Facility Assessment and Consequence Evaluation Tool (FACET3D) User's Guide

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Preface

This Guide describes how to use FACET3D. Because new features are added periodically, check the release date on the front page of this manual. The latest version of this Guide is available from the website (http://www.facet3d.com).

Disclaimer

ABS Consulting makes no warranty, expressed or implied, to users of FACET3D, and accepts no responsibility for its use. Users of FACET3D assume sole responsibility for determining the appropriateness of its use in any particular application; for any conclusions drawn from the results of its use; and for any actions taken or not taken as a result of analyses performed using these tools.

Users are warned that FACET3D is intended for use only by those competent in the fields of blast and risk analysis and is intended only to supplement the informed judgment of the qualified user. The software package is a computer model that may or may not have predictive capability when applied to a specific set of factual circumstances. Lack of accurate predictions by the model could lead to erroneous conclusions with regard to safety. All results should be evaluated by an informed user.

About the Author

Greg Knight is a technical manager at ABS Consulting and is part of the Extreme Loads and Structural Risk (ELSR) group. He received a bachelors of science degree in mechanical engineering from the University of Texas at San Antonio in 2002. He joined ABS Consulting in 2000 and has worked on a variety of public sector and petrochemical projects including facility siting and quantitative risk analysis. He is the original developer of FACET3D around 2001.

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Part I

The Basics of FACET3D

Chapter 1

Introduction

The software described in this document, Facility Assessment and Consequence Evaluation Tool (FACET3D), is a tool for the prediction of blast, fire, and toxic consequences and their impact to buildings and personnel. FACET3D was originally developed to calculate window vulnerability due to high explosive threats. Over the years, it has developed a number of features based upon the needs at the time. Facility siting features including vapor cloud explosion, fire, and toxic models were eventually added, and most recently features for performing quantitative risk analysis (QRA) have been added.

1.1 Features of FACET3D

The first version of FACET3D was released in 2001. It contains capabilities for either the direct calculation of consequences or import of consequences from PHAST[1]. A summary of the main objects in the software is given below. Details on the particulars of these objects, how to use them, and how they work and interact will be discussed in detail later in the guide.

User Defined Mesh Meshes were the first object created in FACET3D. They are analogous to Layers in AutoCAD and are essentially repositories for a number of sub-objects. Meshes have some basic properties related to display such as color and line width. Object contained inside meshes are typical CAD like objects including surfaces, lines, circles, arcs, and text. Most meshes are created through the DXF import process in FACET3D. All but surfaces are typically used in the 2D ground plane as part of the site plan. Surfaces are 3D objects which can be used to build complex buildings. All the surfaces in a mesh are individual objects with no knowledge of other surfaces in that mesh, i.e. there is no connectivity information. Surfaces are used as calculation points for the various models such as explosions and fires. Variables are saved at surfaces for later rendering of hazard contours or further calculation of damage using materials objects in the mesh. Materials are pressure-impulse diagrams that allow damage calculation for applied blast loads.

Pre-defined Buildings Buildings are similar to meshes in that they contain surfaces that define their walls and roof. Unlike free-form meshes, buildings are rectangular structures that are easily defined by their location and size and allow consequences to be shown on their surfaces. They also allow materials for damage calculations as well as parameters for risk calculations such as occupancy data and a vulnerability model.

Threats Threats are all the various models for calculating blast loads. Models include high-explosives (TNT), vapor cloud explosions (both the Baker-Strehlow-Tang (BST) and Multi-

Energy Method (MEM) models), BLEVE, pressure vessel burst (PVB), and a user defined model where the pressure and impulse vs. distance curves are input.

Gauges Gauges are simple 3D locations used for calculating blast loads. They are often quicker than adding a mesh and surface for getting a blast load. Both the incident and reflected loads are recorded with a gauge, whereas a surface will generally record only the applied load (based on its angle of incidence).

Labels Labels are 2D objects that render on the ground plane. They are attached to a world space point but render in screen space such that they are always visible regardless of the 3D models camera orientation. Labels can have markers and leaders.

Congestion Block Congestion blocks are used to support creation of vapor cloud threats. They are 3D volumes with parameters such as congestion, confinement, volume blockage ratio, and/or pipe diameter depending on the model type (BST or MEM). FACET3D has a tool to allow the user to combine congestion blocks with dispersions/vapor clouds (described below) to create explosion sources.

Ignition Sources Ignition sources are 3D points used to limit the size of dispersions/vapor clouds during the threat creation process when they are intersected with congestion blocks.

Jet/Pool Fires Fires come in two types. Pre-defined fires are simply radiation vs. distance point pairs with some additional parameters such as location, flame impingement distance, and pool radius. The radiation vs. distance curves are generally imported from PHAST and are used to calculate radiation at surface and ground plane targets.

The second type is modeled fires. Modeled fires are represented by a series of circles in 3D to define the fire surface. The surface emissive power, SEP (kW/m^2), is also defined. The fire surface is discretized into smaller elements and used by a radiation solver to calculate the view factor to targets and the resulting incident radiation. The radiation solver can account for occlusion and atmospheric transmissivity. While the pre-defined fire type is a unidirectional model, the modeled fire will give non-uniform radiation depending on its size and orientation.

Toxics Toxics are simply concentration vs. distance point pairs that are used to calculate contours. Dose vs. distance pairs are also an option. Exposure time vs. distance can be input to allow concentration data to be used for dose calculations. The toxic result variables include ERPG contours and dose contours for evacuation. This object was used for facility siting studies, but the newer dispersion object duplicates much of the toxic objects functionality and also allows toxic hazards to be used in risk calculations. Toxic objects are not shown by default unless the Program Settings (F9) specifies otherwise or an older file containing Toxic objects is opened.

Regions Regions are 2D polygons that represent some ground plane area. They are typically used to save some feature of the site in the FACET3D file for annotation purposes, but are also used in path finding and API 753 Zone 1 contours. Regions can be easily created using the *Region* commandline command.

Scenarios Scenarios are a risk feature object that serve to group dispersion and fire objects that are related to the same release and to provide base and event frequency for the risk calculations. Scenarios include the process section object with allows the definition of frequency components that define the leak frequency as a function of hole size.

Dispersions Dispersions are typically imported from PHAST. They are defined as a series of segments each of which has multiple cross sections that define the cloud as a function of space and time. Each cross section has the Gaussian dispersion parameters necessary for the segment to calculate the concentration at any location downwind. Dispersions can be flammable, toxic, or both. Flammable dispersions are used to calculate flash fire consequences and create vapor cloud explosion threats. Toxic dispersions can calculate equivalent ERPG contours and cross-wind evacuation dose (toxic lethality) contours.

Weathers Weather objects are used in the risk calculations of hazards that are directionally dependent, such as toxic dispersions. Weathers are typically imported from PHAST along with scenarios and dispersions. They define the weather conditions such as wind speed, temperature, and humidity and the wind rose directional probabilities. Multiple weathers can be defined. The dispersion and fire objects can link to a weather for determining their directional frequency.

Chemicals Chemicals are available from a built-in database. They define the flammable and toxic properties of a chemical. Mixtures of pure chemicals can also be created.

Scripts FACET3D is developed in Visual Basic .NET and has a built-in scripting engine for advanced users. Scripts written in VB.NET against the internal data types allow advanced data manipulation and processing. Typically, scripts can accomplish what a user might take hours of repetitive action to accomplish when large changes to the data objects is required.

Cameras and Movies Since FACET3D scenes are 3D in nature, a system to save and retrieve cameras is available. Cameras for orthogonal top down viewing allow the 3D scene to be observed as essentially 2D. Fly-through paths and movie generation are also available.

Commandline Commands The commandline in FACET3D allows for significant functionality when creating or manipulating scene objects. The commandline is modeled after AutoCAD where aliases are available for commands and options are prompted after the initial command.

Reports A number of spreadsheet reports are available to summarize results. These reports can be generated and viewed in FACET3D as well as saved in Excel format.

Chapter 2

Getting Started

FACET3D is a computer program that facilitates consequence and risk calculations. It has a menu driven GUI interface to allow definition of the problem. All data is saved in an XML (ASCII) file format with the *.f3d extension. A compressed file format is also available (*.f3dc) which is essentially the normal file inside a zip archive. After the problem is defined, the solution is run and results obtained in the form of contours and 3D screen shots as well as spreadsheet reports.

2.1 How to Acquire FACET3D

Instructions on how to download and register FACET3D can be found at the software support website (http://www.facet3d.com). The download is a simple zip file (password protected) that the user can unzip into any folder on the machine. Multiple versions of FACET3D can co-exist on a machine as long as they reside in different directories. The only external dependencies FACET3D has are the Microsoft .NET framework 4.0 and updated OpenGL drivers. FACET3D has been tested on the Windows XP SP3, 7, and 8 operating systems.

2.2 Computer Hardware Requirements

FACET3D will run on relatively modest hardware. Mid-level graphics cards typically have no problems, while integrated graphics may not be sufficient for large models or if their OpenGL support is insufficient. Many of the more time consuming numerical routines in FACET3D have been parallelized such that multi-core processors will show a significant speedup. The same version of FACET3D is able to run as a 32 bit application on 32 bit systems and as a 64 bit application on 64 bit systems due to the .NET Just In Time (JIT) compiler.

2.3 Licensing

A valid user license can be obtained via the LicenseCreatorClient.exe executable in the FACET3D folder. Licenses are saved in the registry and are specific to the machine. A special code is required that can be obtained from the developer.

Chapter 3

User Support

FACET3D is capable of some fairly intensive calculations that can push your computer's processor and memory to its limits. In fact, there are no hardwired bounds within FACET3D that prevent you from starting a calculation that is too large for your hardware. Even if your machine has adequate memory (RAM), you can still set up calculations that can require hours or days to complete. It is difficult to predict at the start of a calculation just how long and how much memory will be required, see Section 9.1 for specific strategies to reduce solver runtime.

Although many features in FACET3D are fairly mature, there are many that are not, especially the newer features. FACET3D is developed at a fast pace with most of the debugging done by the author on project work. Features which I personally don't use much don't get as much vetting as those I do use. Therefore, users are highly encouraged to view the results critically and do some common sense checks when applicable, especially when using a new feature for the first time.

Along with the FACET3D User's Guide, there are resources available on the Internet. These include an Issue Tracker that allows you to report bugs, request new features, and ask specific clarifying questions, and Group Discussions which support more general topics than just specific problems. Both of these resources are for members only (requires a Google account) so email the author with a request for membership. The developer of FACET3D publishes a Blog which has useful tips and techniques.

3.1 Support Requests and Bug Tracking

Because FACET3D development is on-going, problems will inevitably occur with various features. The developer need to know if a certain feature is not working, and reporting problems is encouraged. However, the problem must be clearly identified. The best way to do this is to simplify the input file as much as possible so that the bug can be diagnosed. Also, limit the bug reports to those features that clearly do not work. If an error message originates from the operating system as opposed to FACET3D, first investigate some of the more obvious possibilities, such as memory size, disk space, *etc.*

If that does not solve the problem, report the problem with as much information about the error message and circumstances related to the problem. The input file should be simplified as much as possible. Attach the simplified input file if necessary to the issue when submitting. In this way, the developer can quickly run the problem input file and hopefully diagnose the problem and provide feedback and possible workarounds.

NOTE: Reports of specific problems, feature requests and enhancements should be posted to the Issue Tracker and not the Discussion Group.

Part II

Using FACET3D

Chapter 4

Objects

The objects form can be accessed via the toolbar or by pressing F6. It contains a number of different data objects used to define the model. The form consists of a list view for showing the individual objects in each category (meshes, threats, dispersions, etc.) and a menu with clickable links to perform operations on the items, such as enable/disable or changing their properties. Items in the list can be selected using the mouse with shift and ctrl modifiers as well as with the mutliselect (Ctrl+S) tool, which enables selection of items via name masks. Wildcards (* and ?) are accepted and a pipe (|) can be used as an OR operator to chain multiple selection criteria.

A common operation is enabling and disabling items, which is performed before running the solution. If one or more items is selected, pressing the Toggle Enable link or keyboard shortcut (E) will toggle the enabled state. If no items are selected, the same action brings up a dialog similar to multi-select where the enabled property can be set with a filter.

Most objects have shortcuts in the left window to bulk modify select properties like color and enabled. Pressing F2 when items are selected will open the item editor (if 1 item is selected) or a multi-item editor (if more than 1 item is selected). The multi-item editor allows changing one or more properties to a single value. If a property is listed as <varies>, then the selected group has multiple values currently which will not be changed unless the user changes the value to a specific one.

In the main list view a predefined set of columns showing item properties is provided. The user can add or remove columns via the select columns button in the top-right corner of the form. The selected column set will persist until FACET3D is closed.

Above the main list view is a filter box which allows rows in the list view to be hidden while the filtered set is shown. By default, the filter text operates on all columns and a match will include the row in the display set. Using parenthesis with the column name after the filter text will restrict matching to one column. Multiple filters can be specified using comma delimiters.

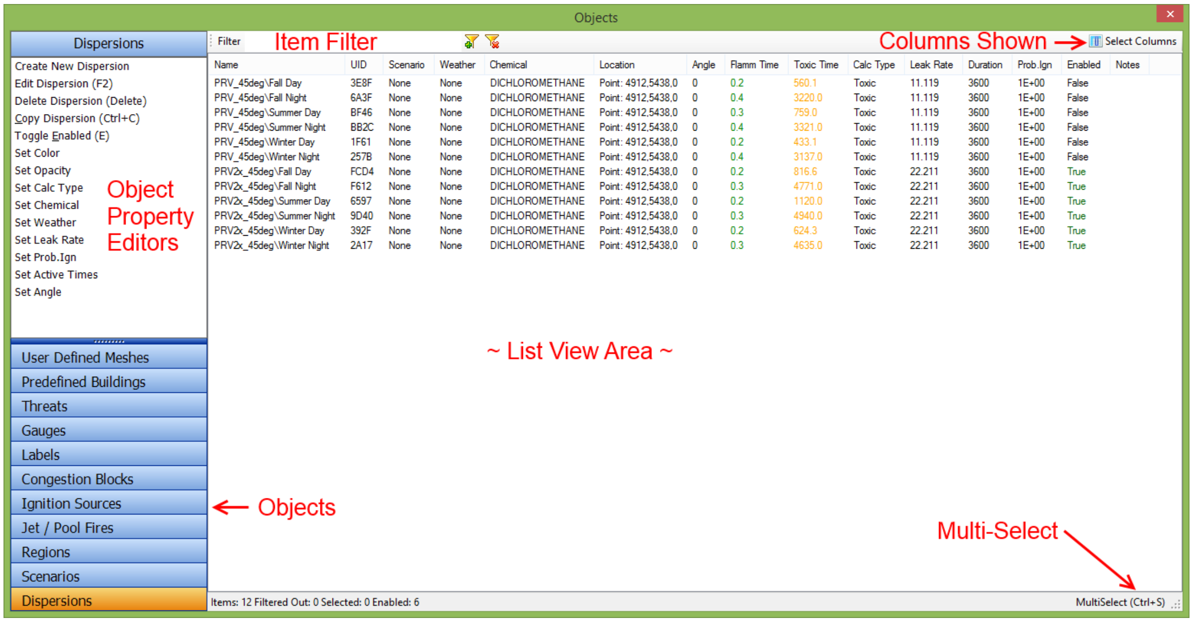


Figure 4.1: Objects Form

4.1 User Defined Meshes

Meshes contain 2D objects like lines, circles, and text, and 3D surfaces. The 2D objects are usually created during DXF import and used to annotate the site plan or the lines themselves represent the site plan. An alternative is to use a scaled picture as the site plan via the Data->Base Plane Textures menu.

Surfaces inside meshes are non-connected, independent, planar triangles or rectangles that together can represent a building, bridge, or any other object. Surfaces act as calculation points during the simulation for pressure, impulse, damage, and radiation values. Surface damage is dependent on the Materials (PI-diagrams) defined in the mesh. Users can Shift+Click (left mouse button) to get maximum surface results for the current variable. Ctrl+Shift+Click will bring up a dialog with results for all active sources for the current variable, sorted by value. This is an easy way to determine which of many threats is causing the highest consequence.

Surfaces can be operated on using the 3D canvas, selection sets, and the command line. Most commands related to surfaces operate on the highlighted surface set. Highlighting surfaces is done using a Shift+Click or the *Highlight* command. Surface quality can be checked and fixed using the *SurfaceErrorCheck* and *SurfaceErrorFix* commands. Neighboring triangle surfaces can be combined using the *CombineTriangles* command. Surfaces can be subdivided to increase contour fidelity using the *Refine* command. Since these commands can significantly alter the model and cannot be undone, it is recommended to save the file before issuing the command in case the results are undesirable or the command (typically *Refine* command) does not return control to the user because of bad input. A list of all commands is available via the Help menu.

4.2 Predefined Buildings

Buildings are rectangular boxes which define structural and occupancy properties. They can be created using the create new building button on the objects form or via the *Building* command. On the building form the user can specify location and size. Bay counts for each direction determine the number of surfaces. Larger bay counts will increase calculation and memory requirements. The permanence flag is for informational purposes only. The Shelter Type flag determines how the building is analyzed for some threats like fire and toxics. Tail time is the duration after the end of a toxic release which people stay in the building not knowing it may be safer outside. During the tail time, inside toxic concentrations will be decreasing but toxic dose will continue to increase.

The structural components tab allows PI diagrams to be defined or added from the library. Windows and door can be added and contribute to risk (windows) and act as evacuation points (doors). At least 1 door should be defined for each building. The risk analysis tab allows individual (multiple) occupancy information and aggregate occupancy information as well as settings used by the explosion and fire vulnerability models during a QRA analysis.

When defining building faces for PI diagrams, remember the wall with normal facing closest to +Y will be set as the north wall. **Therefore, it is critical that the user always lay out the site plan with north in the +Y direction.**

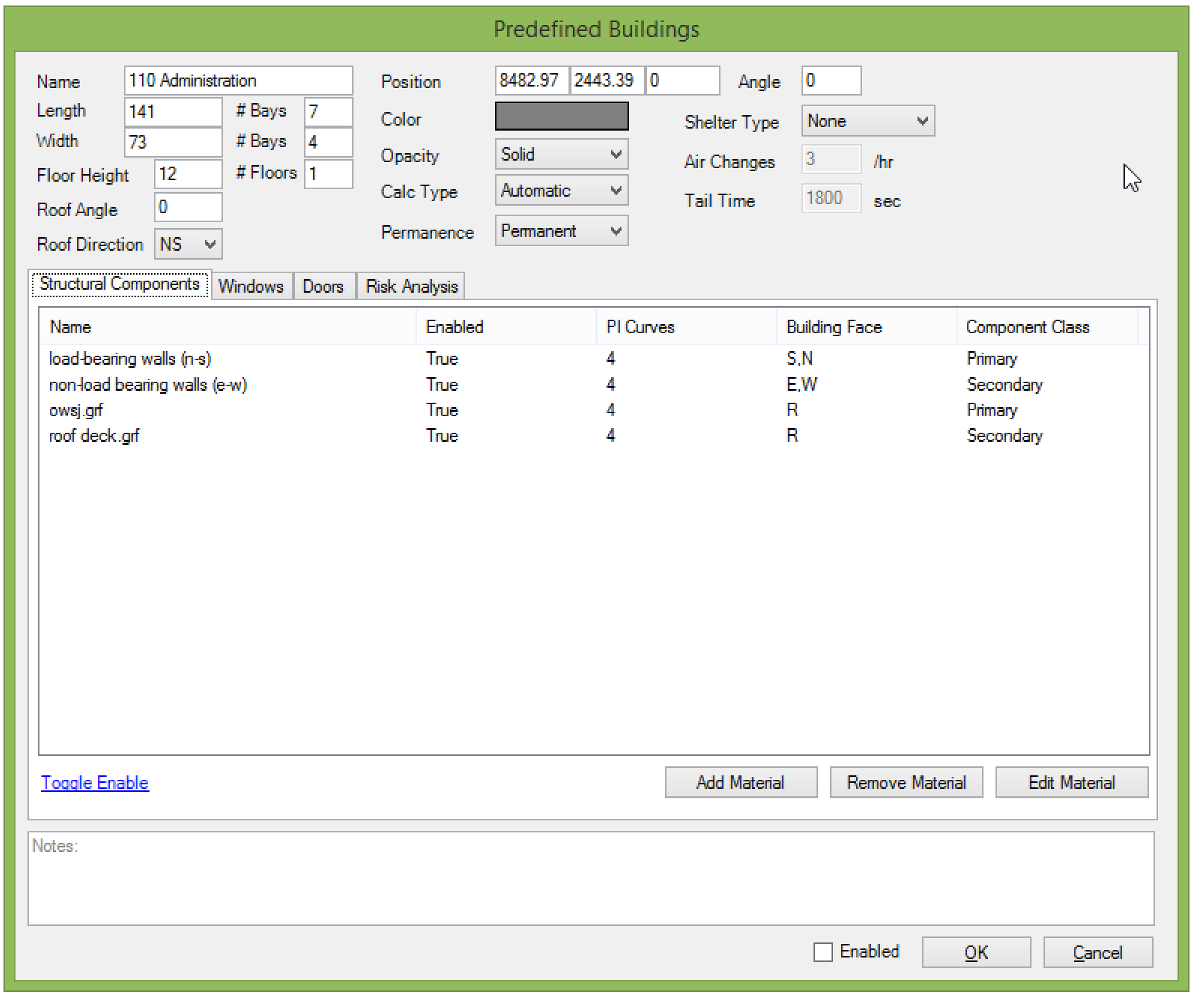


Figure 4.2: Building Form

4.3 Threats

4.3.1 High Explosive

Threats can be either HE, Vapor Cloud (MEM or BST), BLEVE, Pressure Vessel Burst (PVB), or User Defined. The HE model uses hemispherical TNT scaled curves from Kingery and Bulmash [3]. For scaled distance Z > 100, scaled curves from UFC 3-340-02 (TM5-1300) are linearly extrapolated (in logarithmic space).

4.3.2 Vapor Cloud Explosion

Vapor cloud threats can be either Multi-Energy or Baker Strehlow methods. Both have options to define parameters like congestion and confinement, but also give the user the ability to override those inputs and enter the energy and scaled curve (flame speed or severity level) directly.

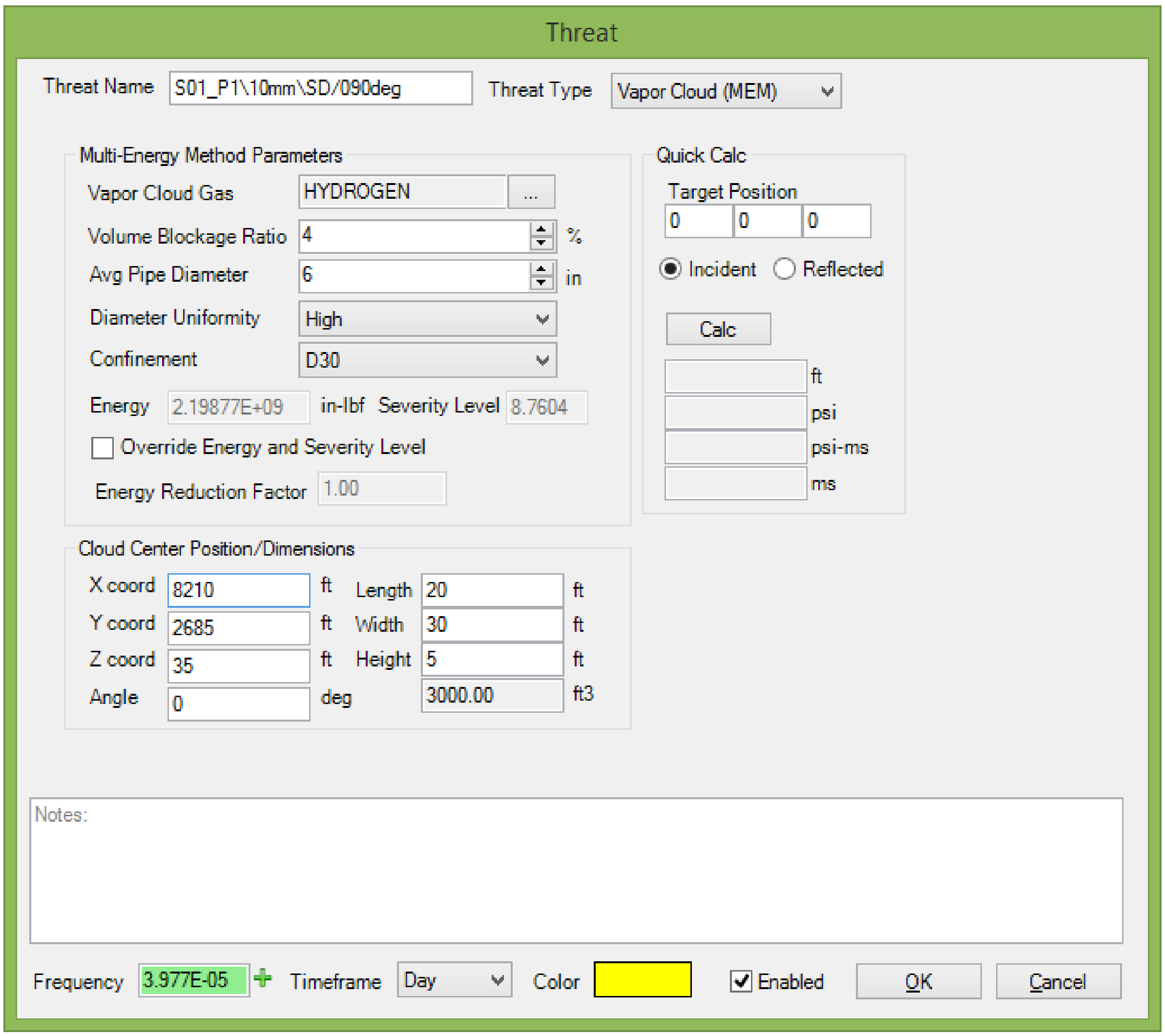


Figure 4.3: Threat Form - MultiEnergy Method Vapor Cloud

Vapor cloud threats can be created automatically from the intersection of flammable dispersions and congestion blocks. The create threats dialog form can be started via the *VaporCloud* command or corresponding toolbar button. Users may create threats for a single dispersion and discrete angles one at a time using the Create Threats button, or may auto-rotate 1 or more dispersions to create many threats. For a single dispersion/wind threat creation, a report on the intersected congestion blocks and resulting threats created is given. The user should become familiar with this report and use it to judge the accuracy of the threats created with respect to the chosen FS/SL when multiple congestion blocks are involved as well as the creation of a single threat or grouped threat depending on the spacing of congestion blocks. The auto-rotate option uses the Wind/Release Angle Step Size on the Options, Risk page.

Two decisions are made during threat creating when multiple congestion blocks are intersected. First, assuming all congestion blocks are neighbors and not separated, the final threat must choose a single FS/SL from the multiple congestion blocks which likely have different FS/SL. The decision is based on the Controlling CB Min Volume Fraction property (20% by default)). Second, if multiple congestion blocks are separated, a grouped threat is created based on the Grouped Threat Control Factor and the Critical Sep. Dist. Method properties. Grouped threats, when analyzed for a target, result in the maximum pressure of all the threats in the group and the sum of the grouped threats impulse being saved on the target.

Create Threats Dialog Options

1. **Congestion Block Volume Limit** The fraction of the congestion block volume that must be intersected for that congestion block to be considered in the threat creation. Prevents very small intersections between cloud and congestion block from skewing results.

2. **Grouped Threat Volume Limit** The fraction of the total intersection volume (all blocks) that a subthreat must meet to be included in the final threat group. Prevents small intersections from overpopulating the group.

3. **Grouped Threat Control Factor** A multiplier on the separation distance to make or prevent nearby intersection volumes from being treated as a single threat vs. a group threat. Values > 1 will increase the grouping distance limit and therefore decrease the likelihood of a group instead of a combined threat.

4. **Congestion Block SubDiv Size** The cube size (ft) which congestion blocks are divided into and then the center of which is tested against the dispersion volume. Small values of 1 or 2 ft combined with many or large congestion blocks can greatly increase the create threats time. Small values should be used if the dispersion is very small, for instance a gas dispersion that is only 3-4 ft in width.

5. **Controlling CB Min Volume Fraction** Used to determine the FS/SL when more than 1 congestion block is combined into a single threat. A value of 0 results in the max FS/SL of all intersections being used for the threat. Each congestion block intersection is represented by a volume (% of total) and FS/SL. The pairs are sorted by FS/SL (ascending) and the % to total is set to the sum of all pairs with $\geq$ FS/SL. Then a linear interpolation of the volume fraction is used to get the FS/SL. For example, consider that 3 intersections give the following %Vol,SL pairs {21%,2.39}, {58%,1}, {21%,4.56}. Sorted by ascending SL with accumulated % volume, we have {100%,1}, {42%,2.39}, {21%,4.56}. Linear interpolation with a volume fraction of 0.4 (40%) gives a threat SL of 2.62.

6. **Critical Sep. Dist. Method** LinearDimm (default) will group two nearby flammable congested volumes if the gap between them co-linear with a line connecting their centers is

less than the maximum of either's center point to edge distance on that same line. EquivRadius has the same criteria, but uses an equivalent projected radius instead of distance from center to edge. The EquivRadius method will fail to group neighboring volumes if large aspect ratios are involved.

7. **Fit Cloud by Only Adjusting Height** When 1 or more congestion blocks is intersected by the cloud and a single threat is to be made from them, an object bounding box is used to fit around all the intersection cubes and then that bounding box is shrunk until its volume matches the summed intersection volumes. Selecting this options will only shrink the bounding box in the Z direction. This is conservative as it will keep the edges of the bounding box nearer the edges of the actual congestion, which for the MEM method can make a difference on targets that are nearby.

8. **Detonate Entire Cloud (Ignore Congestion)** Use the entire cloud volume to make a threat with FS/SL equal to 5.2/10, respectively.

9. **Subtract VBR from Intersected Volume** Reduces the cloud volume and energy some due to the subtraction of volume taken up by equipment and tanks.

10. **Prevent CB Combine Across Region Lines** Regions can be used to limit threat combinations between intersection volumes on opposite sides of the region. Not typically used.

11. **Prevent Energy Reduction** MEM energy reduction occurs when the SL is small. This option forces 100 % of the cloud energy to be used.

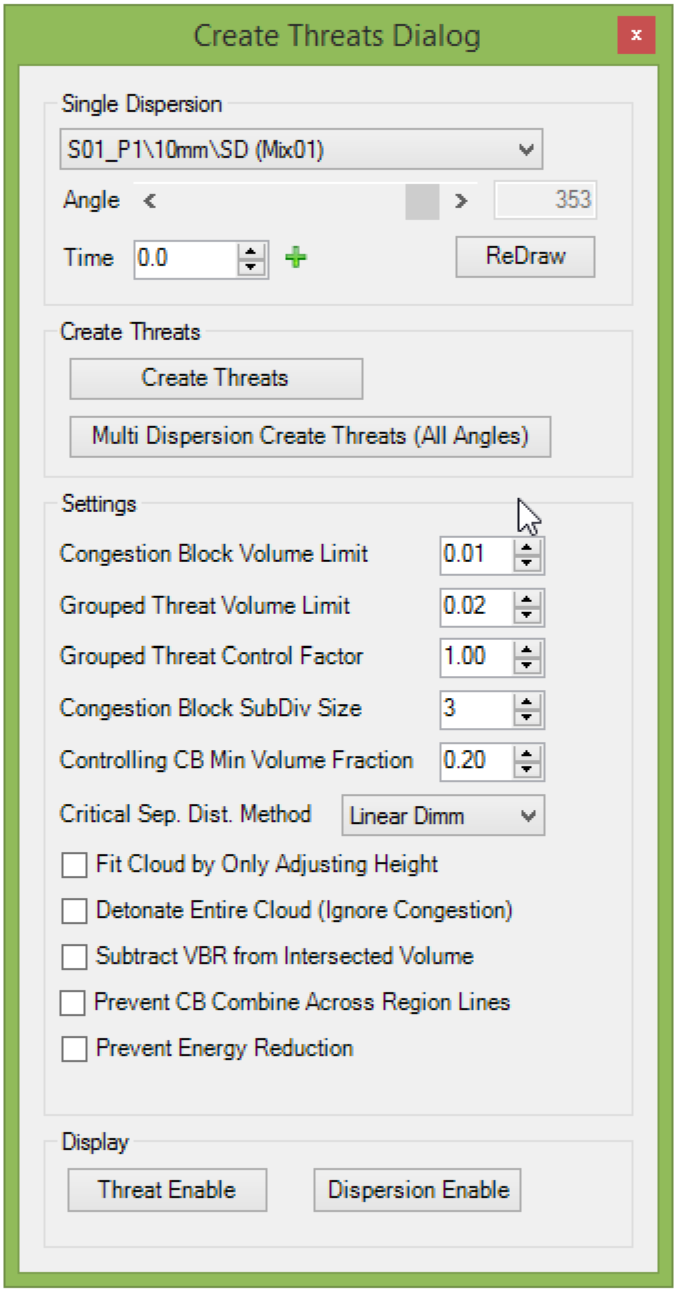


Figure 4.4: Create Threats Dialog

4.3.3 BLEVE/PVB

BLEVE and PVB threats are similar in that the user specifies a material, burst pressure, volume, and fragment fraction. Both models assume a surface burst. The BLEVE burst pressure is typically taken to be 1.21 times the relief valve set point. Fragment fraction is the fraction of energy that accelerates fragments. A value of 0 gives the highest blast loads.

PVB material can be generic Ideal Gas or a specified Real Gas. A database of saturation properties for each chemical is used in the isentropic expansion calculations for Real Gasses.

4.3.4 User Defined

The user defined threat type is simply a user supplied pressure and impulse vs. distance curves. The curves are assumed to be free-field and pressures/impulses for a given target distance will have reflection coefficients applied as necessary.

4.4 Gauges

Gauges are point locations that record pressure and impulse from a threat. The recorded value is not dependent on the surfaces that may be around the gauge; i.e. unlike a CFD gauge it is not going to record reflected pressure if you put it in front of a wall.

Gauges can be created in bulk using the Create Multiple Gauges button on the Objects form and a gauges report can be used to get results. User can also Shift+Click on a gauge and get the results in the message window.

4.5 Labels

Label locations are in model space but the label is always shown in screen space. Labels can be created using the *Label* commandline command. Label options include a text size and color, marker types, and leaders. Users can Shift+Click on labels to get the ID. Also, Ctrl+Alt combined with a left mouse button drag operation moves the label while the same with a right mouse button drag operation moves the text only and adds a leader if the text moves sufficiently far from the label position.

4.6 Congestion Blocks

Congestion blocks are rectangular blocks that define congestion and confinement according to either the MEM or BST vapor cloud explosion models. They are used during threat creation along with dispersions. Congestion block visibility is set in the Options, Rendering form.

4.7 Ignition Sources

Ignition sources are used during threat creation to limit the downwind extents of a dispersion. Any congestion block downwind of the ignition source but inside the dispersion will not be considered in the threat creation. Ignition sources can be created via the *IgnitionSource* commandline command.

4.8 Jet/Pool Fire

Fires can be either predefined radiation vs. distance curves or modeled fires. The former is simply a curve of incident radiation (kW/m2) vs. distance. It is used to calculate radiation at targets as well as thermal dose during evacuations. Radiation values are typically calculated on the base grid, but can be calculated on surface targets if the Ground Contour Only option is not checked under the Options, Variables form. When a predefined curve fire is used to calculate radiation on a surface, the surface normal is used to get an angle between the fire and surface, the cosine of which is used to modify the radiation value such that surfaces that are 90 deg or more from the fire will not receive radiation.

Modeled fires are defined by circles that make up the surface of the fire. The analysis using modeled fires is much slower than predefined curves. A radiation solver calculates the view factors between the fire and target surfaces or the contour grid. The view factor and the fire surface emissive power define the radiation received at a target.

The modeled fire input form can be seen below in Figure 4.5. Modeled fires are defined by circles that form an outer flame surface. These circles should have Cy values of 0 and the Release Angle property used to rotate the flame. For pool fires with flame tilt (Cx value of top circle is $>$ Cx value of base circle), the Wind Angle can be set independent of the Release Angle when doing a consequence analysis. QRAs treat wind angle differently as described in the risk section. The tesselation properties define how the fire surface is discretized. Using a white color will show the discretization using multi-colors.

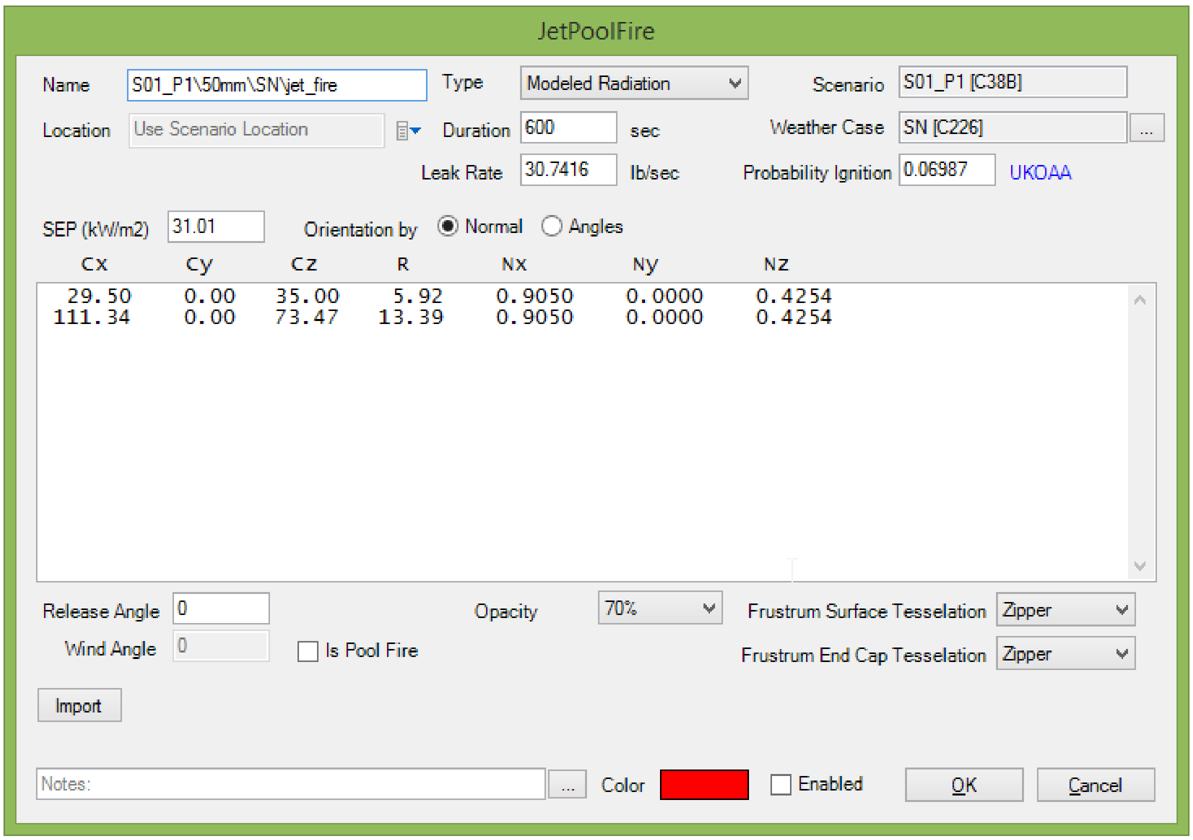


Figure 4.5: Modeled Fire Form

Thermal radiation and dose is calculated for each base grid point. Radiation is calculated either using the appropriate pre-calc'ed curve considering the points location relative to the fire center and direction or rigorously using the full radiation solver if Options, Analysis, Pre-Calc'ed Curves is not used (not recommended for risk calculations due to the long potential run times).

Radiation dose is calculated assuming evacuation. Evacuation occurs at the running speed specified in the Base Grid options. The individual starts at the base grid point or building door and runs directly away from the fire center until the fire analysis option *Safe Radiation Level* is reached or the fire *Duration* is exceeded. The evacuation dose integration step size is 1 second. Dose calculations will be faster if a constant running speed is specified. Dose calculations that do not use the pre-calc'd curves will use interpolation of the base grid radiation result to get the radiation level at each step during evacuation. Therefore, the radiation result variable will have to be calculated in this case (despite the variable option settings) and the many repeated interpolations will take much more time than the pre-calc'd curves method.

Thermal lethality at each base grid point is based on the thermal evacuation dose and/or flame impingement. Any calculation point inside the fire gets a lethality of 1. A number of probit models are available as described in Section 7.1.2.

4.9 Regions

Regions are 2D polygons drawn on the ground plane. They are mostly for annotation, but are also used when creating Zone 1 contours (see Options, Rendering form). For Zone 1 contours, the region boundaries are offset by the Zone 1 distance, which is a function of the largest threat volume in the region. Future use of regions may include population density for outside aggregate risk calculations.

Another region use is as a muster shelter for evacuating personnel when doing a path-finding evacuation. If the region shelter type is set to fire or toxic, a path finding route from base grid points will go to the nearest region, minimizing dose or distance depending on settings on the Options, Base Grid form.

4.10 Scenarios

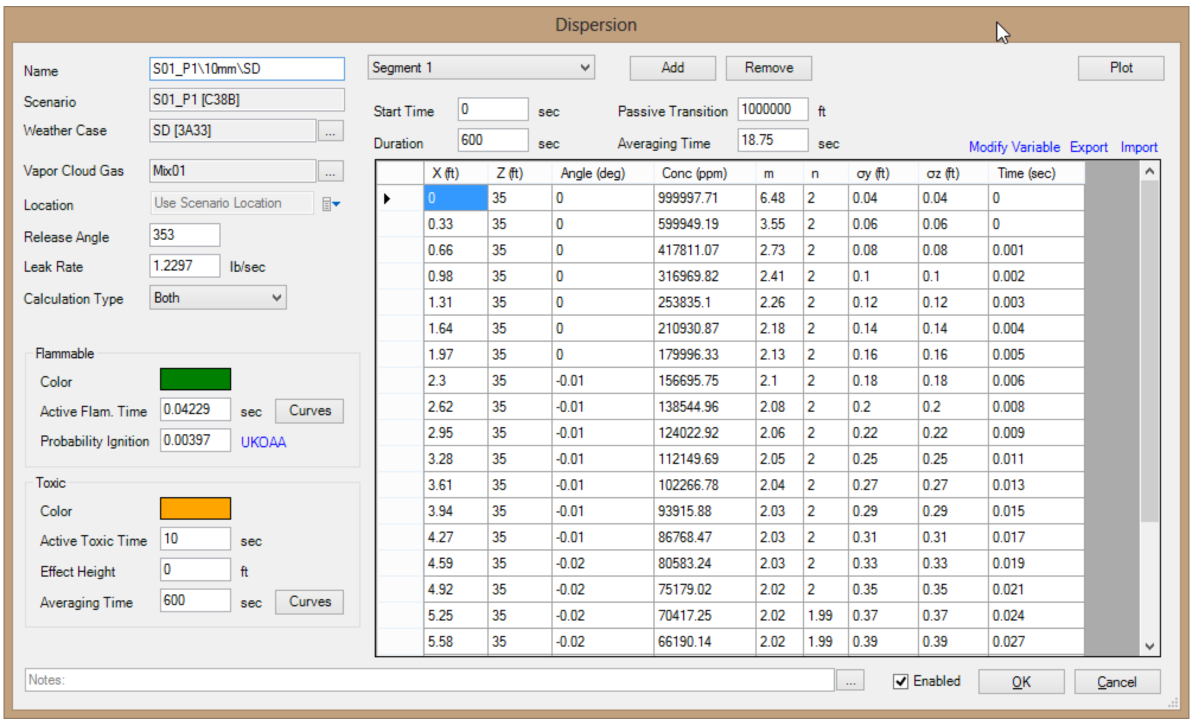
Scenarios are a risk feature object that serve to group dispersion and fire objects that are related to the same release and to provide base and event frequency for the risk calculations. Scenarios include the process section object with allows the definition of frequency components that define the leak frequency as a function of hole size. Frequency components are typically equipment counts in the process stream that have defined leak rates. A database (DNV Leak) of equipment types is included. Scenario process conditions can also be specified but are not currently used.

Scenario consequence events are dispersion and fire objects that link with the scenario. Consequence events include a probability of occurrence and the frequency type (cumulative or distributed) as well as hole size. When a dispersion or fire which has a scenario is calculated, the corresponding consequence event is used to get the frequency. Scenarios will have may consequence events (dispersions/fires), but dispersions/fires will only have one parent scenario.

For more details on scenarios, see Section 6.1.

4.11 Dispersions

Dispersions represent a vapor cloud and are created during PHAST import. The table data represents centerline concentrations and profile constants for off-centerline concentration determination.



X (ft)	Z (ft)	Angle (deg)	Conc (ppm)	m	n	σy (ft)	σz (ft)	Time (sec)
0	35	0	999997.71	6.48	2	0.04	0.04	0
0.33	35	0	599949.19	3.55	2	0.06	0.06	0
0.66	35	0	417811.07	2.73	2	0.08	0.08	0.001
0.98	35	0	316969.82	2.41	2	0.1	0.1	0.002
1.31	35	0	253835.1	2.26	2	0.12	0.12	0.003
1.64	35	0	210930.87	2.18	2	0.14	0.14	0.004
1.97	35	0	179996.33	2.13	2	0.16	0.16	0.005
2.3	35	-0.01	156695.75	2.1	2	0.18	0.18	0.006
2.62	35	-0.01	138544.96	2.08	2	0.2	0.2	0.008
2.95	35	-0.01	124022.92	2.06	2	0.22	0.22	0.009
3.28	35	-0.01	112149.69	2.05	2	0.25	0.25	0.011
3.61	35	-0.01	102266.78	2.04	2	0.27	0.27	0.013
3.94	35	-0.01	93915.88	2.03	2	0.29	0.29	0.015
4.27	35	-0.01	86768.47	2.03	2	0.31	0.31	0.017
4.59	35	-0.02	80583.24	2.03	2	0.33	0.33	0.019
4.92	35	-0.02	75179.02	2.02	2	0.35	0.35	0.021
5.25	35	-0.02	70417.25	2.02	1.99	0.37	0.37	0.024
5.58	35	-0.02	66190.14	2.02	1.99	0.39	0.39	0.027

Figure 4.6: Dispersion Form

Chapter 5

Structural Damage

Damage levels are calculated for buildings and meshes using pressure-impulse diagrams supplied by the user. These PI diagrams are referred to as materials, and consist of between 1 and 5 curves with impulse as the abscissa and pressure the ordinate. Each curve is assigned a damage level [1-5] which indicates its order among the curves. Generally, all points belonging to a damage level curves should be below and to the left of the next higher curve. Intersections of curves, while allowed, should be avoided due to the potential ambiguity of results. Predefined buildings also have fields to define which wall/roof the material (component) belongs on and whether it is a primary or secondary component. An example of a material/component is shown below in Figure 5.1.

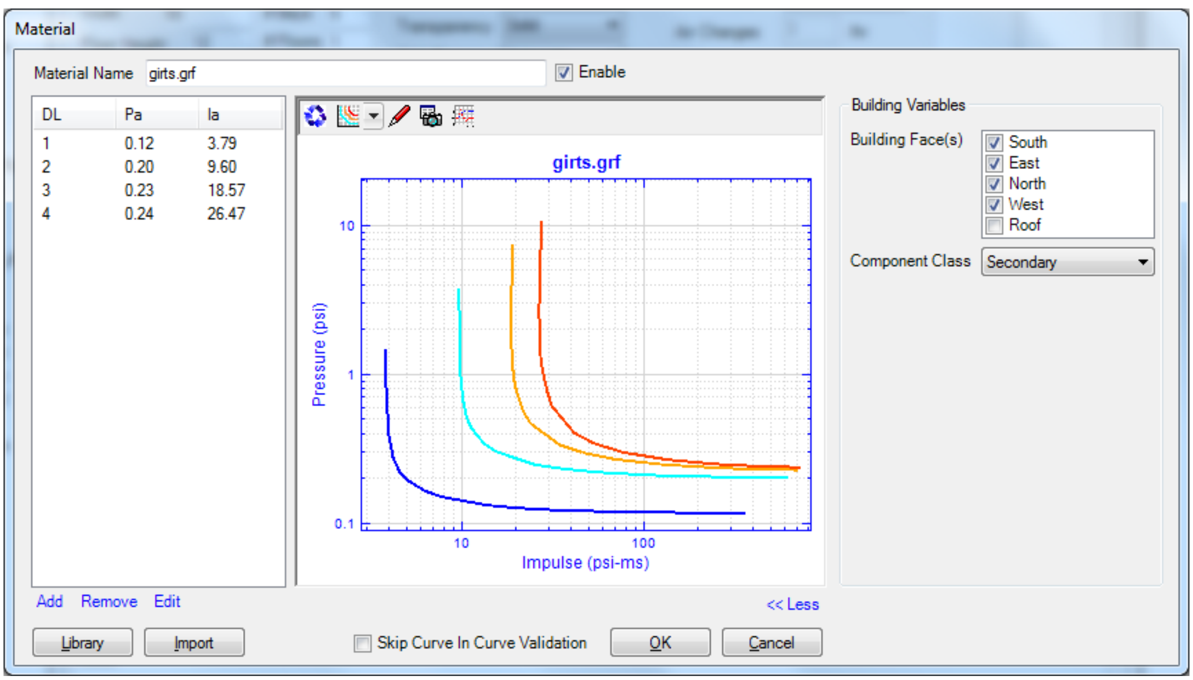


Figure 5.1: Material Form

The calculation of a damage level starts at the material (hereby called component) level. Each component curve set is analysed for a given blast load starting with the highest damage level curve. A polygon is created for the curve by extending the first point pressure to a large value and the last point impulse to a large value. A final point with large pressure and impulse is used to create a complete polygon out of the curve. This polygon is then used to test whether the blast load is contained. If it is, the damage level of the curve is returned. Otherwise, the next lower curve is tested in the same manner, etc. There are six possible damage levels. Level 0 is anywhere below the first curve, even if the curve is not damage level 1. Level 5 is above the damage level 5 curve. The damage variable legend can substitute any value for the damage levels, with the typical usage being an increase from base 0 to base 1, i.e. damage level 0 is reported as CDL 1 (component damage level).

In facility siting work ABS Consulting typically uses SBEDS to develop PI diagrams. Most ductile components will have 4 PI curves which are assigned to DL 1 - 4 in the material form as shown in Figure 5.2.

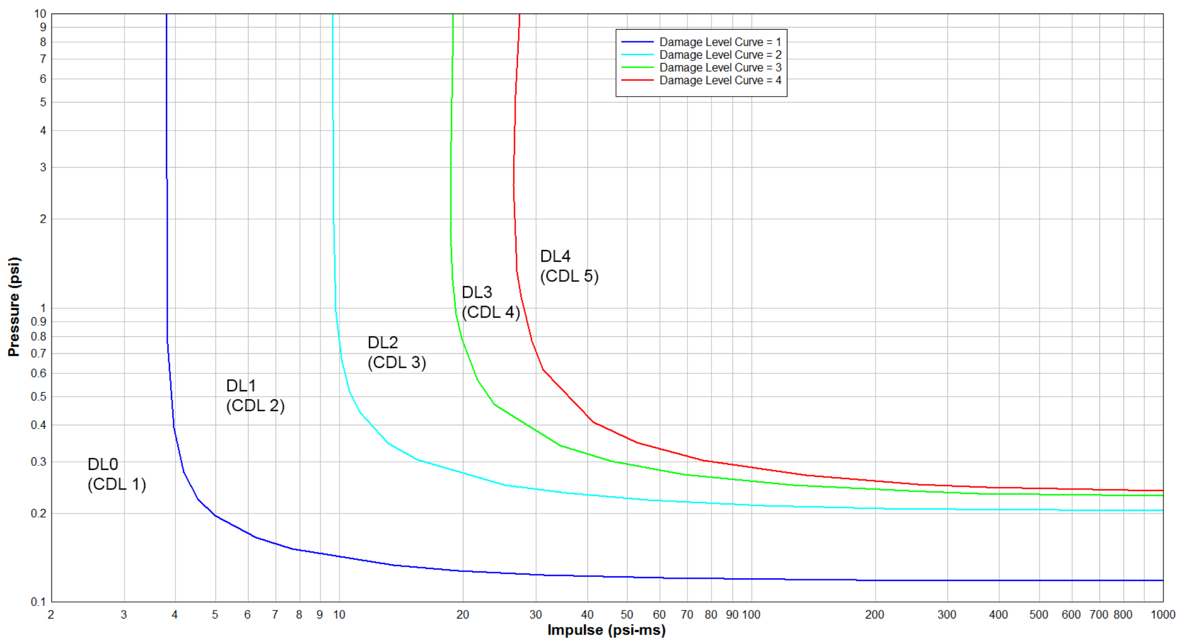


Figure 5.2: Component PI Curves

5.1 Building Damage Level (BDL)

Predefined Buildings have a building damage level (BDL) that is composed of the individual CDLs for all walls and the roof. Two methodologies are available for determining a BDL from the CDL values which may be selected in the Options→Analysis tab. Version 1 (depricated) maps CDLs to BDL according to the following relationships as shown in Table 5.1. Each component results in a BDL with the highest being the reported value. This method was found to be very conservative in some cases since a single weak component such as a wall panel could result in a BDL 5.

Table 5.1: BDL Model Version 1

BDL	Component Damage Level (CDL = DL + 1)	
	Primary	Secondary
5	$\geq$ CDL 4	$\geq$ CDL 5
4	CDL 3	CDL 4
3	CDL 2	CDL 3
2	CDL 1	CDL 2
1	CDL 1	CDL 1

Version 2 of the BDL Model determines BDL values based on 1 or more CDL (DL+1) values depending on which walls/roof they occur on and whether they are primary or secondary. The rules are given below in the given pseudocode with the following notes: 1) Load bearing wall or columns should be set as primary components such that their failure will result in a BDL 5. 2) Metal panels that are multi-span continuous may be ignored while panels with 2 or fewer spans should be secondary components.

```
If {ANY roof CDL >= 5} OR {4+ wall CDL >= 4} Then
    Return BDL 6
ElseIf {ANY roof CDL >= 4} OR {ANY wall PCDL >= 4} OR {2+ wall CDL >= 4} Then
    Return BDL 5
ElseIf {1 wall CDL >= 4} Then
    Return BDL 4
ElseIf {ANY CDL >= 3} Then
    Return BDL 3
ElseIf {ANY CDL >= 2} Then
    Return BDL 2
Else
    Return BDL 1
End If
```

Chapter 6

Risk Calculations

Risk results in FACET3D are a compilation of consequence results from threat, dispersion, and fire objects combined with their frequency. Frequency is a combination of the base leak frequency (F_{base}) defined in the scenario for the given hole size of the consequence event under consideration and a series of probabilities that includes the consequence event probability of occurrence (P_{ev}), ignition probability (P_{ign} - if applicable), weather probability (P_{wthr}), wind probability (P_{wind}), release direction probability (P_{dir}), and release location probability (P_{loc} - for line or polygon locations). Each of the objects involved in the chain are described below and the calculation methods detailed.

6.1 Scenarios

Scenarios hold a collection of consequence events which are essentially links to dispersion and jet/pool fire objects (hereby called simply fire objects). Scenarios can have multiple consequence events, but each dispersion and/or fire can only have one parent scenario. Each consequence event is defined by a dispersion/fire, a probability of event (P_{ev}), a frequency type (distributed or cumulative), and a lower and upper leak diameter. The upper diameter is only used if the frequency type is distributed. The scenario form can be seen below in Figure 6.1.

Each scenario has a frequency distribution as a function of leak size that is defined in the scenarios process section data, which represents parts count data. A set of frequency components (parts count or user defined) is defined each with an amount property and a set of diameter vs. *cumulative* frequency points. When a consequence event requests its base leak frequency, the frequency type determines how the result is obtained. Cumulative frequency type is obtained by getting the frequency from each frequency component for the given diameter and multiplying it by the amount. This result is then summed for all frequency components. Distributed occurs in the same manner with the upper diameter result being subtracted from the lower diameter result. Diameters less than or greater than the extents of the overall curve get the closest value, i.e. no extrapolation is performed. If the frequency component frequency is less than $1{\times}10^{-9}$, then $1{\times}10^{-9}$ is returned. The summed frequency returned (F_{base}) is modified by two values. A *Site Frequency Modification* value as defined in the risk options and a *Unit Frequency Modification* value as defined in the *Process Section Form.*

An alternative to using the *Process Section Form* is to use the frequency override to define a constant frequency vs. hole size. No site or unit modifications are made to the override frequency.

$$\text{Cumulative: } F_{base} = \sum_{i=1}^{n} F_i(dia) \cdot Amount_i$$

$$\text{Distributed: } F_{base} = \sum_{i=1}^{n} F_i(dia) \cdot Amount_i - \sum_{i=1}^{n} F_i(dia_2) \cdot Amount_i$$

Buttons on the Scenario form for Auto Setup and Auto Group can be used to quickly set some consequence event (CE) properties. If the CE names include a ###mm value, auto setup will determine how many unique hole sizes there are and set the diameters and frequency types. The largest hole size releases will have a single diameter and a cumulative frequency type. Smaller hole sizes will be set as distributed. The diameters uses are best explained by example in Figure 6.2, where 10mm, 25mm, and 100mm leaks are setup.

Auto Group sets the GroupID by matching events with the same hole size, frequency type, weather, and Pevent·Pign. A GroupID of 0 is an independent event on an event tree branch termination. A non-zero GroupID represents multiple events that can all happen at an event tree branch termination. For example, ignition of a flammable release could result in a flash fire, explosion, and jet fire, all of which would contribute to the consequence on an individual since they are not mutually exclusive. If each event had a GroupID of 0, each individual consequence and its frequency will be saved such that the final risk is a summation of the risk from each event. If the GroupID is not 0, the consequence probability from all events is combined as described below.

Location Specific Individual Risk (outdoors) and building occupant individual risk is calculated as a simple summation of the risk from each consequence whether the consequence was part of a group event (explosion + jet fire + pool fire) or a standalone event (toxic release). Building Aggregate Risk calculations for a group event with multiple consequences calculates an overall vulnerability for the group event according to $P_{vulnerability} = 1 - (1 - P_1) \cdot (1 - P_2) \cdot ... \cdot (1 - P_n)$ where P1 might be the explosion consequence and P2 the jet fire consequence, etc. The frequency of the group event is calculated as $F_{base} \cdot P_{ev} \cdot P_{ign} \cdot P_{wthr} \cdot P_{loc} \cdot P_{wind} \cdot P_{dir}$.

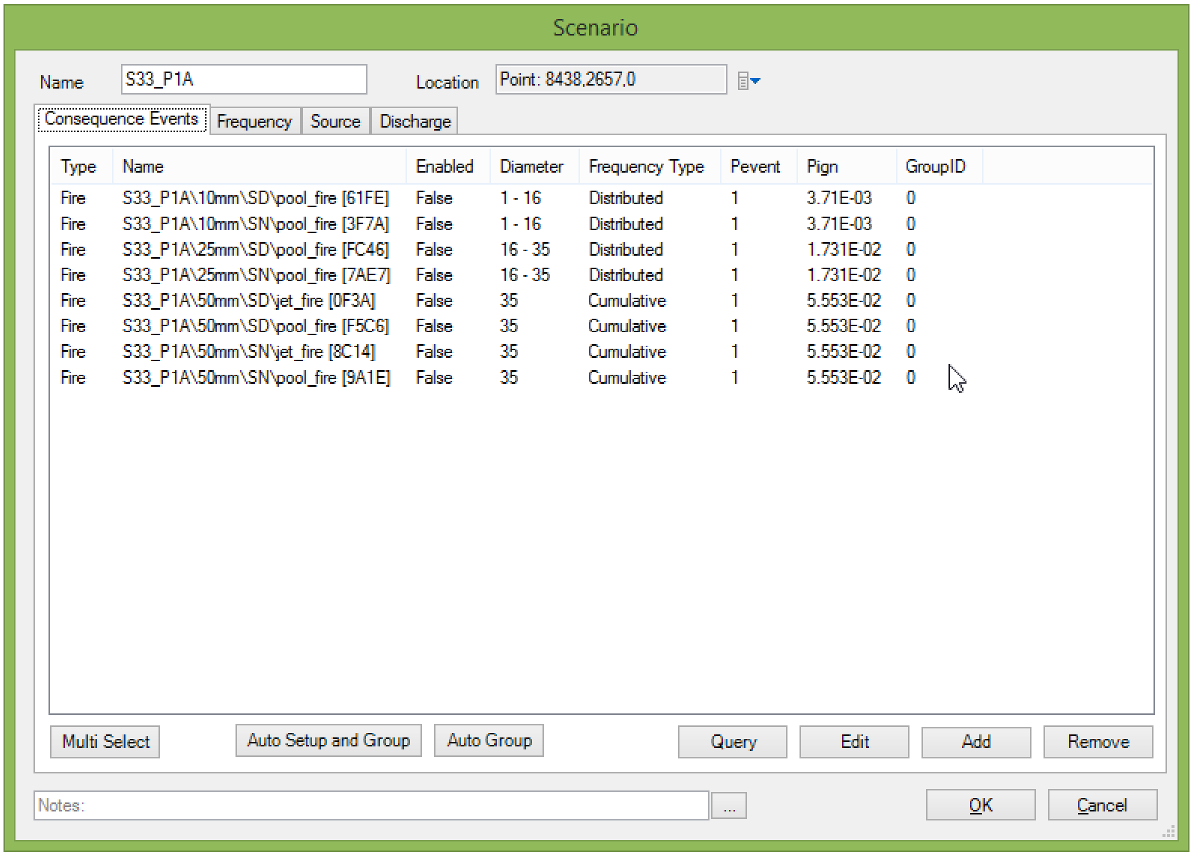


Figure 6.1: Scenario Form

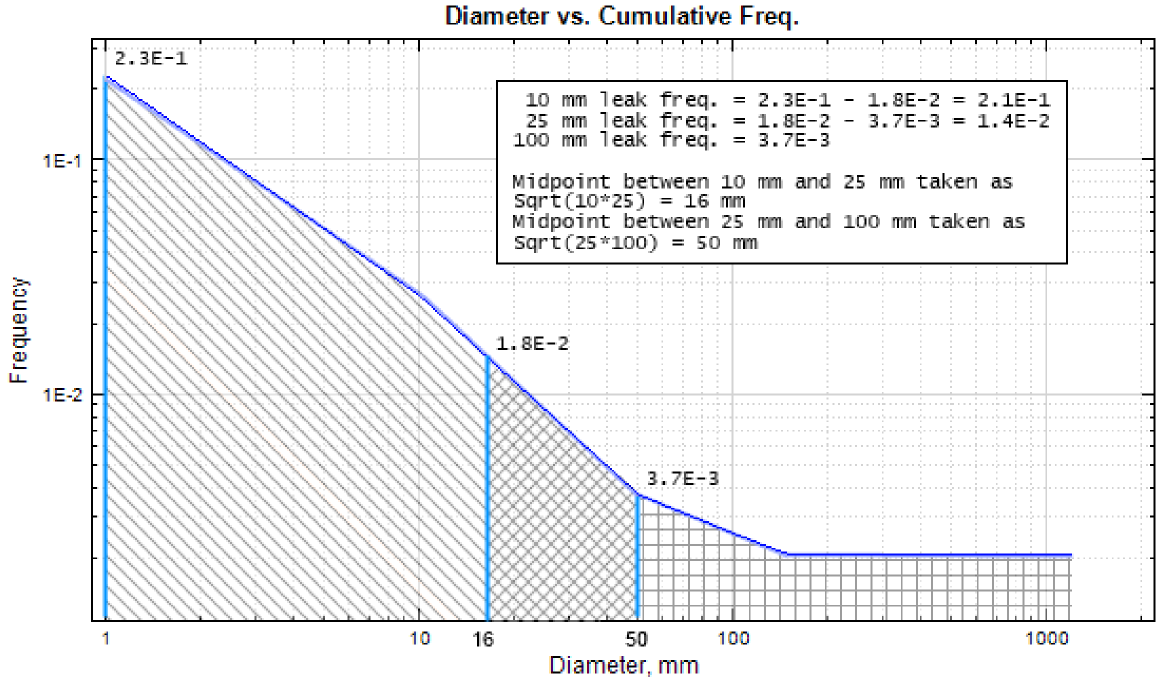


Figure 6.2: Consequence Event Diameter Selection by Freq. Type

6.1.1 Event Probability

Event trees are typically used to determine end result frequencies for consequence events. Scenarios are typically either flammable or toxic releases but can be both flammable and toxic (i.e. benzene or H2S). Each scenario has a base leak frequency as previously described. If a toxic release, the only outcome is a toxic plume. In this example, we assume assume late ignition to be the only outcome. Early ignition is typically very small and is ignored (which is conservative since late ignition has higher consequences). Late ignition probability ($P_{ign-late}$ or just P_{ign}) is defined using the UKOAA model. Following a late ignition, all possible outcomes are modeled and assumed to occur. For example, it may be possible to have an explosion and flash fire (uncongested portions of the vapor cloud) followed by a jet fire and a burning pool fire from a release that has a partial rainout fraction (generates the pool) as well as sufficient inventory to sustain a jet fire after the ignition and explosion. Each outcome in the group will generate a potential vulnerability consequence at a receptor. If the scenario is both toxic and flammable, the event tree splits using the P_{ign} such that no ignition leads to only toxic consequences while ignition leads to only flammable consequences. The event trees for flammable only scenarios is shown in Figure 6.3. The event tree for flammable + toxic scenarios is shown in Figure 6.4. If a scenario is only a toxic, the event tree in Figure 6.4 applies with the $P_{ign-late} = 0$.

In the Scenario Form, if a flammable release is also a toxic release, you should have 2 dispersions (1 of which is toxic) and 1 jet fire in the GroupID (1 pool fire may also be present). The toxic dispersion should be separate from the flammable dispersion since different averaging times will be used. The flammable ignition should be set and the P_{ev} set as 1. The toxic ignition property should be set to $1 - P_{ign}$ (the probability of NO ignition).

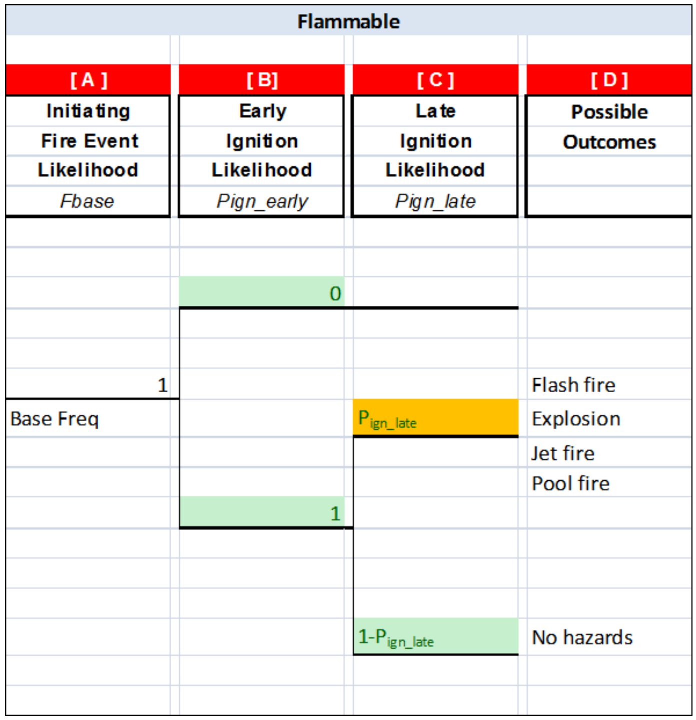


Figure 6.3: Flammable Scenario Event Tree

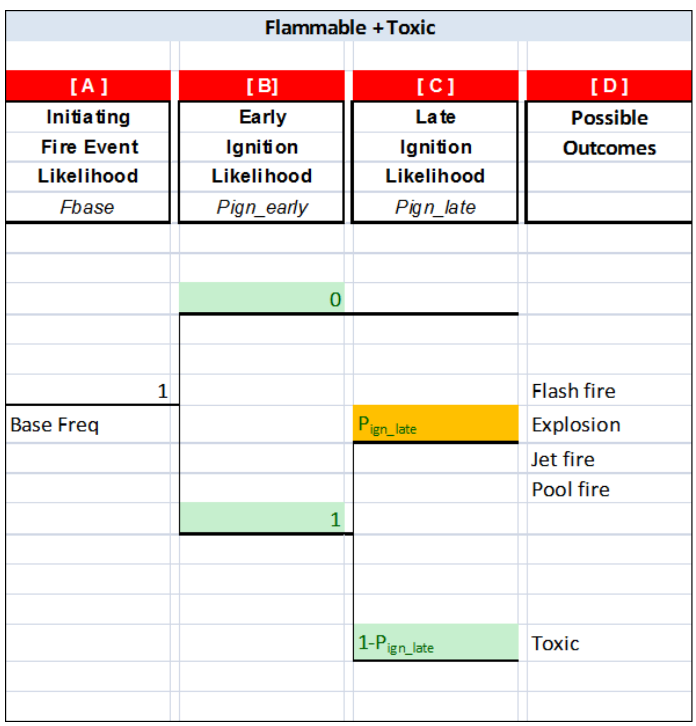


Figure 6.4: Flammable + Toxic Scenario Event Tree

6.2 Weathers

Weathers provide two types of probability. The first is the probability of occurrence, P_{wthr}, for the weather. The value of such depends on how many weathers are being considered in the analysis. If a daytime (Solar Flux $>$ 0) and nighttime weather case are being used by a set of scenarios, each should have a P_{wthr} of 0.5. Another distribution might be as shown in Table 6.1.

Table 6.1: Weather Probabilities

Summer Day	$P_{wthr} = 0.125$
Summer Night	$P_{wthr} = 0.125$
Winter Day	$P_{wthr} = 0.125$
Winter Night	$P_{wthr} = 0.125$
Spring/Fall Day	$P_{wthr} = 0.25$
Spring/Fall Night	$P_{wthr} = 0.25$

The second probability comes from the wind rose data used to calculate wind probability. Wind rose data is entered as the frequency for each of 16 arc angles (22.5° deg each) that the wind is blowing ***from***. The summation of these 16 values must be one. Each arc angle is labeled N, NNE, NE, and so forth. North represents the arc from 349° to 11°, NNE the arc from 12° to 34°, etc. since fractional angles are rounded to the nearest integer. Note the angles given above are for the internal wind rose CW angle convention, where N is 0°, E is 90°, etc. The angle convention that users interact with via object forms that have an angle property or the *Create Threats Dialog* is based on a CCW orientation with E as 0°, N as 90°, etc. Internal conversions are used to transform the user convention to the wind rose convention when calculating wind probabilities.

When an object (dispersion/fire) requests a frequency from a weather object, it includes a center angle and arc angle argument. Essentially, these can be used to get the start and end angles, inclusive, that are to be included when summing the frequency. The weather object first decomposes the 16 arc sector dataset to a 360 arc sector (1 for every degree) dataset. This is done by first using linear interpolation to get a value for each degree angle and then normalizing the values such that they sum to one. This method ensures a smooth transition of frequency around the circle rather than the stepped distribution entered by the user. Finally, all the frequency between the start and end angles, inclusive, are summed and returned to the requesting object.

6.3 Flammable Dispersions

Flammable dispersion objects are used to calculate the flammable concentration variable. This variable determines the consequences due to flash fire. The units are LFL fraction rather than ppm for easy determination of consequences. Values ≥ 1 result in a lethality of 1; otherwise a lethality of 0. The analysis calculates the maximum LFL fraction (at any time) and frequency at each base grid point. The effect height elevation is grade unless the option *Use Flattened Dispersion* is checked. In this case, the effect height is variable with downwind distance and is equal to the centerline height of the cloud. If the option *Use Monotonically Decreasing Curves* is checked then this curve will only decrease with downwind distance, preventing double contours as shown in Figure 6.5 through Figure 6.7.

The full list of probabilities that modify the base leak frequency for a flammable dispersion are

$F_{base} \cdot P_{ev} \cdot P_{ign} \cdot P_{wthr} \cdot P_{loc} \cdot P_{wind}$. Probability of location (P_{loc}) will be 1 for point locations and $1/N_{steps}$ for line and polygon locations that require the dispersion to be stepped along the boundary. The step size will be approximately equal to the base grid size. The final LFL fraction and lethality results and their corresponding frequencies are saved in the *Flammable Concentration* and *Flash Fire Thermal Lethality* result variables, respectively.

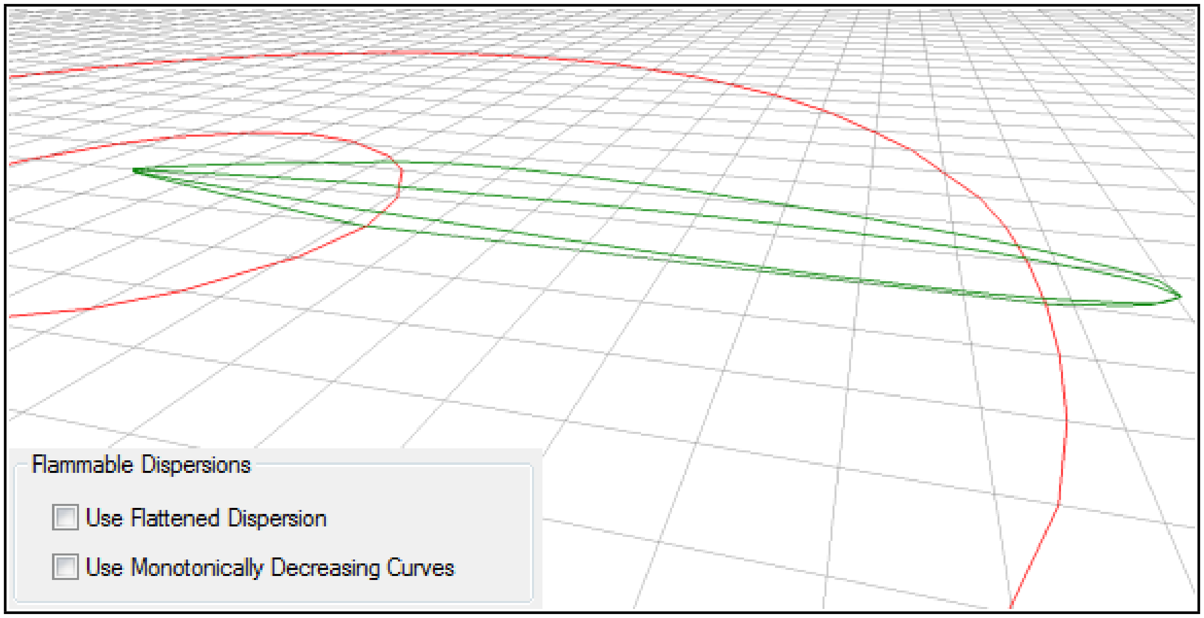


Figure 6.5: Flammable Concentration Contour w/o Flatten and Monotonically Decreasing Options

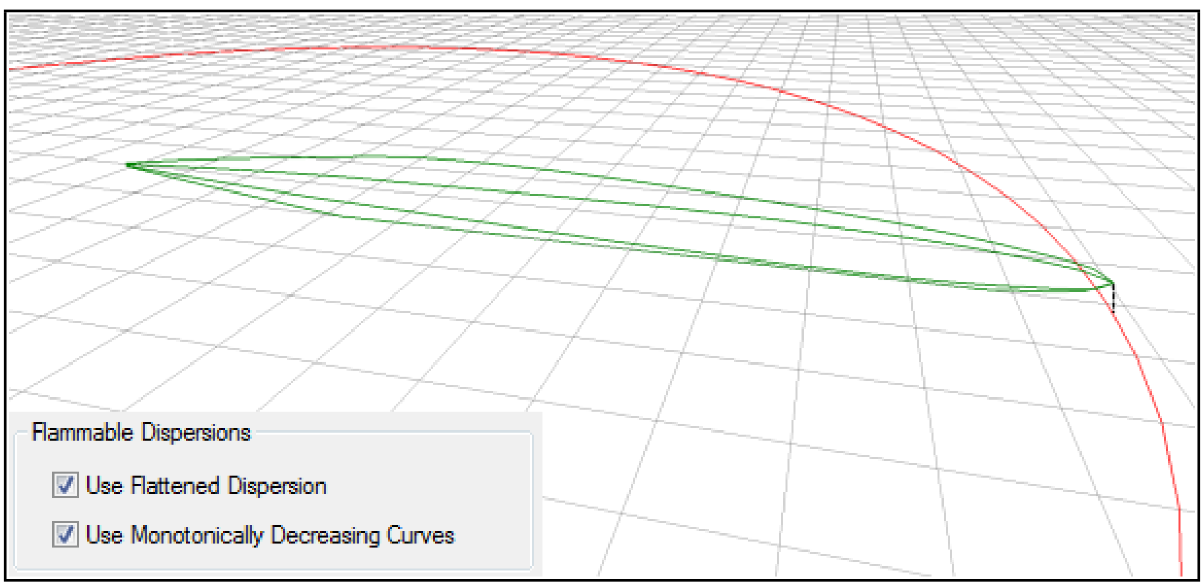


Figure 6.6: Flammable Concentration Contour w/ Flatten and Monotonically Decreasing Options

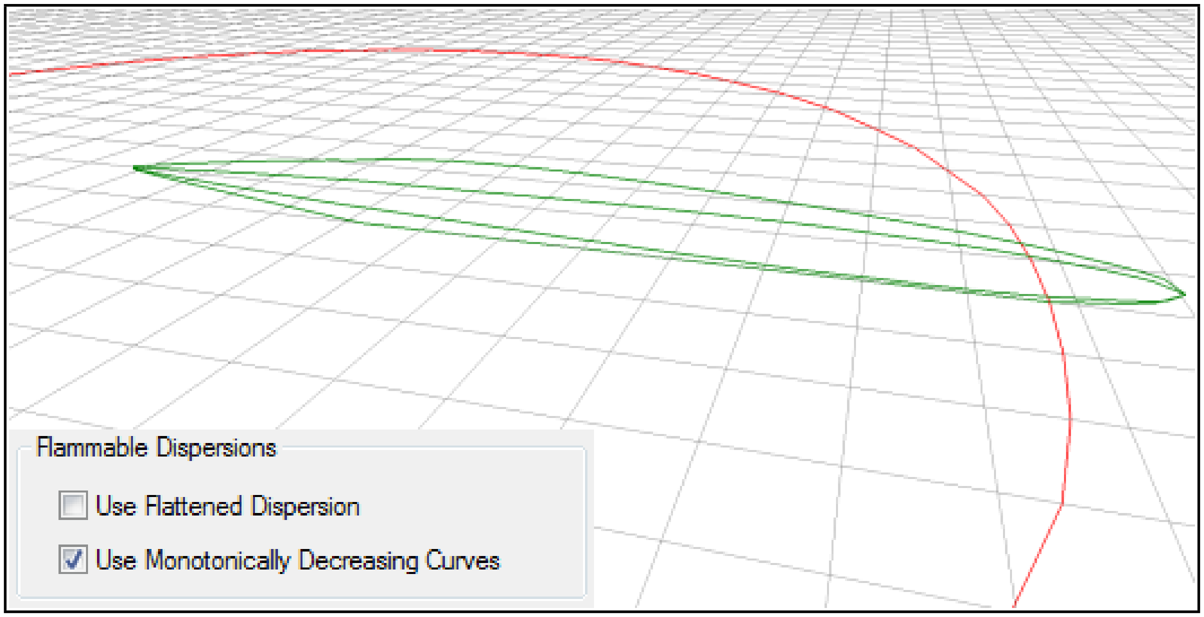


Figure 6.7: Flammable Concentration Contour w/ Only Monotonically Decreasing Option

6.3.1 Buildings

Flashfire consequences for buildings depend on the whether the building is shelter in place or evacuation and whether the building has any large openings. If evacuation, lethality will be 1 if any portion of the building is inside the LFL and the building has large openings (creates an internal explosion). If there are no large openings, lethality will be 1 if all exits are above the LFL. Otherwise, lethality will be 0.

If shelter in place for fire, lethality is based on whether the building ingests sufficient flammables to cause an internal explosion. The building air change rate is used and if the Options, Internal Explosion LFL Fraction value is reached before the dispersion ends, lethality will be 1. A default Internal Explosion LFL Fraction value of 0.5 is used to account for possible pockets of high concentrations. Assuming an ACH of 3, an outdoor concentration of 2x-3x LFL is necessary to reach 0.5 LFL inside for a 10 min dispersion.

6.4 Toxic Dispersions

Toxic lethality for persons outside and evacuation buildings is calculated based on the toxic dose recieved during either a stationary or cross wind evacuation (see Options, Analysis). Typically crosswind is used.

Evacuation dose is stored in the *Toxic Dose* result variable. This dose is converted to a lethality using the chemicals probit constants as shown below. The lethality is stored in the *Toxic Lethality* result variable. The full list of probabilities that modify the base leak frequency for a toxic dispersion are $F_{base} \cdot P_{ev} \cdot P_{ign} \cdot P_{wthr} \cdot P_{loc} \cdot P_{wind}$.

$$Pr = A + B \ln \left(dose_{evacuation}\right)$$
$$Lethality = \frac{1}{2} \cdot \left[1 + erf\left(\frac{Pr - 5}{\sqrt{2}}\right)\right]$$

6.4.1 Buildings

Toxic lethality results for buildings depends on whether the building is marked as shelter in place for toxic. If not a shelter in place building, evacuation is assumed and the lethality calculations occur in the same manner as described from base grid points except that the building exits are the calculation points. The minimum lethality out of all the exits and the associated frequency is saved.

If the building is used for shelter in place, the vulnerability of occupants is dependent on the *Air Changes per Hour* and *Tail Time* settings on the Buildings form. The building center point is used to determine the outdoor concentration vs. time profile. Indoor concentrations are calculated using the ACH rate using a time stepping approach. Indoor dose is also calculated. The tail time defines how long the calculations proceed following the end of the toxic vapor cloud, since occupants may take some time to realize the hazard has past during which time the indoor concentrations will be higher than the outdoor concentrations. Occupant lethality is based on the total indoor dose.

6.5 Jet/Pool Fires

Fires used in the risk calculation must be the modeled type rather than the predefined curve type. Both types are imported from PHAST. Modeled fires represent the fire surface and a surface emissive power. Their orientation can be transformed for discrete release (jet and pool) and wind (pool only) directions.

In risk calculations, the fire *Release Angle* and *Wind Angle* properties will be dynamically changed during the run based on the risk fire option *Wind/Release Angle Step Size.* In order to speed calculations, an array of 360 curves representing radiation vs. distance are pre-computed for the modeled fire if the analysis options *Use PreCalc'd Radiation for All Directions* is checked. The curve origin is taken as the fire center. This array is then used during calculations as the fire is rotated about the release point and/or the wind direction is rotated (for pool fires) using some transformation techniques to ensure the correct curve is used for the given fire orientation and relative base grid point location.

6.5.1 Jet Fires

Jet fires are rotated around the release point at intervals as defined in the option *Wind/Release Angle Step Size.* The probability of each direction (P_{dir}) is taken to be $Angle_{step}/360$. There is no P_{wind} for jet fires.

The entire base grid is calculated for each direction and a single frequency attached to the "foil" of results. The full list of probabilities that modify the base leak frequency for a jet fire are $F_{base} \cdot P_{ev} \cdot P_{ign} \cdot P_{wthr} \cdot P_{loc} \cdot P_{dir}$.

6.5.2 Pool Fire

Pool fires have the same calculation procedure and options as jet fires. For each release direction, the pool is located at some distance from the release which represent the rainout location. The distance to this location depends on the Cx value of the circles defining the pool as shown in Figure 4.5. A pool fire is generally defined by only two circles. The first represents the cylinder base and the second the cylinder top. Wind tilt is defined by the difference in the Cx values, height by the difference in the Cz values. The Cy values should both be 0. The circle normals should be +Z. The *Is Pool Fire* checkbox should also be checked.

To avoid having to double rotate pool fires that have wind tilt (24 angles for release + 24 angles for wind = 576 unique result sets), pools with wind tilt are modified such that the tilt is always toward the target. This decouples wind from pool fire calculation and makes them consistent with the jet fire treatment.

The full list of probabilities that modify the base leak frequency for a pool fire are $F_{base} \cdot P_{ev} \cdot P_{ign} \cdot P_{wthr} \cdot P_{loc} \cdot P_{dir}$.

6.5.3 Buildings

Thermal lethality results for buildings depend on whether the building is set as a shelter in place building for fire hazards. If not a shelter in place building, evacuation is assumed and the thermal lethality results for buildings occur in the same manner as described from base grid points except that the building exits are the calculation points. The minimum lethality out of all the exits and the associated frequency is saved.

If the building is used for shelter in place, the vulnerability of occupants is dependent on the *Building Flammable Vulnerability* options as well as the *Fire Vulnerability* settings on the Buildings form risk tab. The vulnerability of occupants depends on whether the building is predicted to ignite. If the building is flame impinged ignition is assumed to occur. Otherwise, ignition is based on an exponential curve defined by the equation $IR = a + b/\ln(time)$ where IR is the incident radiation (kW/m^2) which will cause ignition at the given time. The "a" value is the *Fire Ignition Model Constant* option defined by default as -7 in the options. The "b" value is calculated based on the supplied long duration value and ignition limit at that duration. The asymptotic long duration ignition limit is defined by the *Ignition Limit (long duration)* input while the time at the limit is defined by the *Fire Long Exposure Duration* option. Recommended values for the Ignition Limit are 12.6 kW/m^2 for wood buildings [5], 25 kW/m^2 for steel buildings with wood backing, and much larger values for masonry buildings. Users should consider the most flammable portion of the exterior (may be the roof) when choosing this value.

If a shelter building is determined to ignite, the vulnerability of occupants is defined by the *Ignition Lethality Fraction*. If less than 1, evacuation calculations are then performed as described above to determine the vulnerability of survivors and the final building lethality is equal to $IgnitionLeth + (1 - IgnitionLeth) \cdot EvacLeth$.

6.6 Explosions

Explosion threats are created manually before the analysis phase. Using flammable dispersions, the dispersion threat creator dialog facilitates threat creation. Threats can be created for individual wind angles using the *Create Threats* button. The wind arc angle will be requested in order to calculate the wind frequency. This angle is the arc from which the cloud can create the threat, typically taken to be the arc which starts when the cloud edge reaches the congestion and ends when the cloud edge leaves the congestion. The *Create Threats (All Angles)* button will automatically rotate the cloud creating threats as necessary at each location step. Also, multiple dispersions can be selected when using this feature and each one will be rotated and intersected with congestion in turn.

Frequency for each threat is calculated at the time the threat is created rather than analysis time. Upon threat creation, a link containing the Dispersion, Wind Angle, and Wind Arc are saved with the MEM or BST threat. This data can be seen by clicking the plus sign next to the frequency textbox. If the threat frequency does not match the frequency calculated using the link data, the frequency textbox will be highlighted in light red in the threat form and the threat objects summary listview. This indicates that a upstream frequency or probability has changed since threat creation. The user can update the threat frequency by selecting the appropriate option from the plus icon context menu. Also, before an analysis is performed, the system will alert the user if any threats that have valid dispersion links have mismatched frequency values and give the option to update the threat frequency.

The full list of probabilities that modify the base leak frequency for an explosion are $F_{base} \cdot P_{ev} \cdot P_{ign} \cdot P_{loc} \cdot P_{wthr} \cdot P_{wind}$. P_{loc} is automatically applied when the *Create Threats (All Angles)* button is used since the dispersion will be stepped along any line or polygon location (for point locations, $P_{loc} = 1$). Users using the *Create Threats* button must manually open the threat and modify the frequency if the dispersion is being manually stepped along multiple locations.

Threat calculations for the base grid include *Pressure*, *Impulse*, *Damage*, and *Blast Lethality* result variables. Each threat creates a "foil" of results for each variable and attaches its associated frequency. Pressure and impulse results are straightforward. Damage results are based on the pressure, impulse, and a set of PI curves defined in the Variable options under the damage variable. Ground contour damage contours do not specifically relate to the risk calculations. Blast lethality is based on human vulnerability to overpressure according to the probit equation $Pr = 1.47 + 1.37\ln(P_{sideon})$[2].

6.6.1 Buildings

Threat calculations for buildings start with the blast loads for each building surface as well as the center of the roof (used for vulnerability calculations only). The surface loads (wall and roof) are used to determine component damage levels (CDL) based on PI diagrams assigned to the building walls/roof. Component damage levels are combined to create a single building damage level (BDL). Occupant lethality is calculated using the BDL and center roof impulse and the model developed by Oswald[6].

6.7 Post Processing Results

6.7.1 Contour Results

Results from each source (dispersion, fire, threat) are saved to a local disk database (SQLite format) during the analysis. The database is destroyed on program exit or a re-run of the analysis. When a user selects a variable for post-processing, all the "foils" with a matching variable type are pulled from the database. All the potential sources that created these foils have an active/unactive state which can be seen in the *Active Result Set* (keyboard shortcut F4). Only those sources which are active will have their "foils" pulled from the database. This allows a subset of results to be examined after a run, if desired. Once a subset of "foils" is pulled, the maximum value at each grid point is determined and displayed.

In the Options, Risk tab a Rendering Frequency option is available to show exceedance contours. The feature allows, for example, the user to show a 5 psi contour at $1{\times}10^{-4}$ events/yr.

The *Individual Risk* result variable is post-processed differently than the other variables as described above. The *Individual Risk* result is a combination of the lethality results and the frequency associated with each. The exposure time fraction of the outdoor individual is 1.

6.7.2 Building Results

Risk is based on the exposure of occupants in one or more predefined buildings. Both individual and aggregate risk is calculated. Both require the lethality to occupants generated from the various dispersion, fire, and toxic sources as well as occupancy information (shift data and time fraction). Occupancy information for each building is defined on the Risk Analysis tab on the building form as shown below in Figure 6.8. For individual risk, the maximum hours any one individual spends in the building per week is required as well as a percentage that defines how many of those hours occur during the day shift (since many consequences only occur during the day or night depending on their linked weather Solar Flux value). For aggregate risk, the shift data is entered as number of persons, hours per week, and percentage day shift.

Risk results are displayed in the building risk report. One or more buildings are selected for the report. This allows aggregate risk (FN curve) to be shown at the building level or for all buildings. Only the active sources are included in the results. To ensure that sources are not left out accidentally, a summary of the active and total sources is given at the beginning of the report.

Individual risk results are reported for each building selected. The risk contributions from all blast, thermal, and toxic sources are given and broken out by day and night. The total of all sources is also given.

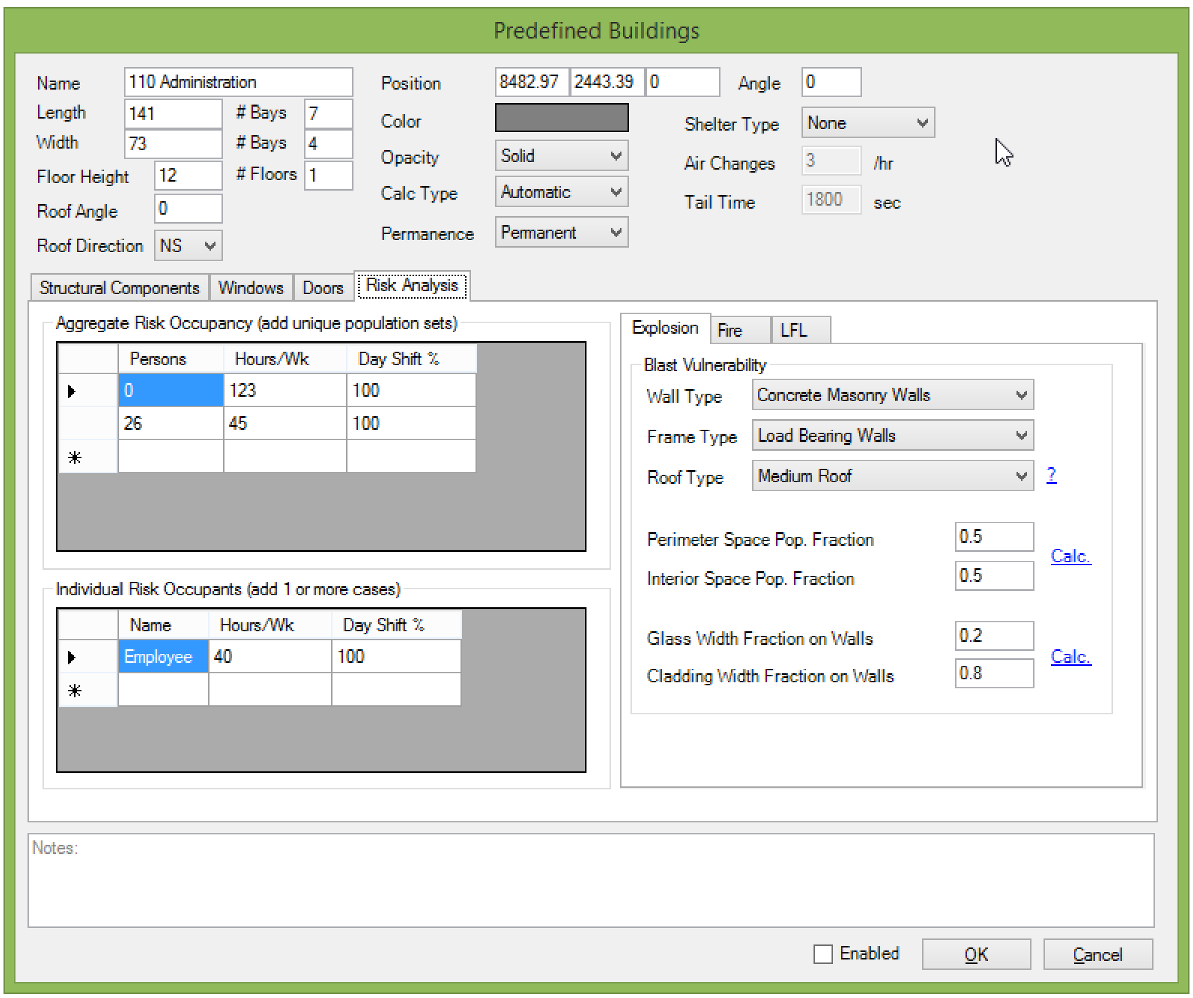


Figure 6.8: Predefined Building Form Risk Tab

Aggregate risk is presented in the form of a F-N curve for one or more buildings. FN pairs are created from blast, thermal, and toxic consequences. Then each row of the aggregate occupancy shift data is enumerated and used to create a FN pairs where $F = Freq \cdot Hours/168$ and $N = Vuln \cdot Persons$. Each pair is created only if the consequence and shift occur during the same period (day or night).FN data pairs are then modified as follows to create the FN curve.

1. All pairs with N or F values of 0 are deleted. These pairs are typically from consequences that do not produce any vulnerability or which have time fractions or frequency of 0.
2. Pairs with N values $<$1 are modified as follows:
   - $F = F \cdot N$
   - $N = 1$
3. All N values are reduced to only unique instances (0.001 used as the default comparison tolerance) and the corresponding F values for each instance are summed
4. N values are sorted in ascending order
5. For each N_i value, the F_i value is cumulatively summed for all N values $\geq N_i$
6. N values are reported with their corresponding cumulative F values
7. N and F values are also reported with added points to create the "stepped" appearance

Chapter 7

File Options

7.1 Analysis

7.1.1 Fire Settings→Modeled Fires

- *View Factor Error Tolerance* will refine fire and target surfaces internally to increase view factor accuracy until the change in the view factor result between successive refinements falls below the tolerance. Use -1 to disable refinement. It is recommended to use a 1% tolerance to check if results change for a given setup. If results do not change from the -1 setting, the tolerance can be set to -1 to save runtime.

- *Include Occlusion Testing* will allow mesh and building surfaces to shield other surfaces and the ground plane from modeled fire radiation.

- *Include Transmissivity* decreases radiation with distance using [7]. Assumes a RH of 40% and temperature of 298.15 K.

- *Truncate Using Ground Plane* will delete modeled fire surfaces that are below grade. It is recommend that if truncation takes place, the SEP (kW/m^2) of the fire is increased such that the total energy emitted via radiation is maintained.

- *Increase SEP Accordingly* will increase the truncated fire SEP based on the surface are that was truncated such that the total power emission (SEP*Area) is maintained. An SEP upper limit of 400 kW/m^2 is enforced.

- *Use Cylinder Flame Shape Models If Possible* will use quick running modeled for modeled pool fires that are right or tilted (toward +X) cylinders. This option is not used if *Use Pre-Calc'd Radiation for All Directions* is checked.

- *Use Pre-Calc'd Radiation for All Directions* precalculates the radiation from a modeled fire in all directions (every degree) so that subsequent calculations on ground contour plane points are fast running. Occlusion is not available with this option.

- *Structured Grid Evac Path* defines how fire and toxic dose calculations on structured grid are performed. Straight line runs directly away from the hazard while minimum gradient follows the minimum gradient away from the hazard, which can take advantage of occlusion areas but also might get stuck in local minimums. Minimum gradient is rarely used.

7.1.2 Fire Settings→Lethality

The fire lethality model is based on probit constants. A number of probit models (Lee's, Eisenberg, Green Book Unprotected, Green Book Protected) are available in the analysis fire options including a user defined model that allows the A and B to be specified directly. The Lees model does not follow the traditional probit model and has been modified by ABS as shown below.

$$Leth(dose) = \begin{cases} 0 & \text{if } dose < 920\ s\left(\frac{kW}{m^2}\right)^{4/3} \\ 1 & \text{if } dose > 4500\ s\left(\frac{kW}{m^2}\right)^{4/3} \\ -0.33334269 + 0.0024596791 \cdot \dfrac{dose}{\ln(dose)} & \text{otherwise} \end{cases}$$

Safe Radiation Level defines the endpoint of an evacuation at which dose stops accumulating. The "runner" will evacuate away from the fire until this contour level is reached. It is important the pre-defined fires radiation vs. distance curves go slightly below this level to ensure the evacuation ends and thermal dose is not over predicted.

7.1.3 Calculation Options

- *Calculate Vertex Loads* will enable 5 calculation points per surface (corners + center). The center is always used for damage calculations. The corners are used to smooth the rendering colors. Unchecked, only the center will be calculated, which saves significant time and disk space in QRA analysis.
- *Disable Calculation Of All Ground Contours* is a quick way to shut off all ground contour calculations, saving significant runtime.

7.1.4 Path Finding Method (HE only)

Blast load calculations by default assume a straight line between threat and target when calculating distance. This line may go through a building whereas the blast wave has to travel around the building. The shorter line therefore may yield conservatively high results. Path finding finds the shortest path to the target. Path finding is only valid for a single HE threat and is computationally expensive.

Two path finding modes are available. *By Node* is a ball and stick model where a ball (node) is placed at each 3D gridpoint and connections made to neighbor nodes in the principal and diagonal directions. Therefore, there are 26 connections from each node. Each connection is tested against all surfaces to see if it is "cut" by a surface. If so, it is no longer a valid path for the algorithm (Dijkstra's Method) to take. The *By Grid* method differs in that each node is boxed and the box tested against surfaces. If the box is intersected, all connections to the node at the center of the box are deleted. The *By Node* method may leak paths through small cracks in a poor quality mesh model if a connection happens to go through the crack. The *By Grid* method is more robust since it turns the mesh model into a slightly expanded "lego" representation that has no cracks. Shift clicking on a surface after the analysis will show the paths, and should be done on a number of surfaces to ensure reasonable paths are being produced.

After the baseline algorithm is done, the resulting path will likely have a lot of small angle changes and right angles in it. *Optimize Paths* tries to simplify the paths using straight line segments as much as possible.

7.1.5 Toxics

Toxic results are dependent on a number of settings, primarily found in two places. First, there is the dispersion object itself which holds the dispersion data imported from PHAST at the core averaging time*. Second, there are the toxic options as shown in Figure 7.1.

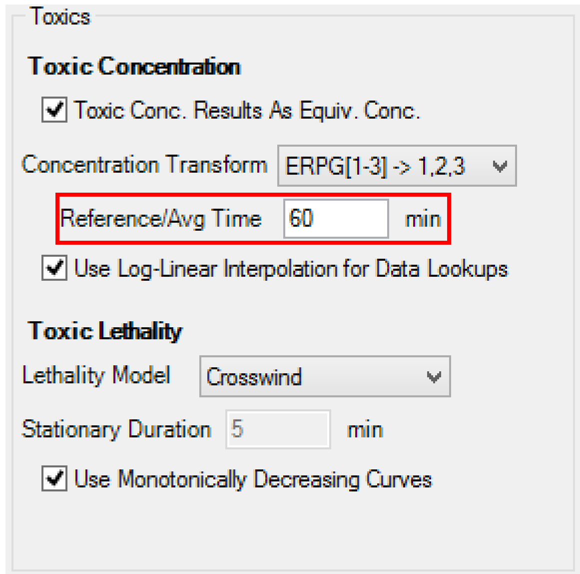


Figure 7.1: Toxic Options

FACET3D calculates two toxic results. First is the toxic concentration variable, which is a direct mapping of the plume concentration at the effect height onto the ground plane contour grid. Second is toxic lethality, either due to cross wind evacuation, stationary evacuation for a specified duration, or shelter in place lethality.

Starting with #2, the lethality calculation, all different types of lethality are calculated using the averaging time specified in the dispersion object form. This averaging time defaults to the PHAST toxic averaging time and is used to transform the dispersion cross section data (in the table) before it goes to the lethality calculations. Therefore, about 5 minutes is usually good since this is on the order of the time needed to evacuate. A larger value may be used if you are doing shelter in place lethality over 1 hour or a stationary evacuation using a duration longer than 5 minutes.

Back to #1, the toxic concentration, which also can use the averaging time in the dispersion form but may instead use the averaging time from the toxic options (red box) if either the Toxic Conc. Results as Equiv. Conc. checkbox or Concentration Transformation combo box options are selected.

Equivalent concentrations are simply the concentrations at each downwind distance that give the same dose for the supplied reference time as the dose given by the original concentration over the duration of the toxic plume. This feature allows plotting equivalent ERPG values when the release duration is less than 1 hour. If the release duration is >= 1 hour, equivalent and original concentrations will be the same.

Concentration Transformations map the original or equivalent concentrations (ppm) to a common baseline so chemicals with different ERPG values can all be shown on the same contour plot. For example, ERPG[1-3]->1,2,3 option will map a curve of decreasing concentrations in ppm vs. downwind distance to a curve passing through the integer values 1, 2, and 3 vs. downwind distance where the ERPG-1 concentration (ppm) gets mapped to the integer 1, the ERPG-2 concentration (ppm) gets mapped to the integer 2, etc. Then, if we request a contour plot of the value 3, we are effectively contouring through the ERPG-3 concentration for all chemicals.

** Averaging time with respect to dispersions is a way to account for the fact that the wind direction varies and does not blow directly downwind toward a target 100% of the time. A short averaging time (18.75 sec in PHAST) represents a near instantaneous snapshot of the dispersion and the centerline concentrations will be the maximum possible as if the wind was blowing directly toward the target. A higher averaging time will result in lower average centerline concentrations (beyond the passive transition zone) to account for the centerline of the plume only being directly over the target some of the time while at other times the target is slightly off centerline resulting in lower concentrations. Many toxic endpoint criteria (ERPG, IDLH) have an implied reference time (duration of exposure), and the averaging time should be set to match.*

7.1.6 Clearing

Clearing of building walls uses the distance from the calculation point (surface center or corner) to the nearest building wall edge or roof line while clearing of mesh surfaces relies on the distance from the surface calculation point to the nearest line in the *Clearing Lines Mesh*. The clearing methodology is described in [4]. Clearing time is $t_c = 3 * Distance/U < t_d$ where t_d is the applied load duration and U is the shock velocity in air defined by $U = 1130 * (1 + 0.058 \cdot P_{so})^{0.5}$. The side on pressure when the rarefaction wave reaches the calculation point is $P_c = P_{so} \cdot (1 - t_c/t_d)$. The cleared impulse is $I_c = 0.5 \cdot t_c \cdot (P + P_c) + 0.5 \cdot (t_d - t_c) \cdot P_c$ where P is the applied pressure on the surface as shown in Figure 7.2.

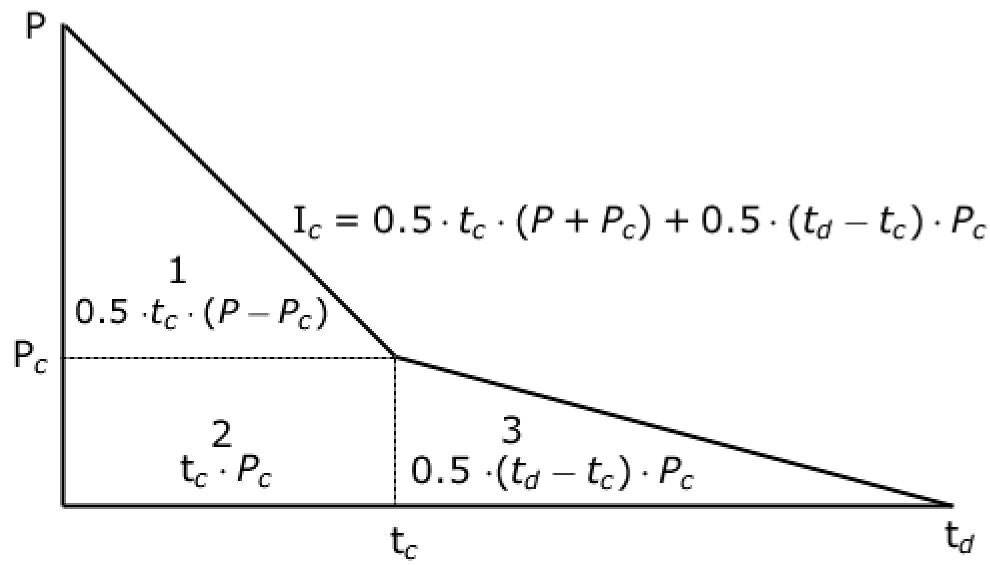


Figure 7.2: Blast Load with Clearing

7.1.7 Buildings

- *Render Building Damage as BDL* will color the entire building according to its BDL. Otherwise, the building surfaces will be colored according to the highest damage level of all PI diagrams (materials) attached to the surface.

- *Show Contours on Doors and Windows* will render the door and window surfaces the same as wall and roof surfaces. Unchecked, doors and windows will be rendered using their preprocessing colors.

- BDL Model is fully described in Section 5.1.

7.2 Risk

- *Site Frequency Modification Factor* is applied to all base frequencies generated by Scenario objects except when the Scenario's override frequency option is used.

- *Render Freq. Ground Contours* allows exceedance contours to be plotted instead of the maximum consequence contour.

- *Wind/Release Angle Step Size* defines the step size that dispersions/fires will be rotated by when doing risk based consequence calculations. If there are many fires, this options can significantly effect run time and results storage. This value should not be changed after threats are created.

- The building fire lethality model for shelter buildings depends on whether the building is predicted to ignite. Details of the *Ignition Model Constant* and *Long Exposure Duration* are given in Section 6.5.3.

7.3 Variables

- *Legend Type* Two types of variable legends are available: continuous and discrete. Only damage uses the discrete legend type.

- *Legend Numeric Format* specifies the format for the legend as well as the output message window during Shift+Click of surfaces or the ground plane.

- *Ground Contour Only Variable* will skip calculating surfaces. For some variables, it is always checked.

- *Ground Contour Damage PI Curves* when the damage variable is selected, a button for PI Curves is visible. These curves determine the damage level on the ground plane grid points given the pressure and impulse.

7.4 Base Grid

- Base grid size can be manually entered or the commandline command "bg" can be used to select a rectangle. The selection will be rounded according to the Default Mesh Size.

- *Mesh Types* include structured and unstructured. Structured grids are the default. Unstructured grids are based on delaunay triangulation and enable the calculation of path finding evacuation for fire and toxic dose calculations. A minimum of 1 evacuation destination via either a building or region with *Shelter Type* set appropriately is required. Unstructured grids are not compatible with QRA analysis.

- *Running Speed vs. Distance* is used evacuation calculations. A constant speed will result in faster analysis run times. Saving of evacuation paths requires substantial database size. A path can be viewed while post-processing if only 1 source is active (F4) upon Shift+Click.

- *Entity Refinement Controls* allow mesh refinement around buildings and sources. A mask (on object name) can be used to restrict which objects get refined. Refinement around sources where high gradients are expected will smooth results. Refinement will increase the time necessary to generate grid points during the analysis run. *Size* controls the element size near the object and *Grow Factor* the rate of transition to the *Default Mesh Size*.

- *Independent Refinement Controls* are location objects (Point, Path, or Polygon - see LocationMaker alias “lm” commandline command) used to both refine the mesh as well as change the mesh weighting which affects the path finding (evacuation) calculations. Using a weight of 1×10^6 or greater will delete elements (polygon locations) such that evacuation routes are forced to circumvent. Using a small weighting factor (0.001) will make travel along the nodes on the location particularly attractive to the path finding solver. In this way, evacuation along predefined paths can be forced.

- *Evacuation Path Weight Constants* are applied globally to the calculated weights for each node to node segment and affect the path finding. By default, the evacuation weights are composed of both a dose and distance component. Since the dose is typically a much larger numeric value than distance between nodes, it controls the path except when the dose goes to 0, for instance outside the *Safe Radiation Level* during thermal dose evacuation. If the dose constant is set to 0, the evacuation will be based on the shortest path. If both constants are 1 (default), the evacuation generally will proceed directly away from the hazard toward the nearest shelter location (building or region). A distance constant of 0 is not recommended since it will result in “wandering” paths outside the *Safe Radiation Level*.

7.5 Rendering

7.5.1 Display Options

- *Show Vertex Loads* controls whether vertex loads are used to smooth colors bands on surfaces or not. Vertex loads must have been calculated.

- *Show Ground Contour Lines* controls the display of the green grid. Note this grid is separate from the *Base Grid Structured* or *Unstructured* grid.

Chapter 8

Commandline Commands

The FACET3D commandline offers ways to operate on the model data. Some commands operate on a selection of data while others create data. A listing of available commands can be found in the Help menu or by issuing the *ListCommands* command. All commands have a shorter alias to save keystrokes. The alias can be changed by modifying the FACET3D.ini file with a text editor.

Commands are active until they are completed or ESC is pressed. Commands will prompt for inputs at each step similar to AutoCAD. Most command sub-commands can be issued by only typing the capitalized letters, saving keystrokes. Also, sub-commands can be chained together (space delimiters) to quickly issue all or part of a command sequence. When the name of an object must be entered or any other text, use quotes to preserve capitalization. Wildcards can be used inside the quotes in some commands when selecting a mesh, building, or other object by name.

Many commands are also available via the toolbar. In fact, clicking the toolbar button simply issues the command for you. Below is a partial listing of commands and comments on their usage:

- *APPENDFILE* (Alias = af) - Append data objects from another FACET3D file. Very useful for combining portions of a different files. Note many objects are dependent on other objects and have links to those dependencies. This command attempts to preserve this dependency, but the user should carefully inspect the file.

- *AREA* (Alias = area) - Returns the total area of all selected surfaces or of a polygon.

- *BASEGRID* (Alias = bg) - Set the dimensions of the base contour grid. The base contour grid defines the grid points used to calculate values and draw contours. The denser and larger the grid, the smoother the contours but with a longer run time and more memory/ disk usage. Redefining the contour grid will invalidate the current solution.

- *BUILDING* (Alias = bld) - Create of modify building objects.

- *CAMERA* (Alias = cam) - Shows a dialog for changing, loading, or saving camera coordinates. This command can fix situations where the model is "lost" due to a camera that is zoomed to far out or mispositioned (use *Dialog* subcommand). It can also reset the camera target point when zooming becomes unresponsive or the rotation center needs to be moved (use *setTarget* subcommand). Cameras can also be saved and retrieved (also via toolbar buttons) to ensure consistent screen shots.

- *CLEAR* (Alias = cl) - Clears the command history and/or message history.

- *COMBINETRIANGLES* (Alias = ct) - Combines neighboring triangle surfaces into a single surface. Command operates on entire selection and is useful after STL import since all surfaces will be triangles. Rectangles generally are desirable because there will be fewer of them and they refine better if that is the next step.
- *CONGESTIONBLOCK* (Alias = cb) - Add, delete, and modify congestion block entities.
- *COPY* (Alias = cp) - Duplicates objects based on a translation vector or copies objects to a different mesh.
- *CULL* (Alias = cull) - Hides surfaces whose normals are pointed away from the camera. Command also available via the toolbar.
- *DELETE* (Alias = de) - Delete highlighted surfaces and lines.
- *DISTANCE* (Alias = dist) - Gets the distance between two points.
- *DRAWBOX* (Alias = db) - Draws a 5 sided box and places the surfaces in a parent mesh.
- *DRAWCIRCLE* (Alias = dc) - Draws a circle at Z=0 in a parent mesh.
- *DRAWLINE* (Alias = dl) - Draws a line at Z=0 in a parent mesh.
- *HIGHLIGHT* (Alias = hl) - Select surface(s), line(s), an entire mesh, an entire building, or all objects in a bounding box. Command is frequently used to prepare a set of objects for another command.
- *IGNITIONSOURCE* (Alias = igs) - Add and modify ignition sources.
- *LABEL* (Alias = lbl) - Add, delete, and modify label entities.
- *LINELOAD* (Alias = ll) - Create lines of discrete HE threats.
- *LISTCOMMANDS* (Alias = ls) - List all available commands and a short description.
- *LOCATIONMAKER* (Alias = lm) - Create point, path, and polygon locations. Locations are used to define the position of many objects. The command will copy the location points to the clipboard after which the user can paste into the objects location property on the appropriate edit form.
- *MAPCFDLOADS* (Alias = cfd) - Maps CFD loads from file onto mesh surfaces. An advanced command to map CFD results from FLACS or TECPLOT into line contours, iso-surfaces, or as blast loads on surfaces.
- *MOVE* (Alias = mv) - Moves objects based on a translation vector or moves the objects to a different mesh.
- *PICOPY* (Alias = pic) - Allows quick copy of multiple materials to multiple meshes/ buildings.
- *PIDELETE* (Alias = pid) - Allows quick deletion of multiple materials in multiple meshes/ buildings.
- *PIENABLE* (Alias = pie) - Enabled materials in selected meshes and buildings based on supplied mask.

- *PIRECALC* (Alias = pir) - Recalculates hazards using existing loads.
- *PIREPLACE* (Alias = pire) - Allows quick replace of multiple materials to multiple meshes/ buildings using a single material.
- *REDRAW* (Alias = re) - Redraws the display including all objects. Pressing ESC will call this command.
- *REFINE* (Alias = ref) - Refines highlighted surfaces using a desired edge length. Always save before calling this command. If you specify to small a size, the refinement may never complete and you will have to kill the FACET3D process.
- *REGION* (Alias = reg) - Create of modify region objects.
- *REVERSENORMALS* (Alias = revn) - Reverse the normals of highlighted mesh surfaces. Normal orientation is critical to get reflected blast loads correct. Normals can be displayed by selected the appropriate checkbox on the Options, Rendering form.
- *ROTATE* (Alias = rot) - Rotates objects based on a rotation origin, axis, and amount.
- *SURFACEERRORCHECK* (Alias = sec) - Checks surfaces for common errors such as zero area and non-planar.
- *SURFACEERRORFIX* (Alias = sef) - Fixes surfaces with common errors such as zero area and non-planar.
- *TRANSFORMOBJECTS* (Alias = to) - Applies a transformation to various data objects in the file.
- *VAPORCLOUD* (Alias = vc) - Modify and use vapor clouds.
- *VARIABLEPROFILE* (Alias = vp) - Reports the linear profile of a variable along a user defined line on the ground plane.
- *VERSIONHISTORY* (Alias = vh) - Displays the program's version history and release dates.
- *ZOOM* (Alias = z) - Zoom model using various methods.

Chapter 9

Best Practices

As FACET3D as developed over the years, it has become a fairly complicated software with a number of features developed to meet a variety of needs. Below are some best practices to follow to get the most out of FACET3D.

9.1 Minimizing Runtime and Maximizing Responsiveness

Below is a list of settings to check or tweak in order to increase FACET3D performance.

1. **Minimize the number of calculation points.** Surfaces and the ground plane are the two main sources of calculation points. For surfaces (both Meshes and Predefined Buildings), uncheck Options→Analysis *Calculate Vertex Loads*. This decreases the calculation points per surface from 5 (center + corners) to 1 (center).

   Calculations performed on the ground plane are minimized by having a coarse mesh. Under Options→Base Grid set the domain size to as small an area as needed and the mesh size no larger than is needed to get reasonable results. Generally, mesh sizes of 20 - 50 ft are used such that the total domain points are less then 50,000. Larger numbers of points will run but with a linear increase in cost. If ground contours are not needed at all, check Options→Analysis *Disable Calculation Of All Ground Contours*.

2. **Turn off unnecessary variables.** Under Options→Variables uncheck variables that are not needed. If a risk study is not being performed, this would include all the lethality variables.

3. **Disable all objects that do not need to be calculated.** Under the objects menu, disabling extra meshes (with surfaces), buildings, threats, fires, toxics, and dispersion objects will speed up the analysis run.

4. **Enable Multi-threading.** Under the program settings menu (F9), enable multi-threading (on by default) to speed up some analysis sections.

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