYRO 666
      DO 37 I=1,IS                                       PYRO 667
      C(I)=P(I)/T/GC                                     PYRO 668
37    CT=CT+C(I)                                         PYRO 669
      RN1=CT                                             PYRO 670
      RN2=CT-DN                                          PYRO 671
      TMPH=TMPH*DN*GC*T/PT+TMPH                          PYRO 672
      DN=TMPH                                            PYRO 673
      PD=PRESD(T)                                        PYRO 674
      PT=PRR(IS)                                         PYRO 675
      IF(MB.EQ.5000)GO TO 72                             PYRO 676
      IF(MB.EQ.3000)GO TO 71                             PYRO 677
      IF(MB.EQ.2000)PT=.5                                PYRO 678
      IF(PT.LE.(POUT-.2))GO TO 69                        PYRO 679
      DO 40 J=1,IS                                       PYRO 680
40    TM(J)=TMPH*P(J)/PT                                 PYRO 681
      D=0.                                               PYRO 682
44    DO 43 IX=1,IR                                      PYRO 683
43    D=AMAX1(ABS(DXA(IX)),D)                            PYRO 684
      IF(D.EQ.0.)GO TO 26                                PYRO 685
      IF(D.GE..0010)GO TO 24                             PYRO 686
27    IF(DL.GE..01*ZTT)GO TO  24                         PYRO 687
      DL=ABS(DL*.005/D)                                  PYRO 688
      IF(DL.GE..01*ZTT)DL=.01001*ZTT                     PYRO 689
      WRITE(6,930)DL,ZIC                                 PYRO 690
      WRITE(6,933)(DXA(I),I,I=1,IR)                      PYRO 691
24    IF(MB.NE.1)GO TO 31                                PYRO 692
      WRITE(6,942)PT,VEL1                                PYRO 693
      WRITE(6,928)(J,C(J),TM(J),DXA(J),J=1,IM)           PYRO 694
      GO TO(46,47,31),IGO                                PYRO 695
46    II=IS+1                                            PYRO 696
      WRITE(6,936)(J,DXA(J),J=II,IR)                     PYRO 697
      GO TO 31                                           PYRO 698
47    II=IR+1                                            PYRO 699
```

```
      WRITE(6,939)(J,C(J),TM(J),J=II,IS)                               PYRO 700
   31 CONTINUE                                                         PYRO 701
      ZICI=ZICI+DL                                                     PYRO 702
      IF(ZICI.LE.(ZTT/25.))GO TO 30                                    PYRO 703
      ZICI=0.                                                          PYRO 704
      MZ=MZ+1                                                          PYRO 705
      WZIC(MZ)=ZIC                                                     PYRO 706
      WT(MZ)=T                                                         PYRO 707
      WTMPH(MZ)=TMPH                                                   PYRO 708
      WPT(MZ)=PT                                                       PYRO 709
      WVEL1(MZ)=VEL1                                                   PYRO 710
      DO 70 J=1,ISS                                                    PYRO 711
      WC(J,MZ)=C(J)                                                    PYRO 712
      WTM(J,MZ)=TM(J)                                                  PYRO 713
   70 WDXA(J,MZ)=DXA(J)                                                PYRO 714
   30 GO TO 300                                                        PYRO 715
   33 PT=PT2                                                           PYRO 716
   69 IWMZ=MZ                                                          PYRO 717
      WRITE(6,916)                                                     PYRO 718
      WRITE(6,951)CARD                                                 PYRO 719
      WRITE(6,9934)ZIC,T,TMPH                                          PYRO 720
      PTTE=PT                                                          PYRO 721
      IF(MAZE.EQ.2)PT=2.                                               PYRO 722
      WRITE(6,942)PT,VEL1                                              PYRO 723
      PT=PTTE                                                          PYRO 724
      DO 64 I=1,IS                                                     PYRO 725
   64 P(I)=PPI(I)                                                      PYRO 726
      IF((PT.GE.(POUT-.2)).AND.(PT.LE.(POUT+.2)))GO TO 65              PYRO 727
      IF(KK.EQ.2)PDP=PDP/2                                             PYRO 728
      IF(KK.EQ.2)GO TO 63                                              PYRO 729
      IF((PT.GE.POUT+.2).AND.(ITEST.EQ.2))PDP=PDP/2.                   PYRO 730
      IF((MAZE.EQ.2).AND.(PT.GE.(POUT-.2)))GO TO 65                    PYRO 731
      IF(MAZE.EQ.2)GO TO 63                                            PYRO 732
      IF((PT.LE.POUT-.2).AND.(ITEST.EQ.3))PDP=PDP/2.                   PYRO 733
      IF((PT.GE.POUT+.2).AND.(ITEST.EQ.2))KK=2                         PYRO 734
      IF((PT.LE.POUT-.2).AND.(ITEST.EQ.3))KK=2                         PYRO 735
      GO TO 63                                                         PYRO 736
   71 MAZE=2                                                           PYRO 737
      PT=.5                                                            PYRO 738
      WRITE(6,952)                                                     PYRO 739
      GO TO 69                                                         PYRO 740
   65 IF(IPLOT.GT.2)GO TO 91                                           PYRO 741
      WRITE(6,918)                                                     PYRO 742
      WRITE(6,951)CARD                                                 PYRO 743
      WRITE(6,963)HR                                                   PYRO 744
      WRITE(6,960)                                                     PYRO 745
      WRITE(6,962)                                                     PYRO 746
      DO 81 I=14,116                                                   PYRO 747
   81 CALL PLOT(I,'*N')                                                PYRO 748
      CALL PLOT(1,'  ')                                                PYRO 749
```

```
      DO 82 I1=1,IWMZ                                                   PYRO 750
      I=IWMZ+1-I1                                                       PYRO 751
      J1=WTM(KEYP,I)/WTM(KEYR,1)*100.+15.                               PYRO 752
      J2=WTM(KEYR,I)/WTM(KEYR,1)*100.+15.                               PYRO 753
      J3=(WT(I)-WT(1))/(WT(IWMZ)-WT(1))*100.+15.                        PYRO 754
      J4=(WPT(I))/6.*100.+15                                            PYRO 755
      WRITE(6,974)WZIC(I)                                               PYRO 756
   82 CALL PLOT(14,'*N',5,IDATO(I1),J1,'EN',J2,'RN',J3,'TN',J4,'PN',116,PYRO 757
     1'*O')                                                             PYRO 758
      DO 83 I=14,116                                                    PYRO 759
   83 CALL PLOT(I,'*N')                                                 PYRO 760
      CALL PLOT(1,'  ')                                                 PYRO 761
      WRITE(6,918)                                                      PYRO 762
   91 KK=1                                                              PYRO 763
      IF((IPLOT.GT.3).OR.(IPLOT.LT.2))GO TO 90                          PYRO 764
      MMM=2                                                             PYRO 765
      DO 75 I=1,IWMZ                                                    PYRO 766
      PT=WPT(I)                                                         PYRO 767
      VEL1=WVEL1(I)                                                     PYRO 768
      ZIC=WZIC(I)                                                       PYRO 769
      T=WT(I)                                                           PYRO 770
      TMPH=WTMPH(I)                                                     PYRO 771
      DO 76 J=1,ISS                                                     PYRO 772
      C(J)=WC(J,I)                                                      PYRO 773
      TM(J)=WTM(J,I)                                                    PYRO 774
   76 DXA(J)=WDXA(J,I)                                                  PYRO 775
      MMM=MMM+1                                                         PYRO 776
      IF(MMM.LE.1)GO TO 41                                              PYRO 777
      MMM=0                                                             PYRO 778
      WRITE(6,918)                                                      PYRO 779
      WRITE(6,951)CARD                                                  PYRO 780
   41 WRITE(6,934)ZIC,T,TMPH                                            PYRO 781
      YIELD=TM(KEYP)/TMPHI/PPI(KEYR)*PI*100.                            PYRO 782
      J2=KEYR*20                                                        PYRO 783
      J1=J2-19                                                          PYRO 784
      J4=KEYP*20                                                        PYRO 785
      J3=J4-19                                                          PYRO 786
      WRITE(6,965)(INAME(L),L=J1,J2),(INAME(L),L=J3,J4),YIELD           PYRO 787
      WRITE(6,942)PT,VEL1                                               PYRO 788
      WRITE(6,929)I                                                     PYRO 789
      WRITE(6,928)(J,C(J),TM(J),DXA(J),J=1,IM)                          PYRO 790
      GO TO(42,45,75),IGO                                               PYRO 791
   42 II=IS+1                                                           PYRO 792
      WRITE(6,933)(J,DXA(J),J=II,IR)                                    PYRO 793
      GO TO 75                                                          PYRO 794
   45 II=IR+1                                                           PYRO 795
      WRITE(6,939)(J,C(J),TM(J),J=II,IS)                                PYRO 796
   75 WRITE(6,916)                                                      PYRO 797
      WRITE(6,916)                                                      PYRO 798
   90 WRITE(6,951)CARD                                                  PYRO 799
```

```
      MB=1                                                    PYRO 800
      MY=1                                                    PYRO 801
      MZ=1                                                    PYRO 802
      WRITE(6,916)                                            PYRO 803
      DO 59 I=1,IR                                            PYRO 804
 59   REOTT=RESC(T,I)                                         PYRO 805
      WRITE(6,916)                                            PYRO 806
C     PRETT=PRESD(I)                                          PYRO 807
      DO 51 I=1,IS                                            PYRO 808
      I1=1+(I-1)*20                                           PYRO 809
      I2=I*20                                                 PYRO 810
 51   WRITE(6,944)I,IDATA(I),(INAME(J),J=I1,I2),C(I),TM(I)    PYRO 811
      YIELD=TM(KEYP)/TMPHI/PPI(KEYR)*PI*100.                  PYRO 812
      J2=KEYR*20                                              PYRO 813
      J1=J2-19                                                PYRO 814
      J4=KEYP*20                                              PYRO 815
      J3=J4-19                                                PYRO 816
      WRITE(6,965)(INAME(I),I=J1,J2),(INAME(I),I=J3,J4),YIELD PYRO 817
      GO TO 50                                                PYRO 818
 63   PTI=PI                                                  PYRO 819
      IF(PT.LT.POUT)GO TO 49                                  PYRO 820
      GO TO 61                                                PYRO 821
 49   PDIR=PI-PT                                              PYRO 822
 67   PTI=PI                                                  PYRO 823
      PI=PI+PUP                                               PYRO 824
      IF(PI.GE.6.1)GO TO 56                                   PYRO 825
      DO 53 I=1,IS                                            PYRO 826
      PPI(I)=PPI(I)*PI/PTI                                    PYRO 827
      P(I)=PPI(I)                                             PYRO 828
 53   C(I)=P(I)/T/GC                                          PYRO 829
      ITEST=2                                                 PYRO 830
      GO TO 58                                                PYRO 831
 61   PTI=PI                                                  PYRO 832
      PI=PI-PUP                                               PYRO 833
      DO 62 I=1,IS                                            PYRO 834
      DO 62 I=1,IS                                            PYRO 835
      PPI(I)=PPI(I)*PI/PTI                                    PYRO 836
 62   P(I)=PPI(I)                                             PYRO 837
      ITEST=3                                                 PYRO 838
      GO TO 58                                                PYRO 839
 50   T=TIN                                                   PYRO 840
      TMPH=TMPHI                                              PYRO 841
      HR=HR+IB                                                PYRO 842
      IGOTO=IGOTO+1                                           PYRO 843
      WRITE(6,945)HR                                          PYRO 844
      DO 52 I=1,100                                           PYRO 845
      RADD(I,IGOTO)=RADI(I)                                   PYRO 846
 52   RADE(I)=RADI(I)                                         PYRO 847
      WRITE(6,944)RADI                                        PYRO 848
      DO 66 I=1,IS                                            PYRO 849
```

```
      P(I)=PPI(I)                                                   PYRO 850
   66 C(I)=P(I)/GC/320.                                             PYRO 851
      ITEST=1                                                       PYRO 852
      MA=1                                                          PYRO 853
      IF(IGOTO.GE.IZZ)GO TO 56                                      PYRO 854
      IF(PT.LT.PRES)GO TO 58                                        PYRO 855
      GO TO 56                                                      PYRO 856
   72 WRITE(6,954)                                                  PYRO 857
      IGOTO=IZZ                                                     PYRO 858
      GO TO 50                                                      PYRO 859
   55 WRITE(6,949)                                                  PYRO 860
   56 WRITE(6,919)                                                  PYRO 861
      IF(IPLOT.GT.2)GO TO 95                                        PYRO 862
      WRITE(6,955)                                                  PYRO 863
      WRITE(6,966)ZTT                                               PYRO 864
      IGOTO=IGOTO-1                                                 PYRO 865
      DO 77 J=14,116                                                PYRO 866
   77 CALL PLOT(J,'*N')                                             PYRO 867
      CALL PLOT(1,'  ')                                             PYRO 868
      DO 78 J=2,100,2                                               PYRO 869
      J1=102-J                                                      PYRO 870
      IJK=0.                                                        PYRO 871
      DO 79 I=1,IGOTO                                               PYRO 872
      IJK=IJK+1                                                     PYRO 873
      IF(IJK.GT.9)IJK=1                                             PYRO 874
      J2=RADD(J1,I)/RAD*50.+65.                                     PYRO 875
      J3=130-J2                                                     PYRO 876
   79 CALL PLOT(14,'*N',J2,IDATP(IJK),J3,IDATP(IJK),116,'*N')       PYRO 877
      IJ=(J+2)/4                                                    PYRO 878
      IF(FLOAT(J/4).EQ.FLOAT(J)/4.)IJ=1                             PYRO 879
   78 CALL PLOT(5,IDATG(IJ),65,'+ ')                                PYRO 880
      DO 80 J=14,116                                                PYRO 881
   80 CALL PLOT(J,'*N')                                             PYRO 882
      CALL PLOT(1,'  ')                                             PYRO 883
      WRITE(6,966)                                                  PYRO 884
      WRITE(6,967)CARD                                              PYRO 885
   95 CONTINUE                                                      PYRO 886
      IGOTO=1                                                       PYRO 887
      MA=1                                                          PYRO 888
      PT=0.                                                         PYRO 889
      DO 73 I=1,IS                                                  PYRO 890
   73 PT=PT+PPI(I)                                                  PYRO 891
      DO 74 I=1,IS                                                  PYRO 892
      PPI(I)=PPI(I)*PSAVE/PT                                        PYRO 893
   74 P(I)=PPI(I)                                                   PYRO 894
      IF(IND.NE.0)RETURN                                            PYRO 895
      READ(5,943)IGOW,(Z(II),II=1,11)                               PYRO 896
      READ(5,950)CARD                                               PYRO 897
      READ(5,958)IB,IZZ,IPLOT                                       PYRO 898
      GO TO(100,110,111),IGOW                                       PYRO 899
```

```
101   CONTINUE                                        PYRO 900
      WRITE(6,921)I,ID                                PYRO 901
      STOP111                                         PYRO 902
102   CONTINUE                                        PYRO 903
      WRITE(6,922)I,ID                                PYRO 904
      STOP112                                         PYRO 905
103   CONTINUE                                        PYRO 906
      WRITE(6,923)J,ID                                PYRO 907
      STOP113                                         PYRO 908
104   CONTINUE                                        PYRO 909
      WRITE(6,924)I,ID                                PYRO 910
      STOP114                                         PYRO 911
105   CONTINUE                                        PYRO 912
      WRITE(6,925)J,ID                                PYRO 913
      STOP115                                         PYRO 914
111   CONTINUE                                        PYRO 915
      WRITE(6,918)                                    PYRO 916
92    WRITE(6,970)(I,I=1,IR)                          PYRO 917
      DO 84 IT=800,1200,10                            PYRO 918
      J=(IT-800)/10+1                                 PYRO 919
      T=IT                                            PYRO 920
      DO 85 N=1,IR                                    PYRO 921
85    WC(J,N)=1./REQC(T,N)                            PYRO 922
84    WRITE(6,969)IT,(WC(J,N),N=1,IR)                 PYRO 923
      WRITE(6,972)(I,I=1,IR)                          PYRO 924
      DO 86 IT=800,1200,10                            PYRO 925
      J=(IT-800)/10+1                                 PYRO 926
      T=IT                                            PYRO 927
      DO 87 N=1,IR                                    PYRO 928
87    WC(J,N)=HEATR(T,N)                              PYRO 929
86    WRITE(6,969)IT,(WC(J,N),N=1,IR)                 PYRO 930
      WRITE(6,975)(I,I=1,IS)                          PYRO 931
      DO 88 IT=800,1200,10                            PYRO 932
      J=(IT-800)/10+1                                 PYRO 933
      T=IT                                            PYRO 934
      DO 89 N=1,IS                                    PYRO 935
89    WC(J,N)=HCP(T,N)                                PYRO 936
88    WRITE(6,973)IT,(WC(J,N),N=1,IS)                 PYRO 937
99    RETURN                                          PYRO 938
106   WRITE(6,935) ID,J                               PYRO 939
      STOP116                                         PYRO 940
26    WRITE(6,931)                                    PYRO 941
      WRITE(6,948)(J,C(J),DXA(J),J=1,IS)              PYRO 942
      STOP26                                          PYRO 943
      END                                             PYRO 944
```

```
      FUNCTION PRR(IS)                                                  PRR 945
      COMMON/TUBE1/IR,IZ,KF(25),KR(25),B(25,10),BB(25,10),DL,IA(25,10)  PRR 946
     1,EA(25),EE(25),RAD,AD                                             PRR 947
      COMMON/PD/P(25),DN,SMWT(25),CLJ(25,2),VI(25),AMWT,VEL1,HI         PRR 948
      COMMON/TH/TMPH,RADI(100),DE(25),ZIC                               PRR 949
      COMMON/PYRO3/Z(11),ZTT,C(25),CP(25,4)                             PRR 950
     1,DH(25),DS(25),DF(25)                                             PRR 951
      COMMON/SET/MY,MZ,IB,IPLOT,DLS                                     PRR 952
      DATA PI/3.1415926/                                                PRR 953
      PT=0.                                                             PRR 954
      PT2=0.                                                            PRR 955
      HRS=IS                                                            PRR 956
      DO 1 I=1,IS                                                       PRR 957
      IF(CLJ(I,1).NE.0.)PT2=PT2+P(I)                                    PRR 958
    1  PT=PT+P(I)                                                       PRR 959
      DO 2 I=1,IS                                                       PRR 960
      IF(CLJ(I,1).EQ.0.)GO TO 5                                         PRR 961
      GO TO 2                                                           PRR 962
    5 IJ=100.001-(ZTT-ZIC)/ZTT*99.                                      PRR 963
      IJJ=100.001-(ZTT-DL-ZIC)/ZTT*99.                                  PRR 964
      IF(IJJ.GT.100)IJJ=100                                             PRR 965
      XNC=ABS(FLOAT(IJ-IJJ))                                            PRR 966
      IF(XNC.LE.0.0)XNC=1.                                              PRR 967
      VOL=TMPH*SMWT(I)*P(I)/PT/DE(I)*HRS                                PRR 968
      DLR=ZTT/100.                                                      PRR 969
      IF((RADI(IJ)**2-VOL/DLR/XNC/PI).LE.0.)GO TO 1001                  PRR 970
      IF(MZ.EQ.5000)RETURN                                              PRR 971
      DO 3 IK=IJ,IJJ                                                    PRR 972
    3 RADI(IK)=SQRT(RADI(IK)**2-VOL/DLR/XNC/PI)                         PRR 973
      IF(CLJ(I,1).EQ.0.)P(I)=0.                                         PRR 974
      GO TO 2                                                           PRR 975
 1001  WRITE(2,9001)PRR,RADI(1),VOL                                     PRR 976
    2 P(I)=P(I)*PT/PT2                                                  PRR 977
      PRR=PT                                                            PRR 978
 9001 FORMAT('  FUNCTION PRR(IS)',/,' PR=',1PE14.5,5X,'RADI(1)=',1PE14.5PRR 979
     1,5X,'VOL=',1PE14.5)                                               PRR 980
      RETURN                                                            PRR 981
      END                                                               PRR 982
```

```
      FUNCTION REOC(T,I)                                                REOC 983
      COMMON/FE/DCP(25,4),HT(25),SO(25),FO(25),FI(25),HO(25)            REOC 984
      COMMON/SET/MY,MZ,IB,IPLOT,DLS                                     REOC 985
      REAL*4 LOG                                                        REOC 986
      DATA  R/1.987/                                                    REOC 987
      ELNK=-HO(I)/R/T+DCP(I,1)/R*LOG(T)+DCP(I,2)/(2.*R)*T+DCP(I,3)/(6.*RREOC 988
     1)*T*T+DCP(I,4)/(12.*R)*T**3+FI(I)                                 REOC 989
      REOC=EXP(-ELNK)                                                   REOC 990
      RETURN                                                            REOC 991
      END                                                               REOC 992
```

```
      FUNCTION PRESD(T)                                                 PRES 993
      COMMON/PYRO3/Z(11),ZTT,C(25),CP(25,4)                             PRES 994
     1,DH(25),DS(25),DF(25)                                             PRES 995
      COMMON/TUBE1/IP,IS,KF(25),KR(25),B(25,10),BB(25,10),DL,IA(25,10)  PRES 996
     1,EA(25),EE(25),RAD,AU                                             PRES 997
      COMMON/PD/P(25),DN,SMWT(25),CLJ(25,2),VI(25),AMWT,VEL1,HI         PRES 998
      COMMON/PT2/TT,RN1,RN2,VIS                                         PRES 999
      COMMON/SET/MY,MZ,IB,IPLOT,DLS                                     PRES1000
      REAL*4 LOG                                                        PRES1001
      PT=PRR(IS)                                                        PRES1002
      IF(MZ.EQ.5000)RETURN                                              PRES1003
C THIS SUBROUTINE CALULATES PRESSURE DROP FROM BERNOULIE LAW            PRES1004
C MODIFIED TO TAKE FRICTION LOSS INTO CONSIDERATION                     PRES1005
      DATA MYY/1/                                                       PRES1006
      IF(MYY.NE.1)GO TO 1                                               PRES1007
      MYY=2                                                             PRES1008
      MAZE=1                                                            PRES1009
      PDP=.2                                                            PRES1010
      DATA A/.4398818/,BI/-.44245917/,CC/.86401820E-1/,D/.77484511E-2/  PRES1011
      DATA A1/2.6693E-5/,A2/1.1620929E-4/,A3/7.37495E4/                 PRES1012
      PRESDT=0.                                                         PRES1013
   11 DO 2 I=1,IS                                                       PRES1014
      IF(CLJ(I,1).EQ.0) GO TO 2                                         PRES1015
      E=LOG(T/CLJ(I,2))                                                 PRES1016
      VI(I)=A1*SQRT(SMWT(I)*T)/(CLJ(I,1)**2*EXP(A+BI*E+CC*E**2+D*E**3)) PRES1017
    2 CONTINUE                                                          PRES1018
      VIS=0.                                                            PRES1019
      DO 3 I=1,IS                                                       PRES1020
      IF(CLJ(I,1).EQ.0.)GO TO 3                                         PRES1021
      V=P(I)/PT*VI (I)                                                  PRES1022
      U=0.                                                              PRES1023
      DO 4 J=1,IS                                                       PRES1024
      IF(CLJ(J,1).EQ.0.)GO TO 4                                         PRES1025
      U=U+P(J)/PT*1./SQRT(8.)/(1.+SMWT(I)/SMWT(J))*(1.+(VI(I)/VI(J))**.5PRES1026
     1*(SMWT(J)/SMWT(I))**.25)**2                                       PRES1027
    4 CONTINUE                                                          PRES1028
      VIS=VIS+V/U                                                       PRES1029
    3 CONTINUE                                                          PRES1030
      VIS=VIS*.0672                                                     PRES1031
    1 AMWT=0.                                                           PRES1032
      VEL2=A2*T/(PT-PRESDT)/RAD**2*DN                                   PRES1033
      DO 5 I=1,IS                                                       PRES1034
    5 AMWT=P(I)/PT*SMWT(I)+AMWT                                         PRES1035
C    GC IN AT.*FT**3 /(OK LB.MOLES)                                     PRES1036
      GC=1.3143                                                         PRES1037
      DEN=PT/(GC*T)*AMWT                                                PRES1038
      IF(DEN.LE.0.)GO TO 21                                             PRES1039
    6 VELA=(VEL1+VEL2)/2.                                               PRES1040
      REMU=2.*RAD*DEN*VELA/VIS                                          PRES1041
      IF(REMU.LE.0.)GO TO 19                                            PRES1042
```

```
      IF(RENU.LE.3500.)GO TO 20                                         PRES1043
      GO TO 10                                                          PRES1044
 20   F=64./RENU                                                        PRES1045
 10   F=0.0056+.5/(RENU**.32)                                           PRES1046
      GO TO 100                                                         PRES1047
 100  PRESD=DEN*(VELA**2*F*DL/RAD+VEL2**2-VEL1**2)/62.4/2116.8          PRES1048
      PRESD=ABS(PRESD)                                                  PRES1049
      P2=PT-PRESD                                                       PRES1050
      IF(P2.LE.0.)GO TO 21                                              PRES1051
      VEL2=A2*T/P2/RAD**2*DN                                            PRES1052
      IF(PRESD.EQ.0.)GO TO 7                                            PRES1053
      IF(ABS((PRESDT-PRESD)/PRESD).LE..001)GO TO 7                      PRES1054
      PRESDT=PRESD                                                      PRES1055
      DEN=(P2+PT)/(2.*GC*T)*AMWT                                        PRES1056
      GO TO 6                                                           PRES1057
 7    PT2=0.                                                            PRES1058
      DO 9 I=1,IS                                                       PRES1059
 9    PT2=PT2+P(I)                                                      PRES1060
      DO 8 I=1,IS                                                       PRES1061
 8    P(I)=P(I)*(PT2-PRESD)/PT2                                         PRES1062
      IF((IPLOT.EQ.2).OR.(IPLOT.EQ.3).AND.(MZ.EQ.1))GO TO 1001          PRES1063
      VEL1=VEL2                                                         PRES1064
      IF(VEL1.GE.1214.5)GO TO 22                                        PRES1065
      IF(VEL1.GE.SQRT(A3*P2/DEN))GO TO 22                               PRES1066
      RETURN                                                            PRES1067
 22   MZ=3000                                                           PRES1068
      PT=.5                                                             PRES1069
      RETURN                                                            PRES1070
 1001  WRITE(6,9001)RENU, VIS,DEN,F,VEL1,VEL2,VELA,T ,PRESD             PRES1071
      VEL1=VEL2                                                         PRES1072
      RETURN                                                            PRES1073
 19   WRITE(6,900)RAD,DEN,VELA,VIS,RENU                                 PRES1074
      WRITE(6,902)T,PT,(P(I),I=1,IS),GC,AMWT,P2                         PRES1075
      MZ=2000                                                           PRES1076
      RETURN                                                            PRES1077
 21   WRITE(6,902)T,PT,(P(I),I=1,IS),GC,AMWT,P2                         PRES1078
      MZ=2000                                                           PRES1079
      RETURN                                                            PRES1080
 900  FORMAT(' RAD=',1PE12.5,'DEN,VELA,VIS,RENU',4(2X,1PE12.5))         PRES1081
 901  FORMAT(' PRESSURE DROP =',1PE12.5,'DEN,VELA,DL,VEL1,VEL2,',5(2X,1PPRES1082
     1E12.5))                                                           PRES1083
 902  FORMAT(' T PT P(1)=P(12), GC AMWT ',10(1X,E8.2))                  PRES1084
 9001 FORMAT(' FUNCTION PRESD(T)',/,' RENU=',1PE14.5,5X,'VIS=',1PE14.5,5PRES1085
     1X,'DEN=',1PE14.5,/,' FRICTION FACTOR= ',1PE14.5,5X,'V1,V2,VA=',3(1PRES1086
     1PE14.5,5X),' TEMPERTURE=',UPF8.2     ,5X,'PRESSURE D=',1PE14.5)   PRES1087
      END                                                               PRES1088
```

```
      FUNCTION HCP(T,I)                                                 HCP 1089
      COMMON/TUBE1/IR,IS,KF(25),KR(25),B(25,10),BB(25,10),DL,IA(25,10)  HCP 1090
     1,EA(25),EE(25),RAD,A0                                             HCP 1091
      COMMON/PYRO3/Z(11),ZTT,C(25),CP(25,4)                             HCP 1092
     1,DH(25),DS(25),DF(25)                                             HCP 1093
      HCP=CP(I,1)+CP(I,2)*T+CP(I,3)*T*T+CP(I,4)*T**3                    HCP 1094
      RETURN                                                            HCP 1095
      END                                                               HCP 1096
```

```
      SUBROUTINE RATE(C1,T,RA)                                           RATE1097
      DATA R/1.987/                                                      RATE1098
      DIMENSION RA(25),C1(25)                                            RATE1099
      COMMON/PD/SLURP(52),CLJ(25,2)                                      RATE1100
      COMMON/TUBE1/IR,IS,KF(25),KR(25),B(25,10),BB(25,10),DL,IA(25,10)   RATE1101
     1,EA(25),EE(25),RAD,AC                                              RATE1102
C1                                                                       RATE1103
      DO34 I=1,IR                                                        RATE1104
      NO=0                                                               RATE1105
      I1=1                                                               RATE1106
      I2=KF(I)                                                           RATE1107
      CF=1.                                                              RATE1108
      DO 35 M=I1,I2                                                      RATE1109
      J=IA(I,M)                                                          RATE1110
       IF(CLJ(J,2).EQ.0.)NO=I                                            RATE1111
      IF(BB(I,M).NE.0.)CF=CF*C1(J)**BB(I,M)                              RATE1112
   35 CONTINUE                                                           RATE1113
      CR=1                                                               RATE1114
      I1=KF(I)+1                                                         RATE1115
      I2=KR(I)+KF(I)                                                     RATE1116
      DO 36 M=I1,I2                                                      RATE1117
      J=IA(I,M)                                                          RATE1118
      IF(CLJ(J,2).EQ.0.)NO=I                                             RATE1119
      IF(BB(I,M).NE.0.)CR=CR*C1(J)**BB(I,M)                              RATE1120
   36 CONTINUE                                                           RATE1121
   34 RA(I)=EA(I)*EXP(-EE(I)/R/T)*(CF-CR*REQC(T,I))                      RATE1122
      RETURN                                                             RATE1123
      END                                                                RATE1124
```

```
      SUBROUTINE MATB(RA1,RA2,PC2,DXA,X1,X2,T1,T2,PT1,PT2)                MATB1125
      DATA GC/1.3413/                                                     MATB1126
      DIMENSION DXA(25),X1(25),X2(25),PC2(25),RA1(25),RA2(25)             MATB1127
      COMMON/TUBE1/IR,IS,KF(25),KR(25),B(25,10),BB(25,10),DL,IA(25,10)    MATB1128
     1,EA(25),EE(25),RAD,AD                                               MATB1129
      DN=0.0                                                              MATB1130
      DO 1 I=1,IR                                                         MATB1131
      K=IA(I,1)                                                           MATB1132
      RA=(RA1(I)+RA2(I))/2.                                               MATB1133
      IF(X1(K).NE.0.)DXA(I)=1.130973355E4*DL*RA*RAD**2/X1(K)              MATB1134
    5 CONTINUE                                                            MATB1135
      IF(X1(K).EQ.0.)DXA(I)=0.                                            MATB1136
    1 CONTINUE                                                            MATB1137
      DO 37 J=1,IS                                                        MATB1138
      X2(J)=X1(J)                                                         MATB1139
   37 CONTINUE                                                            MATB1140
      DO 39 I=1,IR                                                        MATB1141
      K=IA(I,1)                                                           MATB1142
      I1=1                                                                MATB1143
      I2=KF(I)                                                            MATB1144
      DO 38 M=I1,I2                                                       MATB1145
      J=IA(I,M)                                                           MATB1146
      DN=DN-B(I,M)/B(I,1)*X1(K)*DXA(I)                                    MATB1147
   38 X2(J)=X2(J)-B(I,M)/B(I,1)*X1(K)*DXA(I)                              MATB1148
      I1=KF(I)+1                                                          MATB1149
      I2=KR(I)+KF(I)                                                      MATB1150
      DO 39 M=I1,I2                                                       MATB1151
      J=IA(I,M)                                                           MATB1152
      DN=DN+B(I,M)/B(I,1)*X1(K)*DXA(I)                                    MATB1153
   39 X2(J)=X2(J)+B(I,M)/B(I,1)*X1(K)*DXA(I)                              MATB1154
      TMPH=0.0                                                            MATB1155
      DO 42 I=1,IS                                                        MATB1156
   42 TMPH=TMPH+X2(I)                                                     MATB1157
      CALL PRESC(T1,T2,PD,TMPH)                                           MATB1158
      XT2=0.0                                                             MATB1159
      DO 40 I=1,IS                                                        MATB1160
      XT2=XT2+X2(I)                                                       MATB1161
   40 CONTINUE                                                            MATB1162
      PT2=PT1-PD                                                          MATB1163
      DO 41 I=1,IS                                                        MATB1164
      PC2(I)=X2(I)/XT2*PT2/T2/GC                                          MATB1165
   41 CONTINUE                                                            MATB1166
      RETURN                                                              MATB1167
      END                                                                 MATB1168
```

```
        FUNCTION HEATR(T2,I)                                              HEAT1169
        COMMON/FE/DCP(25,4),HT(25),ST(25),FT(25),FI(25),HO(25)            HEAT1170
        COMMON/SET/MY,MB,IB,IPLOT,DLS                                     HEAT1171
        HEATR=HO(I)                                                       HEAT1172
        DO 1 L=1,4                                                        HEAT1173
        X=L                                                               HEAT1174
1       HEATR=HEATR+DCP(I,L)*(T2**L/X)                                    HEAT1175
C       WRITE(2,9001)HEATR,T2,I                                           HEAT1176
        IF((IPLOT.EQ.2).OR.(IPLOT.EQ.3).AND.(MZ.EQ.1))GO TO 1001          HEAT1177
        RETURN                                                            HEAT1178
1001     WRITE(6,9001)HEATR,T2,I                                          HEAT1179
        RETURN                                                            HEAT1180
9001    FORMAT(' HEATR(T,I)', 1PE14.5,'(',0PF8.2,',',I2,')')              HEAT1181
        END                                                               HEAT1182
```

```
      SUBROUTINE HEATB(RADC,TB1,TB2,DXA,X1,X2,TB2C,Q,U)                  HEAT1183
      REAL*4 LOG                                                         HEAT1184
      COMMON/PD/P(25),DN,SMWT(25),CLJ(25,2),VI(25),AMWT,VEL1,HI          HEAT1185
      COMMON/TUBE1/IR,IS,KE(25),KR(25),B(25,10),BB(25,10),DL,IA(25,10)   HEAT1186
     1,EA(25),EE(25),RADI,RADO                                           HEAT1187
      COMMON/TUBE2/IND,TX(100)                                           HEAT1188
      COMMON/TH/TMPZ,RADZ(100),DE(25),ZIC                                HEAT1189
      DATA RO/.001/,RI/.001/,XKST/26./,TSKIN/1120./                      HEAT1190
     1,PI/3.1415926/,XKC/2.90/,IC/0/                                     HEAT1191
C     RO AND RI FOULING FACTORS FROM APPLIED PROCESS DESIGN FOR          HEAT1192
C     CHEMICAL AND PETROCHEMICAL PLANTS BY E.E. LUDWIG PAGES 55-59       HEAT1193
C     THERMOCONDUCTIVITY OF CARBON(GRAPHITE) XKC FROM                    HEAT1194
C     TRANSPORT PHENOMENA BIRD STUART AND LIGHTFOOT PAGE249              HEAT1195
      DIMENSION X1(25),X2(25),DXA(25)                                    HEAT1196
      IF(IND.EQ.0)GO TO 10                                               HEAT1197
      CALL TEJET(TSKIN,ZIC,IND)                                          HEAT1198
10    TAVG=(TB2+TB1)/2.                                                  HEAT1199
      DT1=TSKIN-TAVG                                                     HEAT1200
      DT2=TB2-TB1                                                        HEAT1201
      DT2=TB2-TB1                                                        HEAT1202
      HR=0.0                                                             HEAT1203
      DO 1 I=1,IR                                                        HEAT1204
      K=IA(I,1)                                                          HEAT1205
1     HR=HR+HEATR(TAVG,I)*(X2(K)+X1(K))/2.*DXA(I)/1.8                    HEAT1206
      SH=0.0                                                             HEAT1207
      DO 2 I=1,IS                                                        HEAT1208
2     SH=SH+(X2(I)*HCP(TB2,I)+X1(I)*HCP(TB1,I))/2.*1.8                   HEAT1209
C     HI=F(VEL,COMP)                                                     HEAT1210
      AO=PI*DL*RADO*2.0                                                  HEAT1211
      AI=PI*RADI*DL*2.0                                                  HEAT1212
      AC=PI*RADC*DL*2.0                                                  HEAT1213
      AAVG=(AO-AI)/LOG(AO/AI)                                            HEAT1214
      RST=(RADO-RADI)/XKST                                               HEAT1215
      AAVGC=1.0                                                          HEAT1216
      IF(RADI.NE.RADC)AAVGC=(AI-AC)/LOG(AI/AC)                           HEAT1217
      RC=(RADI-RADC)/XKC                                                 HEAT1218
      RU=RO+RST*AO/AAVG+RI+1./(HI*AC/AO)+RC*AI/AAVGC                     HEAT1219
      U=1./RU                                                            HEAT1220
4     TB2C=TB1+(U*AO*DT1-HR)/SH                                          HEAT1221
      HR=HR/DL                                                           HEAT1222
      Q=U*AO*DT1                                                         HEAT1223
      IC=IC+1                                                            HEAT1224
      IF(IC.LT.10)GO TO 5                                                HEAT1225
      IC=1                                                               HEAT1226
C     WRITE(2,901)Q,HR,SH,HI                                             HEAT1227
C901  FORMAT(' Q=',E14.5,'   HR=',E14.5,'   SH=',E14.5,'   HI=',E14.5)   HEAT1228
5     RETURN                                                             HEAT1229
      END                                                                HEAT1230
```

```
      SUBROUTINE TUBE(T1,TMPH)                                          TUBE1231
      COMMON/PYRO3/Z(11),ZTT,C(25),CP(25,4)                             TUBE1232
     1,DH(25),DS(25),DF(25)                                             TUBE1233
      COMMON/PD/P(25),DN,SMWT(25),CLJ(25,2),VI(25),AMWT,VEL1,HI         TUBE1234
      COMMON/TUBE1/IR,IS,KF(25),KR(25),B(25,10),BB(25,10),DL,IA(25,10)  TUBE1235
     1,EA(25),EE(25),RAD,AD                                             TUBE1236
      COMMON/TUBE2/IND,TX(100),QT(4),QFF                                TUBE1237
      COMMON/TM/TMPZ,RADI(100),DE(25),ZIC                               TUBE1238
      COMMON/W/ WZIC(50),WT(50),WTMPH(50),WPT(50),WVEL1(50),WC(25,50),WTTUBE1239
     1W(25,50),WCXA(25,50),RADP(100,50)                                 TUBE1240
      COMMON/SET/MY,MZ,IB,IPLOT,DLS                                     TUBE1241
      DIMENSION X1(25),X2(25),RA1(25),RA2(25),BRA2(25), BC2(25)         TUBE1242
     1,BBC2(25),DXA(25),BDXA(25),RADF(100)                              TUBE1243
      DATA IL2/1/                                                       TUBE1244
      QTOT=0.0                                                          TUBE1245
      JN=0                                                              TUBE1246
      CALL PZERO(QT(1),4)                                               TUBE1247
      N3=1                                                              TUBE1248
      XN=1.                                                             TUBE1249
      Z85=ZTT/85.                                                       TUBE1250
      Z33=ZTT/3.                                                        TUBE1251
      PT=0.0                                                            TUBE1252
      DO 1 I=1,IS                                                       TUBE1253
      PT=PT+P(I)                                                        TUBE1254
    1 CONTINUE                                                          TUBE1255
      ISS=MAX0(IR,IS)                                                   TUBE1256
      ZICI=0.0                                                          TUBE1257
      MZ=0                                                              TUBE1258
      DO 7 I=1,IS                                                       TUBE1259
      X1(I)=TMPH*P(I)/PT                                                TUBE1260
    7 CONTINUE                                                          TUBE1261
      IF(IL2.GT.1)GO TO 9                                               TUBE1262
      DO 8 I=1,100                                                      TUBE1263
    8 RADF(I)=RAD                                                       TUBE1264
    C DL=10.                                                            TUBE1265
    9 ZIC=0.0                                                           TUBE1266
      T2=T1+10.                                                         TUBE1267
      DL=DLS                                                            TUBE1268
      CALL RATE(C,T1,RA1)                                               TUBE1269
    2 CALL RATE(C,T2,RA2)                                               TUBE1270
      T2OLD=T2                                                          TUBE1271
      ZIC=ZIC+DL                                                        TUBE1272
      ZICI=ZICI+DL                                                      TUBE1273
      IF(ZIC.LT.ZTT)GO TO 4                                             TUBE1274
      DL=ZTT-(ZIC-DL)                                                   TUBE1275
      IF(DL.LE.0)GO TO 10                                               TUBE1276
      ZIC=ZTT                                                           TUBE1277
      ZICI=ZTT                                                          TUBE1278
    4 CI=RADF(INT((ZTT-ZIC)/ZTT*99.+1.))                                TUBE1279
      IF(CI.LE.0.0)CI=RAD                                               TUBE1280
```

```
C906  FORMAT('   I    J    K    M',3X,'X1(K)',5X,'X2(J)',4X,'DXA(I)',5X,'DXTUBE1281
C      11,')                                                        TUBE1282
      CALL MATB(RA1,RA2,BC2,DXA,X1,X2,T1,T2,PT,PT2)                 TUBE1283
      CALL HEATB(CI,T1,T2,DXA,X1,X2,BT2,QINC,UINC)                  TUBE1284
      IF(MZ.GE.1000)RETURN                                          TUBE1285
      IC=0                                                          TUBE1286
 3    CALL RATE(BC2,BT2,BRA2)                                       TUBE1287
      CALL MATB(RA1,BRA2,BBC2,BDXA,X1,X2,T1,BT2,PT,PT2)             TUBE1288
      CALL HEATB(CI,T1,BT2,BDXA,X1,X2,BBT2,QINC,UINC)               TUBE1289
      IF(MZ.GE.1000)RETURN                                          TUBE1290
      IF(ABS((BBT2-BT2)/BBT2).GE.0.0001)GO TO 5                     TUBE1291
      GO TO 6                                                       TUBE1292
 5    BT2=(BBT2+BT2)/2.                                             TUBE1293
      IC=IC+1                                                       TUBE1294
      IF(IC.GE.25)STOP1000                                          TUBE1295
      DO 50 I=1,IS                                                  TUBE1296
      DO 50 I=1,IS                                                  TUBE1297
 50   BC2(I)=BBC2(I)                                                TUBE1298
      GO TO 3                                                       TUBE1299
 6    DT=T2OLD-BBT2                                                 TUBE1300
      IF(ZIC.LE.DL)DT=0.0                                           TUBE1301
      T2=BBT2+(BBT2-T1)-DT                                          TUBE1302
      T1=BBT2                                                       TUBE1303
      TMPH=0.0                                                      TUBE1304
      DO 60 I=1,IS                                                  TUBE1305
      P(I)=P(I)*PT2/PT                                              TUBE1306
      C(I)=BBC2(I)                                                  TUBE1307
      X1(I)=X2(I)                                                   TUBE1308
      TMPH=TMPH+X1(I)                                               TUBE1309
 60   CONTINUE                                                      TUBE1310
      PT=PRR(IS)                                                    TUBE1311
      IF(MZ.GE.1000)RETURN                                          TUBE1312
      DO 61 I=1,IS                                                  TUBE1313
 61   P(I)=PT*X1(I)/TMPH                                            TUBE1314
      IF(ZIC.LT.Z85*XN)GO TO 63                                     TUBE1315
      XN=XN+1.                                                      TUBE1316
      JN=JN+1                                                       TUBE1317
      TX(JN)=T1                                                     TUBE1318
 63   CONTINUE                                                      TUBE1319
      IF(ZICI.LE.(ZTT/30.))GO TO 30                                 TUBE1320
C     WRITE(2,901)T1,T2,PT,ZIC                                      TUBE1321
      ZICI=0.                                                       TUBE1322
      MZ=MZ+1                                                       TUBE1323
      WZIC(MZ)=ZIC                                                  TUBE1324
      WT(MZ)=T2                                                     TUBE1325
      WTMPH(MZ)=TMPH                                                TUBE1326
      WPT(MZ)=PT                                                    TUBE1327
      WVEL1(MZ)=VEL1                                                TUBE1328
      DO 70 J=1,ISS                                                 TUBE1329
      WC(J,MZ)=C(J)                                                 TUBE1330
```

```
          WTM(J,MZ)=X2(J)                                                  TUBE1331
    70    WDXA(J,MZ)=DXA(J)                                                TUBE1332
          IF(ZIC.GE.ZTT)GO TO 10                                           TUBE1333
    C901  FORMAT(1X,'T1=',E10.3,'  T2=',E10.3,'  PT=',E10.3,'  ZIC=',E10.3) TUBE1334
    30    QTOT=QTOT+QINC                                                   TUBE1335
          QT(N3)=QT(N3)+QINC                                               TUBE1336
          IF(ZIC.LT.Z33*FLOAT(N3))GO TO 2                                  TUBE1337
          N3=N3+1                                                          TUBE1338
          GO TO 2                                                          TUBE1339
    10    DO 20 I=1,100                                                    TUBE1340
          RADD(I,1)=RADI(I)                                                TUBE1341
    20    RADF(I)=RADI(I)                                                  TUBE1342
          WRITE(6,902)QTOT                                                 TUBE1343
          IF(JN.LT.85)GO TO 64                                             TUBE1344
          RETURN                                                           TUBE1345
    64    DO 65 I=JN,85                                                    TUBE1346
    65    TX(I)=T1                                                         TUBE1347
    902   FORMAT('       NET HEAT FLUX TO PROCESS  FLUID ',E16.7,' BTU')   TUBE1348
          RETURN                                                           TUBE1349
          END                                                              TUBE1350
```

```
      FUNCTION VIS(T,TCOND)                                           VIS 1351
      REAL*4 LOG                                                      VIS 1352
      COMMON/TUBE1/IR,IS,KF(25),KR(25),B(25,10),BB(25,10),DL,IA(25,10) VIS 1353
     1,EA(25),EE(25),RAD,AO                                           VIS 1354
      COMMON/PYRO3/Z(11),ZTT,C(25),CP(25,4)                           VIS 1355
     1,DH(25),DS(25),DE(25)                                           VIS 1356
      COMMON/PO/P(25),ON,SMWT(25),CLJ(25,2),VI(25),AMWT,VEL1,HI       VIS 1357
      DATA A/.4308818/,BI/-.44245917/,CC/.86401820E-1/,D/.77484511E-2/ VIS 1358
      DATA A1/2.6693E-5/,TOLD/10./                                    VIS 1359
      IF(ABS(T-TOLD).LE.25.)GO TO 5                                   VIS 1360
      TOLD=T                                                          VIS 1361
      PT=0.0                                                          VIS 1362
      DO 1 I=1,IS                                                     VIS 1363
    1 PT=PT+P(I)                                                      VIS 1364
      PRESDT=0.                                                       VIS 1365
   11 DO 2 I=1,IS                                                     VIS 1366
      IF(CLJ(I,1).EQ.0) GO TO 2                                       VIS 1367
      E=LOG(T/CLJ(I,2))                                               VIS 1368
      VI(I)=A1*SQRT(SMWT(I)*T)/(CLJ(I,1)**2*EXP(A+BI*E+CC*E**2+D*E**3)) VIS 1369
    2 CONTINUE                                                        VIS 1370
      VIS=0.                                                          VIS 1371
      TCOND=0.0                                                       VIS 1372
      DO 3 I=1,IS                                                     VIS 1373
      IF(CLJ(I,1).EQ.0.)GO TO 3                                       VIS 1374
      V=P(I)/PT*VI (I)                                                VIS 1375
      TC=(4CP(T,I)+2.484)*VI(I)/SMWT(I)                               VIS 1376
      U=0.                                                            VIS 1377
      DO 4 J=1,IS                                                     VIS 1378
      IF(CLJ(J,1).EQ.0.)GO TO 4                                       VIS 1379
      U=U+P(J)/PT*1./SQRT(8.)/(1.+SMWT(I)/SMWT(J))*(1.+(VI(I)/VI(J))**.5VIS 1380
     1*(SMWT(J)/SMWT(I))**.25)**2                                     VIS 1381
    4 CONTINUE                                                        VIS 1382
      VIS=VIS+V/U                                                     VIS 1383
      TCOND=TCOND+P(I)/PT*TC/U                                        VIS 1384
    3 CONTINUE                                                        VIS 1385
      VIS=VIS*.0672                                                   VIS 1386
      TCOND=TCOND*435.15                                              VIS 1387
C     TERMOCONDUCTIVE IN BTU/(HR-FT**2/FT-OK)                         VIS 1388
C     WRITE(2,907)VIS,TCOND                                           VIS 1389
C907  FORMAT(' VIS=  ',E15.5,'   TCOND=',E15.5)                       VIS 1390
      RETURN                                                          VIS 1391
    5 VIS=VIS                                                         VIS 1392
      RETURN                                                          VIS 1393
      END                                                             VIS 1394
```

```
      SUBROUTINE PRESC(T1,T2,PD,THPH)                                   PRES1395
      REAL*4 LOG                                                        PRES1396
      COMMON/PYRL3/Z(11),ZTT,C(25),CP(25,4)                             PRES1397
     1,DH(25),HS(25),DF(25)                                             PRES1398
      COMMON/TUBE1/IR,IS,KF(25),KR(25),B(25,10),BB(25,10),DL,IA(25,10)  PRES1399
     1,EA(25),EE(25),RAD,AO                                             PRES1400
      COMMON/PD/P(25),DN,SMWT(25),CLJ(25,2),VI(25),AMWT,VEL1,HI         PRES1401
      COMMON/PT2/TT,RN1,RN2,VISS                                        PRES1402
      COMMON/SET/MY,MZ,IB,IPLOT,DLS                                     PRES1403
C THIS SUBROUTINE CALULATES PRESSURE DROP FROM BERNOULIE LAW            PRES1404
C MODIFIED TO TAKE FRICTION LOSS INTO CONSIDERATION                     PRES1405
      DATA A2/1.1620929E-4/,A3/7.37495E4/                               PRES1406
      DATA PRESDT/0.0/,GC/1.3143/                                       PRES1407
      T=(T1+T2)/2.                                                      PRES1408
      VISS=VIS(T,TCOND)                                                 PRES1409
      PT=0.0                                                            PRES1410
      DO 2 I=1,IS                                                       PRES1411
    2 PT=PT+P(I)                                                        PRES1412
    1 AMWT=0.                                                           PRES1413
      HCPB=0.0                                                          PRES1414
      VEL2=A2*T2/(PT-PRESDT)/RAD**2*TMPH                                PRES1415
      DO 5 I=1,IS                                                       PRES1416
      HCPB=HCPB+HCP(T,I)*P(I)/PT/SMWT(I)                                PRES1417
    5 AMWT=P(I)/PT*SMWT(I)+AMWT                                         PRES1418
C     GC IN AT.*FT**3  /(OK LB.MOLES)                                   PRES1419
      DEN=PT/((GC*T)*AMWT                                               PRES1420
      IF(DEN.LE.0.)GO TO 21                                             PRES1421
    6 VELA=(VEL1+VEL2)/2.                                               PRES1422
      RENU=2.*RAD*DEN*VELA/VISS                                         PRES1423
      IF(RENU.LE.0.)GO TO 19                                            PRES1424
      IF(RENU.LE.3500.)GO TO 20                                         PRES1425
      GO TO 10                                                          PRES1426
   20 F=64./RENU                                                        PRES1427
      GO TO 100                                                         PRES1428
   10 F=0.00560+.5/(RENU**.32)                                          PRES1429
  100 PD=DEN*(VELA**2*F*DL/RAD+VEL2**2-VEL1**2)/62.4/2116.8             PRES1430
      PD=ABS(PD)                                                        PRES1431
      P2=PT-PD                                                          PRES1432
      IF(P2.LE.0.)GO TO 21                                              PRES1433
      VEL2=A2*T/P2/RAD**2*TMPH                                          PRES1434
      IF(PD.EQ.0.)GO TO 7                                               PRES1435
      IF(ABS((PRESDT-PD)/PD).LE..001)GO TO 7                            PRES1436
      PRESDT=PD                                                         PRES1437
      DEN=(P2+PT)/(2.*GC*T)*AMWT                                        PRES1438
      GO TO 6                                                           PRES1439
    7 PT2=0.                                                            PRES1440
      DO 9 I=1,IS                                                       PRES1441
    9 PT2=PT2+P(I)                                                      PRES1442
      IF((IPLOT.EQ.2).OR.(IPLOT.EQ.3).AND.(MZ.EQ.1))GO TO 1001          PRES1443
      VEL1=VEL2                                                         PRES1444
```

```
      HI=.0207*TCOND/RAD*RENU**.8*(HCPR*VISS/TCOND*3600.*1.8)**.333333  PRES1445
C     HI IN BTU/(FT**2-HR-DK)                                           PRES1446
      IF(VEL1.GE.1214.5)GO TO 22                                        PRES1447
      IF(VEL1.GE.SQRT(A3*P2/DEN))GO TO 22                               PRES1448
31    CONTINUE                                                          PRES1449
      RETURN                                                            PRES1450
22    MZ=3000                                                           PRES1451
      PT=.5                                                             PRES1452
      RETURN                                                            PRES1453
1001   WRITE(2,9001)RENU, VISS,DEN,F,VEL1,VEL2,VELA,T ,PD              PRES1454
      VEL1=VEL2                                                         PRES1455
      RETURN                                                            PRES1456
19    WRITE(2,900)RAD,DEN,VELA,VISS,RENU                                PRES1457
      WRITE(2,902)T,PT,(P(I),I=1,IS),GC,AMWT,P2                         PRES1458
      MZ=2000                                                           PRES1459
      RETURN                                                            PRES1460
21    WRITE(2,902)T,PT,(P(I),I=1,IS),GC,AMWT,P2                         PRES1461
      MZ=2000                                                           PRES1462
      RETURN                                                            PRES1463
900   FORMAT(' RAD=',1PE12.5,'DEN,VELA,VIS,RENU',/4(2X,1PE12.5))       PRES1464
901   FORMAT(' PRESSURE DROP =',1PE12.5,'DEN,VELA,DL,VEL1,VEL2',/5(2X,1PPRES1465
     1E12.5))                                                           PRES1466
902   FORMAT(' T PT P(1)-P(IS), GC AMWT PT2 ',5(1X,F8.2)/)             PRES1467
9001  FORMAT(' FUNCTION PD(T)',/,' RENU=',1PE14.5,5X,'VISS=',1PE14.5,5X,PRES1468
     1 'DE=',1PE14.5,/,' FRICTION FACTOR= ',1PE14.5,5X,'V1,V2,VA=',3(1PEPRES1469
     114.5,5X),/,' TEMPERTURE=',0PF8.2,'PRESSURE D=',1PE14.5)          PRES1470
      END                                                               PRES1471
```

```
          SUBROUTINE TEMPT(TSKIN,ZIC,IND)                                         TEMP1472
          COMMON/ANDY/T1(60),T2(60),T3(60),C1(10),C2(10),C3(10),ZX(7)             TEMP1473
          IF(IND.EQ.2)GO TO 5                                                     TEMP1474
          ZX(1)=0.0                                                               TEMP1475
          DO 1 I=2,7                                                              TEMP1476
    1     ZX(I)=ZX(I-1)+14./3.                                                    TEMP1477
          CALL PZERO(T1(1),210)                                                   TEMP1478
          CALL READ(3,'TEM1',T1(1),60)                                            TEMP1479
          CALL READ(3,'TEM2',T2(1),60)                                            TEMP1480
          CALL READ(3,'TEM3',T3(1),60)                                            TEMP1481
          X1=FITIT(ZX(1),T1(9),7,5,C1(1),1,1.)                                    TEMP1482
          X3=FITIT(ZX(1),T3(9),7,4,C3(1),1,1.)                                    TEMP1483
          X2=FITIT(ZX(1),T2(9),7,4,C2(1),1,1.)                                    TEMP1484
          WRITE(6,901)X1,X2,X3                                                    TEMP1485
  901     FORMAT(' STANDRARD DEVIATION TEMPERATURE CURVE',3E16.7)                 TEMP1486
          IND=2                                                                   TEMP1487
    5     ZSE=ZIC-FLOAT(INT(ZIC)/56)*56.                                          TEMP1488
          IF(ZSE.GT.28.0)ZSE=56.-ZSE                                              TEMP1489
          IF(ZIC.LT.140.)GO TO 10                                                 TEMP1490
          IF(ZIC.LT.220.)GO TO 15                                                 TEMP1491
          TSKIN=EQUA(ZSE,C3(1))                                                   TEMP1492
          GO TO 18                                                                TEMP1493
   10     TSKIN=EQUA(ZSE,C1(1))                                                   TEMP1494
          GO TO 18                                                                TEMP1495
   15     TSKIN=EQUA(ZSE,C2(1))                                                   TEMP1496
   18     IF(TSKIN.LT.700..OR.TSKIN.GT.1400.)GO TO 20                             TEMP1497
          RETURN                                                                  TEMP1498
   20     WRITE(6,900)TSKIN                                                       TEMP1499
  900     FORMAT(' TEMPERATURE OF REACTOR WALL OUTSIDE OF RANGE T= ',E18.5) TEMP1500
          TSKIN=1120                                                              TEMP1501
          RETURN                                                                  TEMP1502
          END                                                                     TEMP1503
```

```
      SUBROUTINE FURN                                                   FURN1504
      COMMON // DUMMY(3),KK, ICODE, HCODE,                              FURN1505
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                    FURN1506
     A TGRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                       FURN1507
     A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                    FURN1508
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                     FURN1509
     A XSURFX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,                     FURN1510
     A RSTART, TCODE, SCODE, NGRAY, JHCHC,                              FURN1511
     A K1, K2, RCRD(10), TDEP(100), PERM(200),NPRNT                     FURN1512
C                                                                       FURN1513
      COMMON /CPHV/ CPCP(11), HVHV(12)                                  FURN1514
C                                                                       FURN1515
C                                                                       FURN1516
      INTEGER SCODE, TCODE, RSTART, HCODE                               FURN1517
      EQUIVALENCE (DUMMY(1),KHTCL5), (DUMMY(2),KHTCL6),                 FURN1518
     1 (PERM(199),DHTCL5), (PERM(200),DHTCL6)                           FURN1519
C                                                                       FURN1520
C                                                                       FURN1521
C                                                                       FURN1522
C                                                                       FURN1523
      CALL PZERO(DUMMY(1),400)                                          FURN1524
      K1=1                                                              FURN1525
      K2=6                                                              FURN1526
      WRITE(K2,876)                                                     FURN1527
  876 FORMAT (1H1)                                                      FURN1528
C     READ AND WRITE THREE TITLE CARDS HERE                             FURN1529
      DO 802 J=1,3                                                      FURN1530
      READ(K1,801)(PERM(N),N=1,18)                                      FURN1531
  801 FORMAT (18A4)                                                     FURN1532
      WRITE(K2,821)(PERM(N),N=1,18)                                     FURN1533
  821 FORMAT(15X,18A4)                                                  FURN1534
  802 CONTINUE                                                          FURN1535
C                                                                       FURN1536
      NDONE = 0                                                         FURN1537
C                                                                       FURN1538
C     RSTART ---- 0 NO RESTART                                          FURN1539
C                 1 GENERATE RESTART DISKS                              FURN1540
C                 2 CASE USES RESTART DISKS                             FURN1541
C                                                                       FURN1542
C     TCODE ---- 0 ALL VOL AND SURF TEMP TO BE READ IN                  FURN1543
C                1 MIN MAX TEMP KNOWN                                   FURN1544
C                2 CALC MIN MAX TEMP FROM ADIABATIC FLAME TEMP          FURN1545
C                3 USE TEMP DATA FROM RESTART DISKS                     FURN1546
C                                                                       FURN1547
C     SCODE ---- 0 VOL AND SURF TEMP ARE ALL VARIABLES                  FURN1548
C                1 SOME VOL TEMP ARE TO BE HELD CONSTANT                FURN1549
C                2 SOME SURF TEMP ARE TO BE HELD CONSTANT               FURN1550
C                3 SOME VOL + SURF TEMP ARE TO BE HELD CONSTANT !       FURN1551
C     JHCHC ---- 0 MEANINGLESS                                          FURN1552
C                1 REVISE HEAT TRANSFER COEFFICIENTS ONLY IF RSTART = 2 FURN1553
```

```
C                                                                       FURN1554
C       NSTART --- 0 NEW CASE                                           FURN1555
C                  1 PREVIOUS CASES HAVE BEEN RUN - TREAT AS RESTART CASE FURN1556
C                                                                       FURN1557
C       NCASE --- 0 NO MORE CASES TO FOLLOW                             FURN1558
C                 1 ANOTHER CASE WILL FOLLOW                            FURN1559
C                                                                       FURN1560
C       NPRNT --- 0 DETAIL RESULTS PRINTED                              FURN1561
C                 1 DETAILED RESULTS NOT PRINTED                        FURN1562
C                                                                       FURN1563
        READ(K1,2)RSTART,TCODE,SCODE,NGRAY,JHCHC,NSTART,NCASE,NPRNT     FURN1564
      2 FORMAT (8I10)                                                   FURN1565
C                                                                       FURN1566
        IF ( NSTART .NE. 0 ) RSTART = 2                                 FURN1567
C                                                                       FURN1568
        IF ( RSTART .EQ. 2 ) GO TO 6                                    FURN1569
      4 CONTINUE                                                        FURN1570
        GO TO 10                                                        FURN1571
    6   CALL READ(4,'START',DUMMY(1),400)                               FURN1572
        IF ( ZLONG .LE. 0.0 .OR. DUMMY(3) .LE. 0.0 .OR.                 FURN1573
     1 NCOL .LE. 0 .OR. NROW .LE. 0 .OR.                                FURN1574
     2 NSURF .LE. 0 .OR. NVOL .LE. 0 .OR.                               FURN1575
     3 NCR .LE. 0 ) GO TO 111                                           FURN1576
        RSTART=2                                                        FURN1577
        NSTART=1                                                        FURN1578
     10 READ (K1,11)NVNSM, NVMAX, NSMAX, KHTCL5, KHTCL6, DHTCL5, DHTCL6 FURN1579
     11 FORMAT ( 5I10,2F10.2 )                                          FURN1580
C                                                                       FURN1581
        CALL CL1 ( NCASE, NSTART, NVNSM, NVMAX, NSMAX )                 FURN1582
C                                                                       FURN1583
        IF ( RSTART .EQ. 2 ) GO TO 40                                   FURN1584
C                                                                       FURN1585
        RETURN                                                          FURN1586
        ENTRY FURNO                                                     FURN1587
        CALL CL2                                                        FURN1588
 40     CALL CL3                                                        FURN1589
        RETURN                                                          FURN1590
        ENTRY FURN1                                                     FURN1591
        NDONE=0                                                         FURN1592
C                                                                       FURN1593
        DO 60 N=1,NVNSM                                                 FURN1594
        WRITE (K2,2 1) N                                                FURN1595
 2    1 FORMAT (1H1,14X,35HENERGY BALANCE INTERMEDIATE RESULTS/15X,     FURN1596
     1 35(1H-)                               /15X,12HTRIAL NUMBERI10)   FURN1597
        HCODE = 0                                                       FURN1598
        ICODE = 0                                                       FURN1599
        CALL CL4                                                        FURN1600
C                                                                       FURN1601
        DO 52 NV=1,NVMAX                                                FURN1602
        WRITE (K2,2011) NV                                              FURN1603
```

```
 2011 FORMAT (/////15X,60HGAS VOLUME ENERGY BALANCE RESULTS, INTERMEDIATFURN1604
     1E TRIAL NUMBER I10 )                                              FURN1605
      CALL CL5                                                          FURN1606
      IF ( HCODE .EQ. 2 .OR. NV .EQ. NVMAX ) GO TO 54                   FURN1607
   51 CONTINUE                                                          FURN1608
      HCODE = 10                                                        FURN1609
      CALL CL4                                                          FURN1610
      HCODE = 1                                                         FURN1611
   52 CONTINUE                                                          FURN1612
C                                                                       FURN1613
   54 DO 56 NS=1,NSMAX                                                  FURN1614
      WRITE (K2,2021) NS                                                FURN1615
 2021 FORMAT (/////15X,62HSURFACE AREA ENERGY BALANCE RESULTS, INTERMEDIFURN1616
     1ATE TRIAL NUMBERI10)                                              FURN1617
      CALL CL6                                                          FURN1618
   55 IF ( ICODE .EQ. 2 .OR. NS .EQ. NSMAX ) GO TO 57                   FURN1619
      ICODE = 10                                                        FURN1620
      CALL CL4                                                          FURN1621
      ICODE = 1                                                         FURN1622
   56 CONTINUE                                                          FURN1623
C                                                                       FURN1624
57    IF ( HCODE .EQ. 2 . AND. NV .EQ. 1 .AND.                          FURN1625
     1 ICODE .EQ. 2 .AND. NS .EQ. 1 ) NDONE = 1                         FURN1626
      IF ( NDONE .EQ. 1 ) GO TO 70                                      FURN1627
   60 CONTINUE                                                          FURN1628
C                                                                       FURN1629
   70 KK = NDONE                                                        FURN1630
      CALL CL7                                                          FURN1631
C                                                                       FURN1632
C                                                                       FURN1633
      RETURN                                                            FURN1634
   90 IF ( RSTART .EQ. 0 ) GO TO 999                                    FURN1635
      IF ( NCASE .NE. 0 ) GO TO 999                                     FURN1636
  111 WRITE(2,112)                                                      FURN1637
  112 FORMAT('1',20X,'RESTART NO GOOD CHECK DS23')                      FURN1638
  999 RETURN                                                            FURN1639
      END                                                               FURN1640
```

```
      SUBROUTINE CL1 ( NCASE, NSTART, NVNSM, NVMAX, NSMAX )            CL1 1641
C                                                                      CL1 1642
      COMMON // DUMMY(3), KK, ICODE, HCODE,                            CL1 1643
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                   CL1 1644
     A TBRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                      CL1 1645
     A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                   CL1 1646
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                    CL1 1647
     A XSURFX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,                    CL1 1648
     A RSTART, TCODE, SCODE, NGRAY, JHCHC,                             CL1 1649
     A K1, K2, RCRD(10), TOEP(100), PERM(200)                          CL1 1650
C                                                                      CL1 1651
      INTEGER SCODE, TCODE, RSTART, HCODE                              CL1 1652
      EQUIVALENCE (DUMMY(1),KHTCL5), (DUMMY(2),KHTCL6),                CL1 1653
     1 (PERM(199),DHTCL5), (PERM(200),DHTCL6)                          CL1 1654
C                                                                      CL1 1655
      COMMON /ED/ A(10,5), S(12,7), C(11,7), GMW(7)                    CL1 1656
C                                                                      CL1 1657
      WRITE (K2,811) RSTART, TCODE, SCODE, JHCHC, NSTART, NCASE,       CL1 1658
     1 NVNSM, NVMAX, NSMAX, KHTCL5, KHTCL6, DHTCL5, DHTCL6             CL1 1659
  811 FORMAT ( ///// 15X 13HPROBLEM CODES / 15X 13(1H-)                CL1 1660
     A /// 20X 12HRESTART CODE I28                                     CL1 1661
     B / 20X 21HTEMPERATURE DATA CODE I19                              CL1 1662
     C / 20X 23HTEMPERATURE CALCULATION CODE I12                       CL1 1663
     D / 20X 31HHEAT TRANSFER COEFFICIENT CODE I10                     CL1 1664
     E // 20X 18HPREVIOUS CASE CODE I22                                CL1 1665
     F / 20X 20HSUBSEQUENT CASE CODE I20                               CL1 1666
     G // 20X 33HNUMBER OF OVERALL ENERGY BALANCES I17                 CL1 1667
     H / 20X 36HNUMBER OF GAS VOLUME ENERGY BALANCES I14               CL1 1668
     I / 20X 38HNUMBER OF SURFACE AREA ENERGY BALANCES I12             CL1 1669
     M // 20X,68HNUMBER OF GAS VOLUME ENERGY BALANCES USING CURRENT INTECL1 1670
     NRCHANGE AREAS,I12                                                CL1 1671
     D / 20X 72HNUMBER OF SURFACE AREA ENERGY BALANCES USING CURRENT INTCL1 1672
     PERCHANGE AREAS,I10                                               CL1 1673
     A // 20X 47HTOLERANCE ON GAS VOLUME ENERGY BALANCE, DEG. F,       CL1 1674
     L F13.3                                                           CL1 1675
     K / 20X 49HTOLERANCE ON SURFACE AREA ENERGY BALANCE, DEG. F,      CL1 1676
     L F11.3 )                                                         CL1 1677
C                                                                      CL1 1678
      KERR = 0                                                         CL1 1679
C                                                                      CL1 1680
C     DEFINE FURNACE GEOMETRY, AND HEAT RELEASE PATTERN                CL1 1681
C                                                                      CL1 1682
   15 CALL AAA ( KERR )                                                CL1 1683
C                                                                      CL1 1684
C     READ FUEL CODE, EXCESS AIR, FUEL TEMP, BRIDGE WALL TEMP,         CL1 1685
C     AND BOX PRES                                                     CL1 1686
C                                                                      CL1 1687
C     KFUEL ---- 0 OIL FIRING                                          CL1 1688
C                1 GAS FIRING                                          CL1 1689
C                                                                      CL1 1690
```

```
      IF ( RSTART .EQ. 2 ) GO TO 31                                     CL1 1691
   21 READ (K1,23) KFUEL, XAIR, FTEMP, TBRIDG, PRES                      CL1 1692
   23 FORMAT (I10,4F10.0)                                               CL1 1693
      IF ( FTEMP .EQ. [illegible].0 ) FTEMP = 60.0                               CL1 1694
      IF ( TBRIDG .EQ. 0.0 ) TBRIDG = -460.0                            CL1 1695
      WRITE (K2,8020) KFUEL, XAIR, FTEMP                                CL1 1696
 8020 FORMAT (  1H1, 14X, 13HFUEL ANALYSIS / 15X, 13H-------------///   CL1 1697
     1 20X, 23HFUEL CODE (0=OIL,1=GAS) I25 / 20X, 20HEXCESS AIR, PER CENTCL1 1698
     2,    F23.2 / 20X, 30HFUEL-AIR MIXTURE TEMP., DEG. F F18.2)        CL1 1699
      FTEMP = FTEMP + 460.0                                             CL1 1700
      TBRIDG = TBRIDG + 460.0                                           CL1 1701
C                                                                       CL1 1702
C     COMPUTE FUEL ANALYSIS AND THE SPECIFIC HEAT + ENTHALPY DATA       CL1 1703
C                                                                       CL1 1704
   31 CALL BBB ( KERR )                                                 CL1 1705
C                                                                       CL1 1706
C     ESTABLISH TEMPERATURES                                            CL1 1707
C                                                                       CL1 1708
      IF ( RSTART .EQ. 2 .AND. TCODE .EQ. 3 ) GO TO 41                  CL1 1709
      CALL CCC                                                          CL1 1710
C                                                                       CL1 1711
C     ESTABLISH VOLUME AND SURFACE DATA                                 CL1 1712
   41 JUNK = 0                                                          CL1 1713
      IF ( RSTART .EQ. 2 .AND. JHCHC .EQ. 0 ) JUNK = 1                  CL1 1714
      IF ( RSTART .EQ. 2 .AND. JHCHC .EQ. 1 ) JUNK = 2                  CL1 1715
      CALL DDD ( JUNK, KERR )                                           CL1 1716
C                                                                       CL1 1717
C     CHARACTERIZE FLUE GAS                                             CL1 1718
C                                                                       CL1 1719
   51 IF ( RSTART .EQ. 2 ) GO TO 61                                     CL1 1720
      CALL EEE                                                          CL1 1721
C                                                                       CL1 1722
   61 IF ( KERR .EQ. 0 ) RETURN                                         CL1 1723
      STOP                                                              CL1 1724
      END                                                               CL1 1725
```

```
          SUBROUTINE AAA(KAPUT)                                        AAA 1726
          COMMON // DUMMY(3),KK, ICODE, HCODE,                          AAA 1727
         A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(6,3),               AAA 1728
         A TBRIDG, PRES, FLUET, FLUE(5), XMAX, TSINK,                  AAA 1729
         A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,               AAA 1730
         A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                AAA 1731
         A XSURFX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,                AAA 1732
         A RSTART, TCODE, SCODE, NGRAY, JHCHG,                         AAA 1733
         A K1, K2, RCRD(10), TDEP(100), PERM(200)                      AAA 1734
    C                                                                  AAA 1735
          INTEGER SCODE,TCODE,RSTART,HCODE                             AAA 1736
          EQUIVALENCE (Z1(1), Z(1)),(Z2(1),Z( 61))                     AAA 1737
          DIMENSION Z(120),Z1( 60),Z2( 60)                             AAA 1738
          KERR=0                                                       AAA 1739
          IF(RSTART.EQ.2) GO TO 30                                     AAA 1740
    C     FURNACE GEOMETRY- - DIMENSIONS ARE IN FEET                   AAA 1741
          READ(K1,16) NCOL,NROW,XWIDE,YHIGH,ZLONG,XLX,(XSURFX(J),J=1,9)  AAA 1742
       16 FORMAT(2I10/4F10.2/(3F10.2))                                 AAA 1743
          IF(FLOAT(NCOL*NROW)*XWIDE*YHIGH*ZLONG.GT.0.0)GO TO 21        AAA 1744
          KERR=1                                                       AAA 1745
          WRITE(K2,18) NCOL,NROW,XWIDE,YHIGH,ZLONG                     AAA 1746
       18 FORMAT(27H FURNACE GEOMETRY INCORRECT/10X,5HCOL =I5,10X,5HROW =I5 AAA 1747
         1/10X,3HX =F10.4,10X,3HY =F10.4,10X,3H Z=F10.4)               AAA 1748
          GO TO 30                                                     AAA 1749
       21 XO=XWIDE/FLOAT(NCOL)                                         AAA 1750
          YO=YHIGH/FLOAT(NROW)                                         AAA 1751
          NVOL=NCOL*NROW                                               AAA 1752
          NXSXN=0                                                      AAA 1753
          DO 22 J=1,9                                                  AAA 1754
          IF(XSURFX(J).EQ.0.0)GO TO 24                                 AAA 1755
          NXSXN=NXSXN+1                                                AAA 1756
          XSURFX(J)=(AINT(XSURFX(J)/XO+.5))*XO                         AAA 1757
       22 CONTINUE                                                     AAA 1758
       24 NSURF=2*(NCOL+NROW)+NXSXN*NROW                               AAA 1759
          NCR=2*(NCOL+NROW)                                            AAA 1760
          NSSBLK=NSURF/15                                              AAA 1761
          IF(NSSBLK*15-NSURF.EQ.0)GO TO 25                             AAA 1762
          NSSBLK=NSSBLK+1                                              AAA 1763
       25 NGGBLK=NVOL/15                                               AAA 1764
          IF(NGGBLK*15-NVOL.EQ.0) GO TO 26                             AAA 1765
          NGGBLK=NGGBLK+1                                              AAA 1766
       26 NGSBLK=NSSBLK                                                AAA 1767
          NSGBLK=NGGBLK                                                AAA 1768
          IF(NVOL.LE. 60.AND.NSURF.LE. 60)GO TO 28                     AAA 1769
          KERR=1                                                       AAA 1770
          WRITE(K2,27) NVOL,NSURF                                      AAA 1771
       27 FORMAT(' NUMBER OF GAS VOLUMES AND/OR SURFACE AREAS EXCEEDED  60',AAA 1772
         1/,10X,' GAS VOLUMES =',I5,10X,' SURFACE AREAS=',I5)          AAA 1773
          GO TO 30                                                     AAA 1774
       28 WRITE(K2,8000)XWIDE,YHIGH,ZLONG,(J,XSURFX(J),J=1,9),NCOL,    AAA 1775
```

```
           1NROW,XO,YO,NVOL,NSURF                                         AAA 1776
     8000  FORMAT(1H1,14X,' FURNACE GEOMETRY',/,15X,'-----------------------'AAA 1777
           1,///,20X,15HSIZE OF FURNACE  ,//,25X,11HWIDTH, FEET,    F33.2,/,25AAA 1778
           2X, 12HHEIGHT, FEET, F32.2,/,25X,12HLENGTH, FEET, F32.2//,25X,  AAA 1779
           336HINTERMEDIATE TUBE ROW LOCATION, FEET9(/,53X,I5,F10.2)///,20X, AAA 1780
           4'SUBDIVISION OF FURNACE',//,25X,'NO. OF COLUMNS',I29/,25X,     AAA 1781
           5'NO. OF ROWS',I32//,25X,'COLUME WIDTH , FEET',F25.2/,25X,      AAA 1782
           6'ROW HEIGHT, FEET',F28.2//,25X,'NO. OF GAS VOLUMES',I25,/,25X, AAA 1783
           7 ' NO OF SURFACE AREAS',I23)                                   AAA 1784
      C   DUTY(MM BTU/HR),HEAT AVAILABILITY(BTU/LB FUEL)                   AAA 1785
       30  READ(K1,31)HDUTY,HTVAL                                          AAA 1786
       31  FORMAT(2F10.2)                                                  AAA 1787
           IF(HDUTY*HTVAL.NE.0.0)GO TO 33                                  AAA 1788
           KERR=1                                                          AAA 1789
           WRITE(K2,32)HDUTY,HTVAL                                         AAA 1790
       32  FORMAT(' FURNACE FIRING RATE AND OR FUEL HEATING VALUES ARE NOT  AAA 1791
           1COMPLETE'/10X,' FIRING RATE (MM BTU/HR) =',F20.5  ,10X,'FUEL HEATAAA 1792
           2ING VALUE (BTU/LB) =',F10.0)                                   AAA 1793
           GO TO 34                                                        AAA 1794
      C   FRATE= LB FUEL/FT OF FURNACE LENGTH                              AAA 1795
       33  FRATE=HDUTY/HTVAL*1.E6/ZLONG                                    AAA 1796
      C   HEAT RELEASE PATTERN EXPRESSED AS BTU/HR/FT OF FURNACE           AAA 1797
      C   READ DATA IN AS A PERCENTAGE OR FRACTION OF TOTAL HEAT RELEASED  AAA 1798
       34  CALL PZERO(Z(1),120)                                            AAA 1799
           READ(K1,35)(Z1(N),N=1,NVOL)                                     AAA 1800
           READ(K1,35)(Z2(N),N=1,NSURF)                                    AAA 1801
       35  FORMAT(7F10.0)                                                  AAA 1802
           SUM=0.0                                                         AAA 1803
           DO 36 N=1,120                                                   AAA 1804
           SUM=SUM+Z(N)                                                    AAA 1805
       36  CONTINUE                                                        AAA 1806
           IF(HDUTY*ZLONG*SUM.EQ.0.0)GO TO 40                              AAA 1807
           FAC=HDUTY/ZLONG*1.E6/SUM                                        AAA 1808
           DO 37 N=1,120                                                   AAA 1809
           Z(N)=Z(N)*FAC                                                   AAA 1810
       37  CONTINUE                                                        AAA 1811
           CALL WRITE(2,'HGAS',Z1(1), 60)                                  AAA 1812
           CALL WRITE(2,'HSUF',Z2(1), 60)                                  AAA 1813
           WRITE(K2,8010)HDUTY,HTVAL                                       AAA 1814
     8010  FORMAT(1H1,14X,'FURNACE HEAT DUTY AND HEAT RELEASE PATTERN'/     AAA 1815
           115X,'----- -----------------------------------'///20X,'HEAT DUTY AAA 1816
           2,MM BTU/HR  ',E16.5/23X,'HEAT AVAILIBILITY'/25X,'BTU/LB OF FUEL',FAAA 1817
           316.0)                                                          AAA 1818
           WRITE(K2,8020)(Z1(N),N=1,NVOL)                                  AAA 1819
     8020  FORMAT(//20X,'HEAT RELEASE PATTERN --- BTU/HR/FOOT OF FURNACE'//25AAA 1820
           1X,'GAS VOLUMES'//(25X,6E15.0))                                 AAA 1821
           WRITE(K2,8030)(Z2(N),N=1,NSURF)                                 AAA 1822
     8030  FORMAT(/25X,' SURFACE AREAS'//(25X,6E15.0))                     AAA 1823
           IF(KERR.NE.0)KAPUT=KERR                                         AAA 1824
       40  CONTINUE                                                        AAA 1825
```

```
101         RETURN                                                    AAA 1826
102         END                                                       AAA 1827
```

```
      SUBROUTINE BBB(KAPUT)                                             BBB 1828
C    COMPUTE FUEL GAS SPECIFIC HEAT+ENTHAPY                              BBB 1829
C    (SPECIFIC HEAT AND ENTHALPY DATA TO BE STORED IN POLYNOMINAL FORM)  BBB 1830
C                                                                        BBB 1831
      COMMON // DUMMY(3),KK, ICODE, HCODE,                              BBB 1832
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                    BBB 1833
     A TERIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                       BBB 1834
     A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                    BBB 1835
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                     BBB 1836
     A XSUREX(9), XO, YO, ZLENG, NCOL, NROW, NXSXN,                     BBB 1837
     A RSTART, TCODE, SCODE, NGRAY, JHCHC,                              BBB 1838
     A K1, K2, RCRD(10), TDEP(100), PERM(200)                           BBB 1839
C                                                                        BBB 1840
      INTEGER SCODE, TCODE, RSTART, HCODE                               BBB 1841
      COMMON/ED/ A(10,5),Z(12,7),C(11,7),CMW(7)                         BBB 1842
      COMMON/CPHV/ CP(11),HV(12)                                        BBB 1843
      REAL COMP(25),CMWGAS(25),FWT(5)                                   BBB 1844
      DATA CMWGAS /16.,30.1,44.1,2*58.1,2*72.1,86.2,100.2,114.2,28.0,42.BBB 1845
     11,4*56.1,26.1,40.1,54.1,28.0,44.0,2.0,34.1,18.0,28.0/              BBB 1846
      KERR=0                                                            BBB 1847
      IF(RSTART.EQ.2)GO TO 80                                           BBB 1848
      FLUET=1.                                                          BBB 1849
      XMWX=1.                                                           BBB 1850
      IF(KFUEL.NE.0)GO TO 60                                            BBB 1851
C    COMPUTE FUEL GAS ANALYSIS ON A PER FOOT OF FURNACE BASIS           BBB 1852
C    FLUE(1)          CO2                                               BBB 1853
C    FLUE(2)          H2O                                               BBB 1854
C    FLUE(3)          SO2                                               BBB 1855
C    FLUE(4)          O2                                                BBB 1856
C    FLUE(5)          N2                                                BBB 1857
C    FUEL DATA -- OIL FIRING                                            BBB 1858
C    HCRATO= H/C ON WT BASIS                                            BBB 1859
C    FSULF = WT % SULFUR IN FUEL OIL                                    BBB 1860
C    STEAM  = LB STEAM/ LB FUEL OIL                                     BBB 1861
      READ(K1,35)FMW,FAPI,FBP,FWATK,HCRATO,FSULF,STEAM                  BBB 1862
   35 FORMAT(7F10.0)                                                    BBB 1863
      IF(STEAM.LT.0.0.OR.STEAM.GT.1.0)STEAM=0.5                         BBB 1864
      SRATE=FRATE*STEAM                                                 BBB 1865
C    PRIORITY OF MOL WT DETERMINATION                                   BBB 1866
C      1    MOL WT KNOW                                                 BBB 1867
C      2    API+BP                                                      BBB 1868
C      3    BP+WATK                                                     BBB 1869
C      4    API+WATK                                                    BBB 1870
C      5    BP                                                          BBB 1871
      KJ=0                                                              BBB 1872
      IF(FMW.GT.0.)GO TO 57                                             BBB 1873
      IF(FBP.NE.0.0)KJ=4                                                BBB 1874
      IF(FAPI*FWATK.NE..0)KJ=3                                          BBB 1875
      IF(FBP*FWATK.NE.0.0)KJ=2                                          BBB 1876
      IF(FAPI*FBP.NE.0.0)KJ=1                                           BBB 1877
```

```
      IF(KJ.EQ.0)GO TO 53                                              BBB 1878
      GO TO (42,45,46,52),KJ                                           BBB 1879
C     KJ=1  BB CHART 3-25                                              BBB 1880
   42 FBP=AMIN1(FBP,1200.)                                             BBB 1881
      FBP=AMAX1(FBP,100.)                                              BBB 1882
      B=(FBP+460.)/1000.                                               BBB 1883
      IF(FBP.LE.750.)GO TO 43                                          BBB 1884
      FAPI=AMIN1(FAPI,40.)                                             BBB 1885
      FAPI=AMAX1(FAPI,-30.)                                            BBB 1886
      S=141.5/(FAPI+131.5)                                             BBB 1887
      GO TO 44                                                         BBB 1888
   43 FAPI=AMAX1(FAPI,0.)                                              BBB 1889
      S=141.5/(FAPI+131.5)                                             BBB 1890
      SMIN=((0.6256337E-2*B**3-0.40441530)*B**2+                       BBB 1891
     1      0.10806022E01)*B+0.74099427E-1                             BBB 1892
      S=AMAX1(S,SMIN)                                                  BBB 1893
   44 FMW=-458.6322+56.096181*S**4-314.00029*S**3+16.97091*(S*B)**3    BBB 1894
     1 +401.56651*B**2-3.8014449*B**6+24.871805/(S**2*B)-10.016105/(S*BBBB 1895
     2**3)+94.833174*S**4/B+457.37528*S/B-77.255634*(S/B)**3+3.4481747*(BBB 1896
     3S/B)**6-39.325111*S*B**3+22.007505*(B/S)**3-.82716156*(B/S)**6   BBB 1897
      GO TO 57                                                         BBB 1898
C     KJ=2  BB CHART 2-20 TO OBTAIN API THEN DO KJ=1                   BBB 1899
   45 FBP=AMIN1(FBP,1000.)                                             BBB 1900
      FBP=AMAX1(FBP,100.)                                              BBB 1901
      FWATK=AMIN1(FWATK,14.)                                           BBB 1902
      FWATK=AMAX1(FWATK,9.)                                            BBB 1903
      B=(FBP+460.)/1000.                                               BBB 1904
      AK=FWATK/10.                                                     BBB 1905
      FAPI=-102.40915+139.36071*AK-7.90343*AK**2-28.81656*B+0.06136*B**5BBB 1906
     1+9.84756*AK/B-0.16243*(AK/B)**5                                  BBB 1907
      GO TO 42                                                         BBB 1908
C     KJ=3 BB CHART 2-20 TO OBTAIN BP THAN DO KJ=1                     BBB 1909
   46 FWATK=AMIN1(FWATK,14.)                                           BBB 1910
      FWATK=AMAX1(FWATK,9.)                                            BBB 1911
      FAPI=AMIN1(FAPI,105.)                                            BBB 1912
      FAPI=AMAX1(FAPI,-20.)                                            BBB 1913
   47 S=141.5/ (FAPI+131.5)                                            BBB 1914
      AK=FWATK/10.                                                     BBB 1915
      X1=S/AK                                                          BBB 1916
      X2=AK/S                                                          BBB 1917
      B=-0.46639378+(-0.094640507*S**4+0.39503379)*S-0.01592527*AK**5  BBB 1918
     1+((-0.1002351*X1+0.19565272)*X1**2-0.6665293E-1) *X1**2+(-0.31778BBB 1919
     282E-3*X2**4+0.14858729)*X2+0.10089545E+1*(S*AK)**3               BBB 1920
      FBP=B*1000.-460.                                                 BBB 1921
      IF(FBP.GE.100.)GO TO 51                                          BBB 1922
      FAPI=AMAX1(FAPI,24.)                                             BBB 1923
      GO TO 47                                                         BBB 1924
   51 IF(FBP.LE.1000.) GO TO 42                                        BBB 1925
      FAPI=AMIN1(FAPI,42.5)                                            BBB 1926
      GO TO 47                                                         BBB 1927
```

```
C     KJ=4   BB CHART 3-20                                                BBB 1928
 52      B=(FBP+460.)/1000.                                               BBB 1929
         FMW=-1.446891+81.959317*F+152.39287*B**3-9.97706*B**5            BBB 1930
         GO TO 57                                                         BBB 1931
 53      KERR=1                                                           BBB 1932
         WRITE(K2,55)                                                     BBB 1933
 55      FORMAT(' INSUFFICIENT DATA TO COMPUTE MOL WT OF FUEL OIL ')      BBB 1934
         GO TO 80                                                         BBB 1935
C     HC COMPOSITION   X=ATOMS OF CARBON   Y = ATOMS OF HYDROGEN          BBB 1936
 57      IF(HCRATO.NE.0.0)GO TO 59                                        BBB 1937
         KERR=1                                                           BBB 1938
         WRITE(K2,58)                                                     BBB 1939
 58      FORMAT(' HYDROGEN CARBON RATO MUST BE GIVEN TO FUEL GAS COMPOSITIOBBB 1940
        1N')                                                              BBB 1941
         GO TO 80                                                         BBB 1942
 59      HCFAC=12.*HCRATO                                                 BBB 1943
         X=FMW/(12.+HCFAC)                                                BBB 1944
         Y=HCFAC*X                                                        BBB 1945
         FMOL=FRATE/FMW                                                   BBB 1946
C     SULFUR RATE IN LB/HR/FT                                             BBB 1947
         SLBHR=FRATE*FSULF/100.                                           BBB 1948
         WRITE(K2,8030) FMW,FAPI,FBP,FWATK,HCRATO,FSULF,STEAM             BBB 1949
 8030    FORMAT(//20X,'OIL FIRING'//25X,'MOLECULAR WEIGHT',F27.2/25X,'API',BBB 1950
        1F40.2/25X,'BOILING POINT (MEAN)',F23.2/25X,'WATSON K',F35.2//25X,'BBB 1951
        2H/C RATIO, WT.BASIS',F24.4//25X,'WT. % SULFUR',F31.4//25X,'ATOMIZABBB 1952
        3TION STEAM'/30X,'LBS. STEAM/ LB. FUEL OIL',F13.4)                BBB 1953
         FLUE(1)=X*FMOL                                                   BBB 1954
         FLUE(2)=Y/2.*FMOL+SRATE/18.                                      BBB 1955
         FLUE(3)=SLBHR/32.                                                BBB 1956
         REQO2=((X+Y/4.)*FMOL)+SLBHR/32.                                  BBB 1957
         FLUE(4)=REQO2*XAIR/100.                                          BBB 1958
         FLUE(5)=79./21.*REQO2*(1.+XAIR/100.)                             BBB 1959
         GO TO 67                                                         BBB 1960
C     FUEL DATA --- GAS FIRING                                            BBB 1961
 60      READ(K1,35)(COMP(J),J=1,25)                                      BBB 1962
         SUM=0.                                                           BBB 1963
         DO 62 N=1,25                                                     BBB 1964
         SUM=SUM+COMP(N)                                                  BBB 1965
 62      CONTINUE                                                         BBB 1966
         IF(SUM.NE.0.0)GO TO 64                                           BBB 1967
         KERR=1                                                           BBB 1968
         WRITE(K2,63)                                                     BBB 1969
 63      FORMAT(' FUEL COMPOSITION REQUIRED')                             BBB 1970
         GO TO 80                                                         BBB 1971
 64      FMW=0.                                                           BBB 1972
         DO 65 N=1,25                                                     BBB 1973
         COMP(N)=COMP(N)/SUM                                              BBB 1974
         FMW=FMW+COMP(N)*CMWGAS(N)                                        BBB 1975
 65      CONTINUE                                                         BBB 1976
         WRITE(K2,8040)FMW,(COMP(J),J=1,25)                               BBB 1977
```

```
      FMOL=FRATE/FMW                                                    BBB 1978
 8040 FORMAT(//20X,'GAS FIRING'//25X,'MOLECULAR WEIGHT',15X,F12.2//25X,'BBB 1979
     1FUEL COMPOSITION MOLE FRACTION'//30X,'METHANE',F28.6/30X,'ETHAN',FBBB 1980
     229.6/30X,'PROPANE',F29.6/30X,'ISOBUTANE',F26.6/30X,'BUTANE',F29.6/BBB 1981
     330X ,'ISOPENTANE',F25.6/30X,'PENTANE',F28.6/30X,'HEXANE',F29.6/30XBBB 1982
     4,'HEPTANE',F28.6/30X,'OCTANE',F29.6//30X,'ETHYLENE',F27.6/30X,'PROBBB 1983
     5PYLENE',F26.6/30X,'BUTENE-1',F27.6/30X,'C-BUTENE-2,',F25.6/30X,'TBBB 1984
     6-BUTENE-2,',F25.6/30X,'ISOBUTENE',F26.6//30X,'ACETYLENE',F26.6/30XBBB 1985
     7 ,'PROPYNE',F28.6/30X,'BUTYNE-1',F27.6//30X,'CARBON MONOXIDE',F20.BBB 1986
     86 /30X,'CARBON DIOXIDE',F21.6 /30X,'HYDROGEN',F27.6/30X,'HYDROGEN BBB 1987
     9SULFIDE',F19.6/30X,'WATER',F30.6/30X,'NITROGEN',F27.6)            BBB 1988
      DO 66 N=1,25                                                      BBB 1989
      COMP(N)=COMP(N)*FMOL                                              BBB 1990
   66 CONTINUE                                                          BBB 1991
      FLUE(1)=COMP(1)+2.*COMP(2)+3.*COMP(3)+4.*(COMP(4)+COMP(5))+5.*(COMBBB 1992
     1P(7))+6.*COMP(8)+7.*COMP(9)+8.*COMP(10)+2.*COMP(11)+3.*COMP(12)+4.BBB 1993
     2*(COMP(13)+COMP(14)+COMP(15)+COMP(16))+2.*COMP(17)+3.*COMP(18)+4.*BBB 1994
     3COMP(19)+COMP(20)+COMP(21)                                        BBB 1995
      FLUE(2)=2.*COMP(1)+3.*COMP(2)+4.*COMP(3)+5.*(COMP(4)+COMP(5)+COMP(BBB 1996
     16)+COMP(7))+7.*COMP(8)+8.*COMP(9)+9.*COMP(10)+2.*COMP(11)+3.*COMP(BBB 1997
     212)+4.*COMP(13)+4.*(COMP(15)+COMP(16)+COMP(14))+COMP(17)+2.*COMP(1BBB 1998
     38)+3.*COMP(19)+COMP(22)+COMP(23)+COMP(24)                         BBB 1999
      FLUE(3)=COMP(23)                                                  BBB 2000
      REO2=2.*COMP(1)+3.5*COMP(2)+5.*COMP(3)+6.5*(COMP(4)+COMP(5))+8.*(BBB 2001
     1COMP(6)+COMP(7))+9.5*COMP(8)+11.*COMP(9)+12.5*COMP(10)+6.*(COMP(13BBB 2002
     2)+COMP(14)+COMP(15)+COMP(16))+2.5*COMP(17)+4.*COMP(18)+5.5*COMP(19BBB 2003
     39)+.5*COMP(20)+.5*COMP(22)+1.5*COMP(23)                           BBB 2004
      FLUE(4)=REO2*XAIR/100.                                            BBB 2005
      FLUE(5)=79./21.*REO2*(1.+XAIR/100.)+COMP(25)                      BBB 2006
C     NORMALIZE FLUE GAS COMPOSITION AND COMPUTIES TOTAL MOLES OF FLUE  BBB 2007
C             GAS PER FOOT OF FURNACE                                   BBB 2008
   67 FLUET=0.                                                          BBB 2009
      DUMMY(3)=FRATE                                                    BBB 2010
      DO 68 N=1,5                                                       BBB 2011
      FLUET=FLUET+FLUE(N)                                               BBB 2012
   68 CONTINUE                                                          BBB 2013
      DO 69 N=1,5                                                       BBB 2014
      FLUE(N)=FLUE(N)/FLUET                                             BBB 2015
   69 CONTINUE                                                          BBB 2016
C    SPECIFIC HEAT AND ENTHALPY DATA ARE TO BE IN TERMS OF DEG R        BBB 2017
      XMWX=0.                                                           BBB 2018
      DO 71 J=1,5                                                       BBB 2019
      XMWX=XMWX+FLUE(J)*CMW(J)                                          BBB 2020
   71 CONTINUE                                                          BBB 2021
      WRITE(K2,8050)FLUET,XMWX,(FLUE(J),J=1,5)                          BBB 2022
 8050 FORMAT(//20X,'FLUE GAS'//25X,'RATE MOLES/HR PER'/30X,'FOOT OF FURNBBB 2023
     1ACE',F23.2/25X,'MOLECULAR WEIGHT',15X,F12.2//25X,'FLUE GAS COMPOSIBBB 2024
     2TION, MOLE FRACTION'/51X,'CO2' ,F14.6/51X,'H2O',F14.6/51X,'SO2' ,FBBB 2025
     314.6/51X,'O2' ,F15.6/51X,'N2' ,F15.6)                             BBB 2026
      DO 72 J=1,5                                                       BBB 2027
```

```
      FWT(J)=FLUE(J)*CMW(J)/XMWX                          BBB 2028
   72 CONTINUE                                            BBB 2029
      HV(1)=10.                                           BBB 2030
      HV(2)=0.                                            BBB 2031
      DO 75 K=1,10                                        BBB 2032
      HV(K+2)=0.                                          BBB 2033
      DO 74 J=1,5                                         BBB 2034
      HV(K+2)=HV(K+2)+A(K,J)*FWT(J)                       BBB 2035
   74 CONTINUE                                            BBB 2036
   75 CONTINUE                                            BBB 2037
      CP(1)=9.                                            BBB 2038
      DO 77 K=3,12                                        BBB 2039
      CP(K-1)=FLOAT(K-2)*HV(K)/1000.                      BBB 2040
   77 CONTINUE                                            BBB 2041
      CALL WRITE(2,'HV   ',HV(1),12)                      BBB 2042
      CALL WRITE(2,'CP   ',CP(1),11)                      BBB 2043
      GO TO 82                                            BBB 2044
C    BULK FLOW PATTERN                                    BBB 2045
   80 FLUET=FLUET/DUMMY(3)*FRATE                          BBB 2046
      DUMMY(3)=FRATE                                      BBB 2047
   82 CALL FLOW(FLUET*XMWX,KERR)                          BBB 2048
      IF(KERR.NE.0)KAPUT=KERR                             BBB 2049
      RETURN                                              BBB 2050
      END                                                 BBB 2051
```

```
          SUBROUTINE FLOW (FAC,KAPUT)                                    FLOW2052
C      FAC= TOTAL FLUE GAS FLOW RATE PER FOOT OF FURNACE -- LB/HR       FLOW2053
          COMMON // DUMMY(3),KK, ICODE, HCODE,                           FLOW2054
         A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(3,3),                 FLOW2055
         A TBRIDG, PRES, FLUET, FLUE(5), XHWX, TSINK,                    FLOW2056
         A HCP, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                 FLOW2057
         A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                  FLOW2058
         A XSUREX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,                  FLOW2059
         A RSTART, TCODE, SCODE, NGRAY, JHCHC,                           FLOW2060
         A K1, K2, RCRD(10), TDEP(100), PERM(200)                        FLOW2061
          INTEGER SCODE,TCODE,RSTART,HCODE                               FLOW2062
          DIMENSION Z(240),NI(120),GMX(120),GMY(120)                     FLOW2063
          EQUIVALENCE (GMX(1),Z(1)),(GMY(1),Z(121))                      FLOW2064
          KERR=0                                                         FLOW2065
C      READ IN THE BULK FLOW PATTERN -- BASIS IS 1.0 LB/HR/FOOT OF FURNACE FLOW2066
C      X - DIRECTION    (NCOL+1)*NROW                                    FLOW2067
C       Y- DIRECTION    (NROW+1)*NCOL                                    FLOW2068
          CALL PZERO(Z(1),240)                                           FLOW2069
          NX=(NCOL+1)*NROW                                               FLOW2070
          READ(K1,35)(GMX(N),N=1,NX)                                     FLOW2071
   35     FORMAT(7F10.0)                                                 FLOW2072
          NY=(NROW+1)*NCOL                                               FLOW2073
          READ(K1,35)(GMY(N),N=1,NY)                                     FLOW2074
C      ADJUSTES FLOW PATTERN BASED ON ACTUAL TOTAL FLUE GAS FLOW RATE    FLOW2075
C                   PER FOOT OF FURNACE                                  FLOW2076
   36     FFAC=FAC                                                       FLOW2077
          DO 37 N=1,240                                                  FLOW2078
          Z(N)=Z(N)*FFAC                                                 FLOW2079
   37     CONTINUE                                                       FLOW2080
          CALL WRITE(2,'GMX ',GMX(1), NX)                                FLOW2081
          CALL WRITE(2,'GMY ',GMY(1), NY)                                FLOW2082
          WRITE(K2,8099)                                                 FLOW2083
 8099  FORMAT('1',15X,'FLUE GAS FLOW PATTERN,LB/HR/FOOT OF FURNACE'/15X,FLOW2084
        143(1H-))                                                        FLOW2085
          WRITE(K2,8110)(GMX(N),N=1,NX)                                  FLOW2086
 8110  FORMAT(//23X,'X - DIRECTION'//(25X,6E15.0))                       FLOW2087
          WRITE(K2,8120)(GMY(N),N=1,NY)                                  FLOW2088
 8120  FORMAT(//,20X,'Y - DIRECTION',//(25X,6E15.0))                     FLOW2089
C      CHECK EACH GAS VOLUME FOR FLOW BALANCE (IN = OUT)                 FLOW2090
C      MATTERAL BALANCE CHECK ON GAS VOL        JR=ROW NO    JC=COL NO   FLOW2091
C         X -  DIRECTION                                                 FLOW2092
C            IN        JX1=(JR-1)*(NCOL+1)+(JC)                          FLOW2093
C            OUT       JX2= (JR-1)*(NCOL+1)+(JC+1)                       FLOW2094
C         Y - DIRECTION                                                  FLOW2095
C            IN        JY1=(J)                                           FLOW2096
C            OUT       JYZ = (J+NCOL)                                    FLOW2097
   38     K=0                                                            FLOW2098
          CALL NZERO(NI(1),150)                                          FLOW2099
          DO 43 J=1,NVOL                                                 FLOW2100
          JR=0                                                           FLOW2101
```

```
      JC=J                                                              FLOW2102
   40 JR=JR+1                                                           FLOW2103
      IF(JC.LE.NCOL)GO TO 41                                            FLOW2104
      JC=JC-NCOL                                                        FLOW2105
      GO TO 40                                                          FLOW2106
   41 JX1=(JR-1)*(NCOL+1)+JC                                            FLOW2107
      JX2=JX1+1                                                         FLOW2108
      JY1=J                                                             FLOW2109
      JY2=J+NCOL                                                        FLOW2110
      TEST=GMX(JX1)+GMY(JY1)-GMX(JX2)-GMY(JY2)                          FLOW2111
      THAX=(ABS(GMX(JX1))+ABS(GMY(JY1))+ABS(GMX(JX2))+ABS(GMY(JY2)))/2.0FLOW2112
      IF(ABS(TEST).LE.0.00001*THAX)GO TO 43                             FLOW2113
      K=K+1                                                             FLOW2114
      NI(K)=J                                                           FLOW2115
   43 CONTINUE                                                          FLOW2116
      IF(K.EQ.0)GO TO 46                                                FLOW2117
      KERR=1                                                            FLOW2118
      WRITE(K2,44)(NI(KJ),KJ=1,K)                                       FLOW2119
C    CHECK EACH GAS VOLUME FOR FLOW BALANCE (IN = OUT)                  FLOW2120
   44 FORMAT(' GAS VOL DO NOT MATERAL BALANCE'/(1X,10I5))               FLOW2121
C    MATTERAL BALANCE CHECK ON GAS VOL         JR=ROW NO   JC=COL NO    FLOW2122
C       Y - DIRECTION                                                   FLOW2123
C          IN      JY1=L          L=1,2,3.....,NCOL       TOP           FLOW2124
C          OUT     JY2=NCOL*NROW+L=1,2,3......,NCOL       BOTTOM        FLOW2125
C       X - DIRECTION                                                   FLOW2126
C          IN      JX1=L*(NCOL+1)+1  L=0,1,2,3....,NROW-1       LEFT    FLOW2127
C          OUT     JX2=L*(NCOL+1)    L=1,2,3,...,NROW           RIGHT   FLOW2128
   46 TEST=0.0                                                          FLOW2129
      THAX=0.0                                                          FLOW2130
      NN=NCOL*NROW                                                      FLOW2131
      DO 47 L=1,NCOL                                                    FLOW2132
      JY1=L                                                             FLOW2133
      JY2=NN+L                                                          FLOW2134
      TEST=TEST+GMY(JY1)-GMY(JY2)                                       FLOW2135
      THAX=THAX+ABS(GMY(JY1))+ABS(GMY(JY2))                             FLOW2136
   47 CONTINUE                                                          FLOW2137
      NN=NCOL+1                                                         FLOW2138
      DO 48 L=1,NROW                                                    FLOW2139
      JX1=(L-1)*NN+1                                                    FLOW2140
      JX2=L*NN                                                          FLOW2141
      TEST=TEST+GMX(JX1)-GMX(JX2)                                       FLOW2142
      THAX=THAX+ABS(GMX(JX1))+ABS(GMX(JX2))                             FLOW2143
   48 CONTINUE                                                          FLOW2144
      IF(ABS(TEST).LE.0.00001*THAX/2.)GO TO 50                          FLOW2145
      KERR=1                                                            FLOW2146
      WRITE(K2,49)                                                      FLOW2147
   49 FORMAT(' FURNACE BOX DOES NOT OVER ALL MATTERAL BALANCE  ')       FLOW2148
   50 IF(KERR.NE.0)KAPUT=KERR                                           FLOW2149
      RETURN                                                            FLOW2150
      END                                                               FLOW2151
```

```
      SUBROUTINE CCC                                                    CCC 2152
C                                                                       CCC 2153
      COMMON // DUMMY(3),KK, ICODE, HCODE,                              CCC 2154
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                    CCC 2155
     A TBRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                       CCC 2156
     A HCR, HDUTY, HTVAL, ERATE, KFUEL, XAIR, FTEMP,                    CCC 2157
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                     CCC 2158
     A XSURFX(9), XD, YD, ZLCHC, NCOL, NROW, NXSXN,                     CCC 2159
     A RSTART, TCODE, SCODE, NGRAY, JHCHC,                              CCC 2160
     A K1, K2, RCRD(10), TDEP(100), PERM(200)                           CCC 2161
C                                                                       CCC 2162
      INTEGER SCODE, TCODE, RSTART, HCODE                               CCC 2163
      DIMENSION Z(120),Z1( 60),Z2( 60),MM( 60),NN( 60)                  CCC 2164
      EQUIVALENCE (Z1(1),MM(1),Z(1)),(Z2(1),NN(1),Z( 61))               CCC 2165
      WRITE(K2,8200)                                                    CCC 2166
 8200 FORMAT(1H1,15X,'TEMPERTURE DATA'/15X,16(1H-))                     CCC 2167
C   GAS VOLUME AND SURFACE AREA TEMPERATURES                            CCC 2168
   80 CALL PZERO(Z(1),120)                                              CCC 2169
      IF(TCODE.GT.0) GO TO 81                                           CCC 2170
      READ(K1,35)(Z1(N),N=1,NVOL)                                       CCC 2171
   35 FORMAT(7F10.0)                                                    CCC 2172
      READ(K1,35)(Z2(N),N=1,NSURF)                                      CCC 2173
      GO TO 87                                                          CCC 2174
   81 GO TO (82,86),TCODE                                               CCC 2175
   82 READ(K1,35)TMIN,TMAX                                              CCC 2176
   83 DO 84 N=1,NVOL                                                    CCC 2177
      Z1(N)=TMAX                                                        CCC 2178
   84 CONTINUE                                                          CCC 2179
      DO 85 N=1,NSURF                                                   CCC 2180
      Z2(N)=TMIN                                                        CCC 2181
   85 CONTINUE                                                          CCC 2182
      GO TO 87                                                          CCC 2183
   86 CALL AFLAME (TMIN,TMAX)                                           CCC 2184
      GO TO 83                                                          CCC 2185
   87 WRITE(K2,8210)(Z1(N),N=1,NVOL)                                    CCC 2186
 8210 FORMAT(//20X,'GAS VOLUME TEMPERTURE,DEG F.'//(25X,6F15.0))        CCC 2187
      WRITE(K2,8220)(Z2(N),N=1,NSURF)                                   CCC 2188
 8220 FORMAT(//20X,'SURFACE AREA TEMPERTURES,DEG.F. '//(25X,6F15.0))    CCC 2189
      DO 89 N=1,120                                                     CCC 2190
      IF(Z(N).EQ.0.0)GO TO 89                                           CCC 2191
      Z(N)=Z(N)+460.                                                    CCC 2192
   89 CONTINUE                                                          CCC 2193
      CALL WRITE(2,'TEMG',Z1(1), 60)                                    CCC 2194
      CALL WRITE(2,'TEMS',Z2(1), 60)                                    CCC 2195
C   IF ANY VOLUME AND OR SURFACE TEMP ARE TO BE HELD CONSTANT           CCC 2196
C          THEN READ IN VOLUME AND OR SURFACE NUMBER                    CCC 2197
      CALL PZERO(Z(1),120)                                              CCC 2198
      IF(SCODE.EQ.0)GOTO903                                             CCC 2199
      GO TO(900,903,900),SCODE                                          CCC 2200
  900 READ(K1,901)NM,(MM(N),N=1,NM)                                     CCC 2201
```

```
901    FORMAT(I10/(7I10))                                                   CCC 2202
       WRITE(K2,8230)(NN(N),N=1,NM)                                         CCC 2203
8230   FORMAT(//20X,'GAS VOLUME NUMBERS WHICH HAVE KNOWED TEMPERATURES ARCCC 2204
      1E AS FOLLOWS'//(25X,6I15))                                           CCC 2205
       DO 902 N=1,NM                                                        CCC 2206
       K=NN(N)                                                              CCC 2207
       MM(K)=1                                                              CCC 2208
902    CONTINUE                                                             CCC 2209
903    CALL WRITE(2,'CONV',MM(1), 60)                                       CCC 2210
       CALL PZERO(MM(1), 60)                                                CCC 2211
       IF(SCODE.EQ.0)GO TO 913                                              CCC 2212
       GO TO(     913,910,910),SCODE                                        CCC 2213
910    READ(K1,901)NM,(NN(N),N=1,NM)                                        CCC 2214
       WRITE(K2,8231)(NN(N),N=1,NM)                                         CCC 2215
8231   FORMAT(//20X,'SURFACE AREA NUMBERS WHICH HAVE KNOWN TEMPERTURES ARCCC 2216
      1E AS FOLLOWS'//(25X,6I15))                                           CCC 2217
       DO 912 N=1,NM                                                        CCC 2218
       K=NN(N)                                                              CCC 2219
       MM(K)=1                                                              CCC 2220
912    CONTINUE                                                             CCC 2221
913    CALL WRITE(2,'CONS',MM(1), 60)                                       CCC 2222
C      READ IN PROCESS TEMPERATURES ASSOCIATED WITH EACH SURFACE            CCC 2223
       CALL PZERO(Z(1),120)                                                 CCC 2224
       READ(K1,35)(Z(N),N=1,NSURF)                                          CCC 2225
       WRITE(K2,8240)(Z(N),N=1,NSURF)                                       CCC 2226
8240   FORMAT(//20X,'PROCESS TEMPERTURE ASSOCIATED WITH EACH SURFACE,DEG.CCC 2227
      1F.'//(25X,6F15.0))                                                   CCC 2228
       DO 93 N=1,NSURF                                                      CCC 2229
       IF(Z(N).EQ.0.0)GO TO   93                                            CCC 2230
       Z(N)=Z(N)+460.                                                       CCC 2231
93     CONTINUE                                                             CCC 2232
       CALL WRITE(2,'TEMP',Z(1), 60)                                        CCC 2233
C   READ IN AMBIENT TEMPERTURES                                             CCC 2234
       READ(K1,35)TSINK                                                     CCC 2235
       WRITE(K2,8250) TSINK                                                 CCC 2236
8250   FORMAT(//20X,'AMBIENT TEMPERTURE,DEG.F.',F22.0)                      CCC 2237
       TSINK=TSINK+460.                                                     CCC 2238
99     RETURN                                                               CCC 2239
       END                                                                  CCC 2240
```

```
      FUNCTION H(TT,JJ)                                        H    2241
      COMMON /ED/ A(10,5),B(12,7),D(11,7),CMW(7)               H    2242
      H=EQUA(TT/1000.,B(1,JJ))                                 H    2243
      RETURN                                                   H    2244
      END                                                      H    2245
```

```
          SUBROUTINE DDD(JUNK,KAPUT)                                    DDD 2246
          COMMON // DUMMY(3),KK, ICODE, HCODE,                          DDD 2247
         A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                DDD 2248
         A TBRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                   DDD 2249
         A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                DDD 2250
         A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                 DDD 2251
         A XSURFX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,                 DDD 2252
         A RSTART, TCODE, SCODE, NGRAY, JHCHC,                          DDD 2253
         A K1, K2, RCRD(10), TDEP(100), PERM(200)                       DDD 2254
    C                                                                   DDD 2255
          INTEGER SCODE,TCODE,RSTART,HCODE                              DDD 2256
          DIMENSION Z(120),Z1( 60),Z2( 60),NI( 60)                      DDD 2257
          DIMENSION  ALPHA( 60)                                         DDD 2258
          EQUIVALENCE (Z1(1),Z(1)),(Z2(1),Z( 61))                       DDD 2259
          KERR=0                                                        DDD 2260
          IF(JUNK.EQ.0)GO TO 80                                         DDD 2261
          GO TO(111,90),JUNK                                            DDD 2262
    80    WRITE(K2,8300)                                                DDD 2263
    8300  FORMAT(1H1,14X,'SURFACE AREA GAS VOLUME DATA'/15X ,30('-'))   DDD 2264
    C      READ IN SURFACE DATA                                         DDD 2265
          CALL PZERO(Z(1),120)                                          DDD 2266
    C             EMISSIVITY                                            DDD 2267
          READ(K1,35)(Z1(N),N=1,NSURF)                                  DDD 2268
          DO 81 J=1,NSURF                                               DDD 2269
          IF(Z1(J).LT..0001)Z1(J)=.0001                                 DDD 2270
          IF(Z1(J).GT..9999)Z1(J)=.9999                                 DDD 2271
    81    CONTINUE                                                      DDD 2272
          CALL WRITE(1,'ESUR',Z(1), 60)                                 DDD 2273
          WRITE(K2,8310)(Z1(J),J=1,NSURF)                               DDD 2274
    8310  FORMAT(//20X,'SURFACE EMISSIVITY  DIMENSIONLESS'//(25X,6F15.4)) DDD 2275
    C      TRANSMISSIVITY( OUTSIDE SURFACES HAVE A VALUE OF ZERO        DDD 2276
          IF(NSURF.EQ.NCR)GO TO 82                                      DDD 2277
          READ(K1,35)(TAU(J),J=1,9)                                     DDD 2278
    35    FORMAT(7F10.0)                                                DDD 2279
    82    CALL NETTAU                                                   DDD 2280
    C      TEST TO SEE THAT NO SURFACE HAS ZERO OR NEGITIVE REFLECTIVITY DDD 2281
    C          1.0=EMISSIVITY+TRANSMISSIVITY+REFLECTIVITY               DDD 2282
          CALL NZERO(NI(1), 60)                                         DDD 2283
          CALL READ(1,'TSUR',Z2(1), 60)                                 DDD 2284
          WRITE(K2,8229)(Z2(J),J=1,NSURF)                               DDD 2285
    8229  FORMAT(//20X,'SURFACE TRANSMISSIVITY DIMENSIONLESS'//(25X,6F15.4))DDD 2286
          NN=NCR+1                                                      DDD 2287
          IF(NSURF.EQ.NCR)GO TO 832                                     DDD 2288
          DO 831 J=NN,NSURF                                             DDD 2289
    831      ALPHA(J)=1.-Z2(J)                                          DDD 2290
    832   CONTINUE                                                      DDD 2291
          CALL WRITE(1,'ALP ',ALPHA(1), 60)                             DDD 2292
          IF(NN.EQ.NCR+1) GO TO 850                                     DDD 2293
    830   N=0                                                           DDD 2294
          DO 83 J=1,NSURF                                               DDD 2295
```

```
      IF(1.0-Z1(J)-Z2(J).GT.0.0)GO TO 83                              DDD 2296
      N=N+1                                                           DDD 2297
      NI(N)=J                                                         DDD 2298
   83 CONTINUE                                                        DDD 2299
      IF(N.EQ.0)GO TO 850                                             DDD 2300
      KERR=1                                                          DDD 2301
      WRITE(K2,84)(NI(J),J=1,N)                                       DDD 2302
   84 FORMAT('1 SURF HAVE ZERO OR NEGITIVITY REFLECTIVITY'/(10I5))    DDD 2303
C      AREA                                                           DDD 2304
  850 CALL PZERO(Z1(1), 60)                                           DDD 2305
      NM=2*NCOL                                                       DDD 2306
      DO 85 N=1,NM                                                    DDD 2307
      Z(N)=XO                                                         DDD 2308
   85 CONTINUE                                                        DDD 2309
      NM=NM+1                                                         DDD 2310
      DO 86 N=NM,NCR                                                  DDD 2311
      Z(N)=YO                                                         DDD 2312
   86 CONTINUE                                                        DDD 2313
      IF(NXSXN.EQ.0)GO TO 88                                          DDD 2314
      YAREA=YO*2.                                                     DDD 2315
      NM=NCR+1                                                        DDD 2316
      DO 87 N=NM,NSURF                                                DDD 2317
      Z(N)=YAREA*ALPHA(N)                                             DDD 2318
   87 CONTINUE                                                        DDD 2319
   88 CALL WRITE(1,'ASUR',Z(1), 60)                                   DDD 2320
      WRITE(K2,8330)(Z(J),J=1,NSURF)                                  DDD 2321
 8330 FORMAT(//20X,'SURFACE AREA PER FOOT  OF FURNACE SQUARE FEET'//(25XDDD 2322
     1,6F15.4))                                                       DDD 2323
C      READ IN VOLUME DATA                                            DDD 2324
   90 CALL PZERO(Z(1), 60)                                            DDD 2325
C      LUMINOSITY ( GAS VOLUME CORECTION FACTOR  )                    DDD 2326
      READ(K1,35)(Z(N),N=1,NVOL)                                      DDD 2327
      CALL WRITE(1,'XLUM',Z(1), 60)                                   DDD 2328
      WRITE(K2,8340)(Z(J),J=1,NVOL)                                   DDD 2329
 8340 FORMAT(//20X,'GAS VOLUME CORRECTION FACTOR DIMENSIONLESS'//(25X,6FDDD 2330
     115.4))                                                          DDD 2331
C    HEAT TRANSFER COEFFICIENTS                                       DDD 2332
C      HC          SURFACE TO GAS                                     DDD 2333
C      HCP         SURFACE TO PROCESS FLUID                           DDD 2334
C      HCPP        SURFACE TO AMBIENT SINK                            DDD 2335
C    NOTE --- CORRECT BOTH HC AND HCP FOR TUBE-T/ -PLAIN AREA         DDD 2336
      WRITE(K2,8400)                                                  DDD 2337
 8400 FORMAT(1H1,14X,'SURFACE HEAT TRANSFER COEFFICIENTS'/15X,34('-'))  DDD 2338
      HAREA=0.0                                                       DDD 2339
      VAREA=0.0                                                       DDD 2340
C      READ IN WALL ARRANGEMENT                                       DDD 2341
      READ(K1,35)HDIA,HCLCL,HNROW                                     DDD 2342
      IF(HCLCL.EQ.0.0)GO TO 91                                        DDD 2343
      HAREA=HNROW*3.1415927*HDIA/HCLCL                                DDD 2344
C    READ IN INTERMEDIATE WALL TUBE ARRANGEMENT                       DDD 2345
```

```
 91     READ(K1,35)VDIA,VCLCL,VNROW                                  DDD 2346
        IF(VCLCL.EQ.0.0)GO TO 92                                     DDD 2347
        VAREA=VNROW*3.1415927*VDIA/VCLCL                             DDD 2348
 92     WRITE(K2,8410) HDIA,VDIA,HCLCL,VCLCL,HNROW,VNROW,HAREA,VAREA DDD 2349
 8410   FORMAT(//20X,'TUBE ARRANGEMENT'/65X,'WALL1',6X,'INTERMEDIATE'/25X, DDD 2350
       1'DIAMETER,INCHES  ',F28.4,F15.4/25X,'CL-CL DISTANCE,INCHES',F24.4,DDD 2351
       2 F15.4/25X,'NUMBER OF ROWS',F31.4,F15.4/25X,'TUBE PLAIN AREA RATIODDD 2352
       3',F24.4,F13.4)                                               DDD 2353
        CALL PZERO(Z(1),120)                                         DDD 2354
        READ(K1,35)( Z1(N),N=1,NSURF)                                DDD 2355
        READ(K1,35)(Z2(N),N=1,NSURF)                                 DDD 2356
        WRITE(K2,8415)                                               DDD 2357
 8415   FORMAT(//20X,'SURFACE HEAT TRANSFER COEFICIENTS HAVE THE FOLLOWINGDDD 2358
       1 UNITS --- BTU PER HOUR PER'/20X,'SQUARE FOOT OF PLAIN AREA')  DDD 2359
C     CONVERT WALL HEAT TRANSFER COEFFICIENTS                        DDD 2360
        IF(HAREA.EQ.0.0) GO TO 95                                    DDD 2361
        DO 94 N=1,NCR                                                DDD 2362
        Z1(N)=Z1(N)*HAREA                                            DDD 2363
        Z2(N)=Z2(N)*HAREA                                            DDD 2364
 94     CONTINUE                                                     DDD 2365
C     READ IN SURFACE DATA                                           DDD 2366
 95     IF(NX5XH.EQ.0)GO TO 99                                       DDD 2367
        NN=NCR+1                                                     DDD 2368
        DO 98 N=NN,NSURF                                             DDD 2369
        Z1(N)=Z1(N)*VAREA                                            DDD 2370
        Z2(N)=Z2(N)*VAREA                                            DDD 2371
 98     CONTINUE                                                     DDD 2372
 99     CALL WRITE(2,'HC  ',Z1(1), 60)                               DDD 2373
        CALL WRITE(2,'HCP ',Z2(1), 60)                               DDD 2374
        WRITE(K2,8420)(Z1(N),N=1,NSURF)                              DDD 2375
        WRITE(K2,8430)(Z2(N),N=1,NSURF)                              DDD 2376
 8420   FORMAT(//20X,' CORECTED COEFFICIENTS SURFACE TO GAS'//(25X,6F15.4)DDD 2377
       1)                                                            DDD 2378
 8430   FORMAT(//20X,'CORRECTED COEFFICIENT,SURFACE TO PROCESS FLUID'//(25DDD 2379
       1X,6F15.4))                                                   DDD 2380
 100    CALL PZERO(Z(1),120)                                         DDD 2381
        READ(K1,35)(Z(N),N=1,NCR)                                    DDD 2382
        CALL WRITE(2,'HCPP',Z1(1), 60)                               DDD 2383
        WRITE(K2,8440)(Z(N),N=1,NCR)                                 DDD 2384
 8440   FORMAT(//23X,'COEFICIENT SURFACE TO ABIENT'//(25X,6F15.4))   DDD 2385
 110    IF(KERR.NE.0)KAPUT=KERR                                      DDD 2386
 111    RETURN                                                       DDD 2387
        END                                                          DDD 2388
```

```
      SUBROUTINE EEE                                                    EEE 2389
      COMMON // DUMMY(3),KK, ICODE, HCODE,                              EEE 2390
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                    EEE 2391
     A TBRIDG, PRES, FLUET, FLUE(5), XMMX, TSINK,                       EEE 2392
     A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                    EEE 2393
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                     EEE 2394
     A XSURFX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,                     EEE 2395
     A RSTART, TCODE, SCODE, NGRAY, JHCHC,                              EEE 2396
     A K1, K2, RCRD(10), TDEP(100), PERM(200)                           EEE 2397
      INTEGER SCODE,TCODE,RSTART,HCODE                                  EEE 2398
      REAL T(10),A(10),TT(10)                                           EEE 2399
      REAL*4 LOG                                                        EEE 2400
      DATA T/500.,1000.,1500.,2000.,2500.,3000.,3500.,4000.,4500.,5000./EEE 2401
      PCO2=FLUE(1)*PRES                                                 EEE 2402
      PH2O=FLUE(2)*PRES                                                 EEE 2403
      PSO2=FLUE(3)*PRES                                                 EEE 2404
C    CHARACTERIZED REAL GAS BY                                          EEE 2405
C          1 -- CLEAR GAS                                               EEE 2406
C          3 -- GRAY GAS MAXIUM (PRESENT LOGIC VALID FOR 1 GRAY GAS)    EEE 2407
C    COMPUTE ABSORPTION COEFFICIENT FOR THE SINGLE GRAY GAS             EEE 2408
      EE1=EMIS(PCO2,PH2O,PSO2,PRES,TBRIDG,XLX)                          EEE 2409
      EE2=EMIS(PCO2,PH2O,PSO2,PRES,TBRIDG,2.*XLX)                       EEE 2410
      XK(1)=LOG(ABS(EE1/(EE2-EE1)))/XLX                                 EEE 2411
    6 DO  10 J=1,10                                                     EEE 2412
      E1=EMIS(PCO2,PH2O,PSO2,PRES,T(J),XLX)                             EEE 2413
      E2=EMIS(PCO2,PH2O,PSO2,PRES,T(J),2.*XLX)                          EEE 2414
    9 A(J)=E1**2/(2.*E1-E2)                                             EEE 2415
   10 CONTINUE                                                          EEE 2416
      DO 15 J=1,10                                                      EEE 2417
      TT(J)=T(J)/1000.                                                  EEE 2418
   15 CONTINUE                                                          EEE 2419
      SEA=FITIT(TT,A,10,6,ACOEF(1,1),2,1.)                              EEE 2420
      TBR=TBRIDG-460.0                                                  EEE 2421
      WRITE(K2,8600)NGRAY,XLX,(J,XK(J),J=1,3),PRES,TBR,(J,A(J),T(J),J=1,EEE 2422
     110)                                                               EEE 2423
 8600 FORMAT(1H1,14X,'CHARACTERIZATION OF FLUE GAS'/15X,28('-')///20X,',EEE 2424
     1NUMBER OF GRAY GASES',I28/20X,'MEAN BEAN LENGTH ,FEET',F26.2//20X,EEE 2425
     2 'ABSORPTIVITY OF GRAY GAS,RECIPROCAL FEET',3(/153,F15.7)//20X,'PREEE 2426
     3ESSURE ATM.',F32.4//20X,'BRIDGE WALL TEMPERATURE,DEG F',F17.2//20XEEE 2427
     4,'DATA TO CORRELATE ABSORPTIVITY WITH TEMPERATURE'/ 46X,'FACTOR',',EEE 2428
     59X,'DEG. R.',10(/I38,F15.7,F15.1))                                EEE 2429
   20 RETURN                                                            EEE 2430
      END                                                               EEE 2431
```

```
      FUNCTION CP ( TT )                                  CP  2432
C                                                         CP  2433
C     FUNCTION COMPUTES SPECIFIC HEAT OF FLUE GAS         CP  2434
      COMMON /CPHV/ CPCP(11), HVHV(12)                    CP  2435
C                                                         CP  2436
      CP = EQUA ( TT/1000.0, CPCP )                       CP  2437
C                                                         CP  2438
      RETURN                                              CP  2439
      END                                                 CP  2440
```

```
      FUNCTION CZZ(TT,JJ)                                    CZZ 2441
      COMMON /ED/ A(10,5),B(12,7), D(11,7),CMW(7)            CZZ 2442
      DATA NTIME /0/                                         CZZ 2443
      IF(NTIME.NE.0)GO TO 20                                 CZZ 2444
      DO 9 J=1,7                                             CZZ 2445
      D(1,J)=3.                                              CZZ 2446
      DO 8 K=3,12                                            CZZ 2447
      D(K-1,J)=FLOAT(K-2)*B(K,J)/1000.                       CZZ 2448
    8 CONTINUE                                               CZZ 2449
    9 CONTINUE                                               CZZ 2450
      NTIME=1                                                CZZ 2451
   20 CZZ=EQUA(TT/1000.,D(1,JJ))                             CZZ 2452
   99 RETURN                                                 CZZ 2453
      END                                                    CZZ 2454
```

```
      SUBROUTINE AFLAME(TMIN,TMAX)                                      AFLA2455
C                                                                       AFLA2456
      COMMON // DUMMY(3),KK, ICODE, HCODE,                              AFLA2457
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                    AFLA2458
     A TBRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                       AFLA2459
     A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                    AFLA2460
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                     AFLA2461
     A XSURFX(9), XD, YD, ZLENG, NCOL, NROW, NXSXN,                     AFLA2462
     A RSTART, TCODE, SCODE, NGRAY, JHCHC,                              AFLA2463
     A K1, K2, RCRD(10), TDEP(100), PERM(200)                           AFLA2464
C                                                                       AFLA2465
      INTEGER SCODE, TCODE, RSTART, HCODE                               AFLA2466
      COMMON /ED/ A(10, 5),B(12,7),D(11,7),CMW(7)                       AFLA2467
      REAL F(7),AM(6,6),AV(6),AA(6,7)                                   AFLA2468
      REAL*4 LOG                                                        AFLA2469
      EQUIVALENCE (AM(1,1),AA(1,1)),(AV(1),AA(1,7))                     AFLA2470
C    CONSTANTS NEEDED FOR DERIVATIES                                    AFLA2471
      ZKP1(T)=EXP(A1/T+B1)                                              AFLA2472
      PKP1(T)=-ZKP1(T)*A1/T**2                                          AFLA2473
C    EQUILIBRIUM CONSTANT AND PARTIAL DERIVATIVE FOR CO2,H2O,CO, AND O2 AFLA2474
C    FOR H2O,H2,AND O2                                                  AFLA2475
      ZKP2(T)=EXP(A2/T+B2)                                              AFLA2476
      PKP2(T)=-ZKP2(T)*A2/T**2                                          AFLA2477
      DEN=1./2500.-1./5500.                                             AFLA2478
      A1=(LOG(2.77E5)-LOG(17.8))/DEN                                    AFLA2479
      B1=LOG(2.77E5)-A1/2500.                                           AFLA2480
      A2=(LOG(1.26E6)-LOG(2.32))/DEN                                    AFLA2481
      B2=LOG(1.26E6)-A2/2500.                                           AFLA2482
C    MOLES OF FLUE GAS                                                  AFLA2483
C       F(1)   CO2                                                      AFLA2484
C       F(2)=  H2O                                                      AFLA2485
C       F(3)   SO2 - CONSTANT                                           AFLA2486
C       F(4)   O2                                                       AFLA2487
C       F(5)   N2 - CONSTANT                                            AFLA2488
C       F(6)   CO                                                       AFLA2489
C       F(7)   H2                                                       AFLA2490
      DO 13 J=1,5                                                       AFLA2491
      F(J)= FLUE(J)*FLUET                                               AFLA2492
   13 CONTINUE                                                          AFLA2493
      F(6)=0.0                                                          AFLA2494
      F(7)=0.0                                                          AFLA2495
C      CONSTANT                                                         AFLA2496
C       1. TOTAL MASS                                                   AFLA2497
C       2. CARBON ATOMS                                                 AFLA2498
C       3. HYDROGEN ATOMS                                               AFLA2499
      CONWT=0.0                                                         AFLA2500
      DO 14 J=1,7                                                       AFLA2501
      CONWT=CONWT+F(J)*CMW(J)                                           AFLA2502
   14 CONTINUE                                                          AFLA2503
      CARBON=F(1)+F(7)                                                  AFLA2504
```

```
      HYDRO=F(2)+F(7)                                           AFLA2505
      Q=HDUTY*1.66/ZLONG                                        AFLA2506
C      INITIAL GUESSES OF GAS AND TEMPERATURE                   AFLA2507
      NTRY=0                                                    AFLA2508
      CO2=0.25*F(1)                                             AFLA2509
      H2O=0.05*F(2)                                             AFLA2510
      F(1)=F(1)-CO2                                             AFLA2511
      F(2)=F(2)-H2O                                             AFLA2512
      F(4)=F(4)+.5*(CO2+H2O)                                    AFLA2513
      F(6)=CO2                                                  AFLA2514
      F(7)=H2O                                                  AFLA2515
      T=5500.                                                   AFLA2516
C   CALCULATE FROM LAST ITERATION TOTAL NUMBER OF MOLES PRESENT AFLA2517
   20 TOTAL=0.0                                                 AFLA2518
      DO 22 J=1,7                                               AFLA2519
      TOTAL=TOTAL+F(J)                                          AFLA2520
   22 CONTINUE                                                  AFLA2521
C     CALCULATE MOLES OF H2 AND CO KNOWING H2O,CO2,AND O2       AFLA2522
C      PLUS THE APPROPATE EQUILIBRIUM CONSTANTS                 AFLA2523
      F(7)=F(2)/(ZKP1(T)*SQRT(F(4)/TOTAL))                      AFLA2524
      F(6)=F(1)/(ZKP2(T)*SQRT(F(4)/TOTAL))                      AFLA2525
      CALL PZERO(AA(1,1),42)                                    AFLA2526
C   SET UP MATRIX                                               AFLA2527
C      ROW 1                                                    AFLA2528
      AM(1,1)=CMW(1)                                            AFLA2529
      AM(1,2)=CMW(2)                                            AFLA2530
      AM(1,3)=CMW(4)                                            AFLA2531
      AM(1,4)=CMW(6)                                            AFLA2532
      AM(1,7)=CMW(7)                                            AFLA2533
C      ROW 2                                                    AFLA2534
      SQT=SQRT(TOTAL)                                           AFLA2535
      CON=F(1)/(2.*SQT)                                         AFLA2536
      AM(2,1)=-SQT-CON                                          AFLA2537
      AM(2,2)=-CON                                              AFLA2538
      AM(2,3)=F(6)/2.*ZKP1(T)/SQRT(F(4))-CON                    AFLA2539
      AM(2,4)=SQRT(F(4))*ZKP1(T)-CON                            AFLA2540
      AM(2,5)=-CON                                              AFLA2541
      AM(2,6)=F(6)*SQRT(F(4))*PKP1(T)                           AFLA2542
C      ROW 3                                                    AFLA2543
      CON=F(2)/(2.*SQT)                                         AFLA2544
      AM(3,1)=-CON                                              AFLA2545
      AM(3,2)=-SQT-CON                                          AFLA2546
      AM(3,3)=F(7)/2.*ZKP2(T)/SQRT(F(4))-CON                    AFLA2547
      AM(3,4)=-CON                                              AFLA2548
      AM(3,5)=SQRT(F(4))*ZKP2(T)-CON                            AFLA2549
      AM(3,6)=F(7)*SQRT(F(4))*PKP2(T)                           AFLA2550
C      ROW 4                                                    AFLA2551
      AM(4,1)=H(T,1)-H(FTEMP,1)                                 AFLA2552
      AM(4,2)=H(T,2)-H(FTEMP,2)                                 AFLA2553
      AM(4,3)=H(T,4)-H(FTEMP,4)                                 AFLA2554
```

```
      AM(4,4)=H(T,6)-H(FTEMP,6)                                         AFLA2555
      AM(4,5)=H(T,7)-H(FTEMP,7)                                         AFLA2556
      DO 26 J=1,7                                                       AFLA2557
      AM(4,6)=AM(4,6)+F(J)*CZZ(T,J)                                     AFLA2558
   26 CONTINUE                                                          AFLA2559
C      ROW 5                                                            AFLA2560
      AM(5,1)=1.                                                        AFLA2561
      AM(5,4)=1.                                                        AFLA2562
C      ROW 6                                                            AFLA2563
      AM(6,2)=1.                                                        AFLA2564
      AM(6,4)=1.                                                        AFLA2565
C      SET UP VECTORS                                                   AFLA2566
      AV(1)=CONWT-F(1)*CMW(1)-F(2)*CMW(2)-F(4)*CMW(4)-F(6)*CMW(6)-F(7)*CAFLA2567
     1MW(7)                                                             AFLA2568
      AV(2)=-F(6)*SQRT(F(4))*ZKP1(T)+F(1)*SQT                           AFLA2569
      AV(3)=-F(7)*SQRT(F(4))*ZKP2(T)+F(2)*SQT                           AFLA2570
      AV(4)=0                                                           AFLA2571
      DO 29 J=1,7                                                       AFLA2572
      AV(4)=AV(4)+F(J)*(H(FTEMP,J)-H(T,J))                              AFLA2573
   29 CONTINUE                                                          AFLA2574
      AV(5)=-F(1)-F(6)+CARBON                                           AFLA2575
      AV(6)=-F(2)-F(6)+HYDRO                                            AFLA2576
C      SOLVE LINEARIZED SYSTEM                                          AFLA2577
      DO 34 J=1,6                                                       AFLA2578
      SUM=0.                                                            AFLA2579
      DO 32 K=1,6                                                       AFLA2580
      SUM=SUM+AM(J,K)                                                   AFLA2581
   32 CONTINUE                                                          AFLA2582
      DO 33 K=1,6                                                       AFLA2583
      AM(J,K)=AM(J,K)/SUM                                               AFLA2584
   33 CONTINUE                                                          AFLA2585
      AV(J)=AV(J)/SUM                                                   AFLA2586
   34 CONTINUE                                                          AFLA2587
      CALL ISIMEQ(AA,6,7,6)                                             AFLA2588
   35 DF1=AV(1)                                                         AFLA2589
      DF2=AV(2)                                                         AFLA2590
      DF3=AV(3)                                                         AFLA2591
      DF4=AV(4)                                                         AFLA2592
      DF5=AV(5)                                                         AFLA2593
      DT=AV(6)                                                          AFLA2594
C      TEST FOR CONVERGENCE                                             AFLA2595
      CON=.001                                                          AFLA2596
      IF(ABS(DF1).LT.CON*F(1).AND.ABS(DF2).LT.CON*F(2).AND.             AFLA2597
     1   ABS(DF4).LT.CON*F(4).AND.ABS(DF6).LT.CON*F(6).AND.             AFLA2598
     2   ABS(DF7).LT.CON*F(7).AND.ABS(DT).LT.1.)GO TO 50                AFLA2599
C      TEST FOR NEGITIVE OR ZERO NOTIES                                 AFLA2600
   40 IF(F(1)+DF1.GT. 0. .AND.F(2)+DF2.GT.0. .AND.F4+DF4.GT. 0. .AND.F(6)AFLA2601
     1+DF6.GT.0. .AND.F(7)+DF7.GT.0.)GO TO 50                           AFLA2602
      DF1=DF1/2.                                                        AFLA2603
      DF2=DF2/2.                                                        AFLA2604
```

```
      DF4=DF4/2.                                              AFLA2605
      DF6=DF6/2.                                              AFLA2606
      DF7=DF4                                                 AFLA2607
      GO TO 40                                                AFLA2608
C      LIMIT MAXIMUN CORRECTION TO 10 PERCENT OF RATE         AFLA2609
C         AND 100 DEGER FOR TEMPERTURE                        AFLA2610
   50 DF1=SIGN(AMIN1(ABS(DF1),0.1*F(1)),DF1)                  AFLA2611
      DF2=SIGN(AMIN1(ABS(DF2),0.1*F(2)),DF2)                  AFLA2612
      DF4=SIGN(AMIN1(ABS(DF4),0.1*F(4)),DF4)                  AFLA2613
      DF6=SIGN(AMIN1(ABS(DF6),0.1*F(6)),DF6)                  AFLA2614
      DF7=SIGN(AMIN1(ABS(DF7),0.1*F(7)),DF7)                  AFLA2615
      DT=SIGN(AMIN1(ABS(DT),100.),DT)                         AFLA2616
      NTRY=NTRY+1                                             AFLA2617
      F(1)=F(1)+DF1                                           AFLA2618
      F(2)=F(2)+DF2                                           AFLA2619
      F(4)=F(4)+DF4                                           AFLA2620
      F(6)=F(6)+DF6                                           AFLA2621
      F(7)=F(7)+DF7                                           AFLA2622
      T=T+DT                                                  AFLA2623
      IF(NTRY.LT.100)GO TO 20                                 AFLA2624
   60 TMIN=0.75*T-460.                                        AFLA2625
      RETURN                                                  AFLA2626
      END                                                     AFLA2627
```

```
      FUNCTION EMIS(PPCO2,PPH2O,PPSO2,PPRES,TEMP,XXLXX)                 EMIS2628
      DIMENSION PC(7),TC(7),PH(15),PS(4),TS(4),EZ(3),TD(3),CCOF(8),HCOF(EMIS2629
     18),SCOF(8),DCOF(8),TH(15)                                         EMIS2630
      REAL*4 LOG                                                        EMIS2631
      DATA PC/.001,.002,.003,.004,.005,.006,.0063/,TC/2350.,3400.,3950.,EMIS2632
     14300.,4600.,4875.,5000./,PH/.005,.007,.010,.012,.015,.020,.025,.03EMIS2633
     20,.035,.040,.050,.060,.070,.08,.085/,TH/1480.,1795.,2150.,2330.,25EMIS2634
     340.,2840.,3160.,3400.,3590.,3760.,4100.,4375.,4625.,4830.,5000./, EMIS2635
     4PS/.002,.004,.006,.0075/,TS/1450.,2400.,3050.,3500./,TD/720.,1460.EMIS2636
     5,2160./,NTIME/0/                                                  EMIS2637
      IF(NTIME.NE.0)GO TO 10                                            EMIS2638
      DO 1 J=1,7                                                        EMIS2639
      TC(J)=TC(J)/1000.                                                 EMIS2640
    1 CONTINUE                                                          EMIS2641
      S1=FITIT(TC,PC,7,6,CCOF,2,1.0)                                    EMIS2642
      DO 2 J=1,15                                                       EMIS2643
      TH(J)=TH(J)/1000.                                                 EMIS2644
    2 CONTINUE                                                          EMIS2645
      S2=FITIT(TH,PH,15,6,HCOF,2,1.)                                    EMIS2646
      DO 3 J=1,4                                                        EMIS2647
      TS(J)=TS(J)/1000.                                                 EMIS2648
    3 CONTINUE                                                          EMIS2649
      S3=FITIT(TS,PS,4,3,SCOF,2,1.)                                     EMIS2650
      DO 8 J=1,3                                                        EMIS2651
      TD(J)=TD(J)/1000.                                                 EMIS2652
    8 CONTINUE                                                          EMIS2653
      NTIME=1                                                           EMIS2654
C                                                                       EMIS2655
   10 PCO2=PPCO2                                                        EMIS2656
      PH2O=PPH2O                                                        EMIS2657
      PSO2=PPSO2                                                        EMIS2658
      PRES=PPRES                                                        EMIS2659
      TT=TEMP                                                           EMIS2660
      XX=XXLXX                                                          EMIS2661
C   CO2 EMMISSIVITY                                                     EMIS2662
   20 T=AMAX1(500.,TT)                                                  EMIS2663
      T=AMIN1(5000.,T )                                                 EMIS2664
      IF(T.GE.2350.)GO TO 21                                            EMIS2665
      PMIN=.001                                                         EMIS2666
      GO TO 22                                                          EMIS2667
   21 PMIN=EXP(EQUA(T/1000.,CCOF))                                      EMIS2668
   22 PCL=AMAX1(PCO2*XX,PMIN)                                           EMIS2669
      PCL=AMIN1(PCL,5.0)                                                EMIS2670
      A=T/1000.                                                         EMIS2671
      B=PCL                                                             EMIS2672
      C=LOG(PCL)                                                        EMIS2673
      D=A*B                                                             EMIS2674
      E=A*C                                                             EMIS2675
      F=A/B                                                             EMIS2676
      G=B/A                                                             EMIS2677
```

```
          IF(T.GT.2000.)GO TO 23                                            EMIS2678
          ECO2=-.1321461 3E+01+((-0.1947089 6*A+0.5689 1554)*A**2-.1112367E1)*AEMIS2679
         1+(.02085496 6*B-0.36506376)*B+((.68352178E-4*C**3-.018511476)*C+.26EMIS2680
         2049826 )*C+((.001269 0888*D-.02881621)*D+.31656996)*D+((-.5545739E-EMIS2681
         35*E-.10411429E-3)*E**3-.05242469)*E+((.27741309E-13*F**2-.20706362EMIS2682
         4E-6)*F+.49935057E-3)*F+(-.22536606E-2*G+.076587927)*G             EMIS2683
          GO TO 24                                                          EMIS2684
  23      ECO2=-.16873691E1+((.14826325E-3*A**2-.67238054E-2)*A-.03232901)*AEMIS2685
         1**2+(-.96049276E-3*B**2+.2629715 0)*B+(.39288750E-2*C**2+.13660492)EMIS2686
         2*C+(.36392625E-3*D-.77139670E-1)*D+((.35397314E-7*E**2-.49179432E-EMIS2687
         34)*E**2+.74160975E-1)*E+((-.25856067E-16*F+.73653414E-13)*F**3    EMIS2688
         5-.45602351E-3)*F+(.22187E83E-3*G**4-.28814881)*G                  EMIS2689
  24      ECO2=EXP(ECO2)                                                    EMIS2690
C     CO2 EMISSIVITY CORRECTION FACTOR30                                    EMIS2691
  30      PT=AMAX1(.05,PRES)                                                EMIS2692
          PT=AMIN1(5.,PT)                                                   EMIS2693
          PCL=AMAX1(PCO2*XX,.02)                                            EMIS2694
          PCL=AMIN1(PCL,2.5)                                                EMIS2695
          A=LOG(PT)                                                         EMIS2696
          B=A*LOG(PCL)                                                      EMIS2697
          CCO2=((((-.86747709E-3*A-.45999058E-2)*A-.56062809E-2)*A-.6220262EEMIS2698
         1-2)*A+.154125 11)*A+((((.36989449E-6*B+.64 06038E-5)*B-.130 12359E-3EMIS2699
         2)*B-.27531686E-3)*B-.53974179E-1)*B                               EMIS2700
          CCO2=EXP(CCO2)                                                    EMIS2701
C     H2O EMISSIVITY                                                        EMIS2702
  40      T=AMAX1(500.,TT)                                                  EMIS2703
          T=AMIN1(5000.,T)                                                  EMIS2704
          IF(T.GE.1480.)GO TO 41                                            EMIS2705
          PMIN=.005                                                         EMIS2706
          GO TO 42                                                          EMIS2707
  41      PMIN=EXP(EQUA(T/1000.,FCOF))                                      EMIS2708
  42      PWL=AMAX1(EH2O*XX,PMIN)                                           EMIS2709
          PWL=AMIN1(PWL,20.)                                                EMIS2710
          A=T/1000.                                                         EMIS2711
          B=PWL                                                             EMIS2712
          C=LOG(B)                                                          EMIS2713
          D=A*B                                                             EMIS2714
          E=A*C                                                             EMIS2715
          F=A/B                                                             EMIS2716
          G=B/A                                                             EMIS2717
          EH2O=-.92160574+((.36785012E-4*A**3-0.16945229E-1)*A-.2830788)*A- EMIS2718
         1.1787129E-3*B**2+((((.1426699E-3*C+.1324707E-2)*C+.6148B015E-3)*CEMIS2719
         2-.36606564E-1)*C+.31305419)*C+(.46970019E-8*D**2-.98828861E-3)*D+ EMIS2720
         3((.40622711E-5*E**2-.24520978E-2)*E+.6456909E-1)*E+(((.49852337E-1EMIS2721
         42*F**2-.14865877E-6)*F+.49533045E-4)*F-.7292208E-2)*F+(.12739632E-EMIS2722
         58*G**4-.57217605E-2)*G                                            EMIS2723
          EH2O=EXP(EH2O)                                                    EMIS2724
C      H2O CORRECTION FACTOR                                                EMIS2725
  50      PP=AMAX1((PH2O+PRES)/2.,0.0)                                      EMIS2726
          PP=AMIN1(PP,1.2)                                                  EMIS2727
```

```
      PWL=AMAX1(PH2O*XX,.05)                                            EMIS2728
      PWL=AMIN1(PWL,10.)                                                EMIS2729
      A=PP-.5                                                           EMIS2730
      B=PP*LOG(PWL)                                                     EMIS2731
      CH2O=((((-.2029815E-1*A+.25004224)*A-.12401985)*A-.5385303)*A+1.06EMIS2732
     122883)*A+((((-.72108284E-2*B-.87216391E-2)*B+.3961676E-1)*B+.84532EMIS2733
     2464E-2)*B-.19942644)*B+1.0                                        EMIS2734
C     CO2 AND H2O CORRECTION FACTOR                                     EMIS2735
   60 EZ(1)=0.0                                                         EMIS2736
      EZ(2)=0.0                                                         EMIS2737
      EZ(3)=0.0                                                         EMIS2738
      PP=AMAX1(PH2O/(PCO2+PH2O),0.0)                                    EMIS2739
      PP=AMIN1(PP,1.0)                                                  EMIS2740
      PL=AMAX1((PCO2+PH2O)*XX,.2)                                       EMIS2741
      PL=AMIN1(PL,5.0)                                                  EMIS2742
      KODE=0                                                            EMIS2743
      IF(TT.LE.720.)KODE=1                                              EMIS2744
      IF(TT.GE.2160.)KODE=3                                             EMIS2745
      IF(TT.EQ.1460.0)KODE=4                                            EMIS2746
      IF(KODE.EQ.0)KODE=2                                               EMIS2747
      A=PP                                                              EMIS2748
      B=LOG(PL)                                                         EMIS2749
      C=A*B                                                             EMIS2750
      GO TO (61,61,63,62),KODE                                          EMIS2751
   61 EZ(1)=-.67495633E-2+((-.91419565E-1*A+.60735416E-1)*A**3+.03244848EMIS2752
     2)*A+((((.79574955E-3*B+.33302833E-3)*B-.7928822E-4)*B-.3966270E-2)*EMIS2753
     3B+.011549225)*B+((((-.38471551E-2*C-.44283372E-2)*C+.59025659E-2)*EMIS2754
     4C+.01778274)*C-.37889872E-2)*C                                    EMIS2755
      EZ(1)=AMAX1(EZ(1),0.0)                                            EMIS2756
      GO TO (65,62),KODE                                                EMIS2757
   62 EZ(2)=-.51425029E-3+((-0.30954913E-1*A**3-.27576063E-1)*A         EMIS2758
     1+.52277457E-1)*A+((((.82787757E-3*B-.80104563E-4)*B-.26232567E-2)*EMIS2759
     2B+.72816575E-3)*B+.63547973E-2)*B+((((-.69847306E-3*C+.16586398E-2EMIS2760
     3)*C-.41582562E-2)*C-.20869106E-2)*C+.13114829E-1)*C               EMIS2761
      EZ(2)=AMAX1(EZ(2),0.0)                                            EMIS2762
      IF(KODE.EQ.4)GO TO 67                                             EMIS2763
   63 EZ(3)=-.38985195E-2+((-.25438321E-6*A**3-.131836E-2)*A+.15184442E-EMIS2764
     =1)*A+((((.36391264E-3*B-.13022385E-3)*B-.23495424E-2)*B-.1333573E-EMIS2765
     22)*B+.18003497E-1)*B+((((-.64092173E-8*C+.11118057E-5)*C-.69767036EMIS2766
     3E-5)*C-.1335407E-3)*C+.12768373E-2)*C                             EMIS2767
      EZ(3)=AMAX1(EZ(3),0.0)                                            EMIS2768
      IF(KODE.EQ.2)GO TO 66                                             EMIS2769
   65 DELE=EZ(KODE)                                                     EMIS2770
      GO TO 70                                                          EMIS2771
   66 S4=FITIT(TP,EZ,3,2,DCOF,1,1.0)                                    EMIS2772
      DELE=EQUA(TT/1000.,DCOF)                                          EMIS2773
      GO TO 70                                                          EMIS2774
   67 DELE=EZ(2)                                                        EMIS2775
C     SO2 EMISSIVITY                                                    EMIS2776
   70 IF(PSO2.EQ.0.0) GO TO 75                                          EMIS2777
```

```
      T=AMAX1(TT,700.)                                                  EMIS2778
      T=AMIN1(T,3500.)                                                  EMIS2779
      IF(T.GE.1450.)GO TO 71                                            EMIS2780
      PMIN=.002                                                         EMIS2781
      GO TO 72                                                          EMIS2782
   71 PMIN=EXP(EQUA(T/1000.,SCOE))                                      EMIS2783
   72 PSL=AMAX1(PSO2*XX,PMIN)                                           EMIS2784
      PSL=AMIN1(PSL,2.0)                                                EMIS2785
      A=T/1000.                                                         EMIS2786
      B=PSL                                                             EMIS2787
      C=LOG(PSL)                                                        EMIS2788
      D=A*B                                                             EMIS2789
      F=A/B                                                             EMIS2790
      G=B/A                                                             EMIS2791
      ESO2=-.2772374E1+((.202776E-2*A**3-.3155203)*A+.10762355E+1)*A+   EMIS2792
     1(-.20794123*B+.54502462)*B**3+((-.95399255E-4*C**3-.17241112)*C-.5EMIS2793
     225857489)*C-.23427193*D+((.32929102E-5*E+.75033122E-4)*E**3+.281592EMIS2794
     3316)*E+((.46510705E-13*F-.33743806E-10)*F**3+.19603745E-2)*F+     EMIS2795
     4(((-.16889012E-1*G**2+.51539196)*G-.16932033E1)*G+.20649587E1)*G  EMIS2796
      ESO2=EXP(ESO2)                                                    EMIS2797
      GO TO 80                                                          EMIS2798
   75 ESO2=0.0                                                          EMIS2799
   80 EMIS=ECO2*CCO2+EH2O*CH2O-DELE+ESO2                                EMIS2800
      RETURN                                                            EMIS2801
      END                                                               EMIS2802
```

```
      SUBROUTINE NETTAU                                                 NETT2803
C   ZTAUZ == 0  NO INTERMEDIATE SURFACES EXIST      ** NET TAU =1.      NETT2804
C              1  INTERMEDIATE SURFACES EXIST  **  COMPUTE NET TAU      NETT2805
      COMMON // DUMMY(3),KK, ICODE, HCODE,                              NETT2806
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                    NETT2807
     A TBRIDG, PRES, FLUET, FLUE(5), XMAX, TSINK,                       NETT2808
     A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                    NETT2809
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                     NETT2810
     A XSURFX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,                     NETT2811
     A RSTART, TCODE, SCODE, NGRAY, JHCHC,                              NETT2812
     A K1, K2, RCRD(10), TDEP(100), PERM(200)                           NETT2813
C                                                                       NETT2814
      INTEGER SCODE,TCODE,RSTART,HCODE                                  NETT2815
      DIMENSION ZSS(8),ZGS(8),ZSG(3),ZGG(3),Z( 60),AA( 60, 60)          NETT2816
      INTEGER ZTAUZ                                                     NETT2817
C   NET TRANSMISSIVITY SURFACE TO SURFACE                               NETT2818
      DATA ZSS/'ZSS1','ZSS2','ZSS3','ZSS4','ZSS5','ZSS6','ZSS7','ZSS8'/ NETT2819
C   NET TRANSMISSIVITY   SURFACE  TO  GAS                               NETT2820
      DATA ZSG/'ZSG1','ZSG2','ZSG3','ZSG4','ZSG5','ZSG6','ZSG7','ZSG8'/ NETT2821
C   NET TRANSMISSIVITY  GAS TO  SURFACE                                 NETT2822
      DATA ZGS/'ZGS1','ZGS2','ZGS3','ZGS4','ZGS5','ZGS6','ZGS7','ZGS8'/ NETT2823
C   NET TRANSMISSIVITY GAS TO  GAS                                      NETT2824
      DATA ZGG/'ZGG1','ZGG2','ZGG3','ZGG4','ZGG5','ZGG6','ZGG7','ZGG8'/ NETT2825
      NN=2*NCOL                                                         NETT2826
      XTEST=0.001*XO                                                    NETT2827
      HALFXO=XO/2.                                                      NETT2828
      ZTAUZ=0                                                           NETT2829
      IF(NXSXN.NE.0)ZTAUZ=1                                             NETT2830
C     COMPUTE SURFACE TRANSMISSIVITY AND STORE                          NETT2831
      IF(NXSXN.NE.0)GO TO 9                                             NETT2832
      CALL PZERO(Z(1),60)                                               NETT2833
      DO 5 J=1,NXSXN                                                    NETT2834
      MM=NCR+(J-1)*NROW                                                 NETT2835
      DO 4 K=1,NROW                                                     NETT2836
      M=MM+K                                                            NETT2837
      Z(M)=TAU(J)                                                       NETT2838
    4 CONTINUE                                                          NETT2839
    5 CONTINUE                                                          NETT2840
    9 CALL WRITE(1,'TSUR',Z(1), 60)                                     NETT2841
C   NET TAU FOR SURFACE TO SURFACE INTERCHANGE AREA                     NETT2842
   10 CALL PZERO(AA(1,1), 3600)                                         NETT2843
      IF(ZTAUZ.NE.0)GO TO 15                                            NETT2844
      DO 14 K=1,NSURF                                                   NETT2845
      DO 13 J=1,NSURF                                                   NETT2846
      AA(J,K)=1.0                                                       NETT2847
   13 CONTINUE                                                          NETT2848
   14 CONTINUE                                                          NETT2849
      GO TO 47                                                          NETT2850
C     COMPUTE NET TRANSMISSIVITY                                        NETT2851
C     CALULATE LOWER LEFT HALF OF MATRIX                                NETT2852
```

```
 15       DO 43 K=1,NSURF                                   NETT2853
          CALL ZONE (0,K,XE,YE)                             NETT2854
          DO 42 J=K,NSURF                                   NETT2855
          IF(J.EQ.K)GO TO 26                                NETT2856
          XXE=XE                                            NETT2857
          IF(K.LE.NN)XXE=XXE+HALFXO                         NETT2858
          CALL ZONE(0,J,XR,YR)                              NETT2859
          IF(ABS(XE-XR).LT.XTEST)GO TO 26                   NETT2860
          XXR=XR                                            NETT2861
          IF(J.LE.NN)XXR=XXR+HALFXO                         NETT2862
 C      K AND J ARE BOUNDARY SURFACES                       NETT2863
          IF(K.LE.NCR.AND.J.LE.NCR)GO TO 25                 NETT2864
 C      K IS THE BOUNDARY SURFACE                           NETT2865
 C      J IS AN INTERMEDIATE SURFACE                        NETT2866
          IF(K.GT.NCR)GO TO 18                              NETT2867
          IF(XXE-XXR)17,16,16                               NETT2868
 16       XXR=XXR+HALFXO                                    NETT2869
          GO TO 25                                          NETT2870
 17       XXR=XXR-HALFXO                                    NETT2871
          GO TO 25                                          NETT2872
 C      K IS AN INTERMEDIATE SURFACE                        NETT2873
 C      J IS A BOUNDARY SURFACE                             NETT2874
 18       IF(J.GT.NCR)GO TO 21                              NETT2875
          IF(XXR-XXE)20,19,19                               NETT2876
 19       XXE=XXE+HALFXO                                    NETT2877
          GO TO 25                                          NETT2878
 20       XXE=XXE-HALFXO                                    NETT2879
          GO TO 25                                          NETT2880
 C      K AND J ARE INTERMEDIATE SURFACES                   NETT2881
 21       IF(XXR-XXE)23,22,22                               NETT2882
 22       XXR=XXR-HALFXO                                    NETT2883
          XXE=XXE+HALFXO                                    NETT2884
          GO TO 25                                          NETT2885
 23       XXR=XXR+HALFXO                                    NETT2886
          XXE=XXE-HALFXO                                    NETT2887
 25       T=TCALC(XXE,XXR)                                  NETT2888
          GO TO 40                                          NETT2889
 26       T=1.                                              NETT2890
 40       AA(J,K)=T                                         NETT2891
 42       CONTINUE                                          NETT2892
 43       CONTINUE                                          NETT2893
 C      GENERATE UP ER RIGTH OF MATRIX FROM LOWER LEFT      NETT2894
          JJ=NSURF-1                                        NETT2895
          DO 46 J=1,JJ                                      NETT2896
          KJ=J+1                                            NETT2897
          DO 45 K=KJ,NSURF                                  NETT2898
          AA(J,K)=AA(K,J)                                   NETT2899
 45       CONTINUE                                          NETT2900
 46       CONTINUE                                          NETT2901
 C      STORE RESULTS ON DISK                               NETT2902
```

```
47     DO 48 J=1,NSSBLK                                          NETT2903
       CALL WRITE(1,ZSS(J),AA(1,15*J-14), 900)                   NETT2904
48     CONTINUE                                                  NETT2905
C    NET TAU FOR SURFACE TO GAS INTERCHANE  AREA                 NETT2906
50     CALL PZERO(AA(1,1), 3600)                                 NETT2907
       IF(ZTAUZ.NE.0)GO TO 55                                    NETT2908
       DO 53 K=1,NSURF                                           NETT2909
       DO 52 J=1,NVOL                                            NETT2910
       AA(J,K)=1.                                                NETT2911
52     CONTINUE                                                  NETT2912
53     CONTINUE                                                  NETT2913
       GO TO 77                                                  NETT2914
C    CALULATES NET TRANSMISSIVITY                                NETT2915
55     DO 76 K=1,NSURF                                           NETT2916
       CALL ZONE(0,K,XE,YE)                                      NETT2917
       DO 75 J=1,NVOL                                            NETT2918
       XXE=XE                                                    NETT2919
       IF(K.LE.NN)XXE=XXE+HALFXO                                 NETT2920
       CALL ZONE(1,J,XR,YR)                                      NETT2921
       IF(ABS(XE-XR).LT.XTEST)GO TO 63                           NETT2922
       XXR=XR+HALFXO                                             NETT2923
       IF(K.LE.NCR)GO TO 62                                      NETT2924
       IF(XXR-XXE)58,57,57                                       NETT2925
57     XXE=XXE+HALFXO                                            NETT2926
       GO TO 62                                                  NETT2927
58      XXE=XXE-HALFXO                                           NETT2928
62     T=TCALC(XXE,XXR)                                          NETT2929
       GO TO 74                                                  NETT2930
63     T=1.0                                                     NETT2931
74     AA(J,K)=T                                                 NETT2932
75     CONTINUE                                                  NETT2933
76     CONTINUE                                                  NETT2934
C    STORE RESULTS                                               NETT2935
77     DO 78 J=1,NSGBLK                                          NETT2936
       CALL WRITE(1,ZGS(J),AA(1,15*J-14), 900)                   NETT2937
78     CONTINUE                                                  NETT2938
C    NET TAU FOR GAS TO SURFACE INTERCHANGE AREA                 NETT2939
C    SINCE G-S = S-G ALL THAT REMAINS TO BE DONE IS TRANSPOSE MATRIX AA  NETT2940
60     NL=MIN0(NSURF,NVOL)                                       NETT2941
       NN=NL-1                                                   NETT2942
       DO 82 N=1,NN                                              NETT2943
       LL=N+1                                                    NETT2944
       DO 81 L=LL,NL                                             NETT2945
       SAVE=AA(N,L)                                              NETT2946
         AA(N,L)=AA(L,N)                                         NETT2947
       AA(L,N)=SAVE                                              NETT2948
81     CONTINUE                                                  NETT2949
82     CONTINUE                                                  NETT2950
       NL=NL+1                                                   NETT2951
       IF(NSURF-NVOL)83,88,84                                    NETT2952
```

```
      C    NVOL.GT.NSURF                                    NETT2953
      83     USTART=NL                                      NETT2954
             LSTART=1                                       NETT2955
             GO TO 85                                       NETT2956
      C    NSURF.GT.NVOL                                    NETT2957
      84     USTART=1                                       NETT2958
             LSTART=NL                                      NETT2959
      85     DO 87 N=USTART,NVOL                            NETT2960
             DO 86 L=LSTART,NSURF                           NETT2961
             AA(L,N)=AA(N,L)                                NETT2962
             AA(N,L)=0.0                                    NETT2963
      86     CONTINUE                                       NETT2964
      87     CONTINUE                                       NETT2965
      C    STORE RESULTES                                   NETT2966
      88     DO 89 J=1,NSGBLK                               NETT2967
             CALL WRITE(1,ZSG(J),AA(1,15*J-14), 900)        NETT2968
      89     CONTINUE                                       NETT2969
      C    NET TAU FOR GAS TO GAS INTERCHANGE AREA          NETT2970
             CALL PZERO(AA(1,1), 3600)                      NETT2971
             IF(ZTAUZ.NE.0)GO TO 92                         NETT2972
             DO 91 K=1,NVOL                                 NETT2973
             DO 90 J=1,NVOL                                 NETT2974
             AA(J,K)=1.                                     NETT2975
      90     CONTINUE                                       NETT2976
      91     CONTINUE                                       NETT2977
             GO TO 113                                      NETT2978
      C    CALCULATE NET TRANSMISSIVITY                     NETT2979
      C       CALULATE LOWER LEFT HALF OF MATRIX            NETT2980
      92     DO 109 K=1,NVOL                                NETT2981
             CALL ZONE(1,K,XE,YE)                           NETT2982
             XXE=XE+HALFXO                                  NETT2983
             DO 108 J=K,NVOL                                NETT2984
             IF(J.EQ.K)GO TO 97                             NETT2985
             CALL ZONE(1,J,XR,YR)                           NETT2986
             IF(ABS(XE-XR).LT.XTEST)GO TO 97                NETT2987
             XXR=XR+HALFXO                                  NETT2988
             T=TCALC(XXE,XXR)                               NETT2989
             GO TO 105                                      NETT2990
      97     T=1.                                           NETT2991
      105    AA(J,K)=T                                      NETT2992
      108    CONTINUE                                       NETT2993
      109    CONTINUE                                       NETT2994
      C    GENERATE UPPER RIGTH OF MATRIX FROM LOWER LEFT   NETT2995
             JJ=NVOL-1                                      NETT2996
             DO 112 J=1,JJ                                  NETT2997
             KJ=J+1                                         NETT2998
             DO 111 K=KJ,NVOL                               NETT2999
             AA(J,K)=AA(K,J)                                NETT3000
      111    CONTINUE                                       NETT3001
      112    CONTINUE                                       NETT3002
```

```
C       STORE RESULTS                                        NETT3003
  113   DO 114 J=1,NGCBLK                                    NETT3004
        CALL WRITE(1,ZGG(J),AA(1,15*J-14), 900)              NETT3005
  114   CONTINUE                                             NETT3006
        RETURN                                               NETT3007
        END                                                  NETT3008
```

```
      FUNCTION TCALC(XXE,XXR)                                 TCAL3009
      COMMON // DUMMY(3),KK, ICODE, HCODE,                    TCAL3010
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),          TCAL3011
     A TBRIDG, PRES, FLUET, FLUE(5), XHWX, TSINK,             TCAL3012
     A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,          TCAL3013
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,           TCAL3014
     A XSURFX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,           TCAL3015
     A RSTART, TCODE, SCODE, NGRAY, JHCHC,                    TCAL3016
     A K1, K2, RCRD(10), TOEP(100), PERM(200)                 TCAL3017
C                                                             TCAL3018
      INTEGER SCODE,TCODE,RSTART,HCODE                        TCAL3019
      REAL XDOWN(9)                                           TCAL3020
      DATA NTIME/0/                                           TCAL3021
      IF(NTIME.NE.0)GO TO 10                                  TCAL3022
      DO 2 L=1,NXSXN                                          TCAL3023
      LL=NXSXN+1-L                                            TCAL3024
      XDOWN(L)=XSURFX(LL)                                     TCAL3025
    2 CONTINUE                                                TCAL3026
      XTEST=.001*XO                                           TCAL3027
      NTIME=1                                                 TCAL3028
   10 XLT=AMIN1(XXE,XXR)                                      TCAL3029
      XRT=AMAX1(XXE,XXR)                                      TCAL3030
      IF(ABS(XXE-XXR).LT.XTEST)GO TO 40                       TCAL3031
      M1=0                                                    TCAL3032
      M2=0                                                    TCAL3033
C     COMPUTE M1                                              TCAL3034
      DO 12 L=1,NXSXN                                         TCAL3035
      IF(XSURFX(L).GT.XLT)GO TO 14                            TCAL3036
   12 CONTINUE                                                TCAL3037
      GO TO 40                                                TCAL3038
   14 M1=L                                                    TCAL3039
      DO 22 L=1,NXSXN                                         TCAL3040
      IF(XDOWN(L).LT.XRT)GO TO 24                             TCAL3041
   22 CONTINUE                                                TCAL3042
      GO TO 40                                                TCAL3043
   24 M2 =NXSXN-L+1                                           TCAL3044
C     COMPUTE TCALC                                           TCAL3045
      IF(M1.GT.M2)GO TO 40                                    TCAL3046
      TCALC=1.                                                TCAL3047
      DO 32 M=M1,M2                                           TCAL3048
      TCALC=TCALC*TAU(M)                                      TCAL3049
   32 CONTINUE                                                TCAL3050
      GO TO 50                                                TCAL3051
C    ALL INTERMEDIATE SURFACES ARE                            TCAL3052
C      (1) TO LEFT OF XLT                                     TCAL3053
C      (2) TO THE RIGTH OF XRT                                TCAL3054
   40 TCALC=1.                                                TCAL3055
   50 RETURN                                                  TCAL3056
      END                                                     TCAL3057
```

```
      SUBROUTINE ZONE ( KODE, ND, XX, YY )                              ZONE3058
C                                                                       ZONE3059
C     KODE SURFACE AREA / GAS VOLUME ( 0=AREA, 1=VOLUME )               ZONE3060
C     ND NUMBER OF SURFACE OR VOLUME                                    ZONE3061
C     XX/YY COORDINATES REFERENCED TO UPPER LEFT CORNER                 ZONE3062
C                                                                       ZONE3063
C                                                                       ZONE3064
      COMMON // DUMMY(3), KK, ICODE, HCODE,                             ZONE3065
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                    ZONE3066
     A TRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                        ZONE3067
     A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                    ZONE3068
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                     ZONE3069
     A XSURFX(9), XD, YD, ZLONG, NCOL, NROW, NXSXN,                     ZONE3070
     A RSTART, TCODE, SCODE, NGRAY, JHCHC,                              ZONE3071
     A K1, K2, RCRD(10), TDEP(100), PERM(200)                           ZONE3072
C                                                                       ZONE3073
      INTEGER SCODE, TCODE, RSTART, HCODE                               ZONE3074
C                                                                       ZONE3075
C                                                                       ZONE3076
      K = 0                                                             ZONE3077
      L = ND                                                            ZONE3078
      IF ( KODE .NE. 0 ) GO TO 80                                       ZONE3079
C                                                                       ZONE3080
C     SURFACE AREA                                                      ZONE3081
      IF ( L .GT. NCOL ) GO TO 12                                       ZONE3082
C     TOP SURFACE                                                       ZONE3083
      X = XD * FLOAT ( L - 1 )                                          ZONE3084
      Y = 0.0                                                           ZONE3085
      GO TO 99                                                          ZONE3086
   12 L = L - NCOL                                                      ZONE3087
      IF ( L .GT. NCOL ) GO TO 14                                       ZONE3088
C     BOTTOM SURFACE                                                    ZONE3089
      X = XD * FLOAT ( L - 1 )                                          ZONE3090
      Y = YD * FLOAT ( NROW )                                           ZONE3091
      GO TO 99                                                          ZONE3092
   14 L = L - NCOL                                                      ZONE3093
      IF ( L .GT. NROW ) GO TO 16                                       ZONE3094
C     LEFT SIDE                                                         ZONE3095
      X = 0.0                                                           ZONE3096
      Y = YD * FLOAT ( L - 1 )                                          ZONE3097
      GO TO 99                                                          ZONE3098
   16 L = L - NROW                                                      ZONE3099
      IF ( L .GT. NROW ) GO TO 20                                       ZONE3100
C     RIGHT SIDE                                                        ZONE3101
      X = XD * FLOAT ( NCOL )                                           ZONE3102
      Y = YD * FLOAT ( L - 1 )                                          ZONE3103
      GO TO 99                                                          ZONE3104
   20 K = K + 1                                                         ZONE3105
      L = L - NROW                                                      ZONE3106
      IF ( L .GT. NROW ) GO TO 20                                       ZONE3107
```

```
C      INTERMEDIATE SURFACES                              ZONE3108
       X = XSURFX(K)                                      ZONE3109
       Y = YD * FLOAT ( L - 1 )                           ZONE3110
       GO TO 99                                           ZONE3111
C      GAS VOLUME                                         ZONE3112
    80 K = K + 1                                          ZONE3113
       IF ( L .LE. NCOL ) GO TO 81                        ZONE3114
       L = L - NCOL                                       ZONE3115
       GO TO 60                                           ZONE3116
    81 X = XD * FLOAT ( L - 1 )                           ZONE3117
       Y = YD * FLOAT ( K - 1 )                           ZONE3118
C                                                         ZONE3119
    99 XX = X                                             ZONE3120
       YY = Y                                             ZONE3121
       RETURN                                             ZONE3122
       END                                                ZONE3123
```

```
      FUNCTION HV ( TT )                                  HV  3124
C                                                         HV  3125
C     FUNCTION COMPUTES ENTHALPY OF FLUE GAS              HV  3126
C                                                         HV  3127
      COMMON /CPHV/ CPCP(11), HVHV(12)                    HV  3128
C                                                         HV  3129
      HV = EQUA ( TT/1000.0, HVHV )                       HV  3130
C                                                         HV  3131
      RETURN                                              HV  3132
      END                                                 HV  3133
```

```
       SUBROUTINE CL2                                                    CL2 3134
C   CORE LOAD 2                                                          CL2 3135
C                                                                        CL2 3136
C                                                                        CL2 3137
       COMMON // DUMMY(3),KK, ICODE, HCODE,                              CL2 3138
      A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                    CL2 3139
      A TBRIDG, PFES, FLUET, FLUE(5), XMWX, TSINK,                       CL2 3140
      A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                    CL2 3141
      A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                     CL2 3142
      A XSUREX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,                     CL2 3143
      A RSTART, TCODE, SCODE, NGRAY, JHCHC,                              CL2 3144
      A K1, K2, RCRD(10), TDEP(100), PERM(200)                           CL2 3145
C                                                                        CL2 3146
       INTEGER SCODE, TCODE, RSTART, HCODE                               CL2 3147
       COMMON/JAZZ2/ SSNM(8,4),GSNM(8,3),SGNM(8,3),GGNM(8,3),            CL2 3148
      1 ZSS(8),ZGS(8),ZSG(8),ZGG(8)                                      CL2 3149
       COMMON/SPCE2/ AA( 60, 60),BB( 60,15),CC( 60,15),ALPHA( 60)        CL2 3150
       COMMON/GAUSS/ WT(9),XY(9),ARG(9,9),NPT                            CL2 3151
       WRITE(K2,2001)                                                    CL2 3152
 2001  FORMAT(//T10,'CL2 A')                                             CL2 3153
       CALL SSCALC                                                       CL2 3154
       WRITE(K2,2002)                                                    CL2 3155
 2002  FORMAT(T10,'CL2 B')                                               CL2 3156
 60    CALL GSCALC                                                       CL2 3157
       WRITE(K2,2003)                                                    CL2 3158
 2003  FORMAT(T10,'CL2 C')                                               CL2 3159
       CALL GGCALC                                                       CL2 3160
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  CL2 3161
C   TEST OF COMPUTION OF TOTAL INERTCCANGE AREAS                         CL2 3162
C       (1)   SURFACE AS THE EMITTER                                     CL2 3163
C       (2)   VOLUMN AS THE EMITTER                                      CL2 3164
       WRITE(K2,2004)                                                    CL2 3165
 2004  FORMAT(T10,'CL2 D')                                               CL2 3166
 61    CALL PZERO(BB(1,1),1320)                                          CL2 3167
 62    CALL READ(1,'ASUR',BB(1,5), 60)                                   CL2 3168
C   SURFACE AS THE EMITTER                                               CL2 3169
C       NSSBLK=NUMBER OF SURFACE TO SURFACE BLOCKS                       CL2 3170
C       NGSBLK=NUMBER OF SURFACE TO GAS BLOCKS                           CL2 3171
       KMAX=NGRAY+1                                                      CL2 3172
       DO 89 K=1,KMAX                                                    CL2 3173
       IF(K.EQ.KMAX)GO TO 63                                             CL2 3174
       KK=K                                                              CL2 3175
       GO TO 64                                                          CL2 3176
 63    KK=4                                                              CL2 3177
 64    DO 65 J=1,NSSBLK                                                  CL2 3178
       CALL READ(1,SSNM(J,KK),AA(1,15*J-14), 900)                        CL2 3179
 65    CONTINUE                                                          CL2 3180
       DO 67 L=1,NSURF                                                   CL2 3181
       DO 66 N=1,NSURF                                                   CL2 3182
       BB(L,KK)=BB(L,KK)+AA(N,L)                                         CL2 3183
```

```
66    CONTINUE                                                          CL2 3184
67    CONTINUE                                                          CL2 3185
      IF(K.EQ.KMAX)GO TO 90                                             CL2 3186
      DO 72 J=1,NGSBLK                                                  CL2 3187
      CALL READ(1,GSNM(J,KK),AA(1,15*J-14), 900)                        CL2 3188
72    CONTINUE                                                          CL2 3189
      DO 74 L=1,NSURF                                                   CL2 3190
      DO 73 N=1,NVOL                                                    CL2 3191
      BB(L,KK)=BB(L,KK)+AA(N,L)                                         CL2 3192
73    CONTINUE                                                          CL2 3193
74    CONTINUE                                                          CL2 3194
C      GAS AS THE EMITTER                                               CL2 3195
C      NGGBLK=NUMBER OF GAS TO GAS BLOCKS                               CL2 3196
C      NSGBLK=NUMBER OF GAS TO SURFACE BLOCKS                           CL2 3197
      KO=6+2*(KK-1)                                                     CL2 3198
      DO 76 J=1,NGGBLK                                                  CL2 3199
      CALL READ(1,GGNM(J,KK),AA(1,15*J-14), 900)                        CL2 3200
76    CONTINUE                                                          CL2 3201
      DO 79 L=1,NVOL                                                    CL2 3202
      DO 78 N=1,NVOL                                                    CL2 3203
      BB(L,KO)=BB(L,KO)+AA(N,L)                                         CL2 3204
78    CONTINUE                                                          CL2 3205
79    CONTINUE                                                          CL2 3206
      DO 81 J=1,NSGBLK                                                  CL2 3207
      CALL READ(1,SGNM(J,KK),AA(1,15*J-14), 900)                        CL2 3208
81    CONTINUE                                                          CL2 3209
      DO 83 L=1,NVOL                                                    CL2 3210
      DO 82 N=1,NSURF                                                   CL2 3211
      BB(L,KO)=BB(L,KO)+AA(N,L)                                         CL2 3212
82    CONTINUE                                                          CL2 3213
83    CONTINUE                                                          CL2 3214
      CON=4.*XK(KK)*XO*VD                                               CL2 3215
      DO 84 L=1,NVOL                                                    CL2 3216
      BB(L,KO+1)=CON                                                    CL2 3217
84    CONTINUE                                                          CL2 3218
89    CONTINUE                                                          CL2 3219
90    WRITE(K2,91)                                                      CL2 3220
91    FORMAT('1 R EACH CHARACTERISTIC GAS THE SUM OF ALL DIRECT INTERCHCL2 3221
     1ANGE AREAS WITH THE SURFACE AREA AS THE THE EMITTER MUST EQUAL THECL2 3222
     2 AREA'//10X,'GRAY GAS 1',5X,'GRAY GAS 2,',5X,'GRAY GAS 3,',11X,'CLCL2 3223
     2EAR GAS',16X,'AREA')                                              CL2 3224
      WRITE(K2,92)(I,(BB(I,M),M=1,5),I=1,NSURF)                         CL2 3225
92    FORMAT(//(I5,3F15.5,2F20.5))                                      CL2 3226
      WRITE(K2,93)                                                      CL2 3227
93    FORMAT('1FOR EACH CHARACTERISTIC GAS THE SUM OF ALL DIRECT INTERCHCL2 3228
     1ANE AREAS WITH A GAS VOLUME AS THE EMITTER MUST EQUAL THE' /' PRODCL2 3229
     2UCT OF THE GAS ABSORPTION COEFFICIENT AND THE VOLUME MULTIPLIED BYCL2 3230
     2 A CONSTANT OF 4.0'//23X,'GRAY GAS 1',25X,'GRAY GAS 2,',25X,'GRAY CL2 3231
     4 GAS 3,'/15X,' INTER-AREA',6X,'ABS*VOL',10X,'INTER-AREA',6X,'ABS*VCL2 3232
     OL',10X,'INTER-AREA',6X,'ABS*VOL'//)                              CL2 3233
```

```
      WRITE(K2,94)(I,(BB(I,M),M=6,11),I=1,NVOL)         CL2 3234
   94 FORMAT(/(I5,3(3X,2F15.5)))                         CL2 3235
      CALL WRITE(4,'STAR',WT(1),1)                       CL2 3236
      RETURN                                             CL2 3237
      END                                                CL2 3238
```

```
         FUNCTION SS(XXE,YYE,XXR,YYR,NNN,MMM)                          SS 3239
         COMMON // DUMMY(2),KK, ICODE, HCODE,                          SS 3240
       A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                 SS 3241
       A TBRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                    SS 3242
       A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                 SS 3243
       A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                  SS 3244
       A XSURFX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,                  SS 3245
       A RSTART, TCODE, SCODE, NGRAY, JHCHC,                           SS 3246
       A K1, K2, RCRD(10), TDEP(100), PERM(200)                        SS 3247
C                                                                      SS 3248
         INTEGER SCODE,TCODE,RSTART,HCODE                              SS 3249
         COMMON/GAUSS/ WT(9),XY(9),ARG(9,9),NPT                        SS 3250
         DIMENSION W(9),Z(9)                                           SS 3251
         EQUIVALENCE (XY(1),W(1),Z(1))                                 SS 3252
C         NN=1 SURFACE IS HORIZONTAL                                   SS 3253
C         NN=2   SURFACE IS VERTICAL                                   SS 3254
C         RECEIVER ORIENTATION                                         SS 3255
C         MM=1   HORIZONTAL                                            SS 3256
C         MM=2   SURFACE IS VERTICAL                                   SS 3257
         XE=XXE                                                        SS 3258
         YE=YYE                                                        SS 3259
         XR=XXR                                                        SS 3260
         YR=YYR                                                        SS 3261
         NN=NNN                                                        SS 3262
         MM=MMM                                                        SS 3263
         IF(KK.EQ.4)GO TO 23                                           SS 3264
         ZZ=XK(KK)                                                     SS 3265
         GO TO 30                                                      SS 3266
   23    ZZ=0.0                                                        SS 3267
C         J=VARIATION ACROSS EMITTING SURFACE                          SS 3268
C         I=VARIATION ACCROSS RECEIVING SURFACE                        SS 3269
   30    CALL PZERO(ARG(1,1),81)                                       SS 3270
         XX=ABS(XR-XE)                                                 SS 3271
         YY=ABS(YR-YE)                                                 SS 3272
         GO TO(31,32),NN                                               SS 3273
   31    GO TO (51,41),MM                                              SS 3274
   32    GO TO(51,71),MM                                               SS 3275
C       CASE 1 NN=1  MM=2                                              SS 3276
C         EMITTER IS HORIZONTAL    Y CONSTANT                          SS 3277
C         RECEIVER IS VERTICAL     X CONSTANT                          SS 3278
   41    IF(XR.GT.XE)GO TO 42                                          SS 3279
         X1=XX                                                         SS 3280
         X2=XX+XO                                                      SS 3281
         GO TO 43                                                      SS 3282
   42    X1=XX-XO                                                      SS 3283
         X2=XX                                                         SS 3284
   43    IF(YR.LT.YE) GO TO 44                                         SS 3285
         Y1=YY                                                         SS 3286
         Y2=YY+YO                                                      SS 3287
         GO TO 45                                                      SS 3288
```

```
44    Y1=YY-Y0
      Y2=YY
45    DO 47 J=1,NPT
      X=(X2*(1.+W(J))+X1*(1.-W(J)))/2.
      DO 46 I=1,NPT
      Y=(Y2*(1.+Z(I))+Y1*(1.-Z(I)))/2.
      U= SQRT(X**2+Y**2)
      ARG(I,J)=F(ZZ*U)/U**3*X*Y*(X2-X1)/2.*(Y2-Y1)/2.
46    CONTINUE
47    CONTINUE
      GO TO 85
C   CASE 2 NN=2  MM=1
C     EMITTER IS VERTICAL        X CONSTANT
C     RECEIVER IS HORIZONTAL     Y CONSTANT
51    IF(XR.LT.XE)GO TO 52
      X1=XX
      X2=XX+X0
      GO TO 53
52    X1=XX-X0
      X2=XX
53    IF(YR.GT.YE)GO TO 54
      Y1=YY
      Y2=YY+Y0
      GO TO 55
54    Y1=YY-Y0
      Y2=YY
55    DO 57 J=1,NPT
      Y=(Y2*(1.+W(J))+Y1*(1.-W(J)))/2.
      DO 56 I=1,NPT
      X=(X2*(1.+Z(I))+X1*(1.-Z(I)))/2.
      U=SQRT(X**2+Y**2)
      ARG(I,J)=F(ZZ*U)/U**3*X*Y*(Y2-Y1)/2.*(X2-X1)/2.
56    CONTINUE
57    CONTINUE
      GO TO 85
C   CASE 3  NN=1  MM=1
C     EMITTER IS HORIZONTAL      Y CONSTANT
C     RECEIVER IS HORIZONTAL     Y CONSTANT
61    IF(YY.EQ.0.0)GO TO 84
      Y=YY
      X1BAR=0.0
      X2BAR=X0
      DO 65 J=1,NPT
      XBAR=(X2BAR*(1.+W(J))+X1BAR*(1.-W(J)))/2.
      IF(XR.EQ.XE)GO TO 62
      X1=XX-X0+XBAR
      X2=X1+X0
      GO TO 63
62    X1=-XBAR
      X2=X1+X0
```

```
 63     DO 64 I=1,NPT                                              SS 3339
        X=(X2*(1.+Z(I))+X1*(1.-Z(I)))/2.                           SS 3340
        U=SQRT(X**2+Y**2)                                          SS 3341
        ARG(I,J) =F(ZZ*U)/U**3*Y**2*(X2BAR-X1BAR)/2.*(X2-X1)/2.    SS 3342
 64     CONTINUE                                                   SS 3343
 65     CONTINUE                                                   SS 3344
        GO TO 85                                                   SS 3345
C     CASE 4 NN=2  MM=2                                            SS 3346
C        EMITTER IS VERTICAL     X CONSTANT                        SS 3347
C        RECEIVER IS VERTICAL    X CONSTANT                        SS 3348
 71     IF(XX.EQ.0.0)GO TO 84                                      SS 3349
        X=XX                                                       SS 3350
        Y1BAR=0.                                                   SS 3351
        Y2BAR=YD                                                   SS 3352
        DO 75 J=1,NPT                                              SS 3353
        YBAR=(Y2BAR*(1.+W(J))+Y1BAR*(1.-W(J)))/2.                  SS 3354
        IF(YR.EQ.YE)GO TO 72                                       SS 3355
        Y1=YY-YU+YBAR                                              SS 3356
        Y2=Y1+YD                                                   SS 3357
        GO TO 73                                                   SS 3358
 72     Y1=-YBAR                                                   SS 3359
        Y2=Y1+YD                                                   SS 3360
 73     DO 74 I=1,NPT                                              SS 3361
        Y=(Y2*(1.+Z(I))+Y1*(1.-Z(I)))/2.                           SS 3362
        U=SQRT(X**2+Y**2)                                          SS 3363
        ARG(I,J)=F(ZZ*U)/U**3*X**2*(Y2BAR-Y1BAR)/2.*(Y2-Y1)/2.     SS 3364
 74     CONTINUE                                                   SS 3365
 75     CONTINUE                                                   SS 3366
        GO TO 85                                                   SS 3367
C     SURFACES ARE IN THE SAME PLANE BUT NOT ADJACENT              SS 3368
 84     SS=0.0                                                     SS 3369
        GO TO 88                                                   SS 3370
 85     SS=0.                                                      SS 3371
        DO 87 J=1,NPT                                              SS 3372
        FAC=0.0                                                    SS 3373
        DO 86 I=1,NPT                                              SS 3374
        FAC=FAC+WT(I)*ARG(I,J)                                     SS 3375
 86     CONTINUE                                                   SS 3376
        SS=SS+WT(J)*FAC                                            SS 3377
 87     CONTINUE                                                   SS 3378
        SS=SS/3.1415927                                            SS 3379
 88     RETURN                                                     SS 3380
        END                                                        SS 3381
```

A FORTRAN IV (VER L43) SOURCE LISTING: F FUNCTION 03/05/74 PAGE 0083

```
      FUNCTION F(W)                                                     F 3382
C     W=ABSORTIVITY*SQRT(X*X+Y*Y)                                       F 3383
      WW=W                                                              F 3384
      IF(WW.GT.0.0) GO TO 5                                             F 3385
      F=1.5707228                                                       F 3386
      GO TO 99                                                          F 3387
 5    IF(WW.LE.3.9) GO TO 10                                            F 3388
      IF(WW.LE.7.9) GO TO 20                                            F 3389
      IF(WW.LE.11.9)GO TO 30                                            F 3390
      IF(WW.LE.15.9)GO TO 40                                            F 3391
      IF(WW.LE.19.9)GO TO 50                                            F 3392
      F=0.0                                                             F 3393
      GO TO 99                                                          F 3394
 10   V=EXP(-WW)                                                        F 3395
      F=((((-.55633800E-1*V**3+.24494718E+00)*V**2-.52658248)*V+.8587088F 3396
     18)*V+.10520692E+1)*V-.2878833E-02                                 F 3397
      GO TO 99                                                          F 3398
 20   V=EXP(-WW/2.0)                                                    F 3399
      F=(((((.1056065E+07*V**5-.61555166E+03)*V**2+.11892488E3)*V       F 3400
     1+.82146101E02)*V-.26387379E0)*V+.18988744E-2)*1.0E-2              F 3401
      GO TO 99                                                          F 3402
 30   V=EXP(-WW/3.)                                                     F 3403
      F=(((.13272233E+05*V+.66956509E4)*V**2-.47270165)*V+.59591527E-2)*F 3404
     11.0E-4                                                            F 3405
      GO TO 99                                                          F 3406
 40   V=EXP(-WW/4.)                                                     F 3407
      F=((((-.86891805E+9*V**3+.20670843E+7)*V+.54843329E+6)*V**3       F 3408
     1-.17417612E0)*V+.16454718E-2)*1.E-6                               F 3409
      GO TO 99                                                          F 3410
 50   V=EXP(-WW/5.)                                                     F 3411
      F=(((+.16617530E+9*V+.30842624E+8)*V**3                           F 3412
     1-.2399666E+2)*V**2+.46168566E-2)*1.E-8                            F 3413
 99   RETURN                                                            F 3414
      END                                                               F 3415
```

```
      SUBROUTINE SSCALC                                              SSCA3416
C      COMPUTATION OF SURFACE TO SURFACE DIRECT INTERCHANGE AREA      SSCA3417
      COMMON // DUMMY(3),KK, ICODE, HCODE,                           SSCA3418
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                 SSCA3419
     A TBRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                    SSCA3420
     A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                 SSCA3421
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                  SSCA3422
     A XSURFX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,                  SSCA3423
     A RSTART, TCODE, SCODE, NGRAY, JHCHC,                           SSCA3424
     A K1, K2, RCRD(10), TDEP(100), PEPM(200),NPRNT                  SSCA3425
C                                                                    SSCA3426
      INTEGER SCODE,TCODE,RSTART,HCODE                               SSCA3427
C                                                                    SSCA3428
      COMMON/JAZZ2/ SSNM(8,4),GSNM(8,3),SGNM(8,3),GGNM(8,3),        SSCA3429
     1 ZSS(8),ZGS(8),ZSG(8),ZGG(8)                                   SSCA3430
      COMMON/SPCE2/AA( 60, 60),BB( 60,15),CC( 60,15),ALPHA( 60)      SSCA3431
      CALL READ(1,'ALP ',ALPHA(1), 60)                               SSCA3432
C    KK= GAS NUMBER                                                  SSCA3433
      CALL PZERO(BB(1,1),600)                                        SSCA3434
      KMAX=NGRAY+1                                                   SSCA3435
      DO 99 K=1,KMAX                                                 SSCA3436
      CALL PZERO(AA(1,1), 3600)                                      SSCA3437
      IF(K.EQ.KMAX)GO TO 12                                          SSCA3438
      KK=K                                                           SSCA3439
      ZZ=XK(KK)                                                      SSCA3440
      GO TO 21                                                       SSCA3441
   12 KK=4                                                           SSCA3442
      ZZ=0.0                                                         SSCA3443
C    GENERATE ONLY LOWER LEFT OF SURFACE TO SURFACE MATRIX           SSCA3444
C    OBTAIN REMAIDER USEING SYMMETRY OF MATRIX                       SSCA3445
C       N=NUMBER OF EMITTING SURFACES                                SSCA3446
C       M=NUMBER OF RECEIVING SURFACES                               SSCA3447
   21 DO 89 N=1,NSURF                                                SSCA3448
      CALL ZONE(0,N,XE,YE)                                           SSCA3449
      NN=1                                                           SSCA3450
      IF(N.GT.2*NCOL)NN=2                                            SSCA3451
      DO 88 M=N,NSURF                                                SSCA3452
      CALL ZONE(0,M,XR,YR)                                           SSCA3453
      MM=1                                                           SSCA3454
      IF(M.GT.2*NCOL)MM=2                                            SSCA3455
      XX=ABS(XR-XE)                                                  SSCA3456
      YY=ABS(YR-YE)                                                  SSCA3457
      GO TO (31,32),NN                                               SSCA3458
   31 GO TO (61,85),MM                                               SSCA3459
   32 GO TO(85,61),MM                                                SSCA3460
   61 IF(XX+YY.EQ.0.0)GO TO 81                                       SSCA3461
      GO TO 85                                                       SSCA3462
C    A SURFACE CANNOT VIEW ITSELF                                    SSCA3463
   81 AA(M,N)=0.0                                                    SSCA3464
      GO TO 88                                                       SSCA3465
```

```
 85   AA(M,N)=SS(XE,YE,XR,YR,NN,MM)                                SSCA3466
      IF(M.GT.NCR) AA(M,N)=AA(M,N)*ALPHA(M)                        SSCA3467
      IF(N.GT.NCR)AA(M,N)=AA(M,N)*ALPHA(N)                         SSCA3468
 88   CONTINUE                                                     SSCA3469
 89   CONTINUE                                                     SSCA3470
C    COMPLETE UPPER RIGHT OF MATRIX                                SSCA3471
C      N ROW    L COL                                              SSCA3472
 90   NN=NSURF-1                                                   SSCA3473
      DO 94 N=1,NN                                                 SSCA3474
      LL=N+1                                                       SSCA3475
      DO 93 L=LL,NSURF                                             SSCA3476
      AA(N,L)=AA(L,N)                                              SSCA3477
 93   CONTINUE                                                     SSCA3478
 94   CONTINUE                                                     SSCA3479
      DO 945  J=1,NSSBLK                                           SSCA3480
      CALL READ(1,ZSS(J),CC(1,1), 900)                             SSCA3481
      JJ=(J-1)*15                                                  SSCA3482
      MLAST=15                                                     SSCA3483
      IF(J.EQ.NSSBLK)MLAST=NSURF-JJ                                SSCA3484
      DO 943 N=1,MLAST                                             SSCA3485
      DO 941 N=1,NSURF                                             SSCA3486
      MM=JJ+N                                                      SSCA3487
      AA(N,MM)=AA(N,MM)*CC(N,M)                                    SSCA3488
      IF(AA(N,MM).LT.0.)CALL ERROR('SSCC',N,MM)                    SSCA3489
 941  CONTINUE                                                     SSCA3490
 943  CONTINUE                                                     SSCA3491
 945  CONTINUE                                                     SSCA3492
C    NORMALIZED CLEAR GAS SURFACE TO SURFACE INTERCHANGE AREA      SSCA3493
C    SO THAT THEY SUM TO THE AREA OF THE EMITTER                   SSCA3494
      IF(K.NE.KMAX)GO TO 301                                       SSCA3495
 95   NN=2*MCOL                                                    SSCA3496
      DO 209 N=1,NSURF                                             SSCA3497
      IF(N.GT.NN)GO TO 201                                         SSCA3498
      AREA=XO                                                      SSCA3499
      GO TO 203                                                    SSCA3500
 201  IF(N.GT.NCR)GO TO 202                                        SSCA3501
      AREA=YO                                                      SSCA3502
      GO TO 203                                                    SSCA3503
 202  AREA=YO*2.*ALPHA(N)                                          SSCA3504
 203  ZZ=0.0                                                       SSCA3505
      DO 205 M=1,NSURF                                             SSCA3506
      ZZ=ZZ+AA(M,N)                                                SSCA3507
 205  CONTINUE                                                     SSCA3508
 206  ZZ=AREA/ZZ                                                   SSCA3509
      DO 207 M=1,NSURF                                             SSCA3510
      AA(M,N)=AA(M,N)*ZZ                                           SSCA3511
      IF(AA(M,N).LT.0.)CALL ERROR('SSZZ',M,N)                      SSCA3512
 207  CONTINUE                                                     SSCA3513
 209  CONTINUE                                                     SSCA3514
      GO TO 96                                                     SSCA3515
```

```
C     COMPUTE SUM OF SURFACE TO SURFACE INTERCHANGE AREAS                SSCA3516
C     SO THAT THEY CAN BE LATER NORMALIZED TO THE AREA OF THE EMITTER    SSCA3517
  301   DO 303 N=1,NSURF                                                 SSCA3518
        DO 302 M=1,NSURF                                                 SSCA3519
        BB(N,KK)=BB(N,KK)+AA(M,N)                                        SSCA3520
  302   CONTINUE                                                         SSCA3521
  303   CONTINUE                                                         SSCA3522
C     WRITE DATA OUT ON DISK                                             SSCA3523
   96   DO 97 J=1,NSSBLK                                                 SSCA3524
        CALL WRITE(1,SSNM(J,KK),AA(1,15*J-14), 900)                      SSCA3525
   97   CONTINUE                                                         SSCA3526
        IF(K.NE.KMAX)GO TO 99                                            SSCA3527
        IF(NPRNT.EQ.1)GO TO 99                                           SSCA3528
  400   WRITE(K2,401)KK                                                  SSCA3529
  401   FORMAT('1',19X,'SURFACE TO SURFACE DIRECT INTERCHANGE AREAS',10X,'SSCA3530
       1 K= ',I5)                                                        SSCA3531
        CALL PRINT(AA,NSURF,NSURF)                                       SSCA3532
   99   CONTINUE                                                         SSCA3533
  101   RETURN                                                           SSCA3534
        END                                                              SSCA3535
```

```
      SUBROUTINE GSCALC                                              GSCA3536
C   COMPUTATION OF SURFACE TO VOLUME DIRECT INTERCHANGE AREA        GSCA3537
      COMMON // DUMMY(3),KK, ICODE, HCODE,                           GSCA3538
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                 GSCA3539
     A TBRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                    GSCA3540
     A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                 GSCA3541
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                  GSCA3542
     A XSUREX(9), XD, YD, ZLONG, NCOL, IROW, NXSXN,                  GSCA3543
     A RSTART, TCODE, SCODE, NGRAY, JHCHC,                           GSCA3544
     A K1, K2, RCRD(10), TDEP(100), PERM(200),NPRNT                  GSCA3545
C                                                                    GSCA3546
      INTEGER SCODE,TCODE,RSTART,HCODE                               GSCA3547
      COMMON/JAZZ2/ SSNM(8,4),GSNM(8,3),SGNM(8,3),GGNM(8,3),         GSCA3548
     1ZSS(8),ZGS(8),ZSG(8),ZGG(8)                                    GSCA3549
      COMMON/SPCE2/ AA( 60, 60),BB( 60,15),CC( 60,15),ALPHA( 60)     GSCA3550
      XDYD=AMIN1(XD,YD)                                              GSCA3551
      CALL READ(1,'ASUR',BB(1,5), 60)                                GSCA3552
C   KK=GAS NUMBER                                                    GSCA3553
   10 DO 1900 KK=1,NGRAY                                             GSCA3554
      CALL PZERO(AA(1,1), 3600)                                      GSCA3555
C      N=NUMBER OF EMITTING SURFACE                                  GSCA3556
C      M=NUMBER OF RECEIVING VOLUME                                  GSCA3557
      DO 1850 N=1,NSURF                                              GSCA3558
      CALL ZONE(0,N,XE,YE)                                           GSCA3559
      DO 1840 M=1,NVOL                                               GSCA3560
      CALL ZONE(1,M,XR,YR)                                           GSCA3561
C     WRITE(K2,16)N,XE,YE,M,XR,YR                                    GSCA3562
C16   FORMAT(//I5,2F15.5)                                            GSCA3563
      XRA=XR                                                         GSCA3564
      YRA=YR                                                         GSCA3565
      XRB=XR+XD                                                      GSCA3566
      YRB=YR                                                         GSCA3567
      XRC=XR                                                         GSCA3568
      YRC=YR+YD                                                      GSCA3569
      XRD=XR                                                         GSCA3570
      YRD=YR                                                         GSCA3571
C     WRITE(K2,25)XRA,TRA,XRB,YRB,XRC,YRC,XRD,YRD                    GSCA3572
C25   FORMAT(10X,2F15.5)                                             GSCA3573
      IF(N.GT.2*NCOL)GO TO 37                                        GSCA3574
C   HORIZONTAL SURFACES                                              GSCA3575
      NN=1                                                           GSCA3576
      IF(YE.GT.YR)GO TO 30                                           GSCA3577
      IF(XE-XR)100,200,300                                           GSCA3578
   30 IF(XE-XR)1000,1100,1200                                        GSCA3579
C     VERTICAL SURFACES                                              GSCA3580
   37 NN=2                                                           GSCA3581
      IF(XE.GT.XR)GO TO 50                                           GSCA3582
      IF(YE-YR)400,600,800                                           GSCA3583
   50 IF(YE-YR)500,700,900                                           GSCA3584
C      SURFACE AREA TO GAS VOLUME                                    GSCA3585
```

```
C     ORIENTATION 1                                                     GSCA3586
  100 S1=1.                                                             GSCA3587
      S2=-1.                                                            GSCA3588
      S3=-1.                                                            GSCA3589
      S4=1.                                                             GSCA3590
      GO TO 1500                                                        GSCA3591
C     ORIENTATION 2                                                     GSCA3592
  200 IF(ABS(YR-YE).EQ.0.0)GO TO 210                                    GSCA3593
      S1=1.                                                             GSCA3594
      S2=-1.                                                            GSCA3595
      S3=-1.                                                            GSCA3596
      S4=-1.                                                            GSCA3597
      GO TO 1500                                                        GSCA3598
  210 FAC=XO-SS(XE,YE,XRB,YRB,NN,2)-SS(XE,YE,XRC,YRC,NN,1)-SS(XE,YE,XRD,GSCA3599
     1YRD,NN,2)                                                         GSCA3600
      GO TO 1700                                                        GSCA3601
C     ORIENTATION 3                                                     GSCA3602
  300 S1=1.                                                             GSCA3603
      S2=1.                                                             GSCA3604
      S3=-1.                                                            GSCA3605
      S4=-1.                                                            GSCA3606
      GO TO 1500                                                        GSCA3607
C     ORIENTATION 4                                                     GSCA3608
  400 S1=1.                                                             GSCA3609
      S2=-1.                                                            GSCA3610
      S3=-1.                                                            GSCA3611
      S4=1.                                                             GSCA3612
      GO TO 1500                                                        GSCA3613
C     ORIENTATION 5                                                     GSCA3614
  500 S1=1.                                                             GSCA3615
      S2=1.                                                             GSCA3616
      S3=-1.                                                            GSCA3617
      S4=-1.                                                            GSCA3618
      GO TO 1500                                                        GSCA3619
C     ORIENTATION 6                                                     GSCA3620
  600 IF(ABS(XR-XE).EQ.0.0)GO TO 610                                    GSCA3621
      S1=-1.                                                            GSCA3622
      S2=-1.                                                            GSCA3623
      S3=-1.                                                            GSCA3624
      S4=1.                                                             GSCA3625
      GO TO 1500                                                        GSCA3626
  610 FAC=YO-SS(XE,YE,XRA,YRA,NN,1)-SS(XE,YE,XRB,YRB,NN,2)              GSCA3627
     1-SS(XE,YE,XRC,YRC,NN,1)                                           GSCA3628
      GO TO 1700                                                        GSCA3629
C     ORIENTATION 7                                                     GSCA3630
  700 IF(ABS(ABS(XR-XE)-XO).LT.XOYO)GO TO 710                           GSCA3631
      S1=-1.                                                            GSCA3632
      S2=1.                                                             GSCA3633
      S3=-1.                                                            GSCA3634
      S4=-1.                                                            GSCA3635
```

```
          GO TO 1500                                                   GSCA3636
 710      FAC=YD-SS(XE,YE,XRA,YRA,NN,1)-SS(XE,YE,XRC,YRC,NN,1)         GSCA3637
         1-SS(XE,YE,XRD,YRD,NN,2)                                      GSCA3638
          GO TO 1700                                                   GSCA3639
C     ORIENTATION 8                                                    GSCA3640
 800      S1=-1.                                                       GSCA3641
          S2=-1.                                                       GSCA3642
          S3=1.                                                        GSCA3643
          S4=1.                                                        GSCA3644
          GO TO 1500                                                   GSCA3645
C     ORIENTATION 9                                                    GSCA3646
 900      S1=-1.                                                       GSCA3647
          S2=1.                                                        GSCA3648
          S3=1.                                                        GSCA3649
          S4=-1.                                                       GSCA3650
          GO TO 1500                                                   GSCA3651
C     ORIENTATION 10                                                   GSCA3652
 1000     S1=-1.                                                       GSCA3653
          S2=-1.                                                       GSCA3654
          S3=1.                                                        GSCA3655
          S4=1.                                                        GSCA3656
          GO TO 1500                                                   GSCA3657
C     ORIENTATION 11                                                   GSCA3658
 1100     IF(ABS(ABS(YR-YE)-YD).LT.XDYD)GO TO 1110                     GSCA3659
          S1=-1.                                                       GSCA3660
          S2=-1.                                                       GSCA3661
          S3=1.                                                        GSCA3662
          S4=-1.                                                       GSCA3663
          GO TO 1500                                                   GSCA3664
 1110     FAC=XD-SS(XE,YE,XRA,YRA,NN,1)-SS(XE,YE,XRB,YRB,NN,2)         GSCA3665
         1-SS(XE,YE,XRD,YRD,NN,2)                                      GSCA3666
          GO TO 1700                                                   GSCA3667
C     ORIENTATION 12                                                   GSCA3668
 1200     S1=-1.                                                       GSCA3669
          S2=1.                                                        GSCA3670
          S3=1.                                                        GSCA3671
          S4=-1.                                                       GSCA3672
 1500     FAC=SS(XE,YE,XRA,YRA,NN,1)*S1+SS(XE,YE,XRB,YRB,NN,2)*S2      GSCA3673
         1+SS(XE,YE,XRC,YRC,NN,1)*S3+SS(XE,YE,XRD,YRD,NN,2)*S4        GSCA3674
 1700     AA(M,N)=FAC                                                  GSCA3675
          IF(N.GT.NCR)AA(M,N)=FAC*ALPHA(N)                             GSCA3676
 1840     CONTINUE                                                     GSCA3677
 1850     CONTINUE                                                     GSCA3678
          DO 1851 J=1,NGSBLK                                           GSCA3679
          CALL READ(1,ZGS(J),CC(1,1), 900)                             GSCA3680
          JJ=(J-1)*15                                                  GSCA3681
          MLAST=15                                                     GSCA3682
          IF(J.EQ.NGSBLK)MLAST=NVOL-JJ                                 GSCA3683
          DO 1852 M=1,MLAST                                            GSCA3684
          DO 1853 N=1,NVOL                                             GSCA3685
```

```
            MM=JJ+M                                                      GSCA3686
            AA(N,MM)=AA(N,MM)*CC(N,M)                                    GSCA3687
      1853  CONTINUE                                                     GSCA3688
      1852  CONTINUE                                                     GSCA3689
      1851  CONTINUE                                                     GSCA3690
      C   WRITE SURFACE TO VOLUME INTERCHANGE AREA ON DISK               GSCA3691
      1860  DO 1862  J=1,NGSBLK                                          GSCA3692
            CALL WRITE(1,GSNM(J,KK),AA(1,15*J-14), 900)                  GSCA3693
      1862  CONTINUE                                                     GSCA3694
      C   COMPLATE SUM OF INTERCHANGE AREA WITH SURFACE AS EMITTER       GSCA3695
            DO 2002 N=1,NSURF                                            GSCA3696
            DO 2001 M=1,NVOL                                             GSCA3697
            BB(N,KK)=BB(N,KK)+AA(M,N)                                    GSCA3698
      2001  CONTINUE                                                     GSCA3699
      2002  CONTINUE                                                     GSCA3700
      C   NORMALIZE SURFACE TO SURFACE INTERCHANGE AREA                  GSCA3701
            DO 2011 J=1,NSSBLK                                           GSCA3702
            CALL READ(1,SSNM(J,KK),AA(1,15*J-14), 900)                   GSCA3703
      2011  CONTINUE                                                     GSCA3704
            DO 2022 N=1,NSURF                                            GSCA3705
            FAC=BB(N,5)/BB(N,KK)                                         GSCA3706
            DO 2021 M=1,NSURF                                            GSCA3707
            AA(M,N)=AA(M,N)*FAC                                          GSCA3708
      2021  CONTINUE                                                     GSCA3709
      2022  CONTINUE                                                     GSCA3710
            DO 2031 J=1,NSSBLK                                           GSCA3711
            CALL WRITE(1,SSNM(J,KK),AA(1,15*J-14), 900)                  GSCA3712
      2031  CONTINUE                                                     GSCA3713
            IF(NPRNT.EQ.1)GO TO 2040                                     GSCA3714
      4000  WRITE(K2,4001)KK                                             GSCA3715
      4001  FORMAT(1H1,19X,'SURFACE TO SURFACE DIRECT INTERCHANGE AREA',10X,'GSCA3716
           1=',I5)                                                       GSCA3717
            CALL PRINT(AA,NSURF,NSURF)                                   GSCA3718
      C   NORMALIZE SURFACE TO VOLUME INTERCHANGE AREAS                  GSCA3719
      2040  DO 2041 J=1,NGSBLK                                           GSCA3720
            CALL READ(1,GSNM(J,KK),AA(1,15*J-14), 900)                   GSCA3721
      2041  CONTINUE                                                     GSCA3722
            DO 2052 N=1,NSURF                                            GSCA3723
            FAC=BB(N,5)/BB(N,KK)                                         GSCA3724
            DO 2051 M=1,NVOL                                             GSCA3725
            AA(M,N)=AA(M,N)*FAC                                          GSCA3726
      2051  CONTINUE                                                     GSCA3727
      2052  CONTINUE                                                     GSCA3728
            DO 2061 J=1,NGSBLK                                           GSCA3729
            CALL WRITE(1,GSNM(J,KK),AA(1,15*J-14), 900)                  GSCA3730
      2061  CONTINUE                                                     GSCA3731
            IF(NPRNT.EQ.1)GO TO 1870                                     GSCA3732
      5000  WRITE(K2,5001)KK                                             GSCA3733
      5001  FORMAT(1H1,19X,'SURFACE TO VOLUME DIRECT INTERCHANGE AREAS',10X,'KGSCA3734
           1= ',I5)                                                      GSCA3735
```

```
          CALL PRINT(AA,NVOL,NSURF)                                 GSCA3736
C     OBTAIN VOLUME TO SURFACE DIRECT INTERCHANGE AREA              GSCA3737
C     BY TRANSPOSING MATRIX AA(NVOL,NSURF)                          GSCA3738
C         N -- ROW DESIGNATION                                      GSCA3739
C         L -- COLUMN DESIGNATION                                   GSCA3740
C     TRANSPOSE SQUARE PART OF MATRIX                               GSCA3741
 1870     NL=MINO(NSURF,NVOL)                                       GSCA3742
          DO 1872 N=2,NL                                            GSCA3743
          LZ=N-1                                                    GSCA3744
          DO 1871 L=1,LZ                                            GSCA3745
          SAVE=AA(N,L)                                              GSCA3746
          AA(N,L)=AA(L,N)                                           GSCA3747
          AA(L,N)=SAVE                                              GSCA3748
 1871     CONTINUE                                                  GSCA3749
 1872     CONTINUE                                                  GSCA3750
          NZ=NL+1                                                   GSCA3751
          IF(NVOL-NSURF)1873,1878,1874                              GSCA3752
C     NSURF.GT.NVOL          COLUMNS.GT.ROWS                        GSCA3753
 1873     NSTART=1                                                  GSCA3754
          LSTART=NZ                                                 GSCA3755
          GO TO 1875                                                GSCA3756
C     NVOL.GT.NSURF.         ROWS.GT.COLUMNS                        GSCA3757
 1874     NSTART=NZ                                                 GSCA3758
          LSTART=1                                                  GSCA3759
 1875     DO 1877 N=NSTART,NVOL                                     GSCA3760
          DO 1876 L=LSTART,NSURF                                    GSCA3761
          AA(L,N)=AA(N,L)                                           GSCA3762
          AA(N,L)=0.                                                GSCA3763
 1876     CONTINUE                                                  GSCA3764
 1877     CONTINUE                                                  GSCA3765
C     WRITE VOLUME TO SURFACE INTERCHANGE AREAS ON DISK             GSCA3766
 1878     DO 1879 J=1,NSGBLK                                        GSCA3767
          CALL WRITE(1,SGNM(J,KK),AA(1,15*J-14), 900)               GSCA3768
 1879     CONTINUE                                                  GSCA3769
          IF(NPRNT.EQ.1)GO TO 1900                                  GSCA3770
 6000     WRITE(K2,6001)KK                                          GSCA3771
 6001     FORMAT(1H1,19X,'VOLUME TO SURFACE DIRECT INTERCHANGE AREA',10X,'K=GSCA3772
         1',I5)                                                     GSCA3773
          CALL PRINT(AA,NSURF,NVOL)                                 GSCA3774
 1900     CONTINUE                                                  GSCA3775
          RETURN                                                    GSCA3776
          END                                                       GSCA3777
```

```
      SUBROUTINE GGCALC                                           GGCA3778
C   COMPUTE OF VOLUME TO VOLUME DIRECT INTER CHANGE AREAS         GGCA3779
      COMMON // DUMMY(3),KK, ICODE, HCODE,                        GGCA3780
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),              GGCA3781
     A TBRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                 GGCA3782
     A NCK, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,              GGCA3783
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,               GGCA3784
     A XSUBEX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,               GGCA3785
     A RSTART, TCODE, SCODE, NGRAY, JHCHC,                        GGCA3786
     A K1, K2, RCRU(10), TDEP(100), PERM(200),NPRNT               GGCA3787
C                                                                 GGCA3788
      INTEGER SCODE,TCODE,RSTART,HCODE                            GGCA3789
      COMMON/JAZZ2/ SSNM(8,4),GSNM(8,3),SGNM(8,3),GGNM(8,3),      GGCA3790
     1ZSS(8),ZGS(8),ZSG(8),ZGG(8)                                 GGCA3791
      COMMON/SPCE2/ AA( 60, 60),BB( 60,15),CC( 60,15),ALPHA( 60)  GGCA3792
C   KK=GAS NUMBER                                                 GGCA3793
      DO 1900 KK=1,NGRAY                                          GGCA3794
      CALL PZERO(AA(1,1), 3600)                                   GGCA3795
C   GENERATE ONLY LOWER LEFT OF VOLUME TO VOLUME MATRIX           GGCA3796
C   OBTAIN THE REST USING THE SYMMETRY FEATURE OF MATRIX          GGCA3797
C      N=NUMBER OF EMITTING VOLUMES                               GGCA3798
C      M=NUMBER OF RECEIVING VOLUMES                              GGCA3799
      DO 1850 N=1,NVOL                                            GGCA3800
      CALL ZONE(1,N,XE,YE)                                        GGCA3801
      DO 1840 M=N,NVOL                                            GGCA3802
      CALL ZONE(1,M,XR,YR)                                        GGCA3803
C     WRITE(K2,5)N,XE,YE,M,XR,YR                                  GGCA3804
C5    FORMAT(//I5,2F15.5)                                         GGCA3805
C   COORDINATES OF SURFACES MAKING UP RECEIVING VOLUME            GGCA3806
      XRA=XR                                                      GGCA3807
      YRA=YR                                                      GGCA3808
      XRB=XR+XO                                                   GGCA3809
      YRB=YR                                                      GGCA3810
      XRC=XR                                                      GGCA3811
      YRC=YR+YO                                                   GGCA3812
      XRD=XR                                                      GGCA3813
      YRD=YR                                                      GGCA3814
C     WRITE(K2,8)XRA,YRA,XRB,YRB,XRC,YRC,XRD,YRD                  GGCA3815
C8    FORMAT(10X,2F15.5)                                          GGCA3816
      IF(YE-YR)10,20,30                                           GGCA3817
   10 IF(XE-XR)45,50,55                                           GGCA3818
   20 IF(XE-XR)80,1800,60                                         GGCA3819
   30 IF(XE-XR)75,70,65                                           GGCA3820
C   ORIENTATION 1                                                 GGCA3821
C   GAS VOLUME TO GAS VOLUME                                      GGCA3822
   45 S1=1.                                                       GGCA3823
      S2=-1.                                                      GGCA3824
      S3=-1.                                                      GGCA3825
      S4=1.                                                       GGCA3826
      GO TO 1700                                                  GGCA3827
```

```
C     GAS VOLUME TO GAS VOLUME                                            GGCA3828
C     ORIENTATION 2                                                       GGCA3829
50       S1=1.                                                            GGCA3830
         S2=-1.                                                           GGCA3831
         S3=-1.                                                           GGCA3832
         S4=-1.                                                           GGCA3833
         GO TO 1700                                                       GGCA3834
C     GAS VOLUME TO GAS VOLUME                                            GGCA3835
C     ORIENTATION 3                                                       GGCA3836
55       S1=1.                                                            GGCA3837
         S2=1.                                                            GGCA3838
         S3=-1.                                                           GGCA3839
         S4=-1.                                                           GGCA3840
         GO TO 1700                                                       GGCA3841
C     GAS VOLUME TO GAS VOLUME                                            GGCA3842
C     ORIENTATION 4                                                       GGCA3843
60       S1=-1.                                                           GGCA3844
         S2=1.                                                            GGCA3845
         S3=-1.                                                           GGCA3846
         S4=-1.                                                           GGCA3847
         GO TO 1700                                                       GGCA3848
C     GAS VOLUME TO GAS VOLUME                                            GGCA3849
C     ORIENTATION 5                                                       GGCA3850
65       S1=-1.                                                           GGCA3851
         S2=1.                                                            GGCA3852
         S3=1.                                                            GGCA3853
         S4=-1.                                                           GGCA3854
         GO TO 1700                                                       GGCA3855
C     GAS VOLUME TO GAS VOLUME                                            GGCA3856
C     ORIENTATION 6                                                       GGCA3857
70       S1=-1.                                                           GGCA3858
         S2=-1.                                                           GGCA3859
         S3=+1.                                                           GGCA3860
         S4=-1.                                                           GGCA3861
         GO TO 1700                                                       GGCA3862
C     GAS VOLUME TO GAS VOLUME                                            GGCA3863
C     ORIENTATION 7                                                       GGCA3864
75       S1=-1.                                                           GGCA3865
         S2=-1.                                                           GGCA3866
         S3=1.                                                            GGCA3867
         S4=1.                                                            GGCA3868
         GO TO 1700                                                       GGCA3869
C     GAS VOLUME TO GAS VOLUME                                            GGCA3870
C     ORIENTATION 8                                                       GGCA3871
80       S1=-1.                                                           GGCA3872
         S2=-1.                                                           GGCA3873
         S3=-1.                                                           GGCA3874
         S4=1.                                                            GGCA3875
1700  AA(M,N)=SG(XE,YE,XRA,YRA,1)*S1+SG(XE,YE,XRB,YRB,2)*S2               GGCA3876
     1+SG(XE,YE,XRC,YRC,1)*S3+SG(XE,YE,XRD,YRD,2)*S4                      GGCA3877
```

```
      GO TO 1840                                                        GGCA3878
C     A VOLUME CAN SEE ITSELF , BUT WE WILL COMPUTE ITS VALUE LATER     GGCA3879
 1800 AA(M,N)=0.0                                                       GGCA3880
 1840 CONTINUE                                                          GGCA3881
 1850 CONTINUE                                                          GGCA3882
C     COMPLETE UPPER RIGTH OF MATRIX                                    GGCA3883
C       N -- ROW    L -- COL                                            GGCA3884
 1860 N1=NVOL-1                                                         GGCA3885
      DO 1880 N=1,N1                                                    GGCA3886
      L1=N+1                                                            GGCA3887
      DO 1870  L=L1,NVOL                                                GGCA3888
      AA(N,L)=AA(L,N)                                                   GGCA3889
 1870 CONTINUE                                                          GGCA3890
 1880 CONTINUE                                                          GGCA3891
      DO 5881 J=1,NGGBLK                                                GGCA3892
      CALL READ(1,ZGG(J),CC(1,1), 900)                                  GGCA3893
      JJ=(J-1)*15                                                       GGCA3894
      MLAST=15                                                          GGCA3895
      IF(J.EQ.NGGBLK)MLAST=NVOL-JJ                                      GGCA3896
      DO 5882 M=1,MLAST                                                 GGCA3897
      DO 5883 N=1,NVOL                                                  GGCA3898
      MM=JJ+M                                                           GGCA3899
      AA(N,MM)=AA(N,MM)*CC(N,M)                                         GGCA3900
 5883 CONTINUE                                                          GGCA3901
 5882 CONTINUE                                                          GGCA3902
 5881 CONTINUE                                                          GGCA3903
C     COMPUTE GAS TO GAS INTERCHANGE AREA FOR VOLUME VIEWING ITSELF     GGCA3904
      MN=MAX0(NSURF,NVOL)                                               GGCA3905
      CON=4.*XK(KK)*XO*YO                                               GGCA3906
      DO 1885 J=1,NSGBLK                                                GGCA3907
      CALL READ(1,SGNM(J,KK),BB(1,1), 900)                              GGCA3908
      IF(J.EQ.NSGBLK)GO TO 1881                                         GGCA3909
      NN=15                                                             GGCA3910
      GO TO 1882                                                        GGCA3911
 1881 NN=NVOL-(NSGBLK-1)*15                                             GGCA3912
 1882 DO 1884 N=1,NN                                                    GGCA3913
      ZZ=0.                                                             GGCA3914
      NM=N+(J-1)*15                                                     GGCA3915
      DO 1883 M=1,MM                                                    GGCA3916
      ZZ=ZZ+AA(M,NM)*BB(M,N)                                            GGCA3917
 1883 CONTINUE                                                          GGCA3918
      AA(NM,NM)=CON-ZZ                                                  GGCA3919
 1884 CONTINUE                                                          GGCA3920
 1885 CONTINUE                                                          GGCA3921
C     WRITE VOLUME TO VOLUME INTERCHANGE AREA ON DISK                   GGCA3922
 1890 DO 1892 J=1,NGGBLK                                                GGCA3923
      CALL WRITE(1,GGNM(J,KK),AA(1,15*J-14), 900)                       GGCA3924
 1892 CONTINUE                                                          GGCA3925
      IF(NPRNT.EQ.1)GO TO 1900                                          GGCA3926
 5000 WRITE(K2,5001)KK                                                  GGCA3927
```

```
 5001  FORMAT(1H1,19X,'VOLUME TO VOLUME DIRECT INTERCHANGE AREA',10X,'K='GGCA3928
      1,I5)                                                             GGCA3929
       CALL PRINT(AA,NVOL,NVOL)                                          GGCA3930
 1900  CONTINUE                                                          GGCA3931
       RETURN                                                            GGCA3932
       END                                                               GGCA3933
```

```
      FUNCTION SG(XXE,YYE,XXR,YYR,NM)                                   SG 3934
C    THIS FUCTION IS USED TO CALULATE SURFACE TO VOLUME INTERCHANGE AREA SG 3935
C    THE EVALUATION IS MADE UP BY CONSIDERING THE RECEIVING (VOLUME)TO BESG 3936
C    MADE UP OF FOUR SURFACES                                           SG 3937
      COMMON // DUMMY(3),KK, ICODE, HCODE,                              SG 3938
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                    SG 3939
     A TBRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                       SG 3940
     A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                    SG 3941
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                     SG 3942
     A XSURFX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,                     SG 3943
     A RSTART, TCODE, SCODE, NCRAY, JHCHC,                              SG 3944
C                                                                       SG 3945
     A K1, K2, RCRD(10), TDEP(100), PERM(200)                           SG 3946
      INTEGER SCODE,TCODE,RSTART,HCODE                                  SG 3947
C    INTERCHANGE ROLL OF SURFACE TO VOLUME AND USE FUCTION SS           SG 3948
C       TO OBTAIN SURFACE - VOLUME INTERCHANGE AREA CONTRIBUTION        SG 3949
      XOYO=AMIN1(XO,YO)                                                 SG 3950
      XE=XXR                                                            SG 3951
      YE=YYR                                                            SG 3952
      XR=XXE                                                            SG 3953
      YR=YYE                                                            SG 3954
      XRA=XR                                                            SG 3955
      YRA=YR                                                            SG 3956
      XRB=XR+XO                                                         SG 3957
      YRB=YR                                                            SG 3958
      XRC=XR                                                            SG 3959
      YRC=YR+YO                                                         SG 3960
      XRD=XR                                                            SG 3961
      YRD=YR                                                            SG 3962
C    SURFACE ORIENTATION                                                SG 3963
C       NM=1 HORIZONTAL SURFACE                                         SG 3964
C       NM=2   VERTICAL SURFACE                                         SG 3965
      GO TO(20,37),NM                                                   SG 3966
C    HORIZONTAL SURFACES                                                SG 3967
   20 NN=1                                                              SG 3968
      IF(YE.GT.YR)GO TO 30                                              SG 3969
      IF(XE-XR)100,200,300                                              SG 3970
   30 IF(XE-XR)1000,1100,1200                                           SG 3971
C    VERTICAL SURFACES                                                  SG 3972
   37 NN=2                                                              SG 3973
      IF(XE.GT.XR)GO TO 50                                              SG 3974
      IF(YE-YR)400,600,800                                              SG 3975
   50 IF(YE-YR)500,700,900                                              SG 3976
C                                                                       SG 3977
C    ORIENTATION 1                                                      SG 3978
  100 S1=1.                                                             SG 3979
      S2=-1.                                                            SG 3980
      S3=-1.                                                            SG 3981
      S4=1.                                                             SG 3982
      GO TO 1500                                                        SG 3983
```

```
C     ORIENTATION 2                                                     SG  3984
  200 IF(ABS(YR-YE).EQ.0.0)GO TO 210                                    SG  3985
      S1=1.                                                             SG  3986
      S2=-1.                                                            SG  3987
      S3=-1.                                                            SG  3988
      S4=-1.                                                            SG  3989
      GO TO 1500                                                        SG  3990
  210 FAC=XO-SS(XE,YE,XRB,YRB,NN,2)-SS(XE,YE,XRC,YRC,NN,1)-SS(XE,YE,XRD,SG  3991
     1YRD,NN,2)                                                         SG  3992
      GO TO 1700                                                        SG  3993
C     ORIENTATION 3                                                     SG  3994
  300 S1=1.                                                             SG  3995
      S2=1.                                                             SG  3996
      S3=-1.                                                            SG  3997
      S4=-1.                                                            SG  3998
      GO TO 1500                                                        SG  3999
C     ORIENTATION 4                                                     SG  4000
  400 S1=1.                                                             SG  4001
      S2=-1.                                                            SG  4002
      S3=-1.                                                            SG  4003
      S4=1.                                                             SG  4004
      GO TO 1500                                                        SG  4005
C     ORIENTATION 5                                                     SG  4006
  500 S1=1.                                                             SG  4007
      S2=1.                                                             SG  4008
      S3=-1.                                                            SG  4009
      S4=-1.                                                            SG  4010
      GO TO 1500                                                        SG  4011
C     ORIENTATION 6                                                     SG  4012
  600 IF(ABS(XR-XE).EQ.0.0)GO TO 610                                    SG  4013
      S1=-1.                                                            SG  4014
      S2=-1.                                                            SG  4015
      S3=-1.                                                            SG  4016
      S4=1.                                                             SG  4017
      GO TO 1500                                                        SG  4018
  610 FAC=YO-SS(XE,YE,XRA,YRA,NN,1)-SS(XE,YE,XRB,YRB,NN,2)              SG  4019
     1-SS(XE,YE,XRC,YRC,NN,1)                                           SG  4020
      GO TO 1700                                                        SG  4021
C     ORIENTATION 7                                                     SG  4022
  700 IF(ABS(ABS(XR-XE)-XO).LT.XOYO)GO TO 710                           SG  4023
      S1=-1.                                                            SG  4024
      S2=1.                                                             SG  4025
      S3=-1.                                                            SG  4026
      S4=-1.                                                            SG  4027
      GO TO 1500                                                        SG  4028
  710 FAC=YO-SS(XE,YE,XRA,YRA,NN,1)-SS(XE,YE,XRC,YRC,NN,1)              SG  4029
     1-SS(XE,YE,XRD,YRD,NN,2)                                           SG  4030
      GO TO 1700                                                        SG  4031
C     ORIENTATION 8                                                     SG  4032
  800 S1=-1.                                                            SG  4033
```

```
          S2=-1.                                                SG  4034
          S3=1.                                                 SG  4035
          S4=1.                                                 SG  4036
          GO TO 1500                                            SG  4037
C    ORIENTATION 9                                              SG  4038
 900      S1=-1.                                                SG  4039
          S2=1.                                                 SG  4040
          S3=1.                                                 SG  4041
          S4=-1.                                                SG  4042
          GO TO 1500                                            SG  4043
C    ORIENTATION 10                                             SG  4044
 1000     S1=-1.                                                SG  4045
          S2=-1.                                                SG  4046
          S3=1.                                                 SG  4047
          S4=1.                                                 SG  4048
          GO TO 1500                                            SG  4049
C    ORIENTATION 11                                             SG  4050
 1100     IF(ABS(ABS(YR-YE)-YD).LT.XDYD)GO TO 1110              SG  4051
          S1=-1.                                                SG  4052
          S2=-1.                                                SG  4053
          S3=1.                                                 SG  4054
          S4=-1.                                                SG  4055
          GO TO 1500                                            SG  4056
 1110     FAC=XO-SS(XE,YE,XRA,YRA,NN,1)-SS(XE,YE,XRB,YRB,NN,2)  SG  4057
         1-SS(XE,YE,XRD,YRD,NN,2)                               SG  4058
          GO TO 1700                                            SG  4059
C    ORIENTATION 12                                             SG  4060
 1200     S1=-1.                                                SG  4061
          S2=1.                                                 SG  4062
          S3=1.                                                 SG  4063
          S4=-1.                                                SG  4064
 1500     FAC=SS(XE,YE,XRA,YRA,NN,1)*S1+SS(XE,YE,XRB,YRB,NN,2)*S2  SG  4065
         1+SS(XE,YE,XRC,YRC,NN,1)*S3+SS(XE,YE,XRD,YRD,NN,2)*S4  SG  4066
 1700     SG=FAC                                                SG  4067
          RETURN                                                SG  4068
          END                                                   SG  4069
```

```
      SUBROUTINE CL3                                                    CL3 4070
      COMMON // DUMMY(3),KK, ICODE, HCODE,                              CL3 4071
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                    CL3 4072
     A TBRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                       CL3 4073
     A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                    CL3 4074
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                     CL3 4075
     A XSURFX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,                     CL3 4076
     A RSTART, TCODE, SCODE, NGRAY, JHCHC,                              CL3 4077
     A K1, K2, RCRD(10), TDEP(100), PERM(200)                           CL3 4078
C                                                                       CL3 4079
      INTEGER SCODE,TCODE,RSTART,HCODE                                  CL3 4080
      COMMON/JAZZ3/SSNM(8,4),GSNM(8,3),SGNM(8,3),GGNM(8,3),SRSNM(8,4),  CL3 4081
     1SRGNM(8,3),TSSNM(8,4),TGSNM(8,3),TSGNM(8,3),TGGNM(8,3)            CL3 4082
      COMMON/BLOCK/ ESURF( 60),TSURF( 60),ASURF( 60),AEP( 60)           CL3 4083
      COMMON/SPCE3/AA( 60, 60),BB( 60,15),CC( 60,15)                    CL3 4084
      CALL READ(1,'ESUR',ESURF(1), 60)                                  CL3 4085
      CALL READ(1,'ASUR',ASURF(1), 60)                                  CL3 4086
      CALL READ(1,'TSUR',TSURF(1), 60)                                  CL3 4087
      CALL RRRR                                                         CL3 4088
      CALL TTTT                                                         CL3 4089
C    TEST OF COMPUTION OF TOTAL INTERCHANGE AREA                        CL3 4090
C       (1)    SURFACE AS EMITTER                                       CL3 4091
C       (2)    VOLUME AS EMITTER                                        CL3 4092
   61 CALL PZERO(BB(1,1), 660)                                          CL3 4093
      DO 62 L=1,NSURF                                                   CL3 4094
      BB(L,5)=ESURF(L)*ASURF(L)                                         CL3 4095
   62 CONTINUE                                                          CL3 4096
C    SURFACE AS EMITTER                                                 CL3 4097
C       NSSBLK=NUMBER OF SURFACE TO SURFACE BLOCKS                      CL3 4098
C       NGSBLK=NUMBER OF SURFACE TO GAS BLOCKS                          CL3 4099
      KMAX=NGRAY+1                                                      CL3 4100
      DO 69 K=1,KMAX                                                    CL3 4101
      IF(K.EQ.KMAX)GO TO 63                                             CL3 4102
      KK=K                                                              CL3 4103
      GO TO 64                                                          CL3 4104
   63 KK=4                                                              CL3 4105
   64 DO 65 J=1,NSSBLK                                                  CL3 4106
      CALL READ(1,TSSNM(J,KK),AA(1,15*J-14), 900)                       CL3 4107
   65 CONTINUE                                                          CL3 4108
      DO 67 L=1,NSURF                                                   CL3 4109
      DO 66 N=1,NSURF                                                   CL3 4110
                                                                        CL3 4111
      BB(L,KK)=BB(L,KK)+AA(N,L)                                         CL3 4112
   66 CONTINUE                                                          CL3 4113
   67 CONTINUE                                                          CL3 4114
      IF(K.EQ.KMAX)GO TO 90                                             CL3 4115
      DO 72 J=1,NGSBLK                                                  CL3 4116
      CALL READ(1,TGSNM(J,KK),AA(1,15*J-14), 900)                       CL3 4117
   72 CONTINUE                                                          CL3 4118
      DO 74 L=1,NSURF                                                   CL3 4119
```

```
      DO 73 N=1,NVOL
      BB(L,KK)=BB(L,KK)+AA(N,L)
73    CONTINUE
74    CONTINUE
C   GAS AS EMITTER
C      NGGBLK=NUMBER OF GAS TO GAS BLOCKS
C      NSGBLK=NUMBER OFGAS TO SURFACE BLOCKS
      KD=6+2*(KK-1)
      DO 76 J=1,NGGBLK
      CALL READ(1,TGGNM(J,KK),AA(1,15*J-14), 900)
76    CONTINUE
      DO 79 L=1,NVOL
      DO 78 N=1,NVOL
      BB(L,KD)=BB(L,KD)+AA(N,L)
78    CONTINUE
79    CONTINUE
      DO 81 J=1,NSGBLK
      CALL READ(1,TSGNM(J,KK),AA(1,15*J-14), 900)
81    CONTINUE
      DO 86 L=1,NVOL
      DO 85 N=1,NSURF
      BB(L,KD)=BB(L,KD)+AA(N,L)
85    CONTINUE
86    CONTINUE
      CON=4.*XK(KK)*XD*YD
      DO 87 L=1,NVOL
      BB(L,KD+1)=CON
87    CONTINUE
89    CONTINUE
90    WRITE(K2,91)
91    FORMAT('1FOR EACH CHARACTERIST GAS THE SUN OF ALL TOTAL INTERCHANG
     1E AREA WITH THE GAS VOLUME AS THE EMITTER MUST EQUAL THE'/' PRODUC
     2 OF THE EMISSIVITY AND THE AREA'//10X,'GRAY GAS 1',5X,'GRAY GAS 2
     3',5X,'GRAY GAS 3',11X,'CLEAR GAS',8X,'EMISS*AREA'//)
      WRITE(K2,92)(I,(BB(I,M),M=1,5),I=1,NSURF)
92    FORMAT(I5,3F15.5,2F20.5)
      WRITE(K2,93)
93    FORMAT('1FOR EACH CHARACTERIST GAS THE SUM OF THE TOTAL INTERCHANG
     1E AREAS WITH A GAS VOLUME AS THE EMITTER MUST EQUAL THE'/' PRODUCT
     2 OF THE GAS ABSORPTION COEFFICIENT AND THE VOLUME MULTIPLIED BY A
     1 CONSTANT OF 4'//23X,'GRAY GAS 1',25X,'GRAY GAS 2',25X,'GRAY GAS
     23',/15X,'INTER-AREA',6X,'ABS * VOL',10X,'INTER-AREA',6X,'ABS * VOL
     3',10X,'INTER AREA',6X,'ABS * VOL'//)
      WRITE(K2,94)(I,(BB(I,M),M=6,11),I=1,NVOL)
94    FORMAT(/(I5,3(5X,2F15.5)))
      RETURN
      END
```

```
      SUBROUTINE RRRR                                                   RRRR4167
C     COMPUTES SURFACE REFLECTIVITES AND STORE ON DISK 1                RRRR4168
C       (1) = SURFACE  AREA AS EMITTER                                  RRRR4169
C       (2) = GAS VOLUME AS EMITTER                                     RRRR4170
      COMMON // DUMMY(3),KK, ICODE, HCODE,                              RRRR4171
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                    RRRR4172
     A TBRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                       RRRR4173
     A NCR, HOUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                    RRRR4174
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                     RRRR4175
     A XSURFX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,                     RRRR4176
     A RSTART, TCODE, SCODE, NGRAY, JHCHC,                              RRRR4177
     A K1, K2, RCRD(10), TDEP(100), PERM(200)                           RRRR4178
C                                                                       RRRR4179
      INTEGER SCODE,TCODE,RSTART,HCODE                                  RRRR4180
      COMMON/JAZZ3/SSNM(8,4),GSNM(8,3),SGNM(8,3),GGNM(8,3),SRSNM(8,4),  RRRR4181
     1SRGNM(8,3),TSSNM(8,4),TGSNM(8,3),TSGNM(8,3),TGGNM(8,3)            RRRR4182
      COMMON/BLOCK/ ESURF( 60),TSURF( 60),ASURF( 60),AEP( 60)           RRRR4183
      COMMON/SPCE3/AA( 60, 60),BB( 60,15),CC( 60,15)                    RRRR4184
      DIMENSION RHO( 60),FACTR( 60)                                     RRRR4185
C     GENERATE REQUIRED SURFACE PARAMETERS                              RRRR4186
C       REFLECTIVITY                        RHO                         RRRR4187
C       AREA / REFLECTIVITY                 FACTR                       RRRR4188
C       AREA * EMISSIBITY/REFLECTIVITY      AEP                         RRRR4189
      DO 10 JJ=1,NSURF                                                  RRRR4190
      RHO(JJ)=1.-ESURF(JJ)                                              RRRR4191
      FACTR(JJ)=ASURF(JJ)/RHO(JJ)                                       RRRR4192
      AEP(JJ)=FACTR(JJ)*ESURF(JJ)                                       RRRR4193
   10 CONTINUE                                                          RRRR4194
C     KK=GAS NUMBER                                                     RRRR4195
   12 KMAX=1+NGRAY                                                      RRRR4196
      DO 80 K=1,KMAX                                                    RRRR4197
      CALL PZERO(AA(1,1), 3600)                                         RRRR4198
      IF(K.EQ.KMAX)GO TO 16                                             RRRR4199
      KK=K                                                              RRRR4200
      GO TO 18                                                          RRRR4201
   16 KK=4                                                              RRRR4202
C     SET UP MATRIX AND INVERT FOR EACH CHARACTEISTIC GAS               RRRR4203
C     MATRI EQUALS S-S DIRECT INTERCHANGE AREA WITH                     RRRR4204
C     DIAGONAL TERMS ADJUSTED FOR AREA/REFLECTIVITY TERM                RRRR4205
C       NSSBLK = NUMBER OF SURFACE TO SURFACE BLOCKS                    RRRR4206
   18 DO 20 J=1,NSSBLK                                                  RRRR4207
      CALL READ(1,SSNM(J,KK),AA(1,15*J-14), 900)                        RRRR4208
   20 CONTINUE                                                          RRRR4209
      DO 21 JJ=1,NSURF                                                  RRRR4210
      AA(JJ,JJ)=AA(JJ,JJ)-FACTR(JJ)                                     RRRR4211
   21 CONTINUE                                                          RRRR4212
C     OBTAIN INVERSE OF OUTGOING FLUX DENSITY FOR EACH                  RRRR4213
C     CHARACTERISTIC GAS -- SAVE SINCE IT CAN BE USED                   RRRR4214
C     FOR BOTH EMITTERS( SURFACE AREA AND GAS VOLUME )                  RRRR4215
   23 KODE=0                                                            RRRR4216
```

```
      CALL INVERT(NSURF, 60,AA,CC,KODE)                         RRRR4217
   26 IF(KODE.NE.10)GO TO 31                                    RRRR4218
      WRITE(K2,29)                                              RRRR4219
   29 FORMAT('1TROUBLE IN INVERT')                              RRRR4220
      STOP                                                      RRRR4221
C    REFLECTIVITES WITH SURFACE AS EMITTER                      RRRR4222
C    OBTAINED BY MATRIX -- VECTOR  MULTIPLICATION               RRRR4223
C    MATRIX PREVIOUSLY OBTAINED INVERSE                         RRRR4224
C    VECTOR NEGATIVIVE OS S-S DIRECT INTERCHANGE                RRRR4225
C        AREA * EMISSIVITY OF EMITTER                           RRRR4226
C     NSSBLK = NUMBER OF SURFACE TO SURFACE BLOCKS              RRRR4227
   31 DO 49 J =1,NSSBLK                                         RRRR4228
      CALL READ(1,SSNM(J,KK),BB(1,1), 900)                      RRRR4229
      J1=15*(J-1)                                               RRRR4230
      IF(J.EQ.NSSBLK)GO TO 33                                   RRRR4231
      JJMAX=15                                                  RRRR4232
      GO TO 34                                                  RRRR4233
   33 JJMAX=NSURF-(NSSBLK-1)*15                                 RRRR4234
   34 DO 38 JJ=1,JJMAX                                          RRRR4235
      DO 36 N=1,NSURF                                           RRRR4236
      J2=J1+JJ                                                  RRRR4237
      BB(N,JJ)=BB(N,JJ)*ESURF(J2)                               RRRR4238
   36 CONTINUE                                                  RRRR4239
   38 CONTINUE                                                  RRRR4240
      CALL PZERO(CC(1,1), 900)                                  RRRR4241
      DO 46 JJ=1,JJMAX                                          RRRR4242
      DO 44 N=1,NSURF                                           RRRR4243
      DO 42 L=1,NSURF                                           RRRR4244
      CC(N,JJ)=CC(N,JJ)-AA(N,L)*BB(L,JJ)                        RRRR4245
   42 CONTINUE                                                  RRRR4246
   44 CONTINUE                                                  RRRR4247
   46 CONTINUE                                                  RRRR4248
      CALL WRITE(1,SRSNM(J,KK),CC(1,1), 900)                    RRRR4249
   49 CONTINUE                                                  RRRR4250
C    TEST TO SEE IF WE HAVE FINISHED THE CLEAR GAS              RRRR4251
C       THAN COMPUTION IS FINISHED                              RRRR4252
      IF(K.EQ.KMAX)GO TO 90                                     RRRR4253
C    REFLECTIVITY AS GAS AS  EMITTER  (GAS TO SURFACE)          RRRR4254
C    OBTAINED BY MATRIX VECTOR MULIPLICATION                    RRRR4255
C    MATRIX PREVIOUSLY OBTAINED INVERSE                         RRRR4256
C    VECTOR NEGATIVE OF G-S DIRECT INTERCHANGE AREA             RRRR4257
C       NSGBLK = NUMBER OF GAS TO SURFACE BLOCKS                RRRR4258
      DO 69 J=1,NSGBLK                                          RRRR4259
      CALL READ(1,SGNM(J,KK),BB(1,1), 900)                      RRRR4260
      IF(J.EQ.NSGBLK)GO TO 52                                   RRRR4261
      JJMAX=15                                                  RRRR4262
      GO TO 54                                                  RRRR4263
   52 JJMAX=NVOL-(NSGBLK-1)*15                                  RRRR4264
   54 CALL PZERO(CC(1,1), 900)                                  RRRR4265
      DO 66 JJ=1,JJMAX                                          RRRR4266
```

```
      DO 64 N=1,NSURF                                   RRRR4267
      DO 62 L=1,NSURF                                   RRRR4268
      CC(N,JJ)=CC(N,JJ)-AA(N,L)*BB(L,JJ)                RRRR4269
62    CONTINUE                                          RRRR4270
64    CONTINUE                                          RRRR4271
66    CONTINUE                                          RRRR4272
      CALL WRITE(1,SRGNM(J,KK),CC(1,1), 900)            RRRR4273
69    CONTINUE                                          RRRR4274
60    CONTINUE                                          RRRR4275
90    RETURN                                            RRRR4276
      END                                               RRRR4277
```

```
      SUBROUTINE INVERT (NEG,MAX,A,E,KERR)                              INVE4278
      REAL A(MAX,1),E(1)                                                INVE4279
      KERR=0                                                            INVE4280
      NN=NEG                                                            INVE4281
   10 DO 16 I=1,NN                                                      INVE4282
      Q=A(I,I)                                                          INVE4283
      IF(Q.NE.0.0)GO TO 12                                              INVE4284
      KK=10                                                             INVE4285
      GO TO 30                                                          INVE4286
   12 DO 13 J=1,NN                                                      INVE4287
      A(I,J)=A(I,J)/Q                                                   INVE4288
   13 CONTINUE                                                          INVE4289
      A(I,I)=1./Q                                                       INVE4290
      IF(I.EQ.NN)GO TO 20                                               INVE4291
      L=I+1                                                             INVE4292
      DO 15 K=L,NN                                                      INVE4293
      R=A(K,I)                                                          INVE4294
      IF(R.EQ.0.0)GO TO 15                                              INVE4295
      DO 14 J=1,NN                                                      INVE4296
      A(K,J)=A(K,J)-R*A(I,J)                                            INVE4297
   14 CONTINUE                                                          INVE4298
      A(K,I)=-R/Q                                                       INVE4299
   15 CONTINUE                                                          INVE4300
   16 CONTINUE                                                          INVE4301
   20 DO 24 L=2,NN                                                      INVE4302
      I=NN-L+1                                                          INVE4303
      K=I+1                                                             INVE4304
      DO 21 J=K,NN                                                      INVE4305
      E(J)=A(I,J)                                                       INVE4306
      A(I,J)=0.0                                                        INVE4307
   21 CONTINUE                                                          INVE4308
      DO 23 J=1,NN                                                      INVE4309
      DO 22 M=K,NN                                                      INVE4310
      A(I,J)=A(I,J)-E(M)*A(M,J)                                         INVE4311
   22 CONTINUE                                                          INVE4312
   23 CONTINUE                                                          INVE4313
   24 CONTINUE                                                          INVE4314
   30 RETURN                                                            INVE4315
      END                                                               INVE4316
```

```
         SUBROUTINE TTTT                                                TTTT4317
   C     COMPUTE TOTAL INTERCHANGE AREA -- FOR EACH CHARACTERISTIC GAS  TTTT4318
         COMMON // DUMMY(3),KK, ICODE, HCODE,                           TTTT4319
        A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                 TTTT4320
        A TBRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                    TTTT4321
        A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                 TTTT4322
        A NSSBLK, NCSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                  TTTT4323
        A XSURFX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,                  TTTT4324
        A RSTART, TCODE, SCODE, NGRAY, JHCHC,                           TTTT4325
        A K1, K2, RCRD(10), TOEP(100), PERM(200),NPRNT                  TTTT4326
   C                                                                    TTTT4327
         INTEGER SCODE,TCODE,RSTART,HCODE                               TTTT4328
         COMMON/JAZZ3/SSNM(8,4),GSNM(8,3),SGNM(8,3),GGNM(8,3),SRSNM(8,4),  TTTT4329
        1SRGNM(8,3),TSSNM(8,4),TGSNM(8,3),TSGNM(8,3),TGGNM(8,3)         TTTT4330
         COMMON/BLOCK/ ESURF( 60),TSURF( 60),ASURF( 60),AEP( 60)        TTTT4331
         COMMON/SPCE3/AA( 60, 60),EB( 60,15),CC( 60,15)                 TTTT4332
         COMMON/FIX/ FIXS( 60,4),Z( 60)                                 TTTT4333
   C     KK= GAS NUMBER                                                 TTTT4334
         CALL PZERO(FIXS(1,1),240)                                      TTTT4335
         KMAX=1+NGRAY                                                   TTTT4336
         DO 60 K=1,KMAX                                                 TTTT4337
         IF(K.EQ.KMAX)GO TO 8                                           TTTT4338
         KK=K                                                           TTTT4339
         GO TO 11                                                       TTTT4340
    8    KK=4                                                           TTTT4341
   C     SURFACE-TO-SURFACE TOTAL INTERCHANGE AREA                      TTTT4342
   C     OBTAIN BY MULTIPLYING S-S REFLECTIVIY BY AEP OF THE RECEIVER   TTTT4343
   C       AEP=AEP*EMISSIVITY/REFLECTIVITY                              TTTT4344
   C           NSSBLK=NUMBER OF SURFACE TO SURFACE BLOCKS               TTTT4345
   11    CALL PZERO(AA(1,1), 3600)                                      TTTT4346
         DO 12 J=1,NSSBLK                                               TTTT4347
         CALL READ(1,SRSNM(J,KK),AA(1,15*J-14), 900)                    TTTT4348
   12    CONTINUE                                                       TTTT4349
         DO 17 N=1,NSURF                                                TTTT4350
         DO 16 L=1,NSURF                                                TTTT4351
         AA(L,N)=AA(L,N)*AEP(L)                                         TTTT4352
         FIXS(N,KK)=FIXS(N,KK)+AA(L,N)                                  TTTT4353
   16    CONTINUE                                                       TTTT4354
   17    CONTINUE                                                       TTTT4355
         DO 19 J=1,NSSBLK                                               TTTT4356
         CALL WRITE(1,TSSNM(J,KK),AA(1,15*J-14), 900)                   TTTT4357
   19    CONTINUE                                                       TTTT4358
   C     TEST TO SEE IF WE HAVE FINISHED THE CLEAR GAS                  TTTT4359
   C        THEN COMPUTION IS FINISHED                                  TTTT4360
   21    IF(K.EQ.KMAX)GO TO 63                                          TTTT4361
   C     GAS TO SURFACE TOTAL INTERCHANGE AREA                          TTTT4362
   C     OBTAIN BY MULTIPLYING G-S REFLECTIVITY BY AEP OF THE RECEIVER  TTTT4363
   C     AEP V AREA*EMISSIVITY/REFLECTIVITY                             TTTT4364
   C        NSGBLK=NUMBER OF GAS TO SURFACE BLOCKS                      TTTT4365
         CALL PZERO(AA(1,1), 3600)                                      TTTT4366
```

```
      DO 22 J=1,NSGBLK                                          TTTT4367
      CALL READ(1,SRGNM(J,KK),AA(1,15*J-14), 900)               TTTT4368
22    CONTINUE                                                  TTTT4369
      DO 25 N=1,NVOL                                            TTTT4370
      DO 24 L=1,NSURF                                           TTTT4371
      AA(L,N)=AA(L,N)*AEP(L)                                    TTTT4372
24    CONTINUE                                                  TTTT4373
25    CONTINUE                                                  TTTT4374
      DO 27 J=1,NSGBLK                                          TTTT4375
      CALL WRITE(1,TSGUM(J,KK),AA(1,15*J-14), 900)              TTTT4376
27    CONTINUE                                                  TTTT4377
C   SURFACE-TO-GAS TOTAL INTERCHANGE AREA                       TTTT4378
C   SINCE G-S=S-G ALL THAT NEEDS TO BE DONE IS                  TTTT4379
C     TRANSPOSE SURFACE TO GAS MATRIX                           TTTT4380
C      NGSBLK=NUMBER OF SURFACE TO GAS BLOCKS                   TTTT4381
30    NL=MIN0(NVOL,NSURF)                                       TTTT4382
      DO 32 N=2,NL                                              TTTT4383
      LZ=N-1                                                    TTTT4384
      DO 31 L=1,LZ                                              TTTT4385
      SAVE=AA(N,L)                                              TTTT4386
      AA(N,L)=AA(L,N)                                           TTTT4387
      AA(L,N)=SAVE                                              TTTT4388
31    CONTINUE                                                  TTTT4389
32    CONTINUE                                                  TTTT4390
      NZ=NL+1                                                   TTTT4391
      IF(NSURF-NVOL)33,38,34                                    TTTT4392
C   NVOL.GT.NSURF                                               TTTT4393
33    NSTART=1                                                  TTTT4394
      LSTART=NZ                                                 TTTT4395
      GO TO 35                                                  TTTT4396
C   NSURF.GT.NVOL                                               TTTT4397
34    NSTART=NZ                                                 TTTT4398
      LSTART=1                                                  TTTT4399
35    DO 37 N=NSTART,NSURF                                      TTTT4400
      DO 36 L=LSTART,NVOL                                       TTTT4401
      AA(L,N)=AA(N,L)                                           TTTT4402
      AA(N,L)=0.0                                               TTTT4403
36    CONTINUE                                                  TTTT4404
37    CONTINUE                                                  TTTT4405
38    DO 372 N=1,NSURF                                          TTTT4406
      DO 371 L=1,NVOL                                           TTTT4407
      FIXS(N,KK)=FIXS(N,KK)+AA(L,N)                             TTTT4408
371   CONTINUE                                                  TTTT4409
372   CONTINUE                                                  TTTT4410
      DO 39 J=1,NGSBLK                                          TTTT4411
      CALL WRITE(1,TGSNM(J,KK),AA(1,15*J-14), 900)              TTTT4412
39    CONTINUE                                                  TTTT4413
C   GAS TO GAS TOTAL INTERCHANGE AREA                           TTTT4414
C   THIS INTERCHANGE AREA HAS TO COMBINATIONS                   TTTT4415
C      (1) G-G VIA REFLECTION FROM SURFACES                     TTTT4416
```

```
C        (2) G-G VIA DIRECT INTERCHANGE                              TTTT4417
C     COMPUTE (1) FIRST BY MATRIX MULTIPLICATION                     TTTT4418
C         MATRIX SURFACE TO GAS REFLECTIVITY                         TTTT4419
C         VECTOR SURFACE TO GAS DIRECT INTERCHANGE AREA              TTTT4420
C     ADD (2) TO (1) TO GET TOTAL INTERCHANGE AREA                   TTTT4421
C         NGGBLK = NUMBER OF GAS TO GAS BLOCKS                       TTTT4422
C         NGSBLK = NUMBER OF SURFACE TO GAS BLOCKS                   TTTT4423
41       CALL PZERO(AA(1,1), 3600)                                   TTTT4424
         DO 42 J=1,NGSBLK                                            TTTT4425
         CALL READ(1,GSNM(J,KK),AA(1,15*J-14), 900)                  TTTT4426
42       CONTINUE                                                    TTTT4427
         DO 49 J=1,NSGBLK                                            TTTT4428
         CALL PZERO(CC(1,1), 900)                                    TTTT4429
         CALL READ(1,SRGNM(J,KK),BB(1,1), 900)                       TTTT4430
         IF(J.EQ.NSGBLK)GO TO 43                                     TTTT4431
         NMAX=15                                                     TTTT4432
         GO TO 44                                                    TTTT4433
43       NMAX=NVOL-(NSGBLK-1)*15                                     TTTT4434
44       DO 47 N=1,NMAX                                              TTTT4435
         DO 46 L=1,NVOL                                              TTTT4436
         DO 45 M=1,NSURF                                             TTTT4437
         CC(L,N)=CC(L,N)+BB(M,N)*AA(L,M)                             TTTT4438
45       CONTINUE                                                    TTTT4439
46       CONTINUE                                                    TTTT4440
47       CONTINUE                                                    TTTT4441
         CALL WRITE(1,TGGNM(J,KK),CC(1,1), 900)                      TTTT4442
49       CONTINUE                                                    TTTT4443
         DO 59 J=1,NGGBLK                                            TTTT4444
         CALL PZERO(AA(1,1), 900)                                    TTTT4445
         CALL READ(1,GGNM(J,KK),BB(1,1), 900)                        TTTT4446
         CALL READ(1,TGGNM(J,KK),CC(1,1), 900)                       TTTT4447
         IF(J.EQ.NGGBLK)GO TO 51                                     TTTT4448
         NMAX=15                                                     TTTT4449
         GO TO 52                                                    TTTT4450
51       NMAX=NVOL-(NGGBLK-1)*15                                     TTTT4451
52       DO 56 N=1,NMAX                                              TTTT4452
         DO 55 L=1,NVOL                                              TTTT4453
         AA(L,N)=BB(L,N)+CC(L,N)                                     TTTT4454
55       CONTINUE                                                    TTTT4455
56       CONTINUE                                                    TTTT4456
         CALL WRITE(1,TGGNM(J,KK),AA(1,1),900)                       TTTT4457
59       CONTINUE                                                    TTTT4458
60       CONTINUE                                                    TTTT4459
C     NORMALIZE INTERCHANGE AREAS                                    TTTT4460
63       DO 96 K=1,KMAX                                              TTTT4461
         IF(K.EQ.KMAX)GO TO 65                                       TTTT4462
         KK=K                                                        TTTT4463
         GO TO 66                                                    TTTT4464
65       KK=4                                                        TTTT4465
66       DO 67 N=1,NSURF                                             TTTT4466
```

```
      FIXS(N,KK)=ESURF(N)*ASURF(N)/FIXS(N,KK)                  TTTT4467
   67 CONTINUE                                                 TTTT4468
      CALL PZERO(AA(1,1), 3600)                                TTTT4469
      DO 68 J=1,NSSBLK                                         TTTT4470
      CALL READ(1,TSSNM(J,KK),AA(1,15*J-14), 900)              TTTT4471
   68 CONTINUE                                                 TTTT4472
      DO 72 N=1,NSURF                                          TTTT4473
      DO 71 L=1,NSURF                                          TTTT4474
      AA(L,N)=AA(L,N)*FIXS(N,KK)                               TTTT4475
   71 CONTINUE                                                 TTTT4476
   72 CONTINUE                                                 TTTT4477
      DO 73 J=1,NSSBLK                                         TTTT4478
      CALL WRITE(1,TSSNM(J,KK),AA(1,J*15-14), 900)             TTTT4479
   73 CONTINUE                                                 TTTT4480
      IF(NPRNT.EQ.1)GO TO 74                                   TTTT4481
 4000 WRITE(K2,4001)KK                                         TTTT4482
 4001 FORMAT(1H1,19X,'SURFACE TO SURFACE TOTAL INTERCHANGE AREA',10X,'K TTTT4483
     1=',I5)                                                   TTTT4484
      CALL PRINT(AA,NSURF,NSURF)                               TTTT4485
      CALL PRINT(FIXS(1,KK),NSURF,1)                           TTTT4486
   74 IF(K.EQ.KMAX)GO TO 99                                    TTTT4487
      CALL PZERO(AA(1,1), 3600)                                TTTT4488
      DO 76 J=1,NGSBLK                                         TTTT4489
      CALL READ(1,TGSNM(J,KK),AA(1,15*J-14), 900)              TTTT4490
   76 CONTINUE                                                 TTTT4491
      DO 78 N=1,NSURF                                          TTTT4492
      DO 77 L=1,NVOL                                           TTTT4493
      AA(L,N)=AA(L,N)*FIXS(N,KK)                               TTTT4494
   77 CONTINUE                                                 TTTT4495
   78 CONTINUE                                                 TTTT4496
      DO 79 J=1,NGSBLK                                         TTTT4497
      CALL WRITE(1,TGSUM(J,KK),AA(1,15*J-14), 900)             TTTT4498
   79 CONTINUE                                                 TTTT4499
      IF(NPRNT.EQ.1)GO TO 80                                   TTTT4500
 4010 WRITE(K2,4011)KK                                         TTTT4501
 4011 FORMAT(1H1,19X,'SURFACE TO VOLUME TOTAL INTERCHANGE AREA',10X,'K='TTTT4502
     1,I5)                                                     TTTT4503
      CALL PRINT(AA,NVOL,NSURF)                                TTTT4504
   80 NL=MINO(NSURF,NVOL)                                      TTTT4505
      DO 82 N=2,NL                                             TTTT4506
      LZ=N-1                                                   TTTT4507
      DO 81 L=1,LZ                                             TTTT4508
      SAVE=AA(N,L)                                             TTTT4509
      AA(N,L)=AA(L,N)                                          TTTT4510
      AA(L,N)=SAVE                                             TTTT4511
   81 CONTINUE                                                 TTTT4512
   82 CONTINUE                                                 TTTT4513
      NZ=NL+1                                                  TTTT4514
      IF(NVOL-NSURF)83,870,84                                  TTTT4515
C   NSURF.GT.NVOL                                              TTTT4516
```

```
 83     NSTART=1                                                   TTTT4517
        LSTART=NZ                                                  TTTT4518
        GO TO 85                                                   TTTT4519
 C   NVOL.GT.NSURF                                                 TTTT4520
 84     NSTART=NZ                                                  TTTT4521
        LSTART=1                                                   TTTT4522
 85     DO 87 N=NSTART,NVOL                                        TTTT4523
        DO 86 L=LSTART,NSURF                                       TTTT4524
        AA(L,N)=AA(N,L)                                            TTTT4525
        AA(N,L)=0.0                                                TTTT4526
 86     CONTINUE                                                   TTTT4527
 87     CONTINUE                                                   TTTT4528
 870    DO 89 N=1,NVOL                                             TTTT4529
        Z(N)=0.0                                                   TTTT4530
        DO 88 L=1,NSURF                                            TTTT4531
        Z(N)=Z(N)+AA(L,N)                                          TTTT4532
 88     CONTINUE                                                   TTTT4533
 89     CONTINUE                                                   TTTT4534
        DO 90 J=1,NSGBLK                                           TTTT4535
        CALL WRITE(1,TSGNM(J,KK),AA(1,15*J-14), 900)               TTTT4536
 90     CONTINUE                                                   TTTT4537
        IF(NPRNT.EQ.1)GO TO 900                                    TTTT4538
 4020   WRITE(K2,4021)KK                                           TTTT4539
 4021   FORMAT(1H1,19X,'VOLUME TO SURFACE TOTAL INTERCHANGE AREA',10X,'K='TTTT4540
       1,I5)                                                       TTTT4541
        CALL PRINT(AA,NSURF,NVOL)                                  TTTT4542
        CALL PRINT(Z,NVOL,1)                                       TTTT4543
 900    CON=4.0*XO*YO*XK(KK)                                       TTTT4544
        CALL PZERO(AA(1,1), 3600)                                  TTTT4545
        DO 91 J=1,NGGBLK                                           TTTT4546
        CALL READ(1,TGGNM(J,KK),AA(1,15*J-14), 900)                TTTT4547
 91     CONTINUE                                                   TTTT4548
        DO 94 N=1,NVOL                                             TTTT4549
        ZZ=0.0                                                     TTTT4550
        DO 92 L=1,NVOL                                             TTTT4551
        ZZ=ZZ+AA(L,N)                                              TTTT4552
 92     CONTINUE                                                   TTTT4553
        ZZ=(CON-Z(N))/ZZ                                           TTTT4554
        DO 93 L=1,NVOL                                             TTTT4555
        AA(L,N)=AA(L,N)*ZZ                                         TTTT4556
 93     CONTINUE                                                   TTTT4557
 94     CONTINUE                                                   TTTT4558
        DO 95 J=1,NGGBLK                                           TTTT4559
        CALL WRITE(1,TGGNM(J,KK),AA(1,15*J-14), 900)               TTTT4560
 95     CONTINUE                                                   TTTT4561
        IF(NPRNT.EQ.1)GO TO 96                                     TTTT4562
 4030   WRITE(K2,4031)KK                                           TTTT4563
 4031   FORMAT(1H1,19X,'VOLUME TO VOLUME TOTAL INTERCHANGE AREA',10X,'K=',TTTT4564
       1I5)                                                        TTTT4565
        CALL PRINT(AA, NVOL,NVOL)                                  TTTT4566
```

```
251 96    CONTINUE                                      TTTT4567
252 99    RETURN                                        TTTT4568
253       END                                           TTTT4569
```

```
      FUNCTION LOC(KIK)                                                 LOC 4570
C      L  LOC    CODE FOR GAS VOLUME ORINTATION                         LOC 4571
C      K  KK     GAS VOLUME NUMBER                                      LOC 4572
      COMMON // DUMMY(3),KK, ICODE, HCODE,                              LOC 4573
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                    LOC 4574
     A TBRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                       LOC 4575
     A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                    LOC 4576
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                     LOC 4577
     A XSURFX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,                     LOC 4578
     A RSTART, TCODE, SCODE, NGRAY, JHCHC,                              LOC 4579
     A K1, K2, KCRD(10), TDEP(100), PERM(200)                           LOC 4580
C                                                                       LOC 4581
      INTEGER SCODE,TCODE,RSTART,HCODE                                  LOC 4582
      COMMON/GAS/ NX1,NX2,NY1,NY2,HT,HTT,XTEST,ALFA(3),BETA(3),GAMA(3), LOC 4583
     1DELT(3),GMX(120),GMY(120),NC( 60),JX1,JX2,JY1,JY2                 LOC 4584
      COMMON/TTT/ TV(120,2),TS(120,2)                                   LOC 4585
   10 K=KIK                                                             LOC 4586
      CALL PZERO(ALFA(1) ,3)                                            LOC 4587
      CALL PZERO(BETA(1) ,3)                                            LOC 4588
      CALL PZERO(GAMA(1) ,3)                                            LOC 4589
      CALL PZERO(DELT(1),3)                                             LOC 4590
C    FOR GAS VOLUME OBTAIN                                              LOC 4591
C      JR   ROW NUMBER                                                  LOC 4592
C      JC   COLUMN NUMBER                                               LOC 4593
      JR=0                                                              LOC 4594
      JC=K                                                              LOC 4595
   12 JR=JR+1                                                           LOC 4596
      IF(JC.LE.NCOL)GO TO 14                                            LOC 4597
      JC=JC-NCOL                                                        LOC 4598
      GO TO 12                                                          LOC 4599
C    BULK FLOW INDICIES                                                 LOC 4600
C      JX1    X DIRECTION IN                                            LOC 4601
C      JX2                OUT                                           LOC 4602
C      JY1    Y DIRECTION IN                                            LOC 4603
C      JY2                OUT                                           LOC 4604
   14 JX1=(JR-1)*(NCOL+1)+JC                                            LOC 4605
      JX2=JX1+1                                                         LOC 4606
      JY1=K                                                             LOC 4607
      JY2=K+NCOL                                                        LOC 4608
C    COMPUTE VALUE OF L AND NX1,NX2,,NY1,NY2                            LOC 4609
   16 IF(JR.NE.1)GO TO 21                                               LOC 4610
      IF(JC.NE.1)GO TO 17                                               LOC 4611
C    SURF VOL   SURF VOL                                                LOC 4612
      L=1                                                               LOC 4613
      NX1=2*NCOL+1                                                      LOC 4614
      NX2=K+1                                                           LOC 4615
      NY1=1                                                             LOC 4616
      NY2=K+NCOL                                                        LOC 4617
      GO TO 61                                                          LOC 4618
   17 IF(JC.EQ.NCOL)GO TO 19                                            LOC 4619
```

```
      IF(NXSXN.NE.0)GO TO 31                                 LOC 4620
C     VOL    VOL    SURF    VOL                              LOC 4621
18    L=2                                                    LOC 4622
      NX1=K-1                                                LOC 4623
      NX2=K+1                                                LOC 4624
      NY1=K                                                  LOC 4625
      NY2=K+NCOL                                             LOC 4626
      GO TO 81                                               LOC 4627
19    L=3                                                    LOC 4628
C     VOL    SURF    SURF    VOL                             LOC 4629
      NX1=K-1                                                LOC 4630
      NX2=2*NCOL+NROW+1                                      LOC 4631
      NY1=K                                                  LOC 4632
      NY2=K+NCOL                                             LOC 4633
      GO TO 101                                              LOC 4634
21    IF(JR.NE.NROW)GO TO 25                                 LOC 4635
      IF(JC.NE.1)GO TO 22                                    LOC 4636
      L=7                                                    LOC 4637
C     SURR   VOL    VOL    SURF                              LOC 4638
      NX1=2*NCOL+NROW                                        LOC 4639
      NX2=K+1                                                LOC 4640
      NY1=K-NCOL                                             LOC 4641
      NY2=NCOL+1                                             LOC 4642
      GO TO 181                                              LOC 4643
22    IF(JC.EQ.NCOL)GO TO 24                                 LOC 4644
      IF(NXSXN.NE.0)GO TO 31                                 LOC 4645
23    L=8                                                    LOC 4646
C     VOL    VOL    VOL    SURF                              LOC 4647
      NX1=K-1                                                LOC 4648
      NX2=K+1                                                LOC 4649
      NY1=K-NCOL                                             LOC 4650
      NY2=NCOL+JC                                            LOC 4651
      GO TO 201                                              LOC 4652
24    L=9                                                    LOC 4653
C     VOL    SURF    VOL    SURF                             LOC 4654
      NX1=K-1                                                LOC 4655
      NX2=NCR                                                LOC 4656
      NY1=K-NCOL                                             LOC 4657
      NY2=2*NCOL                                             LOC 4658
      GO TO 221                                              LOC 4659
25    IF(JC.NE.1)GO TO 26                                    LOC 4660
      L=4                                                    LOC 4661
C     SURF   VOL    VOL    VOL                               LOC 4662
      NX1=2*NCOL+JR                                          LOC 4663
      NX2=K+1                                                LOC 4664
      NY1=K-NCOL                                             LOC 4665
      NY2=K+NCOL                                             LOC 4666
      GO TO 121                                              LOC 4667
26    IF(JC.NE.NCOL)GO TO 27                                 LOC 4668
      L=6                                                    LOC 4669
```

```
C     VOL SURF   VOL   VUL                                    LOC 4670
         NX1=K-1                                              LOC 4671
         NX2=2*NCOL+NROW+JR                                   LOC 4672
         NY1=K-NCOL                                           LOC 4673
         NY2=K+NCOL                                           LOC 4674
         GO TO 161                                            LOC 4675
27       IF(NXSXN.NE.0)GO TO 31                               LOC 4676
28       L=5                                                  LOC 4677
C     VOL   VOL   VOL VOL                                     LOC 4678
         NX1=K-1                                              LOC 4679
         NX2=K+1                                              LOC 4680
         NY1=K-NCOL                                           LOC 4681
         NY2=K+NCOL                                           LOC 4682
         GO TO  141                                           LOC 4683
C     INTERMEDIATE SURFACE PRESENT                            LOC 4684
C     SURFACE ON LEFT SIDE OF GAS VOLUME                      LOC 4685
C     L=11.OR.13.OR.15                                        LOC 4686
31       XX=XO*FLOAT(JC-1)                                    LOC 4687
         DO 32 J=1,NXSXN                                      LOC 4688
         IF(ABS(XX-XSURFX(J)).GT.XTEST)GO TO 32               LOC 4689
         NSN=J                                                LOC 4690
         GO TO 33                                             LOC 4691
32       CONTINUE                                             LOC 4692
         GO TO 41                                             LOC 4693
33       IF(JR.NE.1)GO TO 34                                  LOC 4694
         L=11                                                 LOC 4695
C     SURF   VOL   SURF   VOL                                 LOC 4696
         NX1=NCR+(NSN-1)*NROW+1                               LOC 4697
         NX2=K+1                                              LOC 4698
         NY1=K                                                LOC 4699
         NY2=K+NCOL                                           LOC 4700
         GO TO 261                                            LOC 4701
34       IF(JR.NE.NROW)GO TO 35                               LOC 4702
         L=13                                                 LOC 4703
C     (?)    VOL VOL   VOL                                    LOC 4704
         NX1=NCR+(NSN-1)*NROW+JR                              LOC 4705
         NX2=K+1                                              LOC 4706
         NY1=K-NCOL                                           LOC 4707
         NY2=K+NCOL                                           LOC 4708
         GO TO 301                                            LOC 4709
35       L=15                                                 LOC 4710
C     SUR   VOL   VOL   SURF                                  LOC 4711
         NX1=NCR+NSN*NROW                                     LOC 4712
         NX2=K+1                                              LOC 4713
         NY1=K-NCOL                                           LOC 4714
         NY2=NCOL+JC                                          LOC 4715
         GO TO 341                                            LOC 4716
C     SURFACE ON RIGTH SIDE OF GAS VOLUME                     LOC 4717
C       L=10.OR.12.OR.14                                      LOC 4718
41       XX=XX+XO                                             LOC 4719
```

```
      DO 42 J=1,NXSXN                                   LOC 4720
      IF(ABS(XX-XSURFX(J)).GT.XTEST)GO TO 42            LOC 4721
      NSN=J                                             LOC 4722
      GO TO 43                                          LOC 4723
42    CONTINUE                                          LOC 4724
      IF(JR.EQ.1)GO TO 18                               LOC 4725
      IF(JR.EQ.NROW)GO TO 23                            LOC 4726
      GO TO 28                                          LOC 4727
43    IF(JR.NE.1)GO TO 44                               LOC 4728
      L=10                                              LOC 4729
C   VOL   SURF   SURF   VOL                             LOC 4730
      NX1=K-1                                           LOC 4731
      NX2=NCR+(NSN-1)*NROW+1                            LOC 4732
      NY1=K                                             LOC 4733
      NY2=K+NCOL                                        LOC 4734
      GO TO 241                                         LOC 4735
44    IF(JR.EQ.NROW)GO TO 45                            LOC 4736
      L=12                                              LOC 4737
C   VOL   SURF   VOL   VOL                              LOC 4738
      NX1=K-1                                           LOC 4739
      NX2=NCR+(NSN-1)*NROW+JR                           LOC 4740
      NY1=K-NCOL                                        LOC 4741
      NY2=K+NCOL                                        LOC 4742
      GO TO 281                                         LOC 4743
45    L=14                                              LOC 4744
C   VOL   SURF   VOL   SURF                             LOC 4745
      NX1=K-1                                           LOC 4746
      NX2=NCR+NSN*NROW                                  LOC 4747
      NY1=K-NCOL                                        LOC 4748
      NY2=NCOL+JC                                       LOC 4749
      GO TO 321                                         LOC 4750
C   COMPUTE HEAT TRANSFER AND BULK FLOW TERMS           LOC 4751
C   L=1                                                 LOC 4752
61    HX=HC(NX1)*YO                                     LOC 4753
      HY=HC(NY1)*XO                                     LOC 4754
      HT=-HX-HY                                         LOC 4755
      HTT=-HX*TS(NX1,1)-HY*TS(NY1,1)                    LOC 4756
      IF(GMX(JX1))62,64,63                              LOC 4757
62    GX=GMX(JX1)*CP(TV(K,1))                           LOC 4758
      ALFA(2)=GX                                        LOC 4759
      ALFA(3)=-GMX(JX1)*HV(TV(K,1))+GX*TV(K,1)          LOC 4760
      GO TO 64                                          LOC 4761
63    ALFA(3)=-GMX(JX1)*HV(FTEMP)                       LOC 4762
64    IF(GMX(JX2))65,67,66                              LOC 4763
65    GX=GMX(JX2)*CP(TV(NX2,1))                         LOC 4764
      GAMA(2)=-GX                                       LOC 4765
      GAMA(3)=GMX(JX2)*HV(TV(NX2,1))-GX*TV(NX2,1)       LOC 4766
      GO TO 67                                          LOC 4767
66    GX=GMX(JX2)*CP(TV(K,1))                           LOC 4768
      GAMA(1)=-GX                                       LOC 4769
```

```
      GAMA(3)=GMX(JX2)*HV(TV(K,1))-GX*TV(K,1)
   67 IF(GMY(JY1))68,70,69
   68 GY=GMY(JY1)*CP(TV(K,1))
      BETA(2)=GY
      BETA(3)=-GMY(JY1)*HV(TV(K,1))+GY*TV(K,1)
      GO TO 70
   69 BETA(3)=-GMY(JY1)*HV(FTEMP)
   70 IF(GMY(JY2))71,999,72
   71 GY=GMY(JY2)*CP(TV(NY2,1))
      DELT(2)=-GY
      DELT(3)=GMY(JY2)*HV(TV(NY2,1))-GY*TV(NY2,1)
      GO TO 999
   72 GY=GMY(JY2)*CP(TV(K,1))
      DELT(1)=-GY
      DELT(3)=+GMY(JY2)*HV(TV(K,1))-GY*TV(K,1)
      GO TO 999
C     L=2
   81 HT=-HC(NY1)*XO
      HTT=HT*TS(NY1,1)
      IF(GMX(JX1))82,84,83
   82 GX=GMX(JX1)*CP(TV(K,1))
      ALFA(2)=GX
      ALFA(3)=-GMX(JX1)*HV(TV(K,1))+GX*TV(K,1)
      GO TO 84
   83 GX=GMX(JX1)*CP(TV(NX1,1))
      ALFA(1)=+GX
      ALFA(3)=-GMX(JX1)*HV(TV(NX1,1))+GX*TV(NX1,1)
   84 IF(GMX(JX2))85,87,86
   85 GX=GMX(JX2)*CP(TV(NX2,1))
      GAMA(2)=-GX
      GAMA(3)=GMX(JX2)*HV(TV(NX2,1))-GX*TV(NX2,1)
      GO TO 87
   86 GX=GMX(JX2)*CP(TV(K,1))
      GAMA(1)=-GX
      GAMA(3)=GMX(JX2)*HV(TV(K,1))-GX*TV(K,1)
   87 IF(GMY(JY1))88,90,89
   88 GY=GMY(JY1)*CP(TV(K,1))
      BETA(2)=GY
      BETA(3)=-GMY(JY1)*HV(TV(K,1))+GY*TV(K,1)
      GO TO 90
   89 BETA(3)=-GMY(JY1)*HV(FTEMP)
   90 IF(GMY(JY2))91,999,92
   91 GY=GMY(JY2)*CP(TV(NY2,1))
      DELT(2)=-GY
      DELT(3)=GMY(JY2)*HV(TV(NY2,1))-GY*TV(NY2,1)
      GO TO 999
   92 GY=GMY(JY2)*CP(TV(K,1))
      DELT(1)=-GY
      DELT(3)=+GMY(JY2)*HV(TV(K,1))-GY*TV(K,1)
      GO TO 999
```

```
C     L=3                                                          LOC 4820
  101 HX=HC(NX2)*YO                                                LOC 4821
      HY=HC(NY1)*XO                                                LOC 4822
      HT=-HX-HY                                                    LOC 4823
      HTT=-HX*TS(NX2,1)-HY*TS(NY1,1)                               LOC 4824
      IF(GMX(JX1))102,104,103                                      LOC 4825
  102 GX=GMX(JX1)*CP(TV(K,1))                                      LOC 4826
      ALFA(2)=GX                                                   LOC 4827
      ALFA(3)=-GMX(JX1)*HV(TV(K,1))+GX*TV(K,1)                     LOC 4828
      GO TO 104                                                    LOC 4829
  103 GX=GMX(JX1)*CP(TV(NX1,1))                                    LOC 4830
      ALFA(1)=+GX                                                  LOC 4831
      ALFA(3)=-GMX(JX1)*HV(TV(NX1,1))+GX*TV(NX1,1)                 LOC 4832
  104 IF(GMX(JX2))105,107,106                                      LOC 4833
  105 GAMA(3)=GMX(JX2)*HV(FTEMP)                                   LOC 4834
      GO TO 107                                                    LOC 4835
  106 GX=GMX(JX2)*CP(TV(K,1))                                      LOC 4836
      GAMA(1)=-GX                                                  LOC 4837
      GAMA(3)=GMX(JX2)*HV(TV(K,1))-GX*TV(K,1)                      LOC 4838
  107 IF(GMY(JY1))108,110,109                                      LOC 4839
  108 GY=GMY(JY1)*CP(TV(K,1))                                      LOC 4840
      BETA(2)=GY                                                   LOC 4841
      BETA(3)=-GMY(JY1)*HV(TV(K,1))+GY*TV(K,1)                     LOC 4842
      GO TO 110                                                    LOC 4843
  109 BETA(3)=-GMY(JY1)*HV(FTEMP)                                  LOC 4844
  110 IF(GMY(JY2))111,999,112                                      LOC 4845
  111 GY=GMY(JY2)*CP(TV(NY2,1))                                    LOC 4846
      DELT(2)=-GY                                                  LOC 4847
      DELT(3)=GMY(JY2)*HV(TV(NY2,1))-GY*TV(NY2,1)                  LOC 4848
      GO TO 999                                                    LOC 4849
  112 GY=GMY(JY2)*CP(TV(K,1))                                      LOC 4850
      DELT(1)=-GY                                                  LOC 4851
      DELT(3)=+GMY(JY2)*HV(TV(K,1))-GY*TV(K,1)                     LOC 4852
      GO TO 999                                                    LOC 4853
C     L=4                                                          LOC 4854
  121 HT= -HC(NX1)*YO                                              LOC 4855
      HTT=HT*TS(NX1,1)                                             LOC 4856
      IF(GMX(JX1))122,124,123                                      LOC 4857
  122 GX=GMX(JX1)*CP(TV(K,1))                                      LOC 4858
      ALFA(2)=GX                                                   LOC 4859
      ALFA(3)=-GMX(JX1)*HV(TV(K,1))+GX*TV(K,1)                     LOC 4860
      GO TO 124                                                    LOC 4861
  123 ALFA(3)=-GMX(JX1)*HV(FTEMP)                                  LOC 4862
  124 IF(GMX(JX2))125,127,126                                      LOC 4863
  125 GX=GMX(JX2)*CP(TV(NX2,1))                                    LOC 4864
      GAMA(2)=-GX                                                  LOC 4865
      GAMA(3)=GMX(JX2)*HV(TV(NX2,1))-GX*TV(NX2,1)                  LOC 4866
      GO TO 127                                                    LOC 4867
  126 GX=GMX(JX2)*CP(TV(K,1))                                      LOC 4868
      GAMA(1)=-GX                                                  LOC 4869
```

```
      GAMA(3)=GMX(JX2)*HV(TV(K,1))-GX*TV(K,1)                     LOC 4870
  127 IF(GMY(JY1))128,130,129                                     LOC 4871
  128 GY=GMY(JY1)*CP(TV(K,1))                                     LOC 4872
      BETA(2)=+GY                                                 LOC 4873
      BETA(3)=-GMY(JY1)*HV(TV(K,1))+GY*TV(K,1)                    LOC 4874
      GO TO 130                                                   LOC 4875
  129 GY=GMY(JY1)*CP(TV(NY1,1))                                   LOC 4876
      BETA(1)= GY                                                 LOC 4877
      BETA(3)=-GMY(JY1)*HV(TV(NY1,1))+GY*TV(NY1,1)                LOC 4878
  130 IF(GMY(JY2))131,999,132                                     LOC 4879
  131 GY=GMY(JY2)*CP(TV(NY2,1))                                   LOC 4880
      DELT(2)=-GY                                                 LOC 4881
      DELT(3)=GMY(JY2)*HV(TV(NY2,1))-GY*TV(NY2,1)                 LOC 4882
      GO TO 999                                                   LOC 4883
  132 GY=GMY(JY2)*CP(TV(K,1))                                     LOC 4884
      DELT(1)=-GY                                                 LOC 4885
      DELT(3)=+GMY(JY2)*HV(TV(K,1))-GY*TV(K,1)                    LOC 4886
      GO TO 999                                                   LOC 4887
C     L=5                                                         LOC 4888
  141 HT=0.0                                                      LOC 4889
      HTT=0.0                                                     LOC 4890
      IF(GMX(JX1))142,144,143                                     LOC 4891
  142 GX=GMX(JX1)*CP(TV(K,1))                                     LOC 4892
      ALFA(2)=GX                                                  LOC 4893
      ALFA(3)=-GMX(JX1)*HV(TV(K,1))+GX*TV(K,1)                    LOC 4894
      GO TO 144                                                   LOC 4895
  143 GX=GMX(JX1)*CP(TV(NX1,1))                                   LOC 4896
      ALFA(1)= GX                                                 LOC 4897
      ALFA(3)=-GMX(JX1)*HV(TV(NX1,1))+GX*TV(NX1,1)                LOC 4898
  144 IF(GMX(JX2))145,147,146                                     LOC 4899
  145 GX=GMX(JX2)*CP(TV(NX2,1))                                   LOC 4900
      GAMA(2)=-GX                                                 LOC 4901
      GAMA(3)=GMX(JX2)*HV(TV(NX2,1))-GX*TV(NX2,1)                 LOC 4902
      GO TO 147                                                   LOC 4903
  146 GX=GMX(JX2)*CP(TV(K,1))                                     LOC 4904
      GAMA(1)=-GX                                                 LOC 4905
      GAMA(3)=GMX(JX2)*HV(TV(K,1))-GX*TV(K,1)                     LOC 4906
  147 IF(GMY(JY1))148,150,149                                     LOC 4907
  148 GY=GMY(JY1)*CP(TV(K,1))                                     LOC 4908
      BETA(2)=GY                                                  LOC 4909
      BETA(3)=-GMY(JY1)*HV(TV(K,1))+GY*TV(K,1)                    LOC 4910
      GO TO 150                                                   LOC 4911
  149 GY=GMY(JY1)*CP(TV(NY1,1))                                   LOC 4912
      BETA(1)=GY                                                  LOC 4913
      BETA(3)=-GMY(JY1)*HV(TV(NY1,1))+GY*TV(NY1,1)                LOC 4914
  150 IF(GMY(JY2))151,999,152                                     LOC 4915
  151 GY=GMY(JY2)*CP(TV(NY2,1))                                   LOC 4916
      DELT(2)=-GY                                                 LOC 4917
      DELT(3)=GMY(JY2)*HV(TV(NY2,1))-GY*TV(NY2,1)                 LOC 4918
      GO TO 999                                                   LOC 4919
```

```
152     GY=GMY(JY2)*CP(TV(K,1))                              LOC 4920
        DELT(1)=-GY                                          LOC 4921
        DELT(3)=+GMY(JY2)*HV(TV(K,1))-GY*TV(K,1)             LOC 4922
        GO TO 999                                            LOC 4923
C       L=6                                                  LOC 4924
161     HT=-HC(NX2)*YO                                       LOC 4925
        HTT=HT*TS(NX2,1)                                     LOC 4926
        IF(GMX(JX1))162,164,163                              LOC 4927
162     GX=GMX(JX1)*CP(TV(K,1))                              LOC 4923
        ALFA(2)=GX                                           LOC 4929
        ALFA(3)=-GMX(JX1)*HV(TV(K,1))+GX*TV(K,1)             LOC 4930
        GO TO 164                                            LOC 4931
163     GX=GMX(JX1)*CP(TV(NX1,1))                            LOC 4932
        ALFA(1)= GX                                          LOC 4933
        ALFA(3)=-GMX(JX1)*HV(TV(NX1,1))+GX*TV(NX1,1)         LOC 4934
164     IF(GMX(JX2))165,167,166                              LOC 4935
165     GAMA(3)= GMX(JX2)*HV(FTEMP)                          LOC 4936
        GO TO 167                                            LOC 4937
166     GX=GMX(JX2)*CP(TV(K,1))                              LOC 4938
        GAMA(1)=-GX                                          LOC 4939
        GAMA(3)=GMX(JX2)*HV(TV(K,1))-GX*TV(K,1)              LOC 4940
167     IF(GMY(JY1))168,170,169                              LOC 4941
168     GY=GMY(JY1)*CP(TV(K,1))                              LOC 4942
        BETA(2)=GY                                           LOC 4943
        BETA(3)=-GMY(JY1)*HV(TV(K,1))+GY*TV(K,1)             LOC 4944
        GO TO 170                                            LOC 4945
169     GY=GMY(JY1)*CP(TV(NY1,1))                            LOC 4946
        BETA(1)=GY                                           LOC 4947
        BETA(3)=-GMY(JY1)*HV(TV(NY1,1))+GY*TV(NY1,1)         LOC 4948
170     IF(GMY(JY2))171,999,172                              LOC 4949
171     GY=GMY(JY2)*CP(TV(NY2,1))                            LOC 4950
        DELT(2)=-GY                                          LOC 4951
        DELT(3)=GMY(JY2)*HV(TV(NY2,1))-GY*TV(NY2,1)          LOC 4952
        GO TO 999                                            LOC 4953
172     GY=GMY(JY2)*CP(TV(K,1))                              LOC 4954
        DELT(1)=-GY                                          LOC 4955
        DELT(3)=+GMY(JY2)*HV(TV(K,1))-GY*TV(K,1)             LOC 4956
        GO TO 999                                            LOC 4957
C       L=7                                                  LOC 4958
181     HX=HC(NX1)*YO                                        LOC 4959
        HY=HC(NY2)*XO                                        LOC 4960
        HT=-HX-HY                                            LOC 4961
        HTT=-HX*TS(NX1,1)-HY*TS(NY2,1)                       LOC 4962
        IF(GMX(JX1))182,184,183                              LOC 4963
182     GX=GMX(JX1)*CP(TV(K,1))                              LOC 4964
        ALFA(2)= GX                                          LOC 4965
        ALFA(3)=-GMX(JX1)*HV(TV(K,1))+GX*TV(K,1)             LOC 4966
        GO TO 184                                            LOC 4967
183     ALFA(3)=-GMX(JX1)*HV(FTEMP)                          LOC 4968
184     IF(GMX(JX2))185,187,186                              LOC 4969
```

```
185   GX=GMX(JX2)*CP(TV(NX2,1))                          LOC 4970
      GAMA(2)=-GX                                        LOC 4971
      GAMA(3)=+GMX(JX2)*HV(TV(NX2,1))-GX*TV(NX2,1)       LOC 4972
      GO TO 187                                          LOC 4973
186   GX=GMX(JX2)*CP(TV(K,1))                            LOC 4974
      GAMA(1)=-GX                                        LOC 4975
      GAMA(3)=+GMX(JX2)*HV(TV(K  ,1))-GX*TV(K  ,1)       LOC 4976
187   IF(GMY(JY1))188,190,189                            LOC 4977
188   GY=GMY(JY1)*CP(TV(K  ,1))                          LOC 4978
      BETA(2)=+GY                                        LOC 4979
      BETA(3)=-GMY(JY1)*HV(TV(K  ,1))+GY*TV(K  ,1)       LOC 4980
      GO TO 190                                          LOC 4981
189   GY=GMY(JY1)*CP(TV(NY1,1))                          LOC 4982
      BETA(1)=+GY                                        LOC 4983
      BETA(3)=-GMY(JY1)*HV(TV(NY1,1))+GY*TV(NY1,1)       LOC 4984
190   IF(GMY(JY2))191,999,192                            LOC 4985
191   DELT(3)=+GMY(JY2)*HV(PTEMP)                        LOC 4986
      GO TO 999                                          LOC 4987
192   GY=GMY(JY2)*CP(TV(K  ,1))                          LOC 4988
      DELT(1)=-GY                                        LOC 4989
      DELT(3)=+GMY(JY2)*HV(TV(K,1))-GY*TV(K,1)           LOC 4990
      GO TO 999                                          LOC 4991
C   L=8                                                  LOC 4992
201   HT=-HC(NY2)*XO                                     LOC 4993
      HTT= HT*TS(NY2,1)                                  LOC 4994
      IF(GMX(JX1))202,204,203                            LOC 4995
202   GX=GMX(JX1)*CP(TV(K,1))                            LOC 4996
      ALFA(2)= GX                                        LOC 4997
      ALFA(3)=-GMX(JX1)*HV(TV(K,1))+GX*TV(K,1)           LOC 4998
      GO TO 204                                          LOC 4999
203   GX=GMX(JX1)*CP(TV(NX1,1))                          LOC 5000
      ALFA(1)=GX                                         LOC 5001
      ALFA(3)=-GMX(JX1)*HV(TV(NX1,1))+GX*TV(NX1,1)       LOC 5002
204   IF(GMX(JX2))205,207,206                            LOC 5003
205   GX=GMX(JX2)*CP(TV(NX2,1))                          LOC 5004
      GAMA(2)=-GX                                        LOC 5005
      GAMA(3)=+GMX(JX2)*HV(TV(NX2,1))-GX*TV(NX2,1)       LOC 5006
      GO TO 207                                          LOC 5007
206   GX=GMX(JX2)*CP(TV(K,1))                            LOC 5008
      GAMA(1)=-GX                                        LOC 5009
      GAMA(3)=+GMX(JX2)*HV(TV(K  ,1))-GX*TV(K  ,1)       LOC 5010
207   IF(GMY(JY1))208,210,209                            LOC 5011
208   GY=GMY(JY1)*CP(TV(K  ,1))                          LOC 5012
      BETA(2)=+GY                                        LOC 5013
      BETA(3)=-GMY(JY1)*HV(TV(K  ,1))+GY*TV(K  ,1)       LOC 5014
      GO TO 210                                          LOC 5015
209   GY=GMY(JY1)*CP(TV(NY1,1))                          LOC 5016
      BETA(1)=+GY                                        LOC 5017
      BETA(3)=-GMY(JY1)*HV(TV(NY1,1))+GY*TV(NY1,1)       LOC 5018
210   IF(GMY(JY2))211,999,212                            LOC 5019
```

```
 211  DELT(3)=+GMY(JY2)*HV(FTEMP)                               LOC 5020
      GO TO 999                                                 LOC 5021
 212  GY=GMY(JY2)*CP(TV(K  ,1))                                 LOC 5022
      DELT(1)=-GY                                               LOC 5023
      DELT(3)=+GMY(JY2)*HV(TV(K,1))-GY*TV(K,1)                  LOC 5024
      GO TO 999                                                 LOC 5025
C     L=9                                                       LOC 5026
 221  HX=HC(NX2)*YO                                             LOC 5027
      HY=HC(NY2)*XO                                             LOC 5028
      HT=-HX-HY                                                 LOC 5029
      HTT=-HX*TS(NX2,1)-HY*TS(NY2,1)                            LOC 5030
      IF(GMX(JX1))222,224,223                                   LOC 5031
 222  GX=GMX(JX1)*CP(TV(K,1))                                   LOC 5032
      ALFA(2)=-GX                                               LOC 5033
      ALFA(3)=-GMX(JX1)*HV(TV(K,1))+GX*TV(K,1)                  LOC 5034
      GO TO 224                                                 LOC 5035
 223  GX=GMX(JX1)*CP(TV(NX1,1))                                 LOC 5036
      ALFA(1)=GX                                                LOC 5037
      ALFA(3)=-GMX(JX1)*HV(TV(NX1,1))+GX*TV(NX1,1)              LOC 5038
 224  IF(GMX(JX2))225,227,226                                   LOC 5039
 225  GAMA(3)=+GMX(JX2)*HV(FTEMP)                               LOC 5040
      GO TO 227                                                 LOC 5041
 226  GX=GMX(JX2)*CP(TV(K,1))                                   LOC 5042
      GAMA(1)=-GX                                               LOC 5043
      GAMA(3)=+GMX(JX2)*HV(TV(K  ,1))-GX*TV(K  ,1)              LOC 5044
 227  IF(GMY(JY1))228,230,229                                   LOC 5045
 228  GY=GMY(JY1)*CP(TV(K  ,1))                                 LOC 5046
      BETA(2)=+GY                                               LOC 5047
      BETA(3)=-GMY(JY1)*HV(TV(K  ,1))+GY*TV(K  ,1)              LOC 5048
      GO TO 230                                                 LOC 5049
 229  GY=GMY(JY1)*CP(TV(NY1,1))                                 LOC 5050
      BETA(1)=+GY                                               LOC 5051
      BETA(3)=-GMY(JY1)*HV(TV(NY1,1))+GY*TV(NY1,1)              LOC 5052
 230  IF(GMY(JY2))231,999,232                                   LOC 5053
 231  DELT(3)=+GMY(JY2)*HV(FTEMP)                               LOC 5054
      GO TO 999                                                 LOC 5055
 232  GY=GMY(JY2)*CP(TV(K  ,1))                                 LOC 5056
      DELT(1)=-GY                                               LOC 5057
      DELT(3)=+GMY(JY2)*HV(TV(K,1))-GY*TV(K,1)                  LOC 5058
      GO TO 999                                                 LOC 5059
C     L=10                                                      LOC 5060
 241  HX=HC(NX2)*YO/2.                                          LOC 5061
      HY=HC(NY1)*XO                                             LOC 5062
      HT=-HX-HY                                                 LOC 5063
      HTT=-HX*TS(NX2,1)-HY*TS(NY1,1)                            LOC 5064
      IF(GMX(JX1))242,244,243                                   LOC 5065
 242  GX=GMX(JX1)*CP(TV(K,1))                                   LOC 5066
      ALFA(2)=-GX                                               LOC 5067
      ALFA(3)=-GMX(JX1)*HV(TV(K,1))+GX*TV(K,1)                  LOC 5068
      GO TO 244                                                 LOC 5069
```

```
243  GX=GMX(JX1)*CP(TV(NX1,1))                               LOC 5070
     ALFA(1)=GX                                              LOC 5071
     ALFA(3)=-GMX(JX1)*HV(TV(NX1,1))+GX*TV(NX1,1)            LOC 5072
244  IF(GMX(JX2))245,247,246                                 LOC 5073
245  GX=GMX(JX2)*CP(TV(K+1,1))                               LOC 5074
     GAMA(2)=-GX                                             LOC 5075
     GAMA(3)=+GMX(JX2)*HV(TV(K+1,1))-GX*TV(K+1,1)            LOC 5076
     GO TO 247                                               LOC 5077
246  GX=GMX(JX2)*CP(TV(K  ,1))                               LOC 5078
     GAMA(1)=-GX                                             LOC 5079
     GAMA(3)=+GMX(JX2)*HV(TV(K  ,1))-GX*TV(K  ,1)            LOC 5080
247  IF(GMY(JY1))248,250,249                                 LOC 5081
248  GY=GMY(JY1)*CP(TV(K  ,1))                               LOC 5082
     BETA(2)=+GY                                             LOC 5083
     BETA(3)=-GMY(JY1)*HV(TV(K  ,1))+GY*TV(K  ,1)            LOC 5084
     GO TO 250                                               LOC 5085
249  BETA(3)=-GMY(JY1)*HV(FTEMP)                             LOC 5086
250  IF(GMY(JY2))251,999,252                                 LOC 5087
251  GY=GMY(JY2)*CP(TV(NY2,1))                               LOC 5088
     DELT(2)=-GY                                             LOC 5089
     DELT(3)=+GMY(JY2)*HV(TV(NY2,1))-GY*TV(NY2,1)            LOC 5090
     GO TO 999                                               LOC 5091
252  GY=GMY(JY2)*CP(TV(K  ,1))                               LOC 5092
     DELT(1)=-GY                                             LOC 5093
     DELT(3)=+GMY(JY2)*HV(TV(K,1))-GY*TV(K,1)                LOC 5094
     GO TO 999                                               LOC 5095
C    L=11                                                    LOC 5096
261  HX=HC(NX1)*YD/2.                                        LOC 5097
     HY=HC(NY1)*XD                                           LOC 5098
     HT=-HX-HY                                               LOC 5099
     HTT=-HX*TS(NX1,1)-HY*TS(NY1,1)                          LOC 5100
     IF(GMX(JX1))262,264,263                                 LOC 5101
262  GX=GMX(JX1)*CP(TV(K,1))                                 LOC 5102
     ALFA(2)= GX                                             LOC 5103
     ALFA(3)=-GMX(JX1)*HV(TV(K,1))+GX*TV(K,1)                LOC 5104
     GO TO 264                                               LOC 5105
263  GX=GMX(JX1)*CP(TV(K-1,1))                               LOC 5106
     ALFA(1)=GX                                              LOC 5107
     ALFA(3)=-GMX(JX1)*HV(TV(K-1,1))+GX*TV(K-1,1)            LOC 5108
264  IF(GMX(JX2))265,267,266                                 LOC 5109
265  GX=GMX(JX2)*CP(TV(NX2,1))                               LOC 5110
     GAMA(2)=-GX                                             LOC 5111
     GAMA(3)=+GMX(JX2)*HV(TV(NX2,1))-GX*TV(NX2,1)            LOC 5112
     GO TO 267                                               LOC 5113
266  GX=GMX(JX2)*CP(TV(K  ,1))                               LOC 5114
     GAMA(1)=-GX                                             LOC 5115
     GAMA(3)=+GMX(JX2)*HV(TV(K  ,1))-GX*TV(K  ,1)            LOC 5116
267  IF(GMY(JY1))268,270,269                                 LOC 5117
268  GY=GMY(JY1)*CP(TV(K  ,1))                               LOC 5118
     BETA(2)=+GY                                             LOC 5119
```

```
          BETA(3)=-GMY(JY1)*HV(TV(K  ,1))+GY*TV(K  ,1)           LOC 5120
          GO TO 270                                              LOC 5121
    269   BETA(3)=-GMY(JY1)*HV(FTEMP)                            LOC 5122
    270   IF(GMY(JY2))271,999,272                                LOC 5123
    271   GY=GMY(JY2)*CP(TV(NY2,1))                              LOC 5124
          DELT(2)=-GY                                            LOC 5125
          DELT(3)=+GMY(JY2)*HV(TV(NY2,1))-GY*TV(NY2,1)           LOC 5126
          GO TO 999                                              LOC 5127
    272   GY=GMY(JY2)*CP(TV(K  ,1))                              LOC 5128
          DELT(1)=-GY                                            LOC 5129
          DELT(3)=+GMY(JY2)*HV(TV(K,1))-GY*TV(K,1)               LOC 5130
          GO TO 999                                              LOC 5131
C    L=12                                                        LOC 5132
    281   HT=-HC(NX2)*YO/2.                                      LOC 5133
          HTT= HT*TS(NX2,1)                                      LOC 5134
          IF(GMX(JX1))282,284,283                                LOC 5135
    282   GX=GMX(JX1)*CP(TV(K,1))                                LOC 5136
          ALFA(2)=-GX                                            LOC 5137
          ALFA(3)=-GMX(JX1)*HV(TV(K,1))+GX*TV(K,1)               LOC 5138
          GO TO 284                                              LOC 5139
    283   GX=GMX(JX1)*CP(TV(NX1,1))                              LOC 5140
          ALFA(1)=GX                                             LOC 5141
          ALFA(3)=-GMX(JX1)*HV(TV(NX1,1))+GX*TV(NX1,1)           LOC 5142
    284   IF(GMX(JX2))285,287,286                                LOC 5143
    285   GX=GMX(JX2)*CP(TV(K+1,1))                              LOC 5144
          GAMA(2)=-GX                                            LOC 5145
          GAMA(3)=+GMX(JX2)*HV(TV(K+1,1))-GX*TV(K+1,1)           LOC 5146
          GO TO 287                                              LOC 5147
    286   GX=GMX(JX2)*CP(TV(K  ,1))                              LOC 5148
          GAMA(1)=-GX                                            LOC 5149
          GAMA(3)=+GMX(JX2)*HV(TV(K  ,1))-GX*TV(K  ,1)           LOC 5150
    287   IF(GMY(JY1))288,290,289                                LOC 5151
    288   GY=GMY(JY1)*CP(TV(K  ,1))                              LOC 5152
          BETA(2)=+GY                                            LOC 5153
          BETA(3)=-GMY(JY1)*HV(TV(K  ,1))+GY*TV(K  ,1)           LOC 5154
          GO TO 290                                              LOC 5155
    289   GY=GMY(JY1)*CP(TV(NY1,1))                              LOC 5156
          BETA(1)=+GY                                            LOC 5157
          BETA(3)=-GMY(JY1)*HV(TV(NY1,1))+GY*TV(NY1,1)           LOC 5158
    290   IF(GMY(JY2))291,999,292                                LOC 5159
    291   GY=GMY(JY2)*CP(TV(NY2,1))                              LOC 5160
          DELT(2)=-GY                                            LOC 5161
          DELT(3)=+GMY(JY2)*HV(TV(NY2,1))-GY*TV(NY2,1)           LOC 5162
          GO TO 999                                              LOC 5163
    292   GY=GMY(JY2)*CP(TV(K  ,1))                              LOC 5164
          DELT(1)=-GY                                            LOC 5165
          DELT(3)=+GMY(JY2)*HV(TV(K,1))-GY*TV(K,1)               LOC 5166
          GO TO 999                                              LOC 5167
C    L=13                                                        LOC 5168
    301   HT=-HC(NX1)*YO/2.                                      LOC 5169
```

```
      HTT= HT*TS(NX1,1)                                      LOC 5170
      IF(GMX(JX1))302,304,303                                LOC 5171
302   GX=GMX(JX1)*CP(TV(K,1))                                LOC 5172
      ALFA(2)= GX                                            LOC 5173
      ALFA(3)=-GMX(JX1)*HV(TV(K,1))+GX*TV(K,1)               LOC 5174
      GO TO 304                                              LOC 5175
303   GX=GMX(JX1)*CP(TV(K-1,1))                              LOC 5176
      ALFA(1)=GX                                             LOC 5177
      ALFA(3)=-GMX(JX1)*HV(TV(K-1,1))+GX*TV(K-1,1)           LOC 5178
304   IF(GMX(JX2))305,307,306                                LOC 5179
305   GX=GMX(JX2)*CP(TV(NX2,1))                              LOC 5180
      GAMA(2)=-GX                                            LOC 5181
      GAMA(3)=+GMX(JX2)*HV(TV(NX2,1))-GX*TV(NX2,1)           LOC 5182
      GO TO 307                                              LOC 5183
306   GX=GMX(JX2)*CP(TV(K  ,1))                              LOC 5184
      GAMA(1)=-GX                                            LOC 5185
      GAMA(3)=+GMX(JX2)*HV(TV(K  ,1))-GX*TV(K  ,1)           LOC 5186
307   IF(GMY(JY1))308,310,309                                LOC 5187
308   GY=GMY(JY1)*CP(TV(K  ,1))                              LOC 5188
      BETA(2)=+GY                                            LOC 5189
      BETA(3)=-GMY(JY1)*HV(TV(K  ,1))+GY*TV(K  ,1)           LOC 5190
      GO TO 310                                              LOC 5191
309   GY=GMY(JY1)*CP(TV(NY1,1))                              LOC 5192
      BETA(1)=+GY                                            LOC 5193
      BETA(3)=-GMY(JY1)*HV(TV(NY1,1))+GY*TV(NY1,1)           LOC 5194
310   IF(GMY(JY2))311,999,312                                LOC 5195
311   GY=GMY(JY2)*CP(TV(NY2,1))                              LOC 5196
      DELT(2)=-GY                                            LOC 5197
      DELT(3)=+GMY(JY2)*HV(TV(NY2,1))-GY*TV(NY2,1)           LOC 5198
      GO TO 999                                              LOC 5199
312   GY=GMY(JY2)*CP(TV(K  ,1))                              LOC 5200
      DELT(1)=-GY                                            LOC 5201
      DELT(3)=+GMY(JY2)*HV(TV(K,1))-GY*TV(K,1)               LOC 5202
      GO TO 999                                              LOC 5203
C     L=14                                                   LOC 5204
321   HX=HC(NX2)*YO/2.                                       LOC 5205
      HY=HC(NY2)*XO                                          LOC 5206
      HT=-HX-HY                                              LOC 5207
      HTT=-HX*TS(NX2,1)-HY*TS(NY2,1)                         LOC 5208
      IF(GMX(JX1))322,324,323                                LOC 5209
322   GX=GMX(JX1)*CP(TV(K,1))                                LOC 5210
      ALFA(2)= GX                                            LOC 5211
      ALFA(3)=-GMX(JX1)*HV(TV(K,1))+GX*TV(K,1)               LOC 5212
      GO TO 324                                              LOC 5213
323   GX=GMX(JX1)*CP(TV(NX1,1))                              LOC 5214
      ALFA(1)=GX                                             LOC 5215
      ALFA(3)=-GMX(JX1)*HV(TV(NX1,1))+GX*TV(NX1,1)           LOC 5216
324   IF(GMX(JX2))325,327,326                                LOC 5217
325   GX=GMX(JX2)*CP(TV(K+1,1))                              LOC 5218
      GAMA(2)=-GX                                            LOC 5219
```

```
      GAMA(3)=+GMX(JX2)*HV(TV(K+1,1))-GX*TV(K+1,1)                 LOC 5220
      GO TO 327                                                    LOC 5221
326   GX=GMX(JX2)*CP(TV(K  ,1))                                    LOC 5222
      GAMA(1)=-GX                                                  LOC 5223
      GAMA(3)=+GMX(JX2)*HV(TV(K  ,1))-GX*TV(K  ,1)                 LOC 5224
327   IF(GMY(JY1))328,330,329                                      LOC 5225
328   GY=GMY(JY1)*CP(TV(K  ,1))                                    LOC 5226
      BETA(2)=+GY                                                  LOC 5227
      BETA(3)=-GMY(JY1)*HV(TV(K  ,1))+GY*TV(K  ,1)                 LOC 5228
      GO TO 330                                                    LOC 5229
329   GY=GMY(JY1)*CP(TV(NY1,1))                                    LOC 5230
      BETA(1)=+GY                                                  LOC 5231
      BETA(3)=-GMY(JY1)*HV(TV(NY1,1))+GY*TV(NY1,1)                 LOC 5232
330   IF(GMY(JY2))331,999,332                                      LOC 5233
331   DELT(3)=+GMY(JY2)*HV(FTEMP)                                  LOC 5234
      GO TO 999                                                    LOC 5235
332   GY=GMY(JY2)*CP(TV(K  ,1))                                    LOC 5236
      DELT(1)=-GY                                                  LOC 5237
      DELT(3)=GMY(JY2)*HV(TV(K,1))-GY*TV(K,1)                      LOC 5238
      GO TO 999                                                    LOC 5239
C   L=15                                                           LOC 5240
341   HX=HC(NX1)*YO/2.                                             LOC 5241
      HY=HC(NY2)*XO                                                LOC 5242
      HT=-HX-HY                                                    LOC 5243
      HTT=-HX*TS(NX1,1)-HY*TS(NY2,1)                               LOC 5244
      IF(GMX(JX1))342,344,343                                      LOC 5245
342   GX=GMX(JX1)*CP(TV(K,1))                                      LOC 5246
      ALFA(2)= GX                                                  LOC 5247
      ALFA(3)=-GMX(JX1)*HV(TV(K,1))+GX*TV(K,1)                     LOC 5248
      GO TO 344                                                    LOC 5249
343   GX=GMX(JX1)*CP(TV(K-1,1))                                    LOC 5250
      ALFA(1)= GX                                                  LOC 5251
      ALFA(3)=-GMX(JX1)*HV(TV(K-1,1))+GX*TV(K-1,1)                 LOC 5252
344   IF(GMX(JX2))345,347,346                                      LOC 5253
345   GX=GMX(JX2)*CP(TV(NX2,1))                                    LOC 5254
      GAMA(2)=-GX                                                  LOC 5255
      GAMA(3)=+GMX(JX2)*HV(TV(NX2,1))-GX*TV(NX2,1)                 LOC 5256
      GO TO 347                                                    LOC 5257
346   GX=GMX(JX2)*CP(TV(K  ,1))                                    LOC 5258
      GAMA(1)=-GX                                                  LOC 5259
      GAMA(3)=+GMX(JX2)*HV(TV(K  ,1))-GX*TV(K  ,1)                 LOC 5260
347   IF(GMY(JY1))348,350,349                                      LOC 5261
348   GY=GMY(JY1)*CP(TV(K  ,1))                                    LOC 5262
      BETA(2)=GY                                                   LOC 5263
      BETA(3)=-GMY(JY1)*HV(TV(K  ,1))+GY*TV(K  ,1)                 LOC 5264
      GO TO 350                                                    LOC 5265
349   GY=GMY(JY1)*CP(TV(NY1,1))                                    LOC 5266
      BETA(1)=GY                                                   LOC 5267
      BETA(3)=-GMY(JY1)*HV(TV(NY1,1))+GY*TV(NY1,1)                 LOC 5268
350   IF(GMY(JY2))351,999,352                                      LOC 5269
```

```
701 351   DELT(3)=GMY(JY2)*HV(PTEMP)                       LOC 5270
702       GO TO 999                                        LOC 5271
703 352   GY=GMY(JY2)*CP(TV(K  ,1))                        LOC 5272
704       DELT(1)=-GY                                      LOC 5273
705       DELT(3)=GMY(JY2) *HV(TV(K,1))-GY*TV(K,1)         LOC 5274
706 999   LOC=L                                            LOC 5275
707       RETURN                                           LOC 5276
708       END                                              LOC 5277
```

```
      SUBROUTINE CL4                                                    CL4 5278
C     COMPUTION OF TOTAL INTERCHANGE AREA --- REAL GAS                  CL4 5279
C     COMPUTION HAS TWO PARTS                                           CL4 5280
C       HCODE=0     INITAL CALULATION OF GAS VOLUME INTERCHANGE AREAS   CL4 5281
C            =10    UPDATE INTERCHANGE AREAS WITH NEW TEMPERTURES       CL4 5282
C       ICODE=0     INITAL CALULATION OF SURFACE AREA INTERCHANGE AREAS CL4 5283
C            =10    UPDATE INTERCHANGE AREA WITH NEW TEMPERTURES        CL4 5284
      COMMON // DUMMY(3),KK, ICODE, HCODE,                              CL4 5285
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                    CL4 5286
     A TBRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                       CL4 5287
     A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                    CL4 5288
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                     CL4 5289
     A XSURFX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,                     CL4 5290
     A RSTART, TCODE, SCODE, NGRAY, JHCHC,                              CL4 5291
     A K1, K2, RCRD(10), TDEP(100), PERM(200),NPRNT                     CL4 5292
C                                                                       CL4 5293
      INTEGER SCODE,TCODE,RSTART,HCODE                                  CL4 5294
      COMMON/SPCE4/AA( 60, 60),BB( 60,15)                               CL4 5295
      COMMON/JAZZ4/TSSNM(8,4), TGSNM(8,3),TSGNM(8,3),TGGNM(8,3),        CL4 5296
     1SS(8),GS(8),SG(8),GG(8)                                           CL4 5297
      DIMENSION T( 60),Z( 60)                                           CL4 5298
      CALL READ(1,'XLUM',Z(1), 60)                                      CL4 5299
      IJK=HCODE+ICODE                                                   CL4 5300
      IF(IJK.EQ.0)GO TO 11                                              CL4 5301
      IF(HCODE.EQ.10)GO TO 11                                           CL4 5302
      IF(ICODE.EQ.10)GO TO 31                                           CL4 5303
   11 CONTINUE                                                          CL4 5304
      CALL READ(2,'TEMG',T(1), 60)                                      CL4 5305
      CALL WRITE(3,'TEMG',T(1), 60)                                     CL4 5306
C     KK=GAS NUMBER                                                     CL4 5307
C     GAS TO SURFACE INTERCHANGE AREA                                   CL4 5308
      CALL PZERO(AA(1,1), 3600)                                         CL4 5309
      DO 18 KK=1,NGRAY                                                  CL4 5310
      DO 17 J=1,NSGBLK                                                  CL4 5311
      MM=15*(J-1)                                                       CL4 5312
      CALL READ(1,TSGNM(J,KK),BB(1,1), 900)                             CL4 5313
      IF(J.EQ.NSGBLK)GO TO 13                                           CL4 5314
      NMAX=15                                                           CL4 5315
      GO TO 14                                                          CL4 5316
   13 NMAX=NVOL-(NSGBLK-1)*15                                           CL4 5317
   14 DO 16 N=1,NMAX                                                    CL4 5318
      M=MM+N                                                            CL4 5319
      ZZ=EXP(EQUA(T(M)/1000.,ACOEF(1,KK)))*Z(M)                         CL4 5320
      DO 15 L=1,NSURF                                                   CL4 5321
      AA(L,M)=AA(L,M)+BB(L,N)*ZZ                                        CL4 5322
   15 CONTINUE                                                          CL4 5323
   16 CONTINUE                                                          CL4 5324
   17 CONTINUE                                                          CL4 5325
   18 CONTINUE                                                          CL4 5326
      DO 19 J=1,NSGBLK                                                  CL4 5327
```

```
         CALL WRITE(2,SG(J),AA(1,15*J-14), 900)                           CL4 5328
   19    CONTINUE                                                         CL4 5329
   6000  IF(NPRNT.EQ.1)GO TO 22                                           CL4 5330
         WRITE(K2,5001)(T(N),N=1,NVOL)                                    CL4 5331
   5001  FORMAT(1H1,19X,'GAS VOLUME TEMPERATURES USED IN EVALUATION OF GAS CL4 5332
        1VOLUMES'/20X,'TEMPERTURE DEPENDENT INTERCHANGE AREA,DEG. R'//(25X,CL4 5333
        26F15.3))                                                         CL4 5334
         WRITE(K2,6001)                                                   CL4 5335
   6001  FORMAT(/'1 ',20X,'VOLUME TO SURFACE INTERCHANGE AREA')           CL4 5336
         CALL PRINT(AA,NSURF,NVOL)                                        CL4 5337
   C      GAS TO GAS INTERCHANGE AREA                                     CL4 5338
   22    CALL PZERO(AA(1,1), 3600)                                        CL4 5339
         DO 28 KK=1,NGRAY                                                 CL4 5340
         DO 27 J=1,NGGBLK                                                 CL4 5341
         MM=15*(J-1)                                                      CL4 5342
         CALL READ(1,TGGMM(J,KK),BB(1,1), 900)                            CL4 5343
         IF(J.EQ.NGGBLK)GO TO 23                                          CL4 5344
         NMAX=15                                                          CL4 5345
         GO TO 24                                                         CL4 5346
   23    NMAX=NVOL-(NGGBLK-1)*15                                          CL4 5347
   24    DO 26 N=1,NMAX                                                   CL4 5348
         M=MM+N                                                           CL4 5349
         ZZ=EXP(EQUA(T(M)/1000.,ACOEF(1,KK)))*Z(M)                        CL4 5350
         DO 25 L=1,NVOL                                                   CL4 5351
         AA(L,M)=AA(L,M)+BB(L,N)*ZZ*Z(L)                                  CL4 5352
   25    CONTINUE                                                         CL4 5353
   26    CONTINUE                                                         CL4 5354
   27    CONTINUE                                                         CL4 5355
   28    CONTINUE                                                         CL4 5356
            DO 29 J=1,NGGBLK                                              CL4 5357
         CALL WRITE(2,GG(J),AA(1,15*J-14), 900)                           CL4 5358
   29    CONTINUE                                                         CL4 5359
         IF(NPRNT.EQ.1)GO TO 30                                           CL4 5360
   6010  WRITE(K2,6002)                                                   CL4 5361
   6002  FORMAT(/'1 ',20X,'VOLUME TO VOLUME INTERCHANGE AREA')            CL4 5362
         CALL PRINT(AA,NVOL,NVOL)                                         CL4 5363
   30    CONTINUE                                                         CL4 5364
         IF(IJK.EQ.0)GO TO 31                                             CL4 5365
         GO TO 67                                                         CL4 5366
   C    PART 2   SURFACE AREA TEMPERTATURE DEPENDENT                      CL4 5367
   31    CALL READ(2,'TEMS',T(1), 60)                                     CL4 5368
         CALL WRITE(3,'TEMS',T(1), 60)                                    CL4 5369
   C    SURFACE TO SURFACE INTERCHANGE AREA                               CL4 5370
   C    KK=GAS NUMBER                                                     CL4 5371
         CALL PZERO(AA(1,1), 3600)                                        CL4 5372
         KMAX=1+NGRAY                                                     CL4 5373
         DO 45 K=1,KMAX                                                   CL4 5374
         IF(K.EQ.KMAX)GO TO 33                                            CL4 5375
         KK=K                                                             CL4 5376
         GO TO 34                                                         CL4 5377
```

```
 33      KK=4                                                        CL4 5378
 34      DO 44 J=1,NSSBLK                                            CL4 5379
         MM=15*(J-1)                                                 CL4 5380
         CALL READ(1,TSSNH(J,KK),BB(1,1), 900)                       CL4 5381
         IF(J.EQ.NSSBLK)GO TO 36                                     CL4 5382
         NMAX=15                                                     CL4 5383
         GO TO 37                                                    CL4 5384
 36      NMAX=NSURF-(NSSBLK-1)*15                                    CL4 5385
 37      DO 43 N=1,NMAX                                              CL4 5386
         M=MM+N                                                      CL4 5387
         IF(KK.EQ.4)GO TO 38                                         CL4 5388
         ZZ=EXP(EQUA(T(M)/1000.,ACOEF(1,KK)))                        CL4 5389
         GO TO 41                                                    CL4 5390
 38      ZZ=1.                                                       CL4 5391
         DO 40 I=1,NGRAY                                             CL4 5392
         ZZ=ZZ-EXP(EQUA(T(M)/1000.,ACOEF(1,I)))                      CL4 5393
 40      CONTINUE                                                    CL4 5394
 41      DO 42 L=1,NSURF                                             CL4 5395
         AA(L,M)=AA(L,M)+BB(L,N)*ZZ                                  CL4 5396
 42      CONTINUE                                                    CL4 5397
 43      CONTINUE                                                    CL4 5398
 44      CONTINUE                                                    CL4 5399
 45      CONTINUE                                                    CL4 5400
         DO 47 J=1,NSSBLK                                            CL4 5401
         CALL WRITE(2,SS(J),AA(1,15*J-14), 900)                      CL4 5402
 47      CONTINUE                                                    CL4 5403
 7000    IF(NPRNT.EQ.1)GO TO 52                                      CL4 5404
         WRITE(K2,5002)(T(N),N=1,NSURF)                              CL4 5405
 5002    FORMAT(1H119X,'SURFACE AREA TEMPERTURE USED IN EVALUATING SURFACE CL4 5406
        1AREA'/20X,'TEMPERTURE DEPENDENT INTERCHANGE AREA,DEG R'//(25X,6F15CL4 5407
        2.3))                                                        CL4 5408
         WRITE(K2,7001)                                              CL4 5409
 7001    FORMAT(/'1 ',20X,'SURFACE TO SURFACE INTERCHANGE AREA')     CL4 5410
         CALL PRINT(AA,NSURF,NSURF)                                  CL4 5411
 C     SURFACE TO SURFACE INTERCHANGE AREA                           CL4 5412
 C     KK=GAS NUMBER                                                 CL4 5413
 52      CALL PZERO(AA(1,1), 3600)                                   CL4 5414
         DO 58 KK=1,NGRAY                                            CL4 5415
         DO 57 J=1,NGSBLK                                            CL4 5416
         MM=(J-1)*15                                                 CL4 5417
         CALL READ(1,TGSNH(J,KK),BB(1,1), 900)                       CL4 5418
         IF(J.EQ.NGSBLK)GO TO 53                                     CL4 5419
         NMAX=15                                                     CL4 5420
         GO TO 54                                                    CL4 5421
 53      NMAX=NSURF-(NGSBLK-1)*15                                    CL4 5422
 54      DO 56 N=1,NMAX                                              CL4 5423
         M=MM+N                                                      CL4 5424
         ZZ=EXP(EQUA(T(M)/1000.,ACOEF(1,KK)))                        CL4 5425
         DO 55 L=1,NVOL                                              CL4 5426
         AA(L,M)=AA(L,M)+BB(L,N)*ZZ*Z(L)                             CL4 5427
```

```
55    CONTINUE                                              CL4 5428
56    CONTINUE                                              CL4 5429
57    CONTINUE                                              CL4 5430
58    CONTINUE                                              CL4 5431
      DO 59 J=1,NGSBLK                                      CL4 5432
      CALL WRITE(2,GS(J),AA(1,15*J-14), 900)                CL4 5433
59    CONTINUE                                              CL4 5434
      IF(NPRNT.EQ.1)GO TO 67                                CL4 5435
7010  WRITE(K2,7011)                                        CL4 5436
7011  FORMAT(//1 1,20X,'SURFACE TO VOLUME INTERCHANGE AREA')  CL4 5437
      CALL PRINT(AA,NVOL,NSURF)                             CL4 5438
67    RETURN                                                CL4 5439
      END                                                   CL4 5440
```

```
      SUBROUTINE CL5                                                  CL5 5441
C     GAS VOLUME HEAT BALANCE                                         CL5 5442
      COMMON // DUMMY(3),KK, ICODE, HCODE,                            CL5 5443
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                  CL5 5444
     A TBRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                     CL5 5445
     A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                  CL5 5446
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                   CL5 5447
     A XSUREX(2), XO, YO, ZLCNG, NCOL, NROW, NXSXN,                   CL5 5448
     A RSTART, TCODE, SCODE, NGRAY, JHCHC,                            CL5 5449
     A K1, K2, RCRD(10), TDEP(100), PERM(200),NPRNT                   CL5 5450
C                                                                     CL5 5451
      INTEGER SCODE,TCODE,RSTART,HCODE                                CL5 5452
      EQUIVALENCE (DUMMY(1),NFMAX),(PERM(199),DHTCL5)                 CL5 5453
      COMMON/GAS/ NX1,NX2,NY1,NY2,HT,HTT,XTEST,ALFA(3),BETA(3),GAMA(3), CL5 5454
     1DELT(3),GMX(120),GMY(120),HC( 60),JX1,JX2,JY1,JY2               CL5 5455
      COMMON/TTT/TV(120,2),TS(120,2)                                  CL5 5456
      COMMON/JAZZ5/ GS(8),SG(8),GG(8)                                 CL5 5457
      COMMON/CPHV/CPCP(11),HVHV(12)                                   CL5 5458
      DIMENSION AA( 60, 60),RHS( 60),AAA( 60, 61),ET( 60),ZZ( 60),MM( 60CL5 5459
     1)                                                               CL5 5460
      EQUIVALENCE (AA(1,1),AAA(1,1)),(RHS(1),AAA(1, 61)),(ZZ(1),MM(1))  CL5 5461
      DATA SIG /0.1713E-8/                                            CL5 5462
      HCODE=1                                                         CL5 5463
      NFIX=0                                                          CL5 5464
      XTEST=.10*XD                                                    CL5 5465
C     RETRIEVE DATA                                                   CL5 5466
C       SURFACE AND VOLUME TEMPERATURES                               CL5 5467
C      HEAT RELEASE PATTERN                                           CL5 5468
C     BULK FLOW PATTERN                                               CL5 5469
C     GAS --- SURFACE HEAT TRANSFER COEFFICIENT                       CL5 5470
      CALL READ(2,'TEMG',TV(1,1), 60)                                 CL5 5471
      CALL READ(2,'TEMS',TS(1,1), 60)                                 CL5 5472
      CALL READ(2,'HGAS',ET(1), 60)                                   CL5 5473
      NX=(NCOL+1)*NROW                                                CL5 5474
      NY=(NROW+1)*NCOL                                                CL5 5475
      CALL READ(2,'GMY ',GMY(1),  NY)                                 CL5 5476
      CALL READ(2,'GMX ',GMX(1),    NX)                               CL5 5477
      CALL READ(2,'HC  ',HC(1), 60)                                   CL5 5478
      CALL READ(2,'CP  ',CPCP(1),11)                                  CL5 5479
      CALL READ(2,'HV  ',HVHV(1),12)                                  CL5 5480
C     COMPUTE TEMPERATURE FACTORS (T**3 ANDT**4)                      CL5 5481
      DO 4 J=1,NSURF                                                  CL5 5482
      TS(J,2)=TS(J,1)**3                                              CL5 5483
    4 CONTINUE                                                        CL5 5484
   10 DO 11 J=1,NVOL                                                  CL5 5485
      TV(J,2)=TV(J,1)**3                                              CL5 5486
   11 CONTINUE                                                        CL5 5487
C     PUT SURFACE TO GAS INTERCHANGE AREA IN AA                       CL5 5488
      CALL PZERO(AA(1,1), 3600)                                       CL5 5489
      DO 15 J=1,NGSBLK                                                CL5 5490
```

```
      CALL READ(2,GS(J),AA(1,15*J-14), 900)                          CL5 5491
   15 CONTINUE                                                       CL5 5492
C   COMPUTE S-G CONTRIBUTION TO RHS --- SUM OVER SURFACE EMITTER FOR CL5 5493
C   EACH GAS RECEIVER ACCOUNTING FOR TEMPERATURE OF EMITTER          CL5 5494
      DO 17 I=1,NVOL                                                 CL5 5495
      RHS(I)=0.0                                                     CL5 5496
      DO 16 J=1,NSURF                                                CL5 5497
      RHS(I)=RHS(I)+AA(I,J)*TS(J,2)                                  CL5 5498
   16 CONTINUE                                                       CL5 5499
      RHS(I)=RHS(I)*(-SIG)                                           CL5 5500
   17 CONTINUE                                                       CL5 5501
C   PUT GAS TO SURFACE AREA IN AA                                    CL5 5502
      CALL PZERO(AA(1,1), 3600)                                      CL5 5503
      DO 23 J=1,NSGBLK                                               CL5 5504
      CALL READ(2,SG(J),AA(1,15*J-14), 900)                          CL5 5505
   23 CONTINUE                                                       CL5 5506
C   COMPUTE G-S CONTRIBUTION TO DIAGONAL OF MATRIX AA AND SAVE IN    CL5 5507
C   TEMPERARY STORAGE -- SUM OVER SURFACE RECEIVER FOR EACH GAS      CL5 5508
C   EMITTER AND STORE IN ZZ                                          CL5 5509
      DO 25 J=1,NVOL                                                 CL5 5510
      ZZ(J)=0.0                                                      CL5 5511
      DO 24 I=1,NSURF                                                CL5 5512
      ZZ(J)=ZZ(J)+AA(I,J)                                            CL5 5513
   24 CONTINUE                                                       CL5 5514
   25 CONTINUE                                                       CL5 5515
C   PUT G-G TOTAL INTERCHANGE AREA IN AA                             CL5 5516
      CALL PZERO(AA(1,1), 3600)                                      CL5 5517
      DO 27 J=1,NGGBLK                                               CL5 5518
      CALL READ(2,GG(J),AA(1,15*J-14), 900)                          CL5 5519
   27 CONTINUE                                                       CL5 5520
C   COMPUTE G-G CONTRIBUTION TO DIAGONAL OF MATRIX AA AND SAVE IN    CL5 5521
C   TEMPERARY STORAGE ALONG WITH G-S CONTRIBUTIONS -- SUM OVER GAS   CL5 5522
C   RECEIVER FOR EACH GAS EMITTER AND ADD IN TEMPORARY STORAGE    ZZ CL5 5523
C   WHEN FINISHED MULTIPLY BY MINUS SIGMA                            CL5 5524
      DO 29 J=1,NVOL                                                 CL5 5525
      DO 28 I=1,NVOL                                                 CL5 5526
      ZZ(J)=ZZ(J)+AA(I,J)                                            CL5 5527
   28 CONTINUE                                                       CL5 5528
      ZZ(J)=ZZ(J)*(-SIG)                                             CL5 5529
   29 CONTINUE                                                       CL5 5530
C   MULTIPLY AA BY SIMGA                                             CL5 5531
      DO 32 J=1,NVOL                                                 CL5 5532
      DO 31 I=1,NVOL                                                 CL5 5533
      AA(I,J)=AA(I,J)*SIG                                            CL5 5534
   31 CONTINUE                                                       CL5 5535
   32 CONTINUE                                                       CL5 5536
C   EACH GAS VOLUME MUST BE ANALYED INDIVDUALLY TO DERTERMINE        CL5 5537
C   CONVECTIVE HEAT TRANSFER TERMS                                   CL5 5538
C      1 -- BULK FLOW ADJACENT SURFACE AND VOLUMES                   CL5 5539
C      2 -- SURFACE HEAT TRANSFER INTO GAS VOLUME                    CL5 5540
```

```
       I=1                                                            CL5 5541
 50    LL=LOC(I)                                                      CL5 5542
       AA(I,I)=AA(I,I)+(HT+ALFA(2)+BETA(2)+GAMA(1)+DELT(1))/TV(I,2)+ZZ(I)CL5 5543
       RHS(I)=RHS(I)+(HTT+ALFA(3)+BETA(3)+GAMA(3)+DELT(3))=ET(I)      CL5 5544
       GO TO(51,52,53,54,55,56,57,58,59,510,511,512,513,514,515),LL   CL5 5545
C      LL=1                                                           CL5 5546
 51    AA(I,NX2)=AA(I,NX2)+GAMA(2)/TV(NX2,2)                          CL5 5547
       AA(I,NY2)=AA(I,NY2)+DELT(2)/TV(NY2,2)                          CL5 5548
       GO TO 60                                                       CL5 5549
C      LL=2                                                           CL5 5550
 52    AA(I,NX1)=AA(I,NX1)+ALFA(1)/TV(NX1,2)                          CL5 5551
       AA(I,NX2)=AA(I,NX2)+GAMA(2)/TV(NX2,2)                          CL5 5552
       AA(I,NY2)=AA(I,NY2)+DELT(2)/TV(NY2,2)                          CL5 5553
       GO TO 60                                                       CL5 5554
C      LL=3                                                           CL5 5555
 53    AA(I,NX1)=AA(I,NX1)+ALFA(1)/TV(NX1,2)                          CL5 5556
       AA(I,NY2)=AA(I,NY2)+DELT(2)/TV(NY2,2)                          CL5 5557
       GO TO 60                                                       CL5 5558
C      LL=4                                                           CL5 5559
 54    AA(I,NX2)=AA(I,NX2)+GAMA(2)/TV(NX2,2)                          CL5 5560
       AA(I,NY1)=AA(I,NY1)+BETA(1)/TV(NY1,2)                          CL5 5561
       AA(I,NY2)=AA(I,NY2)+DELT(2)/TV(NY2,2)                          CL5 5562
       GO TO 60                                                       CL5 5563
C      LL=5                                                           CL5 5564
 55    AA(I,NX1)=AA(I,NX1)+ALFA(1)/TV(NX1,2)                          CL5 5565
       AA(I,NX2)=AA(I,NX2)+GAMA(2)/TV(NX2,2)                          CL5 5566
       AA(I,NY1)=AA(I,NY1)+BETA(1)/TV(NY1,2)                          CL5 5567
       AA(I,NY2)=AA(I,NY2)+DELT(2)/TV(NY2,2)                          CL5 5568
       GO TO 60                                                       CL5 5569
C      LL=6                                                           CL5 5570
 56    AA(I,NX1)=AA(I,NX1)+ALFA(1)/TV(NX1,2)                          CL5 5571
       AA(I,NY1)=AA(I,NY1)+BETA(1)/TV(NY1,2)                          CL5 5572
       AA(I,NY2)=AA(I,NY2)+DELT(2)/TV(NY2,2)                          CL5 5573
       GO TO 60                                                       CL5 5574
C      LL=7                                                           CL5 5575
 57    AA(I,NX2)=AA(I,NX2)+GAMA(2)/TV(NX2,2)                          CL5 5576
       AA(I,NY1)=AA(I,NY1)+BETA(1)/TV(NY1,2)                          CL5 5577
       GO TO 60                                                       CL5 5578
C      LL=8                                                           CL5 5579
 58    AA(I,NX1)=AA(I,NX1)+ALFA(1)/TV(NX1,2)                          CL5 5580
       AA(I,NX2)=AA(I,NX2)+GAMA(2)/TV(NX2,2)                          CL5 5581
       AA(I,NY1)=AA(I,NY1)+BETA(1)/TV(NY1,2)                          CL5 5582
       GO TO 60                                                       CL5 5583
C      LL=9                                                           CL5 5584
 59    AA(I,NX1)=AA(I,NX1)+ALFA(1)/TV(NX1,2)                          CL5 5585
       AA(I,NY1)=AA(I,NY1)+BETA(1)/TV(NY1,2)                          CL5 5586
       GO TO 60                                                       CL5 5587
C      LL=10                                                          CL5 5588
 510   AA(I,NX1)=AA(I,NX1)+ALFA(1)/TV(NX1,2)                          CL5 5589
       AA(I,I+1)=AA(I,I+1)+GAMA(2)/TV(I+1,2)                          CL5 5590
```

```
          AA(I,NY2)=AA(I,NY2)+DELT(2)/TV(NY2,2)                     CL5 5591
          GO TO 60                                                  CL5 5592
C     LL=11                                                         CL5 5593
    511   AA(I,I-1)=AA(I,I-1)+ALFA(1)/TV(I-1,2)                     CL5 5594
          AA(I,NX2)=AA(I,NX2)+GAMA(2)/TV(NX2,2)                     CL5 5595
          AA(I,NY2)=AA(I,NY2)+DELT(2)/TV(NY2,2)                     CL5 5596
          GO TO 60                                                  CL5 5597
C     LL=12                                                         CL5 5598
    512   AA(I,NX1)=AA(I,NX1)+ALFA(1)/TV(NX1,2)                     CL5 5599
          AA(I,I+1)=AA(I,I+1)+GAMA(2)/TV(I+1,2)                     CL5 5600
          AA(I,NY1)=AA(I,NY1)+BETA(1)/TV(NY1,2)                     CL5 5601
          AA(I,NY2)=AA(I,NY2)+DELT(2)/TV(NY2,2)                     CL5 5602
          GO TO 60                                                  CL5 5603
C     LL=13                                                         CL5 5604
    513   AA(I,I-1)=AA(I,I-1)+ALFA(1)/TV(I-1,2)                     CL5 5605
          AA(I,NX2)=AA(I,NX2)+GAMA(2)/TV(NY2,2)                     CL5 5606
          AA(I,NY1)=AA(I,NY1)+BETA(1)/TV(NY1,2)                     CL5 5607
          AA(I,NY2)=AA(I,NY2)+DELT(2)/TV(NY2,2)                     CL5 5608
          GO TO 60                                                  CL5 5609
C     LL=14                                                         CL5 5610
    514   AA(I,NX1)=AA(I,NX1)+ALFA(1)/TV(NX1,2)                     CL5 5611
          AA(I,I+1)=AA(I,I+1)+GAMA(2)/TV(I+1,2)                     CL5 5612
          AA(I,NY1)=AA(I,NY1)+BETA(1)/TV(NY1,2)                     CL5 5613
          GO TO 60                                                  CL5 5614
C     LL=15                                                         CL5 5615
    515   AA(I,I-1)=AA(I,I-1)+ALFA(1)/TV(I-1,2)                     CL5 5616
          AA(I,NX2)=AA(I,NX2)+GAMA(2)/TV(NX2,2)                     CL5 5617
          AA(I,NY1)=AA(I,NY1)+BETA(1)/TV(NY1,2)                     CL5 5618
     60   IF(I.EQ.NVOL)GO TO 61                                     CL5 5619
          I=I+1                                                     CL5 5620
          GO TO 50                                                  CL5 5621
C     FOR VOLUMES WITH KNOWED TEMPERATURE SET DIAGONAL OF AA EQUAL TO  CL5 5622
C     1.0 AND RHS=T**4                                              CL5 5623
     61   CALL READ(2,'CONV',MM(1), 60)                             CL5 5624
          DO 63 I=1,NVOL                                            CL5 5625
          IF(MM(I).EQ.0)GO TO 63                                    CL5 5626
          DO 62 J=1,NVOL                                            CL5 5627
          AA(I,J)=0.0                                               CL5 5628
     62   CONTINUE                                                  CL5 5629
          AA(I,I)=1.                                                CL5 5630
          RHS(I)=TV(I,1)**4                                         CL5 5631
     63   CONTINUE                                                  CL5 5632
C     SOLVE FOR TEMPERATURE OF GAS VOLUME RAISED TO THE FORTH POWER AND  CL5 5633
C     THAN EXTRACT THE FOURTH ROOT                                  CL5 5634
          N=NVOL+1                                                  CL5 5635
          DO 67 I=1,NVOL                                            CL5 5636
          AAA(I,N)=RHS(I)                                           CL5 5637
     67   CONTINUE                                                  CL5 5638
          IF(NPRNT.EQ.1)GO TO 681                                   CL5 5639
    671   WRITE(K2,6000)                                            CL5 5640
```

```
6000 FORMAT(1H1,19X,'GAS VOLUME ENERGY   BALANCE')             CL5 5641
     CALL PRINT(AAA,NVOL,N)                                     CL5 5642
681  CALL ISIMEQ(AAA, 60, 61,NVOL)                              CL5 5643
     DT=0.0                                                     CL5 5644
     DO 69 I=1,NVOL                                             CL5 5645
     RHS(I)=SQRT(SQRT(AAA(I,N)))                                CL5 5646
     DT=AMAX1(ABS(RHS(I)-TV(I,1)),DT)                           CL5 5647
     DEL=RHS(I)-TV(I,1)                                         CL5 5648
     TV(I,1)=TV(I,1)+SIGN(AMIN1(ABS(DEL),250.0),DEL)            CL5 5649
69   CONTINUE                                                   CL5 5650
71   NFIX=NFIX+1                                                CL5 5651
     IF(DT.LT.5.*DHTCL5.OR.NFIX.EQ.NFMAX)GO TO 81               CL5 5652
     IF(DT.LT.250.)GO TO 10                                     CL5 5653
     GO TO 85                                                   CL5 5654
C   COMPARE TEMPERATURES OBTAINED FROM GAS VOLUME HEAT BALANCE WITH   CL5 5655
C   THOSE USED IN OBTAINING GAS VOLUME TEMPERATURE DEPENDENT   CL5 5656
C   INTERCHANGE AREA (G-G AND G-S                               CL5 5657
81   CALL READ(3,'TEMG',ZZ(1), 60)                              CL5 5658
     DT=0.0                                                     CL5 5659
     DO 82 I=1,NVOL                                             CL5 5660
     DT=AMAX1(ABS(ZZ(I)-TV(I,1)) ,DT)                           CL5 5661
82   CONTINUE                                                   CL5 5662
     IF(DT.LT.DHTCL5)ICODE=2                                    CL5 5663
85   CALL WRITE(2,'TEMG',TV(1,1), 60)                           CL5 5664
     WRITE(6,3003)DT                                            CL5 5665
     IF(NPRNT.EQ.1)GO TO 86                                     CL5 5666
     WRITE(K2,3002) (TV(N,1),N=1,NVOL)                          CL5 5667
3002 FORMAT(//20X,'COMPUTED GAS VOLUME TEMPERATURES,DEG.R'//(25X,6F15.3CL5 5668
    1))                                                         CL5 5669
3003 FORMAT(20X,'MAX TEMPERATURE DIFFERENCE FOUND IN COMPUTING GAS VOLUCL5 5670
    1ME',F10.3)                                                 CL5 5671
86   RETURN                                                     CL5 5672
     END                                                        CL5 5673
```

```
          SUBROUTINE CL6                                               CL6 5674
    C   SURFACE AREA HEAT BALANCE                                      CL6 5675
          COMMON // DUMMY(3),KK, ICODE, HCODE,                         CL6 5676
         A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),               CL6 5677
         A TBRIDG, PRES, FLUET, FLUE(5), XMWX, TSINK,                  CL6 5678
         A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, ETEMP,               CL6 5679
         A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                CL6 5680
         A XSUREX(3), XD, YD, ZLONG, NCOL, NROW, NXSXN,                CL6 5681
         A RSTART, TCODE, SCODE, NGRAY, JHCHC,                         CL6 5682
         A K1, K2, RCED(10), TOEP(100), PERM(200),NPRNT                CL6 5683
    C                                                                  CL6 5684
          INTEGER SCODE,TCODE,RSTART,HCODE                             CL6 5685
          EQUIVALENCE (DUMMY(2),NFMAX),(PERM(200),DHTCL6)              CL6 5686
          COMMON/JAZZ6/ SG(8),GS(8),SS(8)                              CL6 5687
          DIMENSION AA( 60, 60),RHS( 60),AAA( 60, 61),ET( 60),ZZ( 60),MM( 60CL6 5688
         1),TV( 60,2),TS( 60,2),TP( 60),HC( 60,3)                      CL6 5689
          EQUIVALENCE (AA(1,1),AAA(1,1)),(RHS(1),AAA(1, 61)),(ZZ(1),MM(1)) CL6 5690
          DATA SIG /0.1713E-8/                                         CL6 5691
          ICODE=1                                                      CL6 5692
          NFIX=0                                                       CL6 5693
    C   RETRIEVE DATA                                                  CL6 5694
    C   SURFACE VOLUME AND PROCESS TEMPERATURES                        CL6 5695
    C      HEAT RELEASE PATTERN                                        CL6 5696
    C      ALL THREE HEAT TRANSFER COEFFICIENTS                        CL6 5697
          CALL READ(2,'TEMG',TV(1,1), 60)                              CL6 5698
          CALL READ(2,'TEMS',TS(1,1), 60)                              CL6 5699
          CALL READ(2,'TEMP',TP(1), 60)                                CL6 5700
          CALL READ(2,'HSUF',ET(1), 60)                                CL6 5701
          CALL READ(2,'HC  ',HC(1,1), 60)                              CL6 5702
          CALL READ(2,'HCP ',HC(1,2), 60)                              CL6 5703
          CALL READ(2,'HCPP',HC(1,3), 60)                              CL6 5704
    C   COMPUTE TEMPERATURE FACTORS (T**3 AND T**4)                    CL6 5705
          DO 8 J=1,NVOL                                                CL6 5706
          TV(J,2)=TV(J,1)**4                                           CL6 5707
    8     CONTINUE                                                     CL6 5708
    10    DO 11 J=1,NSURF                                              CL6 5709
          TS(J,2)=TS(J,1)**3                                           CL6 5710
    11    CONTINUE                                                     CL6 5711
    C     PUT GAS TO SURFACE INTERCHANGE AREA IN AA                    CL6 5712
          CALL  PZERO(AA(1,1), 3600)                                   CL6 5713
          DO 13 J=1,NSGBLK                                             CL6 5714
          CALL READ(2,SG(J),AA(1,15*J-14), 900)                        CL6 5715
    13    CONTINUE                                                     CL6 5716
    C   COMPUTE G-S CONTRIBUTION TO RHS -- SUM OVER GAS EMITTER FOR EACH CL6 5717
    C   SURFACE RECEIVER ACCOUNTING FOR TEMPERATURE OF EMITTER         CL6 5718
          DO 16 I=1,NSURF                                              CL6 5719
          RHS(I)=0.0                                                   CL6 5720
          DO 15 J=1,NVOL                                               CL6 5721
          RHS(I)=RHS(I)+AA(I,J)*TV(J,2)                                CL6 5722
    15    CONTINUE                                                     CL6 5723
```

```
         RHS(I)=RHS(I)*(-SIG)                                       CL6 5724
   16    CONTINUE                                                   CL6 5725
C     PUT SURFACE TO GAS INTERCHANGE AREA IN AA                     CL6 5726
         CALL PZERO(AA(1,1), 3600)                                  CL6 5727
         DO 21 J=1,NGSBLK                                           CL6 5728
         CALL READ(2,GS(J),AA(1,15*J-14), 900)                      CL6 5729
   21    CONTINUE                                                   CL6 5730
C     COMPUTE S-G CONTRIBUTIONS TO DIAGONAL OF MATRIX AA AND SAVE IN CL6 5731
C     TEMPORARY STORAGE -- SUM OVER GAS RECEIVER FOR EACH SURFACE EMITTER CL6 5732
C     AND STORE IN ZZ                                               CL6 5733
         DO 23 J=1,NSURF                                            CL6 5734
         ZZ(J)=0.0                                                  CL6 5735
         DO 22 I=1,NVOL                                             CL6 5736
         ZZ(J)=ZZ(J)+AA(I,J)                                        CL6 5737
   22    CONTINUE                                                   CL6 5738
   23    CONTINUE                                                   CL6 5739
C     PUT SURFACE TO SURFACE INTERCHANGE AREA IN AA                 CL6 5740
         CALL PZERO(AA(1,1), 3600)                                  CL6 5741
         DO 27 J=1,NSSBLK                                           CL6 5742
         CALL READ(2,SS(J),AA(1,15*J-14), 900)                      CL6 5743
   27    CONTINUE                                                   CL6 5744
C     COMPUTE S-S CONTRIBUTION TO DIAGONAL OF MATRIX AA AND SAVE IN CL6 5745
C     TEMPORARY STORAGE ALONG WITH S-G CONTRIBUTION -- SUM OVER SURFACE CL6 5746
C     RECEIVER FOR EACH SURFACE EMITTER AND STORE IN ZZ , WHEN      CL6 5747
C     FINISHED MULTIPLY BY MINUS SIGMA                              CL6 5748
         DO 29 J=1,NSURF                                            CL6 5749
         DO 28 I=1,NSURF                                            CL6 5750
         ZZ(J)=ZZ(J)+AA(I,J)                                        CL6 5751
   28    CONTINUE                                                   CL6 5752
         ZZ(J)=ZZ(J)*(-SIG)                                         CL6 5753
   29    CONTINUE                                                   CL6 5754
C     MULTIPLY AA THROUGH BY SIGMA                                  CL6 5755
         DO 37 J=1,NSURF                                            CL6 5756
         DO 36 I=1,NSURF                                            CL6 5757
         AA(I,J)=AA(I,J)*SIG                                        CL6 5758
   36    CONTINUE                                                   CL6 5759
   37    CONTINUE                                                   CL6 5760
C     COMPLETE MATRIX AND RHS IN TWO STEPS                          CL6 5761
C       1 -- RADIANT AND SOURCE TERMS                               CL6 5762
C       2 -- CONVECTIVE TERMS                                       CL6 5763
         DO 38 I=1,NSURF                                            CL6 5764
         AA(I,I)=AA(I,I)+ZZ(I)                                      CL6 5765
         RHS(I)=RHS(I)-ET(I)                                        CL6 5766
   38    CONTINUE                                                   CL6 5767
         DO49 I=1,NSURF                                             CL6 5768
         CALL IGAS(I,K,I1,I2)                                       CL6 5769
         IF(I.GT.2*NCOL)GO TO 39                                    CL6 5770
         XY=XO                                                      CL6 5771
         GO TO 46                                                   CL6 5772
   39    XY=YO                                                      CL6 5773
```

```
 46      GO TO (47,48),K                                               CL6 5774
 C    K=1 ----- OUTTER SURFACE                                         CL6 5775
 47      AA(I,I)=AA(I,I)-(HC(I,1)+HC(I,2)+HC(I,3))*XY/TS(I,2)          CL6 5776
         RHS(I)=RHS(I)-(HC(I,1)*TV(I1,1)+HC(I,2)*TP(I)+HC(I,3)*TSINK)*XY CL6 5777
         GO TO 49                                                      CL6 5778
 C    K=2 ------- INNER SURFACE                                        CL6 5779
 48      AA(I,I)=AA(I,I)-(HC(I,1)+HC(I,2))*XY/TS(I,2)                  CL6 5780
         RHS(I)=RHS(I)-(HC(I,1)*(TV(I1,1)+TV(I2,1))/2.+HC(I,2)*TP(I))*XY CL6 5781
 49      CONTINUE                                                      CL6 5782
 C    FOR SURFACES WITH KNOWNE TEMPERATURE SET DIAGONAL OF AA EQUAL TO  CL6 5783
 C    1.0 AND RHS EQUAL TO TS**4                                       CL6 5784
         CALL READ(2,'CONS',MM(1), 60)                                 CL6 5785
         DO 54 I=1,NSURF                                               CL6 5786
         IF(MM(I).EQ.0)GO TO 54                                        CL6 5787
         DO 53 J=1,NSURF                                               CL6 5788
         AA(I,J)=0.0                                                   CL6 5789
 53      CONTINUE                                                      CL6 5790
         AA(I,I)=1.                                                    CL6 5791
         RHS(I)=TS(I,1)**4                                             CL6 5792
 54      CONTINUE                                                      CL6 5793
 C    SOLVE FOR TEMPERATURE OF SURFACES ARE RAISED TO THE FOURTH POWER ANDCL6 5794
 C    THEN EXTRACT THE FOURTH ROOT                                     CL6 5795
         N=NSURF+1                                                     CL6 5796
         DO 56 I=1,NSURF                                               CL6 5797
         AAA(I,N)=RHS(I)                                               CL6 5798
 56      CONTINUE                                                      CL6 5799
         IF(NPRNT.EQ.1)GO TO 581                                       CL6 5800
 571     WRITE(K2,6000)                                                CL6 5801
 6000    FORMAT('1',19X,'SURFACE AREA ENERGY BALANCE')                 CL6 5802
         CALL PRINT(AAA,NSURF,N)                                       CL6 5803
 581     CALL ISIMEQ(AAA, 60,61,NSURF)                                 CL6 5804
         DT=0.0                                                        CL6 5805
         DO 62 I=1,NSURF                                               CL6 5806
         RHS(I)=SQRT(SQRT(AAA(I,N)))                                   CL6 5807
         DT=AMAX1(ABS(RHS(I)-TS(I,1)),DT)                              CL6 5808
         DEL=RHS(I)-TS(I,1)                                            CL6 5809
         TS(I,1)=TS(I,1)+SIGN(AMIN1(ABS(DEL),250.0),DEL)               CL6 5810
 62      CONTINUE                                                      CL6 5811
 71      NFIX=NFIX+1                                                   CL6 5812
         IF(DT.LT.5.0*DHTCL6.OR.NFIX.EQ.NFMAX)GO TO 81                 CL6 5813
         IF(DT.LT.250.)GO TO 10                                        CL6 5814
         GO TO 85                                                      CL6 5815
 C    COMPARE AREA                                                     CL6 5816
 C    COMPARE TEMPERATURES OBTAINED FROM SURFACE AREA HEAT BALANCE WITH CL6 5817
 C    THOSE USED IN OBTAINING SURFACE AREA TEMPERATURE DEPENDENT       CL6 5818
 C    INTERCHANGE AREAS(S-S AND S-G)                                   CL6 5819
 81      CALL READ(3,'TEMS',ZZ(1), 60)                                 CL6 5820
         DT=0.                                                         CL6 5821
         DO 82 I=1,NSURF                                               CL6 5822
         DT=AMAX1(ABS( ZZ(I)-TS(I,1)),DT)                              CL6 5823
```

```
 82    CONTINUE                                                         CL6 5824
 85    CALL WRITE(2,'TEMS',TS(1,1), 60)                                 CL6 5825
       IF(DT.LE.DHTCL6)ICODE=2                                          CL6 5826
       WRITE(K2,3002)DT                                                 CL6 5827
       IF(NPRNT.EQ.1)GO TO 86                                           CL6 5828
       WRITE(K2,3001) (TS(N,1),N=1,NSURF)                               CL6 5829
 3001   FORMAT(//20X'COMPUTED SURFACE AREA TEMPERATURES,DEG,R'//(25X,6F15CL6 5830
      1.3))                                                             CL6 5831
 3002  FORMAT(20X,'MAX TEMPERATURE DIFFERENCE IN SURFACE ARAE CALULATION CL6 5832
      1',F12.3)                                                         CL6 5833
 86    RETURN                                                           CL6 5834
       END                                                              CL6 5835
```

```
      SUPROUTINE IGAS(II,KKK,IG1,IG2)                                   IGAS5836
C     SUBROUTIN COMPUTES THE INDEX OF GAS VOLUMES ADJACENT TO SURFACE ARIGAS5837
C      I1          SURFACE AREA INDEX                                   IGAS5838
C      KKK         NUMBER OF AJACENT GAS VOLUMES                        IGAS5839
C      IG1,2       INDEX OF AJACENT GAS VOLUMES                         IGAS5840
      COMMON // DUMMY(3),KK, ICODE, HCODE,                              IGAS5841
     A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),                    IGAS5842
     A TBRIDG, PRES, FLUET, FLUE(5), XMNX, TSINK,                       IGAS5843
     A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,                    IGAS5844
     A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,                     IGAS5845
     A XSURFX(9), XO, YO, ZLONG, NCOL, NROW, NXSXN,                     IGAS5846
     A RSTART, TCODE, SCODE, NGRAY, JHGHG,                              IGAS5847
     A K1, K2, RCRD(10), TDEP(100), PERM(200)                           IGAS5848
C                                                                       IGAS5849
      INTEGER SCODE,TCODE,RSTART,HCODE                                  IGAS5850
      I=II                                                              IGAS5851
      I1=0                                                              IGAS5852
      I2=0                                                              IGAS5853
      K=1                                                               IGAS5854
      IF(I.GT.NCOL)GO TO 11                                             IGAS5855
C    TOP OF FURNACE                                                     IGAS5856
      I1=I                                                              IGAS5857
      GO TO 19                                                          IGAS5858
   11 IF(I.GT.2*NCOL)GO TO 12                                           IGAS5859
C    BOTTOM OF FURNACE                                                  IGAS5860
      I1=NCOL*(NROW-1)+(I-NCOL)                                         IGAS5861
      GO TO 19                                                          IGAS5862
   12 IF(I.GT.2*NCOL+NROW)GO TO 13                                      IGAS5863
C    LEFT SIDE OF FURNACE                                               IGAS5864
      I1=NCOL*(I-2*NCOL-1)+1                                            IGAS5865
      GO TO 19                                                          IGAS5866
   13 IF(I.GT.NCR)GO TO 14                                              IGAS5867
C    RIGTH SIDE OF FURNACE                                              IGAS5868
      I1=(I-2*NCOL-NROW)*NCOL                                           IGAS5869
      GO TO 19                                                          IGAS5870
   14 K=2                                                               IGAS5871
      I=I-NCR                                                           IGAS5872
C    INTER-SURFACE HENCE TWO GAS VOLUMES                                IGAS5873
      DO 17 J=1,9                                                       IGAS5874
      IF(I.GT.NROW)GO TO 15                                             IGAS5875
      I1=(I-1)*NCOL+INT(XSURFX(J)/XO+.1)                                IGAS5876
      I2=I1+1                                                           IGAS5877
      GO TO 19                                                          IGAS5878
   15 I=I-NROW                                                          IGAS5879
   17 CONTINUE                                                          IGAS5880
   19 KKK=K                                                             IGAS5881
      IG1=I1                                                            IGAS5882
      IG2=I2                                                            IGAS5883
      RETURN                                                            IGAS5884
      END                                                               IGAS5885
```

```
         SUBROUTINE CL7                                              CL7 5886
C       FINALE OUTPUT                                                CL7 5887
         COMMON // DUMMY(3),KK, ICODE, HCODE,                        CL7 5888
        A TAU(9), VAREA, HAREA, XLX, XK(3), ACOEF(8,3),              CL7 5889
        A TBRIDG, PRES, FLUET, FLUE(5), XMAX, TSINK,                 CL7 5890
        A NCR, HDUTY, HTVAL, FRATE, KFUEL, XAIR, FTEMP,              CL7 5891
        A NSSBLK, NGSBLK, NSGBLK, NGGBLK, NSURF, NVOL,               CL7 5892
        A XSURFX(9), XD, YD, ZLONG, NCOL, NROW, NXSXN,               CL7 5893
        A KSTART, TCODE, SCODE, NGRAY, JHCHC,                        CL7 5894
        A K1, K2, RGRD(10), TDEP(100), PERM(200)                     CL7 5895
         COMMON/TUBE2/IND,TX(100),OT(4),QFF                          CL7 5896
C                                                                    CL7 5897
         INTEGER SCODE,TCODE,KSTART,HCODE                            CL7 5898
         REAL T( 60),V( 60),Z( 60),HTDEN( 60),GMY(120)               CL7 5899
         DATA IN3/1/                                                 CL7 5900
         NDONE=KK                                                    CL7 5901
         IF(NDONE.EQ.0)GO TO 65                                      CL7 5902
         WRITE(K2,63)                                                CL7 5903
   63    FORMAT('1',14X,'CASE CONVERGED'/15X    ,14('-'))            CL7 5904
         GO TO 70                                                    CL7 5905
   65    WRITE(   K2,66)                                             CL7 5906
   66    FORMAT('1',14X,'CASE NOT CONVERGED'/15X,18('-'))            CL7 5907
   70    CALL READ(2,'TEMG',T(1), 60)                                CL7 5908
         DO 71 N=1,NVOL                                              CL7 5909
         IF(T(N).EQ.0.0)GO TO 71                                     CL7 5910
         T(N)=T(N)-460.                                              CL7 5911
   71    CONTINUE                                                    CL7 5912
         JJ=0                                                        CL7 5913
         TBR=0.0                                                     CL7 5914
         NY=(NROW+1)*NCOL                                            CL7 5915
         CALL READ(2,'GMY ',GMY(1), NY)                              CL7 5916
         DO 710 J=1,NCOL                                             CL7 5917
         IF(GMY(J).GE.0.0)GO TO 710                                  CL7 5918
         JJ=JJ+1                                                     CL7 5919
         TBR=TBR+T(J)                                                CL7 5920
  710    CONTINUE                                                    CL7 5921
         TBR=TBR/FLOAT(JJ)                                           CL7 5922
  712    WRITE(K2,72)(T(N),N=1,NVOL)                                 CL7 5923
   72    FORMAT(//20X,'FINALE GAS VOLUME TEMPERATURE,DEG. F.         CL7 5924
        1'//(25X,6E15.1))                                            CL7 5925
         CALL READ(2,'TEMS',T(1), 60)                                CL7 5926
         DO 78 N=1,NSURF                                             CL7 5927
         IF(T(N).EQ.0.0)GO TO 78                                     CL7 5928
         T(N)=T(N) -460.                                             CL7 5929
   78    CONTINUE                                                    CL7 5930
         WRITE(K2,79)(T(N),N=1,NSURF)                                CL7 5931
   79    FORMAT(//20X,'FINAL  SURFACE AREA TEMPERATURES, DEGREES F.'//(25X,CL7 5932
        16E15.1))                                                    CL7 5933
   80    CALL READ(2,'TEMP',V(1), 60)                                CL7 5934
         DO 82 N=1,NSURF                                             CL7 5935
```

```
      IF(V(N).EQ.0.0)GO TO 82                                           CL7 5936
      V(N)=V(N)-460.                                                    CL7 5937
   82 CONTINUE                                                          CL7 5938
      CALL READ(2,'HCP ',Z(1), 60)                                      CL7 5939
      DO 85 N=1,NSURF                                                   CL7 5940
      HTDEN(N)=Z(N)*(T(N)-V(N))                                         CL7 5941
   85 CONTINUE                                                          CL7 5942
      IF(HAREA.EQ.0.0)GO TO 860                                         CL7 5943
      DO 86 N=1,NCR                                                     CL7 5944
      HTDEN(N)=HTDEN(N)/HAREA                                           CL7 5945
   86 CONTINUE                                                          CL7 5946
  860 IF(NXSXM.EQ.0)GO TO 88                                            CL7 5947
      NN=NCR+1                                                          CL7 5948
      DO 87 N=NN,NSURF                                                  CL7 5949
      HTDEN(N)=HTDEN(N)/VAREA                                           CL7 5950
   87 CONTINUE                                                          CL7 5951
   88 WRITE(K2,89)(HTDEN(N),N=1,NSURF)                                  CL7 5952
  102 FORMAT(' SURFACE TO AREA COEFFICIENT'/(27X,6F15.1))               CL7 5953
   89 FORMAT(//20X,'COMPUTED HEAT DENSITIES,BTU/HR/SQUARE FOOT OF TUBE SCL7 5954
     1URFACE'//(25X,6F15.1))                                            CL7 5955
      HCOMB=HDUTY*1.E6/ZLONG                                            CL7 5956
      HFIN=FLULT*XMWX*HV(FTEMP)                                         CL7 5957
      CALL READ(2,'HCPP',Z(1), 60)                                      CL7 5958
      TSINKF=TSINK -460.                                                CL7 5959
      HAMB=0.0                                                          CL7 5960
      DO 91 N=1,NCR                                                     CL7 5961
      HAMB=HAMB+Z(N)*(T(N)-TSINKF)                                      CL7 5962
   91 CONTINUE                                                          CL7 5963
      HPROC=0.0                                                         CL7 5964
      NN=2*NCOL                                                         CL7 5965
      DO 92 N=1,NN                                                      CL7 5966
      HPROC=HPROC+HTDEN(N)*XC*HAREA                                     CL7 5967
   92 CONTINUE                                                          CL7 5968
      NN=NN+1                                                           CL7 5969
      DO 93 N=NN,NCR                                                    CL7 5970
      HPROC=HPROC+ HTDEN(N)*YO*HAREA                                    CL7 5971
   93 CONTINUE                                                          CL7 5972
      IF( NXSXM.EQ.0)GO TO 95                                           CL7 5973
      DO 94 N=NN,NCR                                                    CL7 5974
      HPROC=HPROC+HTDEN(N)*YC*VAREA                                     CL7 5975
   94 CONTINUE                                                          CL7 5976
   95 HFOUT=FLUET*XMWX*HV(TBR+460.)                                     CL7 5977
      HNET=HCOMB+HFIN-HAMB-HPROC-HFOUT                                  CL7 5978
      WRITE(K2,96)HCOMB,HFIN,HAMB,HPROC,HFOUT,HNET                      CL7 5979
      QFF=HPROC                                                         CL7 5980
   96 FORMAT('1',14X,'FURNACE OVERALL HEAT BALANCE,BTU/HR/FOOT OF FURNACCL7 5981
     1E'/15X,56('-')///20X,'HEAT IN'//25X,'COMBUSTION',F21.0/25X,'FLUE GCL7 5982
     2AS',F23.0//20X,'HEAT OUT'//25X,'AMBIET',F24.0/25X,'PROCESS FLUID',CL7 5983
     3F18.0/25X,'FLUE GAS',F23.0//20X,'NET HEAT BALANCE(HEAT IN-HEAT OUTCL7 5984
     4)',F20.0)                                                         CL7 5985
```

```
      IF(HPROC.LE.0.0)WRITE(K2,103)HPROC,XO,YO,HAREA,VAREA              CL7 5986
  103 FORMAT(' HPROC= ',F8.3,' XO= ',F8.3,' YO= ',F8.3,' HAREA= ',F8.3, CL7 5987
     1' VAREA= ',F8.3)                                                  CL7 5988
      WRITE(K2,97)                                                      CL7 5989
   97 FORMAT('1')                                                       CL7 5990
      HEAT=HCONV+HEIN-HAMB-HPROC                                        CL7 5991
      ENTH=HEAT/FLUET/XMWX                                              CL7 5992
      TSTOP=9000.-460.                                                  CL7 5993
      TT=600.-460.                                                      CL7 5994
      TOL=.01                                                           CL7 5995
   99 IF(KAYA(HV(TT+460.),ENTH,TOL,TT,TSTOP,1))99,105,100               CL7 5996
  100 WRITE(K2,101)ENTH,TT                                              CL7 5997
  101 FORMAT(15X,'BRIDGE WALL TEMPERATURE CANNOT BE COMPUTED'/15X42('-')CL7 5998
     1//20X,'REQUIRED ENTHALPY,BTU/LB',F20.3/20X,'LAST VALUE OF BRIDGE CL7 5999
     2 WALL TEMPERATURE,DEG F',F20.3)                                   CL7 6000
      GO TO 110                                                         CL7 6001
  105 WRITE(K2,106)ENTH,TT                                              CL7 6002
  106 FORMAT(15X,'BRIDGE WALL TEMPERATURE COMPUTION'/15X 35('-')//20X 'RCL7 6003
     1EQUIRED ENTHALPY,BTU/LB',F20.3/20X,'BRIDGE WALL TEMPERATURE,DEG F'CL7 6004
     2 ,F15.3)                                                          CL7 6005
  110 TT=0.0                                                            CL7 6006
      IF(IN3.GT.1)GO TO 999                                             CL7 6007
      IN3=IN3+1                                                         CL7 6008
      N=1                                                               CL7 6009
  120 T(N)=TT                                                           CL7 6010
      V(N)=HV(TT+460.)                                                  CL7 6011
      Z(N)= CP(TT+460.)                                                 CL7 6012
      IF(TT.GE.4000.)GO TO 130                                          CL7 6013
      N=N+1                                                             CL7 6014
      TT=TT+100.                                                        CL7 6015
      GO TO 120                                                         CL7 6016
  130 NN=N                                                              CL7 6017
      WRITE(K2,131)(T(N),V(N),Z(N),N=1,NN)                              CL7 6018
  131 FORMAT('1',14X,'FLUE GAS ENTHALPY AND SPECIFIC HEAT DATA'/15X40('-CL7 6019
     1')///20X,'TEMP,DEG F ',5X,'ENTHALPY,BTU/LB',5X,'SPECFIC HEAT,BTU/LCL7 6020
     2B/LB/DEG'//(F30.1,F21.3,F25.6))                                   CL7 6021
  999 RETURN                                                            CL7 6022
      END                                                               CL7 6023
```

```
      FUNCTION WAYA(A,ANS,TOL,START,STOP,LEVEL)                         WAYA6024
C    ROUTINE TO CONVERGE ON SINGLE VALUED FUNCTION                      WAYA6025
C    A       =CURRENT VALUE OF DEPENDENT VARIABLE                       WAYA6026
C    ANS     =DESIRED VALUE OF DEPENDENT VARIABLE                       WAYA6027
C    TOL     =TOLERANCE                                                 WAYA6028
C    START   =CURRENT VALUE OF INDEPENDENT VARIABLE,A BETTER VALUE RETURNDWAYA6029
C    STOP    =LIMIT OF INDEPENDENT VARIABLE ANSWER BETWEEN START AND STOP WAYA6030
C    LEVEL   =1,2,3 AS A INDEX FOR MULTILEVEL USE                       WAYA6031
C    WAYA WILL VARY START BETWEEN ITS INITIAL VALUE AND STOP UNTIL     WAYA6032
C       ABS(ANS-A).LE.TOL OR 30 TRIALS TAKEN                            WAYA6033
C    ON EXIT WAYA IS                                                    WAYA6034
C       - FOR NOT CONVERGED,REPEAT CALULATIONS WITH A NEW VALUE IN START WAYA6035
C       0 CONVERGED IN LIMITS OR 30 TRIALS TAKEN                        WAYA6036
C       + FOR CANNOT CONVERAGE START OR STOP WILL BE INITIAL VALUE      WAYA6037
C       WHICHEVER GIVES LESSER ERROR,OR ITS INITIAL VALUE IF LEVEL IS   WAYA6038
C       NEGATIVE                                                        WAYA6039
      DIMENSION X1(10),X2(10),Y1(10),Y2(10),KOUNT(10)                   WAYA6040
      DATA KOUNT/10*0/                                                  WAYA6041
C    SET X ,Y , AND LEVEL                                               WAYA6042
      X=START                                                           WAYA6043
      Y=ANS-A                                                           WAYA6044
      L=IABS(LEVEL)                                                     WAYA6045
      WAYA=1.0                                                          WAYA6046
C      SEE IF CONVERGED                                                 WAYA6047
      IF(ABS(Y).LE.TOL)GO TO 70                                         WAYA6048
C    NOT CONVERGED SEE WHICH CALL                                       WAYA6049
      IF(KOUNT(L))60,30,10                                              WAYA6050
C      SECOND OR HIHGER CALL SEE IF Y AND Y1(L) BRACKET ANSWER          WAYA6051
   10 IF(Y*Y1(L).LT.0.0)GO TO 20                                        WAYA6052
C    NO Y-Y1 BRACKET SEE IF SECOND OR HIGHER CALL                       WAYA6053
      IF(KOUNT(L).GT.1)GO TO 30                                         WAYA6054
C    NO BRACKET AT ALL REDO AT START IF THAT LIMIT IS CLOSER OR IF LEVEL WAYA6055
C                                 MINUS                                 WAYA6056
      IF(ABS(Y).LE.ABS(Y1(L)).AND.LEVEL.GT.0)GO TO 80                   WAYA6057
      X=X1(L)                                                           WAYA6058
      KOUNT(L)=-1                                                       WAYA6059
      GO TO 60                                                          WAYA6060
C    Y -Y1 BRACKET STORE X AND Y IN X2(L) AND Y2(L)                     WAYA6061
   20 X2(L)=X                                                           WAYA6062
      Y2(L)=Y                                                           WAYA6063
      GO TO 40                                                          WAYA6064
C    FIRST CALL OR CONVERGING Y -Y1 BRACKET CALL                        WAYA6065
C          STORE RESULT IN X AND Y IN XU AND Y1                         WAYA6066
   30 X1(L)=X                                                           WAYA6067
      Y1(L)=Y                                                           WAYA6068
      X=STOP                                                            WAYA6069
      IF(KOUNT(L).EQ.0)GO TO 50                                         WAYA6070
C    INTERPOLATE NEW X AND CONTINUE OR QUIT DEPENDING ON KOUNT(L)       WAYA6071
   40 X=(X1(L)*(3.*Y2(L)-Y1(L))+X2(L)*(Y2(L)-3.*Y1(L)))/(4.*(Y2(L)-Y1(L)WAYA6072
     1))                                                                WAYA6073
```

```
      IF(KOUNT(L).GE.30)GO TO 70                                    WAYA6074
   50 KOUNT(L)=KOUNT(L)+1                                           WAYA6075
   60 WAYA=-1.                                                      WAYA6076
      GO TO 90                                                      WAYA6077
C     CONVERGED OR TOO MANY TRAILS                                  WAYA6078
   70 WAYA=0.0                                                      WAYA6079
   80 KOUNT(L)=0                                                    WAYA6080
C     SET NEW VALUE OF INDEPENDENT VARIABLE                         WAYA6081
   90 START=X                                                       WAYA6082
      RETURN                                                        WAYA6083
      END                                                           WAYA6084
```

```
      SUBROUTINE PZERO(A,N)                    PZER6085
      DIMENSION A(1),MM(1)                     PZER6086
      DO 1 K=1,N                               PZER6087
    1 A(K)=0.0                                 PZER6088
      RETURN                                   PZER6089
      ENTRY MZERO(MM,N)                        PZER6090
      DO 2 K=1,N                               PZER6091
    2 MM(K)=0                                  PZER6092
      RETURN                                   PZER6093
      END                                      PZER6094
```

```
      FUNCTION FITIT ( X, Y, NO, MAX, C, LN, A )                        FIT 6095
C                                                                       FIT 6096
C     WILL FIT POLYNOMIAL OF ORDER MAX ( MAX .LT. 7 ) TO NO Y VS. X DATAFIT 6097
C     POINTS SUPPLIED IN ARRAYS Y AND X. COEFFICIENTS RETURNED IN ARRAY FIT 6098
C     C IN FORM NEEDED BY FUNCTION EQUA. STANDARD DEVIATION OF Y RETURNEFIT 6099
C     D AS FITIT.                                                       FIT 6100
C                                                                       FIT 6101
C     LN = LOG TRANSFORMATION CODE 1 = Y VS. X                          FIT 6102
C                                  2 = LN Y VS. X                       FIT 6103
C                                  3 = Y VS. LN X                       FIT 6104
C                                  4 = LN Y VS. LN X                    FIT 6105
C                                                                       FIT 6106
C     A = INTERCEPT CODE ZERO = INTERCEPT = 0.0                         FIT 6107
C     NONZERO = INTERCEPT CALCULATED                                    FIT 6108
C                                                                       FIT 6109
      DOUBLE PRECISION D,S,XY,Q                                         FIT 6110
      DIMENSION X(1), Y(1), C(1), D(7), S(7), XY(7,7)                   FIT 6111
      REAL*4 LOG                                                        FIT 6112
C                                                                       FIT 6113
C     SET CONTROLS AND ZEROS AND XY.                                    FIT 6114
C                                                                       FIT 6115
      N = NO                                                            FIT 6116
      M = MIN0 ( MAX + 1, N, 7)                                         FIT 6117
      L = MIN0 ( 4, MAX0 ( 1, LN ) )                                    FIT 6118
      Z = N                                                             FIT 6119
      DO 10 I = 1, M                                                    FIT 6120
      S(I) = 0.0                                                        FIT 6121
      DO 10 J = I, M                                                    FIT 6122
   10 XY(I, J) = 0.0                                                    FIT 6123
C                                                                       FIT 6124
C     FOR EACH DATUM, MOVE Y AND X TO D(1) AND D(2), GET LOGS IF NEEDED FIT 6125
C     AND POWERS OF X, AND ACCUMULATE SUMS, SQUARES, AND CROSS PRODUCTS FIT 6126
C     IN S AND XY.                                                      FIT 6127
C                                                                       FIT 6128
      DO 80 K =1, N                                                     FIT 6129
      D(1) = Y(K)                                                       FIT 6130
      D(2) = X(K)                                                       FIT 6131
      GO TO ( 50, 20, 40, 30 ), L                                       FIT 6132
   20 D(1) =  LOG ( D(1) )                                              FIT 6133
      GO TO 50                                                          FIT 6134
   30 D(1) =  LOG ( D(1) )                                              FIT 6135
   40 D(2) =  LOG ( D(2) )                                              FIT 6136
   50 DO 60 I =3, M                                                     FIT 6137
   60 D(I) = D(2) * D(I - 1)                                            FIT 6138
      DO 70 I = 1, M                                                    FIT 6139
      S(I) = S(I) + D(I)                                                FIT 6140
      DO 70 J = I, M                                                    FIT 6141
   70 XY(I, J) = XY(I, J) + D(I) * D(J)                                 FIT 6142
   80 CONTINUE                                                          FIT 6143
C                                                                       FIT 6144
```

```
C      GET REDUCED SQUARES AND CROSS PRODUCTS IF A NONZERO AND FOLD XY    FIT 6145
C      OVER.                                                               FIT 6146
C                                                                          FIT 6147
       IF ( A .EQ. 0.0 ) GO TO 110                                         FIT 6148
       DO 100 I = 1, M                                                     FIT 6149
       Q = S(I) / 2                                                        FIT 6150
       DO 90 J = I, M                                                      FIT 6151
    90 XY(I, J) = XY(I, J) - Q * S(J)                                      FIT 6152
   100 S(I) = Q                                                            FIT 6153
   110 DO 120 J = 1, M                                                     FIT 6154
       DO 120 I = J, M                                                     FIT 6155
   120 XY(I, J) = XY(J, I)                                                 FIT 6156
C                                                                          FIT 6157
C      SOLVE REGRESSION MATRIX AND GET STANDARD DEVIATION OF Y.            FIT 6158
C                                                                          FIT 6159
       DO 160 I = 2, M                                                     FIT 6160
       Q = XY(I, I)                                                        FIT 6161
       XY(I, I) = 1.0                                                      FIT 6162
       DO 130 J = 1, M                                                     FIT 6163
   130 XY(I, J) = XY(I, J) / Q                                             FIT 6164
       DO 150 K = 1, M                                                     FIT 6165
       IF ( K .EQ. I ) GO TO 150                                           FIT 6166
       Q = XY(K, I)                                                        FIT 6167
       XY(K, I) = 0.0                                                      FIT 6168
       DO 140 J = 1, M                                                     FIT 6169
   140 XY(K, J) = XY(K, J) - XY(I, J) * Q                                  FIT 6170
   150 CONTINUE                                                            FIT 6171
   160 CONTINUE                                                            FIT 6172
       Q=      (MAX0(N-M,1))                                               FIT 6173
       FITIT=0.0                                                           FIT 6174
       IF(XY(1,1).GT.0.)FITIT=DSQRT(XY(1,1)/Q)                             FIT 6175
C                                                                          FIT 6176
C      STORE COEFFICIENTS IN C ARRAY.                                      FIT 6177
C                                                                          FIT 6178
       C(1) = M - 1                                                        FIT 6179
       C(2) = 0.0                                                          FIT 6180
       DO 170 I = 2, M                                                     FIT 6181
       S(1) = S(1) - S(I) * XY(I, 1)                                       FIT 6182
   170 C(I + 1) = XY(I, 1)                                                 FIT 6183
       IF ( A .NE. 0.0 ) C(2) = S(1)                                       FIT 6184
       RETURN                                                              FIT 6185
C                                                                          FIT 6186
       END                                                                 FIT 6187
```

```
      FUNCTION     EQUA  ( X, C )                                 EQUA6188
C                                                                 EQUA6189
C     THIS FUNCTION EVALUATES A SET OF POLYNOMINAL COEFFICIENTS BY  EQUA6190
C     NESTED EXPANSION ---- AS GENERATED BY FUNCTION FITIT.         EQUA6191
C                                                                 EQUA6192
C         Y = AO + A1*X + A2*X**2 + ..... + AM*X**M               EQUA6193
C                                                                 EQUA6194
C               M = C(1)                                          EQUA6195
C                                                                 EQUA6196
C               AO = C(2)                                         EQUA6197
C               A1 = C(3)                                         EQUA6198
C               A2 = C(4)                                         EQUA6199
C               .. . ....                                         EQUA6200
C               .. . ....                                         EQUA6201
C               AM = C(M+2)                                       EQUA6202
C                                                                 EQUA6203
      REAL     C(1)                                               EQUA6204
C                                                                 EQUA6205
      M = C(1)                                                    EQUA6206
      Y = C(M+2)                                                  EQUA6207
      MM = M+2                                                    EQUA6208
      DO  1  J=1,M                                                EQUA6209
      K=MM-J                                                      EQUA6210
      Y=Y*X+C(K)                                                  EQUA6211
    1 CONTINUE                                                    EQUA6212
      EQUA = Y                                                    EQUA6213
      RETURN                                                      EQUA6214
      END                                                         EQUA6215
```

```
      SUBROUTINE READ(IJ,NAME,X,N)                                  READ6216
      COMMON//SLURP(66),NVOL,NSURF,SLURP2(32),NPRNT                 READ6217
      COMMON/ZREAD/ID                                               READ6218
      DIMENSION X(1),XX(60),K(3),KN(150,3),NAMES(150,3)             READ6219
      DATA K/3*0/,KN/1,149*0,1,149*0,1,149*0/,NAMES/450*'    '/     READ6220
      DATA STAR/'STAR'/                                             READ6221
      J=IJ                                                          READ6222
      IF(NAME.EQ.STAR.OR.IJ.EQ.4)GO TO 50                           READ6223
      IF(K(J).EQ.0)GO TO 100                                        READ6224
      KK=K(J)                                                       READ6225
      DO 1 I=1,KK                                                   READ6226
      IF(NAME.EQ.NAMES(I,J))GO TO 10                                READ6227
    1 CONTINUE                                                      READ6228
C      ERROR HAS OCCURED                                            READ6229
  100 CALL ERROR(NAME,KK,J)                                         READ6230
   10 ID=KN(I,J)                                                    READ6231
      J=J+19                                                        READ6232
      IF(FLOAT(N/ 60).EQ.FLOAT(N)/ 60.)GO TO 20                     READ6233
      READ(J'ID)(X(NN),NN=1,N)                                      READ6234
      FIND(J'ID)                                                    READ6235
      J=J-19                                                        READ6236
      RETURN                                                        READ6237
   20 INUM=N/ 60                                                    READ6238
      DO 21 NN1=1,INUM                                              READ6239
      NNX=(NN1-1)* 60+1                                             READ6240
      NNY=NNX+NMAX-1                                                READ6241
      READ(J'ID)(X(NN),NN=NNX,NNY)                                  READ6242
      FIND(J'ID)                                                    READ6243
   21 CONTINUE                                                      READ6244
      RETURN                                                        READ6245
   50 ID=1                                                          READ6246
      READ(23'ID)K,KN,NAMES,NMAX                                    READ6247
      READ(23'ID)SLURP,NVOL,NSURF,SLURP2,NPRNT                      READ6248
      WRITE(6,601)K,KN,NAMES,NMAX                                   READ6249
      K(3)=0                                                        READ6250
      RETURN                                                        READ6251
  743 CONTINUE                                                      READ6252
      J1=K(1)+1                                                     READ6253
      J1=KN(J1,1)-1                                                 READ6254
      DO 51  I=1,J1                                                 READ6255
      READ(24'I)(XX(NN),NN=1,NMAX)                                  READ6256
      WRITE(20'I)(XX(NN),NN=1,NMAX)                                 READ6257
   51 CONTINUE                                                      READ6258
      K(2)=13                                                       READ6259
      DO 53 J2=1,14                                                 READ6260
   53 KN(J2,2)=J2                                                   READ6261
      J2=K(2)+1                                                     READ6262
      J2=KN(J2,2)-1                                                 READ6263
      M=0                                                           READ6264
      DO 52 I=1,13                                                  READ6265
```

```
      L=I                                                               READ6266
      M=M+1                                                             READ6267
      NMAX1=NMAX                                                        READ6268
      IF(I.EQ.3)NMAX1=12                                                READ6269
      IF(I.EQ.4)NMAX1=11                                                READ6270
      IF(I.EQ.6.OR.I.EQ.7)M=M+2                                         READ6271
      READ(25'M,ERR=59)(XX(NN),NN=1,NMAX1)                              READ6272
      WRITE(21'L)(XX(NN),NN=1,NMAX1)                                    READ6273
   52 CONTINUE                                                          READ6274
      RETURN                                                            READ6275
   59 WRITE(2,902)I,K                                                   READ6276
  902 FORMAT(' ERROR IN READ DATA SET=25 RECORD=',I3,'  NMAX=',I3/' TYPEREAD6277
     1E TO CONTINUE PROGRAM TYPE 2 TO STOP')                            READ6278
      RETURN                                                            READ6279
      ENTRY WRITE(IJ,NAME,X,N)                                          READ6280
      IF(NAME.EQ.STAR.OR.IJ.EQ.4)GO TO 150                              READ6281
      J=IJ                                                              READ6282
      IF(K(J).EQ.0)GO TO 115                                            READ6283
      KK=K(J)                                                           READ6284
      DO 2 I=1,KK                                                       READ6285
      IF(NAME.EQ.NAMES(I,J))GO TO 120                                   READ6286
    2  CONTINUE                                                         READ6287
  115 K(J)=K(J)+1                                                       READ6288
      KK=K(J)                                                           READ6289
      NMAX=MAX0(NVOL,NSURF)                                             READ6290
      GO TO 200                                                         READ6291
  120  KK=I                                                             READ6292
  200 NAMES(KK,J)=NAME                                                  READ6293
      ID=KN(KK,J)                                                       READ6294
      J=J+19                                                            READ6295
      IF(FLOAT(N/ 60).EQ.FLOAT(N)/ 60.)GO TO 30                         READ6296
      WRITE(J'ID)(X(NN),NN=1,N)                                         READ6297
      J=J-19                                                            READ6298
      KN(KK+1,J)=ID                                                     READ6299
      RETURN                                                            READ6300
   30 INUM=N/ 60                                                        READ6301
      DO 31 NN1=1,INUM                                                  READ6302
      NNX=(NN1-1)* 60+1                                                 READ6303
      NNY=NNX+NMAX-1                                                    READ6304
   31 WRITE(J'ID)(X(NN),NN=NNX,NNY)                                     READ6305
      J=J-19                                                            READ6306
      KN(KK+1,J)=ID                                                     READ6307
      RETURN                                                            READ6308
  150 ID=1                                                              READ6309
      WRITE(6,901)K,KN,NAMES,NMAX                                       READ6310
  901 FORMAT('1',20X,'K(1)=',I3,3X,'K(2)=',I3,3X,'K(3)=',I3,3X/' ',20X,'READ6311
     1KN VALS'//3(6(25I5/)//)/'1',40X 'NAMES'//18(25(1X,A4)/)/'0NMAX=',IREAD6312
     23)                                                                READ6313
      WRITE(23'ID)K,KN,NAMES,NMAX                                       READ6314
      WRITE(23'ID)SLURP,NVOL,NSURF,SLURP2,NPRNT                         READ6315
```

```
101        RETURN                                              READ6316
102        END                                                 READ6317
```

```
      SUBROUTINE PRINT(AA,N1,N2)                                  PRNT6318
      REAL AA(1)                                                  PRNT6319
      COMMON//SLURP(89),K2,SLURP2(310),K3                         PRNT6320
      IF(K3.EQ.1)RETURN                                           PRNT6321
      IF(N2.EQ.1)GO TO 20                                         PRNT6322
      NJ=N2/6                                                     PRNT6323
      NR=N2-NJ*6                                                  PRNT6324
      IF(NR.NE.0)NJ=NJ+1                                          PRNT6325
      NC=0                                                        PRNT6326
      KK=-5                                                       PRNT6327
      DO 1 J=1,NJ                                                 PRNT6328
      KK=KK+6                                                     PRNT6329
      KL=KK+5                                                     PRNT6330
      IF(J*6.GT.N2)KL=KK+NR-1                                     PRNT6331
      NC=NC+N1+2                                                  PRNT6332
      IF(N1.GT.61)GO TO 4                                         PRNT6333
      IF(NC.GT.61)NC=N1+2                                         PRNT6334
      NC=0                                                        PRNT6335
    3 FORMAT('1')                                                 PRNT6336
    4 WRITE(K2,2)(I,I=KK,KL)                                      PRNT6337
    2 FORMAT(/27X,6(6X,I3,5X))                                    PRNT6338
      DO 1 NX=1,N1                                                PRNT6339
      NF=NX+(KK-1)* 60                                            PRNT6340
      NL=NF+5* 60                                                 PRNT6341
      IF(J*6.GT.N2)NL=NF+(NR-1)* 60                               PRNT6342
    1 WRITE(K2,10)NX,(AA(NY),NY=NF,NL, 60)                        PRNT6343
   10 FORMAT(20X,I3,4X,6(1PE14.6))                                PRNT6344
      RETURN                                                      PRNT6345
   20 WRITE(K2,11)(AA(NY),NY=1,N1)                                PRNT6346
   11 FORMAT(27X,1PE14.6,5E14.6)                                  PRNT6347
      RETURN                                                      PRNT6348
      END                                                         PRNT6349
```

```
      FUNCTION LOG(X)                                   LOG 6350
      REAL*4 LOG                                        LOG 6351
      LOG=ALOG(X)                                       LOG 6352
      RETURN                                            LOG 6353
      END                                               LOG 6354
```

```
      SUBROUTINE ERROR(NAME,N1,N2)                                ERR 6355
C     ALL UNRECOVERABLE ERRORS COME HERE                          ERR 6356
      COMMON//SLURP(89),K2                                        ERR 6357
      WRITE( 2,10)NAME,N1,N2                                      ERR 6358
10    FORMAT(' ',20X,'AN ERROR HAS OCCURED IN SUBROUTINE',2X,A4,2I10) ERR 6359
      CALL WRITE(4,'STAR',X,NN)                                   ERR 6360
      STOP                                                        ERR 6361
      END                                                         ERR 6362
```

```
      SUBROUTINE ISIMEQ(C,NMAX,NNMAX,NN)                              SMEQ6363
      REAL C(NMAX,NNMAX)                                              SMEQ6364
C     CONVERT LOWER LEFT TO ZERO AND DIAGONAL TO 1.0                  SMEQ6365
C     N=ROW   M=COLUMN                                                SMEQ6366
      DO 73 N=1,NN                                                    SMEQ6367
      IF(N-1)60,30,30                                                 SMEQ6368
C     SET ZERO VALUES                                                 SMEQ6369
 30   NM1=N-1                                                         SMEQ6370
      DO 50 M=1,NM1                                                   SMEQ6371
      HOLD=C(N,M)                                                     SMEQ6372
      IF (HOLD)32,50,32                                               SMEQ6373
 32   CONTINUE                                                        SMEQ6374
C32   C(N,M)=0                                                        SMEQ6375
      MP1=M+1                                                         SMEQ6376
      DO 40 K=MP1,NN                                                  SMEQ6377
 40   C(N,K)=C(N,K)-HOLD*C(M,K)                                       SMEQ6378
      C(N,NN+1)=C(N,NN+1)-HOLD*C(M,NN+1)                              SMEQ6379
 50   CONTINUE                                                        SMEQ6380
C     SET DIAGONAL EQUAL TO 1.0                                       SMEQ6381
 60   HOLD=C(N,N)                                                     SMEQ6382
      IF(HOLD)63,200,63                                               SMEQ6383
 63   CONTINUE                                                        SMEQ6384
C63   C(N,N)=1.0                                                      SMEQ6385
      IF(N.EQ.NN)GO TO 72                                             SMEQ6386
 68   NP1=N+1                                                         SMEQ6387
      DO 70 M=NP1,NN                                                  SMEQ6388
 70   C(N,M)=C(N,M)/HOLD                                              SMEQ6389
 72   C(N,NN+1)=C(N,NN+1)/HOLD                                        SMEQ6390
 73   CONTINUE                                                        SMEQ6391
C     CLEAR UPPER RIGHT BY BACK SUBSTITUTION                          SMEQ6392
C     STARTING WITH ROW NN-1                                          SMEQ6393
 74   DO 90 J=2,NN                                                    SMEQ6394
      N=NN+1-J                                                        SMEQ6395
      JM1=J-1                                                         SMEQ6396
      DO 87 K=1,JM1                                                   SMEQ6397
      M=NN+1-K                                                        SMEQ6398
      HOLD=C(N,M)                                                     SMEQ6399
      IF(HOLD)75,87,75                                                SMEQ6400
 75   CONTINUE                                                        SMEQ6401
C75   C(N,M)=0.0                                                      SMEQ6402
      C(N,NN+1)=C(N,NN+1)-HOLD*C(M,NN+1)                              SMEQ6403
 87   CONTINUE                                                        SMEQ6404
 90   CONTINUE                                                        SMEQ6405
      RETURN                                                          SMEQ6406
 200  CALL ERROR('ISIQ',N,M)                                          SMEQ6407
      RETURN                                                          SMEQ6408
      END                                                             SMEQ6409
```

```
      BLOCK DATA                                                        DATA6410
      COMMON/JAZZ2/SSNM(8,4),GSNM(8,3),SGNM(8,3),GGNM(8,3),ZSS(8),      DATA6411
     1ZGS(8),ZSG(8),ZGG(8)                                              DATA6412
C     SURFACE TO SURFACE DIRECT INTERCHANGE AREAS                       DATA6413
      DATA SSNM/'DSSA','DSSB','DSSC','DSSD','DSSE','DSSF','DSSG',       DATA6414
     1     'DSSH','DSSI','DSSJ','DSSK','DSSL','DSSM','DSSN'             DATA6415
     2,'DSSO','DSSP','DSSQ','DSSR','DSSS','DSST','DSSU','DSSV','DSSW',  DATA6416
     3'DSSX','DSSY','DSSZ','DSS1','DSS2','DSS3','DSS4','DSS5','DSS6'/   DATA6417
C     SURFACE TO GAS DIRECT INTERCHANGE AREAS                           DATA6418
      DATA GSNM/'DGSA','DGSB','DGSC','DGSD','DGSE','DGSF','DGSG',       DATA6419
     1     'DGSH','DGSI','DGSJ','DGSK','DGSL','DGSM','DGSN'             DATA6420
     2,'DGSO','DGSP','DGSQ','DGSR','DGSS','DGST','DGSU','DGSV','DGSW',  DATA6421
     3'DGSX'/                                                           DATA6422
C     GAS TO SURFACE DIRECT INTERCHANGE AREA                            DATA6423
      DATA SGNM/'DSGA','DSGB','DSGC','DSGD','DSGE','DSGF','DSGG',       DATA6424
     1     'DSGH','DSGI','DSGJ','DSGK','DSGL','DSGM','DSGN'             DATA6425
     2,'DSGO','DSGP','DSGQ','DSGR','DSGS','DSGT','DSGU','DSGV','DSGW',  DATA6426
     3'DSGX'/                                                           DATA6427
C     GAS TO GAS DIRECT INTERCHANGE AREA                                DATA6428
      DATA GGNM/'DGGA','DGGB','DGGC','DGGD','DGGE','DGGF','DGGG',       DATA6429
     1     'DGGH','DGGI','DGGJ','DGGK','DGGL','DGGM','DGGN'             DATA6430
     2,'DGGO','DGGP','DGGQ','DGGR','DGGS','DGGT','DGGU','DGGV','DGGW',  DATA6431
     3'DGGX'/                                                           DATA6432
C     BET TRANSMISSIVITY   SURFACE TO SURFACE                           DATA6433
      DATA ZSS/'ZSS1','ZSS2','ZSS3','ZSS4','ZSS5','ZSS6','ZSS7','ZSS8'/ DATA6434
C     NET TRANSMISSIVITY   SURFACE  TO  GAS                             DATA6435
      DATA ZSG/'ZSG1','ZSG2','ZSG3','ZSG4','ZSG5','ZSG6','ZSG7','ZSG8'/ DATA6436
C     NET TRANSMISSIVITY  GAS TO  SURFACE                               DATA6437
      DATA ZGS/'ZGS1','ZGS2','ZGS3','ZGS4','ZGS5','ZGS6','ZGS7','ZGS8'/ DATA6438
C     NET TRANSMISSIVITY GAS TO  GAS                                    DATA6439
      DATA ZGG/'ZGG1','ZGG2','ZGG3','ZGG4','ZGG5','ZGG6','ZGG7','ZGG8'/ DATA6440
      COMMON /GAUSS/WT(9),XY(9),ARG(9,9),NPT                            DATA6441
C     GAUSSIAN QUADATURE METHOD USING ZERO OF LEGENDRE                  DATA6442
C     POLYNOMINALS AND THE CORRESPONDING WEIGHTS                        DATA6443
C     WEIGTHS ---- WT                                                   DATA6444
      DATA WT/0.08127439 , 0.18064816 , 0.26061070 , 0.31234708 ,       DATA6445
     1 0.33023936 , 0.31234708 , 0.26061070 , .18064816 , .08127439/    DATA6446
C     ABCISSAS --  XY                                                   DATA6447
      DATA XY /-.96816024,-.83603111,-.61337143,-.32425342,0.0,         DATA6448
     1 .32425342,.61337143,.83603111,.96816024/                         DATA6449
C     NUMBER OF QUADRATURE POINTS                                       DATA6450
      DATA   NPT   /9/                                                  DATA6451
      END                                                               DATA6452
```

```
      BLOCK DATA                                                        DATA6453
      COMMON/JAZZ3/SSNM(8,4),GSNM(8,3),SGNM(8,3),GGNM(8,3),SRSNM(8,4),  DATA6454
     1SRGNM(8,3),TSSNM(8,4),TGSNM(8,3),TSGNM(8,3),TGGNM(8,3)            DATA6455
C     SURFACE TO SURFACE DIRECT INTERCHANGE AREAS                       DATA6456
      DATA SSNM/'DSSA','DSSB','DSSC','DSSD','DSSE','DSSF','DSSG',       DATA6457
     1     'DSSH','DSSI','DSSJ','DSSK','DSSL','DSSM','DSSN'             DATA6458
     2,'DSSO','DSSP','DSSQ','DSSR','DSSS','DSST','DSSU','DSSV','DSSW',  DATA6459
     3'DSSX','DSSY','DSSZ','DSS1','DSS2','DSS3','DSS4','DSS5','DSS6'/   DATA6460
C     SURFACE TO GAS DIRECT INTERCHANGE AREAS                           DATA6461
      DATA GSNM/'DGSA','DGSB','DGSC','DGSD','DGSE','DGSF','DGSG',       DATA6462
     1     'DGSH','DGSI','DGSJ','DGSK','DGSL','DGSM','DGSN'             DATA6463
     2,'DGSO','DGSP','DGSQ','DGSR','DGSS','DGST','DGSU','DGSV','DGSW',  DATA6464
     3'DGSX'/                                                           DATA6465
C     GAS TO SURFACE DIRECT INTERCHANGE AREA                            DATA6466
      DATA SGNM/'DSGA','DSGB','DSGC','DSGD','DSGE','DSGF','DSGG',       DATA6467
     1     'DSGH','DSGI','DSGJ','DSGK','DSGL','DSGM','DSGN'             DATA6468
     2,'DSGO','DSGP','DSGQ','DSGR','DSGS','DSGT','DSGU','DSGV','DSGW',  DATA6469
     3'DSGX'/                                                           DATA6470
C     GAS TO GAS DIRECT INTERCHANGE AREA                                DATA6471
      DATA GGNM/'DGGA','DGGB','DGGC','DGGD','DGGE','DGGF','DGGG',       DATA6472
     1     'DGGH','DGGI','DGGJ','DGGK','DGGL','DGGM','DGGN'             DATA6473
     2,'DGGO','DGGP','DGGQ','DGGR','DGGS','DGGT','DGGU','DGGV','DGGW',  DATA6474
     3'DGGX'/                                                           DATA6475
C     SURFACE REFLECTIVITY WITH SURFACE AS THE EMITTER                  DATA6476
      DATA SRSNM/'SRSA','SRSB','SRSC','SRSD','SRSE','SRSF','SRSG',      DATA6477
     1     'SRSH','SRSI','SRSJ','SRSK','SRSL','SRSM','SRSN'             DATA6478
     2,'SRSO','SRSP','SRSQ','SRSR','SRSS','SRST','SRSU','SRSV','SRSW',  DATA6479
     3'SRSX','SRSY','SRSZ','SRS1','SRS2','SRS3','SRS4','SRS5','SRS6'/   DATA6480
C     SURFACE REFLECTIVITY  WITH GAS AS THE EMITTER                     DATA6481
      DATA SRGNM/'SRGA','SRGB','SRGC','SRGD','SRGE','SRGF','SRGG',      DATA6482
     1     'SRGH','SRGI','SRGJ','SRGK','SRGL','SRGM','SRGN'             DATA6483
     2,'SRGO','SRGP','DRGQ','SRGR','SRGS','SRGT','SRGU','SRGV','SRGW',  DATA6484
     3 'SRGX'/                                                          DATA6485
C     SURFACE TO SURFACE TOTAL INTERCHANGE AREA                         DATA6486
      DATA TSSNM/'TSSA','TSSB','TSSC','TSSD','TSSE','TSSF','TSSG',      DATA6487
     1     'TSSH','TSSI','TSSJ','TSSK','TSSL','TSSM','TSSN'             DATA6488
     2,'TSSO','TSSP','TSSQ','TSSR','TSSS','TSST','TSSU','TSSV','TSSW',  DATA6489
     3'TSSX','TSSY','TSSZ','TSS1','TSS2','TSS3','TSS4','TSS5','TSS6'/   DATA6490
C     SURFACE TO GAS TOTAL INTERCHANGE AREA                             DATA6491
      DATA TGSNM/'TGSA','TGSB','TGSC','TGSD','TGSE','TGSF','TGSG',      DATA6492
     1     'TGSH','TGSI','TGSJ','TGSK','TGSL','TGSM','TGSN'             DATA6493
     2,'TGSO','TGSP','DGSQ','TGSR','TGSS','TGST','TGSU','TGSV','TGSW',  DATA6494
     3'TGSX'/                                                           DATA6495
C     GAS TO SURFACE TOTAL INTERCHANGE AREA                             DATA6496
      DATA TSGNM/'TSGA','TSGB','TSGC','TSGD','TSGE','TSGF','TSGG',      DATA6497
     1     'TSGH','TSGI','TSGJ','TSGK','TSGL','TSGM','TSGN'             DATA6498
     2,'TSGO','TSGP','DSGQ','TSGR','TSGS','TSGT','TSGU','TSGV','TSGW',  DATA6499
     3'TSGX'/                                                           DATA6500
C     GAS TO GAS TOTAL INTERCHANGE AREA                                 DATA6501
      DATA TGGNM/'TGGA','TGGB','TGGC','TGGD','TGGE','TGGF','TGGG',      DATA6502
```

```
      1    'TGGH','TGGI','TGGJ','TGGK','TGGL','TGGM','TGGN'                 DATA6503
      2,'TGGO','TGGP','DGGQ','TGGR','TGGS','TGGT','TGGU','TGGV','TGGW',     DATA6504
      3'TGGX'/                                                              DATA6505
       END                                                                  DATA6506
```

```
      BLOCK DATA                                                        DATA6507
      COMMON/JAZZ4/ TSSNM(8,4),TGSNM(8,3),TSGNM(8,3),TGGNM(8,3),SS(8),  DATA6508
     1 GS(8),SG(8),GG(8)                                                DATA6509
C    SURFACE TO SURFACE TOTAL INTERCHANGE AREA                          DATA6510
      DATA TSSNM/'TSSA','TSSB','TSSC','TSSD','TSSE','TSSF','TSSG',      DATA6511
     1      'TSSH','TSSI','TSSJ','TSSK','TSSL','TSSM','TSSN'            DATA6512
     2,'TSSO','TSSP','TSSQ','TSSR','TSSS','TSST','TSSU','TSSV','TSSW',  DATA6513
     3'TSSX','TSSY','TSSZ','TSS1','TSS2','TSS3','TSS4','TSS5','TSS6'/   DATA6514
C    SURFACE TO GAS TOTAL INTERCHANGE AREA                              DATA6515
      DATA TGSNM/'TGSA','TGSB','TGSC','TGSD','TGSE','TGSF','TGSG',      DATA6516
     1      'TGSH','TGSI','TGSJ','TGSK','TGSL','TGSM','TGSN'            DATA6517
     2,'TGSO','TGSP','DGSQ','TGSR','TGSS','TGST','TGSU','TGSV','TGSW',  DATA6518
     3'TGSX'/                                                           DATA6519
C    GAS TO SURFACE TOTAL INTERCHANGE AREA                              DATA6520
      DATA TSGNM/'TSGA','TSGB','TSGC','TSGD','TSGE','TSGF','TSGG',      DATA6521
     1      'TSGH','TSGI','TSGJ','TSGK','TSGL','TSGM','TSGN'            DATA6522
     2,'TSGO','TSGP','DSGQ','TSGR','TSGS','TSGT','TSGU','TSGV','TSGW',  DATA6523
     3'TSGX'/                                                           DATA6524
C    GAS TO GAS TOTAL INTERCHANGE AREA                                  DATA6525
      DATA TGGNM/'TGGA','TGGB','TGGC','TGGD','TGGE','TGGF','TGGG',      DATA6526
     1      'TGGH','TGGI','TGGJ','TGGK','TGGL','TGGM','TGGN'            DATA6527
     2,'TGGO','TGGP','DGGQ','TGGR','TGGS','TGGT','TGGU','TGGV','TGGW',  DATA6528
     3'TGGX'/                                                           DATA6529
C    SURFACE TO SURFACE INTERCHANGE AREA -- REAL GAS                    DATA6530
      DATA SS/'SS-1','SS-2','SS-3','SS-4','SS-5','SS-6','SS-7','SS-8'/  DATA6531
C    SURFACE TO GAS INTERCHANGE AREA -- REAL GAS                        DATA6532
      DATA GS/'GS-1','GS-2','GS-3','GS-4','GS-5','GS-6','GS-7','GS-8'/  DATA6533
C    GAS TO SURFACE INTERCHANGE AREA REAL GAS                           DATA6534
      DATA SG/'SG-1','SG-2','SG-3','SG-4','SG-5','SG-6','SG-7','SG-8'/  DATA6535
C    GAS TO GAS INTERCHANGE AREA -- REAL GAS                            DATA6536
      DATA GG/'GG-1','GG-2','GG-3','GG-4','GG-5','GG-6','GG-7','GG-8'/  DATA6537
      END                                                               DATA6538
```

```
      BLOCK DATA                                                        DATA6539
      COMMON/JAZZ5/GS(8),SG(8),GG(8)                                    DATA6540
C   SURFACE TO GAS INTERCHANGE AREA -- REAL GAS                         DATA6541
      DATA GS/'GS=1','GS=2','GS=3','GS=4','GS=5','GS=6','GS=7','GS=8'/  DATA6542
C   GAS TO SURFACE INTERCHANGE AREA REAL GAS                            DATA6543
      DATA SG/'SG=1','SG=2','SG=3','SG=4','SG=5','SG=6','SG=7','SG=8'/  DATA6544
C   GAS TO GAS INTERCHANGE AREA -- REAL GAS                             DATA6545
      DATA GG/'GG=1','GG=2','GG=3','GG=4','GG=5','GG=6','GG=7','GG=8'/  DATA6546
      END                                                               DATA6547
```

```
      BLOCK DATA                                                        DATA6548
      COMMON /JAZZ6/ SG(8),GS(8),SS(8)                                  DATA6549
C   SURFACE TO SURFACE INTERCHANGE AREA -- REAL GAS                     DATA6550
      DATA SS/'SS=1','SS=2','SS=3','SS=4','SS=5','SS=6','SS=7','SS=8'/  DATA6551
C   SURFACE TO GAS INTERCHANGE AREA -- REAL GAS                         DATA6552
      DATA GS/'GS=1','GS=2','GS=3','GS=4','GS=5','GS=6','GS=7','GS=8'/  DATA6553
C   GAS TO SURFACE INTERCHANGE AREA REAL GAS                            DATA6554
      DATA SG/'SG=1','SG=2','SG=3','SG=4','SG=5','SG=6','SG=7','SG=8'/  DATA6555
      END                                                               DATA6556
```