# RADEXF: A USER GUIDE

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# 1. INTRODUCTION

RADEXF is a highly flexible, user friendly program to compute the various exchange factors (view factors, direct exchange areas and total exchange areas) required to carry out radiative heat transfer analyses using the zone method. RADEXF is designed to be able to perform calculations not only in idealised enclosures but also in realistic three-dimensional geometries. The atmosphere within the enclosure may itself absorb and emit thermal radiation, thereby participating in the radiative heat exchange. RADEXF allows for this by calculating not just surface to surface exchange factors but also gas to gas, gas to surface and surface to gas exchange factors.

This user guide sets out to give a potential user all the information needed to run RADEXF. Although RADEXF is user friendly, giving clear explanations of what is required at each stage, there are a few concepts, particularly that of the numbering of the zones, which may take the user a little time to become familiar with. These concepts are explained fully in this user guide.

A brief review of the zone method is given in Chapter 2 to remind the user of exactly what RADEXF is calculating. Chapter 3 contains the details of the few minor changes to the source code which may have to be made when moving RADEXF from one system to another. This chapter also describes the way in which RADEXF can be run (that is, with data coming from the terminal or from a number of files).

In order to calculate the exchange factors RADEXF needs to know the geometry of the enclosure and how this is to be split up into zones. The way the enclosure geometry is defined is described in Chapter 4. This geometry definition produces the finest zoning of the enclosure allowed. However, this fine zoning may not be the one required for the heat transfer calculations and so a coarser zoning may be specified. Chapter 5 shows how the coarser zoning is specified and how this zoning relates to the fine zoning produced by the definition of the enclosure geometry.

In order to interpret the results produced by RADEXF it is necessary to understand the systematic method used to order the surface and gas zones. This is explained in detail in Chapter 6.

The radiative properties of the gas are needed before the view factors and direct exchange areas can be calculated. RADEXF allows the user to define a number of different atmospheres. Each atmosphere has a different array of gas zone absorptivities. A complete set of exchange factors is produced for each atmosphere specified. In addition to the somewhat cumbersome method of setting all these absorptivities individually RADEXF offers a number of options which enable the gas absoprtivity array to be defined quickly. All these options are described in Chapter 6.

Although the surface radiative properties do not affect the view factors or direct exchange areas they are required to compute the total exchange areas. Chapter 7 details the options available for setting the surface zone emissivities.

In addition to the geometric details, the gas absorptivity and surface emissivity data there are a few other pieces of information required by RADEXF before it can calculate the exchange factors. This information is outlined in Chapter 9.

The next two chapters cover the files used and created by RADEXF. Chapter 10 deals with the output files, explaining exactly what results are produced. When RADEXF reads its input data from files, each file must have a particular structure. Details of the required structures are found in Chapter 11. Every time RADEXF is run with the data

entered from the terminal, input files are created. These files can be used to run RADEXF either exactly as they stand or with minor editing to examine the effect of small design changes. After editing, these files must still conform to the required structure, otherwise RADEXF will not be able to use them.

Finally, in Chapter 11, a sample run of RADEXF is given to take the user through the entire process from enclosure definition to interpretation of results.

It should be noted that, although RADEXF will calculate radiative exchange factors in any enclosure, it has been developed with industrial furnaces in mind. For this reason some of the terminology used throughout this user guide is oriented towards such applications. For example, the boundary of the enclosure must be divided into walls, hearth and roof. When RADEXF is used for enclosures other than furnaces, the hearth should be interpreted as meaning the floor or base of the enclosure. Objects within the enclosure must be designated as sources or sinks. A source is an object which supplies heat to the enclosure (such as a radiant tube within a furnace); a sink is an object which is heated (such as the load of a furnace).

# 2. THE ZONE METHOD

## 2.1 INTRODUCTION

The zone method, sometimes known as Hottel's method, the Hottel zone method or the radiosity–irradiance method, is the most widely used method of performing radiative heat transfer calculations in enclosures. It was first proposed in 1958 [1]. Since then it has been significantly developed and it has been used extensively to carry out radiative heat transfer analyses in furnaces, boilers and other industrial plant (see, for example, references [2–6]).

This chapter provides a brief outline of the zone method giving the definitions of the key concepts of view factor, direct exchange area and total exchange area. A fuller description of the zone method may be found in reference [7].

## 2.2 BASIC IDEAS

The basic idea of the zone method is to divide the enclosure and the medium it contains into a number of zones. If the medium within the enclosure is transparent to radiation (for example, air) then only the surfaces of the enclosure need to be divided up. However if the enclosed medium itself absorbs and emits radiation (for example, air containing combustion products) then this too must be divided into zones. It is usual to refer to the zones on the enclosure boundary as surface zones and the zones into which the enclosed medium is divided as gas zones.

Each zone must be small enough so that it may be regarded as having uniform temperature and other thermal properties (such as absorptivity or emissivity). It is assumed that all zones which emit radiation are diffuse (that is, there is no directional bias in the way the radiation is emitted). Furthermore, it is assumed that the system may be regarded as grey (that is, there is no spectral variation in the properties of any of the zones).

### 2.2.1 View Factors

When an enclosure has been divided into zones we can define the view factor $F_{ij}$ of zone j from zone i as the fraction of the radiation emitted from zone i which is directly incident upon zone j. This means that the radiation arrives at zone j from zone i without having been reflected at a surface zone within the enclosure. There are explicit mathematical formulae from which the view factors can be calculated. These cover the four cases where the sending zone is a surface or a gas zone and where the receiving zone is a surface or a gas zone. These formulae are:

Surface to Surface

$$F_{ij} = \frac{1}{A_i} \int_{A_i} \int_{A_j} \frac{\cos\theta_i \cos\theta_j \tau(r)}{\pi r^2} \, dA_j \, dA_i \qquad (2.1a)$$

Surface to Gas

$$F_{ij} = \frac{1}{A_i} \int_{A_i} \int_{V_j} \frac{k_{aj} \cos\theta_i \tau(r)}{\pi r^2} \, dV_j \, dA_i \qquad (2.1b)$$

Gas to Surface

$$F_{ij} = \frac{1}{4k_{ai}V_i} \int_{V_i} \int_{A_j} \frac{k_{ai}\cos\theta_j \tau(r)}{\pi r^2} \, dA_j \, dV_i \qquad (2.1c)$$

Gas to Gas

$$F_{ij} = \frac{1}{4k_{ai}V_i} \int_{V_i} \int_{V_j} \frac{k_{ai}k_{aj}\tau(r)}{\pi r^2} \, dV_j \, dV_i \qquad (2.1d)$$

where $A_i$ is the area of surface zone i, $\theta_i$ is the angle between the line joining a general point on the sending surface to a general point in the receiving zone, r is the length of the line connecting a general point in each zone, $k_{ai}$ is the absorptivity of gas zone i and $\tau(r)$ is the transmittance (that is, the fraction of radiation transmitted through a path of length r). The transmittance is given by

$$\tau(r) = \exp\left[ - \int_0^r k_a(s) \, ds \right] \qquad (2.2)$$

where s=0 denotes the start of the path (in the sending zone) and s=r denotes the end of the path (in the receiving zone).

It can be seen that when the gas in the enclosure is clear $k_{ai}=0$ for all gas zones and so $\tau(r)=1$. The only non-zero view factors are then the surface to surface ones.

It can be seen from these mathematical definitions that, for clear gases, the view factors are dependent solely on the enclosure geometry and not on any radiative properties. When the gas participates in the radiative heat transfer the view factors depend on the enclosure geometry and the gas absorptivity but not on any surface properties.

2.2.2 Direct Exchange Areas

The direct exchange areas are closely related to the view factors. They are simply the view factors multiplied by the effective area for radiation of the sending zone. For surface zones this effective area is simply the zone area, whilst for gas zones it is four times the product of the zone absorptivity and the zone volume. Direct exchange areas are usually denoted by lower cases symbols like $s_is_j$, $s_ig_j$, etc.

2.2.3 Total Exchange Areas

In radiative heat transfer calculations it is not just the direct exchange of radiation that is important. It is essential that the total exchange of energy (after possibly many surface reflections) is measured. The zone method requires total exchange areas to be calculated. These are usually denoted by upper case symbols such as $S_iS_j$, $S_iG_j$, etc. and are defined in the following ways:

$$\frac{S_iS_j}{\epsilon_iA_i} = \text{fraction of radiation emitted by surface zone i which is absorbed by surface zone j} \qquad (2.3a)$$

$$\frac{S_iG_j}{\epsilon_iA_i} = \text{fraction of radiation emitted by surface zone i which is absorbed by gas zone j} \qquad (2.3b)$$

$$\frac{G_iS_j}{4k_iV_i} = \text{fraction of radiation emitted by gas zone i which is absorbed by surface zone j} \qquad (2.3c)$$

$$\frac{G_iG_j}{4k_iV_i} = \text{fraction of radiation emitted by gas zone i which is absorbed by gas zone j} \qquad (2.3d)$$

The total amount of radiation emitted from a zone is $\epsilon_i A_i E_{bi}$ for a surface zone and $4k_i V_i E_{bi}$ for a gas zone, where $E_{bi}$ is the blackbody emissive power at the temperature of zone i. So, in a sense, total exchange areas give the effective area of blackbody radiative exchange between two zones.

When the total exchange areas are known the radiative heat loss from a zone can be found, from emission minus absorption, using the following formulae:

For surface zones

$$Q_{si} = \epsilon_i A_i E_{bi} - \Sigma S_j S_i E_{bj} - \Sigma G_j S_i E_{bj} \qquad (2.4a)$$

For gas zones

$$Q_{gi} = 4k_i V_i E_{bi} - \Sigma S_j G_i E_{bj} - \Sigma G_j G_i E_{bj} \qquad (2.4b)$$

where in each of these formulae the first sum is over the surface zones and represents the total amount of radiation emitted by any surface zone which is absorbed by zone i; and the second sum is over the gas zones and represents the total amount of radiation emitted by any gas zone which is absorbed by zone i.

There are no compact integral formulae similar to equations (2.1) giving total exchange areas. They can be calculated from knowledge of the complete set of direct exchange areas. The formulae for the calculation of the matrix of total exchange areas from the direct exchange areas can be found in reference [8]. Total exchange areas require full knowledge of the radiative properties of the enclosure before they can be calculated.

# 3. INSTALLING AND RUNNING RADEXF

## 3.1 SYSTEM DEPENDENCY

The code for RADEXF consists of a main module, RADEXF.F; an include file, COMVAR.F; and various subroutine files DATAIN.F, GEOMRY.F, GSABIN.F, EMISIN.F, FACTALL.F, OUT.F. Virtually all the FORTRAN code used is standard FORTRAN 77 so there is very little system dependency within RADEXF. Very few changes are needed to the basic code when moving it from one machine/operating system configuration to another. The few required changes relate to input and output channel numbers, random number generators and the use of include files.

### 3.1.1 Input and Output Channel Numbers

At various times RADEXF reads from the standard input channel and writes to the standard output channel. Within RADEXF these two channels are known as LUSTIN and LUSTOT respectively. Depending on the operating system in use the numbers of these channels may vary. For example, under UNIX both are channel 0; whilst under VAX/VMS standard input is from channel 5 and standard output is to channel 6.

The variables LUSTIN and LUSTOT are set in the first few exectuable lines of the main program module in RADEXF.F. These lines need to be set according to the operating system in use.

| | |
|---|---|
| Under UNIX: | LUSTIN=0 |
| | LUSTOT=0 |
| Under VAX/VMS: | LUSTIN=5 |
| | LUSTOT=6 |

### 3.1.2 Random Number Generator

Standard FORTRAN 77 does not have a random number generator as an intrinsic function. However virtually all mainframe FORTRAN compilers do. The operation of the random number generators of these different compilers is not identical and so it is important to check in the system FORTRAN compiler manual that the format of the function is correct.

RADEXF assumes that the random number generator is a FORTRAN function called RAN(IRAN). The single argument IRAN is an INTEGER*4 variable. This variable is often called the initial seed for a random sequence. Most random number generators require the user to give IRAN an initial value and then they will generate a sequence of pseudorandom numbers from that initial seed. If the value of IRAN is changed then a new sequence of random numbers will be generated. RADEXF sets the value of IRAN in the first few exectuable lines of the main program module in RADEXF.F and it is then unchanged, being passed to all those subroutines which call the random number generator. The initial value to be given to IRAN will depend on the exact nature of the algorithm used to generate the random numbers. Guidelines will be found in the system FORTRAN compiler manual.

The UNIX FORTRAN compiler requires the initial value of IRAN to be a positive integer. Whilst the VAX/VMS FORTRAN compiler requires the initial value of IRAN to be a large odd integer. It is thus possible to transfer from UNIX to VAX/VMS without making any changes; setting IRAN=987654321 is satisfactory for both compilers. However when using other compilers it may be necessary to change the value of IRAN.

If it is required to use RADEXF on a system for which the FORTRAN compiler's random number generator does not have the form RAN(IRAN) a simple function, called RAN(IRAN), which invokes the compiler's random number generator may be written, compiled and linked to the rest of the RADEXF code.

The differences in the random number generators of different machines mean that when RADEXF is run on different machines it will not produce exactly the same answers.

### 3.1.3 The INCLUDE file

Most FORTRAN compilers have compiler directives which are an extension to standard FORTRAN 77. One such directive is INCLUDE. This allows a file containing FORTRAN code to be textually included in the program source as if the actual contents of the included file had been written there. This is most often used to ensure that COMMON blocks are identical in all the subroutines in which they are used. RADEXF includes the file COMVAR.F in the main program module and in a number of subroutines. The exact form of the compiler directive INCLUDE varies with the operating system.

Under UNIX:

```
$      include comvar.f
```

Under VAX/VMS:

```
       include 'comvar.f'
```

All occurrences of the compiler directive INCLUDE within RADEXF must be changed to the appropriate form for the operating system used. INCLUDE is used twice in RADEXF.F (in the main module and in the block data routine); 18 times in GEOMRY.F (at the start of various subroutines); and 6 times in FACTALL.F (at the start of various subroutines).

## 3.2 ARRAY SIZES

RADEXF is written in FORTRAN 77. This means that arrays must be dimensioned at compilation. One possibility is to ensure that all array dimensions are so large that there is sufficient space to store the data for the largest conceivable run of RADEXF. However, this is very wasteful in that it will generate very large exectuable files which will run more slowly than is necessary. A better option is to allow the user to change the array dimensions when appropriate. The array dimensions are all defined by parameters set in COMVAR.F. If a particular dimension is not large enough all that is required is to alter the relevant parameter in COMVAR.F and then recompile RADEXF. Further details about the meanings of the various parameters are found in Chapter 9.

## 3.3 MODE OF DATA ENTRY

RADEXF will calculate any or all of the three radiative exchange factors, namely, view factors, direct exchange areas and total exchange areas. In order to do so it must know the geometry of the enclosure under consideration, the gas absorptivities and, if total exchange areas are required, the surface emissivities. Thus, there are up to three distinct types of data required. The actual data required is described in detail in the following chapters. The purpose of this section is to describe the options for data entry.

There are three possible modes of data entry: interactive, non-interactive and quasi-interactive.

### 3.3.1 Interactive Data Entry

The geometric, absorptivity and emissivity data (if required) is all entered at the terminal. Three data files, containing the interactively entered data, are created. These data files can be read by RADEXF when used in quasi-interactive or non-interactive mode.

### 3.3.2 Quasi-Interactive Data Entry

The geometric data is read from a file. This data can then, if desired, be modified using an interactive geometric editing facility. If the geometric data is edited in this way a new data file is created. The gas absorptivity data may be read from the terminal, from a file or from both. If this last option is selected data is read firstly from a file and then the user is allowed to enter further data from the terminal. A data file containing all the data used (that is, the data from the file and the data from the terminal) is created. The emissivity data, if required, is read from the terminal or a file. If the data is entered at the terminal a file is created. All files created can be read by RADEXF when used in quasi-interactive or non-interactive mode.

### 3.3.3. Non-Interactive Data Entry

The geometric, absorptivity and emissivity data (if required) are read from three separate data files. These files will usually have been created by an interactive or quasi-interactive run of RADEXF. However, they may be created directly provided they have the correct format. The exact format of these files is given in Chapter 11.

# 4. DEFINING THE GEOMETRY

## 4.1 INTRODUCTION

The first requirement of RADEXF is to know the geometry of the enclosure under consideration. In determining which geometries are allowed, two competing goals have had to be balanced. On the one hand it was desired to make the input procedures relatively simple; whilst on the other hand there was a requirement to have as few restrictions as possible on the geometries that could be represented. In general, as more freedom is allowed in the overall geometry of the enclosure so greater complexity of the input is required. The compromise reached in RADEXF allows a high level of flexibility in the geometries that can be represented whilst at the same time maintaining the input at an acceptable level. This is achieved in the following way. The enclosure must have a uniform external cross-sectional shape. This shape is made up of straight line segments. The plane of the cross-section is regarded as the xy plane and the direction perpendicular to this is the z direction. The cross-section is extruded in the z-direction to obtain a three-dimensional enclosure.

It will often be necessary to place objects within the enclosure. For example, if the enclosure is a furnace, the load which is to be heated and/or radiant tubes as a supply of heat lie within the enclosure. Throughout this user guide any object within the enclosure is referred to as an obstacle. As with the external enclosure shape, a compromise had to be made between flexibility and simplicity of data entry. The balance was achieved by allowing obstacles to be cuboids (rectangular boxes) or cylinders.

The complete geometry is defined in three stages: the uniform cross-section; the extruded direction details; and the obstacles. The following sections describe how this is done.

## 4.2 DEFINING THE ENCLOSURE CROSS-SECTION

The uniform cross-sectional shape is defined by its vertices. RADEXF must be told how many vertices there are and their x,y co-ordinates. RADEXF joins consecutive vertices with straight lines. All enclosures must be closed and so RADEXF automatically joins the last vertex to the first.

For reasons related to the way in which RADEXF carries out its calculations it is important that the first vertex entered is the one at the start of the floor (hearth) of the enclosure and that the vertices are entered in an anticlockwise order. It is not possible for the walls of an enclosure to cross. If any of the line segments defining the enclosure cross-section intersect then RADEXF will give an error message and abort.

In order to have a systematic method of numbering (as described in Chapter 6) RADEXF needs to know which parts of the enclosure cross-section represent the floor (hearth), the roof and the walls. The floor and roof are specified by giving the numbers of the vertices at their start and end. Those parts of the perimeter of the cross-section not included in the floor and roof make up the walls.

As an example, consider the cross-sectional shape shown in Figure 1. This has 7 vertices at (0,0), (4,0), (4,1), (3,1), (2,2), (1,1), (0,1). RADEXF must be told that there are 7 vertices and then the co-ordinates should be given in the order just stated (that, starting at the beginning of the floor and proceeding anticlockwise round the perimeter). The floor is from vertex 1 (0,0) to vertex 2 (4,0); and the roof is from vertex 7 (0,1) to vertex 3 (4,1). The walls are thus vertex 2 to vertex 3 and vertex 7 to vertex 1.

## 4.3 DEFINING THE THIRD DIMENSION

The uniform cross-sectional shape is extruded perpendicular to itself (that is, in the z direction) to make the enclosure three-dimensional. RADEXF needs to know the depth of the extrusion and into how many slices this depth is to be divided. The purpose of dividing the enclosure into slices is to allow it to be zoned in the desired way (this is explained in Chapter 5).

RADEXF must be told how many slices in the z direction are required and the thickness of each slice. From this information it calculates the total depth of the enclosure.

The enclosure shown in Figure 6 has a depth of 2 units. If two equal thickness slices are required RADEXF is told that there are 2 slices, each with thickness 1. The slices do not have to have the same thickness. For example, it would have been possible to have 4 slices with thicknesses 0.5, 0.2, 0.6 and 0.7.

## 4.4 DEFINING THE OBSTACLES

The obstacles recognised by RADEXF are cuboids (rectangular boxes) and cylinders. The cuboids must be aligned so that their edges are parallel to the co-ordinate axes, whilst cylinders must be aligned so that the axis of symmetry is parallel to one of the co-ordinate axes.

RADEXF must be informed how many obstacles there are. Then for each obstacle its shape and location must be specified. The shape is given by a single letter: B for boxes and C for cylinders. RADEXF is not case sensitive; upper and lower case letters are acceptable.

The location of boxes is given by supplying two (x,y,z) co-ordinates, referred to as the low and high co-ordinates of the box. These are the co-ordinates of vertices of the box at opposite ends of a diagonal. The low co-ordinates are the smallest values of x, y and z which lie on the surface of the box. The high co-ordinates are the largest values of x,y, and z which lie on the surface of the box. These co-ordinates are illustrated in Figure 0. It should be noted that in this, and all figures in this guide, a left handed co-ordinate system is used.

A cylinder has two plane circular faces. The cylinder's axis of symmetry is parallel to one of the co-ordinate axes, say the w axis (where w is x, y or z). The w co-ordinates of the centre of these two plane circular faces are wmin and wmax (with wmin<wmax). The plane face whose centre has w co-ordinate wmin is called the low face and the plane face whose centre has w co-ordinate wmax is called the high face. For cylindrical obstacles it is necessary to first specify the (x,y,z) co-ordinates of the centre of the low face. To uniquely define the cylinder once the co-ordinates of the centre of the low face have been set it is necessary to tell RADEXF the radius of the cylinder, the co-ordinate axis to which the cylinder is parallel and the value of wmax (the w co-ordinate of all points on the high face). This information completely defines the cylinder.

When the location of the obstacle, be it box or cylinder, has been defined RADEXF requires one further piece of information about the obstacle. It must know whether the obstacle is a sink (like the load of a furnace) or a source (such as radiant tubes in a furnace). This information is required not primarily by RADEXF (although it will affect the zone number attached to a particular obstacle, see Section 6.4) but by codes which will often be used to process output from RADEXF when furnaces are being modelled. In terms of the calculation of exchange factors it is of no significance whatsoever whether an obstacle is a source or a sink. If RADEXF is being used in an application where this terminology is inappropriate, or where it is not known whether a particular obstacle is a source or a sink the user may choose arbirtrarily whether each obstacle is a source or a sink.

# 5. ZONING THE ENCLOSURE

## 5.1 INTRODUCTION

The purpose of RADEXF is to provide radiative exchange factors which can be used in the zone method. It is thus necessary to be able to divide the enclosure into a number of zones. RADEXF organises its zoning by means of two distinct grids: the fine (geometric) grid and the coarse (heat transfer) grid. The purposes of the two grids and exactly what constitutes them is described below. It should be noted here that the grid lines and the vertices which produce them are merely tools which enable us to define surface and volume elements. The size and shape of the zones is the crucial factor in the radiative heat transfer analysis. The way in which these are defined using fine and coarse grids will often not be unique, but this does not matter as long as the surfaces and volumes are unambiguously and correctly defined.

## 5.2 THE FINE (GEOMETRIC) GRID

Every vertex defines a pair of grid lines: one in the x direction and one in the y direction. For example, suppose there is a vertex at (3,2), then the lines x=3 and y=2 will be grid lines on the fine grid. Often fine grid lines will coincide. For example, the enclosure shown in Figure 1 has seven vertices but there are only 5 x fine grid lines (at x=0, x=1, x=2, x=3 and x=4) and 3 y fine grid lines (at y=0, y=1 and y=2). Thus the basic cross-sectional shape has been divided into 6 elements: four unit squares and two triangles. The perimeter of the cross-section has been divided into 10 line segments.

Each slice in the z direction defines a z fine grid line. So, if the enclosure of Figure 1 is divided into two equal slices there are z fine grid lines at z=0, z=1 and z=2. The ends of the enclosure (in the planes x=0 and x=4) are then each made up of two unit squares (one in each slice); the floor of the enclosure is made up of 8 unit squares (4 in each slice) and the roof is divided into 8 parts: 4 horizontal unit squares in the plane y=1 and 4 inclined rectangles.

The fine grid represents the smallest number of grid lines necessary to represent the geometry (hence the geometric grid). It can be used to define a zoning of the enclosure. For the enclosure of Figure 1 the wall surface in the plane z=0 has been divided into 6 zones, similarly for the wall surface in the plane z=2. The boundary in each of the two slices has been divided into 10 zones. The enclosed volume has been divided into 12 volume zones (6 in each slice). The volumes produced by the fine grid lines are sometimes referred to as cells.

Whatever the geometry, one purpose of the fine grid is to define the geometry as accurately as required. For some geometries, the fine grid may have a second function, namely, to achieve the zoning required for the exchange information. This is because the fine grid gives the finest zoning of the enclosure which is permissible. Sometimes, from the heat transfer point of view, this zoning may not be regarded as fine enough. In such cases extra fine grid lines may be added by specifying extra vertices and/or by having more (and hence thinner) slices. The extra vertices are simply points which lie on the straight line segments that make up the perimeter of the cross-section

For example, suppose the cross-sectional shape is a unit square. This may be defined by its four corners ((0,0), (1,0), (1,1) and (0,1)) leading to only 2 x fine grid lines and 2 y fine grid lines. This gives only one surface zone in the plane z=0 and only one volume zone in each slice. These zones may be too large for the assumptions of uniform properties within each zone to be reasonably accurate. Smaller zones may be achieved by

introducing extra (artificial) vertices at the mid-points of any two perpendicular sides (say, ($\frac{1}{2}$,0) and (1,$\frac{1}{2}$)). The extra vertices do not alter the actual shape of the enclosure, but they do introduce extra fine grid lines, dividing each slice into four volume zones.

The enclosure shown in Figure 1 may be defined by the 12 vertices (0,0), (0.5,0), (1.5,0), (3.5,0), (4,0), (4,0.5), (4,1), (3,1), (2.5,1.5), (2,2), (1,1), (0,1). This produces fine grid lines at x=0, x=0.5, x=1, x=1.5, x=2, x=2.5, x=3, x=3.5, x=4 and y=0, y=0.5, y=1, y=1.5, y=2. There is no need to include vertices at (1,0), (2,0), (2.5,0) and (3,0) as the grid lines at x=1, x=2, x=2.5, x=3 are already produced by other vertices. If desired these vertices may be included but the fine grid produced will be exactly the same.

Usually, however, the problem will not be that the grid imposed by the vertices is not fine enough, but that it is too fine for the radiative exchange analysis (for example, it may produce too many zones). In these cases sets of the fine grid zones must be grouped together to make up coarse grid zones. The coarse grid (or heat transfer grid) is a subset of the fine grid and produces a more sensible number of zones. The details of the specification of the coarse grid are given in the next section.

## 5.3 THE COARSE (HEAT TRANSFER) GRID

The fine grid arises from the need to accurately represent the geometry of the enclosure. The zoning produced by the fine grid may not be the one required for the heat transfer analysis. As discussed in the last section, if this zoning is not fine enough extra vertices may be added. To combat the more frequent problem of the geometric grid being too fine a second grid, the coarse grid, is defined.

The coarse grid is made up of a subset of the fine grid lines. This is achieved by nominating certain vertices to be on the coarse grid. Only x and y fine grid lines which pass through nominated vertices are deemed to be on the coarse grid. For the enclosure of Figure 1 it may be that it is desired to divided the cross-section into the four regions shown in Figure 3, rather than the six regions of Figure 1. This can be done by defining the shape using 9 vertices: (0,0), (1,0), (3,0), (4,0), (4,1), (3,1), (2,2), (1,1), (0,1). Vertices 1, 2, 3, 4 and 7 are nominated as lying on the coarse grid. This produces coarse grid lines at x=0, x=1, x=2, x=3, x=4 and at y=0, y=2. It should be observed that for this example the vertices (1,0) and (3,0) are not needed to define the shape of the cross-section of the enclosure, but without them the desired coarse grid cannot be achieved. The vertices at (1,1) and (3,1) cannot be used to produce the grid lines x=1 and x=3 as they will also include the grid line y=1, which is not wanted.

RADEXF automatically includes the fine grid lines with the least and greatest value in each co-ordinate direction (the extreme fine grid lines) within the coarse grid irrespective of whether vertices lying on these grid lines have been nominated as being on the coarse grid. The automatic inclusion of extreme fine grid lines within the coarse grid extends the range of coarse grid zoning which may be produced. For the enclosure shown in Figure 1 it may be desired to divided the cross-section into only three regions, by the lines x=1 and x=3, as shown in Figure 4. In order to achieve this the vertex at (2,2) must not be specified as part of the coarse grid. Without the automatic inclusion of extreme fine grid lines the vertex at (2,2) would be the only way of including the line y=2 within the coarse grid. The division shown in Figure 4 can be achieved by using the same nine vertices as before to define the shape and then nominating only vertices 1, 2, 3 and 4 as being on the coarse grid. It should be noted that this is not the only way of achieving the desired coarse grid. Vertices 1 and 4 do not need to be included on the coarse grid as the lines x=0, x=4 and y=0 would automatically be part of the coarse grid as they are extreme fine grid lines. This serves to reinforce the point made earlier that it is the actual zoning produced that matters and not the particular combination of vertices used to arrive at it.

The idea of using a coarse grid is also available in the z direction. Fine grid lines lie at the end of each slice. The user may select some or all of these as comprising the coarse

grid. Again the extreme fine grid lines are automatically placed on the coarse grid.

## 5.4 CHECKING AND CHANGING THE GRIDS

The cross-sectional shape of the enclosure and the coarse gridding in the x and y directions are defined at the same time. After the co-ordinates of each vertex have been entered RADEXF reads an input data flag which specifies whether or not that vertex lies on the coarse grid. When RADEXF is used in interactive or quasi-interactive mode a facility is available which allows the user to check the cross-sectional shape defined and if it is not correct to alter it without aborting that run of RADEXF and beginning again.

When all the vertex data has been entered the option is given of producing a picture of the cross-section. This is a crude "line printer" type picture. A graphics terminal is not required to produce such a picture - it can be produced on any terminal screen.

Whether or not the user requested a picture the option is given of reviewing the vertices. If this option is selected a list of the vertices that have been defined and their coarse grid flags is given. The user can then edit this list if desired. Four options are available within the vertex editor: extra vertices can be added, existing vertices can be altered or deleted, the whole set of vertices can be rejected and vertex entry restarted. When the user exits from the vertex editor the picture option is given again so that any changes made to the cross-sectional shape may be visually checked if desired.

## 5.5 WARNINGS

In order to prevent some of the subroutines within RADEXF from being unnecessarily complicated (and thereby reducing computational speed) it has been necessary to impose certain geometrical restrictions. In practice the user will rarely, if ever, notice these restrictions.

1. In the fine grid, each cell may not contain more than 1 sloping wall. A cell can contain more than one wall; however all but one (at most) of these must be along x or y grid lines.

2. In the fine grid, only one obstacle is allowed in each cell. If this is a problem for a particular enclosure, it can be overcome by adding new vertices. This introduces new grid lines, thereby splitting cells which would have contained more than one obstacle into smaller cells each of which contain at most one obstacle.

3. In the fine grid, the circular cross-section of cylindrical obstacles must lie within one cell.

If any of these restrictions is contravened RADEXF will produce an error message warning the user about what has happened and the run will abort.

# 6. ZONE NUMBERING

## 6.1 INTRODUCTION

In order to be able to interpret the results produced by RADEXF it is necessary to know the way in which RADEXF numbers the surface and gas zones which have been defined by the coarse grid. The user needs to know which surfaces of the enclosure comprise surface zone I and which part of the enclosed volume is being referred to when considering gas zone J. The following sections described the systematic method used by RADEXF to number the surface and gas zones.

## 6.2 EXTERNAL SURFACE ZONE NUMBERING

The results of RADEXF are the relevant exchange factors for the zones produced by the coarse grid outlined in the last section. In order to be able to interpret these results the user must understand how RADEXF numbers the zones. The generality of the enclosure shapes which may be defined requires a systematic method of ordering the zones so that it is possible for the user to determine which zones a particular exchange factor refers to.

The systematic method used by RADEXF is based on using the unique box which just bounds the entire enclosure. The extreme grid lines (fine or coarse - they are the same) define a box which runs from $x=X_1$ to $x=X_2$, from $y=Y_1$ to $y=Y_2$ and from $z=Z_1$ to $z=Z_2$ (where in each case $.1<.2$). No smaller box contains the entire enclosure, whilst any larger box has some spare capacity which could be removed without removing any of the enclosure. Each face of this box is divided into a number of rectangles by the coarse grid lines. Each surface zone of the enclosure is associated with one of these rectangular sub-faces by "projection" outwards. This means that surface zones in the planes $z=Z_1$ and $z=Z_2$ are associated with the rectangular sub-face of the bounding box of which they are a part. Surface zones that make up the floor are associated with rectangular sub-faces in the face $y=Y_1$ of the bounding box. Similarly, zones in the roof of the enclosure are "projected" onto bounding box sub-faces in the plane $y=Y_2$. Zones in the left wall are "projected" onto the face $x=X_1$, and those in the right wall are associated with sub-faces of the face $x=X_2$. This outward projection onto the bounding box is made unique by knowledge of the location of roof, walls and hearth.

The method just described allows each coarse grid zone to be associated with a rectangular sub-face of the bounding box. All that is now required is to number the faces of the bounding box in a systematic way and the surface zone numbering is complete. To describe this method of numbering in abstract is somewhat verbose. It is easier to illustrate by an example.

Consider the enclosure of Figure 1. This may be defined by the seven vertices shown in Figure 1. The uniform depth of 2 units may be split into 2 slices each of width 1. If all fine grid lines are included on the coarse grid the resulting heat transfer grid consists of the grid lines x=0, x=1, x=2, x=3, x=4; y=0, y=1, y=2; and z=0, z=1, z=2. The bounding box thus runs from x=0 to x=4, from y=0 to y=2 and from z=0 to z=2. The number of divisions in the three co-ordinate directions is thus 4, 2 and 2 respectively. The bounding box, with its faces divided into rectangular sub-faces is shown in Figure 5. There are a total of 40 sub-faces. These are numbered in the following way. Firstly, those in the face x=0 are numbered. Within this face the numbering proceeds along the bottom row (that is, the smallest y co-ordinates) in the direction of z increasing (numbers 1 and 2). Then the next row is numbered in the direction of z increasing (numbers 3 and 4). In this example there are only two rows and so the face x=0 has been

numbered. The next stage is to number all sub-faces between x=0 and x=1. There are 8 of these. Those in the faces z=0 and z=2 are numbered first, again starting at the bottom and working upwards. These are faces 5, 6, 7 and 8 (as shown in Figure 5). The floor comes next (numbers 9 and 10) in the direction of z increasing and then the roof (numbers 11 and 12) again with z increasing. All the sub-faces between x=1 and x=2 are numbered next, using the same order as for the last eight (that is, walls z=0 and z=2 together, floor and roof). These are sub-faces 13-20. The same method continues through the x divisions (numbers 21-28 in the next x division and 29-36 in the final x division). Finally the right face x=4 is numbered, starting from the bottom row and working up the rows, each time in the direction of z increasing (numbers 37-40).

Essentially, this numbering could be described as cycling in z, embedded in cycling in y, embedded in cycling in x. It can readily be observed that if there are N divisions in the x direction, M in the y direction and L in the z direction then the total number of sub-faces of the bounding box will be 2(NM+ML+LN).

The way in which the surface zones of the enclosure are associated with the sub-faces of the bounding box is straightforward in this example. Each surface zone lying in the planes z=0 and z=2 are associated with the sub-face of which it is a part (or the whole). Similarly with the ends of the enclosure in the planes x=0 and x=4 and the floor of the enclosure in the plane y=0. The roof of the enclosure is projected upwards onto the top of the bounding box (the plane y=2) in the obvious manner, as illustrated in Figure 6.

It should be observed that whilst every surface zone of an enclosure is associated with a unique sub-face of the bounding box there may be some sub-faces which have no surface zone associated with them (in the example, sub-faces 3, 4, 7, 8, 31, 32, 39, 40). Zones like this have no exchange factors and so no results will be given for them in the output file. In the example, there are 40 sub-faces of the bounding box but the enclosure has only 32 surface zones. These surface zones are however not numbered 1 to 32, but with a subset of the numbers 1-40 in the way just described. The results file gives only 32 surface to surface exchange factors for each surface zone as there are, in reality, only 32 surface zones.

In this example the association of enclosure surface zones with sub-faces of the bounding box is obvious. However, this may not always be the case. If the ends of the enclosure are not simple vertical walls there may be some ambiguity about where the walls, roof and floor begin and end. This is why the user must tell RADEXF the vertices which mark the ends of the roof and the floor whilst defining the cross-sectional shape of the enclosure. With the roof and floor set in this way all ambiguity is removed.

## 6.3 GAS ZONE NUMBERING

The numbering of the gas zones is very straightforward compared to the numbering of the external surface zones. The coarse grid lines divide the bounding box into a number of cuboids. Each volume zone produced by the coarse grid is a part (or all) of just one of these cuboids. These cuboids are numbered in the same spirit of cycling in z, embedded in cycling in y, embedded in cycling in x. So, the gas zones in the first x division are numbered first, starting with the bottom row moving in the direction of z increasing. Moving up through the rows, each time numbering in the direction of z increasing completes the numbering of the cuboids in the first x division. The subsequent x divisions can be numbered in the same way. The numbering of the 16 cuboids of the bounding box of Figure 5 is shown in Figure 7.

If there are N divisions in the x direction, M in the y direction and L in the z direction then it is easy to see that there are NML cuboids within the bounding box. There is a simple formula for calculating the number of a particular gas zone within an enclosure. Suppose a gas zone lies within (or is all of) the cuboid in x division I, y division J and z division K then its number is (I-1)ML+(J-1)L+K. The numbering of the gas zones of the enclosure used as the example of the last section is shown in Figure 8.

Just as with surface zones, it can be seen that whilst every gas zone is uniquely associated with a cuboid within the bounding box there are some cuboids which have no gas zone associated with them. In the example, cuboids 3, 4, 15, 16 have no gas zone associated with them. This is because the enclosure actually has only 12 gas zones. Results will only be given for these 12 zones.

## 6.4 OBSTACLE ZONE NUMBERING

The obstacles within the enclosure have surfaces which must be divided into zones and which must then be numbered. The obstacle surface zones must be numbered in a systematic way. As described in the last section the bounding box is divided by the coarse grid lines into a number of cuboids (NML in the notation of the last section), each of which is, or contains, a volume zone. Each fine grid cell may contain at most one obstacle. There is no such restriction in the coarse grid. There may be more than one obstacle in a coarse grid volume zone. Also, an obstacle may occupy space in more than one coarse grid zone.

Although, geometrically, RADEXF allows more than one obstacle in a coarse volume zone, from the heat transfer point of view there are only two obstacle surface zones within each volume. Firstly all the sink (load) surfaces in the volume zone are taken together to form a surface zone and then all the source surfaces are taken together to form a second surface zone. This means that there are 2NML obstacle surface zones, although many of them may be surface zones with zero area (and therefore no exchange factors) as many cuboids may contain no obstacle. No exchange factors are produced for such zones.

A method of numbering the cuboids has been described for the gas zone numbering. Using this numbering there is a simple formula for determining the numbers of the obstacle surfaces in a particular cuboid. The sink surfaces in cuboid I are surface zone number $2(NM+ML+LN)+2I-1$, whilst the source surfaces in cuboid I are surface zone number $2(NM+ML+LN)+2I$. The component $2(NM+ML+LN)$ represents the number of external surface zones.

The systematic method of numbering the surface zones just described makes it possible to determine, from the number of a surface zone, exactly which part of the surface of an enclosure it represents.

# 7. DEFINING THE GAS ABSORPTIVITES

## 7.1 INTRODUCTION

RADEXF must be informed of the nature of the gas contained within the enclosure. It needs to know the absorptivity of the atmosphere in each gas zone. For a given geometrical configuration RADEXF can calculate the exchange factors for a number of different atmospheres. This is particularly important if a "sum of grey gases" model is being used to represent an atmosphere which exhibits some spectral variation in the radiation it emits and absorbs. Exchange factors are automatically calculated for a clear atmosphere (that is, one which does not participate in the radiative energy exchange). Further exchange factors are calculated at the request of the user. A complete set of exchange factors is calculated for each atmosphere which is defined.

In order to use the zone method it is necessary that each gas zone has uniform absorptivity. However, different zones may have different absorptivities.

To simplify the user's task in defining the gas absorptivity thoughout the enclosure RADEXF offers a number of options. These are:

1. Gas absorptivity uniform throughout the enclosure.
2. Gas absorptivity set individually for each zone.
3. Gas absorptivity set using a "sum of grey gases" model with uniform excess air throughout the enclosure and no carbon particles present.
4. Gas absorptivity set using a "sum of grey gases" model with uniform excess air and uniform carbon concentration throughout the enclosure.
5. Gas absorptivity set using a "sum of grey gases" model with uniform excess air throughout the enclosure and carbon concentration set indiviually for each zone.
6. Gas absorptivity set using a "sum of grey gases" model both with excess air level and carbon concentration set individually for each zone.

The following six sections describe the data required by each of these options. The grey gas model uses three gases. Full details of this model can be found in Appendix A.

## 7.2 UNIFORM ABSORPTIVITY

This is the most straightforward way of setting the gas absorptivity. RADEXF requires a single value which it then automatically allocates to each zone.

## 7.3 INDIVIDUALLY SET ABSORPTIVITIES

The value of the absorptivity for each gas zone must be provided. If these data are entered interactively the user will be prompted for each value with a summary of the volume whose absorptivity is about to be set.

## 7.4 "SUM OF GREY GASES" MODEL - UNIFORM EXCESS AIR, NO CARBON

The user must first select the fuel type used in the combustion. There are three possibilities: natural gas, gas oil and heavy fuel oil. RADEXF must then be told the excess air level that produced the combustion products and from this calculates two absorptivity values. Two atmospheres with uniform absorptivity throughout the enclosure are then defined and so two complete sets of exchange factors will be produced. The

user must average these appropriately to obtain the directed flux areas.

## 7.5 "SUM OF GREY GASES" MODEL - UNIFORM EXCESS AIR & CARBON CONCENTRATION

The user must first select the fuel type used in the combustion. There are three possibilities: natural gas, gas oil and heavy fuel oil. RADEXF must then be told the excess air level that produced the combustion products and the carbon particle concentration. From these it calculates six absorptivity values. Six atmospheres with uniform absorptivity throughout the enclosure are then defined and so six complete sets of exchange factors will be produced. The user must average these appropriately to obtain the directed flux areas.

## 7.6 "SUM OF GREY GASES" MODEL - UNIFORM EXCESS AIR & VARYING CARBON CONCENTRATION

The user must first select the fuel type used in the combustion. There are three possibilities: natural gas, gas oil and heavy fuel oil. RADEXF must then be told the excess air level that produced the combustion products and the carbon particle concentration for each gas zone. From these it calculates six absorptivity values for each zone, thereby defining six different atmospheres. Six complete sets of exchange factors will be produced. The user must average these appropriately to obtain the directed flux areas.

## 7.7 "SUM OF GREY GASES" MODEL - VARYING EXCESS AIR & CARBON CONCENTRATION

The user must first select the fuel type used in the combustion. There are three possibilities: natural gas, gas oil and heavy fuel oil. In order to allow the gas composition to vary throughout the enclosure the excess air level is given for each zone. The concentration of carbon particles is also given for each zone. RADEXF calculates six absorptivity values for each zone, thereby defining six different atmospheres. Six complete sets of exchange factors will be produced. The user must average these appropriately to obtain the directed flux areas.

# 8. DEFINING THE SURFACE EMISSIVITIES

## 8.1 INTRODUCTION

If total exchange areas are required it is necessary to know the emissivities of all the surface zones. One of the basic assumptions of the zone method is that the emissivity of each zone is uniform. However, different zones may have different emissivities.

To simplify the user's task of defining the surface zone emissivities RADEXF offers a number of options. These are:

1. Surface emissivity uniform throughout the enclosure.
2. Surface emissivities set according to five basic values.
3. Surface emissivities set individually for each zone.
4. Surface emissivities set according to five basic values and then the values for nominated individual zones changed.

The following four sections describe the data required by each of these options.

## 8.2 UNIFORM EMISSIVITY

This is the most straightforward way of setting the surface zone emissivities. RADEXF requires a single value which it then automatically allocates to each zone.

## 8.3 FIVE BASIC VALUES

The user specifies five emissivity values; one each for the walls, floor, roof, sources and sinks. RADEXF then allocates to each surface zone the appropriate emissivity value.

## 8.4 INDIVIDUALLY SET EMISSIVITIES

The value of the emissivity for each surface zone must be provided. If these data are entered interactively the user will be prompted for each value with a summary of the piece of surface whose emissivity is about to be set.

## 8.5 FIVE BASIC VALUES - INDIVIDUAL MODIFICATION

The user begins by specifying five emissivity values: one each for the walls, floor, roof, sources and sinks. RADEXF then allocates to each surface zone the appropriate emissivity value. The user can then choose individual zones whose emissivity has not been correctly set by this method and specify the correct value for these zones. This option is particularly useful if the enclosure is a room with a window in one wall. All the wall zones apart from the window have the same emissivity while the window zone has a different emissivity. If the user selects this option then at least one zone emissivity must be altered. If emissivity data are being entered at the terminal the user is prompted for the number of the zone whose emissivity is to be changed. When the user has responded RADEXF displays a message giving the current value of the emissivity and prompts for a new value. When the new value has been given RADEXF asks if any further zones are to have their emissivities altered. This process continues until the user replies "no" when asked if any more zones are to have their emissivities changed.

# 9. ADDITIONAL INPUT INFORMATION

## 9.1 INTRODUCTION

Whatever mode of data entry is used for giving RADEXF the geometric data, the gas absorptivity data and the surface emissivity data (if required) there is some information which must always be entered from the terminal. (Strictly speaking this information comes from the command process which is running RADEXF. This will usually be the terminal; however if RADEXF is to be run in the background as a batch job the information can come from the controlling batch file.) This data includes the names of the files to be used or created and various run specific information which is outlined in the following sections.

## 9.2 PARAMETERS

It was mentioned in Section 3.2 that many of the data storage arrays used by RADEXF are dimensioned by FORTRAN parameter statements. The values of the parameters are set in COMVAR.F. After the title screen RADEXF displays the current values of all the array dimensioning parameters. The user should check that these are all satisfactory (that is neither too small or much too large). If any are unsatisfactory the user should choose the abort option offered at this point, change the values of the parameters in COMVAR.F and recompile RADEXF and its subroutines. The various parameters are defined below. The functions of the parameters can also be found in the comments in COMVAR.F.

NVMAX One more than the maximum number of vertices allowed (ie up to NVMAX-1 vertices are allowed)
NZMAX One more than the maximum number of slices allowed (ie up to NZMAX-1 slices are allowed)
NOBMAX Maximum number of obstacles allowed
MXWLCL Maximum number of walls allowed in a fine grid cell
MXELEM Maximum number of fine grid surface zones allowed
MXELMV Maximum number of fine grid gas zones allowed
MXZN Maximum number of coarse grid surface zones allowed
MXVZN Maximum number of coarse grid gas zones allowed
MXCP Maximum number of fine grid surface zones allowed to make up a coarse grid surface zone
MXVZNC Maximum number of fine grid gas zones allowed to make up a coarse grid gas zone
NATMAX Maximum number of atmospheres allowed (hence, maximum number of complete exchange factors sets allowed)

## 9.3 RUN SPECIFIC INFORMATION

### 9.3.1 Run Title

To help identify the output from a particular run of RADEXF the user must specify a title for the run. This can be up to 50 characters long. The title will be displayed on the first line of the main results file.

### 9.3.2 Exchange Factor Type

RADEXF can calculate view factors, direct exchange areas, total exchange areas or all three kinds of exchange factors. The user must specify which kind of exchange factors are required by the particular run. This information will appear in the run details file.

9.3.4 Data Input Mode

The user must specify from where RADEXF is to read its data. This may be from the terminal (interactive), from both the terminal and data files (quasi-interactive) or from data files alone (non-interactive) (as described in Section 3.3).

9.3.5 Number of Rays

RADEXF uses a Monte Carlo technique to calculate the requested exchange factors. This involves tracing rays, fired from randomly located points in randomly selected directions, until they hit a surface. RADEXF needs to know how many rays to fire from each surface. There are three options for the user. The total number of rays fired from all surfaces zones is set by a parameter NTTRAY. These rays are allocated amongst the surface zones in such a way that the number fired from each zone is proportional to its area. This is the default option. It is recommended that this default option be selected by all but experienced users. The other options are to override NTTRAY and specify a different value for the total number of rays to be fired. Alternatively, the user may specify directly the ray density. This is the number of rays fired from unit area of surface. These options will be useful if very high accuracy in the exchange factor values is required. Generally speaking, the greater the number of rays fired the greater the accuracy of the exchange factors. However, it must be remembered that, due to the stochastic nature of the method, the errors may not behave entirely consistently.

In certain circumstances, such as highly complicated geometries, the default option may not be appropriate. It is difficult to lay down any concrete rules about whether or not a sufficient number of rays has been used. Whenever the enclosure under consideration has some feature, like symmetry, the user is advised to check the results to ensure that the exchange factors produced display (approximately) that symmetry.

# 10. OUTPUT FILES

## 10.1 INTRODUCTION

RADEXF produces two output files: a main results file and a run details file. The main results file contains the details of the surface and gas zones and the exchange factors for all the atmospheres defined. The run details file contains the details of the input and output files used during the run of RADEXF. Full details of the two files are found in the following two sections.

## 10.2 MAIN RESULTS FILE

The format of the information in the main results file is given below. In this description of the file text in upper case is exactly as it appears in the output file. Single, lower case, italicised letters represent numerical values which will depend on the input data. Text in quotes gives a description of the output.

| | |
|---|---|
| Line 1: | "Run title" |
| Line 2: | TOTAL NUMBER OF RAYS IS *rt* - RAY DENSITY IS *rd* |
| Line 3: | *a b c* ("Numbers of coarse grid x, y, z cells") |
| Line 4: | ZONES 1 TO *d* ARE WALL SURFACE ZONES |
| Line 5: | ZONES *d*+1 TO *e* ARE OBSTACLE SURFACE ZONES |
| Line 6: | IT IS POSSIBLE FOR SURFACE ZONES TO HAVE ZERO AREA |
| Line 7: | RESULTS ARE ONLY GIVEN FOR ZONES WITH NON-ZERO AREA |
| Line 8: | IN THIS CASE THERE ARE *f* ZONES WITH ZERO AREA |
| Line 9: | THERE ARE *e-f* ZONES WITH NON-ZERO AREA |
| Line 10: | *h* ARE WALL SURFACE ZONES - ZONE NUMBER AREAS & EMISSIVITIES BELOW |
| Next *h* lines: | *i j k* ("Zone number", "Zone area", "Zone emissivity") |
| Line 11+*h*: | *l* OBSTACLE SURFACE ZONES - ZONE NUMBER AREAS & EMISSIVITIES BELOW |
| Next *l* lines | *m n p* ("Zone number", "Zone area", "Zone emissivity") |
| Line 12+*h*+*l*: | *q* VOLUME ZONES |
| Line 13+*h*+*l*: | *r* HAVE NON-ZERO VOLUME |
| Line 14+*h*+*l*: | *s* DIFFERENT ATMOPSHERES ARE CONSIDERED |
| Line 15+*h*+*l*: | ZONE NUMBER, X,Y,Z COARSE CELL NUMBERS, VOLUME |
| Line 16+*h*+*l*: | & ABSORPTIVITY FOR EACH ATMOSPHERE ARE GIVEN BELOW |
| *r* blocks of: | *t u v w x* ("zone no.", "x,y,z coarse cell numbers", "volume") |
| | *s* "absorptivity values" (These are given 6 per line) |
| Many lines: | "Exchange Factor Values" |

The format of the block of lines giving the exchange factor values is given below. The number of lines in each of the *r* blocks giving the zone number, x,y,z coarse cell numbers, volume and absorptivity for each atmosphere is $2+\{(s-1)/6\}$, where $\{.\}$ denotes the integer part. Thus the total number of lines of data in the output file before the commencent of the exchange factor values is:

$$16+h+l+r\left[2+\{(s-1)/6\}\right]$$

where *h* is the number of wall surface zones with non-zero area,
*l* is the number of obstacle surface zones with non-zero area,
*r* is the number of volume zones with non-zero volume,
*s* is the number of different atmospheres considered

### 10.2.1 Format of Exchange Factor Values

Continuing with the above notation, there are $s$ sets of exchange factors (as there are $s$ different atmospheres). The complete set of exchange factors for each atmosphere is given together, in the order: surface to surface, surface to gas, gas to gas, gas to surface. The first atmosphere, which is always automatically clear, is different to this. As the gas absorptivity is zero everywhere the only non-zero exchange factors are the surface to surface ones, so only these are given in the output file. The actual format for the first atmosphere is shown below.

| | |
|---|---|
| | ATMOSPHERE 1 SURFACE TO SURFACE "exchange factor name" |
| $h+l$ blocks: | SENDING SURFACE ZONE $y$ |
| | $h+l$ "exchange factor values" (These are given 6 per line) |

For subsequent atmospheres the format is:

| | |
|---|---|
| | ATMOPSHERE $z$ SURFACE TO SURFACE "exchange factor name" |
| $h+l$ blocks: | SENDING SURFACE ZONE $y$ |
| | $h+l$ "exchange factor values" (These are given 6 per line) |
| | ATMOPSHERE $z$ SURFACE TO GAS "exchange factor name" |
| $h+l$ blocks: | SENDING SURFACE ZONE $y$ |
| | $r$ "exchange factor values" (These are given 6 per line) |
| | ATMOSPHERE $z$ GAS TO GAS "exchange factor name" |
| $r$ blocks: | SENDING GAS ZONE $y$ |
| | $r$ "exchange factor values" (These are given 6 per line) |
| | ATMOPSHERE $z$ GAS TO SURFACE "exchange factor name" |
| $r$ blocks: | SENDING GAS ZONE $y$ |
| | $h+l$ "exhange factor values" (These are given 6 per line) |

The total number of lines needed for this first atmopshere is

$$1+(h+l)[\{(h+l-1)/6\}+2]$$

The total number of lines needed for each subsequent atmosphere is

$$4+(h+l+r)[\{(h+l-1)/6\}+\{(r-1)/6\}+4]$$

where, as before, $\{.\}$ denotes the integer part.

When RADEXF has been requested to calculate the values of all exchange factors, not just a single kind, these appear in the output file in basically the same format. The values are given for each atmosphere in turn. Firstly, the view factors are output according to the pattern above, then the direct exchange areas and finally the total exchange areas.

## 10.3 RUN DETAILS FILE

The run details file is a short file which basically records where the data came from and the names of the main results file produced by this data. Where data is read from a file, the file name is given. Where data is entered at the terminal, the name of the file in which the data is saved is given. The contents of the main results file are also named (that is, the type of exchange factor calculated is given). The final record of the run details output file gives the ray density that was used for the calculation of the exchange factors.

# 11. SKELETAL INPUT FILES

## 11.1 INTRODUCTION

Usually, when RADEXF reads data from files it will be reading files which were produced by RADEXF during earlier runs. These data files are annotated so that the user can see what information is given on each line of the file. These files can be edited if desired before they are read again by RADEXF. Alternatively, input data files may be created from scratch. In either of these situations it is important that the final file submitted to RADEXF has the correct format. The skeletal form of the three kinds of input files are given below.

For all numerical values the READ statements in RADEXF are free format (the FORTRAN '*' format). However where character variables are required (when specifying obstacle types and for yes/no flags) these are read using a FORTRAN FORMAT (1X,A1). In other words the character (B or C or Y or N) must appear in column 2 of the line.

## 11.2 GEOMETRIC DATA FILE

The skeletal form of this file is given below.

| | | |
|---|---|---|
| Line 1: | $n$ | (Number of vertices) |
| $n$ blocks of | $xi$ $yi$ | (x,y co-ordinates of vertex $i$) |
| 2 lines | 0 or 1 | (Vertex $i$ coarse grid flag: 1=Yes, 0=No) |
| Line $2n$+2: | $p$ | (Number of vertex at end of floor) |
| Line $2n$+3: | $q$ | (Number of vertex at start of roof) |
| Line $2n$+4: | $r$ | (Number of vertex at end of roof) |
| Line $2n$+5: | $s$ | (Number of slices) |
| $s$ lines: | $ti$ | (Thickness of slice $i$) |
| $s$-1 lines: | 0 or 1 | (Internal z grid line coarse grid flag: 1=Yes, 0=No) |
| Line $2n$+$2s$+5: | $u$ | (Number of obstacles) |
| $u$ blocks of | B or C | (Type of obstacle $i$: B=box, C=cylinder) |
| 4 lines | $xli$ $yli$ $zli$ | (Low x,y,z co-ordinates of obstacle $i$) |
| | $xhi$ $yhi$ $zhi$ | (High co-ordinates of obstacle $i$) |
| | 0 or 1 | (Source/sink flag: 0=source, 1=sink) |

It should be noted that, although there are $s$ slices in the z direction, only $s$-1 z coarse grid flags are given. The $s$ slices generate s+1 fine grid lines; however, the first and last are automatically placed on the coarse grid. So, coarse grid information is required only for the internal ones.

The low x,y,z co-ordinates of each obstacle are the co-ordinates of the low corner of a box or the co-ordinates of the centre of the low face for a cylinder (as described in Section 4.4). For a box the high co-ordinates of the obstacle are the co-ordinates of the high corner (as described in Section 4.4). For a cylinder the high co-ordinates of the obstacle are the radius, a co-ordinate direction indicator (1=x, 2=y, 3=z) and the high axial co-ordinate.

## 11.3 GAS ABSORPTIVITY DATA FILE

The skeletal form of this file is given below.

| | | |
|---|---|---|
| Line 1: | *n m l* | (Number of coarse grid x, y, z cells) |
| Number of | *i* | (Gas absorptivity input option number) |
| blocks | "Data required by input option *i*" | |
| Last line: | 0 | (End of gas absorptivity specification) |

As a number of atmospheres may be defined for a single run of RADEXF there may be a number of blocks in the data file. It should be noted that the number of atmospheres defined by a block depends on the option number. Option 1 (uniform absorptivity) and option 2 (individually specified absorptivites) each define 1 atmosphere. Option 3 (sum of grey gases, uniform excess air, no carbon) defines 2 atmospheres. Options 4–6 (sum of grey gases, uniform or varying excess air, uniform or varying carbon concentration) define 6 atmospheres. When creating an input file from scratch or editing an existing file to produce more atmospheres the total number of atmospheres defined should be checked. If this exceeds the value of the parameter NATMAX set in COMVAR.F an error will occur when RADEXF tries to read the data. To use such an input file the value of NATMAX will need to be increased and RADEXF and its subroutines recompiled.

If exchange factors are required only for a clear gas the gas absorptivity data file will have just two lines: line 1 and the last line in the above skeleton.

The first line of the gas absorptivity input file gives the numbers of coarse grid cells in each of the co–ordinate directions. These are used to perform a check if an input option which requires values to be specified on a zone by zone basis is chosen (options 2, 5 and 6). If the currently defined coarse grid has different numbers of coarse grid cells then there will either be too much or not enough data in the input file. RADEXF will give an error message and abort the run.

The data required by each input option are different. They are outlined below.

### 11.3.1 Input Option 1 – Uniform Absorptivity

After the first line giving the input option number (1), only one further line is required giving the uniform value of the gas absorptivity. The skeletal form of the block is given below.

| | | |
|---|---|---|
| Line 1: | 1 | (Absorptivity input option) |
| Line 2: | *a* | (Uniform absorptivity value) |

### 11.3.2 Input Option 2 – Individually Specified Absorptivities

After the first line giving the input option number (2), the absorptivity values for all the gas zones with non–zero volumes are given, one per line, in numerical order of the zones (as described in Section 6.3). The skeletal form of the block is given below.

| | | |
|---|---|---|
| Line 1: | 2 | (Absorptivity input option) |
| *b* lines: | *ai* | (Absorptivity of zone *i*) |

### 11.3.3 Input Option 3 – Sum of Grey Gases, Uniform Excess Air, No Carbon

After the first line giving the input option number (3), two further lines are required. The first of these two lines gives the fuel type (1=natural gas, 2=gas oil, 3=heavy fuel oil). The second gives the excess air level, as a percentage, used in producing the

combustion products. The skeletal form of the block is given below.

| | | |
|---|---|---|
| Line 1: | 3 | (Absorptivity input option) |
| Line 2: | *f* | (Fuel type:1=nat gas,2=gas oil,3=heavy fuel oil) |
| Line 3: | *e* | (Excess air level %) |

11.3.4 Input Option 4 - Sum of Grey Gases, Uniform Excess Air, Uniform Carbon Concentration

After the first line giving the input option number (4), three further lines are required. The first of these three lines gives the fuel type (1=natural gas, 2=gas oil, 3=heavy fuel oil). The second gives the excess air level, as a percentage, used in producing the combustion products. The third gives the carbon concentration in kg/m$^3$. The skeletal form of the block is given below.

| | | |
|---|---|---|
| Line 1: | 1 | (Absorptivity input option) |
| Line 2: | *f* | (Fuel type: 1=nat gas,2=gas oil, 3=heavy fuel oil) |
| Line 3: | *e* | (Excess air level %) |
| Line 4: | *c* | (Carbon concentration kg/m$^3$) |

11.3.5 Input Option 5 - Sum of Grey Gases, Uniform Excess Air, Varying Carbon Concentration

The first three lines gives the input option number (5), the fuel type (1=natural gas,, 2=gas oil, 3=heavy fuel oil) and the excess are level, as a percentage, used in producing the combustion products. These lines are followed by the carbon concentration, in kg/m$^3$, for each gas zone which has non-zero volume. One carbon concentration value is given per line. The values are given in numerical order of the gas zones (as described in Section 6.3). The skeletal form of the block is given below.

| | | |
|---|---|---|
| Line 1: | 5 | (Absorptivity input option) |
| Line 2: | *a* | (Fuel type: 1=nat gas,2=gas oil,3=heavy fuel oil) |
| Line 3: | *e* | (Excess air level %) |
| *b* lines: | *ci* | (Carbon concentration, kg/m$^3$, in zone *i*) |

11.3.6 Input Option 6 - Sum of Grey Gases, Varying Excess Air & Varying Carbon Concentration

After the first two lines giving the input option number (6) and the fuel type (1=natural gas, 2=gas oil, 3=heavy fuel oil), there are two lines for each gas zone which has non-zero volume. The first of these two lines gives the excess air level, as a percentage, used to produce the combustion products in the zone. The second gives the carbon concentration, in kg/m$^3$, in the zone. The values are given in numerical order of the gas zones (as described in Section 6.3). The skeletal form of the block is given below.

| | | |
|---|---|---|
| Line 1: | 6 | (Absorptivity input option) |
| Line 2: | *f* | (Fuel type: 1=nat gas,2=gas oil,3=heavy fuel oil) |
| *b* blocks | *ei* | (Excess air level, %, in zone *i*) |
| of 2 lines | *ci* | (Carbon concentration, kg/m$^3$, in zone *i*) |

## 11.4 SURFACE EMISSIVITY DATA FILE

The data required depend on the input option selected. The specifications of the data files for each input option are given below.

### 11.4.1 Input Option 1 - Uniform Emissivity

The file has two lines giving the input option number and the uniform emissivty value. The skeletal form of this file is given below.

| | | |
|---|---|---|
| Line 1: | 1 | (Emissivity input option) |
| Line 2: | *a* | (Uniform emissivity value) |

### 11.4.2 Input Option 2 - Five Basic Values

The file has six lines giving, in turn, the input option number, the emissivity values for the floor (hearth), walls, roof, load (sinks) and sources. The skeletal form of this file is given below.

| | | |
|---|---|---|
| Line 1: | 2 | (Emissivity input option) |
| Line 2: | *a* | (Floor (hearth) emissivity) |
| Line 3: | *b* | (Wall emissivity) |
| Line 4: | *c* | (Roof emissivity) |
| Line 5: | *d* | (Sink (load) emissivity) |
| Line 6: | *e* | (Source emissivity) |

### 11.4.3 Input Option 3 - Individually Specified Emissivities

The first line of the file gives the input option number. The second line gives the total number of surface zones (including the surface zones with zero area). If there are n, m and l coarse grid cells in the x, y and z directions respectively this total number is 2(nm+ml+ln+nml). If this total number does not match up with the total number of surface zones in the currently defined geometry there will either be too much data or too little. RADEXF will give an error message and abort the run. The total number of surface zones is followed by the individual zone emissivities, one for each zone (including those zones which have zero area - these are assigned zero emissivities in files created by RADEXF). These values are given one per line. The skeletal form of this file is given below.

| | | |
|---|---|---|
| Line 1: | 3 | (Emissivity input option number) |
| Line 2: | *a* | (Number of surface zones) |
| *a* lines: | *bi* | (Emissivity of zone *i*) |

### 11.4.4 Input Option 4 - Five Basic Values, Individual Zone Modification

The first six lines of the file give, respectively, the input option number, the floor (hearth), wall, roof, sink (load) and source emissivities (as for input option 2). These lines are followed by the number of the first zone whose emissivity is to be changed (if this option is selected there must always be at least one such zone). The next line gives the new emissivity for this zone. There may now follow any number of three line blocks. The first line of these three must have a Y in the second column. This indicates that more changes are to be made. The second line gives the number of the zone whose emissivity is to be changed and the third line gives the new emissivity of this zone. The last line of the file must have a N in column two, indicating that no further changes are to be made to the emissivities. The skeletal form of this file is given below.

| | | |
|---|---|---|
| Line 1: | 4 | (Emissivity input option number) |
| Line 2: | *a* | (Floor (hearth) emissivity) |
| Line 3: | *b* | (Wall emissivity) |
| Line 4: | *c* | (Roof emissivity) |
| Line 5: | *d* | (Sink (load) emissivity) |
| Line 6: | *e* | (Source emissivity) |
| Line 7: | *f* | (Zone whose emissivity is to be changed) |
| Line 8: | *g* | (New emissivity value for zone *f*) |
| As many blocks | Y | (More changes Yes or No) |
| of three lines | *h* | (Zone whose emissivity is to be changed) |
| as wanted | *i* | (New emissivity value for zone *h*) |
| Last Line: | N | (More changes Yes or No) |

# 12 SAMPLE RUNS OF RADEXF

## 12.1 INTRODUCTION

The purpose of this chapter is to illustrate the use of RADEXF in all three of its input modes. The enclosure shown in Figure 6 is used as a sample enclosure. The cross-sectional shape is defined by the seven vertices shown in Figure 1, there are two slices of unit thickness and the coarse grid is the same as the fine grid. This produces the coarse grid zoning shown in Figures 6 and 8. The following section describes the use of RADEXF in interactive mode with all the data entered at the terminal. This creates a number of files which may be used for input in further runs of RADEXF. This is demonstrated in Section 12.3, where the details of a non-interactive run of RADEXF are given. Finally, the use of RADEXF in quasi-interactive mode is illustrated. This run reads the geometric data from the file created by the interactive run. Then, by using the interactive vertex editor within RADEXF, the coarse grid is modified to produce fewer coarse grid zones. The surface emissivity data are read from the file created by the interactive run of RADEXF. Similarly, some of the gas absorptivity data are read from the file created during the interactive run; the rest is read from the terminal.

## 12.2 INTERACTIVE DATA ENTRY

In what follows, a complete record of a run of RADEXF is given. The explanations, messages and prompts given by RADEXF are shown in standard script, as they appear on the screen. Whenever RADEXF requires the user to supply information it gives an explanatory message followed by the prompt >>. This symbol is the sign that the user should input data.

The user replies in this sample run are shown in italics. Where it is necessary to explain a particular input, comments are made immediately after the input. These comments, which form no part of the run of RADEXF, are in brackets and in italics.

Once the user has given the appropriate command to the operating system to run RADEXF the screen is cleared and the run begins with the title display. The run proceeds as shown on the next few pages.

```
RRRRR       AAAA     DDDDDD    EEEEEEE  XX     XX  FFFFFFFF
RRRRRRR     AAAA     DDDDDD    EEEEEEE  XX     XX  FFFFFFFF
RR   RR    AA  AA    DD  DD    EE        XX   XX   FF
RR    RR   AA  AA    DD   DD   EE         XX XX    FF
RR    RR  AA    AA   DD   DD   EE          XXX     FF
RR   RR   AA    AA   DD    DD  EEEE        XXX     FF
RRRRRRR   AA    AA   DD    DD  EEEE        XXX     FFFFF
RRRRR     AAAAAAAA   DD    DD  EEEE        XXX     FFFFF
RRRR      AAAAAAAA   DD   DD   EE         XX XX    FF
RR RR     AA    AA   DD   DD   EE        XX   XX   FF
RR  RR    AA    AA   DD  DD    EE        XX   XX   FF
RR   RR   AA    AA   DDDDDD    EEEEEEE  XX     XX  FF
RR    RR  AA    AA   DDDDDD    EEEEEEE  XX     XX  FF
```

A program to calculate RADiative EXchange Factors

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<< PRESS RETURN TO CONTINUE >>

*(This is the title page and requires no information to be supplied. The user should press the RETURN key as instructed. The screen is then cleared.)*

VALUES OF THE GLOBAL PARAMETERS

RADEXF requires certain arrays to be dimensioned at compilation.
If these arrays are not big enough for the geometry the run will fail.
Check the values given below and if any are too small, then abort the run
change the appropriate parameters in COMVAR.F and re-compile RADEXF

The maximum number of vertices allowed (NVMAX-1) is 7
The maximum number of slices allowed (NZMAX-1) is 4
The maximum number of obstacles (NOBMAX) allowed is 4
The maximum number of walls (MXWLCL) allowed in a cell is 4
The maximum number of fine surface zones (MXELEM) allowed is 80
The maximum number of fine volume zones (MXELMV) allowed is 20
The maximum number of coarse surface zones (MXZN) allowed is 72
The maximum number of coarse volume zones (MXVZN) allowed is 20
The maximum number of fine surface zones in a coarse surface zone (MXCP) is
6
The maximum number of fine volume zones in a coarse volume zone (MXVZNC) is
4
The maximum number of atmopsheres allowed (NATMAX) is 12

If all these values are acceptable then enter Y otherwise enter N
(After N, RADEXF will stop - you should change the required parameters
in comvar.f and recompile RADEXF and run again)

ARE ALL THE VALUES SATISFACTORY (Y or N) >> Y

*(The user should check that the arrays within RADEXF are large enough. If any are too small, changes should be made to the relevant parameter values in COMVAR.F and the whole of RADEXF recompiled. Assuming the parameters are all large enough, as in this case, the answer Y is given, the screen is then cleared and the run continues.)*

```
Enter a title for this run of RADEXF (up to 50 characters) >>
Sample Run for User Guide

There are three types of exchange factors
     1. View Factors
     2. Direct Exchange Areas
     3. Total Exchange Areas
RADEXF will calculate any or all of these
Enter number of those you require (1-4) [4=All] >> 3

RADEXF may be run in one of three modes:
    1.  TOTALLY INTERACTIVE - all data is entered at the terminal
    2.  QUASI-INTERACTIVE - some data from files, some from the terminal
        (Geometric data must be from a file)
    3.  NON-INTERACTIVE - all data from files

Select the mode (1-3) required for this run >> 1

Exchange factors are calculated using a Monte Carlo method
This involves tracing rays fired from each zone
The number of rays to be fired can be varied
The default option is to fire 20000 rays in total from all the surfaces
Do you want the default option (Y/N)? >> Y
```

*(All the data entered thus far must be entered from the command process, usually the terminal, every time RADEXF is run; even if RADEXF is to be run in non-interactive mode. The data required from this point on depend upon the selected mode of data entry. The different requirements are illustrated in this and subsequent sections. For interactive data entry, as selected for this run, the screen is cleared and the geometry definition phase begins.)*

## GEOMETRY DEFINITION PHASE

### INTERACTIVE GEOMETRY DEFINITION

The enclosure must have a uniform cross-sectional shape in the x-y plane. This shape is formed from straight line segments, whose ends are vertices. The last vertex is automatically joined to the first by RADEXF.

The geometry of the enclosure defines the finest zoning allowed. Grid lines are drawn in the x and y directions through each vertex to produce the FINE or GEOMETRIC grid. The actual zones are taken from a COARSE or HEAT TRANSFER grid, defined by some or all the fine grid lines.

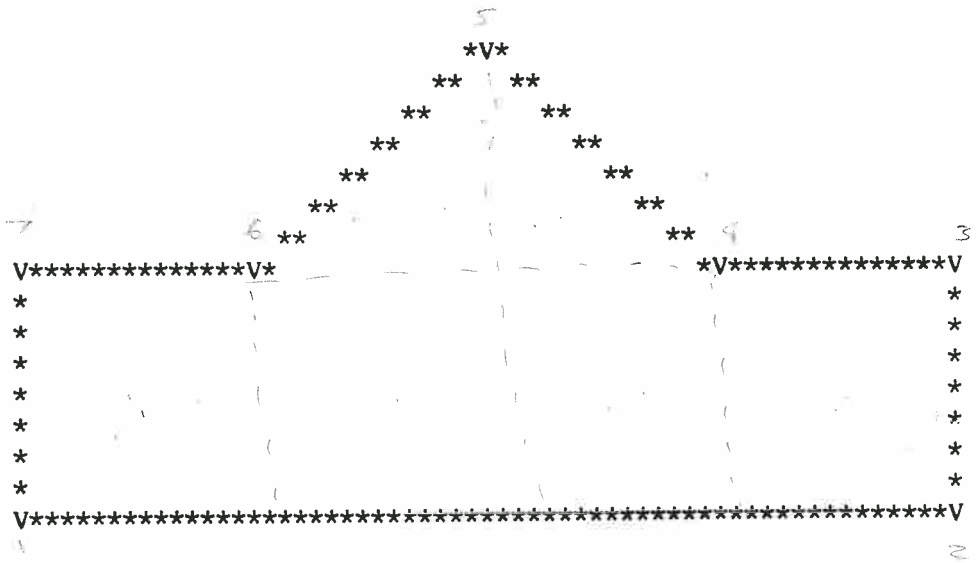
If a vertex is placed on the coarse grid then the x and y grid lines through the vertex are put in the coarse grid. The extreme fine grid lines are automatically included in the coarse grid.

```
The vertices are given by their x,y co-ordinates
and must be entered in ANTI-CLOCKWISE order
Begin at the START of the floor (hearth)

HOW MANY VERTICES? >> 7
```

```
Enter x,y co-ordinates of vertex   1 >> 0,0
To put vertex on coarse grid enter 1 otherwise enter 0: >> 1
Enter x,y co-ordinates of vertex   2 >> 4,0
To put vertex on coarse grid enter 1 otherwise enter 0: >> 1
Enter x,y co-ordinates of vertex   3 >> 4,1
To put vertex on coarse grid enter 1 otherwise enter 0: >> 1
Enter x,y co-ordinates of vertex   4 >> 3,1
To put vertex on coarse grid enter 1 otherwise enter 0: >> 1
Enter x,y co-ordinates of vertex   5 >> 2,2
To put vertex on coarse grid enter 1 otherwise enter 0: >> 1
Enter x,y co-ordinates of vertex   6 >> 1,1
To put vertex on coarse grid enter 1 otherwise enter 0: >> 1
Enter x,y co-ordinates of vertex   7 >> 0,1
To put vertex on coarse grid enter 1 otherwise enter 0: >> 1
Do you want a picture of the cross-section (Y/N)? >> Y
```

*(The option of a picture of the cross-section is to allow the user to check visually that the vertices that have been defined do indeed produce the desired shape. If the user is confident that the correct shape has been defined a picture need not be requested. When one is, the screen is cleared and the following appears.)*



```
V=vertex

                    << PRESS RETURN TO CONTINUE >>
```

*(The picture is a crude line-printer type outline. It is, however, good enough to indicate the shape of the cross-section. No further data are required at this point and so the user should press RETURN as instructed.)*

```
Do you wish to review the vertices (Y/N)? >> N
```

*(If the picture has shown that the cross-section is incorrect, the user can choose to alter the vertices using the interactive vertex editor. In this case all the vertices are correct and so the editor is not invoked. In Section 12.4 the use of the interactive vertex editor is illustrated.)*

```
In order to assemble the surface elements into zones
It is necessary to know the boundaries of the floor & roof
The floor & roof must begin and end at vertices
Here is a list of the vertices giving their co-ords

Vertex   1 Co-ords:      .000000       .000000
Vertex   2 Co-ords:     4.000000       .000000
Vertex   3 Co-ords:     4.000000      1.000000
Vertex   4 Co-ords:     3.000000      1.000000
Vertex   5 Co-ords:     2.000000      2.000000
Vertex   6 Co-ords:     1.000000      1.000000
Vertex   7 Co-ords:      .000000      1.000000

The floor starts at vertex 1
Enter the vertex number where it ends >> 2
The start of the roof is the end with the smaller x co-ord
Enter the vertex number of the start of the roof >> 7
The roof must end at a vertex between the end of the floor
& the start of the roof
Enter this vertex number >> 3
```

*(This completes the definition of the cross-section and the screen is cleared.)*

```
Z GRID INFORMATION
In the z direction the enclosure is divided into a number of slices
All slices have the cross-section already defined by the vertices
But they may each have different thicknesses


HOW MANY SLICES? >> 2
Enter thickness of slice  1 >> 1
Enter thickness of slice  2 >> 1
Specify which z grid lines are on coarse grid
The first & last grid lines are automatically

Grid line  2 is at z=    1.000000
Is this on the coarse grid?
Enter 1 for YES or 0 for NO >> 1


All z grid information has now been given
External shape of enclosure is now defined

                << PRESS RETURN TO CONTINUE >>
```

*(When the user has pressed RETURN the screen is cleared and the obstacle definition phase begins. In this example this phase is very short as there are no obstacles in the enclosure.)*

```
OBSTACLE DEFINITION PHASE

All obstacles are either boxes or cylinders
Boxes are specified by the co-ordinates of the low and high corners
Cylinders are specified by the co-ordinates of the centre of the low plane
face, the radius, co-ordinates direction and co-ordinate of the high plane
face

HOW MANY OBSTACLES? >> 0

Obstacle definition phase completed


All geometric data has now been entered
This data will be saved in a file.

Enter a name for the GEOMETRIC data file >> FIGIIN.D
End of geometry definition phase
```

*(Whenever geometric data are entered or modified at the terminal the new data are automatically saved in a file which may be used as input in further runs of RADEXF. The user must supply a name for this file.)*

```
<< PRESS RETURN TO CONTINUE >>
```

*(The screen is cleared at this point and then the gas absorptivity definition phase begins.)*

```
GAS ABSORPTIVITY DEFINITION PHASE
================================

Gas absorptivity data will be saved in a file

Enter a name for the GAS ABSORPTIVITY data file >> FIGIAB.D
```

*(Whenever gas absorptivity data are entered at the terminal a file is created which can be used for non-interactive input in further runs of RADEXF. The user must supply a name for this file. When the name has been specified, the screen is cleared and the run continues as shown on the next page.)*

INTERACTIVE GAS ABSORPTIVITY DEFINITION

RADEXF will compute exchange areas for a number of different atmospheres
(ie a number of different gas absorptivity arrays)
Exchange areas for a clear (non-participating) gas are always calculated
Exchange areas for other atmospheres are calculated as requested

A number of options are available for defining participating atmospheres
    Absorptivity uniform throughout the enclosure
    Absorptivity specified zone by zone
    Absorptivity specified via a sum of grey gases

When using a sum of grey gases the carbon concentration must be specified
If no carbon is present this creates 2 atmospheres - one for each grey gas
If carbon is present this creates 6 atmospheres - two each for the clear gas and the 2 grey gases

Up to 12 different atmospheres may be defined
If this is not enough abort this run and change the value of the parameter NATMAX in the file comvar.f and recompile the whole program

DO YOU WISH TO ABORT (Y/N)? >> N
*(If the user wishes to define more atmopsheres than are allowed the abort option should be selected. This is a second chance, as the parameter NATMAX is one whose value the user should have checked in the global parameter value check at the start of the run.)*

Exchange areas for a clear gas are automatically produced

Up to 12 different atmospheres may be defined
So far 1 have been set *(N.B. This is the clear atmosphere)*
Hence 11 more may be defined
A sum of grey gases including carbon needs 6
A sum of grey gases with no carbon needs 2
Other specifications need just 1 atmosphere

Are any more atmospheres required (Y/N)? >> Y

The options for specifying the gas absorptivities are:
1. Specify a single value for the whole enclosure
2. Specify on a zone-by-zone basis
3. Sum of grey gases, uniform excess air & no carbon
4. Sum of grey gases, uniform excess air & uniform carbon concentration
5. Sum of grey gases, uniform excess air & varying carbon concentration
6. Sum of grey gases, varying excess air & varying carbon concentration

Enter option number (1-6) >> 3
Specify fuel type:-
    1. Natural Gas
    2. Gas Oil
    3. Heavy Fuel Oil
Enter fuel type >> 1
Enter the excess air level (%) >> 10
Up to 12 different atmospheres may be defined
So far 3 have been set
Hence 9 more may be defined
A sum of grey gases including carbon needs 6
A sum of grey gases with no carbon needs 2
Other specifications need just 1 atmosphere

```
Are any more atmospheres required (Y/N)?  >> N

End of gas absorptivity definiton phase

                << PRESS RETURN TO CONTINUE >>
```

*(The screen is now cleared and the surface emissivity definition phase can begin.)*

```
SURFACE EMISSIVITY DEFINITION PHASE
-----------------------------------

Enter a name for the SURFACE EMISSIVITY data file >> FIGIEM.D
```

*(Whenever surface emissivity data are entered at the terminal a file is created which can be used for non-interactive input in further runs of RADEXF. The user must supply a name for this file.)*

```
There are three basic emissivity options
     1. All emissivities the same
     2. Emissivities specified by 5 values, one each
        for hearth, walls, roof, load and source
     3. Emissivities entered on a zone-by-zone basis
There is a further option available
     4. Begin with option 2 then change nominated individual values
Enter option number (1-4) >> 2
Enter the hearth emissivity >> 0.8
Enter the wall emissivity >> 0.9
Enter the roof emissivity >> 0.95
Enter the load emissivity >> 0.9
Enter the source emissivity >> 0.9
```

*(Notice that, although there are no obstacles, RADEXF still requires values for the load and source emissivities. As there are no obstacles these emissivity values will not be assigned to any surface zones and so arbitrary values may be given.)*

```
End of surface emissivity defintion phase

                << PRESS RETURN TO CONTINUE >>
```

*(All the data required by RADEXF in order to carry out its calculations have now been given. All that is needed now is to tell RADEXF where to put the results it produces. After the screen is cleared the user is prompted for appropriate file names.)*

```
OUTPUT FILE NAMES
-----------------

Enter name for results file >> FIGIRES.D
Enter name for run details output file >> FIGIRUN.D

All data necessary to run RADEXF has been entered

Calculations may now commence

                << PRESS RETURN TO CONTINUE >>
```

*(The length of time required for the calculations will depend on the total number of rays to be fired. As an indication that RADEXF is still running a message is given each time RADEXF proceeds to a new zone. The time between messages will not be constant – it depends on the area of, and hence the number of rays to be fired from, the current zone.)*

```
PROCESSING SURFACE ELEMENT   1 OF  32
PROCESSING SURFACE ELEMENT   2 OF  32
PROCESSING SURFACE ELEMENT   3 OF  32
PROCESSING SURFACE ELEMENT   4 OF  32
PROCESSING SURFACE ELEMENT   5 OF  32
PROCESSING SURFACE ELEMENT   6 OF  32
PROCESSING SURFACE ELEMENT   7 OF  32
PROCESSING SURFACE ELEMENT   8 OF  32
PROCESSING SURFACE ELEMENT   9 OF  32
PROCESSING SURFACE ELEMENT  10 OF  32
PROCESSING SURFACE ELEMENT  11 OF  32
PROCESSING SURFACE ELEMENT  12 OF  32
PROCESSING SURFACE ELEMENT  13 OF  32
PROCESSING SURFACE ELEMENT  14 OF  32
PROCESSING SURFACE ELEMENT  15 OF  32
PROCESSING SURFACE ELEMENT  16 OF  32
PROCESSING SURFACE ELEMENT  17 OF  32
PROCESSING SURFACE ELEMENT  18 OF  32
PROCESSING SURFACE ELEMENT  19 OF  32
PROCESSING SURFACE ELEMENT  20 OF  32
PROCESSING SURFACE ELEMENT  21 OF  32
PROCESSING SURFACE ELEMENT  22 OF  32
PROCESSING SURFACE ELEMENT  23 OF  32
PROCESSING SURFACE ELEMENT  24 OF  32
PROCESSING SURFACE ELEMENT  25 OF  32
PROCESSING SURFACE ELEMENT  26 OF  32
PROCESSING SURFACE ELEMENT  27 OF  32
PROCESSING SURFACE ELEMENT  28 OF  32
PROCESSING SURFACE ELEMENT  29 OF  32
PROCESSING SURFACE ELEMENT  30 OF  32
PROCESSING SURFACE ELEMENT  31 OF  32
PROCESSING SURFACE ELEMENT  32 OF  32
PROCESSING VOLUME ELEMENT   1 OF  12
PROCESSING VOLUME ELEMENT   2 OF  12
PROCESSING VOLUME ELEMENT   3 OF  12
PROCESSING VOLUME ELEMENT   4 OF  12
PROCESSING VOLUME ELEMENT   5 OF  12
PROCESSING VOLUME ELEMENT   6 OF  12
PROCESSING VOLUME ELEMENT   7 OF  12
PROCESSING VOLUME ELEMENT   8 OF  12
PROCESSING VOLUME ELEMENT   9 OF  12
PROCESSING VOLUME ELEMENT  10 OF  12
PROCESSING VOLUME ELEMENT  11 OF  12
PROCESSING VOLUME ELEMENT  12 OF  12
```

*(When all the calculations are complete the screen is cleared and messages are given indicating that output is taking place.)*

```
COMMENCE OUTPUT PHASE

Writing header in EXCHANGE FACTOR output file

TOTAL EXCHANGE AREAS  being written to results file

TOTAL EXCHANGE AREAS  being written to results file

TOTAL EXCHANGE AREAS  being written to results file
```

*(This message appears three times because in this run there are three different atmospheres defined and hence three complete sets of total exchange areas are produced.)*

```
Writing run details output file

Programmed STOP
```

*(This run of RADEXF is now over.)*

### 12.2.1 Geometric Data File

The interactive run of RADEXF just described creates a geometric data file FIG1IN.D which may be used as input for subsequent runs of RADEXF. The contents of this file are shown below.

```
   7                                  NO. OF VERTICES
    .000000      .000000              CO-ORDS OF VERTEX   1
1                                     COARSE GRID FLAG 1=Y,0=N
   4.000000      .000000              CO-ORDS OF VERTEX   2
1                                     COARSE GRID FLAG 1=Y,0=N
   4.000000     1.000000              CO-ORDS OF VERTEX   3
1                                     COARSE GRID FLAG 1=Y,0=N
   3.000000     1.000000              CO-ORDS OF VERTEX   4
1                                     COARSE GRID FLAG 1=Y,0=N
   2.000000     2.000000              CO-ORDS OF VERTEX   5
1                                     COARSE GRID FLAG 1=Y,0=N
   1.000000     1.000000              CO-ORDS OF VERTEX   6
1                                     COARSE GRID FLAG 1=Y,0=N
    .000000     1.000000              CO-ORDS OF VERTEX   7
1                                     COARSE GRID FLAG 1=Y,0=N
   2                                  VERTEX AT END OF FLOOR
   7                                  VERTEX AT START OF ROOF
   3                                  VERTEX AT END OF ROOF
   2                                  NO. OF SLICES
  1.000000                            THICKNESS OF SLICE  1
   1.000000                           THICKNESS OF SLICE  2
1                                     COARSE GRID FLAG 1=Y,0=N
   0                                  NO. OF OBSTACLES
```

It can be seen that this conforms to the skeletal pattern given in Chapter 11. This file can be used exactly as it stands or it can be edited independently of RADEXF (perhaps by including some obstacles) to produce a geometry file for a different (but similar) enclosure.

### 12.2.2 Gas Absorptivity Data File

The interactive run of RADEXF just described creates a gas absorptivity data file FIG1AB.D which may be used as input for subsequent runs of RADEXF. The contents of this file are shown below.

```
   4     2     2                    NO. OF COARSE X,Y,Z CELLS
 3                                  GAS ABSORPTIVITY OPTION
 1                                  FUEL TYPE:1-NAT GAS,2-GAS OIL
   10.0000                          EXCESS AIR LEVEL %
 0                                  END OF GAS ABSORPTIVITIES
```

It can be seen that this file conforms to the skeletal pattern outlined in Chapter 11. This file can be used as input for subsequent runs of RADEXF. It may be used with geometries other than the one defined during the run which produced it. As gas absorptivity option 3 (sum of grey gases, uniform excess air level, no carbon present) does not require any data to be entered on a zone by zone basis a check of the number of coarse grid cells will not be made. So, this file may be used to create this atmosphere in any geometry regardless of how many coarse grid cells there are. This file may be used exactly as it stands, or edited and then used to produce different gas conditions.

### 12.2.3 Surface Emissivity Data File

The interactive run of RADEXF just described creates a surface emissivity data file FIG1EM.D which may be used as input for subsequent runs of RADEXF. The contents of this file are shown below.

```
 2                                  EMISSIVITY INPUT OPTION
     .8000                          HEARTH EMISSIVITY
   .900000                          WALL EMISSIVITY
     .9500                          ROOF EMISSIVITY
   .900000                          LOAD EMISSIVITY
   .900000                          SOURCE EMISSIVITY
```

It can be seen that this file conforms to the skeletal pattern outlined in Chapter 11. This file can be used with any geometry as it is independent of the number of coarse grid cells. It may be used exactly as it stands or it may be edited to change some of the emissivity values.

### 12.2.4 Output FIles

The interactive run of RADEXF just described produces two output files: FIG1RES.D and FIG1RUN.D. The first of these contains all the total exchange areas for the three different atmospheres. Because there are quite a large number of surface zones (32) this file is over 1000 lines long. Its contents will not be shown here (a results file is shown in Section 12.4, where the number of zones involved is much smaller). The file FIG1RUN.D is much shorter, as it only gives details of the location of the data used in the run. Its contents are listed below.

RUN DETAILS FROM RADEXF

```
Run title:  Sample Run for User Guide
Geometric data:     Entered interactively
                    Saved in -  FIG1IN.D
Absorptivity data:  Entered interactively
                    Saved in -  FIG1AB.D
Emissivity data:    Entered interactively
                    Saved in -  FIG1EM.D

Results file -  FIG1RES.D
Results file contains:  TOTAL EXCHANGE AREAS
All exchange factors calculated using a ray density of  632 rays per unit area
```

## 12.3 NON-INTERACTIVE DATA ENTRY

If the geometric, gas absorptivity and surface emissivity data is all to be read from files the user need supply RADEXF with little more than the appropriate file names. A complete record of such a run of RADEXF, using the data files just created by the interactive run of RADEXF, described in the last section, is given on the next page. Data which the user must supply is given in italics, always after the prompt >>. Explanatory comments are given in italics and in brackets.

```
RRRRR       AAAA     DDDDDD    EEEEEEE  XX     XX  FFFFFFFF
RRRRRRR     AAAA     DDDDDD    EEEEEEE  XX     XX  FFFFFFFF
RR   RR    AA  AA    DD  DD    EE        XX   XX   FF
RR    RR   AA  AA    DD   DD   EE        XX   XX   FF
RR    RR  AA    AA   DD   DD   EE         XX XX    FF
RR   RR   AA    AA   DD    DD  EEEE       XXXXX    FF
RRRRRRR   AA    AA   DD    DD  EEEE        XXX     FFFFF
RRRRR     AAAAAAAA   DD    DD  EEEE       XXXXX    FFFFF
RRRR      AAAAAAAA   DD   DD   EE         XX XX    FF
RR RR     AA    AA   DD   DD   EE        XX   XX   FF
RR  RR    AA    AA   DD  DD    EE        XX   XX   FF
RR   RR   AA    AA   DDDDDD    EEEEEEE  XX     XX  FF
RR    RR  AA    AA   DDDDDD    EEEEEEE  XX     XX  FF
```

A program to calculate RADiative EXchange Factors

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<< PRESS RETURN TO CONTINUE >>

*(The user should press return, as instructed, at this point.)*

VALUES OF THE GLOBAL PARAMETERS

RADEXF requires certain arrays to be dimensioned at compilation.
If these arrays are not big enough for the geometry the run will fail.
Check the values given below and if any are too small, then abort the run
change the appropriate parameters in COMVAR.F and re-compile RADEXF

The maximum number of vertices allowed (NVMAX-1) is 7
The maximum number of slices allowed (NZMAX-1) is 4
The maximum number of obstacles (NOBMAX) allowed is 4
The maximum number of walls (MXWLCL) allowed in a cell is 4
The maximum number of fine surface zones (MXELEM) allowed is 80
The maximum number of fine volume zones (MXELMV) allowed is 20
The maximum number of coarse surface zones (MXZN) allowed is 72
The maximum number of coarse volume zones (MXVZN) allowed is 20
The maximum number of fine surface zones in a coarse surface zone (MXCP) is
6
The maximum number of fine volume zones in a coarse volume zone (MXVZNC) is
4
The maximum number of atmopsheres allowed (NATMAX) is 12

If all these values are acceptable then enter Y otherwise enter N
(After N, RADEXF will stop - you should change the required parameters
in comvar.f and recompile RADEXF and run again)

ARE ALL THE VALUES SATISFACTORY (Y or N) >> *y*

*(Although all data is being entered from files some basic information must be entered at the terminal. The user should check that the arrays are large enough for the run about to take place.)*

Enter a title for this run of RADEXF (up to 50 characters) >>
*Sample Run for User Guide (Non-Interactive)*

```
There are three types of exchange factors
     1. View Factors
     2. Direct Exchange Areas
     3. Total Exchange Areas
RADEXF will calculate any or all of these
Enter number of those you require (1-4) [4=All] >> 3

RADEXF may be run in one of three modes:
    1.  TOTALLY INTERACTIVE - all data is entered at the terminal
    2.  QUASI-INTERACTIVE - some data from files, some from the terminal
        (Geometric data must be from a file)
    3.  NON-INTERACTIVE - all data from files

Select the mode (1-3) required for this run >> 3

Exchange factors are calculated using a Monte Carlo method
This involves tracing rays fired from each zone
The number of rays to be fired can be varied
The default option is to fire 20000 rays in total from all the surfaces
Do you want the default option (Y/N)? >>  y


GEOMETRY DEFINITION PHASE
-------------------------


Enter the name of the GEOMETRIC data file >> FIG1IN.D
End of geometry definition phase

                    << PRESS RETURN TO CONTINUE >>


GAS ABSORPTIVITY DEFINITION PHASE
---------------------------------


Some/all gas absorptivity data is from a file


Enter the name of the GAS ABSORPTIVITY data file >> FIG1AB.D

End of gas absorptivity definiton phase

                    << PRESS RETURN TO CONTINUE >>


SURFACE EMISSIVITY DEFINITION PHASE
-----------------------------------


Enter the name of the SURFACE EMISSIVITY data file >> FIG1EM.D

End of surface emissivity defintion phase

                    << PRESS RETURN TO CONTINUE >>
```

OUTPUT FILE NAMES

Enter name for results file >> *FIGIRESN.D*
Enter name for run details output file >> *FIGIRUNN.D*

All data necessary to run RADEXF has been entered

Calculations may now commence

<< PRESS RETURN TO CONTINUE >>

```
PROCESSING SURFACE ELEMENT    1 OF  32
PROCESSING SURFACE ELEMENT    2 OF  32
PROCESSING SURFACE ELEMENT    3 OF  32
PROCESSING SURFACE ELEMENT    4 OF  32
PROCESSING SURFACE ELEMENT    5 OF  32
PROCESSING SURFACE ELEMENT    6 OF  32
PROCESSING SURFACE ELEMENT    7 OF  32
PROCESSING SURFACE ELEMENT    8 OF  32
PROCESSING SURFACE ELEMENT    9 OF  32
PROCESSING SURFACE ELEMENT   10 OF  32
PROCESSING SURFACE ELEMENT   11 OF  32
PROCESSING SURFACE ELEMENT   12 OF  32
PROCESSING SURFACE ELEMENT   13 OF  32
PROCESSING SURFACE ELEMENT   14 OF  32
PROCESSING SURFACE ELEMENT   15 OF  32
PROCESSING SURFACE ELEMENT   16 OF  32
PROCESSING SURFACE ELEMENT   17 OF  32
PROCESSING SURFACE ELEMENT   18 OF  32
PROCESSING SURFACE ELEMENT   19 OF  32
PROCESSING SURFACE ELEMENT   20 OF  32
PROCESSING SURFACE ELEMENT   21 OF  32
PROCESSING SURFACE ELEMENT   22 OF  32
PROCESSING SURFACE ELEMENT   23 OF  32
PROCESSING SURFACE ELEMENT   24 OF  32
PROCESSING SURFACE ELEMENT   25 OF  32
PROCESSING SURFACE ELEMENT   26 OF  32
PROCESSING SURFACE ELEMENT   27 OF  32
PROCESSING SURFACE ELEMENT   28 OF  32
PROCESSING SURFACE ELEMENT   29 OF  32
PROCESSING SURFACE ELEMENT   30 OF  32
PROCESSING SURFACE ELEMENT   31 OF  32
PROCESSING SURFACE ELEMENT   32 OF  32
PROCESSING VOLUME ELEMENT    1 OF  12
PROCESSING VOLUME ELEMENT    2 OF  12
PROCESSING VOLUME ELEMENT    3 OF  12
PROCESSING VOLUME ELEMENT    4 OF  12
PROCESSING VOLUME ELEMENT    5 OF  12
PROCESSING VOLUME ELEMENT    6 OF  12
PROCESSING VOLUME ELEMENT    7 OF  12
PROCESSING VOLUME ELEMENT    8 OF  12
PROCESSING VOLUME ELEMENT    9 OF  12
PROCESSING VOLUME ELEMENT   10 OF  12
PROCESSING VOLUME ELEMENT   11 OF  12
PROCESSING VOLUME ELEMENT   12 OF  12
```

```
COMMENCE OUTPUT PHASE


Writing header in EXCHANGE FACTOR output file

TOTAL EXCHANGE AREAS  being written to results file

TOTAL EXCHANGE AREAS  being written to results file

TOTAL EXCHANGE AREAS  being written to results file

Writing run details output file

Programmed STOP
```

As all the geometric, gas absorptivity and surface emissivity data are read fron files no new data files are created. The results produced by this run of RADEXF are exactly the same as those produced by the interactive run described in the last section. The run details in the file FIG1RUNN.D records the location of the input data and the results. Its contents are shown below.

```
RUN DETAILS FROM RADEXF
-----------------------

Run title:  Sample Run for User Guide (Non-Interactive)
Geometric data:     Read from -  FIG1IN.D
Absorptivity data: Read from -  FIG1AB.D
Emissivitiy data:  Read from -  FIG1EM.D

Results file -  FIG1RESN.D
Results file contains:  TOTAL EXCHANGE AREAS
All exchange factors calculated using a ray density of  632 rays per unit area
```

## 12.4 QUASI-INTERACTIVE DATA ENTRY

When the user wishes to repeat a run of RADEXF with very similar data to a previous run quasi-interactive data entry mode should be used. This allows the user to read some data from files and some from the terminal. Some of the data read from files may be amended interactively.

An example of the use of quasi-interactive data entry will now be given. The enclosure is the same as that used in Sections 12.2 and 12.3, however a much coarser gridding will be produced and some internal obstacles will be added. The coarse zoning produced has two cells in the x direction, 1 in the y direction and 1 in the z direction, giving 10 surface zones and 2 gas zones. Total exchange areas will be calculated for the same atmospheres as in Sections 12.2 and 12.3 and also for a new atmosphere with uniform absorptivity.

The full details of this run are given below.

```
RRRRR        AAAA     DDDDDD    EEEEEEE  XX      XX  FFFFFFFF
RRRRRRR      AAAA     DDDDDD    EEEEEEE  XX      XX  FFFFFFFF
RR    RR    AA  AA    DD  DD    EE        XX    XX   FF
RR     RR   AA  AA    DD   DD   EE        XX    XX   FF
RR     RR  AA    AA   DD   DD   EE         XX XX     FF
RR    RR   AA    AA   DD    DD  EEEE       XXXXX     FF
RRRRRRR    AA    AA   DD    DD  EEEE        XXX      FFFFF
RRRRR      AAAAAAAA   DD    DD  EEEE       XXXXX     FFFFF
RRRR       AAAAAAAA   DD   DD   EE         XX XX     FF
RR RR      AA    AA   DD   DD   EE        XX   XX    FF
RR  RR     AA    AA   DD  DD    EE        XX   XX    FF
RR   RR    AA    AA   DDDDDD    EEEEEEE  XX      XX  FF
RR    RR   AA    AA   DDDDDD    EEEEEEE  XX      XX  FF
```

A program to calculate RADiative EXchange Factors

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<< PRESS RETURN TO CONTINUE >>

VALUES OF THE GLOBAL PARAMETERS

RADEXF requires certain arrays to be dimensioned at compilation.
If these arrays are not big enough for the geometry the run will fail.
Check the values given below and if any are too small, then abort the run
change the appropriate parameters in COMVAR.F and re-compile RADEXF

The maximum number of vertices allowed (NVMAX-1) is 7
The maximum number of slices allowed (NZMAX-1) is 4
The maximum number of obstacles (NOBMAX) allowed is 4
The maximum number of walls (MXWLCL) allowed in a cell is 4
The maximum number of fine surface zones (MXELEM) allowed is 80
The maximum number of fine volume zones (MXELMV) allowed is 20
The maximum number of coarse surface zones (MXZN) allowed is 72
The maximum number of coarse volume zones (MXVZN) allowed is 20
The maximum number of fine surface zones in a coarse surface zone (MXCP) is
6
The maximum number of fine volume zones in a coarse volume zone (MXVZNC) is
4
The maximum number of atmopsheres allowed (NATMAX) is 12

If all these values are acceptable then enter Y otherwise enter N
(After N, RADEXF will stop - you should change the required parameters
in comvar.f and recompile RADEXF and run again)

ARE ALL THE VALUES SATISFACTORY (Y or N) >> y

*(The user is planning to alter some data read from data files (otherwise non-interactive data entry would be used) and so a check should be made that the arrays are large enough to accommodate the data required by RADEXF.)*

Enter a title for this run of RADEXF (up to 50 characters) >>
*Sample Run for User Guide (Quasi-Interactive)*

```
There are three types of exchange factors
     1. View Factors
     2. Direct Exchange Areas
     3. Total Exchange Areas
RADEXF will calculate any or all of these
Enter number of those you require (1-4) [4=All] >> 3

RADEXF may be run in one of three modes:
    1.  TOTALLY INTERACTIVE - all data is entered at the terminal
    2.  QUASI-INTERACTIVE - some data from files, some from the terminal
        (Geometric data must be from a file)
    3.  NON-INTERACTIVE - all data from files

Select the mode (1-3) required for this run >> 2

Exchange factors are calculated using a Monte Carlo method
This involves tracing rays fired from each zone
The number of rays to be fired can be varied
The default option is to fire 20000 rays in total from all the surfaces
Do you want the default option (Y/N)? >> y


GEOMETRY DEFINITION PHASE
=========================


The GEOMETRIC data must come from a file


Enter the name of the GEOMETRIC data file >> FIG1IN.D
```

*(In quasi-interactive mode the geometry must come from a file. It may be altered, as it will be for this run.)*

```
Do you want a picture of the cross-section (Y/N)? >> n
Do you wish to review the vertices (Y/N)? >> y
```

*(This invokes the vertex editor which allows the cross-section of the enclosure to be modified.)*

```
VERTEX REVIEW
You may amend the vertices as follows:
    1.  Add new vertices (one at a time)
    2.  Change an existing vertex
    3.  Delete vertices (one at a time)
    4.  Reject all current vertices and start
        vertex entry again
    5.  Finish reviewing vertices


  7 vertices are allowed
  7 vertices have been defined
 Their co-ordinates and coarse grid flags are below
Vertex   1 Co-ords:   .00000E+00    .00000E+00    On coarse grid  T
Vertex   2 Co-ords:   4.0000        .00000E+00    On coarse grid  T
Vertex   3 Co-ords:   4.0000        1.0000        On coarse grid  T
Vertex   4 Co-ords:   3.0000        1.0000        On coarse grid  T
Vertex   5 Co-ords:   2.0000        2.0000        On coarse grid  T
Vertex   6 Co-ords:   1.0000        1.0000        On coarse grid  T
Vertex   7 Co-ords:   .00000E+00    1.0000        On coarse grid  T
```

```
 Select a review option
 1. Add  2. Change  3. Delete  4. Restart  5. Finish
```

*(In this case the coarse grid flags of vertices 3, 4, 6 and 7 need to be altered, whilst their co-ordinates stay the same, so the 'Change' option is selected. Each of these vertices has to be dealt with separately.)*

```
 Enter option number (1-5) >> 2
 Enter number of vertex to be changed (1-  7) >> 3
 Enter new x and y co-ordinates >> 4,1
```

*(Although the co-ordinates of this vertex are not to be altered their values must be entered again.)*

```
 If vertex is on coarse grid enter 1 otherwise enter 0 >> 0
```

*(This removes the vertex from the coarse grid. Vertices 4, 6 and 7 are altered in the same way.)*

```
   7 vertices are allowed
   7 vertices have been defined
  Their co-ordinates and coarse grid flags are below
Vertex   1 Co-ords:   .00000E+00    .00000E+00   On coarse grid  T
Vertex   2 Co-ords:   4.0000        .00000E+00   On coarse grid  T
Vertex   3 Co-ords:   4.0000        1.0000       On coarse grid  F
Vertex   4 Co-ords:   3.0000        1.0000       On coarse grid  T
Vertex   5 Co-ords:   2.0000        2.0000       On coarse grid  T
Vertex   6 Co-ords:   1.0000        1.0000       On coarse grid  T
Vertex   7 Co-ords:   .00000E+00    1.0000       On coarse grid  T

 Select a review option
 1. Add  2. Change  3. Delete  4. Restart  5. Finish
 Enter option number (1-5) >> 2
 Enter number of vertex to be changed (1-  7) >> 4
 Enter new x and y co-ordinates >> 3,1
 If vertex is on coarse grid enter 1 otherwise enter 0 >> 0

   7 vertices are allowed
   7 vertices have been defined
  Their co-ordinates and coarse grid flags are below
Vertex   1 Co-ords:   .00000E+00    .00000E+00   On coarse grid  T
Vertex   2 Co-ords:   4.0000        .00000E+00   On coarse grid  T
Vertex   3 Co-ords:   4.0000        1.0000       On coarse grid  F
Vertex   4 Co-ords:   3.0000        1.0000       On coarse grid  F
Vertex   5 Co-ords:   2.0000        2.0000       On coarse grid  T
Vertex   6 Co-ords:   1.0000        1.0000       On coarse grid  T
Vertex   7 Co-ords:   .00000E+00    1.0000       On coarse grid  T

 Select a review option
 1. Add  2. Change  3. Delete  4. Restart  5. Finish
 Enter option number (1-5) >> 2
 Enter number of vertex to be changed (1-  7) >> 6
 Enter new x and y co-ordinates >> 1,1
 If vertex is on coarse grid enter 1 otherwise enter 0 >> 0

   7 vertices are allowed
   7 vertices have been defined
  Their co-ordinates and coarse grid flags are below
```

```
Vertex   1 Co-ords:   .00000E+00    .00000E+00   On coarse grid  T
Vertex   2 Co-ords:   4.0000        .00000E+00   On coarse grid  T
Vertex   3 Co-ords:   4.0000        1.0000       On coarse grid  F
Vertex   4 Co-ords:   3.0000        1.0000       On coarse grid  F
Vertex   5 Co-ords:   2.0000        2.0000       On coarse grid  T
Vertex   6 Co-ords:   1.0000        1.0000       On coarse grid  F
Vertex   7 Co-ords:   .00000E+00    1.0000       On coarse grid  T

Select a review option
1. Add  2. Change  3. Delete  4. Restart  5. Finish
Enter option number (1-5) >> 2
Enter number of vertex to be changed (1-  7) >> 7
Enter new x and y co-ordinates >> 0,1
If vertex is on coarse grid enter 1 otherwise enter 0 >> 0

  7 vertices are allowed
  7 vertices have been defined
 Their co-ordinates and coarse grid flags are below
Vertex   1 Co-ords:   .00000E+00    .00000E+00   On coarse grid  T
Vertex   2 Co-ords:   4.0000        .00000E+00   On coarse grid  T
Vertex   3 Co-ords:   4.0000        1.0000       On coarse grid  F
Vertex   4 Co-ords:   3.0000        1.0000       On coarse grid  F
Vertex   5 Co-ords:   2.0000        2.0000       On coarse grid  T
Vertex   6 Co-ords:   1.0000        1.0000       On coarse grid  F
Vertex   7 Co-ords:   .00000E+00    1.0000       On coarse grid  F

Select a review option
1. Add  2. Change  3. Delete  4. Restart  5. Finish
```

*(All the required coarse grid flags have been altered so now the required option is number 5.)*

```
Enter option number (1-5) >> 5
Do you want a picture of the cross-section (Y/N)? >> n
```

*(It is perhaps advisable for the user to check visually at this point to ensure that the cross-section has the desired shape.)*

```
Do you wish to review the vertices (Y/N)? >> n
```

*(If the user still has not defined exactly the enclosure desired further changes may be made to the cross-section shape by re-invoking the vertex editor.)*

```
Changes have been made to the vertices read from input data file
Do you want to read floor & roof start & end from input data file (Y/N)? >> y
```

*(Extra vertices may have been added so it is important to check that the floor and roof will be delineated by the correct vertices. If the answer to this question is 'N' the user will be prompted to enter the relevant vertex numbers from the terminal.)*

```
Changes have been made to the vertices read from input data file
Do you want to read z-slice data from input data file (Y/N)? >> n
```

*(As the cross-section data has been altered it is quite possible that the user may wish to alter the z-direction data as well.)*

```
Z GRID INFORMATION
In the z direction the enclosure is divided into a number of slices
All slices have the cross-section already defined by the vertices
But they may each have different thicknesses
```

```
HOW MANY SLICES? >> 1
Enter thickness of slice  1 >> 2
Only 1 slice so both zgrid lines are on coarse grid


All z grid information has now been given
External shape of enclosure is now defined


                << PRESS RETURN TO CONTINUE >>

Changes have been made to the vertices read from input data file
Do you want to read obstacle data from input data file (Y/N)? >> n
```

*(The obstacles may have to be changed if the cross-sectional shape has been altered. If the user wishes to change only the location of the obstacles, and not the cross-sectional shape or coarse grid, then the vertex editor must still be invoked and a "change" made. This "change" could be to change a vertex, but when the new information is given it is exactly the same as the old information. RADEXF records this as a change in the external geometry and will subsequently prompt to see if the obstacles should be read from the input file.)*

```
OBSTACLE DEFINITION PHASE


All obstacles are either boxes or cylinders
Boxes are specified by the co-ordinates of the low and high corners
Cylinders are specified by the co-ordinates of the centre of the low plane face
the radius, co-ordinates direction and co-ordinate of the high plane face


HOW MANY OBSTACLES? >> 3
```

*(A box shaped load on the floor of the enclosure and two cylindrical heating pipes will be included in the enclosure.)*

```
Is obstacle  1 a box (B) or a cylinder (C)?  >>  B
Enter low co-ordinates of the box >>
1.0,0.0,0.0
Enter high co-ordinates of the box >>
3.0,0.25,2.0
Enter 1 for a SINK or 0 for a SOURCE >>  1
```

*(The load obstacle must be designated as a sink, to distinguish it from the heating pipes which are sources, because all load surfaces within a coarse zone are added together to determine the exchange factors.)*

```
Is obstacle  2 a box (B) or a cylinder (C)?  >>  C
Enter co-ordinates of centre of low plane face of the cylinder >>
1.5,1.25,0.0
Enter radius of the cylinder >> 0.1
The axis of the cylinder must be in a co-ordinate direction
Enter 1 for X, 2 for Y, 3 for Z >>  3
Enter Z co-ordinate of high plane face >>  2
Enter 1 for a SINK or 0 for a SOURCE >> 0
Is obstacle  3 a box (B) or a cylinder (C)?  >> C
Enter co-ordinates of centre of low plane face of the cylinder >>
```

```
2.5,1.25,0.0
Enter radius of the cylinder >> 0.1
The axis of the cylinder must be in a co-ordinate direction
Enter 1 for X, 2 for Y, 3 for Z >>  3
Enter Z co-ordinate of high plane face >> 2
Enter 1 for a SINK or 0 for a SOURCE >> 0
```

*(Both heating tubes run through the full depth of the enclosure, that is, from z=0 to z=2. The set of co-ordinates entered for the centre of the low face are the co-ordinates of the centre of the circle in the plane z=0. The z co-ordinate at the high face is z=2. Both tubes are nominated as sources. As the tubes lie in different coarse volume zones the exchange factors produced relate to the tubes individually. If they were both in the same coarse volume zone then the exchange factors would relate to the two tubes together.)*

```
Obstacle definition phase completed


Changes have been made to the geometric data file
A new file will be created

Enter a name for the GEOMETRIC data file >> FIG1INQ.D
```

*(Although the geometric data was originally read from a file it has been altered and so the altered data is saved.)*

```
End of geometry definition phase

                    << PRESS RETURN TO CONTINUE >>

GAS ABSORPTIVITY DEFINITION PHASE
---------------------------------

Gas emissivity data may be entered from:
    1.   The terminal only
    2.   A file then more from the terminal
    3.   A file only
Enter option number (1-3) >> 2
```

*(The atmospheres created by the interactive run of RADEXF in Section 12.2 are to be used along with an atmosphere with uniform gas absorptivity of 0.1.)*

```
Some/all gas absorptivity data is from a file


Enter the name of the GAS ABSORPTIVITY data file >> FIG1AB.D
The gas absorptivity data is from a file and the terminal
It will all be saved together in a new file


Enter a name for the GAS ABSORPTIVITY data file >> FIG1ABQ.D
```

```
INTERACTIVE GAS ABSORPTIVITY DEFINITION
=======================================

RADEXF will compute exchange areas for a number of different atmospheres
(ie a number of different gas absorptivity arrays)
Exchange areas for a clear (non-participating) gas are always calculated
Exchange areas for other atmospheres are calculated as requested

A number of options are available for defining participating atmospheres
     Absorptivity uniform throughout the enclosure
     Absorptivity specified zone by zone
     Absorptivity specified via a sum of grey gases

When using a sum of grey gases the carbon concentration must be specified
If no carbon is present this creates 2 atmospheres - one for each grey gas
If carbon is present this creates 6 atmospheres - two each for the clear gas
and the 2 grey gases

Up to  12 different atmospheres may be defined
If this is not enough abort this run and change the value of the parameter
NATMAX in the file comvar.f and recompile the whole program

DO YOU WISH TO ABORT (Y/N)? >> n

  3 atmopsheres have been read from a file

Up to  12 different atmospheres may be defined
So far   3 have been set
Hence    9 more may be defined
A sum of grey gases including carbon needs 6
A sum of grey gases with no carbon needs 2
Other specifications need just 1 atmosphere

Are any more atmospheres required (Y/N)?  >> y

The options for specifying the gas absorptivities are:
  1. Specify a single value for the whole enclosure
  2. Specify on a zone-by-zone basis
  3. Sum of grey gases, uniform excess air & no carbon
  4. Sum of grey gases, uniform excess air & uniform carbon concentration
  5. Sum of grey gases, uniform excess air & varying carbon concentration
  6. Sum of grey gases, varying excess air & varying carbon concentration

Enter option number (1-6) >> 1
Enter the gas absorption coefficient >> 0.1
Up to  12 different atmospheres may be defined
So far   4 have been set
Hence    8 more may be defined
A sum of grey gases including carbon needs 6
A sum of grey gases with no carbon needs 2
Other specifications need just 1 atmosphere

Are any more atmospheres required (Y/N)?  >> n

End of gas absorptivity definiton phase

                << PRESS RETURN TO CONTINUE >>
```

```
SURFACE EMISSIVITY DEFINITION PHASE
-----------------------------------

Emissivity data may come from:
     1.  The terminal
     2.  A file
Enter option number (1 or 2) >> 2
Enter the name of the SURFACE EMISSIVITY data file >> FIGIEM.D
```

*(There is no facility, at present, to alter existing emissivities interactively from within RADEXF.)*

```
End of surface emissivity defintion phase

                    << PRESS RETURN TO CONTINUE >>

OUTPUT FILE NAMES
-----------------

Enter name for results file >> FIGIRESQ.D
Enter name for run details output file >> FIGIRUNQ.D

All data necessary to run RADEXF has been entered

Calculations may now commence

                    << PRESS RETURN TO CONTINUE >>

PROCESSING SURFACE ELEMENT    1 OF  26
PROCESSING SURFACE ELEMENT    2 OF  26
PROCESSING SURFACE ELEMENT    3 OF  26
PROCESSING SURFACE ELEMENT    4 OF  26
PROCESSING SURFACE ELEMENT    5 OF  26
PROCESSING SURFACE ELEMENT    6 OF  26
PROCESSING SURFACE ELEMENT    7 OF  26
PROCESSING SURFACE ELEMENT    8 OF  26
PROCESSING SURFACE ELEMENT    9 OF  26
PROCESSING SURFACE ELEMENT   10 OF  26
PROCESSING SURFACE ELEMENT   11 OF  26
PROCESSING SURFACE ELEMENT   12 OF  26
PROCESSING SURFACE ELEMENT   13 OF  26
PROCESSING SURFACE ELEMENT   14 OF  26
PROCESSING SURFACE ELEMENT   15 OF  26
PROCESSING SURFACE ELEMENT   16 OF  26
PROCESSING SURFACE ELEMENT   17 OF  26
PROCESSING SURFACE ELEMENT   18 OF  26
PROCESSING SURFACE ELEMENT   19 OF  26
PROCESSING SURFACE ELEMENT   20 OF  26
PROCESSING SURFACE ELEMENT   21 OF  26
PROCESSING SURFACE ELEMENT   22 OF  26
PROCESSING SURFACE ELEMENT   23 OF  26
PROCESSING SURFACE ELEMENT   24 OF  26
PROCESSING SURFACE ELEMENT   25 OF  26
PROCESSING SURFACE ELEMENT   26 OF  26
PROCESSING VOLUME ELEMENT    1 OF   6
PROCESSING VOLUME ELEMENT    2 OF   6
PROCESSING VOLUME ELEMENT    3 OF   6
PROCESSING VOLUME ELEMENT    4 OF   6
PROCESSING VOLUME ELEMENT    5 OF   6
PROCESSING VOLUME ELEMENT    6 OF   6
```

```
COMMENCE OUTPUT PHASE

Writing header in EXCHANGE FACTOR output file

TOTAL EXCHANGE AREAS  being written to results file

TOTAL EXCHANGE AREAS  being written to results file

TOTAL EXCHANGE AREAS  being written to results file

TOTAL EXCHANGE AREAS  being written to results file

Writing run details output file

Programmed STOP
```

### 12.4.1 Geometric Data File

The geometric data was originally read from FIG1IN.D, but then it was altered using the interactive vertex editor within RADEXF. This allowed the coarser gridding to be produced. It was further altered to include three internal obstacles. A new data file, FIG1INQ.D, was produced from the actual geometric data used. The contents of this file are given below. It can be seen that this file differs from the one given in Section 12.2.1 in the values of the coarse grid flags for vertices 3, 4, 6 and 7, in the z slice details and in the obstacle details. The contents of this file are shown below.

```
  7                                   NO. OF VERTICES
   .000000     .000000                CO-ORDS OF VERTEX   1
1                                     COARSE GRID FLAG 1=Y,0=N
  4.000000     .000000                CO-ORDS OF VERTEX   2
1                                     COARSE GRID FLAG 1=Y,0=N
  4.000000    1.000000                CO-ORDS OF VERTEX   3
0                                     COARSE GRID FLAG 1=Y,0=N
  3.000000    1.000000                CO-ORDS OF VERTEX   4
0                                     COARSE GRID FLAG 1=Y,0=N
  2.000000    2.000000                CO-ORDS OF VERTEX   5
1                                     COARSE GRID FLAG 1=Y,0=N
  1.000000    1.000000                CO-ORDS OF VERTEX   6
0                                     COARSE GRID FLAG 1=Y,0=N
   .000000    1.000000                CO-ORDS OF VERTEX   7
0                                     COARSE GRID FLAG 1=Y,0=N
  2                                   VERTEX AT END OF FLOOR
  7                                   VERTEX AT START OF ROOF
  3                                   VERTEX AT END OF ROOF
  1                                   NO. OF SLICES
  2.000000                            THICKNESS OF SLICE  1
  3                                   NO. OF OBSTACLES
B                                     OBSTACLE  1 TYPE
  1.000000     .000000     .000000    LOW CO-ORDS OF OBSTACLE  1
  3.000000     .250000    2.000000    HIGH CO-ORDS OF OBSTACLE  1
1                                     SINK/SOURCE FLAG 1=SINK
C                                     OBSTACLE  2 TYPE
  1.500000    1.250000     .000000    LOW CO-ORDS OF OBSTACLE  2
   .100000    3.000000    2.000000    HIGH CO-ORDS OF OBSTACLE  2
0                                     SINK/SOURCE FLAG 1=SINK
C                                     OBSTACLE  3 TYPE
  2.500000    1.250000     .000000    LOW CO-ORDS OF OBSTACLE  3
   .100000    3.000000    2.000000    HIGH CO-ORDS OF OBSTACLE  3
0                                     SINK/SOURCE FLAG 1=SINK
```

### 12.4.2 Gas Absorptivity Data File

Some gas absorptivity data were read from the file FIG1AB.D and then extra data were entered from the terminal. A new gas absorptivity data file, FIG1ABQ.D, was created which holds all the gas absorptivity data used in this run of RADEXF. The contents of this file are given below. It can be seen that it contains the contents of FIG1AB.D, shown in Section 12.2.2, and then some further lines recording the extra atmosphere that was defined. The contents of this file are shown below.

```
  2     1     1                    NO. OF COARSE X,Y,Z CELLS
3                                  GAS ABSORPTIVITY OPTION
1                                  FUEL TYPE:1-NAT GAS,2-GAS OIL
  10.0000                          EXCESS AIR LEVEL %
  2     1     1                    NO. OF COARSE X,Y,Z CELLS
1                                  GAS ABSORPTIVITY OPTION
  .100000                          UNIFORM ABSORP. COEFF
0                                  END OF GAS ABSORPTIVITIES
```

### 12.4.3 Surface Emissivity Data File

The surface emissivity data were read from the file FIG1EM.D. This data was not changed in any way so no new file is created.

### 12.4.4 Output Files

The run details output file, FIG1RUNQ.D, contains details of where the original data came from and also where the actual data used is located. The contents of this file are given below.

```
RUN DETAILS FROM RADEXF
=======================

Run title:  Sample Run for User Guide (Quasi-Interactive)
Geometric data:    Read from -  FIG1IN.D
                   Changed interactively
                   New data saved in -  FIG1INQ.D
Absorptivity data: Read from -  FIG1AB.D
                   More data added interactively
                   Old & new data saved in -  FIG1ABQ.D
Emissivity data:   Read from -  FIG1EM.D

Results file -  FIG1RESQ.D
Results file contains:  TOTAL EXCHANGE AREAS
All exchange factors calculated using a ray density of  587 rays per unit area
```

The total exchange areas were written to the file FIG1RESQ.D. The contents of this file are given below. It should be noted that these results are not exactly repeatable. If RADEXF is run on a different machine to the one which produced these results a different random number generator will be used and so slightly different results will be obtained.

```
Sample Run for User Guide (Quasi-Interactive)
TOTAL NUMBER OR RAYS IS   20000  -  RAY DENSITY IS     587
  2     1     1                        NO. OF COARSE GRID CELLS IN X,Y,Z
ZONES   1 TO  10 ARE WALL SURFACE ZONES
ZONES  11 TO  14 ARE OBSTACLE SURFACE ZONES
IT IS POSSIBLE FOR SURFACE ZONES TO HAVE ZERO AREA
RESULTS ARE ONLY GIVEN FOR ZONES WITH NON-ZERO AREA
IN THIS CASE THERE ARE  0 ZONES WITH ZERO AREA
THERE ARE  14 ZONES WITH NON-ZERO AREA
 10 WALL SURFACE ZONES - ZONE NUMBER AREAS & EMISSIVITIES BELOW
  1   2.000000        .9000000          NO./AREA/EMISSIVITY WALL ZONE   1
  2   2.218584        .9000000          NO./AREA/EMISSIVITY WALL ZONE   2
  3   2.218584        .9000000          NO./AREA/EMISSIVITY WALL ZONE   3
  4   2.000000        .8000000          NO./AREA/EMISSIVITY WALL ZONE   4
  5   4.828427        .9500000          NO./AREA/EMISSIVITY WALL ZONE   5
  6   2.218584        .9000000          NO./AREA/EMISSIVITY WALL ZONE   6
  7   2.218584        .9000000          NO./AREA/EMISSIVITY WALL ZONE   7
  8   2.000000        .8000000          NO./AREA/EMISSIVITY WALL ZONE   8
  9   4.828427        .9500000          NO./AREA/EMISSIVITY WALL ZONE   9
 10   2.000000        .9000000          NO./AREA/EMISSIVITY WALL ZONE  10
  4 OBSTACLE SURFACE ZONES - ZONE NUMBER AREAS & EMISSIVITIES BELOW
 11   2.500000        .9000000          NO./AREA/EMISSIVITY OBST ZONE   1
 12   1.256637        .9000000          NO./AREA/EMISSIVITY OBST ZONE   2
 13   2.500000        .9000000          NO./AREA/EMISSIVITY OBST ZONE   3
 14   1.256637        .9000000          NO./AREA/EMISSIVITY OBST ZONE   4
  2 VOLUME ZONES
  2 HAVE NON-ZERO VOLUME
 4 DIFFERENT ATMOPSHERES ARE CONSIDERED
ZONE NUMBER, X,Y,Z COARSE CELL NUMBERS, VOLUME
& ABSORPTIVITY FOR EACH ATMOPSHERE ARE GIVEN BELOW
  1    1    1    1    4.43717
  .0000E+00     .4893         17.90         .1000
  2    2    1    1    4.43717
  .0000E+00     .4893         17.90         .1000
ATMOSPHERE  1 SURFACE TO SURFACE TOTAL EXCHANGE AREAS
SENDING SURFACE ZONE   1
 .3052E-01     .2351         .2513         .3643         .4581         .2912E-01
 .2832E-01     .2682E-02     .6777E-01     .5174E-01     .1974         .3193E-01
 .2480E-01     .2690E-01
SENDING SURFACE ZONE   2
 .2351         .2121E-01     .2138         .2145         .5170         .7502E-02
 .8817E-01     .7935E-02     .1472         .3749E-01     .3078         .8943E-01
 .6771E-01     .4185E-01
SENDING SURFACE ZONE   3
 .2513         .2138         .2076E-01     .2113         .5115         .1051
 .7322E-02     .3917E-02     .1661         .3537E-01     .2788         .8887E-01
 .6768E-01     .3491E-01
SENDING SURFACE ZONE   4
 .3643         .2145         .2113         .1668E-01     .5062         .5648E-02
 .8986E-02     .9752E-03     .5912E-01     .2931E-02     .1510         .4095E-01
 .4509E-02     .1273E 01
SENDING SURFACE ZONE   5
 .4581         .5170         .5115         .5062         .1255         .1644
 .1523         .5488E-01     .5234         .6650E-01     .6445         .4440
 .2934         .1255
SENDING SURFACE ZONE   6
 .2912E-01     .7502E-02     .1051         .5648E-02     .1644         .2121E-01
 .2219         .2131         .4944         .2516         .7332E-01     .3408E-01
 .2966         .7890E-01
```

```
SENDING SURFACE ZONE   7
 .2832E-01     .8817E-01     .7322E-02     .8986E-02     .1523         .2219
 .2175E-01     .2115         .4903         .2734         .6263E-01     .3811E-01
 .2972         .9483E-01
SENDING SURFACE ZONE   8
 .2682E-02     .7935E-02     .3917E-02     .9752E-03     .5488E-01     .2131
 .2115         .1625E-01     .5248         .3475         .4540E-02     .1080E-01
 .1597         .4140E-01
SENDING SURFACE ZONE   9
 .6777E-01     .1472         .1661         .5912E-01     .5234         .4944
 .4903         .5248         .1265         .4507         .3123         .1333
 .6508         .4403
SENDING SURFACE ZONE  10
 .5174E-01     .3749E-01     .3537E-01     .2931E-02     .6650E-01     .2516
 .2734         .3475         .4507         .2937E-01     .2386E-01     .2483E-01
 .1823         .2242E-01
SENDING SURFACE ZONE  11
 .1974         .3078         .2788         .1510         .6445         .7332E-01
 .6263E-01     .4540E-02     .3123         .2386E-01     .2173E-01     .1033
 .1005E-01     .5889E-01
SENDING SURFACE ZONE  12
 .3193E-01     .8943E-01     .8887E-01     .4095E-01     .4440         .3408E-01
 .3811E-01     .1080E-01     .1333         .2483E-01     .1033         .4347E-02
 .5602E-01     .3097E-01
SENDING SURFACE ZONE  13
 .2480E-01     .6771E-01     .6768E-01     .4509E-02     .2934         .2966
 .2972         .1597         .6508         .1823         .1005E-01     .5602E-01
 .2220E-01     .1170
SENDING SURFACE ZONE  14
 .2690E-01     .4185E-01     .3491E-01     .1273E-01     .1255         .7890E-01
 .9483E-01     .4140E-01     .4403         .2242E-01     .5889E-01     .3097E-01
 .1170         .4419E-02
ATMOSPHERE  2 SURFACE TO SURFACE TOTAL EXCHANGE AREAS
SENDING SURFACE ZONE   1
 .1597E-01     .1562         .1639         .2732         .3431         .6672E-02
 .6713E-02     .3815E-03     .1575E-01     .7068E-02     .1059         .1378E-01
 .7182E-02     .7398E-02
SENDING SURFACE ZONE   2
 .1562         .8764E-02     .7523E-01     .1402         .3500         .1899E-02
 .2638E-01     .2109E-02     .7001E-01     .8525E-02     .2131         .6682E-01
 .3380E-01     .2122E-01
SENDING SURFACE ZONE   3
 .1639         .7523E-01     .8622E-02     .1425         .3478         .3242E-01
 .1823E-02     .9591E-03     .8188E-01     .8353E-02     .1940         .6579E-01
 .3288E-01     .1729E-01
SENDING SURFACE ZONE   4
 .2732         .1402         .1425         .8241E-02     .2748         .1407E-02
 .2471E-02     .1535E-03     .1647E-01     .4095E-03     .1237         .1826E-01
 .1142E-02     .3801E-02
SENDING SURFACE ZONE   5
 .3431         .3500         .3478         .2748         .5525E-01     .7851E-01
 .7342E-01     .1538E-01     .3569         .1543E-01     .3567         .3951
 .1216         .7469E-01
SENDING SURFACE ZONE   6
 .6672E-02     .1899E-02     .3242E-01     .1407E-02     .7851E-01     .8999E-02
 .8087E-01     .1467         .3517         .1624         .3601E-01     .1698E-01
 .2057         .5860E-01
SENDING SURFACE ZONE   7
 .6713E-02     .2638E-01     .1823E-02     .2471E-02     .7342E-01     .8087E-01
 .9255E-02     .1465         .3417         .1770         .2933E-01     .1926E-01
```

```
 .2040          .6861E-01
SENDING SURFACE ZONE   8
 .3815E-03      .2109E-02      .9591E-03      .1535E-03      .1538E-01      .1467
 .1465          .8048E-02      .2913          .2557          .1171E-02      .3325E-02
 .1320          .1879E-01
SENDING SURFACE ZONE   9
 .1575E-01      .7001E-01      .8188E-01      .1647E-01      .3569          .3517
 .3417          .2913          .5400E-01      .3106          .1302          .7977E-01
 .3537          .3772
SENDING SURFACE ZONE  10
 .7068E-02      .8525E-02      .8353E-02      .4095E-03      .1543E-01      .1624
 .1770          .2557          .3106          .1456E-01      .6640E-02      .6810E-02
 .9634E-01      .9524E-02
SENDING SURFACE ZONE  11
 .1059          .2131          .1940          .1237          .3567          .3601E-01
 .2933E-01      .1171E-02      .1302          .6640E-02      .9472E-02      .6010E-01
 .2844E-02      .2875E-01
SENDING SURFACE ZONE  12
 .1378E-01      .6682E-01      .6579E-01      .1826E-01      .3951          .1698E-01
 .1926E-01      .3325E-02      .7977E-01      .6810E-02      .6010E-01      .2629E-02
 .2779E-01      .1877E-01
SENDING SURFACE ZONE  13
 .7182E-02      .3380E-01      .3288E-01      .1142E-02      .1216          .2057
 .2040          .1320          .3537          .9634E-01      .2844E-02      .2779E-01
 .9774E-02      .6802E-01
SENDING SURFACE ZONE  14
 .7398E-02      .2122E-01      .1729E-01      .3801E-02      .7469E-01      .5860E-01
 .6861E-01      .1879E-01      .3772          .9524E-02      .2875E-01      .1877E-01
 .6802E-01      .2483E-02
ATMOSPHERE  2 SURFACE TO GAS TOTAL EXCHANGE AREAS
SENDING SURFACE ZONE   1
 .6416          .3512E-01
SENDING SURFACE ZONE   2
 .6982          .1243
SENDING SURFACE ZONE   3
 .7200          .1034
SENDING SURFACE ZONE   4
 .5843          .9030E-02
SENDING SURFACE ZONE   5
 1.431          .2972
SENDING SURFACE ZONE   6
 .1034          .7044
SENDING SURFACE ZONE   7
 .1047          .7046
SENDING SURFACE ZONE   8
 .1089E-01      .5664
SENDING SURFACE ZONE   9
 .2988          1.457
SENDING SURFACE ZONE  10
 .3635E-01      .6842
SENDING SURFACE ZONE  11
 .8186          .1335
SENDING SURFACE ZONE  12
 .2649          .7091E-01
SENDING SURFACE ZONE  13
 .1639          .7892
SENDING SURFACE ZONE  14
 .7503E-01      .2808
ATMOSPHERE  2 GAS TO GAS TOTAL EXCHANGE AREAS
SENDING GAS ZONE   1
```

```
 2.350          .3825
SENDING GAS ZONE   2
 .3742          2.350
ATMOSPHERE  2 GAS TO SURFACE TOTAL EXCHANGE AREAS
SENDING GAS ZONE   1
 .6416          .6982          .7200          .5843          1.431          .1034
 .1047          .1089E-01      .2988          .3635E-01      .8186          .2649
 .1639          .7503E-01
SENDING GAS ZONE   2
 .3512E-01      .1243          .1034          .9030E-02      .2972          .7044
 .7046          .5664          1.457          .6842          .1335          .7091E-01
 .7892          .2808
ATMOSPHERE  3 SURFACE TO SURFACE TOTAL EXCHANGE AREAS
SENDING SURFACE ZONE   1
 .4494E-04      .7831E-02      .9594E-02      .1423E-01      .2046E-01      .2544E-07
 .5850E-07      .7063E-10      .5232E-05      .1360E-08      .4553E-04      .1356E-04
 .3595E-07      .2033E-08
SENDING SURFACE ZONE   2
 .7831E-02      .2861E-04      .3053E-04      .6305E-02      .2317E-01      .4934E-06
 .2220E-06      .6852E-07      .3721E-03      .9343E-07      .1167E-01      .7662E-02
 .7638E-04      .3066E-06
SENDING SURFACE ZONE   3
 .9594E-02      .3053E-04      .3392E-04      .8746E-02      .2066E-01      .4439E-06
 .1385E-06      .4687E-08      .2476E-03      .6212E-07      .1255E-01      .6110E-02
 .4882E-05      .1378E-06
SENDING SURFACE ZONE   4
 .1423E-01      .6305E-02      .8746E-02      .3034E-04      .3613E-04      .4333E-06
 .1954E-07      .2375E-09      .2559E-06      .3002E-09      .1519E-01      .5668E-05
 .2947E-07      .3235E-09
SENDING SURFACE ZONE   5
 .2046E-01      .2317E-01      .2066E-01      .3613E-04      .1710E-03      .1024E-03
 .2485E-03      .1613E-06      .2105E-01      .5482E-05      .2957E-04      .2969E-01
 .3530E-06      .7783E-05
SENDING SURFACE ZONE   6
 .2544E-07      .4934E-06      .4439E-06      .4333E-06      .1024E-03      .3153E-04
 .3418E-04      .8419E-02      .2116E-01      .9231E-02      .5774E-03      .4795E-07
 .1173E-01      .5809E-02
SENDING SURFACE ZONE   7
 .5850E-07      .2220E-06      .1385E-06      .1954E-07      .2485E-03      .3418E-04
 .3788E-04      .7772E-02      .2168E-01      .1276E-01      .2579E-04      .2099E-06
 .1316E-01      .6795E-02
SENDING SURFACE ZONE   8
 .7063E-10      .6852E-07      .4687E-08      .2375E-09      .1613E-06      .8419E-02
 .7772E-02      .4245E-04      .4287E-04      .1758E-01      .2817E-06      .1458E-09
 .1806E-01      .5669E-05
SENDING SURFACE ZONE   9
 .5232E-05      .3721E-03      .2476E-03      .2559E-06      .2105E-01      .2116E-01
 .2168E-01      .4287E-04      .1835E-03      .2177E-01      .1126E-05      .7434E-05
 .2979E-04      .3163E-01
SENDING SURFACE ZONE  10
 .1360E-08      .9343E-07      .6212E-07      .3002E-09      .5482E-05      .9231E-02
 .1276E-01      .1758E-01      .2177E-01      .6745E-04      .3150E-06      .2028E-08
 .6492E-04      .1569E-04
SENDING SURFACE ZONE  11
 .4553E-04      .1167E-01      .1255E-01      .1519E-01      .2957E-04      .5774E-03
 .2579E-04      .2817E-06      .1126E-05      .3150E-06      .5238E-04      .9247E-05
 .4486E-06      .1967E-06
SENDING SURFACE ZONE  12
 .1356E-04      .7662E-02      .6110E-02      .5668E-05      .2969E-01      .4795E-07
 .2099E-06      .1458E-09      .7434E-05      .2028E-08      .9247E-05      .1545E-04
```

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 .3446E-07     .6220E-08
SENDING SURFACE ZONE  13
 .3595E-07     .7638E-04     .4882E-05     .2947E-07     .3530E-06     .1173E-01
 .1316E-01     .1806E-01     .2979E-04     .6492E-04     .4486E-06     .3446E-07
 .6820E-04     .8768E-05
SENDING SURFACE ZONE  14
 .2033E-08     .3066E-06     .1378E-06     .3235E-09     .7783E-05     .5809E-02
 .6795E-02     .5669E-05     .3163E-01     .1569E-04     .1967E-06     .6220E-08
 .8768E-05     .1591E-04
ATMOSPHERE  3 SURFACE TO GAS TOTAL EXCHANGE AREAS
SENDING SURFACE ZONE   1
 1.748         .3624E-04
SENDING SURFACE ZONE   2
 1.926         .1343E-01
SENDING SURFACE ZONE   3
 1.919         .1941E-01
SENDING SURFACE ZONE   4
 1.555         .2566E-04
SENDING SURFACE ZONE   5
 4.386         .8531E-01
SENDING SURFACE ZONE   6
 .1537E-01     1.924
SENDING SURFACE ZONE   7
 .1136E-01     1.923
SENDING SURFACE ZONE   8
 .3746E-04     1.548
SENDING SURFACE ZONE   9
 .3154E-01     4.437
SENDING SURFACE ZONE  10
 .2389E-04     1.738
SENDING SURFACE ZONE  11
 2.195         .1533E-01
SENDING SURFACE ZONE  12
 1.087         .7604E-04
SENDING SURFACE ZONE  13
 .2844E-01     2.178
SENDING SURFACE ZONE  14
 .5071E-04     1.087
ATMOSPHERE  3 GAS TO GAS TOTAL EXCHANGE AREAS
SENDING GAS ZONE   1
 299.9         3.012
SENDING GAS ZONE   2
 2.477         300.3
ATMOSPHERE  3 GAS TO SURFACE TOTAL EXCHANGE AREAS
SENDING GAS ZONE   1
 1.748         1.926         1.919         1.555         4.386         .1537E-01
 .1136E-01     .3746E-04     .3154E-01     .2389E-04     2.195         1.087
 .2844E-01     .5071E-04
SENDING GAS ZONE   2
 .3624E-04     .1343E-01     .1941E-01     .2566E-04     .8531E-01     1.924
 1.923         1.548         4.437         1.738         .1533E-01     .7604E-04
 2.178         1.087
ATMOSPHERE  4 SURFACE TO SURFACE TOTAL EXCHANGE AREAS
SENDING SURFACE ZONE   1
 .2629E-01     .2143         .2275         .3416         .4284         .2136E-01
 .2092E-01     .1773E-02     .4982E-01     .3441E-01     .1735         .2674E-01
 .1911E-01     .2060E-01
SENDING SURFACE ZONE   2
 .2143         .1728E-01     .1718         .1953         .4744         .5486E-02
 .6863E-01     .5984E-02     .1248         .2745E-01     .2842         .8365E-01
```

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 .5811E-01     .3609E-01
SENDING SURFACE ZONE   3
 .2275         .1718         .1682E-01     .1931         .4678         .8242E-01
 .5330E-02     .2886E-02     .1416         .2612E-01     .2568         .8298E-01
 .5787E-01     .2995E-01
SENDING SURFACE ZONE   4
 .3416         .1953         .1931         .1422E-01     .4459         .4196E-02
 .6830E-02     .6620E-03     .4530E-01     .1930E-02     .1443         .3465E-01
 .3357E-02     .9907E-02
SENDING SURFACE ZONE   5
 .4284         .4744         .4678         .4459         .1040         .1397
 .1296         .4214E-01     .4787         .4889E-01     .5714         .4333
 .2446         .1123
SENDING SURFACE ZONE   6
 .2136E-01     .5486E-02     .8242E-01     .4196E-02     .1397         .1742E-01
 .1810         .1966         .4586         .2279         .6280E-01     .2934E-01
 .2742         .7368E-01
SENDING SURFACE ZONE   7
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 .1785E-01     .1954         .4520         .2475         .5317E-01     .3284E-01
 .2736         .8810E-01
SENDING SURFACE ZONE   8
 .1773E-02     .5984E-02     .2886E-02     .6620E-03     .4214E-01     .1966
 .1954         .1390E-01     .4650         .3246         .3400E-02     .8461E-02
 .1529         .3514E-01
SENDING SURFACE ZONE   9
 .4982E-01     .1248         .1416         .4530E-01     .4787         .4586
 .4520         .4650         .1042         .4132         .2605         .1196
 .5720         .4243
SENDING SURFACE ZONE  10
 .3441E-01     .2745E-01     .2612E-01     .1930E-02     .4889E-01     .2279
 .2475         .3246         .4132         .2500E-01     .1821E-01     .1900E-01
 .1592         .1866E-01
SENDING SURFACE ZONE  11
 .1735         .2842         .2568         .1443         .5714         .6280E-01
 .5317E-01     .3400E-02     .2605         .1821E-01     .1804E-01     .9237E-01
 .7677E-02     .5070E-01
SENDING SURFACE ZONE  12
 .2674E-01     .8365E-01     .8298E-01     .3465E-01     .4333         .2934E-01
 .3284E-01     .8461E-02     .1196         .1900E-01     .9237E-01     .3850E-02
 .4841E-01     .2789E-01
SENDING SURFACE ZONE  13
 .1911E-01     .5811E-01     .5787E-01     .3357E-02     .2446         .2742
 .2736         .1529         .5720         .1592         .7677E-02     .4841E-01
 .1844E-01     .1045
SENDING SURFACE ZONE  14
 .2060E-01     .3609E-01     .2995E-01     .9907E-02     .1123         .7368E-01
 .8810E-01     .3514E-01     .4243         .1866E-01     .5070E-01     .2789E-01
 .1045         .3839E-02
ATMOSPHERE  4 SURFACE TO GAS TOTAL EXCHANGE AREAS
SENDING SURFACE ZONE   1
 .1727         .2103E-01
SENDING SURFACE ZONE   2
 .1859         .4337E-01
SENDING SURFACE ZONE   3
 .1968         .3709E-01
SENDING SURFACE ZONE   4
 .1541         .4721E-02
SENDING SURFACE ZONE   5
 .3653         .1007
```

```
SENDING SURFACE ZONE   6
 .3741E-01     .1846
SENDING SURFACE ZONE   7
 .3657E-01     .1875
SENDING SURFACE ZONE   8
 .5533E-02     .1457
SENDING SURFACE ZONE   9
 .1007         .3767
SENDING SURFACE ZONE  10
 .2181E-01     .1861
SENDING SURFACE ZONE  11
 .2097         .4333E-01
SENDING SURFACE ZONE  12
 .6512E-01     .2278E-01
SENDING SURFACE ZONE  13
 .5201E-01     .2040
SENDING SURFACE ZONE  14
 .2494E-01     .7032E-01
ATMOSPHERE  4 GAS TO GAS TOTAL EXCHANGE AREAS
SENDING GAS ZONE   1
 .1204         .2597E-01
SENDING GAS ZONE   2
 .2542E-01     .1215
ATMOSPHERE  4 GAS TO SURFACE TOTAL EXCHANGE AREAS
SENDING GAS ZONE   1
 .1727         .1859         .1968         .1541         .3653         .3741E-01
 .3657E-01     .5533E-02     .1007         .2181E-01     .2097         .6512E-01
 .5201E-01     .2494E-01
SENDING GAS ZONE   2
 .2103E-01     .4337E-01     .3709E-01     .4721E-02     .1007         .1846
 .1875         .1457         .3767         .1861         .4333E-01     .2278E-01
 .2040         .7032E-01
```

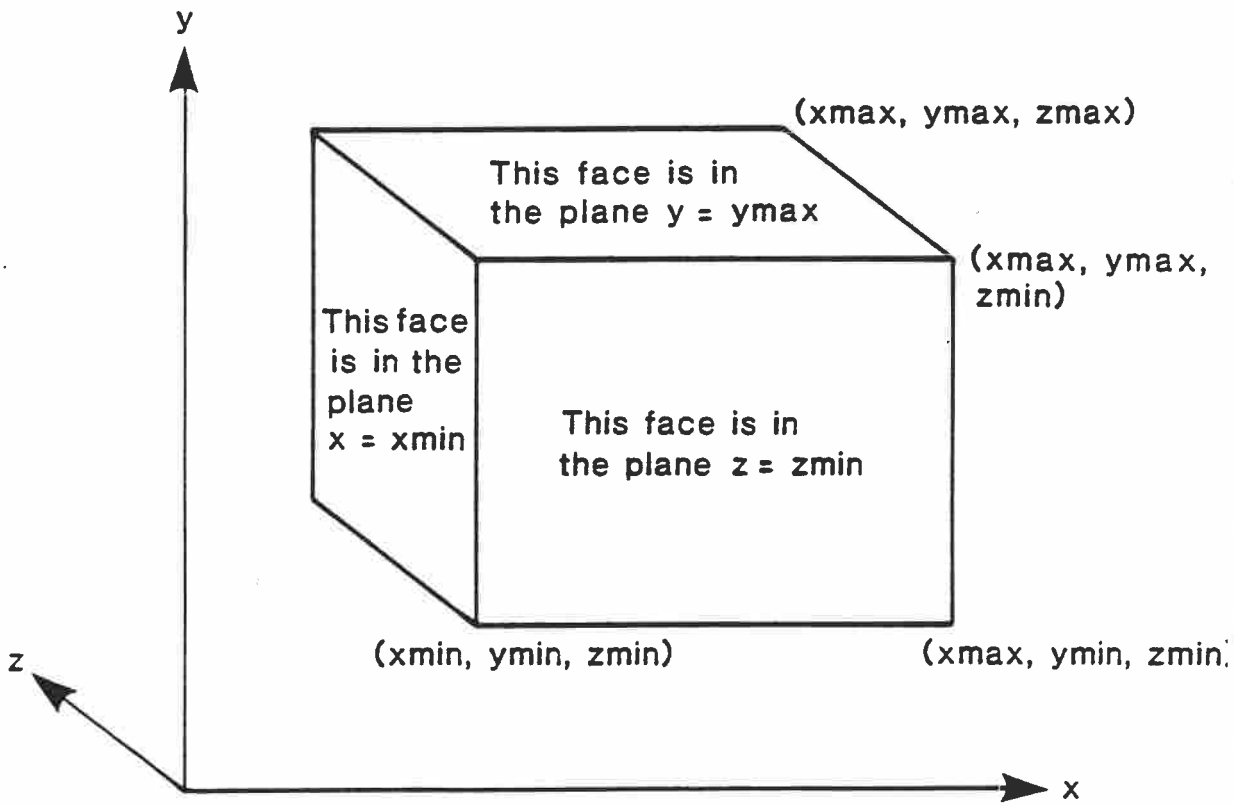
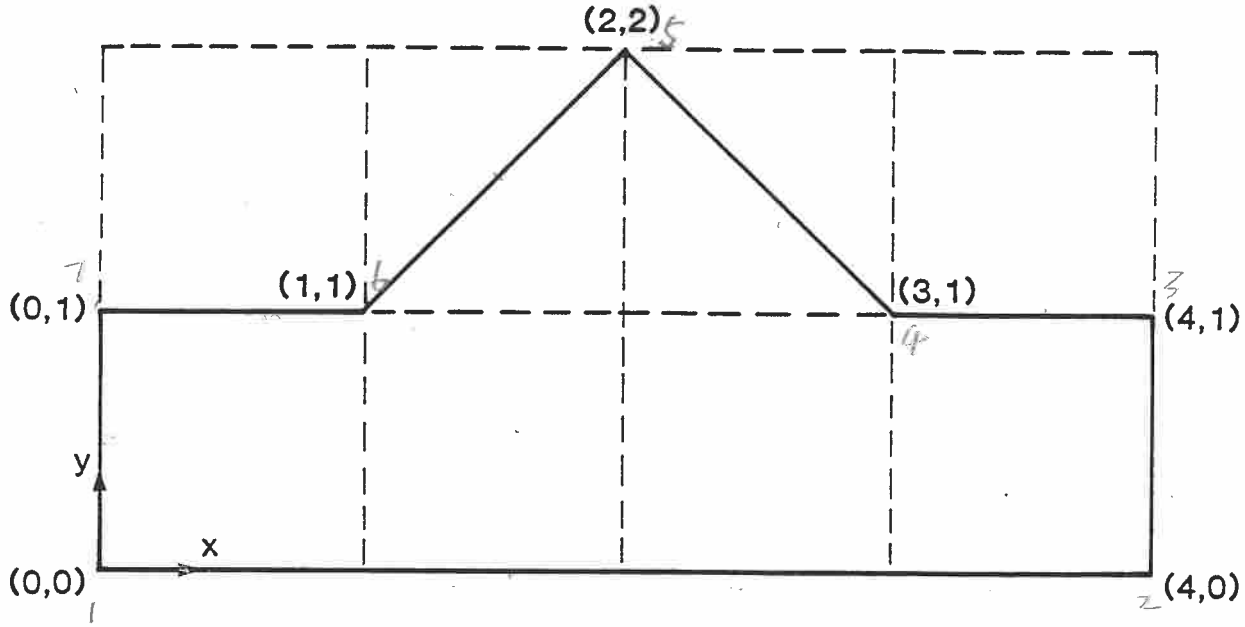
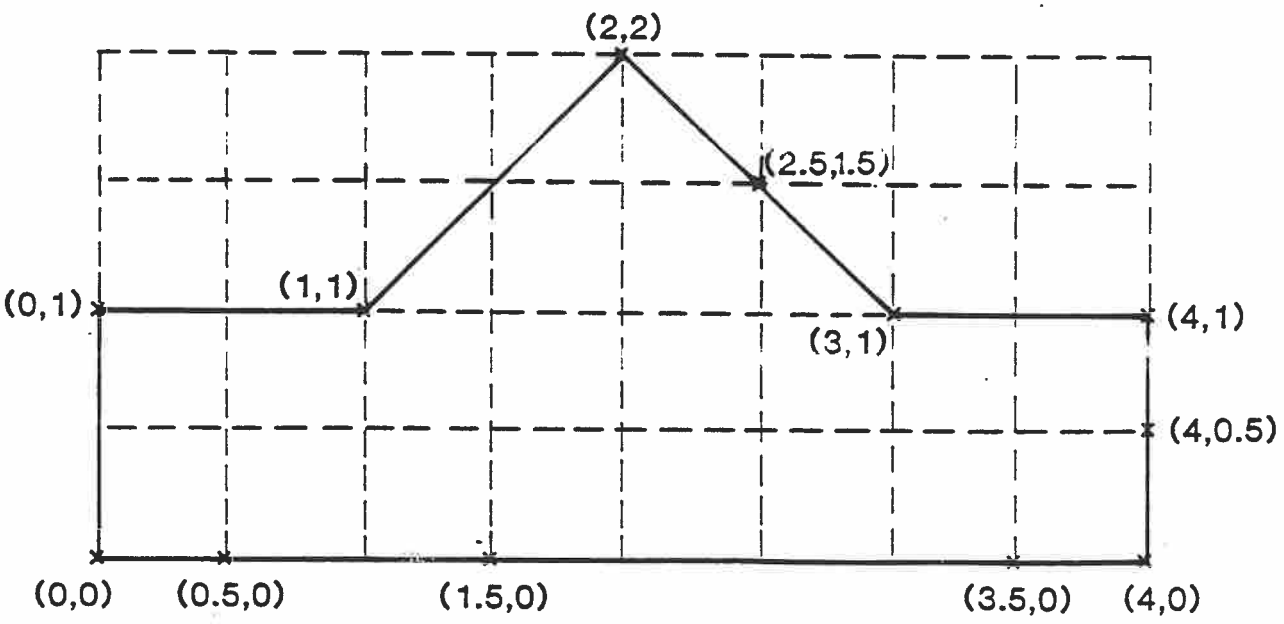



FIG. 0. CO-ORDINATES OF BOX OBSTACLES




Uniform depth – 2 units

FIG. 1.




Finer elements by artificial vertices

FIG. 2.

Coarse grid vertices marked • (5 in total)
Grid – line y = 1 missing from coarse grid since no coarse grid vertex has y = 1

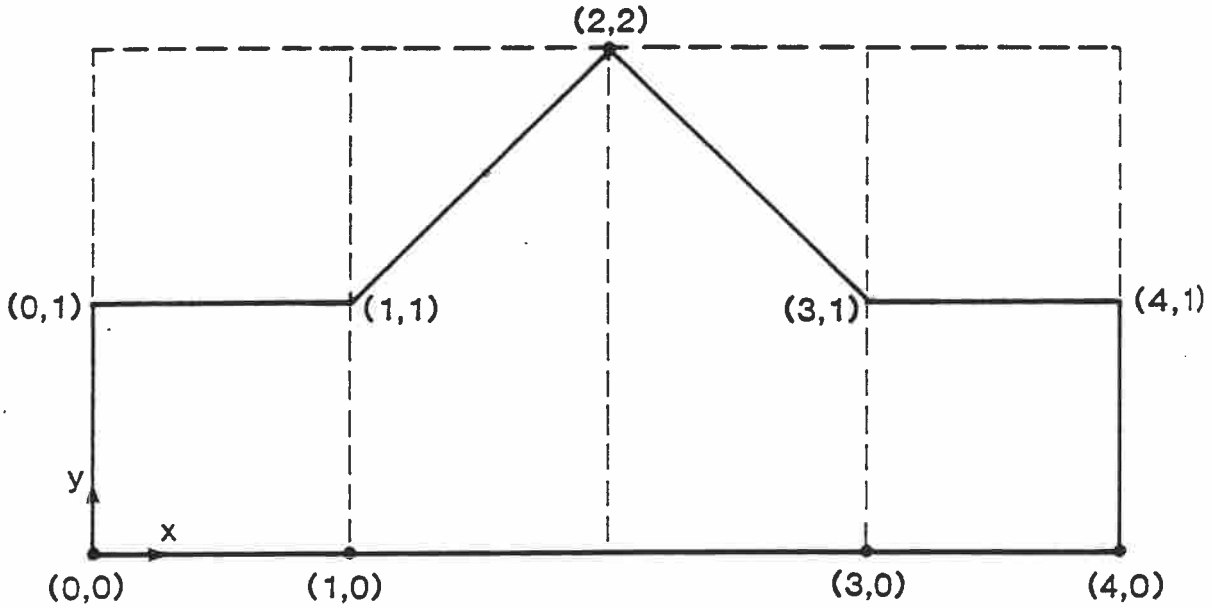
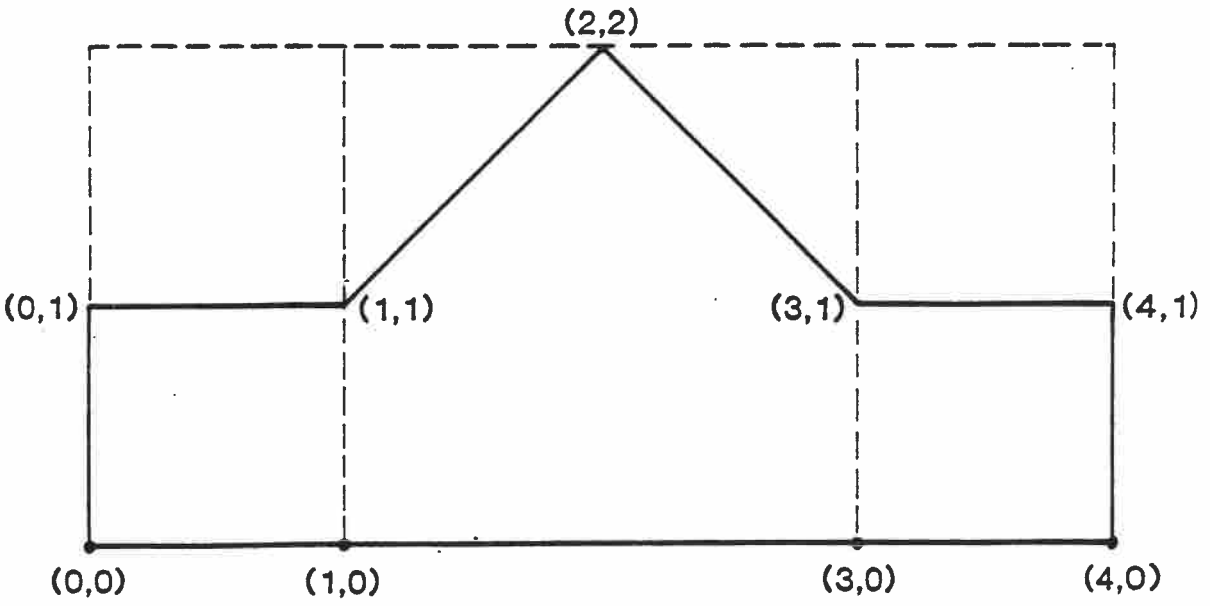
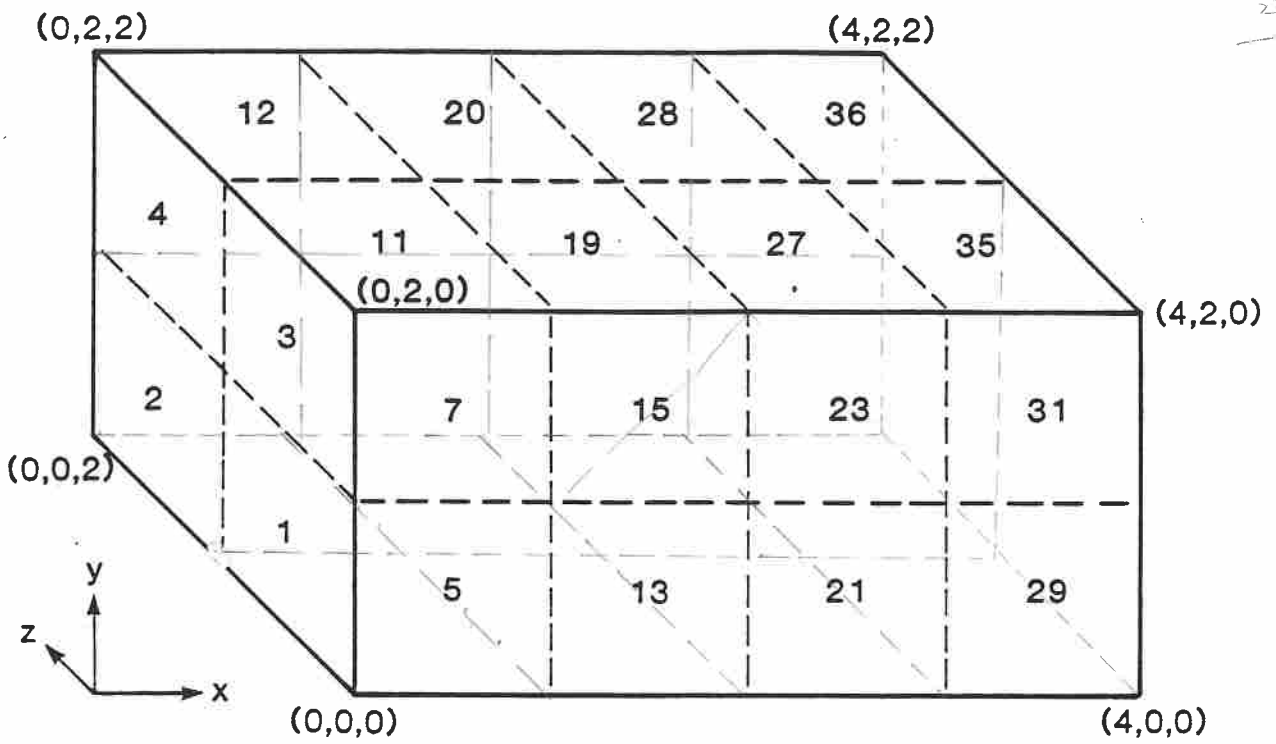


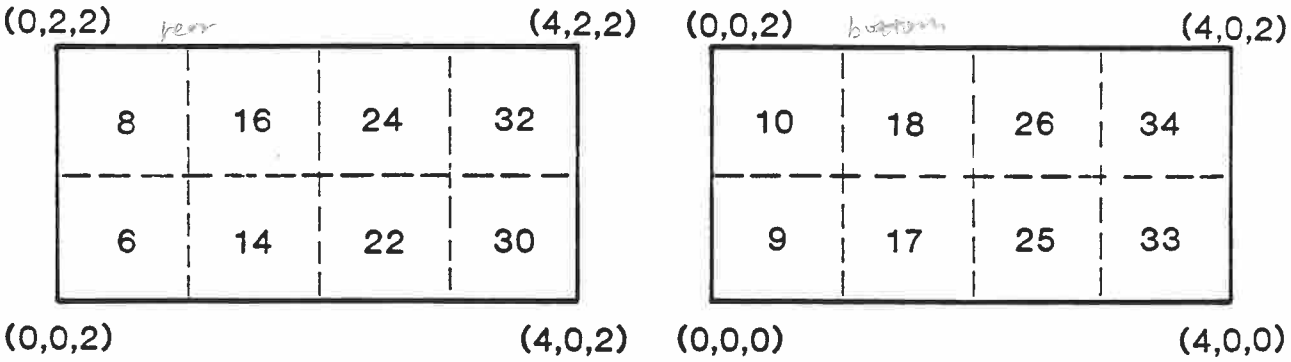

FIG . 3.




Four coarse grid vertices (marked • ) 3 surface elements

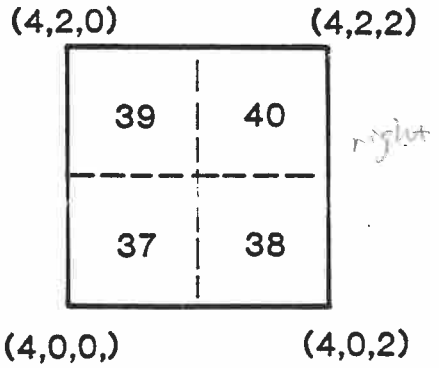
FIG 4



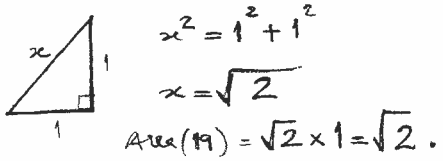

Plane z = 2

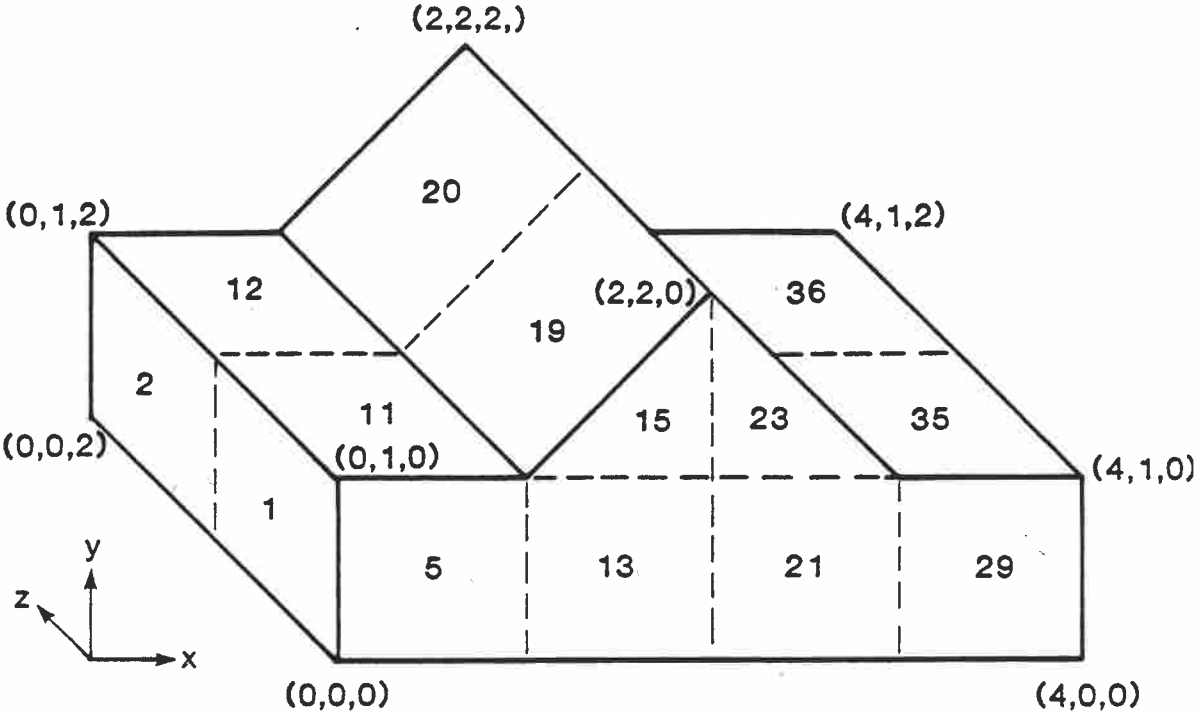
Plane y = 0

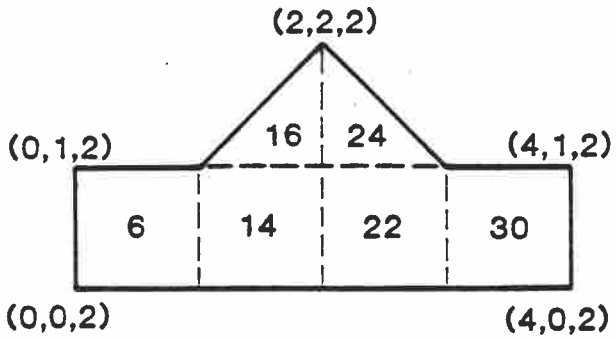



Plane x = 4

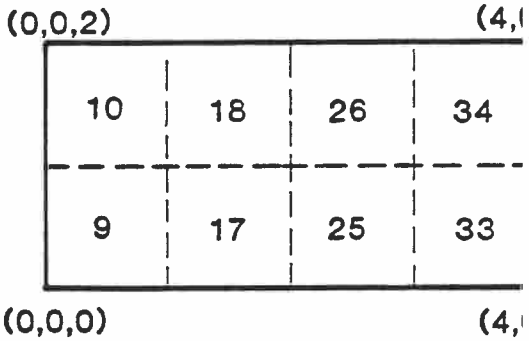
FIG. 5. NUMBERING OF RECTANGULAR SUB-FACES FOR BOUNDING BOX



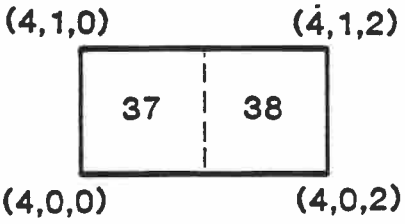




Plane z = 2




Plane y = 0 (Hearth)




Plane x = 4

Numbering of surface zones (NB. masked sloping face in top diagram is zones 27 and 28)

FIG. 6.

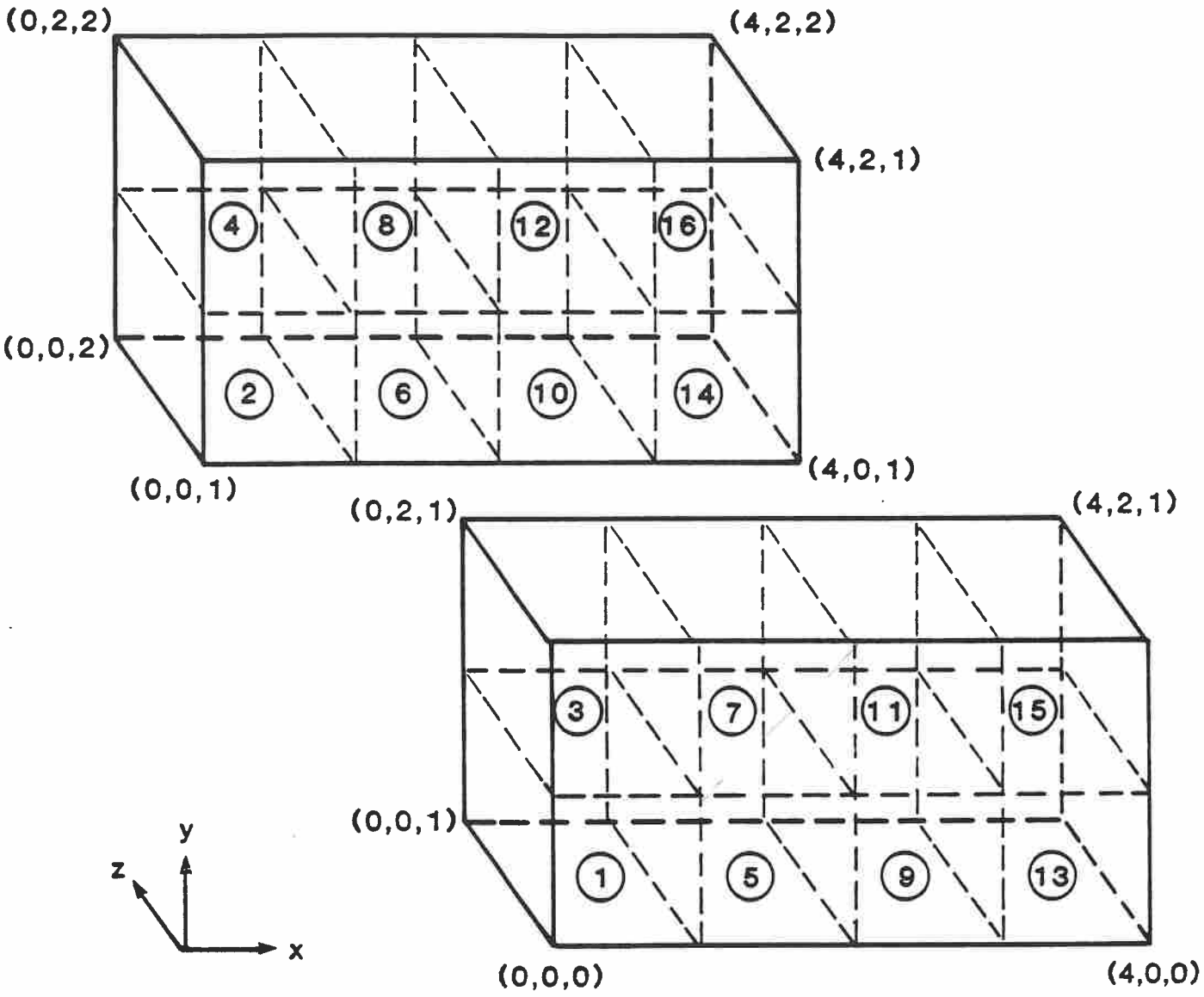



FIG. 7. NUMBERING OF CUBOIDS IN BOUNDING BOX
EXPLODED VIEW OF THE TWO SLICES

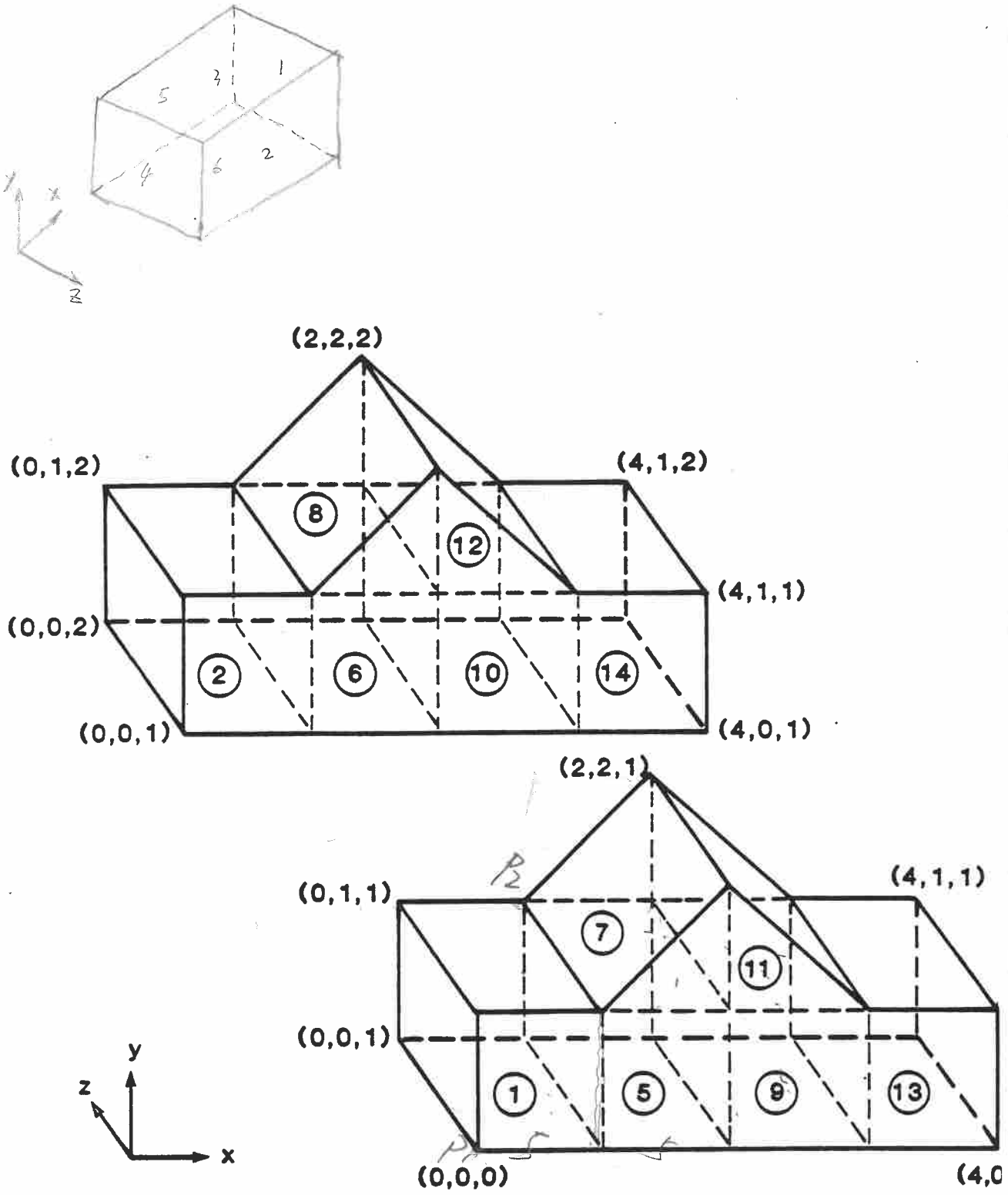



FIG. 8. NUMBERING OF GAS ZONES

## APPENDIX A - SUM OF GREY GASES MODEL

A number of the options for defining the gas absorptivity use a sum of grey gases model. The details of this model are given in this Appendix.

The calculation of radiative heat transfer in an enclosure containing non-grey gases is greatly simplified if the grey gas assumption can be retained. It has been shown that it is possible to represent the absorptivity (or emissivity) for some real atmospheres (including the combustion products of fossil fuels) as a weighted sum of the absorptivities of a number of grey gases [A1]. RADEXF provides this facility using the three grey gas model of [A2] and [A3]. The first of these three grey gases is a clear gas. The absorptivity of the other two grey gases depends on the fuel type. The values, taken from [A2] and [A3], are given in the table below.

| Fuel Type | Clear Gas | Grey Gas 1 | Grey Gas 2 |
|---|---|---|---|
| Natural Gas | 0.0 | 1.88 | 68.8 |
| Gas Oil | 0.0 | 2.5 | 109.0 |
| Heavy Fuel Oil | 0.0 | 2.5 | 109.0 |

If there is any soot present then this too can be represented using a sum of grey gases. Two grey gases are used and the absorptivities for each of these components are 350 and 1780 [A3].

It can thus be seen that there are six different absorptivities produced by an atmosphere containing soot (each of the grey gas components is combined with each of the soot components). If there is no soot then only two different absorptivities are produced (N.B. the clear gas is ignored in this case as RADEXF automatically calculates exchange factors for an atmosphere with zero absorptivity).

The different absorptivities for each component in the representation are calculated using the formula:

$$\text{Absorptivity} = \text{Gas component absorptivity} * \text{Partial pressure of } CO_2 \text{ and } H_2O + \text{Soot type absorptivity} * \text{Carbon concentration}$$

The carbon concentration is data which the user is prompted for. The combined partial pressure of $CO_2$ and $H_2O$ in the combustion products is calculated from the fuel type and the excess air level, both of which are supplied by the user in response to prompts from RADEXF. Although the grey gas components for gas oil and heavy fuel oil have the same absorptivities the combined partial pressure of $CO_2$ and $H_2O$ differ with the fuel type and so the final absorptivities produced from the formula above are different.

It should be noted that RADEXF does not calculate the total radiative transfer through a 'real' gas represented as a sum of grey gases. It calculates the requested exchange factor for each of the components of the grey gas. The weights to be used in the weighted sum of the grey gas components depend on the temperatures of the surfaces and gases within the enclosure and this information is not known to RADEXF.

## APPENDIX A REFERENCES

A1. H.C Hottel and A.F. Sarofim, *Radiative Transfer*, McGraw-Hill, New York, 1967.

A2. B. Leckner, "The Spectral and Total Emissivity of Water Vapour and Carbon Dioxide", *Comb. & Flame*, Vol. 19, pp.33-48, 1972.

A3. J.S. Truelove, "A Mixed Grey Gas Model for Flame Radiation", *United Kingdom Atomic Energy Authority Report, AERE-R-8494*, Harwell, 1976.

## REFERENCES


1. H.C. Hottel and E.S. Cohen, "Radiant Heat Transfer in a Gas-Filled Enclosure: Allowance for Non-Uniformity of Gas Temperature", *AIChE J.*, Vol. 4, pp.3-14, 1958.

2. T.R. Johnson and J.M. Beer, "Radiative Heat Transfer in Furnaces - Further Development of the Zone Method of Analysis", *14th Symposium (International) on Combustion*, pp.639-649, The Combustion Institute, Pittsburgh, PA, 1972.

3. H.A.J. Vercammen and G.F. Froment, "An Improved Zone Method Using Monte Carlo Techniques for Simulation of Radiation in Industrial Furnaces", *Int. J. Heat Mass Transfer*, Vol. 23, No. 3, pp.329-336, 1980.

4. T.F. Smith, Z.F. Shen and A.M. Alturki, "Radiative and Convective Transfer in a Cylindrical Enclosure for a Real Gas", *Trans. ASME J. Heat Transfer*, Vol. 107, pp.482-485, 1985.

5. F.R. Steward and H.K. Guruz, "Mathematical Simulation of an Industrial Boiler by the Zone Method of Analysis", *Heat Transfer in Flames*, N.H. Afgan and J.M. Beer (eds.), pp.47-51, Scripta, Washington D.C., 1974.

6. C.W. Clausen and T.F. Smith, "Radiative and Convective Heat Transfer for Real Gas Flow Through a Tube with Specified Wall Heat Flux", *Trans. ASME J. Heat Transfer*, Vol. 101, No. 2, pp.376-378, 1979.

7. D.A. Lawson, "Numerical Methods for Radiative Heat Transfer in Multidimensional Enclosures", Research Report prepared for British Gas MRS under contract MRS/2130/88.

8. J.J. Noble, "The Zone Method: Explicit Matrix Relations for Total Exchange Areas", *Int. J. Heat Mass Transfer*, Vol. 18, No. 2, pp. 261-269, 1975.

# RADEX: A USER GUIDE

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CONTENTS