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SAND2000-8225
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User's Guide for the KBERT 2.0 Code

For the Knowledge-Based Estimation of Hazards of Radioactive Material Releases from DOE Nuclear Facilities

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Releases from DOE Nuclear Facilities

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ABSTRACT

The possibility of worker exposure to radioactive materials during accidents at nuclear facilities is a principal concern of the DOE. The KBERT analysis tool has been developed at Sandia National Laboratories under DOE support to address this issue by assisting in the estimation of risks posed by accidents at chemical and nuclear facilities. KBERT is an acronym for Knowledge-Based system for Estimating hazards of Radioactive material release Transients. KBERT's primary purpose is to predict doses to in-facility workers due to accidental releases of radioactivity. Models are also in KBERT for predicting doses to the public based upon plume dispersal models. This report gives detailed instructions on how a user, starting with knowledge of design, layout and potential hazards of a facility, can use KBERT to assess the risks to workers in that facility and to the public as a result of releases from the facility. A key feature of KBERT is the inclusion of the non-facility-specific material release, radioactive decay, and dose databases (i.e., "knowledge bases") that might also be needed for such an assessment. The material release characteristics are based on the 1994 DOE Handbook for airborne release fractions/rates and respirable fractions for nonreactor nuclear facilities. Another important feature of KBERT is the inclusion of a transparent interface between KBERT and the Nuclear Regulatory Commission's CONTAIN code. This interface enables KBERT to use the validated and proven flow models in CONTAIN to predict inter-room air flows. Potential applications of KBERT include the evaluation of the consequences of evacuation practices, the effect of personal protection equipment, and the degree of containment of hazardous materials.

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KBERT 2.0 User's Guide

1. Introduction

Accident risks faced by workers at Department of Energy (DOE) facilities are receiving increased attention because of heightened awareness, aging of facilities, changing mission, and the advent of new activities (e.g., decontamination and decommissioning). The KBERT software has been developed at Sandia National Laboratories under DOE sponsorship to address these issues by assisting in the estimation of risks due to accidents at chemical and nuclear facilities. The emphasis of KBERT is on the calculation of doses to in-facility workers produced by accidental releases of radioactivity. This report describes the KBERT software and provides instructions for its use. This document covers several major enhancements that have been added to KBERT since the original user's guide was published on the earlier prototype version of KBERT [BRO95]. The most significant advance is the inclusion of a transparent interface between KBERT and the NRC's CONTAIN code [MUR98] for computing inter-room air flows within KBERT.

1.1 Overview of KBERT

The KBERT software can be used for qualitative or quantitative risk analyses, assessments of heating ventilation and air conditioning (HVAC) systems, the evaluation of alarm systems, and the assessment of evacuation plans. Facilities are modeled in KBERT as a number of rooms connected by hallways, HVAC ducts, and other flowpaths. The DOE Handbook [DOE94] database for the amounts of material released to the atmosphere for each type of accident and the associated respirable fraction of the released material is incorporated in KBERT as a separate database that KBERT accesses transparently to the user. The user may also view this database directly using the Microsoft Access database software that is available commercially. KBERT uses mechanistic models of aerosol transport within a facility given either user prescribed air flow rates or air flow rates obtained using the CONTAIN code [MUR98]. An interface that is completely transparent to the user is provided in KBERT to invoke the CONTAIN code in the latter case. Note that CONTAIN is a Nuclear Regulatory Commission (NRC) sponsored code that must be obtained through appropriate NRC channels in order to use this feature of KBERT.

Filters that mitigate radionuclide exposures in an accident can be modeled in any flowpath. Worker movements in response to alarms can be modeled by specifying a detailed evacuation plan for each worker or group of workers. Dose models include the effects of inhalation, cloudshine, groundshine, and skin contamination. The effect of half or full mask personal protection equipment is modeled, including shine protection, and skin protection. Output from KBERT includes airborne and surface concentrations of hazardous material throughout the facility as well as whole-body doses and risk to workers. Plume dispersal models are also provided in KBERT for estimating doses to the public caused by material releases from the facility.

All of the features described above are accessible through an intuitive easy to use graphical user interface. The cornerstone of this user interface is a familiar floor-plan view where the user manipulates objects that represent rooms and other features of the facility with a mouse to describe the facility layout. This same user interface can be used to query the results of a KBERT calculation, including radiological conditions in the rooms and the doses of workers in the facility and the public.

1.2 Guide to this Document

Chapter 2 describes how to begin using KBERT, including installing the software on the computer where it will be used.

Chapter 3 briefly describes the models in KBERT that are used to calculate the release, transport, and removal of radioactive material in the facility. The interface to CONTAIN for calculating air flows in KBERT is also described in this chapter. Additional leak path models as detailed by Heames and Brockmann [HEA94] could be implemented within KBERT. The models used to calculate dose to in-facility workers are also briefly described; however, the reader is referred to Monroe's [MON94] assessment for a detailed description of the dose models. Reading this section is not required to learn how to use KBERT; however, all users are encouraged to eventually read this section to gain an understanding of the modeling approach and key assumptions made.

Chapter 4 provides instructions for specifying input to KBERT. All required and optional inputs are described in this chapter, including instructions for defining the physical facility layout, workers in the facility, events and the materials at risk, and various options. The dialog boxes where most KBERT input is solicited are also shown and described in this chapter. Analysts planning to use KBERT will want to read this chapter in detail.

Chapter 5 describes how to run KBERT. Running KBERT once a facility has been defined is quite straightforward. Most experienced analysts, particularly those experienced in using software written for Microsoft Windows, will probably be able to run KBERT without referring to Chapter 5. This chapter is therefore best treated as a reference or for when one wants to perform more advanced KBERT functions.

The last chapter, **Chapter 6**, describes how to obtain output from KBERT. KBERT primarily produces screen output; however, there are provisions for cutting and pasting output graphics into other Windows applications for printing and saving. Like the input, the interpretation of KBERT output is rather obvious. One not so obvious output feature of KBERT is the Inspect Bar. Analysts should find this feature of KBERT invaluable for extracting key results from an analysis. The Inspect Bar is described in Chapter 6 along with a brief description of the other output features.

2. Getting Started

2.1 Hardware and Software Requirements

To use KBERT, you need:

- An IBM-compatible PC with a Pentium II 233 Mhz processor or greater.

- 64 MB of RAM – large problems may require more memory
- Microsoft Windows 95/98 or Windows NT 4.0 or higher
- SVGA graphics display capable of 1024x768 resolution (set to 256 colors)
- A mouse or compatible pointing device.
- A hard disk with at least 200 MB of free space – large problems may require more

Some video configurations may cause problems for KBERT in displaying the main screen, particularly when the video mode is set to greater than 256 colors. Such problems can be easily identified when KBERT first begins by a blank, white main screen. Should this problem occur, it can be corrected by setting the video mode to 256 colors and restarting KBERT.

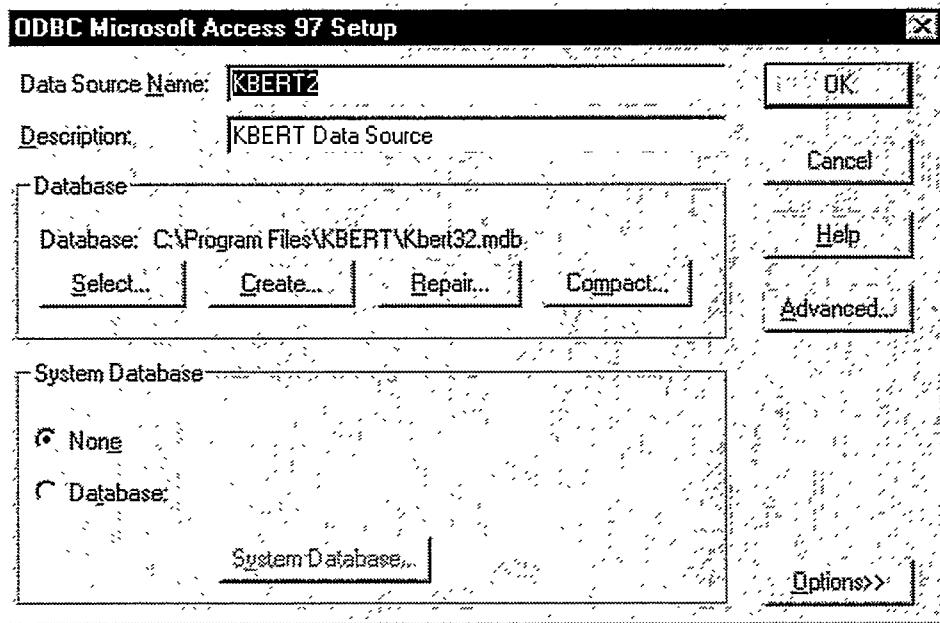
2.2 Installation

2.2.1 Main Automatic Installation Step

KBERT is distributed either on CD-ROM or via the KBERT web site. To obtain access to the KBERT web site you must have the appropriate authorization from the DOE sponsor and from Sandia National Laboratories. The installation process is the same with both distribution options. A single self-extracting executable file is present on the CD-ROM and on the KBERT web site. To install KBERT this executable file must be run from the target installation machine. This program will guide you through the installation process using a standard Windows installation wizard approach. This setup procedure should automatically register KBERT with your operating system and set up the KBERT database. If you are running Windows NT, you must have administrator privileges for this to operate properly. If you do not have these privileges then you should contact your system administrator and request that they perform the KBERT installation for you.

2.2.2 ODBC Database Access Setup

Before you run KBERT for the first time, you should first confirm that the ODBC interface is properly configured for KBERT. Microsoft Open Database Connectivity (ODBC) is a programming language interface for database connectivity. This interface should be configured to tell the KBERT application where to find the database it needs to run. This configuration can be checked by initiating the “ODBC Administrator” from the Windows control panel. You should have a KBERT2 data source present on the “User DSN” tab. If you do not have a data source with this name then you should add it. The properties of that data source should look as follows:



where the database location is specific to your computer and should be the location where you installed the KBERT code and database. The default location and name of that database is given in the above figure.

Once you have confirmed the existence of the KBERT2 datasource in ODBC, you will be ready to run KBERT.

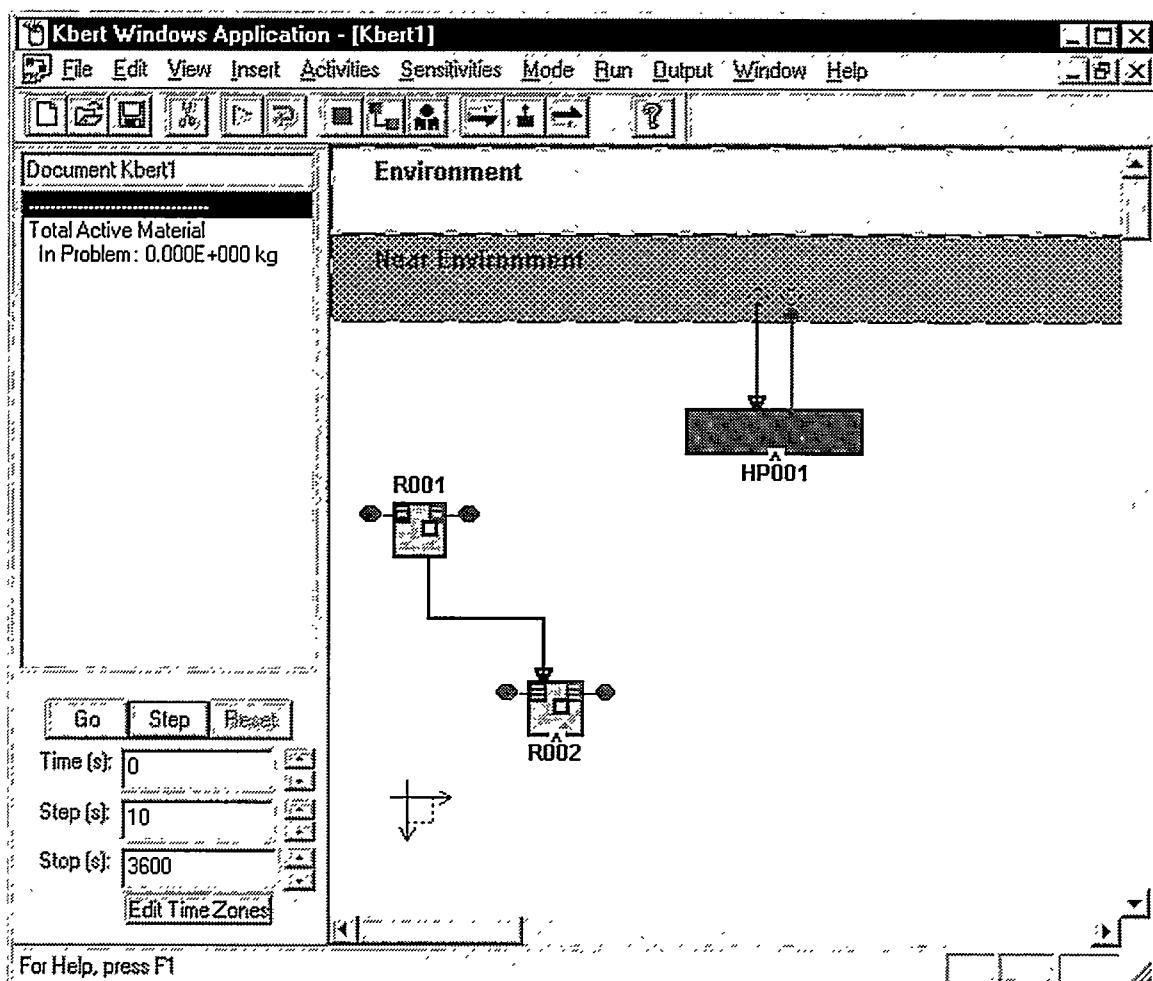
2.3 Starting the KBERT Software

Normally KBERT loads as a full screen application with a generic one room facility shown on the screen. Typically you use this simple facility as a starting point to create your own facilities, but you can delete the one room and/or the HVAC system and start from scratch. You can also load a facility from disk that you have created in a previous KBERT session as described in the following section. Note that facility files saved from previous beta versions of KBERT may not be loaded into the version described herein. When the KBERT icon is set up, normally no parameters are given following its name. If instead you specify the name of a facility file that exists on your hard disk following the KBERT executable program name in the icon's shortcut, that facility will automatically load when you double click on the KBERT icon.

2.4 The KBERT Main Screen

A simple facility represented in KBERT is shown in the following figure. In this figure the boxes labeled "R001" and "R002" are rooms, and the black line connecting the two represents a doorway (i.e., a flowpath) between the two rooms. Typically a facility will be modeled in KBERT with several rooms and several flowpaths. Rooms that have events defined in them will be shown on screen with a small red square in the bottom left hand corner. Connections between the rooms and the HVAC system are also shown in the facility layout as the lines with circles on one end and grids within the rooms on the other.

Circles will be shown in other situations when flowpaths are connecting rooms to the environment or to rooms on other levels in a facility. In these cases the color of the circles indicate the type of room the flowpath is connecting to. The box labeled "HP001" represents an HVAC system plenum. The flowpath connections between the plenum and the environment are shown as lines to the near environment at the top of the figure. Filters are shown as small gray boxes on the flowpath where they are defined. All facilities have a near environment and a far environment. These two special rooms cannot be removed. They are used to predict doses to the public and to accumulate source term data associated with material releases from the facility.



The above figure also shows a small box within each of the two rooms in the facility. These small boxes represent people, or workers, in the facility. People can also be added to the two environment rooms to represent the public.

Rooms and workers are examples of KBERT facility elements. A prominent feature on the KBERT screen is the Inspect Bar shown on the left side of the above figure. This bar provides information about the currently selected facility element, if any. If nothing is selected the Inspect Bar shows only the total active material (i.e., the material at risk that

has actually been released) in the system, as in the above figure. Just below the Inspect Bar are controls for setting the time step information and for running the analysis.

All facility elements described in Section 3.1, with the exception of Structures and Filters, may be selected by clicking (pressing and releasing) the left mouse button. All selectable elements can also be moved with the mouse, although the range of motion may be limited. For example, workers initially assigned to a room may not be moved outside of that room with the mouse. To move an element, use a left button drag operation (press the left mouse button over the element, move the mouse, then release the button).

Other useful mouse operations are as follows:

1. Keyboard shift + left button click selects an element and the elements connected to it, and all elements already selected. This is useful, for example, for examining the connectivity of a plenum, by selecting the plenum and all of its source and return ducts.
2. Left button double click on an element invokes the input dialog box for that element, whenever it is permissible to modify the input parameters for the element.
3. Left button drag starting at a blank portion of the screen selects all elements within the rectangle defined by the starting and end points of the drag operation.
4. Left button drag of a handle (the black squares outlining a selected element) changes the aspect ratio of rooms and plenums, and the connection pathway of standard flow paths. Note that the beginning and end handles of standard flowpaths determine only the position of the connection along one side of a room. To change the side of the room or plenum to which the connection is made, use one of the internal handles.

2.5 Loading and Saving Files

In KBERT, all aspects of a user defined facility can be saved in a file. By default, KBERT files are given the “.fac” extension. You can override this to give your files any extension, but this is *not* recommended. Files may be saved by selecting the “Save” or “Save As” option under the File menu. Alternatively, you can click the save icon on the toolbar to save the current file. When files are saved, they are reset to time zero; therefore, analysis results are never saved to the KBERT file. To review the results of a given analysis, the file must be loaded and re-run.

Previously saved files may be loaded by selecting “Open” from the File menu. Only files saved by the current version of KBERT may be loaded into KBERT. Any attempt to open a file not saved by the current version of KBERT will produce an error message. If the open is successful, the facility previously saved will be shown on screen. Note that KBERT is a “multiple document interface” or MDI Windows application; therefore, multiple facilities may be loaded at any given time. The Window menu item is used to switch between different facility models that are loaded at the same time. However, the user is cautioned that KBERT is memory intensive and unless the user’s machine has a large amount of memory (> 128 MB), it is recommended that only one facility be loaded at any given time if calculations are to be performed. Multiple files can be loaded on machines with modest memory capacity for viewing and comparison purposes.

All facilities loaded into KBERT from disk will be set to time zero, ready for you to start an analysis. The last four items on the File menu above the Exit selection lists the last four files loaded into KBERT. This can be used as a shortcut to quickly load any one of the last four files you have analyzed. Typically only files with the “.fac” extension are listed in the Load dialog box; however, files with other extensions can be listed by changing the selection of “Files of Type:” on the Open dialog box to “All”.

In addition to the normal file load and save menu items, the user will find two special options on the File menu named “Import Exodus” and “Export Exodus” that can normally be ignored. These options are for loading and saving files in a Sandia specific format. For more information about this format, the reader should contact Sandia National Laboratories and/or see Reference SCH98.

3. KBERT Software Description

3.1 Facility Elements

The KBERT software represents facilities as a collection of interconnected elements on the screen. The following elements are included: rooms, HVAC plenums, flowpaths, filters, and structures. All of these, except structures, are visible on the main KBERT screen. Although structures are not shown graphically, their attributes may be specified from within the Room dialog box. Filters are defined with the Flowpath dialog box. All other facility elements are defined from their own dialog box that is invoked by clicking on their screen symbol from the toolbar or via the insert menu item. Specifics about each facility element are discussed in the sections below.

3.1.1 Rooms

Rooms are the basic components used to describe a facility. A facility is described as one or more rooms interconnected by doorways and/or HVAC ducts. A facility can have any number of rooms. Each room can contain workers, structures (floor, wall, and roof structures are used to define aerosol deposition areas within a room), materials at risk, and events.

Rooms are shown on screen as green-colored rectangles. The area of the rectangle is proportional to the cross-sectional floor area of the room that it represents. Note that this is a major change in the visual representation of rooms from previous KBERT versions. The room height is no longer represented visually on screen. To access the height of the room the user must go into the Room dialog box and edit the height field. With this new visual layout approach in KBERT the room layout on screen more closely approaches a birds-eye view of the facility. While the user is not required to position the rooms in a fashion that mirrors the floor plan of the facility, this is strongly recommended in most cases. By taking this approach fewer doorway lines will cross each other and the layout in KBERT will be more appealing and easier to manage. The size of the layout area has also been significantly increased from previous versions so there is now ample room to model multiple floors in a facility.

Room physical characteristics, including embedded structures, events, and physical size are specified in the Room dialog box. The Room dialog box is accessed by double clicking on the rectangle that represents the room of interest. New rooms are added to a facility by selecting the “Room” option under the Insert menu or by selecting the button containing the green square in the toolbar. The room will be inserted at the location of the crosshairs on the main screen.

3.1.2 Environment Rooms

Each facility always has two environment rooms, a near environment and a far environment. The far environment room is called “environment” by default. These special rooms represent the out of doors and provide a source of fresh air and exhaust from the facility for ventilation systems. These special rooms are also used by the plume dispersion model in KBERT to predict doses to the public in the event of releases of radioactive material from the facility. The near environment room differs from the far environment room only in the handling of the plume dispersal model as discussed in Chapter 4. Like regular rooms, the environment rooms can contain any number of people, but in these cases they would represent the public instead of workers. Workers can also be modeled to evacuate to either the near or far environment rooms, but a caution is issued when this is entered into a worker’s evacuation plan since the plume model assumes that people are initially present in the environment. Events cannot take place in either of the two environment rooms.

The far environment room is represented as a fixed light blue band at the top of the KBERT main window. The near environment room is represented as a fixed dark blue band just below the far environment room. The on-screen size and location of these two rooms cannot be modified by the user. The physical characteristics of these two rooms can be modified from the Room dialog box, but changes to these rooms typically have very little effect on the outcome of the analysis.

3.1.3 HVAC Plenums

An HVAC plenum is a special type of room used to represent the common volume of an HVAC system. Plenums are distinguished from standard rooms on screen by their magenta color. Note that the displayed area of the rectangle representing an HVAC plenum, unlike that of rooms, is not keyed to its cross-sectional area and is arbitrary. Return and source vents in a given HVAC system connect to the same HVAC plenum. When a new facility is created one HVAC plenum is automatically included (each HVAC system has exactly one HVAC plenum). This initial HVAC system can be kept, deleted, or additional HVAC systems can be added at the user’s discretion. Any number of plenums may be added to a given facility. Each new HVAC plenum represents a new separate HVAC system. Air and materials drawn from rooms into one HVAC plenum are not mixed with air and materials drawn from rooms into other HVAC plenums. The characteristics of HVAC plenums are defined using the same Room dialog box described in the previous section. Unlike previous KBERT versions, standard (doorway) flowpaths can now be connected to and between HVAC plenums as well as HVAC ducts. Normally only HVAC ducts are connected to HVAC plenums, but use of standard flowpaths

provides additional flexibility. Workers and events are not allowed in HVAC plenums. HVAC systems are added by selecting the “HVAC System” option under the Insert menu or by selecting the button containing the purple rectangle in the toolbar.

3.1.4 Structures

Structures are embedded within rooms and are used to define deposition surfaces for aerosols. There are three types of structures that can be included in a room: floors, walls, and roofs. Normally each room will contain one of each type; however, the user can delete or add new structures prior to starting a run. The two environment rooms are initially created with no structures. Structures may be added to an environment room, but this is not recommended. HVAC plenums are not allowed to contain structures. All other rooms are created with three structures, one of each type. The area of the structures created in a room are automatically calculated to be the appropriate areas for a cube with the volume of the room. If you change the volume of a room after its initial creation, KBERT will not automatically re-adjust the areas of the structures in that room. Floor structures have the most noticeable effect on analysis results, since gravitational settling is the only aerosol deposition model included. All structures affect heat transfer modeling in CONTAIN which can have a minor effect on inter-room flows. To accommodate potential future KBERT extensions, where deposition mechanisms onto walls and roofs are possible, users are encouraged to define rooms with the appropriate wall and roof areas as well as floor areas. Structures are not shown visually on the KBERT screen; however, the deposited mass on structures is shown in the Inspect Bar when a room is selected.

3.1.5 Flowpaths

Three types of flowpaths are used to connect rooms in a facility. The first type is a standard flowpath, which is used to represent doorways, windows, and other interconnections such as pipes. The second type is an HVAC source duct, which is used to represent flow into a room from an HVAC plenum as a result of the HVAC system operation. The third type is an HVAC return duct, which is used to represent air and airborne material flow from a room back into the HVAC plenum.

Standard flowpaths are shown on screen as black lines. The shape of the connecting line is automatically determined from the relative locations of the connected rooms. An arrow is placed on either side pointing toward the “to” room. An important feature of standard flowpaths is that under certain conditions they are represented internally within KBERT as two separate flow pathways. These conditions are discussed in Section 4.1.5. This scheme allows countercurrent flow typical of flow through doorways to be captured by the flow model. If the flowpath is one with a user-specified flow rate, then the flow rate for both pathways may be given directly.

Source HVAC ducts are shown as a small red grid with a line connecting it to a circle on the left side of the room. Return HVAC ducts are shown as a small green grid with a line connecting it to a circle on the right side of the room. Source HVAC ducts representing fresh air to the facility and return HVAC ducts representing exhaust from the facility are

shown as green and red arrows on the HVAC plenum. The other end of these flowpaths are circles with the same color as the environment room that they connect to. The characteristics of flowpaths are described within the Flowpath dialog box that is accessed by double clicking anywhere on the flowpath of interest. For HVAC ducts the mouse should be double clicked on the small grid inside the room to invoke the Flowpath dialog box.

HVAC source and return ducts must be identified with a given HVAC plenum. HVAC source ducts can be specified between the environment and plenum to represent fresh air flow into a facility and HVAC return ducts can be specified to represent exhaust from a facility. If the source side flow is to be kept separate from the return side, then two or more HVAC plenums should be included. The HVAC source ducts should be connected to a different HVAC plenum from that for the return ducts. New flowpaths are added by selecting either the “Doorway”, “Source Duct”, or “Return Duct” option under the Insert menu or by selecting any of the three corresponding shortcut buttons on the toolbar.

A common modeling task is the representation of pressure blowdowns, such as those caused by the rupture of a high pressure container. Such blowdowns can be modeled with the CONTAIN flow model; however, there are special considerations that must be taken into account. Typically a pressure blowdown event follows a period of normal operations that lead to a certain set of initial conditions for the blowdown event. There are no provisions in KBERT to model both the pre-blowdown and post-blowdown phase of an accident as a single analysis. To model such events, the user should run KBERT twice, preserving the results of the first analysis to specify as the initial conditions for the analysis with the blowdown event. These initial conditions will include thermal-hydraulic conditions of each room and steady state flow rates through the flowpaths in the facility. In particular, note that the flow rates in pressure-driven flowpaths (including doorways, windows, and other leak pathways) prior to the blowdown will be non-zero. The flowpath for the blowdown itself is typically modeled as a pressure-driven flowpath, and unlike the other flowpaths in the facility, it will usually have an initial flow rate of zero. However, the Flowpath dialog box allows non-zero initial flow rates to be specified in pressure-driven flowpaths. The user is referred to the CONTAIN code manual for further user guidance on calculations involving pressure blowdowns in complex facilities.

3.1.6 Filters

Filters may be specified to trap airborne materials on any flowpath, including doorways and HVAC ducts and are shown on screen as rectangular gray boxes. Although one would normally not include a filter on a doorway, this is allowed because standard flowpaths are also used to represent pipes which can be filtered. Each filter may be given a unique user specified constant or time dependent aerosol removal efficiency, and a constant removal efficiency for elemental and organic iodine. Only airborne aerosol material and iodine are affected by filters; other non-aerosol materials pass through filters unaffected. Filters are specified by first editing the flowpath where they are located and then pressing the “Filter” button in the Flowpath dialog box.

A new model is included for predicting HEPA filter failure as a function of filter collection area, maximum fan head speed, head loss coefficient, and filter age. The theory behind this new model is described in Appendix A.

3.2 Workers

Workers are represented within a facility either individually or as groups that move together. Each worker or worker group is represented on screen as a small yellow square within one of the rooms. Unlike previous KBERT versions, workers may no longer be moved from room to room by dragging their icons. This feature caused modeling inconsistencies for cases where the evacuation model had been defined, so it has been removed. Each worker or worker group can be given its own evacuation plan which defines how they move following the initiation of an accident. Finally, each worker can be given personal protective equipment consisting of either skin protection, full or half mask, self contained breathing apparatus, and shine shielding using options in the Worker dialog box. The Worker dialog box is accessed by double clicking on the yellow square for the worker of interest. New workers are added to a room by first clicking on the room and then selecting “Worker” under the Insert menu. Also, when a room is created the user is asked if a new worker should be automatically added to the room.

3.3 Materials at Risk and Events

The radiological materials involved in an accident (i.e., the materials at risk) and the characteristics of the release event are specified in the Event dialog box. The Event dialog box utilizes the KBERT database that embodies the recommendations in the DOE Handbook [DOE94] for airborne release fractions/rates and respirable fractions for accidents in nonreactor nuclear facilities. This database includes data for a variety of release events, such as fires, spills, and explosions. However, KBERT does not handle criticalities. KBERT handles all interactions with the database as required; however, interested users may view the database directly if they have the Microsoft Access commercial database program. The user is cautioned that any changes made to this database are likely to change KBERT results, thus negating the validation of KBERT. It is also possible that for certain changes KBERT will not function properly. For this reason, any modification of the database is strongly discouraged. An important feature of KBERT is that it promotes the use of appropriate combinations of release data, events, and materials at risk in the simulation. However, arbitrary release characteristics may be entered in the Event dialog box as user-specified values that will override the database values.

The KBERT database provides an instantaneous airborne release fraction, ARF, and/or a continuous airborne release rate, ARR. The mass M of material released into the atmosphere from an event in a given time step dt is:

$$\begin{aligned} M &= MAR \cdot ARF \quad (t = t_s) \\ &= MAR \cdot ARR \cdot dt \quad (t > t_s) \end{aligned}$$

where t_s is the event start time that is specified in the Event dialog box and MAR is the total mass of material at risk. Normally this start time is equal to zero. Note that the ARF is only used on the first time step. The released material will not begin to distribute through the facility and affect workers until subsequent time steps.

When mass M is released into the atmosphere of the room during a time step, the following equation is used to calculate the respirable fraction of the material:

$$RF(t+dt) = \frac{RF(t) \cdot M(t) + RF \cdot M}{M(t) + M}$$

where M is the mass of material released during this time step, RF is the respirable fraction of the material at risk as taken from the database, $M(t)$ is the mass of the same material present in the atmosphere at the beginning of this time step, and $RF(t)$ is the respirable fraction of the material in the atmosphere at the beginning of this time step. Often, RF and $RF(t)$ will be the same. However, in general $RF(t)$ can change with time.

The values of ARF, ARR, and RF, if stored directly in the database, are extracted from the database and shown in the Event dialog box. If any of these values are calculated from a formula, the calculated value will be shown whenever all relevant information has been supplied. In some cases the formula used requires one or more attributes to be specified by the user. In these cases the words “Attributes Required” will be shown in the dialog box and the user will be required to press the Attributes button and provide these user-specified parameters before the Event dialog box is closed.

There are actually three values for ARF, ARR, and RF in the database corresponding to minimum, nominal, and maximum (bounding) values. Initially the nominal value is shown in the Event dialog box. A pull-down menu is provided to allow the user to show either the minimum, nominal or the maximum values. The Sensitivities menu allows the user to pick which set is actually used in the analysis. (The Sensitivities menu allows the minimum, nominal, or maximum value to be consistently selected in all models using this three-value uncertainty characterization. However, in the present KBERT version only the release models use this characterization.)

3.4 Material Flows

Two options exist for representing air flow in KBERT. For most problems the user should allow the CONTAIN code to be invoked automatically through the KBERT interface to compute air flows. Note that the details of CONTAIN’s input structure are completely hidden from the user. However, the user has certain responsibilities for specifying flow parameters in the flow paths for this option as described in Section 4. When CONTAIN is used to compute the flows, CONTAIN also calculates the thermal hydraulic conditions in the facility and passes that information back to KBERT. For very simple problems, the user can also choose to specify the air flow rates directly. In both cases, airborne active material flow is driven by the air flow rates through the flowpaths.

KBERT uses either the specified flow rates or the rates determined by CONTAIN to move airborne material between the interconnected rooms as described below.

The time dependent flow equation for active material species k in room i is given by

$$\frac{dm_{i,k}}{dt} = \sum_{j \rightarrow i} \left(\frac{m_{j,k} \cdot Q_{ji}}{V_j} \right) - m_{i,k} \cdot \left(\frac{\sum_{i \rightarrow j} Q_{ij}}{V_i} \right)$$

where $m_{i,k}$ is the mass of species k in room i, V_i is the volume of room i, Q_{ij} is the volumetric flow rate from room i to room j. This approach hinges on the assumption that airborne active materials are present in sufficiently low concentration that they do not affect the gas flow. A rule of thumb that quantifies this assumption is that average distance between particles is at least 10 times the particle diameter, for the aerosolized species. A further assumption is that active materials flow between rooms with the gas flow with very little slip, i.e., at the same velocity as the gas flow. Technically, this is valid for small particles and low flow rates, and is a reasonable approximation for most cases. When filters are present, the flow between rooms is modeled according to the following modified version of the flow equation

$$\frac{dm_{i,k}}{dt} = \sum_{j \rightarrow i} \left(\frac{m_{j,k} \cdot Q_{ji}}{V_j} \cdot (1 - \varepsilon_{kji}) \right) - m_{i,k} \cdot \left(\frac{\sum_{i \rightarrow j} Q_{ij}}{V_i} \right)$$

where $m_{i,k}$ is the mass of species k in room i, and ε_{kji} is the filter removal efficiency in flowpath ji for that species type. The fraction that does not flow through to room i gets trapped in the filter.

Unlike previous versions of KBERT, the thermal hydraulic conditions in the rooms are not computed within KBERT itself. Instead, these are computed in CONTAIN and passed back to KBERT automatically along with the time dependent flow information.

CONTAIN does not process aerosol flow information because KBERT includes its own models for aerosol removal effects, including the effect of filters and aerosol gravitational settling. If CONTAIN is not used to compute air flows, the thermal hydraulic conditions in the rooms will be constant in time and set to the initial condition values.

3.5 Dose Models

Mechanistic models are included in KBERT for calculating dose to workers in the facility and to the public. The public is modeled as a worker located in the near environment room. The four dose pathways considered in KBERT are inhalation, cloudshine, groundshine, and dermal contact. The dose conversion factors used in the dose calculations are taken from References ECK88 and ECK93. The inhalation, cloudshine, and groundshine doses displayed as output from KBERT correspond to the whole-body equivalent dose effective (EDE) as defined in Reference ICRP87. The skin dose corresponds to that from dermal contact (i.e., deposition) of materials on the skin. The full health effects output present in previous KBERT versions has been removed because

experience with the earlier versions indicated that this output was not used to assist decision-making. However, the dominant risk factor, based on Reference ICRP87, is still calculated and displayed in the Inspect Bar when a worker has been selected (see Section 6.4). The dose models are described in more detail in Reference MON94. Information about the specific implementation of these models in KBERT is provided in this section.

Inhalation dose received by a worker in a room during a time step is directly related to the activity in the room, the breathing rate of the worker in question, and a dose conversion factor that relates inhaled activity to dose. Half lives of all materials that can be airborne in KBERT are automatically extracted from the KBERT database. A default worker breathing rate ($3.5e-4 \text{ m}^3/\text{s}$) is provided, but the user may change this to any value desired. The dose conversion factors are stored in the KBERT database for each material. The appropriate conversion factor for each radioactive isotope is automatically extracted from the database and used in the inhalation dose calculation. If a worker has an evacuation plan, then the dose environment can change as the worker moves from one room to another. The dose rate in the new room is based on the activity in that room. The cumulative inhalation dose received at any given time is equal to the sum of the doses received during all time steps leading up to that time.

Cloudshine dose calculations follow an identical logic; however, the dose conversion factors are different from those of the inhalation model. Again, the appropriate conversion factor that relates airborne activity to cloudshine dose is automatically extracted from the KBERT database and used in the dose calculation. The cloudshine model in KBERT is described in Reference MON94 and includes a geometric factor to account for the finite size of rooms.

The groundshine model is based on the amount of radioactive material deposited on the structures in the facility. As aerosols deposit on structures, KBERT calculates the mass and activity attributed to deposited material. The groundshine model uses the activities corresponding to the room occupied by the worker. The dose conversion factor relating surface specific activity to groundshine dose is extracted from the KBERT database for each deposited radioactive material and used in the groundshine model.

3.6 Aerosol Removal by Gravitational Settling

Materials at risk released from events enter the atmosphere of rooms as aerosols. The mean size of the released aerosol material is calculated as a function of its respirable fraction, RF, as follows [ACG85]:

$$\begin{aligned}
 D_{\text{mean}} &= 10^5 \text{ m} & \text{if } RF = 0.0 \\
 &= 10^6 \text{ m} & \text{if } RF = 1.0 \\
 &= 10^{(5+RF)} \text{ m} & \text{otherwise.}
 \end{aligned}$$

This size is important because it is used to calculate the aerosol settling rate by gravity. Note that an $RF < 0$ will result in a $D_{\text{mean}} > 10^{-5} \text{ m}$. A negative RF is allowed so that aerosol transport sensitivity studies may be performed for large aerosols. When $RF < 0$, the respirability of the aerosol for dose purposes is taken to be zero.

The following equation is used to evaluate the settling velocity V_g of aerosol in a room:

$$V_g = \frac{D_{mean}^2 \cdot 1000 \cdot g \cdot C_s}{18\mu} \quad , \quad C_s = 1 + \frac{2\lambda}{D_{mean}} \left(F_{slip} + 0.4 \cdot e^{-\left[\frac{I.I \cdot D_{mean}}{2\lambda} \right]} \right).$$

where μ is the viscosity of air, g is the acceleration of gravity, λ is the mean free path of air, and F_{slip} is a slip factor equal to 1.257. The viscosity and mean free path of air, for simplicity, are taken to be those at standard temperature and pressure. As this equation shows, V_g is a strong function of the airborne particle size. This model for gravitational settling is similar to that found in the CONTAIN code, although a more sophisticated multisize representation of aerosols is used in the latter. The limitation of using only the mean size in the KBERT aerosol treatment can be assessed through sensitivity studies by changing the RF of the released aerosols in the simulation.

The settling velocity is used to calculate the deposition rate of airborne aerosol onto floors and onto workers. The rate of aerosol removal onto a given surface is given by

$$\frac{l}{m} \frac{dm}{dt} = V_g \cdot \frac{A}{Vol}$$

where V_g is the settling velocity given above, A is the surface area of the floor or of the worker, m is the mass of aerosol in the room atmosphere, and Vol is the volume of the room. Additional deposition mechanisms that could be implemented in future versions of KBERT are discussed in Reference HEA94.

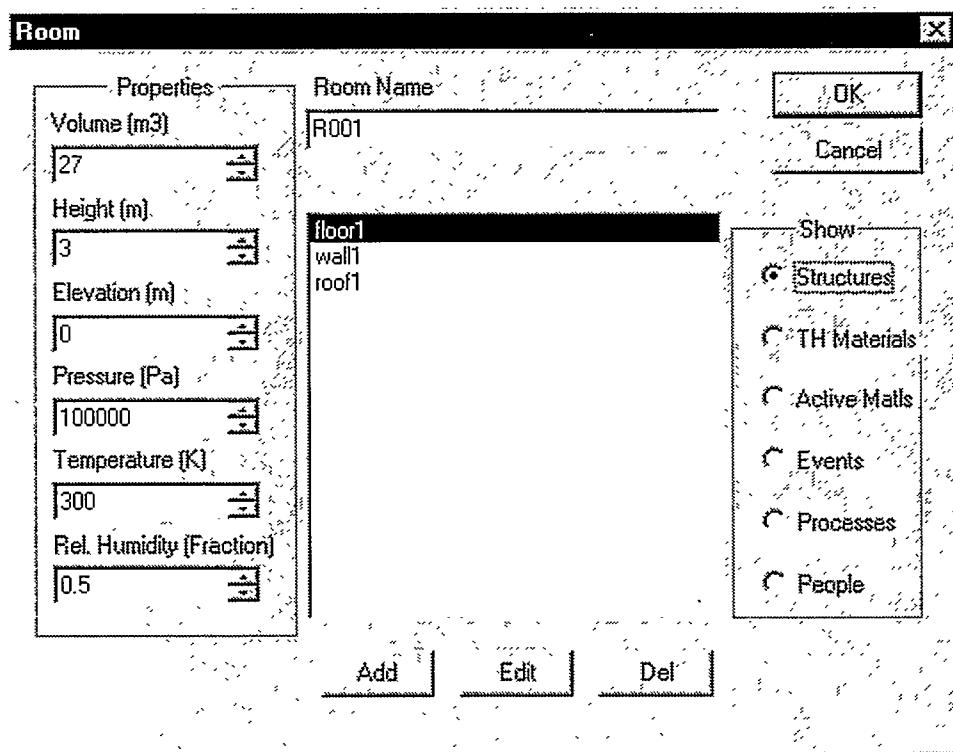
4. Input Instructions

This section describes the KBERT input which is accomplished through dialog boxes and the main KBERT menu. Most of the dialog boxes can be opened from the Insert menu or by double clicking the facility element of interest. In each section a picture of the dialog box is shown and each control on that box is discussed. The main menu is described in Section 4.5.

4.1 Facility Elements

4.1.1 Rooms

Rooms are defined or modified using the Room dialog box shown below.



The contents of the list in this dialog box changes when a different option button is selected on the right hand side of the box. In the view shown above, the structures present in the room are listed by name. The TH Materials button will cause all the thermal hydraulic materials to be listed. These are the materials that are passed to the CONTAIN code for handling within the air flow model. The Active Matls button will cause all other materials to be listed. This includes aerosols and other airborne radionuclides initially present in the room. The Events button will list all the events defined in this room. Events are the cornerstone of KBERT's modeling of accidents and are discussed in great detail in Section 4.3 below. The Processes button is for future expansion of KBERT's modeling capabilities. Currently there is a simple parametric spray model, but this model has not been fully verified and validated so it is not documented and its use is not allowed. The last button is the People button which will show the workers in the room in the list.

Each control in the Room dialog box is explained below.

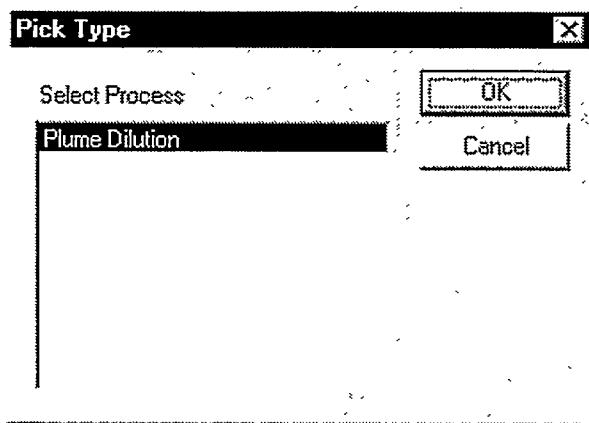
Room Name	Edit box used to specify a unique name for the room. This name is referred to in the results presented in the Run Accident Simulation dialog box, the Inspect Bar, and the history plots. By default a unique generic name is created when a new room is added, but users are encouraged to give rooms specific names that have meaning to them.
Volume	Edit box used to specify the volume of the room. The volume must be positive. The size of the room on screen will be proportional to the value specified here. This value is also used to calculate the default areas of structures created in this room.
Height	Edit box used to specify the height of the room. Note that this value will have no impact on the visual representation of the room onscreen. This value is also used to calculate the aerosol gravitational deposition rate and the default areas of structures in the room.
Elevation	Edit box used to specify the vertical elevation of the room, where 0 is the ground floor. If CONTAIN is used to compute air flows, this value is passed to CONTAIN for use in calculating the gravitational head.
Pressure	Edit box used to specify the initial pressure of the room. If CONTAIN is used to compute air flows, this value is passed to CONTAIN for use in the flow model for computing the air flow rates and the thermal hydraulic conditions.
Temperature	Edit box used to specify the initial temperature of the room. If CONTAIN is used to compute air flows, this value is passed to CONTAIN for use in the flow model for computing the air flow rates and the thermal hydraulic conditions.
Rel Humidity	Edit box used to specify the initial relative humidity of the air in the room. If CONTAIN is used to compute air flows, this value is passed to CONTAIN for use in the flow model for computing the thermal hydraulic conditions.
Option buttons	A group of six option buttons, labeled Structures, TH Materials, Active Mats, Events, Processes, and People used to select what is shown in the main list box in the center of the dialog box. Only one of these buttons can be selected at a given time. When a different button is selected, the dialog box changes to show different information. Any item in the list may be double clicked and it will invoke a dialog box specific to that item where more information can be found and/or edited. The edit button below the list performs the same action as double clicking on the selected item.
Add	Push button used to add objects to a room. The type of item added depends upon which radio button is selected on the right side of the dialog box. For example, if the TH Material item is selected, then "Add" will invoke a dialog box that will allow another material to be added to the TH Material list.

Edit	Push button used to edit the selected item on the list. This performs the same action as double clicking on the item of interest.
Del	Push button to delete objects from a room. When the “Del” button is pushed a confirmation dialog box will be shown; if No is selected the item will not be deleted; if Yes is selected the item is deleted.

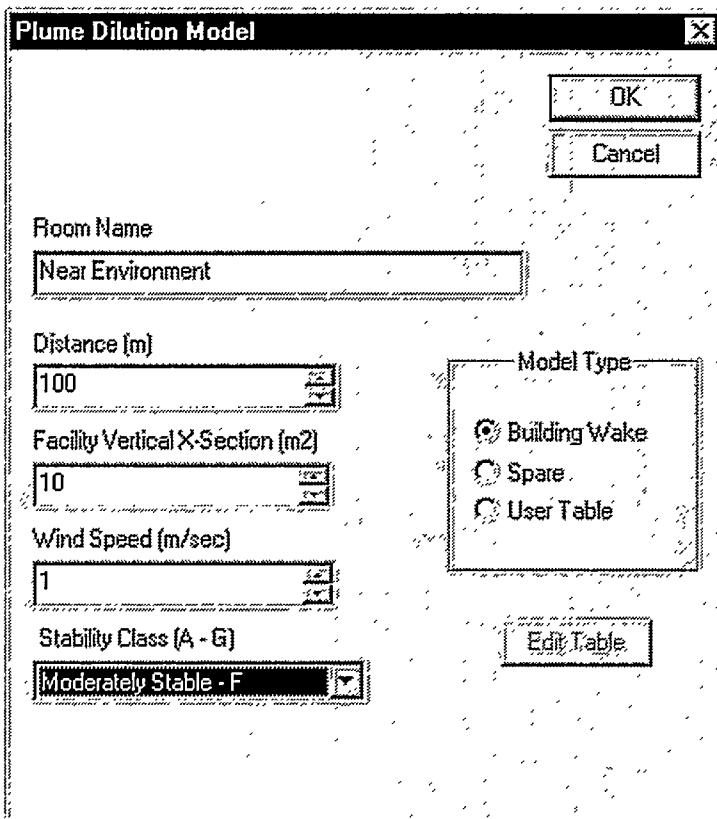
4.1.2 Environment Rooms

Two environment rooms are always present in every KBERT facility, a near environment and a far environment. These two special rooms may not be deleted nor can new ones be created. The name of the far environment is simply “Environment” and the name of the near environment is “Near Environment.” The properties of the two environment rooms can be modified using the same room dialog box described above; however, certain restrictions apply to environment rooms. Events may not be added, and in general structures should not be added either, although the latter is not prohibited. The volume, height, elevation, pressure, temperature, and relative humidity of the environment rooms typically should not be altered. The temperature may be altered to represent different seasons of the year; however, this will typically have very little effect on the outcome of the analysis.

The dispersal of radioactive material released from the facility is modeled in KBERT by adding the “Plume Dilution” process to the near environment room. Note that this process may not be added to the far environment room, and only one such process may be present in the near environment room. Adding this process is done by selecting the “Process” radio button in the Room dialog box and clicking the “Add” button. The only process available to add will be “Plume Dilution” as shown below.



When OK is selected this process is added and the following dialog box will be invoked to specify the various options and parameters associated with the plume dilution model. This same dialog box can be invoked by editing the existing plume dilution models in the near environment. The plume dilution model is described in Appendix B.



Each of the options are described below.

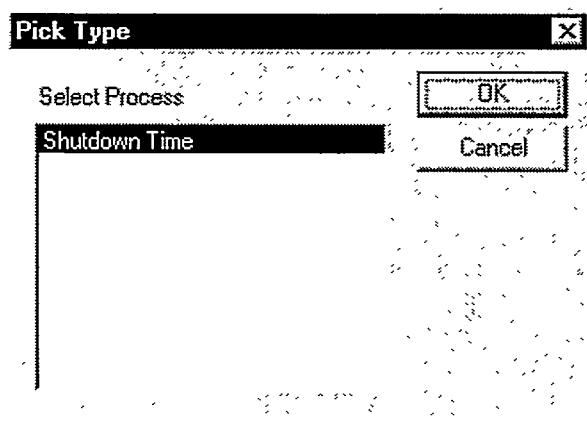
Distance	Edit box used to specify the distance between the release point and the person exposed.
Facility Vertical X-Section	Cross section of the facility as defined in the plume dispersal model.
Wind Speed	Average wind speed outside of the facility used in the plume dispersal model.
Stability Class	One of the six available stability classes is selected in this drop down input box.
Model Type	The type of plume dispersal is specified by selecting one of the three radio buttons shown above. If the user table is selected, then the Edit Table button will be enabled and must be selected to specify the dilution as a function of time.

4.1.3 HVAC Plenums

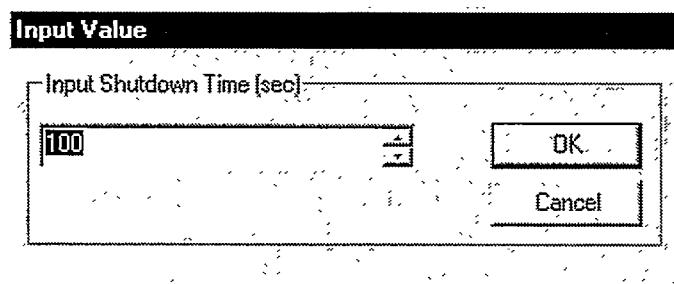
HVAC plenums are special types of rooms (see Section 3.1.2) that represent the volume of a particular HVAC system in a facility. The input options available in the Room dialog box apply also to HVAC plenums; however, some actions will not be allowed,

such as the addition of a worker, an event, or a structure. This is because these items may not be added to HVAC plenums.

A special shutdown time process is available only in HVAC plenums. This is accessed by selecting the “Process” radio button in the Room dialog box and clicking the “Add” button. The only process available to add will be “Shutdown Time” as shown below.



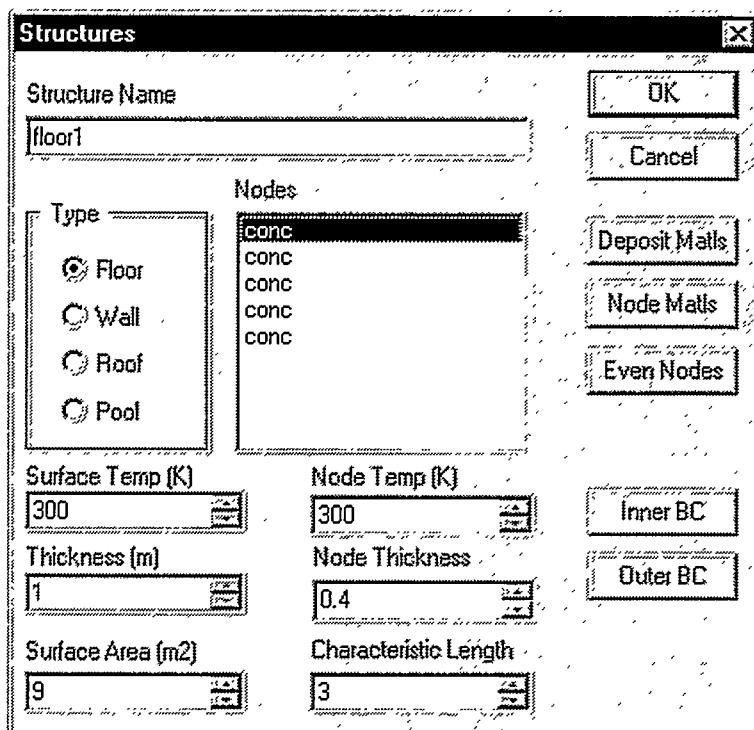
Upon selecting OK, the shutdown process will be added to the room and the user will be prompted for the shutdown time as shown below.



All ducts connected to this HVAC plenum will be shut down to zero flow at the time given in this dialog box. Once a shutdown time process has been specified it will remain in effect, even if the process is removed; therefore, to effectively remove the shutdown time process, the user should edit the shutdown time process and specify a large time in the above box. This feature is useful for simulating the shutdown of a HVAC system in a facility. Note that the shutdown time will override all other flow specifications, such as the time-dependent flow profiles discussed in Section 4.1.5.

4.1.4 Structures

The Structures dialog box shown below is used to specify the name, area, and temperature of a structure within a room. The characteristic length is also specified here, which is used in CONTAIN in the natural convection heat transfer model.



Each option in the Structures dialog box is explained below.

Structure Name	Edit box used to specify a unique name for the structure.
Surface Temp	Edit box used to specify the surface temperature of the structure. KBERT does not calculate changes in structure temperature; however, CONTAIN uses this value to perform heat transfer calculations and it can have an effect on the flow model.
Thickness	An automatically generated field representing the thickness of the structure from the sum of the node thicknesses that are specified in the Node Thicknesses edit box (see below).
Surface Area	Edit box used to specify the surface area of this structure exposed to the atmosphere of the room where this structure is located.
Node Temp	Edit box used to specify the temperature of individual nodes in the structure. As different nodes are selected, this value changes to represent the temperature of that node. These values are used in the heat conduction model in CONTAIN and typically has little effect on the flow calculation.
Node Thickness	Edit box used to specify the thickness of the individual nodes in the structures. The sum of the thicknesses of all the nodes is automatically calculated and displayed in the Thickness field which cannot be edited directly. The thickness of the structure is only used in the CONTAIN heat conduction model and typically has little effect on the flow calculation.

Characteristic Length	Edit box used to specify the characteristic length of the structure. This value is passed to CONTAIN for use in the atmosphere to structure heat convection model.
Deposit Matls	Push button used to invoke the Edit Materials dialog box. This dialog box is used to specify materials on the structure. If radioactive materials are added to structures, they will contribute to the groundshine dose calculation. Materials are typically added to floor structures throughout the analysis as a result of aerosol deposition by gravitational settling. This button is used only to specify additional materials.
Node Matls	This button does nothing in the current version. In future versions this button could be used to enable materials other than concrete to be specified as the node materials. Currently all structures are made of concrete in KBERT. One consequence is that the Nodes window, which displays the material present in each node, will always display "conc," which is an abbreviation for concrete. The makeup of structures has very little impact on the flow calculation in CONTAIN for typical KBERT applications.
Even Nodes	This button does nothing and should be ignored.
Inner BC	This button does nothing and should be ignored.
Outer BC	This button does nothing and should be ignored.

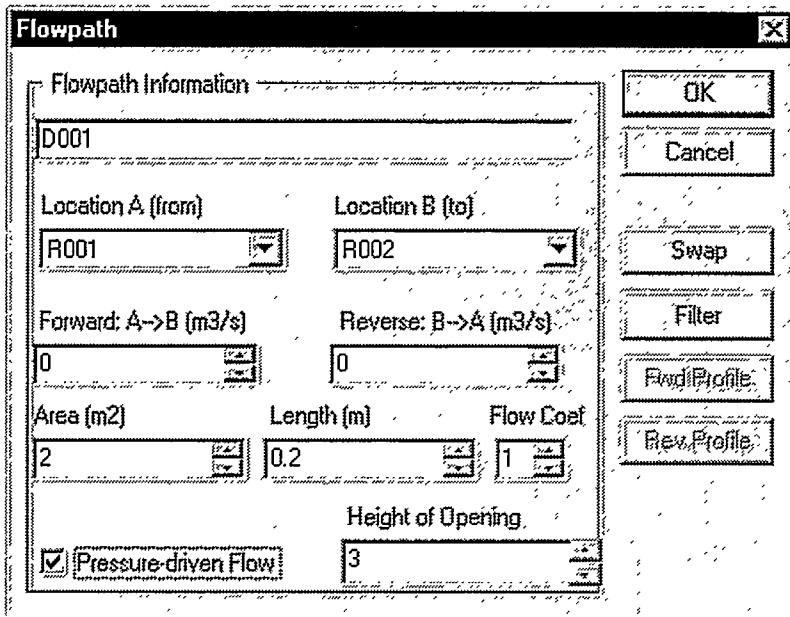
4.1.5 Flowpaths

Flowpaths are the modeling element used in KBERT to represent doorways and heating and ventilation ductwork.

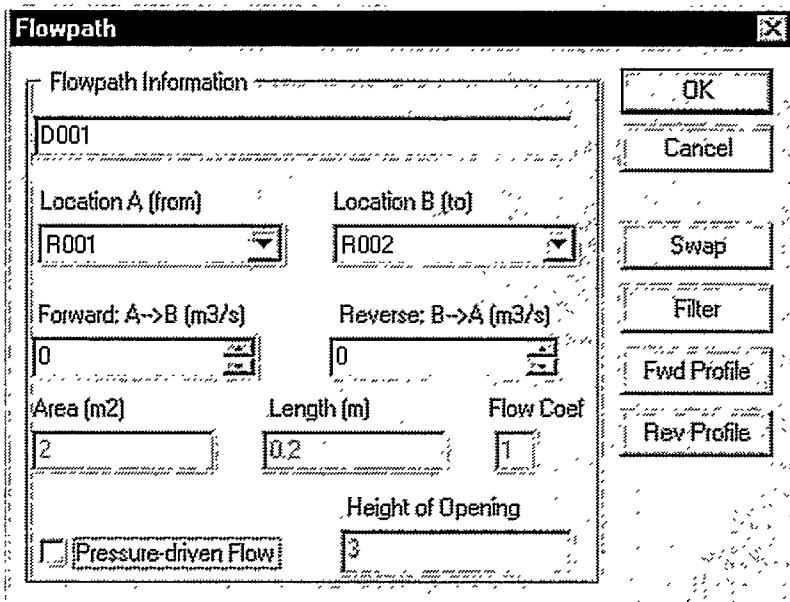
4.1.5.1 Standard Flowpaths

Standard flowpaths are typically used for doorways in a facility; however, they may also be used to represent other flowpaths such as windows, pipes or known leakage pathways. Standard flowpath input is provided using the dialog box shown below. Note that under certain conditions each standard KBERT flowpath is represented internally by two separate pathways. This representation is done to enable the physics of countercurrent flow in a given doorway or other flowpath to be represented. The characteristics of the flowpath connections are specified in the Flowpath dialog box shown below.

For pressure-driven flow, this dialog box appears as follows:



If the “Pressure-driven Flow” check box is not selected, the Flowpath dialog box appears as follows:



Note that a countercurrent flowpath representation will be used for a standard flowpath whenever the “Reverse: B → A” edit box is not grayed-out. This is always the case for a standard flowpath if the pressure-driven flow option has not been selected. If the pressure-driven flow option has been selected, then a countercurrent flow representation is used provided (1) the two connected rooms and/or plenums have the same center-of-volume elevation, and (2) the height of the flowpath opening is equal to or greater than one-half of the minimum of the heights of the two connected rooms and/or plenums. For

a pressure-driven countercurrent flowpath, “forward” flow refers to the flow in the lower half of the flow junction; “reverse” flow refers to the flow in the upper half of the junction.

Note that the pressure-driven flow option is designed to be used with the CONTAIN mode for calculating thermal-hydraulic conditions. If the pressure-driven flow option is selected but the CONTAIN mode is not, constant flow rates equal to the initial condition values shown in the above dialog box will be used.

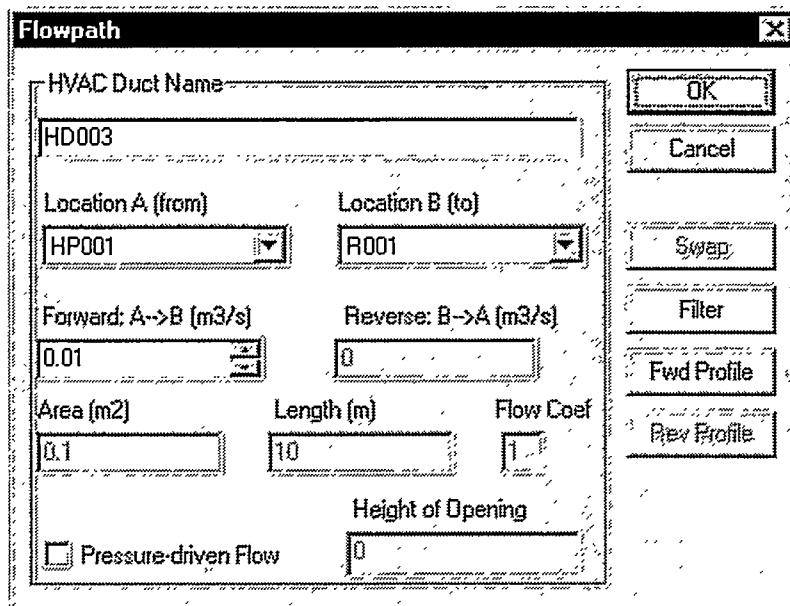
Note that the values that must be specified in the above dialog box with user specified flow rates are different from those that must be specified for pressure-driven flowpaths. Each option is discussed below.

Flowpath Name	Edit box used to specify a unique name for the flowpath. A unique name for each flowpath is provided by default; however, the user may want to provide a more meaningful name for certain key flowpaths.
Location A (from)	Drop down list to select the originating location of the flowpath. Note that the from and to locations are used in the output to report results.
Location B (to)	Drop down list to select the destination location of the flowpath. Location A cannot be the same as Location B. Regular flowpaths may be used to connect rooms to other rooms, rooms to HVAC plenums, and HVAC plenums, to other HVAC plenums.
Forward A->B	Edit box to specify the flowrate in m^3/s from Location A to Location B. This edit box is always available. When the Pressure-driven check box is selected this value represents the initial flowrate.
Reverse B->A	Edit box to specify flow rate in m^3/s from Location B to Location A. This edit box is available only when countercurrent flow modeling is allowed. Otherwise, it is grayed-out. When the Pressure-driven check box is selected and this edit box is available, the value displayed represents the initial flow rate in the reverse direction.
Area	Edit box to specify area of the flow path in meters ² . This edit box is only available when pressure-driven flow is selected.
Length	Edit box to specify length of the flow path in meters. This edit box is only available when pressure-driven flow is selected.
Flow Coef	Edit box to specify the loss coefficient of the flow path. Values on the order of 1.0 are typical for this value. This edit box is only available when pressure-driven flow is selected.
Height of Opening	Edit box to specify the height of the flow opening. This value is used to split the flowpath into two countercurrent paths when the conditions discussed above are satisfied.
Swap	Push button to swap the names of Location A and Location B.
Filter	Push button to invoke the Filter dialog box. This dialog box is used to define the removal efficiency of the filter in the flowpath. Note that all flowpaths can have a filter. Only filters with non-zero removal efficiencies are shown on the main screen. The filter input dialog box invoked with this button is described in Section 4.1.6.

Fwd Profile	Push button to invoke the dialog box is to specify flow rate multipliers in the forward direction as a function of time. The user table input dialog box is described in Section 4.4.1. This option is only available when pressure-driven flow is not selected.
Rev Profile	Push button to invoke the dialog box is to specify flow rate multipliers in the reverse direction as a function of time. The user table input dialog box is described in Section 4.4.1. This option is only available when pressure-driven flow is not selected.

4.1.5.2 HVAC Ducts

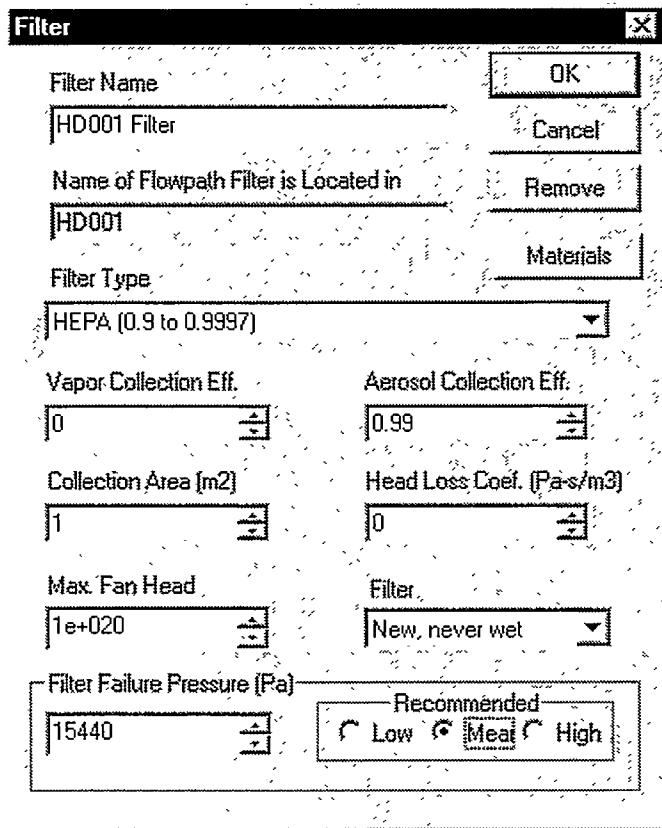
HVAC ducts are specified using the same dialog box discussed above, but certain features are disabled. This is because flow may only occur in one direction for HVAC ducts. Note also that the user typically specifies the flow rate through these types of flowpaths; therefore, by default the pressure-driven flow option is turned off for HVAC ducts. Pressure-driven flow can be turned on for HVAC ducts but this is in general not recommended. If this is done then HVAC ducts will be exactly like a standard flowpath but without the possibility of countercurrent flow.



The one difference between this dialog box and the standard flowpath box is that one drop down list only contains a list of the HVAC plenums in the facility, and the other excludes HVAC plenums. This is done because HVAC ducts connect rooms to a given HVAC plenum. Notice also that the “Swap” button is grayed and not available in the HVAC Duct dialog box because of the specific assignment of the HVAC plenum as either Location A or Location B, depending on whether the duct is a source duct or return duct.

4.1.6 Filters

Filters may be added to any flowpath to model the removal of contaminant from the air. Data is embedded within KBERT for recommending aerosol collection efficiencies for certain filter types, and a simple model is included for estimating HEPA filter failure as a function of filter age and conditions. The filter module in KBERT will also remove volatile iodine and cesium vapors; however, no model is available for predicting the filter collection efficiency for vapors.



The controls in this dialog box are described below.

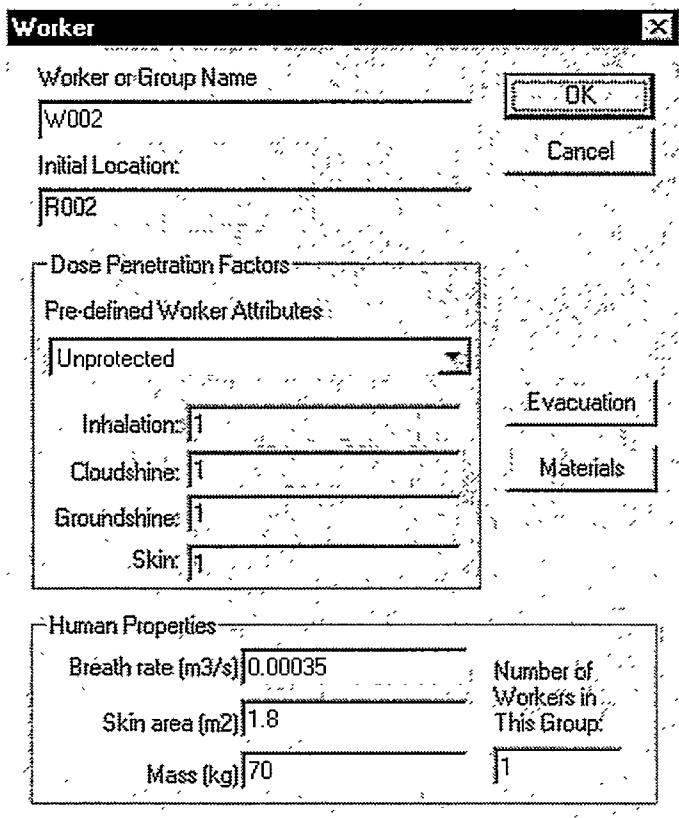
Filter Name	An edit box used to set the name of the filter so that it can be identified elsewhere in the program.
Location of Filter	A display only box used to show the name of the flowpath where the filter resides so that it can be identified elsewhere in the program.
Filter Type	A pull-down menu which lists the following available pre-programmed choices for filter type: HEPA, sand bed, water spray scrubber, electrostatic precipitator, user defined, and none. Each filter type, except the user defined type, has an associated aerosol collection efficiency value. The "User Specified" option does not suggest a value but lets you set the aerosol collection efficiency to any value between 0 and 1.0 (for 100%). If the HEPA filter type is selected, the filter failure model will be available. The parameters associated with this model are described below.

Aerosol Collection	
Efficiency	An edit box which allows you to set or modify the filter collection efficiency to any value between 0 and 1.0.
Vapor Collection	
Efficiency	An edit box which allows you to set or modify the filter collection efficiency for volatile vapors to any value between 0 and 1.0.
Collection Area	Collection area of the filter. This area is only used in the filter failure model as described in Appendix A. By default this area is the area of the parent flowpath.
Head Loss Coef	Parameter used in the filter failure model as described in Appendix A.
Max Fan Head	Parameter used in the filter failure model as described in Appendix A.
Filter	Drop down list used to select the conditions and age of the filter. The options include: "New, never wet", "Aged, never wet", and "Dry, previously wet". Aged filters and wet filters have lower failure pressures than new and dry ones.
Recommended	The recommended value for each type of failure pressure is set for HEPA filters upon selection of one of the Low, Mean, or High radio buttons. These failure pressures depend on the condition and age of the filter.
Filter Failure Pressure	Predicted failure pressure based upon the above selected parameters. This value can be overridden by the user as desired.
Remove	This button is used to remove the filter from the flowpath. This method should be used to remove a filter that has been previously defined in a flowpath, as opposed to setting the filter collection efficiency to zero.
Materials	This button invokes the Materials dialog box which allows the user to assign an initial amount of filtered material to a flowpath filter. This dialog box is described in Section 4.3.3.

4.2 Workers

4.2.1 Physical Characteristics

Any definition of or modification to the physical characteristics of a worker must be done from the Worker dialog box. This dialog box is also the entry point for defining the evacuation plan for a worker.



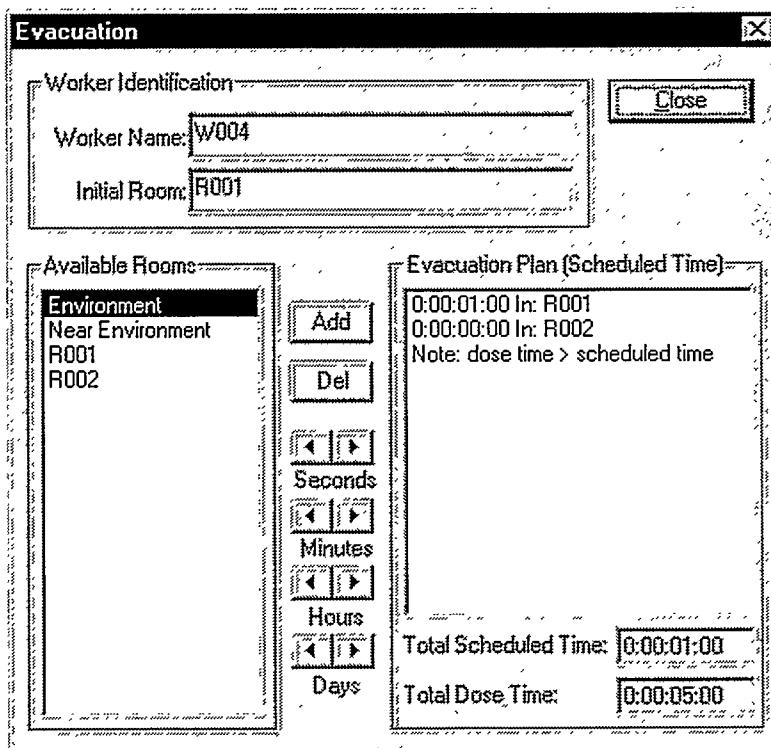
The controls in the Worker dialog box are explained below:

Worker or Group Name	This edit box is used to specify a unique name for the worker or group of workers. A unique name is assigned by default when the worker or group is created.
Initial Location	This display-only field shows the name of the room where the worker or group was created. This is the initial location of the worker at the start of the simulation. Note that the location of the worker will vary in time as the simulation progresses if an evacuation plan is provided.
Breath Rate	The average adult male breathing rate is shown above and is the default value used for inhalation dose calculations. Average values for males were used for workers because these numbers were readily available. This value may be set by the user, for example, to account for anxiety or movement.
Skin Area	The average adult male exposed skin area is shown above and is the default value used for skin deposition calculations. A different value may be specified here by the user.
Mass	The average adult male mass is shown above and is the default value used for dose calculations. A different value may be specified here by the user, for example, to more accurately model women workers.

Number of Workers in This Group	A worker symbol can indicate any number of workers who all evacuate together along the same route and at the same time. This value is the number of workers represented by this worker symbol.
Pre-defined Worker Attributes	This pull-down menu includes a list of choices of worker protection devices. When a selection is made, the protection factors associated with the choice will appear in the four categories of dose shielding factors. If "User defined" is selected, the four dose shielding factors will become accessible for editing and the user may then input values between 0 and 1.
Dose Penetration Factors	There are four factors that influence radiation dose in KBERT. They include: Inhalation, Cloudshine, Groundshine and Skin Dose. A value of 1 in a category implies full exposure to the hazardous material; 0 in a category implies full protection.

4.2.2 Evacuation

Each worker or worker group can be assigned a particular evacuation path, which consists of a list of rooms visited and the time spent in each room during the evacuation. The evacuation plan is specified by pressing the "Evacuation" button in the Worker dialog box, which brings up the following Evacuation dialog box.



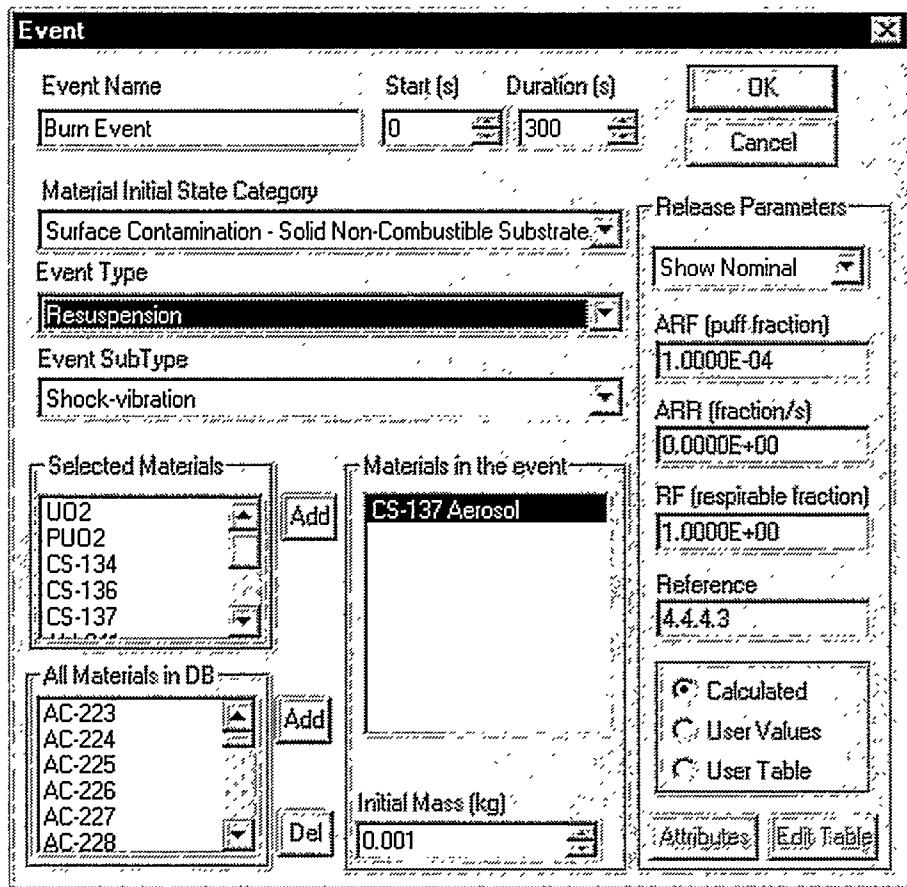
Each control in the Evacuation dialog box is explained below:

Worker Name	This display only box is used to specify a unique name for the worker or worker group.
Initial Room	This display only box is used to specify a unique name for the initial room where the worker will begin the simulation.
Available Rooms	This box contains the names of all the rooms in the facility. The user can choose from this list when specifying the sequence of rooms along the evacuation route of the worker(s).
Add	This control will add the selected room from the Available Rooms list to the evacuation plan. The room will be added immediately after the room that is currently selected in the evacuation plan.
Del	This control will remove the selected room from the evacuation plan.
Evacuation Plan	The evacuation plan lists the rooms that the worker(s) will visit while evacuating. The rooms are listed in the order in which the worker(s) will visit them. The scheduled time shown on the left side of each entry in the plan indicates the amount of time the worker(s) will spend in the indicated room before moving to the next. The worker always begins the simulation in the room where the worker was created. The worker will remain in the last room of the evacuation plan for the duration of the simulation, and accumulate dose there, whenever the total time of the simulation, or total time over which dose is accumulated, exceeds the total time scheduled for the worker. In the above example plan the worker will spend 4 hours accumulating dose in room R002.
Seconds, Minutes, Hours, Days	These controls are used to add or subtract the indicated time unit from the duration time of the currently selected room in the evacuation plan.

4.3 Materials at Risk and Events

4.3.1 Events

Events are added to rooms to model accidental releases of material. The Event dialog box is invoked by pressing the “Add” button with the “Events” radio button selected in the Room dialog box. Material releases may also be represented with a user-specified source table of material for the room of interest. The advantage of using the Event dialog box is that it encapsulates the recommended release fractions and respirable fractions in the DOE Handbook [DOE94]. The actual data associated with the various release events are captured in the KBERT database file. The Event dialog box is shown below. This is one of the most complex dialog boxes in the KBERT program, so the user should review this section carefully prior to use of the Event dialog.



Event Name

This edit box is used to give a unique name to the event.

Material Initial State Category

This pull-down menu is used to select the appropriate initial state of the material at risk. The selection made here is used to provide appropriate choices in the Event Type list. Each new selection will also change the contents of the Selected Materials list box discussed below. If one or more materials have already been added to an event and the Material Initial State Category changes, the user will be prompted to keep or delete the existing material from the event. This is because it is possible that the new Material Initial State Category could be incompatible with the materials already present in the event.

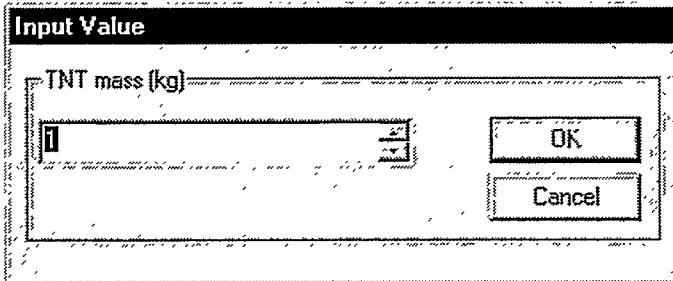
Event Type

This pull-down menu allows the user to select the type of event that causes the release of material. The selection made here is used to provide appropriate choices in the Event Subtype list below.

Event Subtype

This pull-down menu allows the user to select the specific event based on the event type and initial state selected.

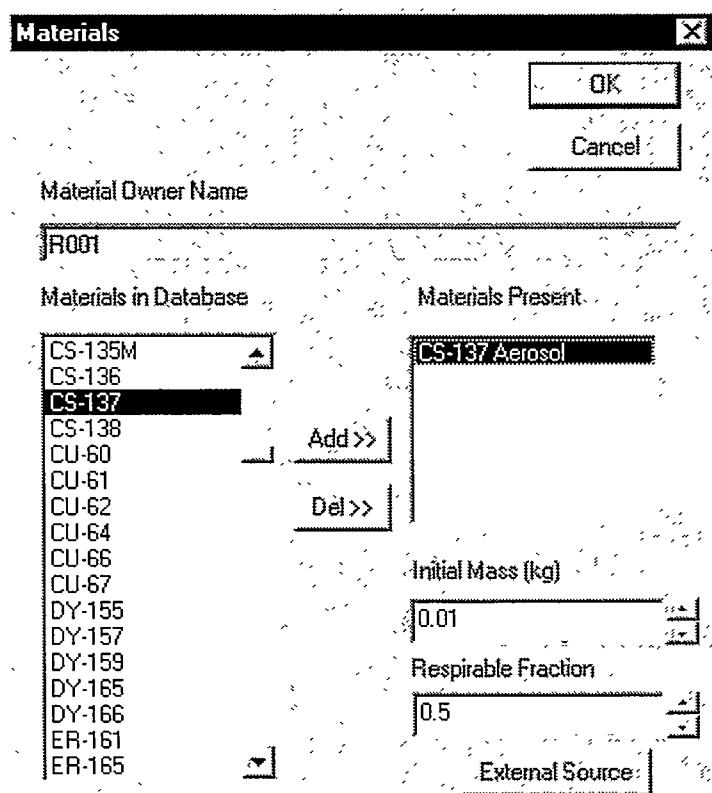
Selected Materials	List box that shows all the materials in the KBERT database for which recommended release fraction/rate and respirable fraction data exist. The user may select one or more of these materials and add them to the list of materials to include in the event. All of the materials in this list are guaranteed to be compatible with the event type selected above in accordance with the recommendations in the DOE Handbook.
All Materials in DB	All of the materials in the KBERT database are listed in this list box. Like the list above, one or more of the materials listed may be added to the list of materials in the event. Unlike the materials in the above list, the materials shown in this list are not in general compatible with the event type. This feature was included so that the user may include materials in events that were not explicitly identified in the DOE Handbook, but that the user feels would behave similarly to those materials that are in the DOE Handbook.
Materials in the Event	A list of materials in the event. These are the materials that are released into the atmosphere of the room in accordance with the other parameters specified in this dialog box. The mass of each material is specified by selecting that material and then entering a value in the Initial Mass field below this list box. Typically there will be only one material in a given event; however, multiple materials can be selected and added to the list if the user so chooses.
Add	Button used to add a material to the event. The top Add button will add a material from the recommended list of candidate materials at risk. The bottom Add button will add a material from the main database shown in the list on the bottom left corner of the dialog box. More than one material may be selected at a given time and added with one press of the Add button.
Del	Button used to delete a material from the event. The selected materials will be deleted. More than one material may be selected at a given time and deleted with one press of the Del button.
ARF	The airborne release fraction, taken from the KBERT database, indicates the fraction of the material at risk that will be released when the event commences.
ARR	The airborne release rate, taken from the KBERT database, indicates the rate at which the material at risk will be released into the surrounding air for the duration of the event. The duration is specified in the duration edit box explained in the following section, 4.3.2.
RF	The respirable fraction, taken from the KBERT database, indicates the portion of the airborne material which is small enough to be inhaled deeply. Such deep inhalation requires particle diameters $< 10^{-5}$ m.

Show Nominal/ Show Minimum/ Show Maximum	This drop down box includes these three display options for displaying the corresponding values of ARF, ARR, and RF. The three sets of values are provided to support KBERT's sensitivity calculation capabilities that are described in Section 5.0.
Reference	A section number in the DOE Handbook where the user can find documentation of the material release fraction/rate and respirable fraction used in KBERT for this situation.
Calculated/ User Value/ User Table	Only one of these three buttons can be selected at any given time. When "Calculated" has been selected the values provided by KBERT taken from the database representation of the DOE Handbook will be used for the simulation. In some cases the user will be required to supply some attributes, such as material density, so that the formulae can be evaluated. This will be indicated in the ARF field when applicable. When the "User Value" radio button is selected the release fraction fields will become editable and the user will be allowed to override the KBERT provided values. Caution must be exercised to specify sensible (e.g., positive) and defensible values. The third option provides even more flexibility by allowing the user to specify a time-dependent table of release rates and respirable fractions. This is done by pressing the "Edit Table" button just below the User Table radio button. The release rate and the respirable fraction values are specified using the standard user-table input described in Section 4.4.
Attributes	When "Calculated" has been specified, the user may be required to supply some user-specified attributes that will be used in the formulation of the three values above (ARF, ARR, RF). These attributes are specified in a simple edit box as shown below for the case of the TNT mass involved in an explosive release.
Start	 <p>This edit box is used to specify the time at which the event will commence. For puff releases, i.e., when the release fraction is non-zero and the release rate is zero, this value is the time of the puff release. For gradual releases, this value is the start time of that release.</p>

Duration	This edit box is used to specify the length of time that the event will continue to release the material at risk. Note that if the release rate (ARR) is zero, then this value will have no effect. The release fraction (ARF) is applied instantaneously at the time denoted by the start value given above.
Initial Mass	The user may define the amount of material at risk that will be involved in the event during the simulation using this edit box. If there are multiple materials at risk, then the initial mass will be for the material selected in the “Materials in the event” list box.

4.3.2 Adding Materials Outside of Events

Materials can be manually added to the following facility objects: rooms, HVAC plenums, environment rooms, structures, workers, events, and filters. For rooms, HVAC plenums, and environment rooms this is done by selecting the “Active Materials” radio button and pressing the “Add” button in the room dialog box. Thermal-hydraulic (TH) materials may also be added using the user table feature. This is very useful for modeling explosions and other energy excursions. This is done by selecting the TH Materials radio button and pressing either the “Add” or “Edit” buttons in the room dialog box. Deposited materials may be added to structures by pressing the “Deposit Materials” button in the Structure dialog box. Radioactive material may be deposited directly onto the skin of a worker at the beginning of a calculation by pressing the “Materials” button in the Worker dialog box. Material may be deposited directly onto a filter by selecting the “Materials” button from the Filter dialog box. All of the above actions will invoke the Materials dialog box described below:

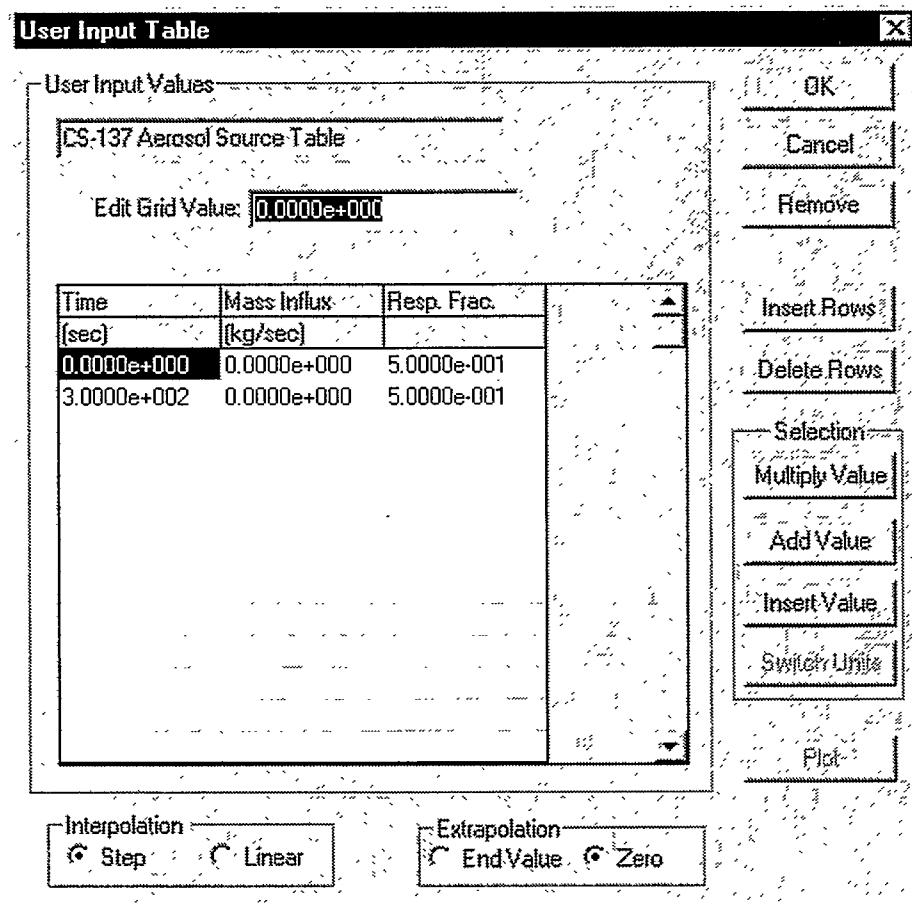


Material Owner Name	Static box showing the location of the materials. The location cannot be changed; this is simply to remind the user where the material is being added.
Materials Database	List box showing all the materials available in the materials database. Any material from the database can be added by selecting it with the mouse and then pressing the “Add” button (see below).
Materials Present	List box showing all the materials present in the facility at the location given in the Location edit box. The amount of each material is shown in the Initial Mass box when that material is highlighted.
Add	Push button used to add the selected materials from the database to the location. If the material is being added to the room atmosphere a Pick Type dialog box is shown (see below) where the user must select to what extent the added material is respirable.
Del	Push button used to remove the materials selected in the Materials Present list box.
Respirable Fraction	User specified respirable fraction of the material that is being manually added to a KBERT room. This field is only meaningful when the material is being added to a room. Note that the respirable fractions are provided by the KBERT database for materials that enter a room through Events. The size of the aerosol will be governed by the formula given in the beginning of Section 3.6. If the material is being added to a structure, worker, or filter, this field will not be available since only airborne materials can be respirable.
Initial Mass	Edit box used to specify the initial mass of the material selected in the Materials Present list box.
External Source	Button to invoke the user table feature for specifying a time dependent source of material. This feature is very similar to the User Table feature in the event dialog box, with the only difference being that this table provides mass flux values, while the event dialog box user table feature provides release rate values that is multiplied by the mass at risk to obtain the mass flux into the room. Either approach may be used with similar results. For TH materials, this dialog box will include two columns, one for mass flux and one for specific enthalpy, thus enabling gases with different energy contents to be introduced into the room. This is the best approach for representing explosions or other energetic events that occur in the facility. The following section describes the user table input feature in detail.

4.4 User Table Inputs

The same flexible dialog box is used to specify time dependent information in KBERT for various purposes. This includes time dependent user specified flow rates, material deposition on filters, structures, and workers, release rates and respirable fractions, active

material source tables, thermal hydraulic material source tables, and time zone information. A typical user table dialog box is shown below.



The controls in this dialog box are described below. The non-editable display box near the top of the dialog box is provided to identify the table being edited.

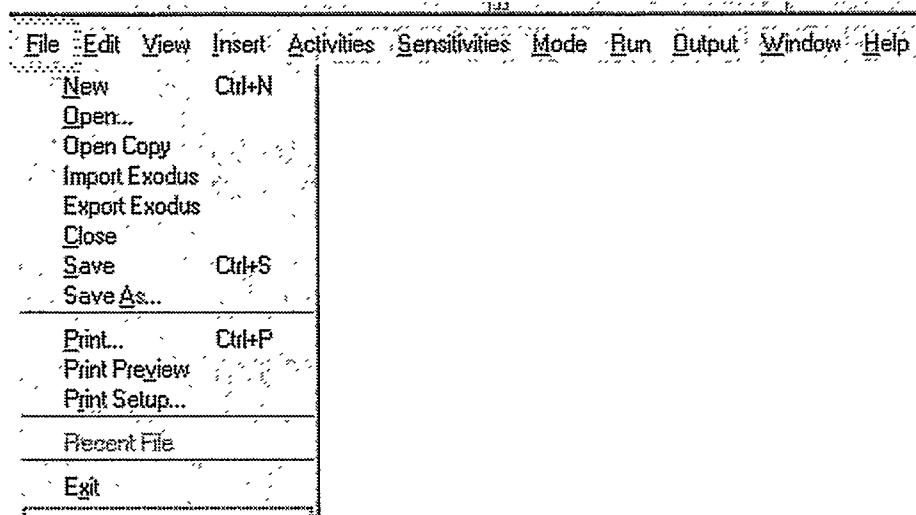
Edit Grid Value Edit box used to change the values of the selected table entry.

Time The first column in the table holds the time values. Each user input table can have its own unique time values.

Other columns	One or more columns will be shown to the right of the Time column. The title and units of these columns will depend upon the subject of the user table. For example, the box shown above is associated with the active material external source feature, so the columns represent the mass flux and the respirable fraction of that material. The user should carefully look at the units to ensure that the intended representation is given in the table. The interpolation and extrapolation of the values in these columns is shown in the Interpolation and Extrapolation check boxes at the bottom of the dialog box. In some but not all cases the type of interpolation/extrapolation may be selected by the user. Note that “end value” extrapolation uses either the first or last value of a column for times outside the range of the table, depending on whether the time is closer to the first or last time, respectively, in the Time column. “Zero” extrapolation uses a zero value outside of the range of the table for all of the non-Time columns. In the above example, the mass flux and respirable fraction would be taken to be zero for times > 300 s, even if the mass flux entry at 300 s were set to a nonzero value.
Insert Rows	One or more rows will be inserted above the cursor point
Delete Rows	The selected rows will be deleted
Multiply Value	The values highlighted in the table will be multiplied by the user provided numerical value. Upon selection of this button the user will be prompted for the multiplier in a simple dialog box.
Add Value	The values highlighted in the table will be added to the user provided numerical value. Upon selection of this button the user will be prompted for the value to add in a simple dialog box.
Insert Value	The values highlighted in the table will be replaced by the user provided numerical value. Upon selection of this button the user will be prompted for the new value in a simple dialog box.

4.5 Main Menu

The main menu in KBERT is shown below. As this figure shows, the main menu has several top level menu choices, and each choice has several sub-items beneath it. The figure below shows the sub-items beneath the File menu item. The following discussion briefly describes each of the menu items and sub-items.



File

New	Create a new facility with the default elements of two environment rooms, one HVAC plenum, one room, one worker in that room, and HVAC vents to and from the room. Note that KBERT is a "multiple document interface" windows program where more than one facility can be loaded into memory for editing at the same time.
Open	Loads a previously created facility file.
Open Copy	Creates a copy of the previously saved facility file for the current KBERT view and loads it for editing or comparison purposes.
Import Exodus	Load file with a Sandia specific format. For more information about this format, the reader should contact Sandia National Laboratories and/or see Reference SCH98.
Export Exodus	Save file in a Sandia specific format. For more information about this format, the reader should contact Sandia National Laboratories and/or see Reference SCH98.
Close	Closes the current facility file.
Save	Saves the current facility file to disk with the same name previously specified. If this is the first time the file has been saved, this command is equivalent to Save As.
Save As	Saves the current facility file to disk with a new name.
Print	Prints the main screen view onto the printer
Exit	Exits the KBERT application.

Edit

Delete	Deletes the currently selected item or items. Caution should be exercised in using this command since there is no "undo" capability in KBERT.
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Edit Object	Invokes the dialog box associated with defining parameters for the selected facility item.
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Note that the other standard Windows cut, copy, and paste features typically found on the Edit menu are also found in the KBERT main menu, but they are grayed out because these features are not supported.

View

Toolbar	Toggles the toolbar at the top of the main screen off and on. With this toolbar turned off, more area is available onscreen for manipulating facility elements.
Status Bar	Toggles the status bar at the bottom of the main screen off and on. With this toolbar turned off, more area is available onscreen for manipulating facility elements.
Inspect Bar	Toggles the Inspect Bar on the left side of the screen off and on. The Inspect Bar consumes a substantial amount of screen real-estate, so the user may find it easier to work with the Inspect Bar turned off when constructing new facility models. Once a problem is run and results are being examined, the user will want to turn the Inspect Bar back on.
Zoom In	This menu selection causes the elements in the KBERT view to enlarge by about 10%.
Zoom Out	This menu selection causes the elements in the KBERT view to reduce by about 10%.

Insert

Room	Inserts a room into the facility at the location of the crosshairs. The best way to locate a new room in the desired onscreen position is to first click the mouse on the desired location to set the crosshairs in place, and then select this menu item. The room dialog box will be invoked upon the selection of this menu item.
Doorway	Inserts a regular flowpath into the facility. The rooms that this flowpath will connect to are set in the flowpath dialog box, which is displayed upon selection of this menu item. By default, these rooms will be the last two rooms the user has selected.
Source Duct	Inserts a HVAC flowpath that connects a HVAC plenum room to a regular room in the facility. Source ducts blow air from the HVAC plenum into the room. The room and HVAC plenum room that this flowpath will connect are set in the flowpath dialog box, which is displayed upon selection of this menu item. By default, the room and plenum will be the last room and last plenum the user has selected.

Return Duct	Inserts a HVAC flowpath that connects a regular room to a HVAC plenum room. Return ducts draw air from a regular room back into a HVAC plenum room. The room and HVAC plenum room that this flowpath will connect are set in the flowpath dialog box, which is displayed upon selection of this menu item. By default, the room and plenum will be the last room and last plenum the user has selected.
HVAC Plenum	Inserts a new HVAC plenum room into the facility and invokes the HVAC plenum room dialog box.
Activities	
Enable Decay	Toggles the modeling of radioactive decay off and on for the entire problem. By default the decay model is turned on so that radioactive materials in the facility will decay and daughter materials will be generated.
All Daughters	Toggles off and on the detailed radioactive decay transmutation treatment. In the detailed option the complete radioactive transmutation equations are modeled where materials decay to their daughters, and those daughter materials will decay to their daughters, and so on. By default only significant decays will be modeled. (Significant decays are those that will reduce the mass of the parent by more than 0.01% over the course of the problem.) While this treatment is only an approximation of the full transmutation equations, it consumes considerably less memory and processing time. More importantly, the simple decay model is consistent with the accuracy of the dose conversion constants in the dose model. Therefore, if the user is interested only in the prediction of dose, the default simple decay model should be used. If the user is more interested in detailed transmutation calculations, for example, for accurate predictions of all possible isotopes involved in facility contamination, the more detailed transmutation model that includes all daughters should be used.

Sensitivities

Nominal Dose	With this option selected, the nominal release fraction values and respirable fraction values in all events in the facility will be used. These options are used to determine the effects of the uncertainty in the release fraction data in the DOE Handbook upon the results of a given accident scenario. This is done by making three separate runs with the only differences being the sensitivity option selected here.
Minimum Dose	With this option selected, the minimum release fraction values and respirable fraction values in all events in the facility will be used.
Maximum Dose	With this option selected, the maximum release fraction values and respirable fraction values in all events in the facility will be used.

Mode

KBERT/ CONTAIN	Sets the option to use CONTAIN to model flows in the facility. Thermal-hydraulic conditions in the facility will also be modeled by CONTAIN when this option is selected. This is discussed in more detail in Section 5.0.
KBERT Only	Sets the option to use internal KBERT options for modeling flows in the facility. If this option is selected, the user should provide flow rate data for all flowpaths in the facility. Also, thermal hydraulic conditions will be fixed in time with this option. This is discussed in more detail in Section 5.0.

Run

Go	Runs the simulation through all of the defined time zones. This is discussed in more detail in Section 5.3.
Step	Runs the simulation for one time step. This is discussed in more detail in Section 5.3.
Reset	Resets the simulation to conditions prior to the run or first step. This is discussed in more detail in Section 5.3.
Edit Time Zones	Edits the time zone information associated with running the simulation. This is discussed in more detail in Section 5.2.

Output

Current Step	Invokes the dialog box to view the output at the current time step. This is discussed in more detail in Section 6.0.
History Plots	Invokes the dialog box to view the output as a function of simulation time in tabular and graphical forms. This is discussed in more detail in Section 6.0.

Window

The window menu commands in KBERT are standard to all Windows “Multiple Document Interface” or MDI applications. MDI applications are those that can have more than one document open at one time. The items described briefly below are used to arrange the visual display of these documents within their respective windows on screen.

Cascade	Arranges all windows on screen in a cascading arrangement such that the title bar for each window is visible and thus can be easily selected.
Tile Horz	Arranges all windows on screen to be tiled horizontally. In this configuration the width of each window will be the full size of the KBERT main screen. The height of each window will be set so that all windows will be visible on screen without overlapping.
Tile Vert	Arranges all windows on screen to be tiled vertically. In this configuration the height of each window will be the full size of the KBERT main screen. The width of each window will be set so that all windows will be visible on screen without overlapping.
Arrange Icons	Arranges all of the icons when the documents are minimized. This menu item has no effect when the selected window is not minimized.
File list	A list of the documents loaded into KBERT for editing. If one of these names is selected then that window will become the active one for user editing.

Help

Index	Displays the KBERT online help file. Note that such a file currently does not exist. This function will become operational if a help file is developed named KBERT.HLP and stored in the directory where KBERT is installed.
About	Displays an information box about KBERT

5. Running KBERT

The previous chapters have described how to build facility models within the KBERT software. This chapter will describe how to run KBERT.

5.1 KBERT/CONTAIN Interface

The first major decision a user must make is whether or not CONTAIN will be used to predict flows in a facility. Manually providing flow rate information in KBERT without the assistance of CONTAIN can be a tricky and time consuming activity, and in general, this is not recommended. Section 4.5 describes the menu item used to select whether or not CONTAIN will be used to predict flows. If CONTAIN is to be used to predict flows, then the user may elect to have certain flowpaths governed by the “Pressure-driven Flow” option described in Section 4.1.5.1. If the KBERT-only option is selected, then each flowpath should have either a user specified constant flow rate or a user-provided flow rate table.

When the KBERT/CONTAIN option is used the following sequence of events will occur. First, KBERT will analyze the facility configuration specified by the user and automatically generate a CONTAIN input deck for computing inter-room flow results. The generated CONTAIN input file has the name “input” and is guaranteed to be free of syntactical errors as well as an accurate representation of the KBERT facility specification. This is one of the main advantages of using KBERT over using CONTAIN directly to predict inter-room flow and aerosol transport. Second, KBERT will invoke the execution of the CONTAIN code. This code is called “cnt20apil.exe” and must be in the same directory as the KBERT executable file. When CONTAIN is executed a text-based window will be opened while CONTAIN is executing. A summary line will be printed at frequent intervals in this text-based window. Note that CONTAIN is very memory intensive and as a result other windows activities are likely to be suspended during its execution. It is also worth noting that CONTAIN is executed in its own thread so that KBERT on-screen activity can continue while it is executing.

Once CONTAIN finishes executing, the text window will be automatically closed. This signifies that control is being passed from CONTAIN to its post-processor program, called POSTCON. POSTCON reads the binary output file generated by CONTAIN and produces data pairs of results versus time for use in KBERT. Namely, this step produces x/y data pairs for room pressure, room temperature, flow rates through each flow path, and thermal-hydraulic material concentrations. The input instruction file for POSTCON named “pinp” is automatically generated by KBERT to ensure that this step is performed correctly. The details of the interface between CONTAIN and POSTCON are completely hidden from the user.

When POSTCON finishes processing the output of CONTAIN into a format that KBERT can digest, control is passed back to KBERT and the pertinent results are read into the data structures in KBERT. The file that KBERT actually reads to import the flow calculation results is called “pvec”. This file includes time dependent room pressure, room temperature, intercell flow rates, and thermal-hydraulic material concentrations. This is done at the first time step in KBERT. Therefore, if the user selects “Step” from the run menu, the results from the complete time sequence are computed and read into KBERT on the first step. Steps taken after the first step will proceed through the analysis with no further interaction with CONTAIN. For more information about CONTAIN and its various interface files, the reader is directed to the CONTAIN 2.0 code manual [MUR98].

KBERT will automatically save CONTAIN input files and POSTCON “pvec” files from prior runs, in case a calculation with the same thermal-hydraulic conditions is re-run later. If the KBERT facility file has been saved at least once, these other files will have a name with the same root as that of the facility files, plus an extension equal to “.inp” and “.pvc,” respectively. After many runs, the user may wish to delete the CONTAIN and POSTCON files that have been saved but are no longer needed from the KBERT directory.

5.2 Time Steps and Time Zones

To perform an analysis with KBERT one must specify an appropriate time step and accident duration. For simple problems a single “time zone” can be used which can be specified on the main screen just beneath the Inspect Bar. For more complex problems provisions are in KBERT for specifying several time zones with varying time steps. To access this feature the “Edit Time Zones” button on the main screen should be pressed, or the “Edit Time Zones” menu sub-item can be selected from the Run menu item. Time zone information is provided using the familiar user table dialog box described in Section 4.4. Note that timestep values can be specified only in the Time Zones table, when it is active. (To remove this table, press the “Remove” button in the table dialog box.)

5.3 Problem Execution

There are three functions used to control the execution of KBERT: Go, Step, and Reset. The “Go” function runs the entire simulation through all of the defined time zones. Once this option is chosen there is no way to stop the analysis before it completes. However, one can use the “Step” function first to view a few time step results first and then invoke the “Go” function to complete the analysis.

The “Step” function takes one time step at a time, thus allowing the user to step through the analysis gradually inspecting results along the way. When the KBERT/CONTAIN option is used, the first step taken will invoke CONTAIN and compute the flow information for the entire analysis. Subsequent steps will use these results without further involvement of the KBERT/CONTAIN interface. Typically the user will want to step through a few time steps before running the entire simulation.

The “Reset” function returns the analysis time counter back to the beginning of the simulation. This function is usually used to perform sensitivity calculations. To perform sensitivity calculations, the problem is run once and the key results of interest are recorded, the reset function is invoked, a parameter is modified, the calculation is run again, and the key results of interest are again recorded. This is repeated as many times as needed. This is particularly useful for performing sensitivity calculations involving parameters that do not affect the thermal-hydraulic results. In such a case KBERT will automatically sense that CONTAIN need not be re-run and the flow results from the previous run will be used. This logic enables sensitivity calculations to be quickly and easily performed. Facility flowpath configuration changes, room size or thermal-hydraulic condition changes, thermal-hydraulic material source rate changes will all result in the need to re-run CONTAIN.

6. Viewing Output

There are three types of output available to the user in KBERT following the execution of a problem. The first method is for quickly examining multiple values for a given time step, typically for the end of run time. Section 6.1 describes this option which is available by selecting the “Current Step” item underneath the “Output” menu item. The second method involves time dependent text and graphical output. Section 6.2 describes this option. The final method is to view information in the Inspect Bar on the main KBERT

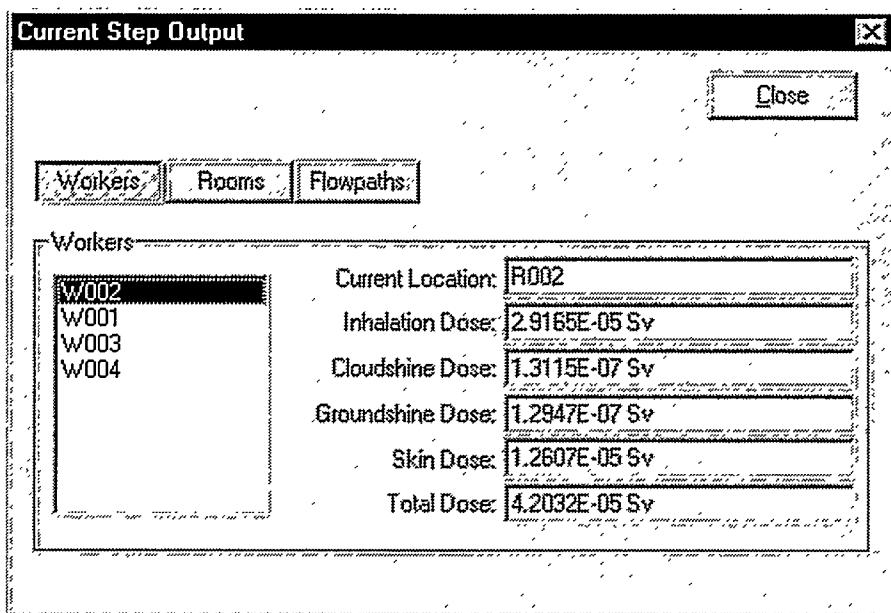
screen upon the selection of either a room, flowpath, or worker in the main KBERT view. The Inspect Bar output is described in Section 6.3.

6.1 Current Step Output

The current step output dialog box is invoked from the main menu by selecting the “current step” item underneath the “Output” menu item. This dialog box provides three types of results: workers, rooms, and flowpaths, depending upon which option is chosen in the current step output dialog box. These three result types are described in detail below.

6.1.1 Worker Output

This screen can be accessed by selecting the “Workers” radio button on the current step output dialog box as shown below.



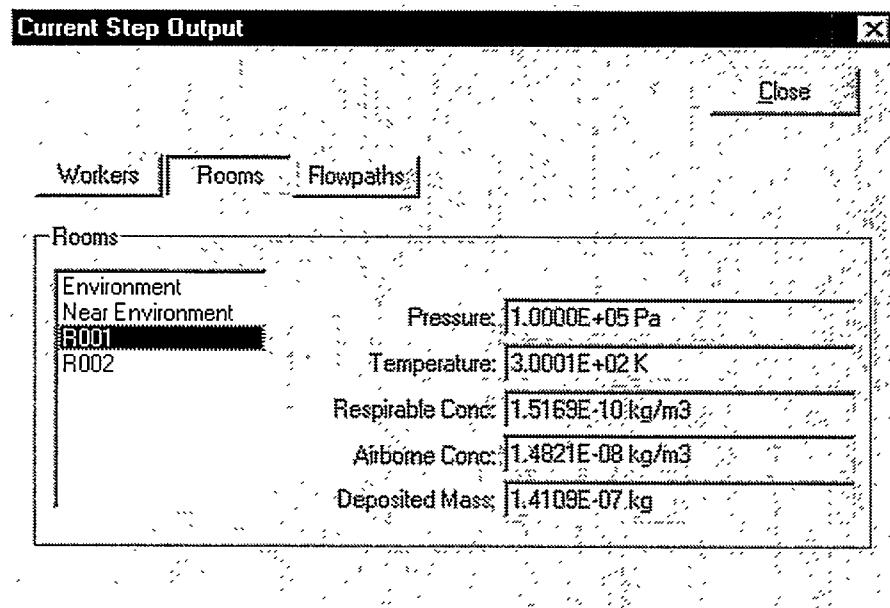
Each output shown in this dialog box view is explained below:

Workers	This list box shows all the workers or worker groups in the facility. The blue bar indicates the currently selected worker(s), which can be changed with a mouse click on the new worker(s) of choice.
Current Location	This display-only field shows the name of the room where the selected worker(s) is located at the current time in the simulation.
Inhalation Dose	This display-only field shows the total inhalation dose received thus far by the selected worker. If a group of workers is involved, each worker will have received the dose displayed.
Cloudshine Dose	This display-only field shows the total cloudshine dose received thus far by the selected worker(s).

Groundshine Dose	This display-only field shows the total groundshine dose received thus far by the selected worker(s).
Skin Dose	This display-only field shows the total skin dose received thus far by the selected worker(s).
Total Dose	The sum of the above doses.

6.1.2 Room Output

This screen can be accessed by selecting the “Rooms” radio button on the current step output dialog box as shown below.



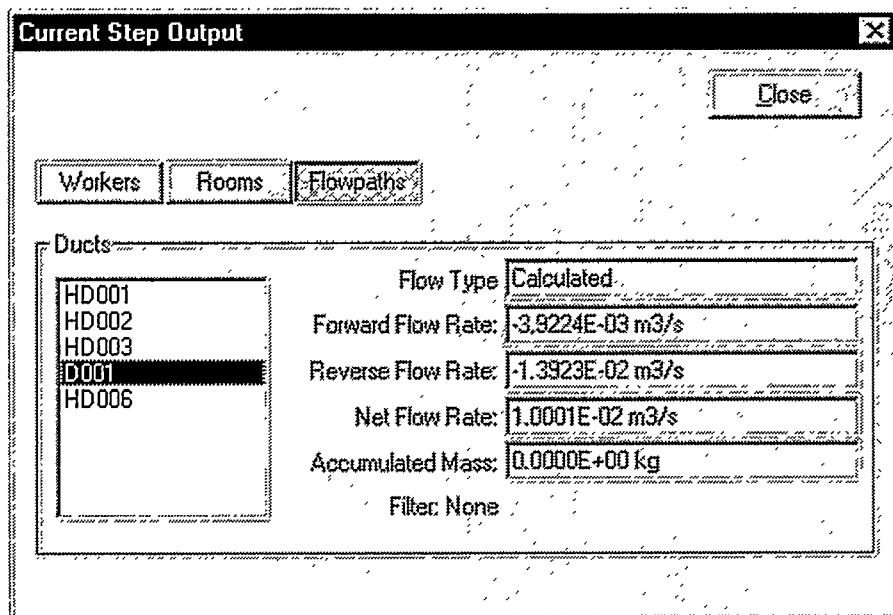
Each output shown in this dialog box view is explained below:

Rooms	This list box shows all the rooms in the facility. The blue bar indicates the currently selected room, which can be changed with a mouse click on the new room of choice.
Pressure	Current air pressure in the selected room. This value is obtained from CONTAIN if that run mode was selected.
Temperature	Current temperature in the selected room. This value is obtained from CONTAIN if that run mode was selected.
Respirable Conc	This field shows the current total airborne respirable concentration of materials at risk within the selected room.
Airborne Conc	This field shows the current total airborne concentration of materials at risk within the selected room. There will often be more airborne material than respirable material because respirable fractions associated with material release events are often less than 1.0.

Deposited Mass This field shows the amount of deposited mass in the selected room. This value will include the mass deposited on any of the surfaces that the room contains.

6.1.3 Flowpath Output

This screen can be accessed by selecting the “Flowpaths” radio button on the current step output dialog box as shown below.



Each output shown in this dialog box view is explained below:

Flowpaths	This list box shows all the flowpaths in the facility. The blue bar indicates the currently selected flowpath, which can be changed with a mouse click on the new flowpath of choice.
Flow Type	This field will show either “Calculated” or “User Specified” indicating whether flow through this path is calculated by CONTAIN within the pressure-driven flow option or if a constant flow value or a table has been provided by the user for flow in this path. Note that if the flow rates are “Calculated” and the CONTAIN mode is not invoked, the flow rates will be taken to be constant and fixed at the initial condition values shown in the Flowpath dialog box.

Forward Flow Rate	Certain flowpaths are divided into two parts in KBERT to represent the possibility of concurrent flow in doorways. For countercurrent flowpaths, this field shows the rate of flow through the forward half of the flowpath at the current time in the simulation. This flow rate will be updated as the simulation progresses. Note that this value may not always be a positive number, since flow may occur in either direction through either half of a flowpath. For example, if concurrent flow is not occurring then the flowpath halves will typically show values with opposite signs. In the case of a HVAC duct or a flowpath not suited to countercurrent flow modeling, the flowpath will only have one part; therefore, the Reverse Flow Rate field will be set to zero.
Reverse Flow Rate	This field shows the rate of flow through the flowpath in the reverse half of a countercurrent flowpath. See the description above for more information about the two halves of a countercurrent flow path.
Net Flow Rate	This field shows the net rate of flow through the flowpath of choice at the current time in the simulation. The value will be positive if the net flow is in the positive direction (from the originating room to the destination room) and will be negative if the net flow is in the negative direction. This value is defined as the “Forward Flow Rate” – “Reverse Flow Rate”.
Accumulated Mass	Mass of the material that has accumulated on the filter in the selected flowpath. If no filter exists on this flowpath, the accumulated mass will be zero. Mass is not allowed to settle in an unfiltered flowpath.
Filter	It is possible to have a filter on any flowpath in a KBERT facility. This field shows the status of the filter if one has been included in this flowpath. If there is no filter on the chosen flowpath, this field will indicate “none”. If a filter is present and operational this field will indicate “intact”. If the filter model in KBERT predicts a failure this field will indicate the failure mode.

6.2 Material Concentrations in Rooms and Plenums

Concentrations of the material at risk within the facility can be viewed directly through a dot-density representation of the total suspended volume concentration within each room or plenum element in the KBERT view. In this representation, the dot-density (i.e., the number of dots per unit area within a room or plenum) is scaled to the average volume concentration of material that would be airborne within the facility at the end of the problem, if there were no deposition or leakage of that material. The dot-density representation is useful for observing the propagation of material within the facility, in conjunction with the “Step” mode of problem execution discussed in Section 5.3. No user input is required to enable the dot-density representation.

6.3 Time Dependent Output

Tabular and plot output is available in KBERT by selecting the “History/Plots” item under the “Output” main menu item. One must first obtain tabular output as described below before a plot can be generated.

6.3.1 Table Output

The dialog box for text output in KBERT is shown below. This dialog box allows essentially all KBERT time history results to be displayed in table format. Four types of output are provided as denoted by the four tabs at the top of this dialog box: "Rooms", "Flowpaths", "Workers", and "Deposition". The left side of the dialog box contains controls for adding columns to the table on the right side of the box. The contents of these controls change when a different tab on the top of the dialog box is chosen. For example, information about rooms is shown when the "Rooms" tab is selected, information about flowpaths is shown when the "Flowpaths" tab is selected, and so on. The controls and their contents for each of the four tabs are described below.

Room	Parameter Histories		
R001	Select->	# 1	# 2
Category	Time (sec)	R001	R001
Materials	CS-137 Aerosol	floor1-CS-137	Airborne Conc
Variable	0.000e+000	0.000e+000	0.000e+000
CS-137 Aerosol	1.000e+001	6.000e-007	0.000e+000
PU-239 Aerosol	2.000e+001	5.907e-007	2.222e-008
Total Airborne	3.000e+001	5.816e-007	2.154e-008
Airborne Conc.	4.000e+001	5.726e-007	2.121e-008
	5.000e+001	5.637e-007	2.088e-008
	6.000e+001	5.550e-007	2.056e-008
	7.000e+001	5.475e-007	2.028e-008
	8.000e+001	5.401e-007	2.000e-008
	9.000e+001	5.328e-007	1.973e-008
	1.000e+002	5.256e-007	1.947e-008
	1.100e+002	5.186e-007	1.935e-008
	1.200e+002	5.116e-007	1.909e-008

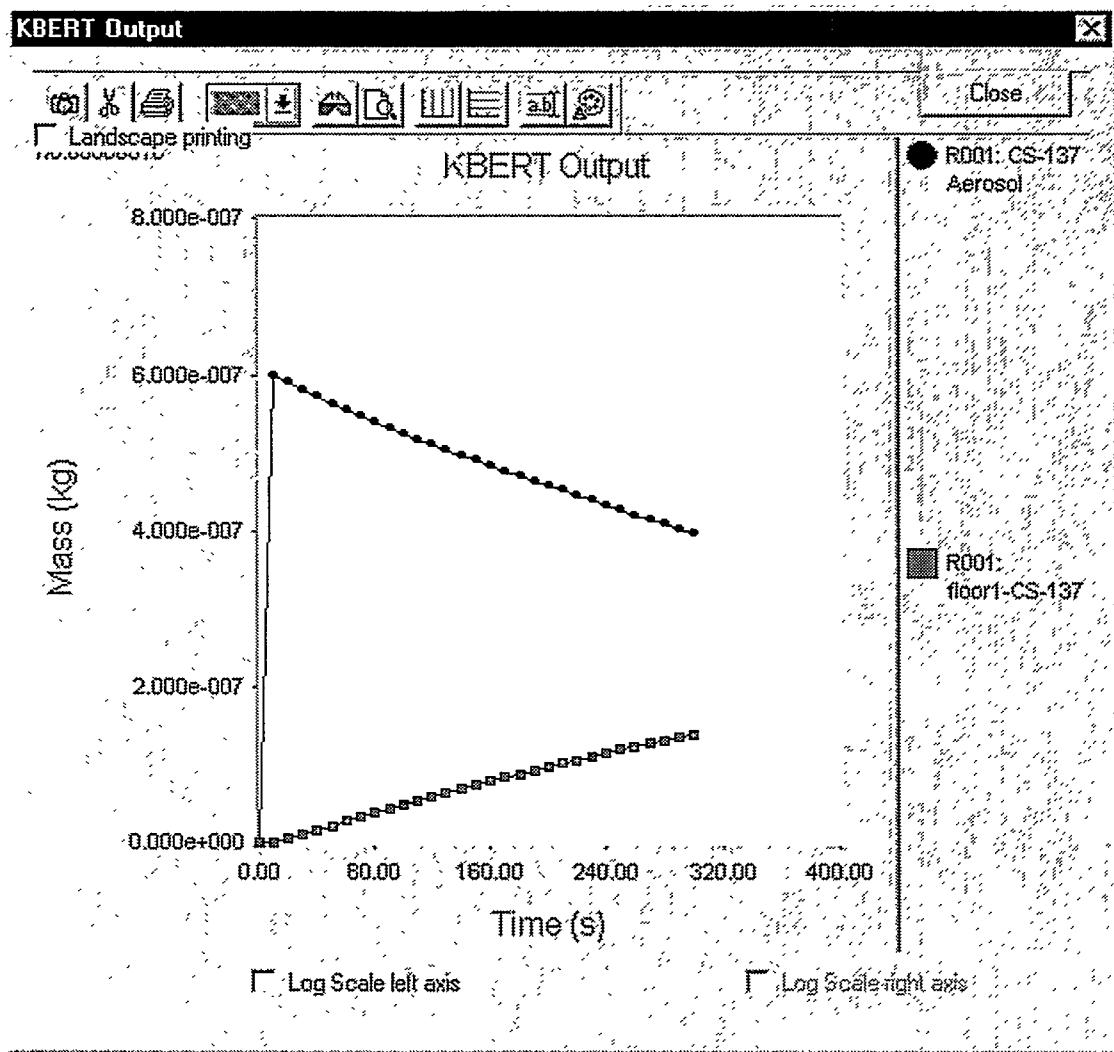
Room: Vol= 2.7000e+001, Ht= 3.0000e+000, Elev= 0.0000e+000

Rooms tab	<p>This tab contains information about all of the rooms in the problem. The topmost drop-down control contains a list of the rooms in the facility where the user selects the room of interest. This list includes the two environment rooms and all other rooms defined by the user. It does not include the HVAC plenums. To find out information about the HVAC plenums, the user must use the main screen view and the Inspect Bar as described in Section 6.4. The second drop-down control contains a list of selectable categories that includes: Materials, Conditions, Gas Masses, and Surface T (where "T" stands for temperature). This selection will affect what is displayed in the Variable list. The items displayed in the Variable list can be added to the table for display and potentially for plotting. The Materials category will display all active materials in the selected room in the Variable list. In addition, the Variable list will contain a "Total Airborne" item and a "Airborne Conc" item. The "Total Airborne" item represents the sum of all active material masses that are airborne in the selected room. The "Airborne Conc" item represents the airborne concentration, which is the total active airborne mass divided by the room volume. The Conditions category will display Pressure, Temperature, Density, and Humidity in the Variable list. The Gas Masses category will display all thermal-hydraulic gases in the selected room in the Variable list. Surface T will display the surface temperature of structures in the room. When Surface T is selected the structures in the room will be shown in the Variable list.</p>
Flowpaths tab	<p>This tab contains information about all flowpaths in the problem. The topmost drop-down control will contain a list of the flowpaths in the facility where the user selects the one of interest. This list includes regular flowpaths and HVAC ducts. The second drop-down control has two items: Flow Rates and Filter Masses. When Flow Rates is selected the Variable list will contain Forward and Reverse items. When Filter Masses is selected the Variable list will contain a list of all materials that have been captured on the filter on the flowpath. If there is no filter on the flowpath, the Variable list will be empty.</p>
Workers tab	<p>This tab contains information about all people defined in the model. The topmost drop-down control will contain a list of the people in the model. This includes people within the facility itself representing workers and people in the environment rooms representing the public. The second drop-down control has two items: Doses and Materials. When Doses is selected the Variables list will contain the types of computed doses, including: Inhalation, Cloudshine, Groundshine, Skin, and Total. When Materials is selected the materials that have settled onto the skin of the person selected will be shown in the Variable list. The last item in this list is Total Mass.</p>

Deposition tab	This tab contains information about deposited mass in the facility. The topmost drop-down control will contain a list of rooms in the model. The entries are identical to those on the Rooms tab. The second drop-down control will contain a list of structures in the room. The only structures that will contain deposited mass will be floors. The Variables list will contain a list of materials that have deposited onto the selected structure in the selected room. The last item in this list is Total Mass. Note that the mass settled onto a person is on the Workers tab.
Ins	Inserts the item selected in the Variable list to the table. The output results associated with this item will be inserted into the table to the left of the currently selected column.
Del	The columns selected in the output table will be deleted from the table. This is done without a warning prompt.
Cyc	When two or more columns are selected this function will move the last column to the position of the first column. All other columns will be shifted to the right. This function is useful for moving columns around so that data of interest for plotting can be located contiguously in the table. This is needed because only contiguously located columns may be plotted.
Plot	Plots the selected non-time columns, or portions thereof, against time. Clicking this button will invoke the dialog box described in the following section. Note that the selected columns must have the same units in order to be plotted along a given Y axis.
Plot 2-Y	Plots the selected columns on the primary Y axis and a second set of selected columns on the secondary Y axis. (The X axis is always time.) The user will be instructed to select the second set of columns and then to press this button a second time to display the dual-axis plot.
Status bar	Displays information about the item selected in the topmost drop-down list.

6.3.2 Graphical Output

Any contiguous set of columns that are positioned next to each other and have the same units may be plotted by selecting the columns desired and pressing the Plot button. When the two columns selected in the example shown in the previous section are plotted, the following graphics dialog box is produced. Note that all rows of each selected column are plotted in this example. A subset of the rows can also be plotted, as long as the rows are contiguous. This can be useful for “zeroing-in” on a particular time interval. To do this, simply select the appropriate subset of rows within a contiguous set of columns.



The above screen contains controls for copying the graph to the clipboard for pasting into other Windows application, printing the graph, and for manipulating and customizing the visual appearance of the graph. The first button copies the graph to the clipboard in bitmap format. The second button copies the data onto the clipboard in text format, which can be pasted into a spreadsheet. The third button prints the graph onto a printer. The remaining buttons provide the following customization options in the order shown: Line color, zoom, three dimensional view, vertical grid lines, horizontal grid lines, titles, and text fonts. All of these controls alter the appearance of the graph except for the line color control which is not enabled and thus does nothing in KBERT. Two check boxes are provided on the bottom of the dialog box for displaying the graph data on a log scale. If there are data sets with zeros the zero points will be shown as seven orders of magnitude smaller than the smallest non-zero data value in the first data set. The second check box is for the secondary Y axis and will only be enabled if the Plot 2-Y option was used to plot data onto both Y axes. All of the other plot customization controls are self explanatory. Note that the KBERT graphics module uses the Chart FX commercial graphics control

product. This control is automatically installed with KBERT and a user license is provided.

6.4 Inspect Bar

The Inspect Bar gives the user summary information about the selected facility element in the facility view. Different information is displayed depending upon the type of facility element that is selected. KBERT provides three different views in the Inspect Bar depending upon whether a room, duct, or worker is selected with the mouse. These three views are shown below.

Room R001	Doorway D001	Worker W004
<p>Room Data:</p> <p>Volume : 2.700E+001 m³ Height : 3.000E+000 m Elevation : 0.000E+000 m</p> <p>Room Conditions:</p> <p>Pressure : 1.000E+005 Pa Temperature: 3.000E+002 K Gas Density: 1.149E+000 kg/m³ Rel.Humidity: 4.998E-001 unit</p> <p>Active Materials:</p> <p>Resp. Conc.: 1.517E-010 kg/m³ Airbn. Conc.: 1.482E-008 kg/m³ Deposition : 1.411E-007 kg Room Total : 5.413E-007 kg</p> <p>Total Active Material In Problem: 2.000E-003 kg</p>	<p>Flow Data:</p> <p>From : R001 To : R002 Flow Area : 2.000E+000 m² Flow Coef. : 1.000E+000 Iner. Length: 2.000E-001 m</p> <p>Flow Conditions:</p> <p>Forward : -3.922E-003 m³/s Reverse : -1.392E-002 m³/s Net Rate : 1.000E-002 m³/s</p> <p>Total Active Material In Problem: 2.000E-003 kg</p>	<p>Worker Data:</p> <p>Group Size : 1.000E+000 Inhal. Rate : 3.500E-004 m³/s Skin Area : 1.800E+000 m² Inhal. PF : 1.000E+000 Origin: R001</p> <p>Dose Information:</p> <p>Inhalation : 1.528E-004 Sv Cloudshine : 7.393E-007 Sv Groundshine: 2.440E-007 Sv Skin Dose : 0.000E+000 Sv Total : 1.538E-004 Sv Risk Factor : 8.255E-007</p> <p>Total Active Material In Problem: 2.000E-003 kg</p>

The data in these three different views of the Inspect Bar shown above are described below:

Room View

The first set of data describes the physical dimensions of the room. The second set is a summary of the room's thermal-hydraulic conditions. The third is a summary of the active materials in the room, including airborne and deposited masses. All views end with a data item for the total amount of active material in the problem. This value is used as a check on the material mass balance and should not change values throughout the calculation. This view is the only way to obtain a summary of the conditions in a HVAC plenum room. To accomplish this the HVAC plenum room of interest should be selected and the information in the Inspect Bar will change to represent the data associated with that plenum.

Flowpath View	The first section displays a summary of the flowpath including the names of the rooms that this flowpath connects and the flowpath's physical attributes. The information shown here for pressure-driven flowpaths will be different from the information shown for flowpaths with user-defined flow rates. The second section shows the flow rate output information. A third section displaying filter information will be present if a filter is defined in the flowpath.
Worker View	The first section of this Inspect Bar view displays information about the selected worker, including the originating room. This room may differ from the worker's current room if the worker has an evacuation plan. The second section contains results for each type of dose that a worker can receive. The last line in this section gives the dominant risk factor which indicates the probability of lethal effects from the received dose. This value is used to change the color of the worker on the main screen from yellow to red as this value changes from zero for no dose and no risk to 1.0 for a high dose and high risk. The equations for computing risk are documented in Reference MON94 and are based on the health effects defined in Reference ICRP87.

7. Summary

This manual provides a general description of the KBERT analysis tool and provides instructions on how a user can use KBERT to assess the possible consequences to workers in that facility and to the public, starting with knowledge of the design, layout and potential hazards of a facility. KBERT is a tool that allows a user to simulate possible accidents and observe the predicted consequences. Potential applications of KBERT include the evaluation of the consequences of evacuation practices, effect of personal protection equipment, and the degree of containment of hazardous materials.

8. References

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Appendix A Filter Failure Model

A.1 Introduction

This appendix describes the model in KBERT for the pressure drop and failure criteria of filters. For high efficiency particulate aerosol (HEPA) filters, this model also includes the effects of aerosol loading on the pressure drop and failure criteria. In the absence of this loading model, the failure pressure for a new clean filter would be that for a new loaded filter. Failure is a function of pressure drop across the filter and of materials and construction of the filter. Filter loading affects the pressure drop at a given flow but unless the loading also affects the material strength of the media, the failure pressure drop is unchanged. The mechanical strength of the filter media and the attachment of the filter media pack into the frame are the two factors that determine whether or not a filter will fail. Those factors are affected by moisture, heat, and age. The efficiency of a filter is affected by loading, flow through the filter, and damage. Bergman et al. [BER94] present suggested criteria for determining the performance of HEPA filters during and after design basis accidents. These authors have surveyed the literature on filter performance and report failure pressure drops for new, aged, thermally stressed, wet, and previously wet HEPA filters. They however do not give a method for calculating the pressure drop as a function of loading. We have surveyed the literature and present a rationale for determining the pressure drop across a filter as a function of filter loading. The effects of humidity and water aerosol loading are discussed below. However, in the current version of the HEPA filter model in KBERT, the pressure drop as a function of filter loading is modeled without taking wetting effects into account.

As a preface it should be noted that filter efficiency is not as difficult to model as filter loading and failure. As a first cut, the particle collection efficiency of a dry loaded filter is greater than that of a dry unloaded filter. The presence of water in a filter can reduce the collection efficiency as can an increase in air flow through the filter. A pressure pulse can greatly reduce the collection efficiency over the duration of the pulse. Generally, as long as the filter is intact, the collection efficiency remains high during normal operation; the implication here is that aging, *per se*, does not adversely affect the filtration efficiency. Aging, and exposure to moisture and high temperature, can act to structurally weaken the filter media, its attachment to the frame, or both. In this respect, the filter's ability to withstand a given pressure drop can be compromised. It is the loading of the filter and the pressure drop produced by flow through the loaded filter that need to be modeled.

The current implementation in KBERT for flow through filters allows the user either to specify flow rates directly or to specify parameters that determine the flows on the basis of the pressure difference across a flowpath. Filter loading, including wetting, can in actuality change the flows through filters as they become loaded. Incorporation of the effects of filter loading on flows would require substantial modification of the flow models. Such modifications are beyond the scope of current code development. Therefore, volumetric flow rates are treated as independent of loading. However, once these flow rates are determined, the resulting filter loads can be readily calculated.

A.2 Filter Loading Criteria

Two limiting conditions arise from filter loading: 1) a cessation of flow and 2) a cessation of particle removal. In the first condition, the filter becomes loaded to a point that the flow to first approximation can no longer occur through the loaded filter. If the limiting pressure drop is less than a failure pressure drop of the filter, flow ceases. In the second condition, the pressure drop is sufficient to fail the filter, and the filter fails with the consequence that particle penetration goes to 100%. The pressure drop across a filter is evaluated based on the flow and mass loading of the filter and is compared to pressure drop criteria to determine the response of the system.

There are two pressure drop criteria in the filter model implementation. The first presumes that a fan is driving the flow through the filter and is based on the maximum pressure drop ΔP_{fan} the fan can produce across the flowpath containing the filter. The second is the filter failure pressure drop, ΔP_{fail} . If there is more than one flow path leaving the plenum upstream of the filter, ΔP_{fan} can be affected by flow balancing among the paths and may be much less than the ultimate pressure drop the fan can produce. The failure pressure drop, ΔP_{fail} , is determined by the condition of the filter. When the pressure drop across the filter based on loading exceeds the lower of these two pressure drops, a diagnostic message is given. If the filter failure criterion is exceeded, resuspension of 1% of the previously collected material is assumed to occur [DOE94], and the penetration is changed to 100% for subsequent material transport through that flow path. If the maximum pressure drop is exceeded, then the calculation should be revised and a zero flow condition through filter should be imposed at the appropriate time.

The maximum pressure drop must be supplied by the user, based on the fan curve of the fan used on that flow path. The failure criteria are determined from the literature review provided by Bergman et al. [BER94] for dry HEPA filters and are given in the table below.

Filter Condition	Failure Pressure Drop (inches water gauge)		
	Mean	Low	High
New Filter, Dry	62	37	90
Aged filter (15-19 yr.), Dry	38	13	78
Dry Filter, previously wet	40	22	49

To use the filter model the user will in general need to know or provide the following HVAC and filter characteristics:

1. The measured penetration and filter pressure drop at a specified flow rate so that the flow through the filter can be calculated (a typical value is 99.5% collection efficiency

at 0.472 m³/sec (1000 cfm) through each filter with a 249 Pa (1" water) pressure drop)

2. The total area of filter media in the filter (a typical value is 18.58 m² (200 ft²))
3. The condition of the filter (new, aged, or previously wet) for HEPA filters
4. The maximum pressure drop the fan can produce across the flow path containing the filter

A.3 Filter Pressure Drop

A 2 ft. x 2 ft. HEPA rated at 1000 cfm typically has 200 ft² of filter media in the media pack. This filter at its rated flow will have face velocity normal to the media of 5 ft/min. The pressure drop at the rated flow is less than or equal to 1 inch of water (250 Pa). Different HEPA filters may have more filter media within the filter pack and may be rated at a higher flow rate but generally, the design face velocity of the gas flow to the filter media itself is about 5 ft/min. Newer filters may have different areas of media and different flow ratings, and this is something that the user may need to determine.

The pressure drop, ΔP , through a filter can be described by the sum of the pressure drop through a clean filter and the pressure drop contribution from the loading.

$$\Delta P = K_1 \cdot \frac{Q}{Area} + K_2 \cdot \frac{Q}{Area} \cdot w$$

where

K_1 is the clean filter resistance coefficient

Q is the volumetric flow rate through the filter

$Area$ is the area of filter media contained in the filter

K_2 is the resistance coefficient for a loaded filter

w is the mass collected on the filter per unit area of filter media

The above relationship holds for a dry filter. For a wet filter, the pressure drop can exhibit a non-linear relationship with respect to loading that is discussed below but not currently modeled in KBERT.

A.3.1 Unloaded, Clean Filter

The proportionality constant K_1 is defined as the pressure drop across the filter per unit face velocity

$$K_1 = \frac{Area \cdot \Delta P_R}{Q_R}$$

where

ΔP_R is the reference pressure drop of a clean filter

Q_R is the volumetric flow at the reference pressure drop

Based on design parameters for a HEPA filter with 200 ft^2 of media operating at a rated flow of 1000 cfm and rated pressure drop of 1 inch of water we have

$$K_1 = \frac{200 \text{ ft}^2 \cdot 1 \text{ inch water}}{1000 \text{ cfm}} = 0.2 \cdot \frac{\text{inch water}}{\text{ft} \cdot \text{min}^{-1}} = 9800 \cdot \frac{\text{Pa}}{\text{m} \cdot \text{sec}^{-1}}$$

This is 1 inch of water per 5 ft/min (0.03 m/sec) face velocity, an upper limit based on the filter design requirements. If the area of the filter media is known and pressure drop and volumetric flow data are available, then K_1 can be calculated. The value of K_1 measured by Novick et al. [NOV90] is

$$K_1 = 0.163 \cdot \frac{\text{inch water}}{\text{ft} \cdot \text{min}^{-1}} = 7970 \cdot \frac{\text{Pa}}{\text{m} \cdot \text{sec}^{-1}}$$

This value is less than the default value based on filter requirements. It is recommended that the measured pressure drop and flow data along with the filter area be used to determine K_1 . (Note that in the filter model the user is asked to specify a "Head Loss Coefficient," which is defined as $K_1/Area$.)

A.3.2 Loaded Filter, Not Caked

Filters load primarily at the surface and after a while, a cake of collected material forms so that most of the filtration takes place through the cake. This effectively changes the filter media and consequently the pressure drop. We can estimate the amount of material that the filter collects before the formation of the particle cake over the surface. Japuntich et al. [JAP94] have shown that the mass of material that is collected on a filter prior to the onset of cake formation (i.e., the amount of material necessary to have cake formation) can be expressed (at least for supermicron particles) as a function of filter properties.

$$w_c = \frac{2}{3} \rho_p d_f \left(\sqrt{\frac{\pi}{2\alpha}} - 1 \right)$$

where

- w_c is the mass required per unit area of filter media for caking
- d_f is the filter fiber diameter (typically 1 to 2 μm)
- α is the solid volume fraction of the filter (typically 0.1)
- ρ_p is the material density of the aerosol material (typically 2 to 4 kg/m^3)

Thus for typical filter media,

$$d_f = 1.5 \mu\text{m}$$

$$\alpha = 0.1$$

$$\rho_p = 2000 \text{ kg/m}^3$$

$$w_c = 0.0089 \text{ kg/m}^2$$

The mass collected on a typical HEPA with 200 ft^2 (18.5 m^2) of filter media before the onset of cake formation would then be about 0.17 kg.

Because filter pressure drop increases more rapidly with mass loading after the onset of cake formation than before, filters are usually changed out before cake formation begins. Typically, a pressure drop of about 2 inches of water at the rated flow is a filter change-out criterion. We can assume that, roughly, cake formation begins after a filter has been loaded to a total pressure drop of about 2 inches of water with about 0.25 kg material.

The pressure drop as a function of loading up to the point of cake formation can be approximated by a linear relationship of the form

$$\Delta P = K_1 \cdot \frac{Q}{\text{Area}} + K_{2pc} \cdot \frac{Q}{\text{Area}} \cdot w$$

where

$$w < w_c \text{ and}$$

$$K_{2pc} \text{ is the pre-cake coefficient}$$

The difficulty here is that the coefficient K_{2pc} is dependent on the size and material density of particle as well as the filter fiber diameter and solid volume fraction. The

approach taken here will be to ignore this loading and to assume that cake formation begins immediately so that a correlation of pressure drop through cake will be used.

A.3.3 Caked Filter

The significant loading of a filter begins after cake formation and in an accident scenario, cake formation will not have been established at the beginning of the scenario. The loading to the onset of cake formation can be ignored, assuming that cake formation begins immediately. This is a reasonable assumption for most cases where the failure pressure drop is considerably higher than the pressure drop allowed before change out. We will assume that the pressure drop arising from cake formation will dominate and that the pressure drop expression as a function of w can be written as

$$\Delta P = K_1 \cdot \frac{Q}{Area} + K_2 \cdot \frac{Q}{Area} \cdot w$$

where the first term on the right hand side is the pressure drop through a clean filter, the second term is the pressure drop in the filter due to caking.

The difficulty here again is that the coefficient K_2 is dependent on the size and material density of particles comprising the cake as well as the packing density of the cake. Here we will forsake mechanistic modeling in favor of experimental correlations.

M. Osaki and A. Kanagawa [OSA89] offer data that suggests the relationship for K_2 is

$$K_2 = \frac{1100}{\rho_p \cdot DGM} \cdot \frac{\text{Pa}}{\text{m} \cdot \text{sec}^{-1}}$$

For a value of DGM , the mean particle size in the cake, of $1 \mu\text{m}$ and material density, ρ_p , equal to 3 kg/m^3 , K_2 is

$$K_2 = 3.67 \cdot 10^5 \cdot \text{sec}^{-1}$$

More recent data from V. J. Novick, J. F. Klassen, P. R. Monson, and T. A. Long [NOV92] yield a correlation for K_2 as a function of the mass median particle diameter, DGM only. The correlation is for K_2 fit to data for NaCl , NH_4Cl , and Al_2O_3 aerosols. The material density of these materials covers the range of 2 to 4 kg/m^3 and the correlation has no material density dependence in this range.

$$K_2 = \left[\frac{0.9494 \cdot m}{DGM} - 1.586 \cdot 10^5 \right] \cdot \text{sec}^{-1}$$

For a value of DGM of 1 μm , K_2 from the Novick et al. correlation is

$$K_2 = 7.91 \cdot 10^5 \cdot \text{sec}^{-1}$$

which is higher than the Osaki and Kanagawa value for a material density of $\rho_p = 3 \text{ kg/m}^3$. The Osaki and Kangawa correlation would underpredict the pressure drop across a loaded filter for the data of Novick et al. For a material density of 1.39 kg/m^3 , the Osaki and Kanagawa correlation equals the Novick et al. correlation at $DGM = 1 \mu\text{m}$.

Thus for HEPA filters we will use the Novick et al. correlation for K_2 which gives the following relationship for pressure drop as a function of loading

$$\Delta P = K_1 \cdot \frac{Q}{Area} + \left[\frac{0.9494 \cdot m}{DGM} - 1.586 \cdot 10^5 \right] \cdot \text{sec}^{-1} \cdot \frac{Q}{Area} \cdot w$$

As discussed above, in the filter model the user is asked to specify a "Head Loss Coefficient," which is the value of $K_1/Area$. Also note that for non-HEPA filters, the second term in the above equation is taken to be zero.

The loading to the onset of cake formation can be ignored, assuming that cake formation begins immediately. This is a reasonable assumption for most cases where the failure pressure drop is considerably higher than the pressure drop allowed before change-out.

This expression is applicable to conditions for dry aerosols in air very near 293 K, 1 atmosphere pressure, and with low humidity and no liquid aerosols. Effects of humidity and water (or other liquid) aerosols produce different loading characteristics, as discussed in the next section, but are presently ignored.

A.4 Effects of Humidity and Water Aerosols on Filter Loading

There are contradictory data on the effect of relative humidity on pressure drop across loaded HEPA filters. Although KBERT does not model this effect or the effects of water aerosol loading on filters, a summary of what has been observed is given here. With respect to the former, some data, such as that of Gupta et al. [GUP93] and Vendel and Letourneau [VEN94] show a decrease in pressure drop across a filter at higher humidity for both hygroscopic and non-hygroscopic aerosols. On the other hand, Ricketts et al. [RIC92] state that high humidity can cause the pressure drop across loaded filters to

increase. An increase in pressure drop with increasing humidity is also assumed in Reference BER94.

Hygroscopic aerosols, however, do produce a nonlinear increase in pressure drop with loading at given humidity. At a certain mass loading, the pressure drop at a given flow rate abruptly rises, going almost straight up with slight increase in mass loading. This behavior is similar to that seen in loading a filter with water aerosols. This abrupt increase in pressure drop with loading occurred at NaCl loadings between 0.4 to 1 kg on a HEPA filter at relative humidities over 80% [GUP93].

The same effect of an abrupt increase in pressure drop with slight increase in loading is seen for water aerosols. Ricketts et al. [RIC92] report plugging of clean filters when loaded with 20 to 40 kg of water aerosol. One would expect lower loadings to produce plugging of already loaded filters, and these authors report about an order of magnitude less water loading to produce the same effects on a dust laden filter.

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Appendix B Plume Dispersion Model

B.1 Introduction

This appendix describes the model for calculating the atmospheric dispersion involved in the release of materials from a facility. This model is based on the NRC Regulation Guide 1.145 [NRC83] and in KBERT is referred to as the "plume dilution" model. Note that the present model is applicable to non-buoyant releases from vents and other building penetrations and therefore is more appropriately called a building wake model rather than a plume model. Stack releases and buoyant plumes are also addressed in the Regulation Guide but have not been included in the present model. In order to simulate these other types of dispersion, the user may elect to bypass the model and specify the dispersion directly in tabular form, as a function of time.

In the present model

1. The user may either select a wind speed at a height of 10 m or use the default of 1 m/s.
2. The user may either select a Pasquill turbulence class (A through G) or use the default of class F.
3. The user may either select a cross-sectional area, transverse to the wind direction, for the source building or use the default of 10 m².

B.2 Model for Releases Through Vents or Other Building Penetrations

This class of release includes all release points that are effectively lower than two and one-half times the height of adjacent solid structures. Release points that are higher than two and one-half times the height of adjacent solid structures are classed as stack releases and are not calculated by this model. Within this class, two sets of meteorological conditions are treated: (1) neutral [D] and stable [E, F, and G] atmospheric conditions typical of a nighttime release, and (2) strong [A,B] and moderate [B,C] atmospheric mixing conditions typical of a daytime release.

During neutral (D) or stable (E, F, &G) atmospheric stability conditions when the wind speed is less than 6 meters per second, horizontal plume meander is also considered. χ/Q is calculated for ground-level concentrations at the plume center-line from:

$$\chi/Q = \frac{1}{\overline{U_{10}} \left(\pi \sigma_y \sigma_z + \frac{1}{2} A \right)} \quad (B-1)$$

$$\chi/Q = \frac{1}{\overline{U_{10}} (3\pi \sigma_y \sigma_z)} \quad (B-2)$$

$$\chi/Q = \frac{1}{\overline{U}_{10}(\pi \Sigma_y \sigma_z)} \quad (B-3)$$

where

- χ/Q is the relative concentration $((\text{Ci}/\text{m}^3)/(\text{Ci}/\text{s}))$,
- \overline{U}_{10} is the average wind speed at 10 meters above the facility grade (m/sec),
- σ_y is the average lateral plume spread (m), a function of atmospheric stability and distance,
- σ_z is the average vertical plume spread (m), a function of atmospheric stability and distance,
- Σ_y is the average lateral plume spread with meander and building wake effects (m), a function of wind speed, atmospheric stability and distance, and
- A is the smallest vertical-plane cross-sectional area of the facility containing the release location (m^2).

These equations assume that the release is continuous, constant, and of sufficient duration to establish a representative mean concentration. They also assume that the material being released is reflected by the ground. χ/Q values are calculated by determining the maximum value determined from Equations (B-1) and (B-2). This value is then compared with Equation (B-3) and the lower of these two selected.

During strong or moderate atmospheric conditions, or when the wind speed is greater than 6 m/s, the appropriate χ/Q is the higher value calculated using only Equations (B-1) and (B-2).

B.3 Plume Spread Correlation.

The plume spread correlations, or diffusion coefficients, are obtained from the Reference NRC83 as a function of the atmospheric stability and the distance from the source, x .

$$\sigma_y = A_{\text{METY}} x^{0.9031} \quad (B-4)$$

$$\sigma_z = A_{\text{METZ}} x^{B_{\text{METZ}}} + C_{\text{METZ}} \quad (B-5)$$

where the coefficients are given in the following tables

		Coefficient for Lateral Plume Spread Correlation						
Atmospheric Stability Class	A	B	C	D	E	F	G	
A_{METY}	0.3658	0.2751	0.2089	0.1471	0.1046	0.0722	0.0481	

		Coefficient for Vertical Plume Spread Correlation						
		Distances < 100 m						
Atmospheric Stability Class	A	B	C	D	E	F	G	
A_{METZ}	0.192	0.156	0.116	0.079	0.063	0.053	0.032	
B_{METZ}	0.936	0.922	0.905	0.881	0.871	0.814	0.814	
C_{METZ}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

		Coefficient for Vertical Plume Spread Correlation						
		100 m < Distances < 1000 m						
Atmospheric Stability Class	A	B	C	D	E	F	G	
A_{METZ}	0.00066	0.0382	0.113	0.222	0.211	0.086	0.052	
B_{METZ}	1.941	1.149	0.911	0.725	0.678	0.74	0.74	
C_{METZ}	9.27	3.3	0.0	-1.7	-1.3	-0.35	-0.21	

	Coefficient for Vertical Plume Spread Correlation Distances > 1000 m						
	A	B	C	D	E	F	G
A _{METZ}	0.00024	0.055	0.113	1.26	6.73	18.05	10.83
B _{METZ}	2.094	1.098	0.911	0.516	0.305	0.18	0.18
C _{METZ}	-9.6	2.0	0.0	-13.0	-34.0	-48.6	-29.2

The correlation for lateral plume spread with meander and building wake effects, Σ_y , is a function of the distance, x , and the lateral plume spread, σ_y , defined above.

For distances less than 800 m

$$\Sigma_y = M\sigma_y \quad (B-6)$$

For distances greater than 800 m

$$\Sigma_y = (M - 1)\sigma_{y800} + \sigma_y \quad (B-7)$$

where M is a function of the stability class and wind speed as

$$M = 10^{\log_{10}(M_0\alpha)} \quad (B-8)$$

where α is the wind speed correction fraction. It is equal to 1 for a wind speed less than 2 m/s, and is equal to 0 for a wind speed greater than 6 m/s. For a wind speed between 2 and 6 m/s, α is equal to

$$\alpha = 1 .63 - 2.096\log_{10}(\overline{U_{10}}) \quad (B-9)$$

Also M_0 is the limiting value for the correction factor as shown in the table below.

	M ₀ , Limiting Correction Factor						
Atmospheric Stability Class	A	B	C	D	E	F	G
M ₀	1.0	1.0	1.0	2.0	3.0	4.0	6.0

References:

[NRC83] US Nuclear Regulatory Commission, Regulatory Guide 1.145, Atmospheric Dispersion Models for Potential Accidents at Nuclear Power Plants, Office of Nuclear Regulatory Research, February 1983.

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