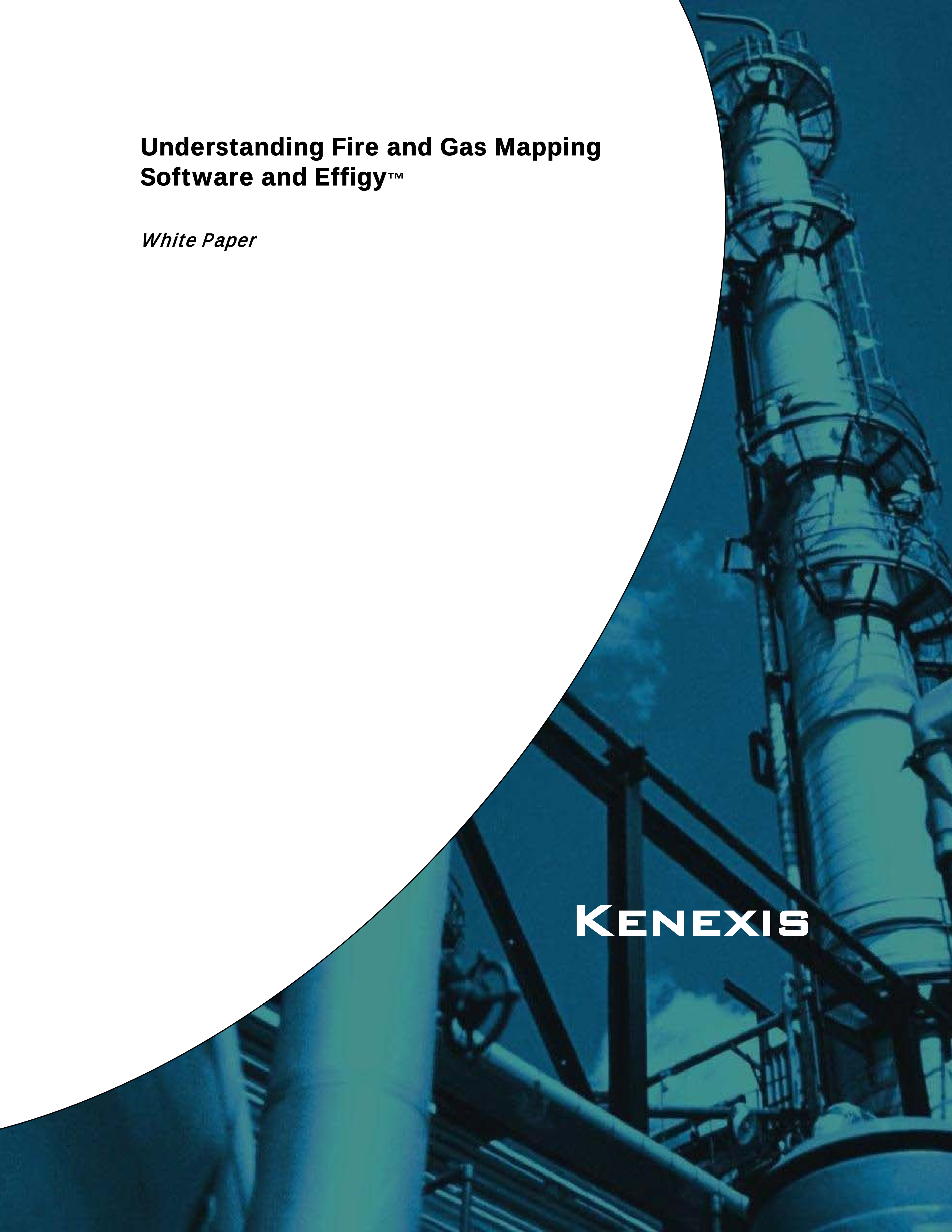
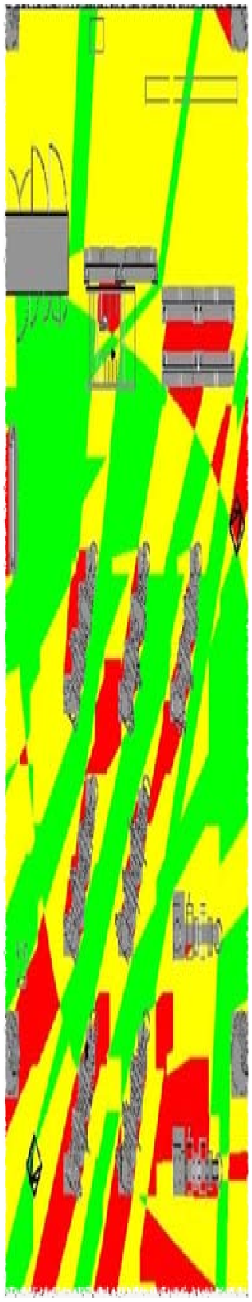
Understanding Fire and Gas Mapping Software and Effigy™

White Paper



KENEXIS



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Introduction

The "rule of thumb" based approach for placing fire and gas detectors that has traditionally been used has lead to inconsistent designs whose basis is usually poorly documented. This has made verification and validation difficult and confusing, and has made determination of whether or not the tolerable risk level has been achieved impossible

For many years, the design of fire and gas detection and suppression systems was performed utilizing rules-of-thumb that were applied by seasoned experts. The heuristics that lead to the placement and orientation of fire and gas detector arrays were rarely documented to any significant degree. This made verification and validation of the design of fire and gas detection systems difficult and confusing, and the determination of whether or not a tolerable level of risk had been achieved impossible.

For a few decades now, the process industries have become more adept and familiar with explicitly analyzing process risks. As the use of formal risk studies has increased, so has the sophistication and level of quantification employed in these studies. Risk management started out with qualitative analyses, such as Hazards and Operability (HAZOP) studies, and progressed to order-of-magnitude quantification, such as Layer of Protection Analysis (LOPA). In some cases, very quantitative analyses are performed for special risk situations and equipment design tasks, such as calculation of the Safety Integrity Level (SIL) achieved by Safety Instrumented Systems (SIS).

Since the late 1990's, many operating companies have been designing SIS in accordance with the IEC 61511 (ISA 84.00.01)[1], which requires the selection of a numerical performance target for each Safety Instrumented Function (SIF) – which is essentially a control loop dedicated to the prevention of a specific hazard. The achievement of this target is the quantitatively verified using a combination of statistics, reliability engineering, and probability math. This performance-based approach has lead to a great deal of success in application. As a result, there is a strong desire to apply this approach to fire and gas detection and suppression systems, which were after all, instrumented systems.

Once the IEC 61511 style approach began to be applied to Fire and Gas Detection and Suppression Systems (FGS), it was quickly determined that there were a few key weaknesses in the IEC 61511 approach, as applied to fire and gas systems, that made direct adoption problematic, if not entirely invalid. These problems are related to the fact the fire and gas systems are mitigative in nature, i.e., decreasing the magnitude of a consequences as opposed to preventing the loss of containment altogether. Prevention is the foundation upon which most of the techniques and calculations that underpin the IEC 61511 standard are based, although the standard neglects to explicitly state when and where the prevention assumption is made. Furthermore, the SIL concept only considers the random hardware failures of the equipment in determining the amount of risk reduction that a SIF can provide. For a fire and gas system a much more important component of achieved risk reduction is the "coverage" of the fire and gas detector array, as data[2] indicates that

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[1] IEC 61511 – Functional Safety: Safety Instrumented Systems for the Process Industry Sector. ANSI/ISA-84.00.01-2004 (IEC 61511 Mod) is the US version of the IEC 61511 standard.

[2] Offshore Hydrocarbon Release Statistics, 2002, United Kingdom Health and Safety Executive.

more than 30% of MAJOR releases are not detected by existing fixed fire and gas detection equipment, and many of these failures to detect major releases are not the result of failed pieces of equipment, but lack of having detectors positioned to sense the loss of containment.

In order to address these limitations, the International Society for Automation (ISA) released a technical report whose objective was to supplement the IEC 61511 standard with additional guidance on how to apply the IEC 61511 risk-based and performance-based techniques to fire and gas detection and suppression systems. The result of this effort was the ISA TR84.00.07 Technical Report[3]. In essence, this technical report came to the conclusion that the SIS safety lifecycle and associated techniques and metrics are entirely appropriate for fire and gas systems, and also provided additional information and alternative techniques for areas where fire and gas systems diverge from SIS. The primary addition was the concept of adding a secondary performance metric to the SIL, specifically coverage.

ISA TR84.00.07 recommends the implementation of a coverage target for each detector array. This coverage target should be selected using a risk-based approach, and then quantitatively verified. The technical report defines two different types of coverage.

Geographic Coverage – Which is the fraction of the area, at a given elevation of interest, of a defined zone that a detector array is capable of detecting a fire or gas release.

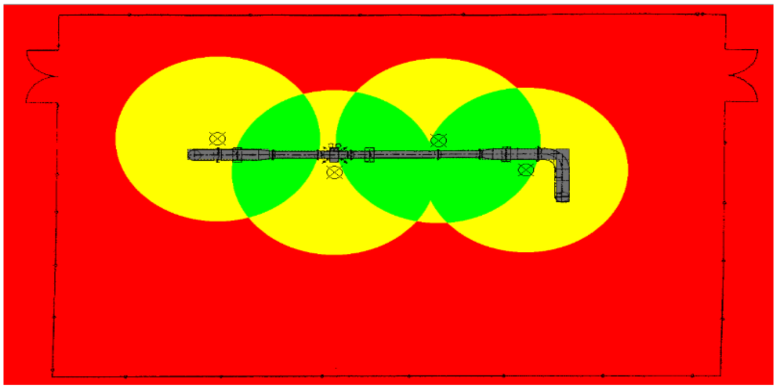

Figure 1 – Typical Gas Detector Geographic Coverage Map for a Metering Station from Kenexis Effigy ™

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[3] ISA-TR84.00.07 – Guidance on the Evaluation of Fire, Combustible Gas, and Toxic Gas System Effectiveness, 15 January 2010.

Scenario Coverage – Which is the fraction of all of the hazard scenarios (fires in the case of fire detection, and leaks in the case of gas detection) that a detector array is capable of detecting.

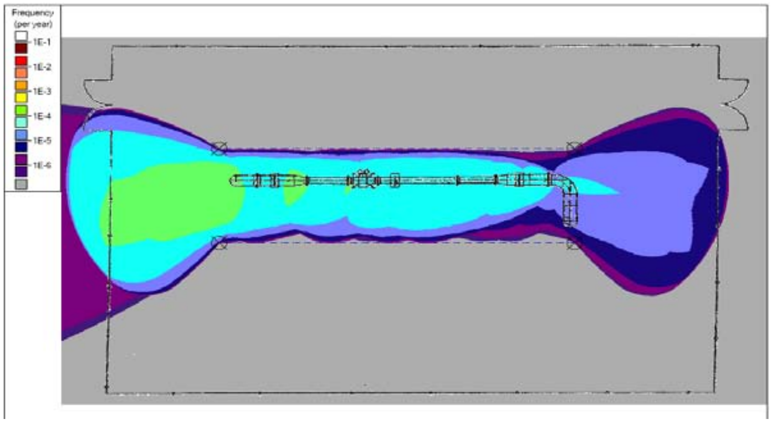

Figure 2 – Typical Gas Detector Scenario Coverage Map (Shown as Residual Geographic Risk) for a Metering Station for Kenexis Effigy ™

Geographic coverage is easier to calculate, and is only a function of the detector array itself, and any potential obstructions to the view of optical detection systems. Scenario coverage, on the other hand, is much more complicated to calculate because it requires not only knowing what the detector system is capable of (given the detrimental effect of obstructions), but also knowing where leaks will come from, how frequently they will occur, and what their "shape" will be given that they occur. Although scenario coverage is more complex to calculate, it is also a much richer measurement of the actual risk and required to perform a fully quantitative risk assessment of the effectiveness of FGS.

While two different types of coverage have been defined, and sophisticated software should be easily capable of calculating results for either type of coverage, the geographic coverage approach is much more commonly used at this time, and is expected to be the de facto approach for most operating companies in the future, relegating the scenario coverage approach to special situations where the risk is high or poorly understood. The more straightforward approach of geographic coverage has been able to provide satisfactory results through rigorous calibration of geographic risk targets to actual risk reduction requirements (which is estimated using efficient order-of-magnitude style techniques, similar to LOPA). Additionally, techniques that limit the "graded area[4]" of a fire or gas detection zone to an area that is in proximity to leak sources has also vastly improved the efficacy of the more streamlined geographic coverage based techniques.

Since the release of the technical report there has been a lot of interest and research into techniques and tools for performing coverage assessments. While the technical report identified the need to select and

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[4] A graded area is a sub-section of a fire and gas zone to which performance targets are applied. The graded areas are usually established by identifying all equipment of concern that may be considered potential leak sources, and then establishing a perimeter around those equipment items for analysis.

verify coverage targets, it did not provide much information on the techniques and tools that can and should be used to perform this task (beyond defining what coverage is), leaving the details to be provided by specialists in this field. The purpose of this white paper is to present an overview of the various techniques that can be employed to calculate coverage targets, emphasizing the key factors that impact the ability to achieve performance metrics, and highlighting the strengths and limitations of the various approaches. This White Paper also presents the Kenexis Effigy™ software tool and explains how it develops its results.

Overview of Fire and Gas Mapping

Before delving into the algorithms and techniques that are employed by the various software tools that assist in computer aided fire and gas mapping, it is important to fundamentally understand what a fire coverage map and gas coverage map represents, and at a basic level understand how they can be created.

Fire and gas mapping must necessarily be performed fully considering three-dimensional attributes of the space, the cone of visions of the detector, and the vision obstruction caused by physical objects in the area. The Kenexis Effigy™ Fire and Gas Coverage Mapping Software Application fully considers all of these aspects in a fully three-dimensional way. As far as we are able to ascertain, Effigy™ is the only commercially available software application that provides this capability.

The "Cone of Vision"

The first consideration when performing fire and gas mapping is the capabilities of the detector equipment. When assessing the capabilities of optical fire detection systems the performance capabilities are defined by a specific detector's "cone of vision". When an equipment vendor presents a cone-of-vision, it is usually presented as a single "slice" of it's three dimensional nature, as shown below.

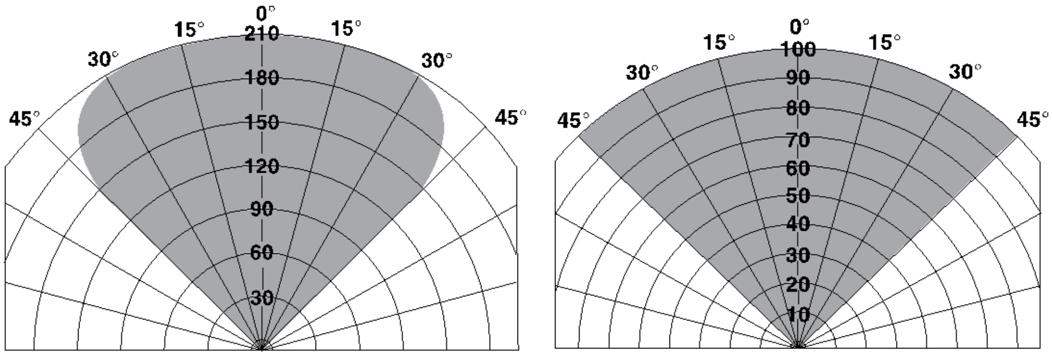

Figure 3 – Cone of Vision for Triple IR Optical Fire Detector for n-Heptane Pan Fire (Left) and Methane Jet Fire (Right) at "Very High" Sensitivity

When an equipment vendor presents a cone-of-vision drawing for an optical fire detector, the result usually looks somewhat like a baseball diamond with a 45 degree angle (depending on vendor) away from the center line on each side, and a roughly circular top whose curve gets more and more severe as the angle from the centerline increases (as a result of the Corona Effect). The cone-of-vision diagrams are created by plotting data obtained during an ANSI/FM Approvals 3260[5] performance test of the equipment. During this test, the distance (at various angles) where the detector is activated by the test case fire is tracked and recorded.

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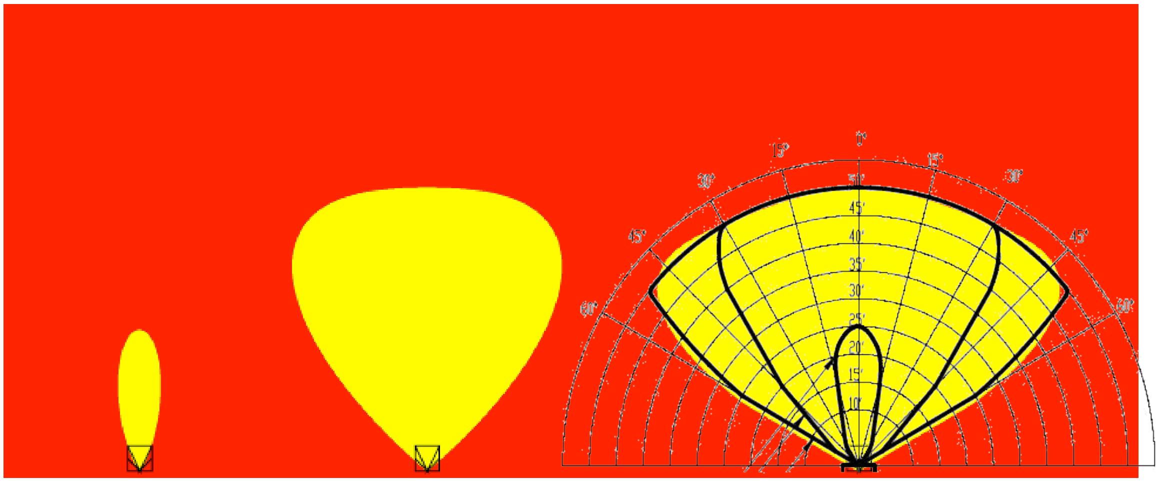
[5] ANSI/FM Approvals 3260 – American National Standard for Radiant Energy-Sensing Fire Detectors for Automatic Fire Alarm Signaling

The tests are performed with fire detectors and their target fires at roughly the same elevation, and with the fire detectors parallel to the ground. The results of these tests should form the basis for how any particular detector's capabilities should be quantified. As such, when a fire and gas mapping tool models the coverage of a fire detector scenario where the fire detector is parallel to the ground, and the elevation of interest is the same elevation as the elevation of the detector – for a design basis fire whose radiant heat output matches the radiant heat of the cone-of-vision test case, the coverage map and the cone-of-vision drawings should be identical. This is demonstrated for Kenexis Effigy™ in *Figure 4*.



50 % Sensitivity

75 % Sensitivity

100 % Sensitivity

Figure 4 – Kenexis Effigy Coverage Mapping Output for a Detronics X3301 Optical Fire Detector for n-Heptane Overlaid with the Published Coverage Map – Three Sensitivity Settings

Two very important factors should be noted when viewing cones-of-vision, such as the ones presented in *Figure 3*. First the cone-of-vision that is obtained by any particular detector is unique to three factors.

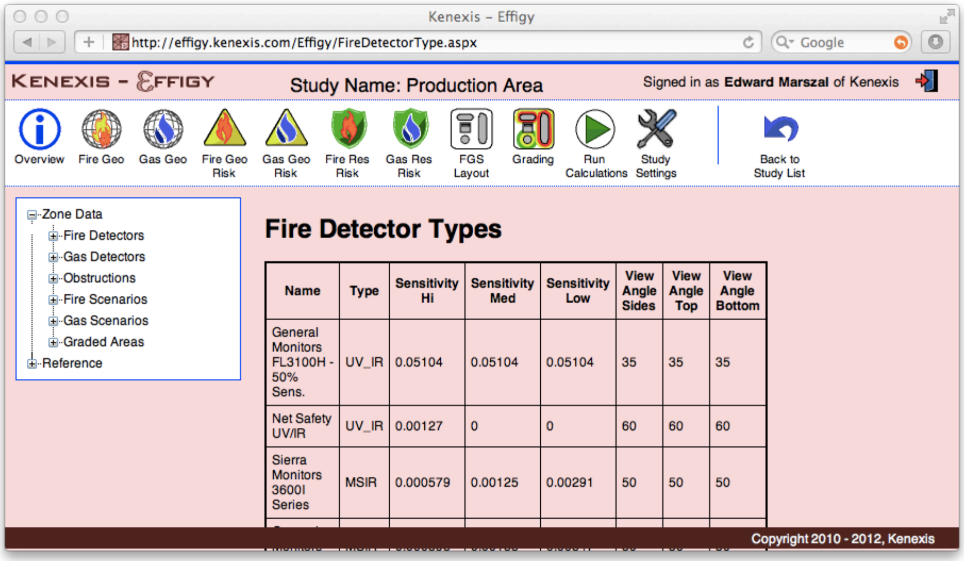
- Fire Type (i.e., the chemical that is being combusted)
- Sensitivity (i.e., different sensitivity settings change results)
- Detector Model (i.e., each model from each vendor will have different results from cone-of-vision testing)

Each model of fire detector from the multitude of vendors who supply optical fire detectors is different, and fire and gas mapping will need to accommodate this fact. It is not possible to have a single "generic" detector that represents all sensitivities, of all models, for all components. As shown in *Figure 3*, the maximum centerline detectable distance for n-Heptane is twice the distance for methane. Use of generic detector maps that are intended to apply to any vendor's equipment will lead to an unacceptable amount of error in the mapping. The attributes of each fire detector that need to be individually tracked by model including the following:

- Detector Technology Type
- Angle of View from Centerline to Sides (Sweep Angle)

- Angle of View from Centerline to Top
- Angle of View from Centerline to Bottom
- Centerline View Distance Factor[6]
- "Corona Effect"[7] Curve Fitting Parameters

Kenexis addresses this issue in the Kenexis Effigy software package by providing a comprehensive database of fire detection equipment that users can select from when performing an FGS Mapping project. The database includes factors for all of the items included in the table above and includes information for all major fire and gas equipment vendors. Additionally, Kenexis is willing and able to include data for any equipment item for which ANSI/FM 3260 test data has been collected. A screen shot that shows a portion of the data available in Kenexis Effigy is shown in *Figure 5*.



Fire Detector Types

Name	Type	Sensitivity Hi	Sensitivity Med	Sensitivity Low	View Angle Sides	View Angle Top	View Angle Bottom
General Monitors FL3100H - 50% Sens.	UV_IR	0.05104	0.05104	0.05104	35	35	35
Net Safety UV/IR	UV_IR	0.00127	0	0	60	60	60
Sierra Monitors 3600I Series	MSIR	0.000579	0.00125	0.00291	50	50	50

Figure 5 – Effigy Screenshot Showing Detector List – Including Sensitivity Settings by Detector and by Species of Interest

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[6] The maximum centerline distance is not sufficient for characterizing performance of a fire detector because it is based on a single design basis fire that may not be consistent with the design basis fire desired to be modeled for any particular project. A means needs to be included to scale the distance at which a project's design basis fire can be viewed by the detector based on the fire size used during the ANSI/FM3260 testing. In Effigy™, this is referred to as the Sensitivity Factor.

[7] The "Corona Effect" is the name given to the phenomenon whereby the decrease in viewable distance of an optical fire detector increases with increasing angle away from the centerline. A plot of angle from centerline versus decrease in distance makes the shape of a crown.

Rotating and Slicing the "Cone of Vision"

It is important to realize that the cone-of-vision presented by the equipment vendor is only a two-dimensional slice of what is in reality a three dimensional object. *Figure 5* presents several three dimensional renderings of what a cone-of-vision would look like if it were visible, rotated through several different angles.

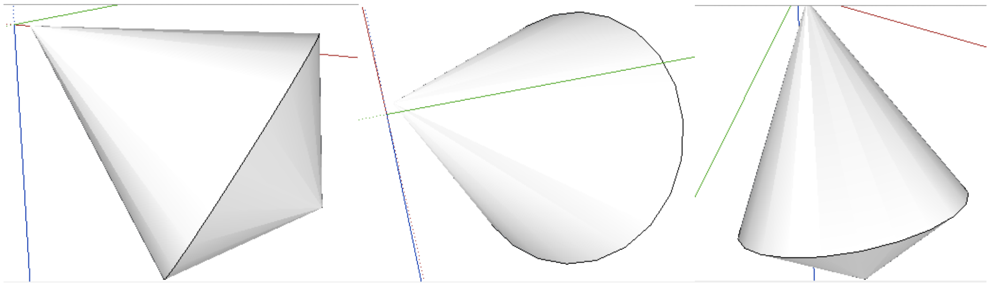


Figure 5 – Three-Dimensional Drawing of a Typical Cone of Vision from Different Angles

The shape shown on a fire and gas map that represents the coverage of an optical fire detector is effectively a "slice" of the cone-of-vision as it intersects with the plane that represents the elevation of interest, or in the terminology of 3D modeling, a "section plane". The shape of that slice that is presented in vendor cone-of-vision drawings (such as *Figure 3*) is entirely dependent on the slice being taken through the centerline of the detector and with the plane of the slice being exactly the same angle as the angle at which the detector is oriented. *Figure 6* presents a graphical representation of taking this slice and rotating it in a 3D model.

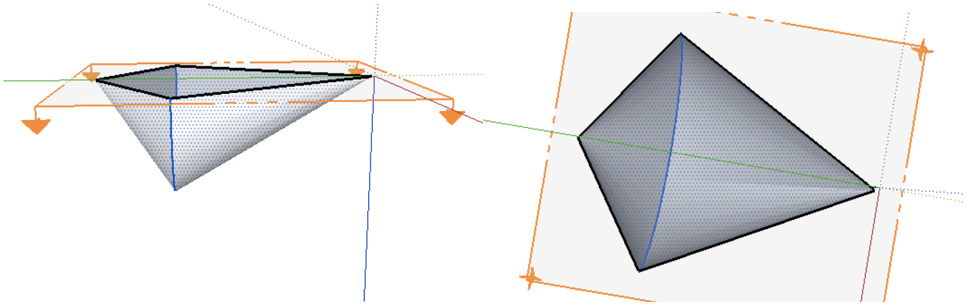


Figure 6 – Cone of Vision 3D Model with Section Plane through Centerline

While vendor cone-of-vision drawings are the section plane through the centerline of the detector, real world installations almost never have the plane of interest through the centerline of the detector. In general, the plane of interest for a fire detector mapping study is usually parallel to the surface of the facility and often near grade level (elevation = 0). Optical fire detectors are typically mounted such that they are elevated above grade and then pointed downwards. As a result, the section plane is virtually always at an angle to the centerline of the cone-of-vision, and the origin point of the detector is typically a significant distance off the plane of interest. As a result, the section plane shown in the fire and gas map results will bear little resemblance to the cone-of-vision drawings that are provided by the detector vendors. Instead, they will take a more elliptical shape that results from taking a conic section from an angle that is closer to perpendicular to the centerline. A graphical representation of this off-centerline section plane that is the actual intersection of the cone of vision with the plane of interest is presented in *Figure 7*, in a 3D model.

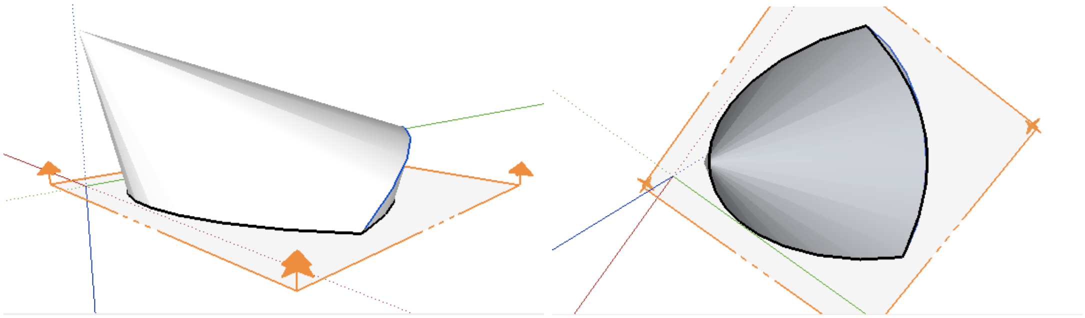


Figure 7 – Cone of Vision 3D Model with "Off Centerline" Section Plane

Manual methods of fire detector mapping and some unsophisticated software programs model the cone-of-vision as a two dimensional slice through the centerline. These methods will present results that show a map of fire detection coverage that appears remarkably similar to the shape that is presented in equipment vendor cone-of-vision drawings, as presented in their product literature. These methods perform the equivalent of taking a scaled cone of vision graph from the vendor literature, or possibly a "generic" cone of vision if different detector models are not differentiated, and tracing it on to the plot plan of the facility. Fire coverage maps generated by these unsophisticated methods can easily be identified. For the map generated by any single detector, the map coverage presented in the map will start at exactly the same location as the detector, and will form a perfect angle with straight lines away from the detector. While this type of analysis may provide a modicum of useful information, the amount of error in the coverage map will be very significant.

If a detector cone-of-vision is considered in three dimensions, it's shape will look more like an oval, parabola, or hyperbola depending on the angle that the detector centerline makes with the floor of the room that is under analysis (as demonstrated in *Figure 7*). If the detector does not reach the end of it's detectable distance, the projection of the cone-of-vision onto the plane of interest (the one for which the results are being calculated) is defined by traditional conic sections of analytical geometry.

As the detector becomes elevated from the plane of measurement, the distance away from the detector at which map shows fire coverage will increase. As an example, if a detector were oriented parallel to the plane of interest, and if that detector also had a cone of vision that was 45 degrees from centerline, then with each 1 meter increase in elevation away from the plan of interest, the fire coverage map at the plane of interest would move one meter away from the detector. *Figure 8* shows a progression of fire coverage maps where a detector is placed at one (1) meter, which is also defined as the elevation of interest. In the subsequent maps, the detector is located at the same point in the X-Y plane, but its elevation is raised to 3 meters and then 5 meters.

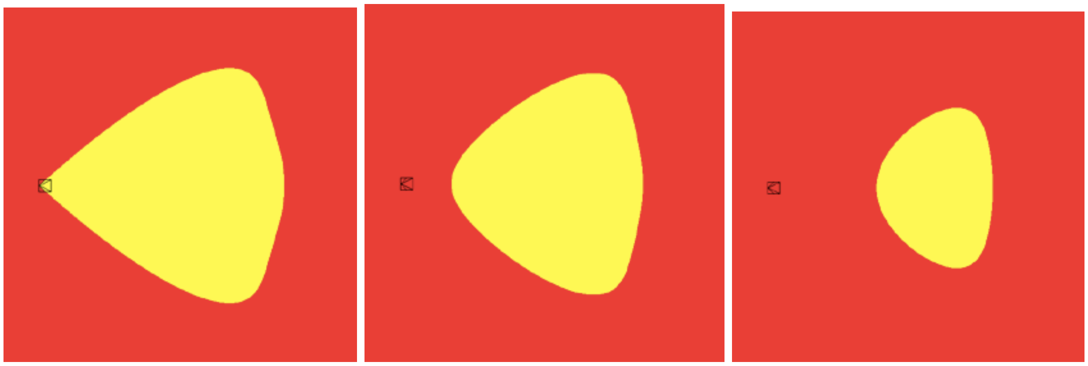


Figure 8 – Effect of Fire Detector Elevation Change
Elevation of Interest = 1 m
Detector Elevations, 1 m, 3 m, 5 m

Additionally as the detector angles down away from being parallel with the floor (or other plane of interest), the shape of the fire coverage map begins to be more curved. When the detector centerline is parallel with the floor the fire coverage map essentially makes straight lines away from the detector centerline. As the angle of declination increases, the map becomes more and more curved until it ultimately becomes a circle when the detector is pointing directly down, perpendicular to the plane of interest. *Figure 9* presents a progression of angle of declination changes, beginning where the detector left off in *Figure 8*, at a declination angle of 0° (parallel to grade) along with an elevation of 5 meters, and then progressing through 23° and 45° at the same elevation.

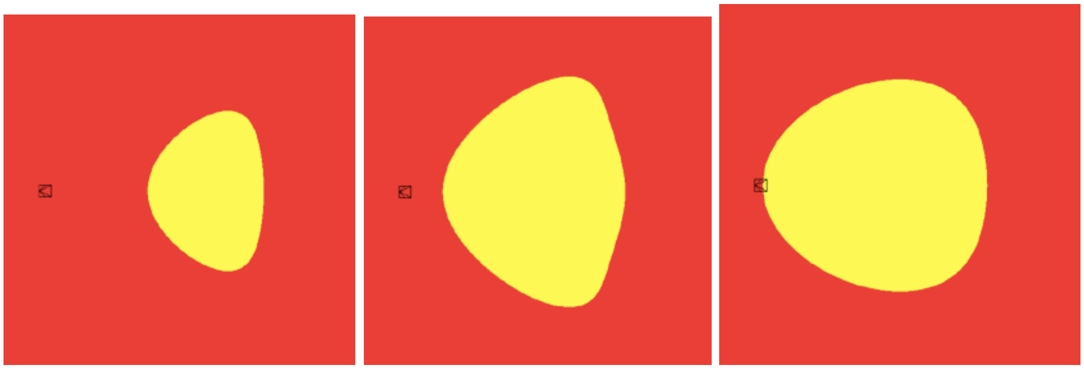
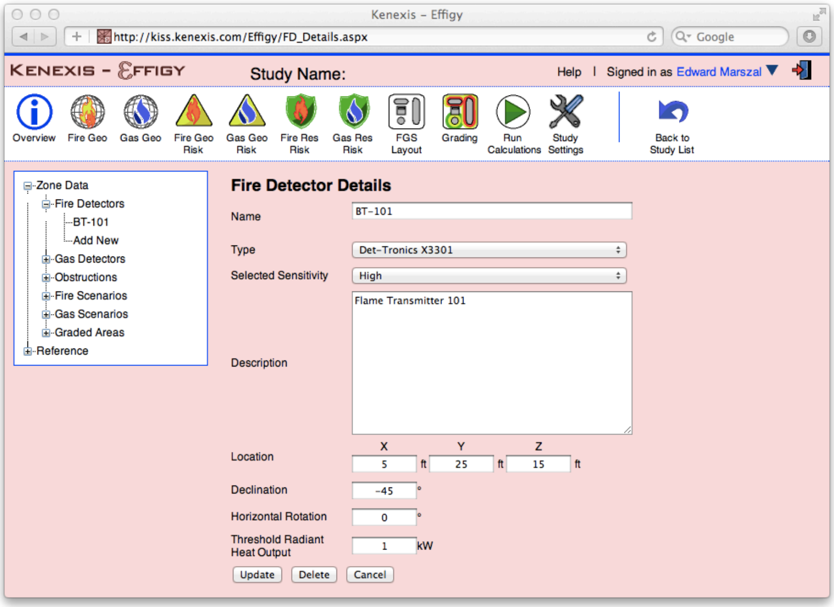


Figure 9 – Effect of Fire Detector Declination Angle Change
Elevation of Interest = 1 m, Detector Elevation = 5 m
Detector Declination Angles, 0° (parallel to grade), 23° and 45°

Kenexis Effigy™ elegantly models detector cone-of-vision in all of these situations. It properly accounts for elevation above plane of interest, angle of declination created curvature, various angles away from centerline the different sensors are capable of measuring, and the various detection distances (considering multiple sensitivity settings, and multiple fire types) from different vendor products in different chemical applications. Additionally, this analysis can be performed at any elevation of interest as selected by the user. *Figure 10* is a screen shot of a detector definition page, showing the variety of options that can be analyzed in the toolkit.



Fire Detector Details

Name	BT-101
Type	Det-Tronics X3301
Selected Sensitivity	High
Description	Flame Transmitter 101
Location	X 5 ft, Y 25 ft, Z 15 ft
Declination	-45 °
Horizontal Rotation	0 °
Threshold Radiant Heat Output	1 kW

Figure 10 – Effigy Fire Detector Input Page

Gas Detector Performance Attributes

The performance attributes of a specific model of a gas detector are important, but not as important as for fire detectors, when performing a mapping assessment. The two performance criteria for a gas detection arrays are the detector's ability to detect a gas of a certain concentration, and the size of the gas cloud of interest. As a result, the coverage maps generated by a gas detector mapping exercise will not typically vary from vendor to vendor.

The performance criterion that is of most interest, and will have the most effect on a gas detector mapping is the size of the gas cloud of interest. In general, there are two paradigms for selecting a the gas cloud size of interest:

- Minimum Cloud Size Causing Harm
- Minimum Cloud Size Based on Release Conditions

The minimum cloud size that can cause harm is a commonly utilized approach in the process industries for hydrocarbon gas detection. This approach is the basis for the spacing for the traditional "grid" that has historically been used to place gas detectors. When using this paradigm the fundamental concept is that any gas cloud that is sufficiently large that if ignited it will create an explosion that will cause significant damage should be detectable by the installed gas detection array. A report from the UK Health and Safety Executive[8] and conventional wisdom have agreed that a "significant" explosion is one where the flame front of the ignited gas cloud reaches speeds sufficient to generate a peak overpressure in the resultant shock wave of greater than 150

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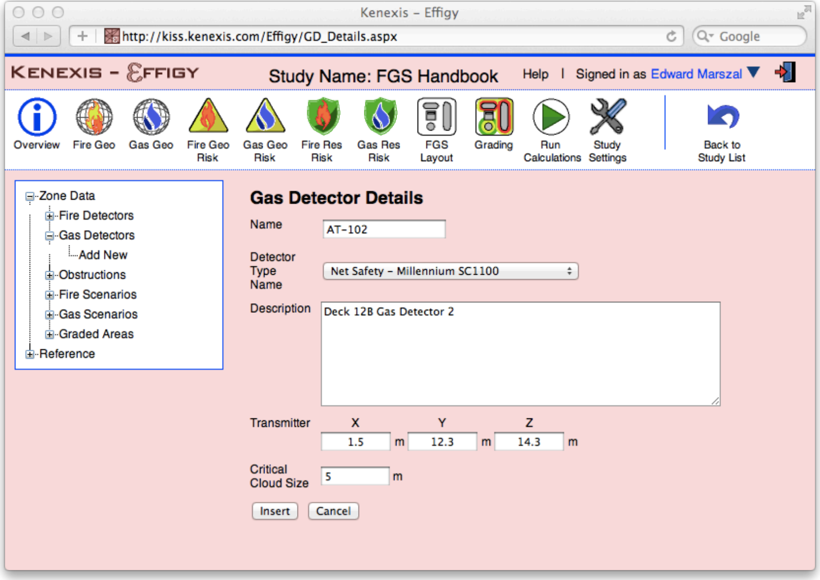
[8] Offshore Technology Report – OTO 93 002 – Offshore Gas Detector Siting Criterion, Investigation of Detector Spacing, United Kingdom, Health and Safety Executive

millibar (2.2 PSI). After a review of literature analyzing peak overpressure and flame speed in experimental conditions, HSE concluded that cloud sizes that are less than 6 meters in length are not expected to result in damaging over-pressures from explosion. This conclusion is customized for offshore production where methane is the species of concern and the obstruction blockage ratio is 30-40%. If other chemicals such as Propane, or worse yet Ethylene, are the concern, much smaller clouds can result in significantly more damage. On the other hand, large open facilities such as refinery tank farms could have much larger clouds (10 meters or more) that will not result in significant damage because there is a lack of confinement and obstructions.

The other paradigm to design-basis gas cloud size determination is the estimation of the minimum cloud size that could be credibly created by a leak, given the processing conditions of the equipment. This approach is very important and commonly used in toxic gas detection situations where the minimum cloud size that can cause is harm is very small, and much smaller than the cloud that will actually result from even the smallest process equipment leak. When using the “Minimum Cloud Size Based on Release Conditions” paradigm, the minimum cloud size is determined by calculating the release rate through the minimum credible hole size – typically 5mm diameter, representing a situations such as a flange leak – and then using dispersion modeling to determine the distance to which that release scenario will result in a gas concentration at or above the critical endpoint concentration (typically IDLH or LD50 for fatality – 20 minute dose).

After the cloud size of interest is determined and the gas detection equipment is selected, that information can be input into Kenexis Effigy™ and subsequently utilized to determine the gas detection array’s geographic coverage. *Figure 11* presents an Effigy™ gas detector input screen where the design-basis gas cloud size is entered along with the gas detector model and its orientation and location information.



Study Name: FGS Handbook

Signed in as Edward Marszal

Gas Detector Details

Name: AT-102

Detector Type Name: Net Safety – Millennium SC1100

Description: Deck 12B Gas Detector 2

Transmitter: X 1.5 m, Y 12.3 m, Z 14.3 m

Critical Cloud Size: 5 m

Figure 11 – Effigy Gas Detector Input Page

The gas detector input page shown in *Figure 11* is for a point detector. Effigy™ is also capable of modeling open path detectors.

Gas Detection Mapping

Once the cloud size of interest is known, gas geographic coverage mapping can proceed. As discussed previously, geographic gas detection coverage is a strong function of the design basis gas cloud size. When we refer to cloud size, we are most interested in the cloud length, because it is the length of the path of flame propagation that has the most impact of the amount of overpressure that can be generated. Determining coverage is a matter of finding the space around a detector where if a gas cloud of the size of interest or larger exists it will be detected.

For point gas detection equipment a gas cloud whose length is the design-basis length, for example – 5 meters, will be detected as long as is source of release of less than 5 meters from the detector. This essentially results in the three dimensional shape of a point detector's coverage being spherical, as shown in *Figure 12*.

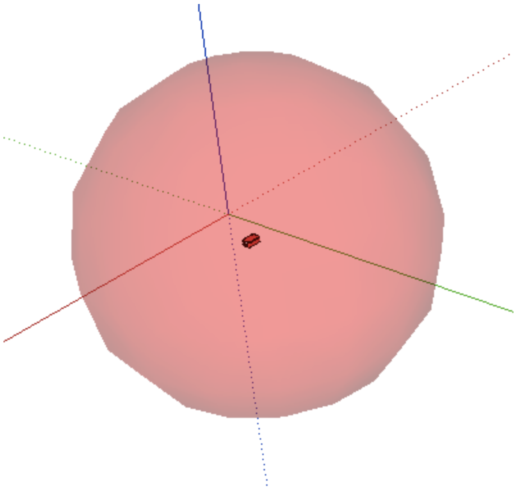


Figure 12 – 3D Model Representation of Point Gas Detector Coverage

The three dimensional coverage of an open path gas detector can be considered in a similar way, but instead of the distance to the point of detection, the distance would be to the line that forms the detector beam. Of course, the distance of the beam would need to be adjusted away from the cloud size of interest to the a fraction of the cloud size of interest, considering the length of the gas cloud that intersects with the detector beam. The resulting shape of coverage would resemble a tube with spherical ends.

Given that the three dimensional shapes are known and are a well defined function of the location of the detector and the cloud size of interest, the coverage map can be generated by taking a section plane of the sphere (for a point detector) or tube with spherical ends (for an open path detector) at the elevation of interest. This activity is conceptually shown in *Figure 13*.

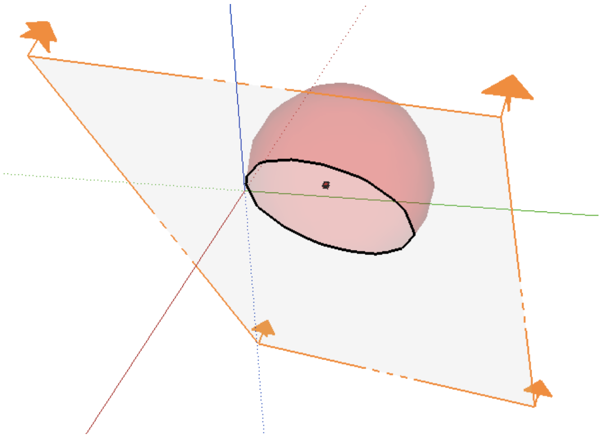
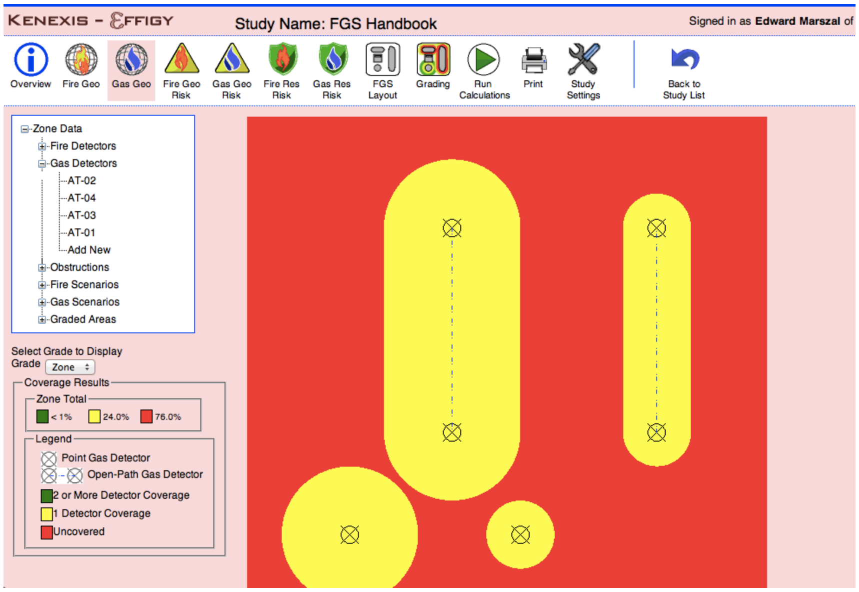


Figure 13 – Section Plane of a Coverage Sphere of Point Gas Detector Coverage

While it appears that determining coverage of a gas detector array is as simple as drawing circles whose diameter is the length of the cloud size of interest, it is not quite that simple. As shown in *Figure 13*, the section plane at the elevation of interest may not be the full diameter of the sphere. In fact, the section plane of the coverage sphere will only be the diameter of the cloud size of interest if the detector is located at the elevation of interest. Any movement away from the elevation of interest will result in the diameter of the section plane being smaller than the diameter of the coverage sphere.

Kenexis Effigy™ accurately models the effects of cloud size selection and position of detectors in reference to the plane of the elevation of interest. *Figure 14* shows an Effigy™ gas coverage map that includes identical detectors (both point and open path) with identical design basis cloud sizes, but located at different elevations. The mapping results show the difference in covered area depending on elevation. The figure also shows the tabular results for coverage in addition to the graphical map. As *Figure 14* demonstrates, Effigy™ calculates the numerical coverage metric for the entire three-dimensional space as a whole (shown as zone total). If desired, the coverage for only a single elevation can be calculated as an alternative.



Study Name: FGS Handbook

Signed in as **Edward Marszal** of

Select Grade to Display
Grade: Zone

Coverage Results
Zone Total
🟩 < 1% 🟨 24.0% 🟥 76.0%

Figure 14 – Effigy Gas Detection Geographic Coverage Mapping Results

The Impact of Obstructions

The next attribute of three-dimensionality that should be considered for fire and gas mapping studies is the impact of the obstruction caused by pieces of equipment and other structures that block the line-of-sight of detection equipment. It should be apparent that this factor is very important to fire detection, and will be discussed at length in this section, but it is also important for gas detection, which will be discussed in the following section.

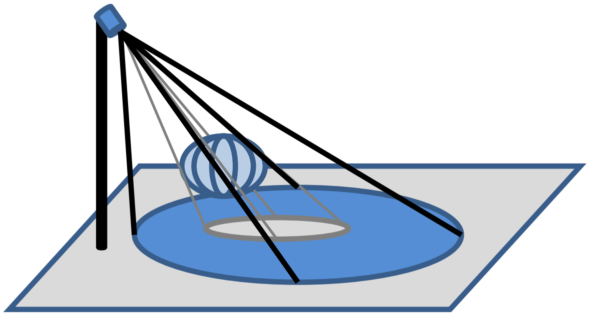


Figure 15 – The Effect of an Obstruction on Optical Fire Detector Coverage

As was discussed in the previous sections, a map of the performance of an optical fire detector is a function of its cone-of-vision and its location and orientation. These factors combine to result in a map, for a given plane, of what the detector can "see" and what it cannot. When on obstruction is placed between the detector and the plane of interest, the obstruction prevents the detector from viewing what is behind the obstruction, decreasing the coverage provided by the detector. This concept is shown in *Figure 15*. The fire detector map that results from a detector with an obstruction included will include a "shadow" of no coverage in the area where the obstruction blocks the view of the detector on the plane of interest.

In order to accurately model the effect of the obstruction, and generate the obstruction's shadow on the coverage map, the modeling process must consider the shape and orientation of all obstructions. Kenexis Effigy™ considers a wide range of geometries, as shown in *Figure 16*, fully in three dimension using sophisticated analytical geometric techniques.

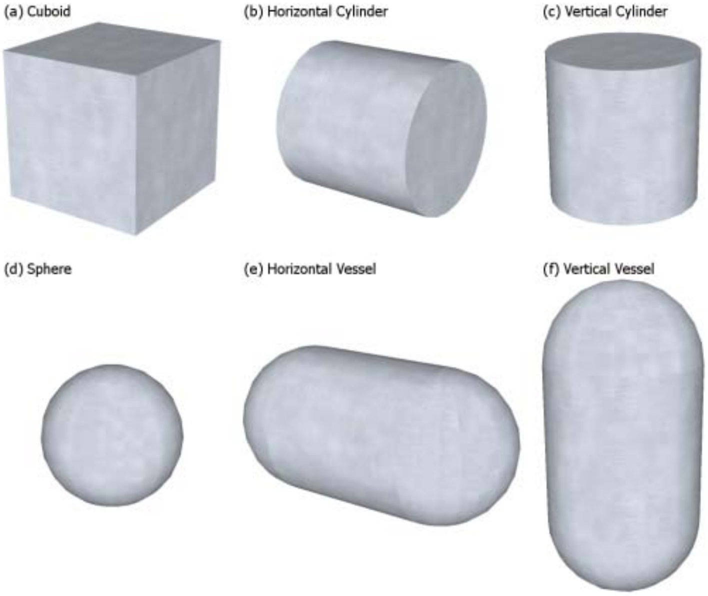
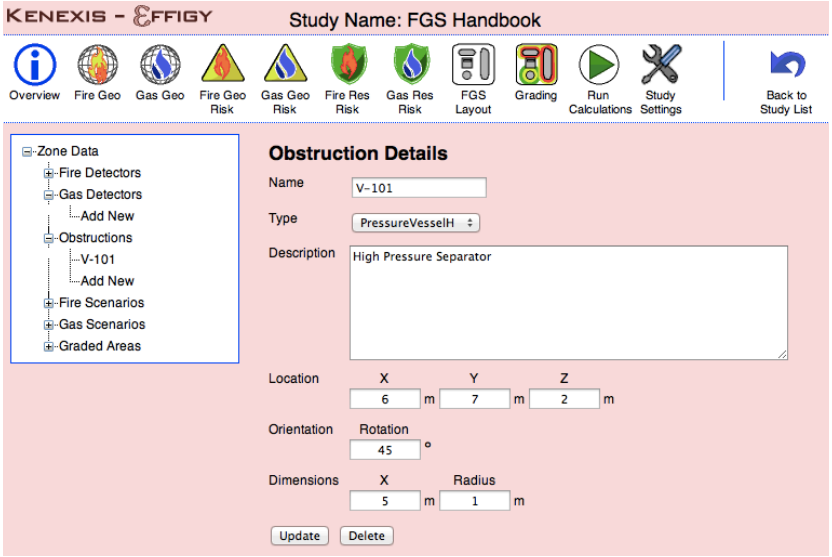


Figure 16 – Typical Obstruction Geometries Modeled by Effigy

The Effigy™ application allows direct input of obstructions, along with automatic input of files from 3D CAD applications. Manual entry of obstructions allow manipulation of the type, size, and location of each obstruction, along with the ability to manipulate the orientation of the obstruction along all three planes. A screen shot of the effigy obstruction input screen is shown in *Figure 17*.



Study Name: FGS Handbook

Obstruction Details

Name: V-101

Type: PressureVesselH

Description: High Pressure Separator

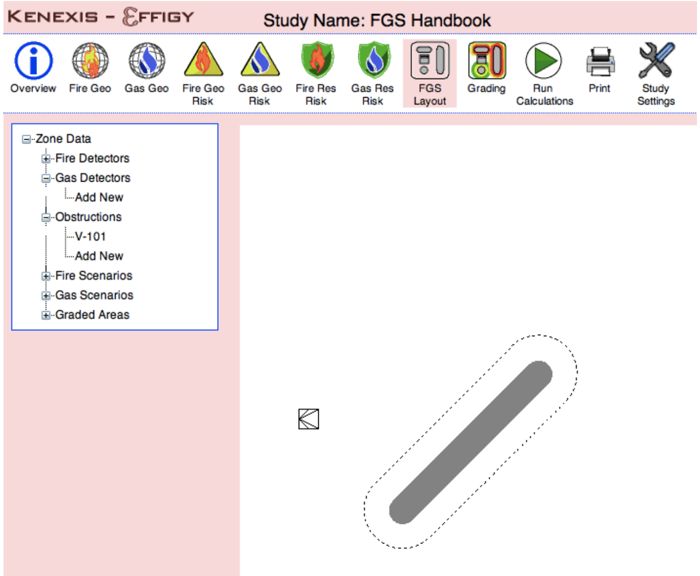
Location: X 6 m, Y 7 m, Z 2 m

Orientation: Rotation 45 °

Dimensions: X 5 m, Radius 1 m

Figure 17 – Effigy Obstruction Input Screen

After inputting the data defining an obstruction, more information about the obstruction can be obtained by viewing the FGS Layout Page, which will show the extents of the obstruction. The obstruction whose data was input in *Figure 17* can be seen in FGS Layout format in *Figure 18*. Note that the dashed lines indicate the full extent of the vessel while the grayed area represents the obstructed area on the plane of interest.



Study Name: FGS Handbook

Figure 18 – Effigy FGS Layout View of a Horizontal Pressure Vessel Obstruction

A two-dimensional analysis of obstruction shadows results in some degree of inaccuracy. Variations of two-dimensional analysis are commonly performed during manual analysis and by unsophisticated two-dimensional computer modeling tools. The two-dimensional shadow analysis is an extension of the two dimensional cone of vision. The first step in the process would be to plot the two-dimensional cone of vision on to the facility plot plan. Next step would be to basically draw a line from the centerline of the detector to the edged of any physical objects that are inside the cone of vision, and extend those lines to the edge of the cone of vision. Anything behind the obstruction would be removed from the coverage map.

Some applications may also limit the length of the two-dimensional shadow by calculating the "length" of the shadow by triangulating with the height of the obstruction. While this additional effort improves accuracy somewhat, overall, the two-dimensional shadow analysis approach is still quite inaccurate. The inaccuracy stems from several oversights:

1) the shape of the shadow will vary depending on the elevation and angle of declination,
2) the length of the shadow will vary depending on the elevation and angle of declination of the detector,
3) the starting and ending points of the shadows will vary depending on the height and elevation of a the obstructions.

Maps that are generated by two-dimensional methods are easily identified. First off, if the cone of vision is two-dimensional (as described above) then the shadow analysis will necessarily be two-dimensional. Even if some effort is made to consider the height of obstructions in calculating shadow length, the results will still be poor. Furthermore, the shadows will always appear to be attached to the obstructions, when this may not be the case. Consider *Figure 19*, where an Effigy™ map of a single fire detector is obstructed by an elevated pressure vessel is compared to the results of an unsophisticated model that employs a 2D cone of vision technique.

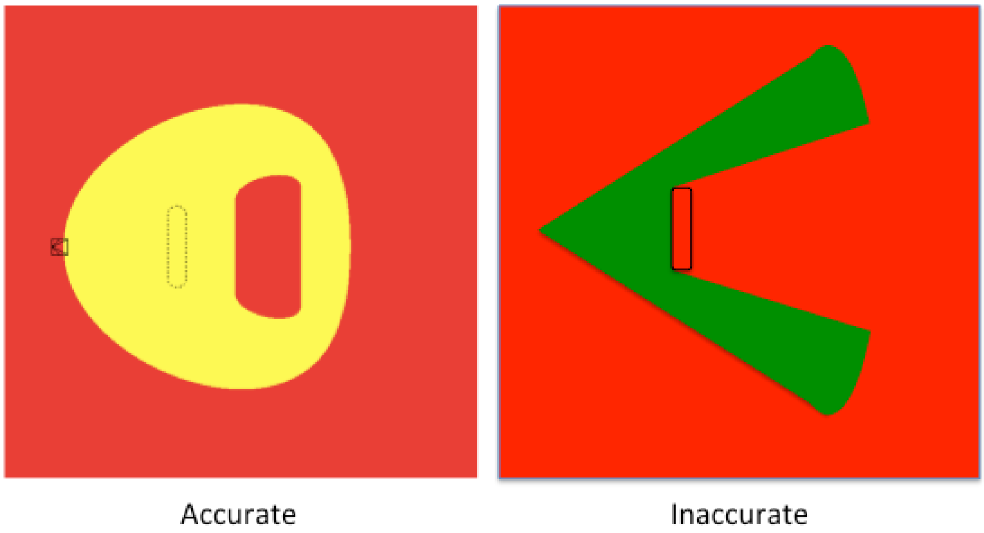

Accurate
Inaccurate

Figure 19 – An accurate 3D Effigy Model of an Elevated Obstruction versus a 2D Method

Obstructions in Gas Mapping

At first glance it would appear that obstructions have no impact to gas detection mapping, as gas detectors to not depend on a field of view that can be blocked by equipment items. This initial impression is not entirely correct. Obstructions do have an impact on the coverage of gas detection systems in so much as they limit the actual area that is required to be covered. If a gas detector covered area contains a pressure vessel, then coverage of gas leaks inside the vessel is not necessary. As such, the area inside the vessel should be removed from the total area the needs to be covered when the calculation is undertaken.

Comparing Geographic Coverage and Scenario Coverage

All of the preceding discussion of fire and gas mapping is related to the creation of geographic coverage maps. Geographic coverage mapping is currently the most common form of fire and gas mapping and expected to remain the standard format for the foreseeable future due to its relative ease of execution coupled with sufficient accuracy for its purpose. While geographic coverage is by far the more common approach, the ISA 84.00.07 technical report also defines an entirely different concept for calculating the effectiveness of a fire or gas detector array called Scenario Coverage. Geographic Coverage simply calculates a fractional area (or fractional volume) that the detector array can “see”. This analysis only requires knowledge of the performance attributes of the FGS equipment and the physical layout of the plant equipment that would form obstructions to the field of view of the detection equipment.

Scenario coverage works differently. Instead of determining detectable area fraction, scenario coverage determines the fraction of the release scenarios that can be detected. Unlike geographic coverage, scenario coverage explicitly considers the process and environmental factors that define how frequently a loss of containment occurs along with the physical manifestation of that release. For example, if a loss of containment occurs in a process facility as the result of a flange leak, a gas cloud will be created whose size and location is the result of a number of factors including:

- Released material composition
- Release pressure
- Release temperature
- Release hole size
- Release frequency
- Wind direction
- Atmospheric stability
- Relative humidity
- Effect of release impingement on nearby equipment items

Scenario coverage provides much richer insight into the true risk reduction capabilities of a FGS, but is also exponentially more difficult and time consuming to perform than geographic coverage. As a result, scenario coverage is typically only done when a full QRA style FGS design basis is required – which would typically only occur for a very special or unique hazard or during the “calibration” process for semi-quantitative tools for determination of geographic risk targets.

In general, scenario coverage calculation requires the following steps to be executed.

1. Identify and define a potential leak source (along with frequency of release)
2. Define the range of scenarios that will be modeled for the leak source (i.e., hole sizes and weather conditions)
3. Collect parameters (process and weather) required to model the size of the leak
4. Perform dispersion / fire modeling to characterize the size of the release
5. Plot the leak on a diagram of the facility under study in the all of the relevant orientations
6. Determine for each individual leak (or fire, if ignited) whether or not there is a detector that would identify the leak or fire.
7. Calculate coverage as the frequency of detected release scenarios divided by the frequency of all release scenarios.

When performing this type of analysis, at the end of step four you will have a large series of design basis gas clouds. *Figure 20* shows a "footprint" depiction of one release scenario. The scenario that generates the footprint shown in Figure 20 is only one out of a series of release scenarios that can occur, representing a single release orientation and wind direction.

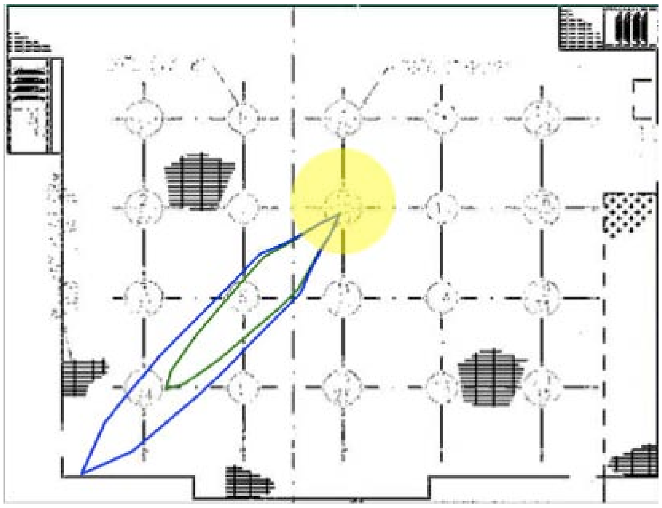


Figure 20 – Example "Footprint" Depiction of a Gas Release

Kenexis Effigy™ performs internal calculations on a release scenario that consider a full set of potential release orientations (all direction), and also adjusts for wind direction. *Figure 21* shows a representation of the single release scenario shown in *Figure 20* as it is rotated in only 8 directions. Effigy™ orients the release in 720 wind-adjusted directions.

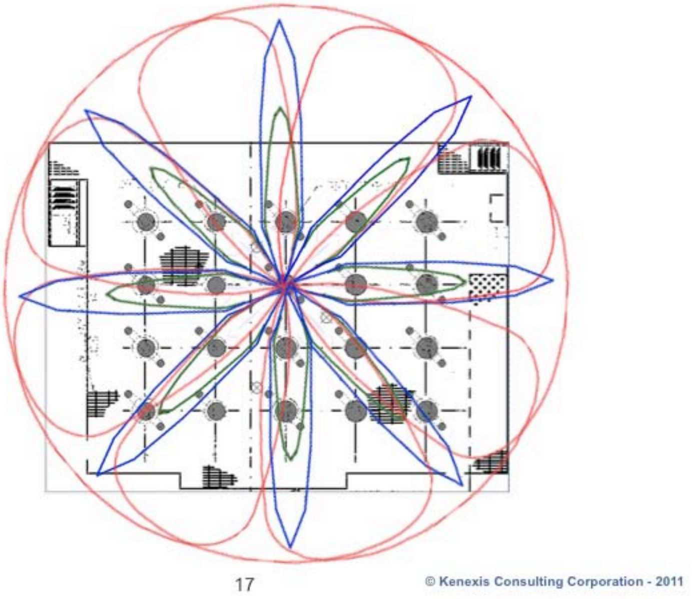


Figure 20 – A Gas Release "Footprint" Depiction Rotated in Eight Directions

As each of the 720 scenarios is plotted, the frequency at which that release is expected to occur is also plotted. A resulting graph can then be created which shows, through color-coding, the frequency at which a release (or fire) is expected to be present in any particular location. This is also known in quantitative risk analysis as a geographic risk. *Figure 21* presents a geographic risk profile without considering the beneficial effect of fire and gas detection for a single release point (in this case, an oil production wellhead).

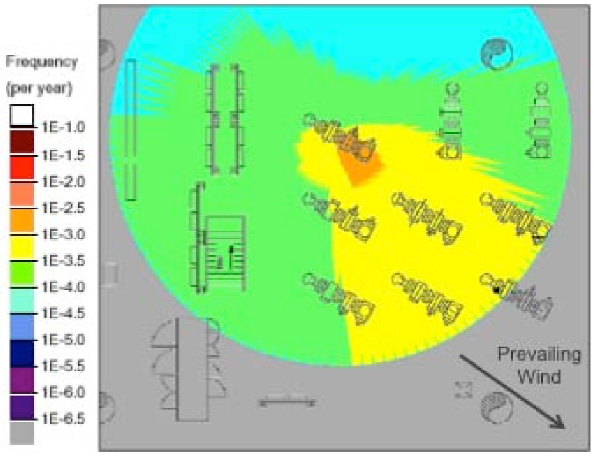
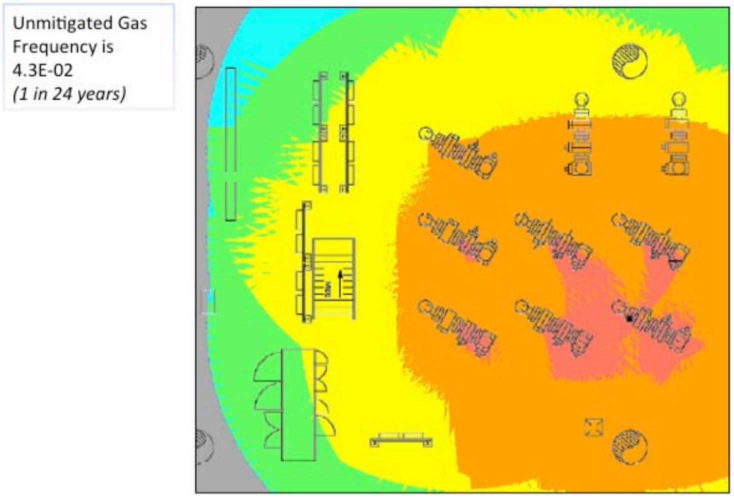


Figure 21 – Geographic Risk Profile (Scenario Coverage) for One Release Point and No Detectors

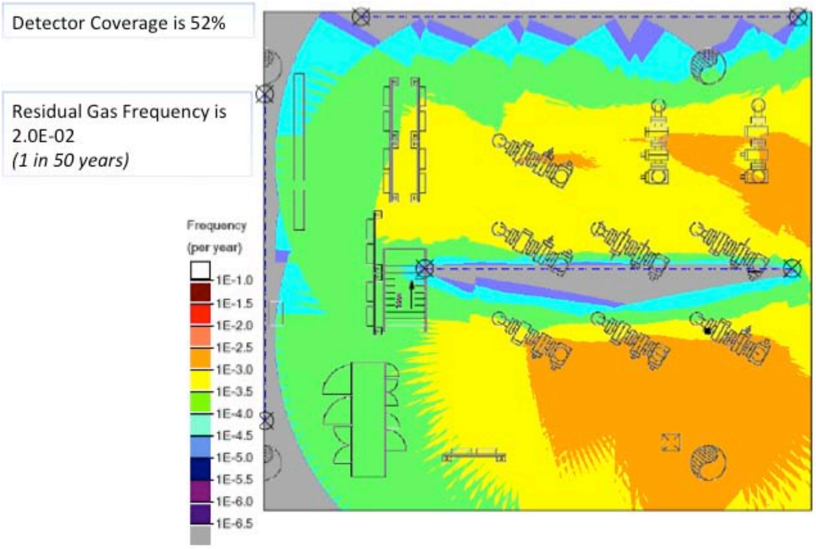
The next step in the process is to include all of the scenarios for ALL of the equipment items from which a leak could emanate. This composite geographic risk profile (still with no beneficial effect of FGS equipment) is shown in *Figure 22*.



Unmitigated Gas Frequency is 4.3E-02 *(1 in 24 years)*

Figure 22 – Geographic Risk Profile (Scenario Coverage), Multiple Release Points, No Detectors

Once the unmitigated risk profile is created, the impact of fire and gas detection equipment can be determined. In order to do this, each individual release scenario must be assessed in order to determine whether or not the detector array will be able to detect the release. This can be as simple as a gas cloud plot crossing over a point gas detector. Somewhat more sophisticated analysis is required to make this assessment for open path detectors and optical fire detector arrays. If a scenario is detected by the FGS system, it is “removed” from the plot of geographic risk, and its frequency deducted from the total frequency. The ultimate output of this effort is a geographic risk profile drawing that only shows the release scenarios that are NOT detected along with a tabulation of the percentage of release scenario frequency that is detected, as shown in *Figure 23*.



Detector Coverage is 52%

Residual Gas Frequency is 2.0E-02 *(1 in 50 years)*

Figure 23 – Typical Scenario Coverage Results

This figure is the same process as shown in *Figure 22*, but the beneficial effect of two point gas detectors and a single open path gas detector is included.

Using Graded Areas to Limit Analysis to Hazardous Areas

Based on the previous section, the power of scenario coverage calculations is readily apparent, but the extreme level of effort is also quite obvious. In practice, the much less time consuming task of scenario coverage calculation has been able to provide results with a similar degree of accuracy with significantly less effort as long as the risk tools are appropriately calibrated and the analysis is limited to an appropriately sized "graded area". The limitation of geographic coverage of not being able to address where leaks are coming from can be addressed in a geographic coverage modeling technique and modeling tool by limiting the area that is to be considered in the course of the analysis to areas where leaks are expected to occur or where gas clouds or fires are expected to be present. Using a systematic approach to establish the extents and grading (risk ranking) of graded areas will significantly improve FGS design. The improvement comes from a decreased cost associated with installing fewer detectors because they will only be located where a hazard actually exists, and also allowing for a higher coverage targets (more risk reduction) in areas where a true risk exists.

Graded area determination is an exercise in identifying potential leak sources for flammable materials, and then establishing an inclusion zone around the leak source that represents the area where a gas cloud or fire might exist if a release from a potential leak source were to occur. For instance, an organization's fire and gas design philosophy might include three grades of fire coverage. Each grade of fire coverage will also include a distance away from each leak source (which is a graded piece of process equipment) that must be included in the analysis. The process is very analogous to establishing electrical area classifications. The result of this process is a graded area map, such as the one shown in Figure 24, where each equipment item results in a grade, along with an extents-of-graded-area for which coverage results will be calculated.

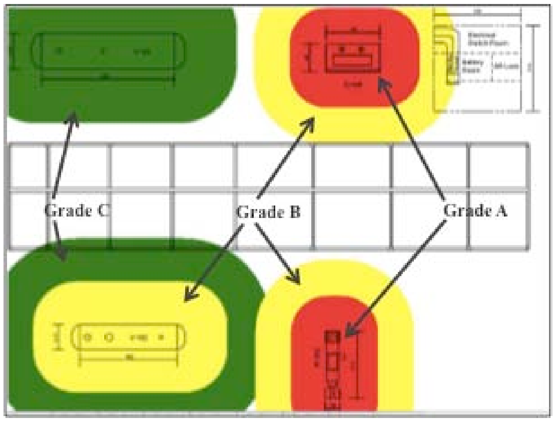


Figure 23 – Extents of Graded Area Map

Conclusion and Path Forward

As a result of the ISA TR84.00.07 technical report, industry has made great strides in making the process of developing a design basis for fire and gas detection and suppression systems more systematic and consistent. The use of computer-aided fire-and-gas mapping tools can greatly improve the design process, limiting the amount of equipment that is required while also ensuring that tolerable goals are met. With the release of Kenexis Effigy this technology is now available, proven, and ready for use.