KENEXIS

Fire and Gas Systems Engineering Handbook

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About Kenexis

Kenexis is a global engineering consulting company that is focused on the implementation of engineered safeguards in process plants. Instrumented safeguards are physical devices that can detect that an unwanted or out-of-control situation is occurring in the process plant and take remedial action to move the process to a safe state. Some typical examples of instrumented safeguards shown below.

- Safety Instrumented Systems
- Fire and Gas Detection Systems
- Alarm Management Systems
- Pressure Relief Systems
- Industrial Control System Security
- Machine Safeguarding Systems

Kenexis helps our clients to deploy these systems by working as an independent expert third-party advisor who assists in the development of the design basis of these systems and validation that these systems are implemented in accordance with the design basis over their entire lifecycle. Since Kenexis does not sell or recommend any hardware or perform any detailed engineering services, Kenexis is uniquely positioned to act as an independent advisor with no conflicts of interest that might sway the direction of decisions in the development of the design basis.

Kenexis applies a risk-based approach in assisting our clients to determine their engineered safeguard needs. The risks that are posed by the processes that our clients operate can be determined and developed through Process Hazards Analyses (PHA) which Kenexis can both facilitate and actively participate in. Once the needs for instrumented safeguards are identified, the design basis for those safeguards is further developed by considering the codes and standards that apply to the design of each specific safeguard along with the level of risk reduction that those safeguards are required to provide. Considering these two factors Kenexis prepares design basis documentation that defines the requirements in sufficient detail to allow equipment to be selected and purchased, but general enough to ensure that any technology or equipment vendor that is capable of meeting the technical requirements can provide an appropriate solution. Kenexis design basis documents are unique in their ability to allow end users to compare alternatives from multiple vendors and select the solution that best suits their requirements.

After the design basis is complete, our clients work with equipment vendors, systems integrators, and engineering companies to physically implement the solution. After the safeguards are implemented, Kenexis helps our clients by performing validation services and ongoing support services to ensure that the safeguards were selected, designed, and installed in accordance with the design basis documentation, and that the system design and design basis documentation are maintained in an evergreen fashion.

About the Authors

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Preface

Fire and Gas Systems (FGS) constitute some of the most widely used yet difficult to design safeguards in the process industries. Prior to the release of a risk-based standard for the design of FGS, designs were traditionally implemented using rules of thumb and engineering heuristics. These systems were usually reliable from the standpoint of control systems hardware; however, they often suffered from two main flaws.

The first flaw was that FGS were often unable to detect hazards due to an insufficient number of or poorly located detectors. This was true at least in part due to the lack of rigorous methods for evaluating coverage of detector arrays. The second FGS flaw has been a relatively high frequency of spurious activation. This has led to many FGS systems that are bypassed or ignored. This has been in part due to poor instrument selection and installation; however, rigorous methods for evaluating sensor design and layout did not exist prior to the development of ISA technical report ISA84 TR84.00.07 – *Guidance on the Evaluation of Fire, Combustible Gas and Toxic Gas System Effectiveness*.

The ISA technical report provides end-user companies with a risk-based approach to FGS design that is in-line with their guidelines for tolerable risk. The technical report allows for design flexibility, where designs can be tailored to provide dependable risk reduction capability. Like Safety Instrument Systems (SIS), FGS can be designed in a good, better, and best fashion, which matches the system performance with the amount of risk reduction needed.

The downside of the flexibility of risk-based design is that a degree of analytical complexity is introduced to the design process. In order to make risk-based decisions, one needs to understand the type of hazard in the process and the risk, which is no small feat and typically out of the “comfort zone” of FGS designers. One should also understand concepts of reliability engineering as applied to FGS design.

In the years following the release of the ISA Technical Report, several methods have evolved (including those by the authors of this book) to address specific aspects of performance-based FGS design. The authors of this book determined that it would be valuable to distill this information down into a handbook that allows everyday practitioners to have a quick reference to the most salient points in the field of performance-based FGS design.

This book provides a practical discussion of performance-based FGS design. The information is presented in a fashion that leans toward assistance in execution of the tasks without belaboring the theoretical underpinnings of the equations and data that are used. In addition, this book reflects the leading and most accepted methodologies for performing tasks, especially in areas where the ISA Technical report allows great flexibility to the users to select from many options for compliance.

The authors of this book hope you enjoy the contents and find the information educational and useful on a day-to-day basis.

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Introduction

Fire and Gas Systems (FGS) are a subset of instrumented safeguards that detect hazardous conditions, provide early warning, and take appropriate mitigation actions to safeguard people and assets. Implementing FGS in a process plant has been a challenging endeavor for many years. Process plants often contain a much wider array of hazards than in traditional building fire protection engineering. Process plant hazards include hydrocarbon fires, combustible gas releases, and the possibility of acute toxic gas hazards. The plant environment is often outdoors, which adds complexity in making informed decisions about hazard detection and mitigation.

All instrumented safeguards need a *basis of safety*, which is the underlying technical justification used to make decisions about the design of the equipment that will promote safe operations. Choosing the right *basis of safety* for FGS design should be through a systematic process, and the selection done in a manner that is transparent, well-understood, and well-documented. Historically, code compliance has provided adequate technical justification for a safe design, but prescriptive codes for fire detection are not well-suited to process plants. The problem requires a flexible approach that establishes how the system should perform before a design is chosen. Performance-based design starts with defining process hazards, measuring the magnitude of the hazard or risk, and only then selecting the FGS design such that it will provide the adequate performance.

In this performance-based FGS design process, the type and number of detectors are determined, the detectors are placed in proper locations, and the correct technology is selected; all such design choices being inline with the underlying *basis of safety*. In addition, the *basis of safety* needs to specify the requirements to test and maintain FGS equipment to achieve good mechanical integrity. Mechanical integrity requirements include the type of preventive maintenance tasks that will need to be performed on the equipment and the frequency at which those tasks will be performed.

For FGS, there have been two general ways that the basis of safety has been defined. The more traditional method is a prescriptive basis. Prescriptive standards, such as those standards from the National Fire Protection Association (NFPA) and the European norms will define what type of equipment is required, where it needs to be installed, and how it should be maintained and tested. The most well-used standards are the *National Fire Alarm Code NFPA 72* and *European Norm EN 54*. The fire alarm code and associated standards are really built around the protection of occupied buildings, such as office buildings, hospitals, and schools. They are not geared toward the very specialized requirements of processing flammable and toxic materials. As a result, alternative techniques are increasingly being used to improve FGS design. These performance-based methods, which utilize hazard and risk assessments to make informed decisions, allow for optimal FGS design in areas where the more traditional prescriptive standards are inadequate, inefficient, or don’t exist for the design basis hazards.

Industry required additional guidance to address the gaps within prescriptive FGS standards. Performance-based standards for the application of fire and gas detection equipment are rapidly being adopted as the preferred solution to bridge these gaps. Performance-based design has already been used successfully in safety instrumented systems (SIS) design through the IEC 61511 and ANSI/ISA 84.00.01 standards. There has been widespread acceptance of these standards and successful implementation for safety instrumentation in general. As a result, numerous operating companies and engineering companies strongly desired to use the performance based concepts and techniques in these standards to design not only their emergency shutdown system, the traditional SIS, but also the fire and gas detection systems. The International Society for Automation (ISA) developed a working group under the ISA-84 Standards Panel specifically to address performance-based fire and gas system design. Working Group 7 created technical report TR 84.00.07 – *Guidance on the Evaluation of Fire, Combustible Gas, and Toxic Gas System Effectiveness.* ISA published this in 2010 to provide guidance on how fire and gas systems can be designed in accordance with the principles of IEC 61511. Nothing in the Technical Report mandates use of IEC 61511 for FGS design as a hazard mitigation system. Application of the Technical Report is at the discretion of the user.

In general, the IEC 61511 standard specifies that performance targets for each safety instrumented function (SIF) based on the risk associated with the hazard that the SIF is intended to <u>prevent</u>. This approach works well for safety instrumented systems, but it falls short for fire and gas detection systems. This is because FGS, in general, do not prevent a hazard; they mitigate a hazard, making the magnitude and severity smaller instead of preventing it altogether. As a result of the fundamental differences between hazard prevention and hazard mitigation systems, additional analysis is needed in order to accurately assess the risk and ensure effectiveness of the proposed FGS design. For example, instead of just assigning a Safety Integrity Level (SIL) target or safety availability to the instrumented function in the FGS, it is also important to specify detector coverage for FGS. Performance-based FGS design strongly recommends that detector coverage should be quantified, verified, and validated when using a performance-based FGS design in addition to considering the safety availability for the FGS function.

ISA TR84.00.07 was specifically written for the process industries and was not intended to encompass every fire and gas detection application. In a typical process plant, only the areas of the facility that contain process equipment are intended to be covered by the Technical Report. ISA TR84.00.07 is not meant to completely replace prescriptive design codes, which are still going to apply to many areas in a facility. For example, one would still want to design the fire alarm system in the control building, motor control centers, and other occupied buildings using requirements from the applicable fire alarm code, such as NFPA 72. ISA TR84.00.07 is a supplement for additional considerations like toxic gas detection and fire and gas detections in process areas.

This raises the question “which approach should I use? Should I use the performance-based approach where I analyze the risk and apply as many instrumented safeguards as are required to mitigate that risk, or do I follow a completely prescriptive approach where I just follow a rule set and check off the numbers as they are completed?" In reality, it is best to use a combination of both prescriptive and performance-based methods. Many of the fire and gas system elements are going to be adequately addressed by the prescriptive standards. Prescriptive standards result in a rigorous design, as well as usually being effective and relatively quick. Performance-based standards, although more flexible, are typically more time consuming, due to the increased analysis required. For those elements of the FGS that can be adequately addressed using prescriptive methods, it is reasonable to address them based on the prescriptive requirements for the sake of efficiency and effectiveness. However, there are elements that, although they may be addressed by prescriptive standards, could be better designed by using performance-based methods, allowing for better detector placement and more effective determination of quantity of sensors required. In addition, some FGS elements that are often found in the process industries are not covered by prescriptive standards. Using performance-based techniques to address these shortcomings in the prescriptive standards is the only real option for process plant FGS.

Disclaimers

The concepts underlying a performance-based approach to FGS design is often suitable because these concepts are not adequately addressed by applicable national codes that contain prescriptive requirements for fire alarm systems. Nothing in this handbook suggests that prescriptive standards are invalid or should not be followed where required by local legal requirements. In process plants, supplementing the national standard with performance-based analysis is consistent with principles of recognized practices and standards.

A well-designed FGS will detect a large percentage of hazards which may occur that are within the basis-of-design. Some fires, combustible gas, and toxic gas hazards may not be detected or detectable by the system developed using these guidelines. It should be understood that there are limitations on the effectiveness of even well-designed FGS.

The intent of FGS is not to prevent hazards, but rather to mitigate an already hazardous situation. Therefore, a well-designed FGS that performs adequately on demand may still result in a situation resulting in loss-of-life or asset damage. Nothing in this handbook is intended to suggest otherwise.

Kenexis strongly recommends that release prevention should be the primary goal of any risk management activity. Nothing herein is intended to suggest otherwise. Beyond release prevention, Kenexis recognizes that FGS have a critical role in mitigating the consequences of accidents that do occur, but Kenexis does not intend to suggest that FGS should be relied upon where accident prevention is first feasible and achievable.

There are no requirements to apply ANSI/ISA 84.00.01-2004 *Functional Safety: Safety Instrumented Systems for the Process Industries* in situations where the primary intent of a safety function is to mitigate rather than prevent a hazard.

Lifecycle

ISA Technical Report TR 84.00.07 – *Guidance on the Evaluation of Fire, Combustible Gas, and Toxic Gas System Effectiveness*, 2010 - has defined a lifecycle for evaluating the performance of Fire and Gas Systems (FGS). This lifecycle is similar to the Safety Instrumented Systems (SIS) lifecycle in the IEC 61511 and ANSI/ISA 84.00.01 standards, but has a few more tasks that are specifically related to evaluating hazards and risk protected by FGS.

Figure 1 – Fire and Gas System Lifecycle ISA TR 84.00.07

The lifecycle starts with **identifying areas of concern**. Applying FGS across the board to every process area of a facility may not be practical or necessary. Before specifying an FGS, the process hazards and equipment under control should be analyzed to determine whether there are significant hazards or risks that warrant hazard detection.

The next step is to **identify hazard scenarios** for areas of concern, which will define what type of hazard detection may be needed. This includes identifying the potential sources of release of hazardous material as well as the flammable and toxic hazards associated with those sources.

For each hazard scenario, the next step is to **analyze the consequences** that may occur as the result of those hazardous events. Consequences can include hydrocarbon fires, combustible gas cloud formation and ignition, or toxic gas dispersion. Analyzing these consequences will include determining the possible impact on people and the plant in the event those consequences were to occur. To the extent the consequences are more severe, a higher level of FGS performance would be specified.

In addition to analyzing the magnitudes of consequences, the **frequency (or likelihood) of the consequences** should be analyzed. More frequent demands on the FGS indicate higher risk, and this would warrant a higher level of FGS performance.

Considering all this information, we perform an **unmitigated risk assessment** to measure the risk associated with the hazard scenarios before considering the possible benefit of an FGS. Similar to risk assessment for SIS purposes, the unmitigated risk will be compared to a predefined risk target in order to gauge the tolerability of that risk.

If the unmitigated risk is tolerable, then no FGS would be considered ‘required’ based on the assessment of the hazard and risk. Implementation of an FGS would be ‘optional’ in this case unless otherwise dictated by legal or good practice requirements. However, if the unmitigated risk is not tolerable, then the design of an FGS should proceed to the next step of the safety lifecycle, which is **identifying Risk Reduction Requirements** for the FGS. These requirements would define the required performance of an FGS in terms of detector coverage as well as safety availability. These performance targets will drive the equipment needs, voting schemes for the system, placement of detectors, and the testing and maintenance of the FGS.

The next step is to **develop an initial FGS design**. The benefit of the designer's experience is not discounted in the ISA technical report and should not be ignored. Initial layout of FGS detectors should use heuristics from experienced engineers based on the type of equipment, the type of facility, and how the various pieces of process equipment are laid out. The initial design can use heuristics and rules-of-thumb similar to prescriptive methods, but will also use a trial-and-error approach to achieve sufficient performance of the system. The key step advocated by ISA 84 TR.00.07 is that the initial design is *verified* by rigorous detector coverage mapping and safety availability assessment.

After the initial design is laid out, **detector coverage** is analyzed. The suitability of detector type and layout, in terms of how much coverage a detector array can achieve, is specifically calculated instead of simply looking at rules of thumb as a final arbiter on where equipment should be placed. The detector coverage is analyzed in a quantitative manner, and this usually necessitates the use of sophisticated computerized modeling tools. Detector coverage should achieve a threshold value to indicate suitable FGS *performance*.

In addition to the coverage, the **safety availability** of the fire and gas equipment is also calculated. The electrical / electronic equipment in the system will be specified and the safety availability will be calculated in a way similar to that for the achieved SIL for a safety instrumented function, which is done in accordance with the IEC 61511 or ANSI/ISA 84.00.01 standards. This verifies the system has an acceptably low probability of failure during a demand. Safety Availability should meet or exceed target values to indicate suitable FGS *performance*.

Finally, **perform a mitigated risk assessment**. While the unmitigated risk assessment originally considered the hazard and risk without the benefit of the FGS, the mitigated risk assessment considers the risk after the proposed FGS has been put in place. If the mitigated risk is tolerable, then the initial fire and gas system design has been validated. If the proposed design does not achieve tolerable risk, then we examine the areas where the design fell short, propose a new design, and re-analyze the system in terms of coverage and safety availability. We continue in an iterative fashion until the FGS design meets the requirements for risk tolerance.

ISA TR 84.00.07 is consistent with the underlying principles contained within ISA and IEC standards for SIS in that it promotes design of critical instrumentation and control systems that are commensurate with the level of hazard and risk posed by the process.

It is not appropriate to use the ISA's lifecycle as a precise flow chart for how to execute a full engineering project as if was never intented for that purpose. Therefore, the safety life cycle shown in *Figure 1*, and as presented in the TR84.00.07

technical report, was developed in such a way that each defined step contains the practical requirements and expectations for each step in an engineering design lifecycle. *Figure 2* shows this as a more-typical work flow that would be used for executing a FGS design project.

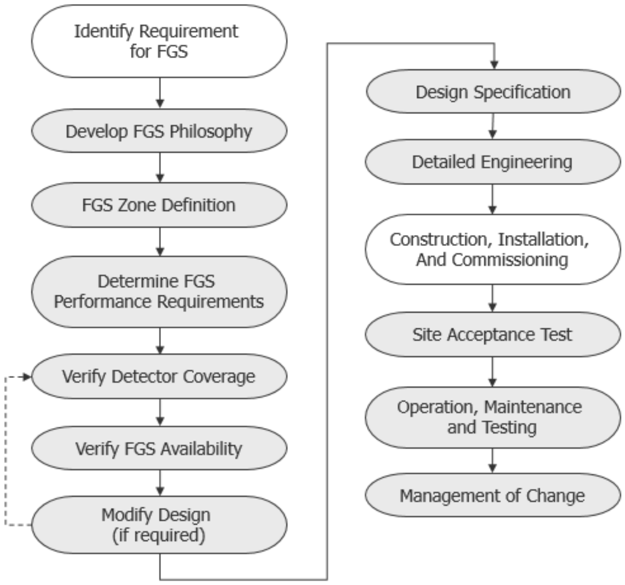


Figure 2 – FGS Typical Work Flow

The typical work flow begins with the identification of a requirement for analysis of a fire and gas system. This is the event that requires an engineer to evaluate the need for a fire and gas system. This might be the result of:

- Regulatory Requirements
- Standardized Design Practices

- Corporate standards from an operating company or an engineering company
- Process Hazards Analysis (PHA) Recommendations
- Recommendations from an Auditor, usually through hazard insurance or regulatory oversight

Whatever the trigger, a request for an FGS to be considered will lead to this work flow. The first phase of the work flow is the development of the Fire and Gas Philosophy, which should actually be in place prior to execution of any specific project.

This philosophy is a well-reasoned technical basis that achieves the goal of hazard detection and, in some cases, hazard mitigation. It is documented as a set of policies, performance target criteria, analysis methods, and procedures surrounding fire and gas hazard evaluation and FGS system design. There are many choices that a designer faces which can only be answered after a company defines its philosophy for hazard detection and mitigation. While a wide range of design choices might comply with ISA TR 84.00.07, the 'right' choices often come down to following a well-reasoned FGS philosophy. For example, should gas detectors be positioned to detect accumulations of gas in areas of confinement and congestion or should they be placed in proximity to sources of leaks? The 'correct' answer needs to arise from your organization's philosophy on hazard detection and hazard mitigation. Having a sound philosophy (and having it well-documented) will ensure that FGS design is specified consistently from plant to plant, and from facility to facility within the same organization.

The next step in the work flow is to *Define Hazard Zones*. FGS often monitor multiple hazards in distinct and separate zones, which are geographically limited. Zones are defined with regard to specific FGS actions that need to be taken and hazards that are present within a certain area. Zone definition aids in identifying and analyzing performance requirements that are aligned with the hazards within a specific zone. Once the FGS is implemented, well-defined zones aid in rapid identification of hazard location and proper response actions.

The next step in the work flow is to determine *Performance Requirements* for every zone. Consistent with the principles of IEC 61511, we desire to first understand how well the system should perform, and only subsequently endeavor to design a system that achieves that performance. Requirements are set for performance of control system hardware (safety availability targets) as well as hazard detection performance (detector coverage targets). These requirements will give us the design criteria, or targets, that the FGS should meet or exceed in order to acceptably mitigate the identified hazards in each zone.

After the performance targets have been specified, we should select an initial FGS design and *verify* that those performance targets have been achieved. We first *Verify Detector Coverage* using quantitative models to calculate the coverage that is achievable in a zone. This is done by modeling the proposed layout of detectors and comparing that value against the target coverage. We then *Verify Safety Availability* of the FGS functions, which is the probability that the FGS hardware will perform its intended action during an actual demand. This is accomplished by using reliability engineering methods defined in IEC 61511 and ANSI/ISA 84.00.01 standards. The best resource for the techniques and tools for safety availability calculations is the ISA technical report on SIL verification, TR 84.00.02, *Safety Instrumented Functions (SIF)-Safety Integrity Level (SIL) Evaluation Techniques*.

If either the detector coverage targets or the safety availability targets are not achieved, we should modify the initial FGS design and re-analyze. We study coverage maps and availability calculations to determine where the design could be improved. Detector placements are altered or other attributes changed such as component redundancy, test intervals, and even the type of equipment employed, with the goal of improving coverage and availability. We re-run verification calculations and continue this process in a recursive manner until the performance targets have been achieved.

After the performance of the FGS design has been verified, the next step in the work flow is to specify the conceptual design of the FGS. This will be in a set of FGS Requirements Specification documents, similar to a Safety Requirement Specification (SRS) for a traditional SIS. This specification will include detector placement drawings, FGS Cause and Effect Diagrams as well as general requirements for the FGS performance, including proper equipment configuration, system response to fault conditions, and Human Machine Interface (HMI) requirements.

After the FGS has been specified, the detailed engineering phase commences. This lifecycle step includes many work tasks, most of which are not uncommon to any instrumentation and control engineering project. The detailed designers develop Loop Diagrams, Cable Schedules, PLC Programs. Cabinets are designed, and instruments are procured. The control system equipment is assembled configured in the factory. Procedures need to be developed for operating and maintaining the FGS, including testing procedures and other preventive maintenance tasks. Detailed FGS design concludes with a Factory Acceptance Test (FAT) that verifies the functionality of the FGS logic. Throughout this phase of the lifecycle, it is important to conform to the FGS requirements specifications developed in the conceptual design.

After the design is completed, the construction, installation, and commissioning phase begins. This is the step in the lifecycle in which the equipment is installed in accordance with the FGS Requirements Specification. After installation and commissioning has occurred, there is a validation step. This step is sometimes referred to as a site acceptance test (SAT), where the FGS design and functionality will be verified to ensure that it meets the specifications. The fully-integrated FGS will be function tested before completing the SAT.

After the SAT, the system is turned over to site operations and maintenance for day-to-day use. Normal operations will include simple things such as responding to alarms, responding to system fault alarms, periodic function testing, and preventive maintenance tasks. The maintenance tasks ensure that the specified FGS level-of-performance will be achieved throughout the life cycle of the facility.

Finally, Management of Change (MoC) is necessary whenever a modification which could impact the FGS is proposed. Essentially any change that occurs to the facility or to the FGS itself needs to be evaluated and properly authorized prior to being implemented. This, in turn, drives the designers to look back to the appropriate phase in the lifecycle to determine if the proposed change can result in significant impacts beyond the design capability of the FGS. This MoC process ensures that the required performance of the FGS and the actual design will match as changes are made.

Starting Point: Requirement for FGS Evaluation

The FGS safety lifecycle starts with a need to conduct a performance-based Fire and Gas System design. There are many hazard and risk studies that may result in a recommendation to implement a fire and gas system or verify that an existing system is adequate. These studies include Process Hazard Analyses (PHA) such as a Hazard and Operability (HAZOP) study, checklist, or what-if study. The hazard scenarios being considered during these studies may lead to concerns by the study team that certain hazardous conditions should be detected and effectively mitigated. This results in a recommendation for the implementation of, or at least the study of, FGS. Also, other more-detailed risk analysis techniques such as layer protection analysis (LOPA) often recommend that a FGS be evaluated or implemented.

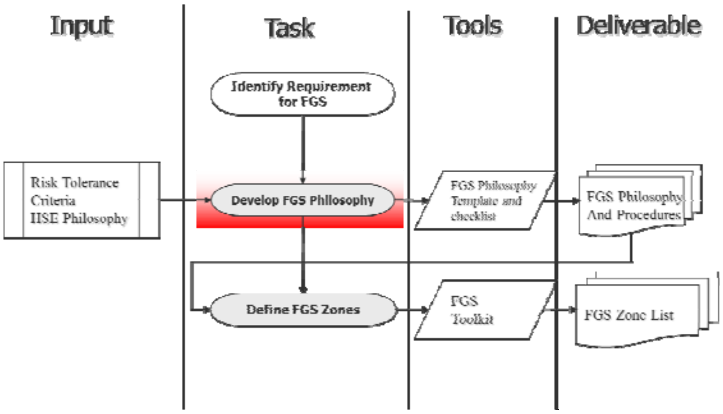
In certain locales, the use of Quantitative Risk Assessment (QRA) is required to obtain a license to operate a process plant. Often, a QRA study may actually assume that a FGS is in place and in operation when they analyze their risk. Worse, the QRA probably assumes a level of performance for the system, such as being “95% effective” in detecting a hazard. The basis of such assumptions is usually undocumented, and the ability of the system to achieve that performance is unknown. Recently, more operators are questioning whether the performance of the existing system is in accordance with the QRA assumptions.

In many cases, FGS in process plants are required by government regulation. Many regulating bodies will prescribe that the operator of certain type of facility, such as a liquefied petroleum gas storage facility, is required to implement some degree of fire and gas detection. There are also industry standards and corporate standards that require the use of FGS for certain types of facilities or certain types of process equipment.

In some cases as insurance carriers audit a facility, they scrutinize the installed FGS, particularly the number and location of detectors. If the auditor believes the system to be inadequate, they will make a recommendation for specific changes or wholesale upgrades. The penalty for not implementing a recommended FGS can range from increased insurance premiums to outright refusal to underwrite the policy.

Regardless of the mechanism that caused the FGS to be recommended, the ISA's Technical Report TR 84.00.07 provides an excellent framework for addressing the recommendation. Whether a complete design of an FGS is required, or simply an assessment to rule out the need for FGS, the ISA TR contains the techniques and framework for FGS decision making.

FGS Philosophy Development



Before your first attempt at a performance-based FGS design, you should develop a sound philosophy for design. This is typically done prior to any specific design activities and need not recur every time a FGS project is undertaken. FGS philosophy is typically established either at the site level or at the corporate level, and then applied consistently to all equipment, processes, and facilities within an organization. Elements of a sound FGS philosophy may be contained in-part or in-whole within a company's design standards for FGS, and it is often developed to support an overall philosophy for fire protection or plant Emergency Shutdown (ESD).

As in any performance-based design, FGS engineering in this context relies on achieving a performance goal or objective, so it is critical to define those objectives before we start. We should understand what hazards should be considered in the design, what magnitude of hazard severity should be detectable, and the criteria for successful system operation when subject to a demand. Therefore, the FGS philosophy includes multiple elements, and a comprehensive list of those FGS Philosophy elements is provided in *Appendix C*. The most-critical elements are further discussed here.

One main purpose of the FGS philosophy is to standardize the methods for characterizing the hazards which should be prevented/mitigated by the FGS. The FGS Philosophy should include criteria for *hazard identification*. For example, criteria should be established to determine whether or not specific process equipment presents a hazard that requires FGS detection. These criteria might include considerations such as composition of the material that is contained in the process equipment, flammability data, toxicity data, molecular weight and the operating conditions (such as temperature and pressure) at which the material is being processed. Using these criteria, the hazards associated with an equipment item or an area can be determined, which is necessary for a performance-based FGS design. For example, the FGS philosophy should establish criteria for combustible gas detection to be evaluated when storing or processing a material that has a flash point below a threshold value, such as 100 F (37 C).

These hazards then need to be evaluated, and the FGS Philosophy is important in understanding how the evaluation should proceed. Fire and Gas Systems are most-often used to *mitigate* a hazard – rather than *prevent* a hazard; therefore a couple of decisions need to be made:

- What level of hazard severity or risk rises to the level that warrants any FGS detection and mitigation? What severity warrants a *high* FGS performance… requires *medium*-level performance, or only requires a *low* / minimal level of FGS performance?

- What magnitude of hazard should be detectable? Is incipient-level hazard detection needed?

The first question requires establishing the degree of hazard or risk that we are trying to mitigate with an FGS design. A sufficiently low risk may not require detection and mitigation, whereas significant risks may warrant detection and mitigation at a high level of performance. For example, a small hydrocarbon fire that goes undetected could escalate into a large, uncontrolled fire with attendant loss-of-life and major asset damage. Due to inadequate detection, a flammable vapor cloud could grow to a size that could result in a severe blast if ignited. Your FGS philosophy should define the analysis needed to establish FGS detection requirements and performance requirements. The philosophy should detail the criteria and procedures used to categorize these risks and to select *performance requirements* for FGS hazard detection and mitigation. It will be important to document to what degree personnel safety and/or asset protection wre considered when making decisions regarding which hazard criteria require detection and those that do not require detection. These techniques are discussed in a later section in this handbook.

Once the need for FGS detection is established in a project, we will need to make allowances for or permit some severity of hazard to remain undetected. Practically speaking, not every hazard will be detectable, especially if the severity is quite small. A very small fire may need to grow to a size that is sufficient to warrant detection, preferably well-below the severity that could cause hazard escalation. A very small toxic release could result in a localized hazard, for which it is impractical to locate sufficient numbers of fixed toxic gas detectors. Your FGS Philosophy will need to establish the objective of the detection system, as well as the size / magnitude of a hazard that requires detection. For example:

- Detect a threshold 50 kW hydrocarbon fire (equivalent to 1 ft x 1 ft liquid pool fire) through an incipient-level fire detection system. The objective is to provide early warning and effect proper automatic ESD or manual response.

- In normally unmanned facilities, design only for asset protection in the event of fire. Detect and suppress a 500 kW hydrocarbon fire before it can result in asset damage beyond the area or origin. No incipient level fire detection required in such instances.

- Detect a threshold 5 meter combustible gas accumulation in any area of an offshore platform that has a significant degree of confinement or equipment congestion. The objective is to prevent accumulation of gas at or above the size that could result in a severe vapor cloud explosion / blast.

- Detect a toxic gas release from a pinhole leak (3 mm equivalent hole diameter). The objective is to provide early-warning to personnel to take precautionary actions.

- Detect any combustible gas release of any size / extent before it migrates beyond the immediate unit or operating area. The objective is to minimize the chance of ignition of a combustible gas cloud in areas where ignition sources are not well-controlled.

Of course, some of these scenarios could be defined by other hazard and risk studies, such as a fire hazard analysis for the purpose of establishing passive fire protection requirements or a Quantitative Risk Analysis (QRA) of process hazards. Be careful, however, since most of these studies do not evaluate *incipient-level* hazards, but rather *major accident* hazards. Establishing fire and gas detection requirements from such studies may result in detectors being positioned to only detect large-scale hazards, and it may result in loss of early FGS detection capability, which is critical to successful hazard mitigation.

In addition to setting up the methods by which the FGS design is to be analyzed, there are many practical FGS design considerations that the philosophy should address. Often these choices are best made by use of internally-consistent heuristics, or rules of thumb, which can be applied consistently from project to project. These include:

- Criteria for how to define zones of detection, what the boundaries of those zones should be, and to establish clear communication of the detected hazard and the appropriate response action.

- Criteria for selecting detector technology that is most appropriate for detecting fires or gas release. For instance, rules for when to use frangible bulbs or bimetallic heat detectors as opposed to optical fire detection equipment.

- How events are alarmed, when they are alarmed, and the behavior of those alarms in terms of audible annunciation and visible signaling.
- When manual activation is required and where those manual activation systems or manual alarm call points (MAC) will be installed.
- How to vote detection equipment when FGS executive actions are required such as ESD or deluge, thereby reducing the likelihood of spurious activation.
- Criteria for selecting which setpoints are going to be used first to activate alarms, and then higher detector set points for FGS executive to be taken.

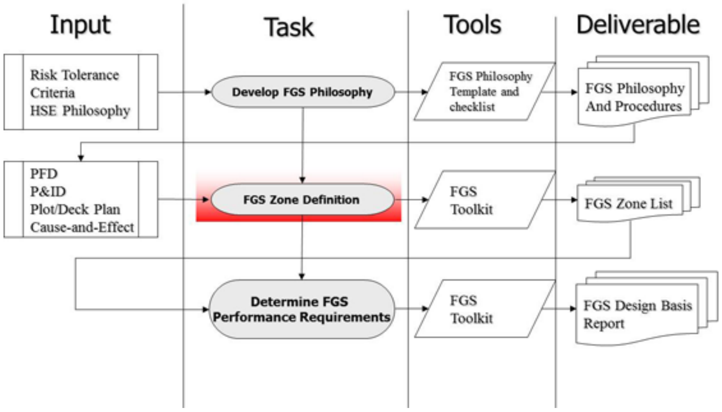
There are a few procedures that will necessarily arise from the development of the FGS philosophy, including:

- A *hazard identification* procedure, which guides what hazards require evaluation of FGS detection requirements.
- A procedure for *defining zones* and extents of those FGS zones
- A procedure for establishing FGS *performance targets* for the equipment and the associated zones

- Rules, procedures, and standardized tools for assessing and verifying that the performance targets have been achieved for both *safety availability* and *detector coverage*

These procedures are needed for a performance-based FGS design, and they ensure that a consistent design philosophy is used from equipment-to-equipment, unit-to-unit, and between facilities. All should be defined prior to going into any project, and this should be done at a higher level in the organization and then consistently applied across all equipment and all facilities. Make sure your FGS philosophy is well-though-out and approved by key stakeholders *before* you embark on your first performance-based FGS design.

Definition of Fire and Gas Zones



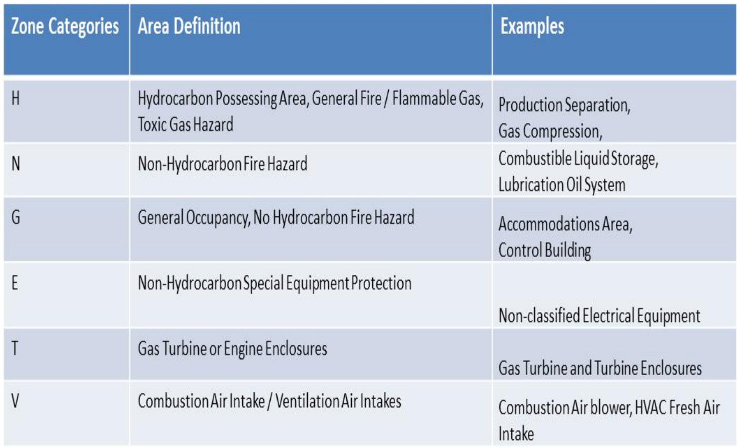
The next step in the work flow is the definition of zones. Before starting zone definition, it is essential to have a good understanding of the hazardous materials and their properties, the process equipment, and the operating conditions. This will require having specific engineering documents, including: Process Flow Diagrams (PFDs), Material Safety Data Sheets (MSDS), Piping and Instrumentation Diagrams (P&IDs), and facility Plot Plans showing where equipment is physically located. These documents will allow the design team to define hazard zones based on geographic location of the equipment as well as the hazards that are present. The result of this task will be the zone list for design of the FGS.

Zone definition is important because different areas in a facility have different hazards with varying levels of severity or risk. There may be process areas with toxic hazards (e.g., hydrogen sulfide, etc.) that are distinct from other process areas that have only fire or combustible gas hazards. Even without the presence of toxic hazards, some process areas may have only hydrocarbon liquid fire hazards while other areas may be prone to volatile gas releases. Each area may require different types of FGS detection as well as different levels of *performance* to mitigate those hazards. In each of these process zones, the FGS design objective is to provide general coverage of hydrocarbon fire and gas hazards. We call this the “area coverage” objective.

In addition to area coverage, we also need to identify non-process locations, such as occupied buildings or buildings containing unclassified electrical equipment, where we may need to provide protection from gas migration and ingress from adjacent process areas. This could involve protection for combustible gas ingress, toxic gas ingress, or both. The intent is to prevent the migration of combustible gas or toxic gas hazards from the process area to non-process areas where they can either impact humans or be ignited by electrical equipment. The FGS design objective is to “segregate” a process area from a non-process area. At this point, we only need to develop a list of all locations that should be studied, not make decisions about detection requirements needed to fulfill the “segregation” design objective. When developing a list of such areas, it is important to identify points-of-ingress such as HVAC air intakes or doorways.

Understanding what hazards are present will help define the zones, segregate the zones from each other, and establish performance targets for each zone. In addition, good zone definition will allow rapid and effective communication of the detected hazard and enable personnel to take proper precautionary actions.

Once all of the candidate zones have been defined, the next step is to categorize them. The categorization will aid in the selection of the appropriate techniques that should be employed for design. The zone categories we use in *performance-based* FGS design are shown in *Figure 3* (see *Appendix D* for more details). These categories define different attributes of a process zone that will guide us in how to design FGS.



Zone Categories	Area Definition	Examples
H	Hydrocarbon Possessing Area, General Fire / Flammable Gas, Toxic Gas Hazard	Production Separation, Gas Compression,
N	Non-Hydrocarbon Fire Hazard	Combustible Liquid Storage, Lubrication Oil System
G	General Occupancy, No Hydrocarbon Fire Hazard	Accommodations Area, Control Building
E	Non-Hydrocarbon Special Equipment Protection	Non-classified Electrical Equipment
T	Gas Turbine or Engine Enclosures	Gas Turbine and Turbine Enclosures
V	Combustion Air Intake / Ventilation Air Intakes	Combustion Air blower, HVAC Fresh Air Intake

Figure 3 – Zone Categories

Category H zones are areas that process hydrocarbon liquids or gases. They contain leak sources that may result in hydrocarbon fire hazards or combustible gas hazards. These zones may also have toxic gas hazards if toxic materials are being processed in that area (e.g., hydrogen sulfide, or H2S). Examples of this type of zone include a separator area on an oil and gas platform, a natural gas compression area in a gas plant, or an oil distillation process in a petroleum refinery. Category H zones will be evaluated using *performance-based* FGS design methods described in this handbook.

The next zone type is Category N. While these are still process areas that may contain fire hazards, they are non-hydrocarbon fire hazards. This type of zone could include hazardous materials such as methanol storage tanks, or lubricating oil systems for turbo-machinery. The reason that these zones should be separated from hydrocarbon process areas is because the sensors that are used to detect these fires and gas releases may be different from those that would be used in traditional hydrocarbon processing areas. In addition, it is appropriate in some cases to apply engineering rules-of-thumb or heuristics to specify detection requirements rather than use performance-based FGS design techniques for Category N zones.

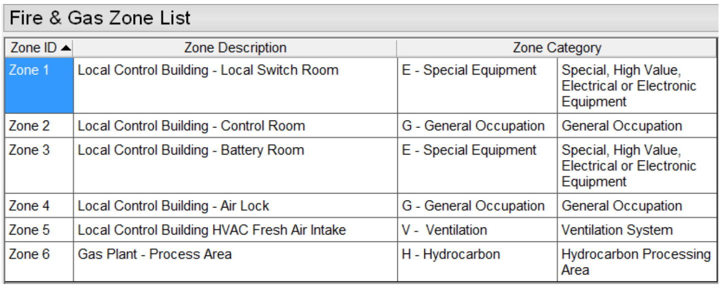
The next type of zone is Category G. This classification is reserved for areas of "General Occupancy" where there is no hydrocarbon fire hazard. This would include occupied buildings like accommodation areas on oil and gas platforms, control buildings, workshops in process areas, and any other buildings in non-process areas that are normally occupied by people. In Category G areas, fire detection is provided using prescriptive rules per the applicable national fire code.

The Category E zone is reserved for non-process areas with electrical equipment protection. This is typically a zone of unclassified electrical equipment. This would include motor control centers, instrumentation and electrical buildings, analyzer shelters, and marshaling rack rooms. In all cases, these locations require evaluation of the potential for hydrocarbon gases to migrate from a process area and ingress into the unclassified area, which would pose a credible source of gas cloud ignition. In addition to providing appropriate detection of electrical equipment fire hazards, the primary *performance-based* FGS design objective is to provide adequate “segregation” of these areas. This may require combustible gas detection at doorways or HVAC air intakes.

Zone Category T is dedicated to turbine enclosures or engine enclosures. These types of areas have very specific, and in some cases, very prescriptive requirements for the type, installation, and configuration of the fire and gas equipment that is employed. The need for “segregation” to prevent combustible gas ingress may need to be studied, but fire protection requirements are usually prescribed by the vendor of this packaged equipment.

Finally, we develop a list of areas, technically also considered Zones, designated as Category V. These include ventilation air intakes, and occupied or occupiable buildings. It also includes other points of ingress for gas to enter an occupied area, such as air locks or single, normally-closed doorways. In Category V, the *performance-based* FGS design is primarily concerned with “segregating” the process area hazards of flammable or toxic gases and preventing those hazards from migrating into an occupied or occupiable building.

The result of the zone definition is a zone list similar to the one shown in *Figure 4*. The complete list of candidate zones for a facility is created during this task. The zone list should include identification of the zone, typically a tag number that defines the zone, with a verbal description that contains context describing where the zone is located and what the zone contains. The FGS zone list should also include the selected zone category, as well as some of the attributes of the zone that justify the selection of the chosen category.

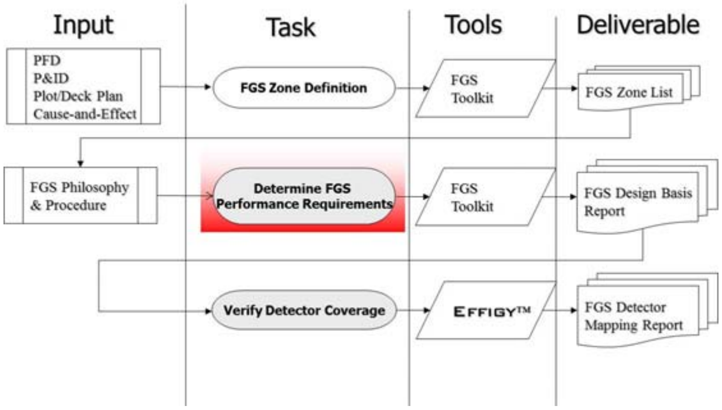


Fire & Gas Zone List

Zone ID ▲	Zone Description	Zone Category	
Zone 1	Local Control Building - Local Switch Room	E - Special Equipment	Special, High Value, Electrical or Electronic Equipment
Zone 2	Local Control Building - Control Room	G - General Occupation	General Occupation
Zone 3	Local Control Building - Battery Room	E - Special Equipment	Special, High Value, Electrical or Electronic Equipment
Zone 4	Local Control Building - Air Lock	G - General Occupation	General Occupation
Zone 5	Local Control Building HVAC Fresh Air Intake	V - Ventilation	Ventilation System
Zone 6	Gas Plant - Process Area	H - Hydrocarbon	Hydrocarbon Processing Area

Figure 4 – Example FGS Zone List

Fire and Gas Performance Targets



The next step in the workflow is to determine the FGS *performance requirements*. This is a key step in performance-based FGS engineering. Before specifying any details of the design, it is important to first specify how well the system should perform. In this context, *performance* means the ability of the system to reliably detect the hazard of concern and take the proper safety actions to mitigate that hazardous condition. Without specifying an adequate level of performance the system may not be capable of achieving those objectives. Of course, no engineering system is ever 100% dependable, so it is important to specify *how much* performance we require; or conversely, to what degree will we tolerate an FGS failure to detect and mitigate?

As described by the ISA's Technical Report, the two primary modes of FGS failure are:

- Inadequate Coverage. Insufficient number, type, or location of fire or gas detectors resulting in a hazard that is not detected by the FGS.

- Inadequate Safety Availability. Component failures of FGS hardware that result in the FGS being in an unavailable state when a demand condition arises.

In order to ensure adequate performance, requirements should be defined in terms of both FGS *detector coverage* and FGS *safety availability*. Selecting these performance targets for fire and gas systems is essentially an exercise in hazard and risk analysis. Fire and gas hazards / risks are analyzed for process equipment in a specific area, and then performance targets are selected that will reduce those risks to tolerable levels. To do this, we need a model that will define the degree of hazard / risk, as well as allow us to examine how various levels of FGS performance will mitigate the hazard and reduce risk to tolerable levels. Therefore, the risk model needs to be sensitive to both the coverage that is provided by the FGS detector array as well as the reliability associated with the FGS components.

The simplified risk model in the ISA's Technical report is shown in *Figure 5*, and it illustrates the need to evaluate both *detector coverage* and FGS *safety availability*. In concept, we need to provide sufficient performance for both detector coverage (measured as a probability of successful detection) and FGS safety availability in order to achieve a tolerable situation. To the extent that a hazard is more severe or the likelihood is greater, we will require more coverage and availability to achieve a tolerable risk. To the extent that a hazard is less severe and less likely, for lower performance is acceptable to achieve our risk goals. Tolerability of risk decisions are outside the scope of this handbook, but are usually defined on a company-by-company basis using corporate risk guidelines.

The benefit of the FGS is defined as *Mitigated Risk*, which represents the likelihood of an FGS-mitigated consequence.

The risk of FGS failure is defined as *Residual Risk*, which represents the likelihood that the FGS fails to detect or take the required mitigation actions.

The *Effectiveness* of the FGS is represented as the product of probabilities associated with *Detector Coverage* and FGS Safety Availability. This *Effectiveness* can be viewed as the degree to which the consequence has been successfully mitigated.

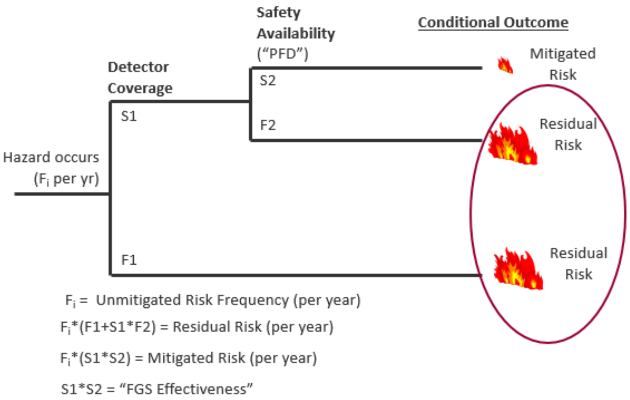


Figure 5 Simplified Risk Model for FGS Engineering

When specifying performance targets, it is necessary to understand the hazard we intend to mitigate, the severity of the *consequences*, and the *likelihood* of the hazard. Although related, the analysis needs to separately consider hydrocarbon fire hazards, combustible gas hazards, and toxic gas hazards. This is because different performance requirements may arise for these different means of hazard detection.

The analysis should evaluate the hazards for which the FGS will be designed. The *FGS Philosophy Document* should identify the FGS design objectives and the severity / magnitude of hazards that are intended to be detected. Very small hazards may not require detection until they achieve a threshold size. Conversely, we should consider that the FGS may not be effective in taking action in the event of large-scale or catastrophic hazards; but, rather, the FGS will be most effective in taking action when there is an incipient-level hazard that has the potential to escalate into a large-scale or major-hazard event. Therefore, the hazard / risk analysis for FGS design should evaluate hazards scenarios that are in line with these intended design objectives.

When evaluating the severity of hazards, the analysis should take into account variables such as the type of equipment employed in the process, the material present in the equipment, and the operating conditions such as pressures and temperatures. All of these factors will affect the magnitude of the consequence, or the size of the fire or gas cloud. Likelihood estimates should take into account the equipment in the zone. Equipment such as pumps and compressors have a much higher likelihood to develop a leak than fixed equipment, such as pressure vessels or welded piping. The analysis should also evaluate factors that could aggravate or mitigate the degree of hazard / risk. These include the degree of human occupancy in a zone, the presence (or absence) of ignition sources, and the value of assets being protected in the zone if the objectives include commercial loss prevention in addition to safety.

Analyzing these factors and using our risk model will enable the selection of the performance targets for certain equipment or an entire zone, specifically the targets for safety availability of the fire and gas loops and the coverage of the fire and gas detector array. There are two common approaches to selecting these performance targets: *semi-quantitative* and *fully quantitative*.

> Semi-quantitative approaches: have a level of effort similar to Layer of Protection Analysis (LOPA). They use lookup tables and “order of

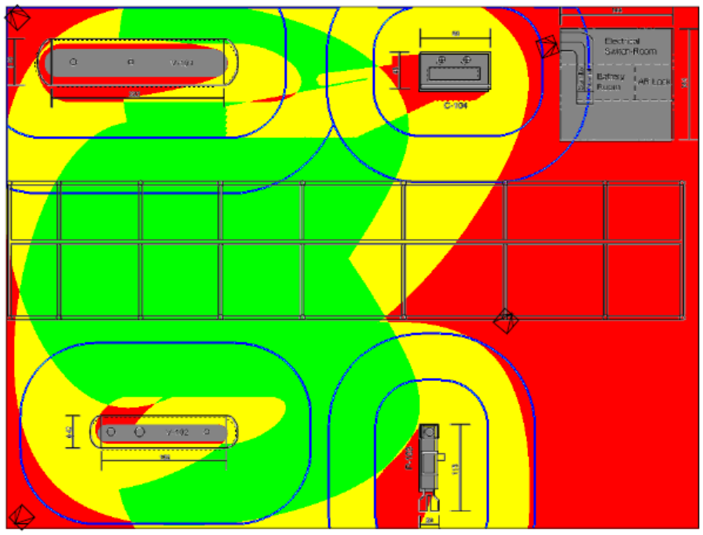
magnitude" selections to categorize various risk parameters and thereby establish the needed performance requirements. These semi-quantitative techniques need to be calibrated to ensure that these coarse level-of-effort tools provide satisfactory results. The calibration verifies the user's risk tolerance criteria have been satisfied when applying the technique.

Fully quantitative risk analysis: verifies that quantitative risk tolerances have been achieved using detailed quantification of the hazard and risk. While the fully quantitative analysis provides more accurate results, they are also extremely time consuming and can be very expensive. As a result, wherever possible we recommend using semi-quantitative approaches that have been calibrated using quantitative risk analysis techniques.

Regardless of the method chosen to determine the performance targets, the same types of performance targets will be defined: *detector coverage* and *safety availability*.

In advance of selecting the method, we should consider what type of detector coverage evaluation will be used. ISA Technical Report TR 84.00.07 defines two types of coverage that may be evaluated: geographic coverage and scenario coverage.

Geographic Coverage is a type of coverage which essentially asks what fraction of a geographic area is being monitored by a fire or gas detector array. This type of coverage determines whether or not the detector array would be able to detect a specific size / magnitude of hazard if a fire or a gas release were to occur in a specific location. Geographic coverage is usually presented in terms of a color-coded map in addition to tabular results. For instance, the color-coded map might show red where no detectors can see the fire, yellow where only one detector can see the fire, and green where two or more detectors can see the fire (see the example fire detection coverage map in *Figure 6*). That map will typically also be supplemented with tables reporting the coverage calculated in terms of percentages. Percentages are provided for the monitored areas that have no coverage, one detector coverage, or two or more detector coverage. When specifying performance requirements using *semi-quantitative* techniques, geographic coverage is used to compare achieved coverage with target coverage.



Coverage		Color Code
2 Detectors	35%	🟩
1 Detector	25%	🟨
No Detectors	40%	🟥

Figure 6 – FGS Fire Detector Geographic Coverage

The second type of detector coverage is *Scenario Coverage*. Thus far in the discussion of geographic coverage techniques, the relative likelihood of a fire or gas release in any specific location within a monitored area was not considered. The only factor that was determined was essentially “what can the detector see”. We ignored locations where fires and gas releases are more likely to occur, and thus where we might preferentially need to locate detectors. In reality, these factors are not being ignored but are evaluated when considering *scenario* coverage.

When calculating *scenario*-based coverage, the location, magnitude and likelihood of specific hazard scenarios are evaluated. Scenario coverage is the appropriate metric when performing a fully quantitative analysis of performance targets. For each of those hazard scenarios (which can number into the dozens or hundreds), we calculate how many fire or gas detectors can detect the scenario. The outcome of the scenario coverage analysis will essentially be a visual map that depicts where the hazards can occur as well as showing where we have good coverage versus where we are lacking coverage. This is similar to a geographic risk contour in the context of Quantitative Risk Analysis (QRA). With respect to performing coverage calculations, there will also be a tabular calculation of the fraction of the hazard scenarios that are: not detected, detected by only one detector, and detected by two or more detectors. These fractions are weighted by the frequency of the hazard scenario to yield an accurate representation of the risk reduction. The percentage of detected scenarios is reported as the ‘scenario coverage’.

In addition to calculating coverage and setting performance targets for coverage, we recommend establishing performance targets for the probability of failure on demand of the equipment that comprises the instrumented fire and gas function. In a slight contrast to the pure SIL concept of IEC 61511, the ISA 84.00.07 technical report defines that the metric be achieved in terms of safety availability, not SIL. *Safety Availability* is more appropriate than SIL as a performance metric for several reasons. Very high SIL targets such as SIL 3 and SIL 4 are entirely inappropriate for FGS design in general area coverage applications where detector coverage exceeding 90 to 99% is not feasible. After considering detector coverage, the difference between the probability of failure allowed for a SIL 2 function and a SIL 3 function is not likely to be significant in the overall risk. Even the achievement of SIL 2 for a single fire and gas system loop is not expected to reduce the probability of failure of the overall loop because this component of the loop is imperceptibly low in relation to all the other risk factors. As a result, trying to achieve even better performance for the probability of failure on demand is essentially a waste of resources.

Second, in SIS engineering, SIL represents a measure of the amount of risk reduction for a Safety Instrumented Function. However, this does not translate to an FGS function which provides hazard mitigation, not prevention. Reducing the probability of hardware failure is not directly proportional to risk reduction because the successful activation of an FGS function still results in a reduced but measurable hazard. Therefore, the term *Safety Availability* properly describes the probability of the equipment functioning properly on a demand, but it does not connote actual risk reduction.

Fully Quantitative Approach

In order to understand the different approaches for setting performance targets, it is best to start with the fully quantitative approach. This is true not only for fire and gas system design, but also for safety instrumented systems design and risk analysis in general. It becomes easier to look at a semi-quantitative approach by understanding what simplifications have been made to the fully quantitative approach. It also assists in understanding why the simplifications will still result in a risk calculation that provides an effective design, although the amount of effort expended on the risk analysis is an order-of-magnitude smaller.

The first step in the fully quantitative analysis is to identify the hazard scenarios. The hazard scenarios include all credible loss of containment scenarios. This requires looking at each piece of equipment that has potential for loss of containment, including vessels, tanks, process piping, flanges, instruments, valves, pumps, compressors, heat exchangers, etc. Next, it is necessary to identify the process-specific factors that affect the release scenario, or define the magnitude of what we refer to as the *source term* in quantitative risk analysis. These factors will include: the leak size, the location of the equipment, the orientation of the release, the phase of the release (is it a liquid, a gas, or a two phase release), process pressure, process temperature, and vapor-liquid equilibrium data to determine if a liquid will pool, and if that pool will volatilize.

The fully quantitative approach uses rigorous mathematical models to estimate the severity of the consequence that can occur. The consequences are characterized by source term modeling, which defines the characteristics of a liquid, vapor, or two-phase release from containment. The source term is then analyzed using fire modeling or gas dispersion modeling to determine the size / extent of the hazard that could result. Momentum driven jet fires or pool fires are evaluated to determine the capability to be detected by fire detection. Gas dispersion models help us understand the capability to detect a gas cloud. Vapor cloud fire / explosion models may also be used to determine the worst-case impact on people and equipment. The impact on personnel due to exposure to toxic materials is similarly assessed using toxicology data.

In order to understand the potential benefit of FGS detection / mitigation, we need to evaluate severity for both an unmitigated fire and a mitigated fire. Similarly we evaluate the severity of both an unmitigated gas release and a mitigated gas release. To do this, we consider the potential benefit of the FGS in its ability to reduce several factors:

- Reduced release duration / quantity
- Reduced fire intensity due to active fire suppression
- Reduced duration of toxic gas exposure
- Reduced probability of vapor cloud ignition

As illustrated in *Figure 5*, these severity calculations will be important to understanding the *Mitigated Risk* and *Residual Risk*.

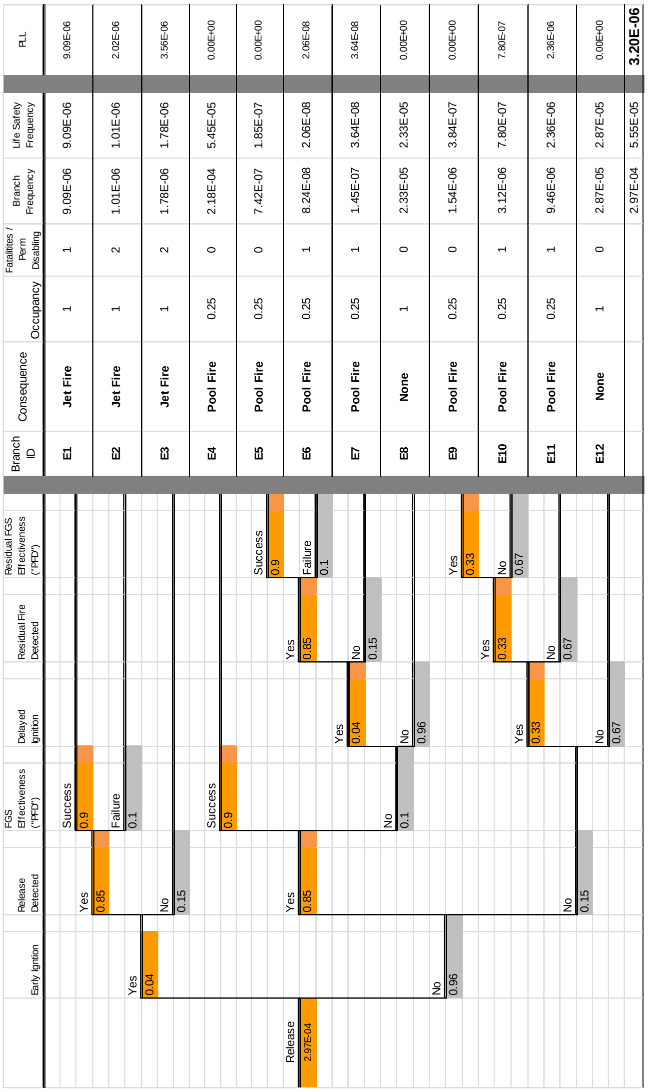
When performing this analysis, some release scenarios may be determined to have an extremely low likelihood or extremely low severity consequence, at which time these scenarios can be noted as negligible without further consideration. This simplifies the analysis and decreases the amount of time required to perform the analysis. The result of this task is a detailed list of all the release scenarios with enough detail for a consequence analysis and a likelihood analysis to be undertaken. For each of the release scenarios, a list of the potential incident outcomes such as jet fires, flash fires, vapor cloud fires, and pool fires is identified. *Appendix E* contains tables of the geographic extents (a.k.a., “footprint”) of a range of typical loss of containment scenarios.

The likelihood of releases is calculated, but in a way that is different than many would expect, especially those with a background in techniques such as Layer Of Protection Analysis (LOPA). For FGS risk analysis, it is not assumed that all the causes of loss of containment can be well-defined using LOPA. We assume that LOPA techniques should have adequately reduced those risks using hazard prevention and the application of Independent Protection Layers. FGS hazard <u>mitigation</u>, on the other hand, is used to control those risks that are not well-defined or not adequately reduced using Independent Protection Layers and LOPA. Instead of trying to calculate how frequently a release will occur based on a set of known initiating events, we use statistical techniques that describe the frequency of loss of containment. A statistical / probabilistic technique is used to estimate future release frequency based on historical data, such as the offshore release statistics from the UK Health and Safety Executive, or the CCPS Process Equipment Reliability Database (PERD). While there are some openly available sources that can be of use, ultimately these analyses need to be applicable to the facility that is under study. For each type of equipment under study, the likelihood of small leaks, medium leaks, and large leaks should be considered, but only in the context of releases that could have the potential to escalate to higher severity events were it not for the benefit of the FGS. In industry databases, the hole size distribution is typically presented as percentages of the leak rates that manifests as ranges of equivalent diameter hole, commonly 5mm, 25mm, 75mm, and rupture / full diameter.

Based on historical failure data from industry, these statistics are applied to determine the estimated likelihood of a leak and to predict statistically the distribution of leak sizes that could occur. This use of historical statistics is in marked contrast to LOPA, which is a fault propagation model to estimate hazard likelihood. *Appendix F* contains tables of some equipment leak frequencies and a distribution of leak sizes.

After the consequences and the likelihood are estimated, a risk integration task is performed. Risk integration is the process by which consequence and likelihood are aggregated for all possible scenario outcomes to calculate the overall risk for a piece of equipment. During the risk integration, each event outcome is correlated with its associated level of consequence severity. *Event Trees* are then used to analyze each incident outcome, including modification of the risk posed by each incident outcome using the various aggravating or mitigating factors. Aggravating / mitigating factors are based on the site-specific factors and these factors include the probability of release *ignition, occupancy* of personnel in the hazard area, *toxicity* of the released gas (if applicable), and the *degree of confinement / congestion* which could promote a vapor cloud explosion. Each of the event outcomes is integrated using a risk integration tool for a fire and gas zone, or possibly overall for a facility. For each scenario outcome, there is a frequency of occurrence, a consequence associated with occurrence in terms of life safety frequency and equipment damage, and a zone size or a zone “footprint” for the hazard. Each of the scenario outcomes, which can number hundreds or thousands, needs to be combined using the risk integration tool.

Detector Coverage and *Safety Availability* are incorporated into the overall risk analysis, as shown in the risk integration Event Tree in *Figure 7*. The event tree shows the progression of a scenario from the initial loss of containment appearing on the left all the way through all of the potential incident outcomes on the right. The event tree calculation begins with a loss of containment event or release and its associated frequency. Subsequently, aggravating / mitigating factors are considered. In the case of *Figure 7*, probability of *ignition*, *detector coverage*, and FGS *Safety Availability* are all considered. *Figure 7* shows selected performance targets of 85% for detector coverage (in this case *scenario*-based coverage) and a FGS *Safety Availability* of 90%. Using these values, along with the consequence associated with each branch, risk metrics can be calculated for each branch. These metrics are summed across all branches to obtain overall risk results for the scenario. Those risk metrics can then be compared against the tolerable risk targets. If the risk target is achieved, then the selected FGS design is adequate. If not, then the *Detector Coverage* and/or *Safety Availability* should be increased. This may require a corresponding FGS design change. This process of achieving performance targets begins by selecting areas with poor performance and progressively increasing the amount of detectors and the safety availability of the FGS until the tolerable risk target has been achieved. This entire process occurs in a recursive fashion.



Branch ID	Consequence	Occupancy	Fatalitites / Perm Disabling	Branch Frequency	Life Safety Frequency	PLL
E1	**Jet Fire**	1	1	9.09E-06	9.09E-06	9.09E-06
E2	**Jet Fire**	1	2	1.01E-06	1.01E-06	2.02E-06
E3	**Jet Fire**	1	2	1.78E-06	1.78E-06	3.56E-06
E4	**Pool Fire**	0.25	0	2.18E-04	5.45E-05	0.00E+00
E5	**Pool Fire**	0.25	0	7.42E-07	1.85E-07	0.00E+00
E6	**Pool Fire**	0.25	1	8.24E-08	2.06E-08	2.06E-08
E7	**Pool Fire**	0.25	1	1.45E-07	3.64E-08	3.64E-08
E8	**None**	1	0	2.33E-05	2.33E-05	0.00E+00
E9	**Pool Fire**	0.25	0	1.54E-06	3.84E-07	0.00E+00
E10	**Pool Fire**	0.25	1	3.12E-06	7.80E-07	7.80E-07
E11	**Pool Fire**	0.25	1	9.46E-06	2.36E-06	2.36E-06
E12	**None**	1	0	2.87E-05	2.87E-05	0.00E+00
				2.97E-04	5.55E-05	**3.20E-06**

Figure 7 –Event Tree for Fully Quantitative Analysis

The outcome of the fully quantitative analysis is the calculation of the overall probable loss of life (PLL) for the area under study. The results will typically also include such outputs as the risk profile prior to mitigation by the FGS, the risk profile after mitigation by the fire and gas system, the achieved scenario coverage of the detector array, and the safety availability of the FGS function. The risk analysis outcome should be presented in a tabular format to determine if the coverage targets have been achieved. *Figure 7* is oversimplified for conceptual demonstration only, and an actual project would require many such event trees that cover the span of equipment being monitored by the FGS.

After calculating the <u>achieved</u> coverage and <u>achieved</u> safety availability (as described in subsequent sections) the risk integration can be redone using those achieved values in the appropriate coverage and availability branches of the Event Tree. The calculated risk from the existing FGS design is compared against the company-specific risk tolerance criteria. If the risk is tolerable, then the design should be considered acceptable. However, if it is determined that the risk with the existing design is not tolerable, a recommendation for a modified FGS should be made in order to reduce risk to tolerable levels.

After a preliminary FGS design has been proposed (either the design of an existing system or a “first pass” detector placement by an experienced FGS Engineer using design heuristics), all of the defined hazard scenarios need to be re-examined using the scenario coverage techniques and the calculation of safety availability to determine the beneficial effect that the FGS has on achieving the overall tolerability of risk targets. The analysis will result in either a tolerable level of risk being achieved or, if the tolerable level of risk is not achieved, the FGS design will need to be modified again. Redesign proceeds with the identification and modification of the weak points in the current design and then reanalysis in a recursive fashion until tolerable risk levels have been achieved.

Semi-Quantitative Approach

With the knowledge of the fully quantitative approach, we can better understand the semi-quantitative approach and the underlying simplifications. The semi-quantitative approach results in a process that most practitioners feel is much more efficient while providing reasonably accurate FGS design results. This is true provided that the fully quantitative risk analysis techniques have been used to calibrate the semi-quantitative parameters. The semi-quantitative approach analyzes the risk that equipment poses using calibrated risk assessment tables that define factors associated with the frequency and magnitude of hazards associated with equipment in a given zone. The risk factors are ranked or scored by the team or person performing the study. The factors considered typically include the following:

- *Likelihood* of a release based on the type of equipment

- *Consequence* of release scenarios based on equipment operating temperature and pressures and the composition of the material contained in the equipment

- *Aggravating / Mitigating Factors* that will either decrease or increase the risk in the event of a loss of containment within the zone.

Once the score has been selected for each these categories used in the semi-quantitative approach, the scores will be used with a calibrated risk tool to determine a *Hazard Grade*. The hazard grade represents the degree of hazard or risk associated with the equipment within an FGS monitored area or zone. The hazard grade will directly correlate to FGS performance targets (coverage and safety availability) that reduce risk to tolerable levels. For instance, a typical set of zones are Grade A, Grade B and Grade C, with A representing a very high hazard / risk, and C representing a low hazard / risk. The high risk may require 90% geographic coverage and 95% safety availability while the low risk grade C might only require 60% geographic coverage and 90% safety availability to achieve tolerable risk goals.

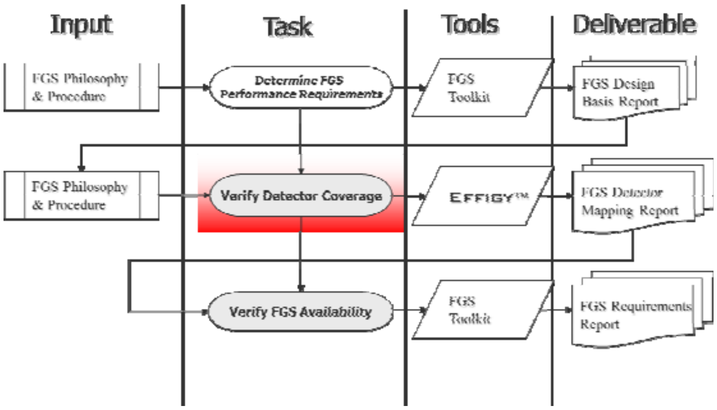
The primary factor that determines if a semi-quantitative approach ensures that tolerable risk levels are achieved is a detailed and comprehensive calibration of the tables and the performance targets that are used in the semi-quantitative approach. This calibration will ensure that when a Grade C is selected, the associated safety availability and coverage targets will allow tolerable risk to be achieved. This calibration process is typically performed by doing a fully quantitative analysis of typical process zones that have been assigned preliminary performance targets or zone grades. Once several typical zones have been assessed using the fully quantitative approach and the semi-quantitative approach, the results can be compared.

If the results are different, then the scoring factors and performance targets of the semi-quantitative approach need to be recursively adjusted until the fully quantitative and semi-quantitative approaches yield the same results.

It should be noted that the semi-quantitative technique and the calibration process are based on *Geographic Coverage* as opposed to *Scenario Coverage*. This approach is acceptable because it has been verified through numerous fully quantitative risk calibrations. As the calculation for geographic coverage is significantly easier to perform than scenario coverage, most organization's performance based fire and gas philosophies recommend the use of geographic coverage as opposed to scenario coverage.

An example of a typical semi-quantitative performance target selection approach, complete with a table of typical grades and performance criteria, is presented in *Appendix G*.

Verifying Detector Coverage



The next step is verifying that the FGS detector coverage target has been achieved. The result of this analysis will be a visual fire and gas map that provides a color-coded definition of which areas are covered and the degree to which they are covered, as well as tabular information that defines the calculated coverage in a monitored area. We highly recommend performing coverage verification calculations using a computer-aided fire and gas mapping software. This is because manual methods can be extremely time consuming while still yielding poor results. See *Appendix I* for a detailed discussion of fire and gas mapping software.

Performance verification is not a new concept to safety critical control systems. This is required under the ANSI/ISA 84 standard and IEC 61511 Standard for designing Safety Instrumented Systems. However, the addition of detector coverage is a significant and fundamental difference between the ISA Technical Report TR 84.00.07 and the IEC 61511 standard. While *Safety Availability*, which corresponds to the Safety Integrity Level (SIL), is still considered for FGS Engineering, *Detector Coverage* represents a new metric that must also be weighed when designing a system. *Safety Availability* cannot be relied upon as the sole metric or even the primary metric for FGS performance verification. This is because the most FGS failures are not attributed to the electronic equipment itself, but rather the failure of a sensor to be in a location where it will be able to detect a gas release or a fire. This could result in either a hazard not being detected by any detectors or an inadequate number of detectors in place given the specified voting scheme.

Ignoring detector coverage may very well lead to the failure of an FGS designed even to the highest level of integrity or *safety availability*. An important statistic generated by the UK Health and Safety Executive (HSE) was that more than 30% of major gas releases in North Sea oil and gas production platforms were not detected by the fixed gas detection systems. This strongly indicates that there is a coverage problem with FGS detectors as opposed to an integrity problem with FGS hardware.

In order to ensure that the detector layout is adequate, the achieved coverage should be evaluated quantitatively. Calculating achieved coverage involves determining the probability that the fire and gas detection array can “sense” the hazard in a zone, and then comparing it to the coverage target to determine adequacy. This assessment should consider site-specific factors such as (for fire) obstructions or (for gas) local wind conditions. Obstructions are important because optical fire detector views should not be impeded by pipe work, cable trays, or other objects. Only through coverage modeling in three dimensions (3D) can it be assured that fire or gas detection layout is adequate. A detector layout that “appears” to be adequate and reliable based on engineering heuristics may have a hidden flaw that can defeat the system.

There are two methods for calculating coverage that are defined in the ISA Technical Report: *geographic coverage* and *scenario coverage*.

- Geographic coverage: the fraction of the area at a given elevation of analysis of a defined monitored process area that, if a gas release or fire were to occur in a given geographic location, would be detected by the release detection equipment considering the detector arrangements.

- Scenario coverage: the fraction of the release scenario frequency that would occur as a result of the loss of containment from pieces of equipment of a defined and monitored processed area that can be detected by release detection equipment, considering the frequency and magnitude of the release scenarios and the defined voting arrangement of the fire and gas system.

Both of these coverage metrics have their place, depending on the hazard evaluated, the design objectives stated in the FGS philosophy, and level of quantification required. Geographic coverage is more easily calculated, is not dependent on process release calculations, and yet very powerful for specifications and design. It is most often used for fire coverage mapping and occasionally for gas coverage. Scenario coverage is more rigorous and more time consuming because it requires knowledge of a range of potential releases and their locations; however, this level of detail may be needed when performing gas detector coverage that is sensitive to site meteorological conditions or when using a "QRA-level" of detailed quantification.

When performing a fire and gas detector coverage assessment, several attributes of the zone being analyzed and the equipment used for fire and gas detection need to be considered. The first consideration is the performance attributes of the detectors. Detector capabilities and performance are generally calculated or measured by the equipment vendor, usually through standardized tests performed in accordance with testing protocols developed by an independent Nationally Recognized Testing Laboratory. *Figure 8* illustrates the performance of an optical fire detector for three different sensitivity settings: high, medium, and low. Different vendors will provide different cones-of-vision and have different performance characteristics. When creating a coverage map, the software (or other procedure used to perform the modeling) should accurately reproduce the cone of vision of that specific device. A generic model cannot be used and applied to all detectors.

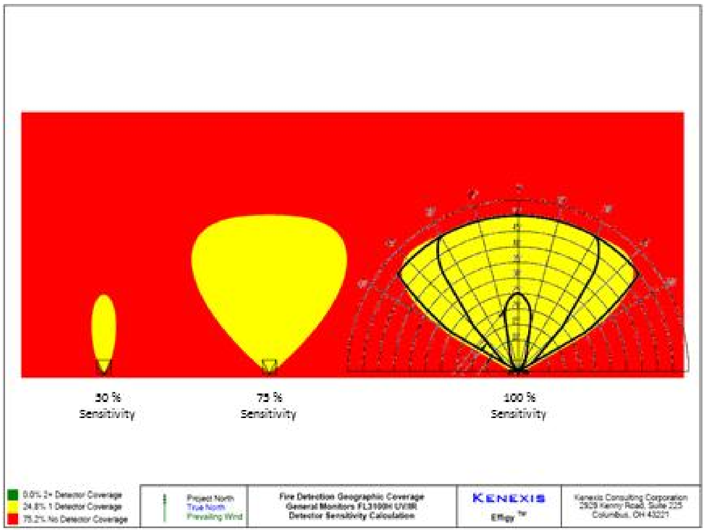


Figure 8 – Optical Flame Detector Cone of Vision

It is important to understand that the cone of vision that is drawn in the literature from the equipment vender is only valid under a specific set of conditions. In order for the cone of vision to precisely match what is supplied by the equipment vendor, the detector that is being analyzed must be located exactly at the elevation of interest, meaning that the detector elevation and the elevation of interest are identical. Furthermore, the detector has to be oriented so that its line of sight is exactly parallel with the plane of the elevation of interest. Only under this narrow set of circumstances will a calculated coverage map exactly match the cone of vision that is provided by the equipment vendor. As the detector is elevated further above the elevation of interest and the angle of declination increases (meaning the detector is pointed down, toward the floor) the shape of the cone of vision dramatically changes. No longer is the cone of vision a sharp 45 degree angle beginning at the detector location, as shown in Figure 8 at 100% sensitivity. Instead, the cone of vision becomes something that looks more elliptical until the angle of declination is such that the detector is pointing straight down. At this angle, depending on the make and model of the optical fire detector, the coverage map will become circular. To account for these differences in elevation, the detector coverage should be calculated based on three dimensional modeling. Fire and gas mapping is essentially performed using analytical geometry. The field-of-vision of an optical fire detector is essentially a cone, and the intersection of a cone with a plane can be used, through analytical geometry, to generate a footprint of the cone of vision on the elevation of interest. For more information on equations employed in analytical geometry, see *Appendix H*.

There are also other important considerations when performing the fire detector coverage mapping. The analysis needs to not only consider the cone-of-vision of the optical fire detector at the elevation of interest, but it also needs to consider the effects caused by objects that are in the path of the detector. Any obstruction between the fire detector and the elevation of interest will cast a “shadow” on the elevation of interest which then needs to be accounted for on the coverage map. In *Figure 9*, a spherical object casts a shadow on the elevation of interest, preventing the detector from “seeing” a hazard located in the shadow.

The results of the fire and gas mapping are important in two ways. First, the graphical results are an easily interpreted report of where coverage is adequate and where it is lacking. In addition, it is important that the achieved coverage metric is compared against the coverage target to ensure that the performance targets are met.

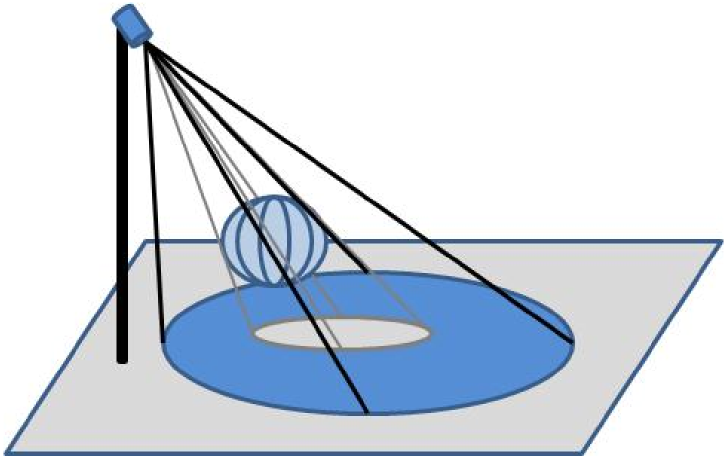


Figure 9 – Effect of Obstruction on Fire Detection

The fire and gas mapping output should look like *Figure 10* and *Figure 11*. *Figure 10* shows a typical geographic fire detector coverage map. The coverage maps are rendered in grayscale for the handbook. The areas of the map that are shown in green (medium gray) are covered by two or more detectors, areas that are shown in yellow (light gray) are only covered by a single detector, and areas that are shown in red (dark gray) are not covered by any detectors. Areas that are greyed out (surrounded by a black outline) are areas where equipment is located at the elevation of interest, and thus need to be removed from the calculation of coverage as the location is inside the vessel and the fire and gas system is not expected to cover the inside of the vessel or piece of equipment.

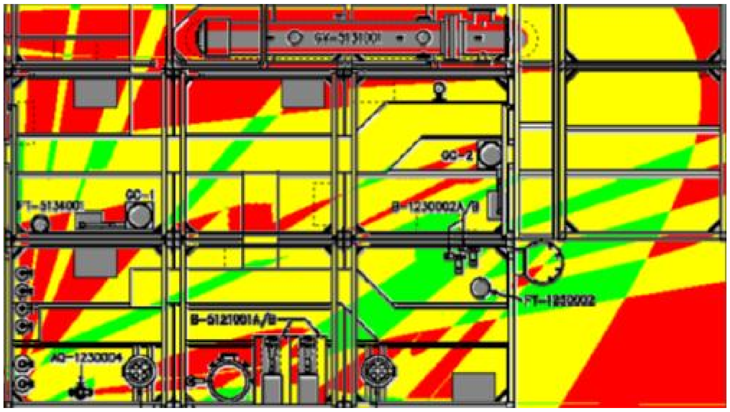


Figure 10 – Geographic Fire Detector Coverage Map

The coverage map shown in *Figure 11* presents a geographic coverage map for detection of gas accumulation. The geographic gas detector coverage map appears substantially similar to the fire detection map in that the color scheme is dependent on the number of detectors that can “sense” a gas accumulation of a given size that is centered at particular location. The coverage map shown in *Figure 11* includes coverage for both point gas detectors and open path gas detectors. Geographic coverage for gas detectors is meaningful only when the performance objective is to detect a threshold size of gas accumulation within a monitored area. This is particularly important when we desire to limit the potential size / intensity of a blast or vapor cloud explosion from occurring in the event that the gas cloud ignites. Often this is desired in offshore oil and gas platforms as a key survivability criterion. The objective is typically to sense a threshold 5 meter (16 foot) gas cloud (or larger) in confined or congested areas of the platform. The desire is to limit the size and extent of the gas cloud by detection and automatic ESD and safe depressuring of the facility. When this is the FGS performance objective, the geographic gas coverage map can be interpreted as the confidence of the ability of the gas sensor array to detect a threshold 5 meter accumulation given the fact that a 5 meter spherical gas cloud could be centered at any point throughout the monitored area.

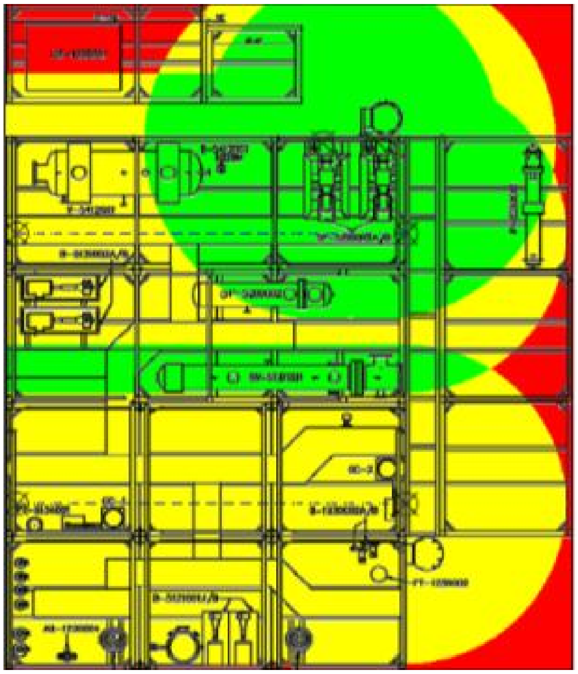


Figure 11 – Geographic Gas Detector Coverage Map

The previous two FGS maps showed the geographic coverage, while *Figure 12* and *Figure 13* show *Scenario Coverage*. In scenario coverage, the risk profile is shown as a function of location. Essentially, a color at any particular location is indicative of the frequency at which a gas release or a fire scenario will exist at that given location. The warmer (lighter) colors denote a higher likelihood that a hazard will exist at that location, and cooler (darker) colors represent a lower frequency. *Figure 12* depicts the risk profile for a gas metering skid, which indicates that areas closer to the metering skid have higher risk of gas release. As the distance from the metering skid increases, the risk associated with a release lessens, as expected. A larger release that could result in combustible gas at a greater distance from process equipment is less likely than a small release with a very localized hazard.

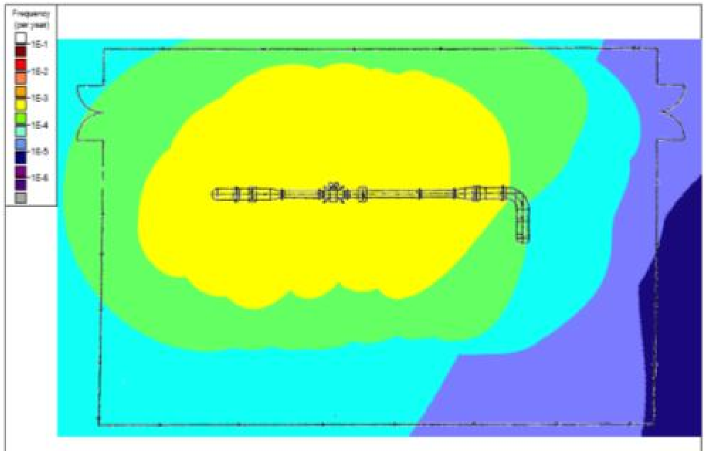


Figure 12 – Unmitigated Scenario Based Risk Map

The risk profile presented in *Figure 12* is the unmitigated risk of combustible gas. Unmitigated risk simply considers the leak sources, the dispersion modeling of the leak, and the frequency at which those leaks are expected to occur. The unmitigated risk does not consider the beneficial effect of the FGS. The unmitigated risk profile can be modified by considering the scenario coverage and the beneficial effect of the fire and gas detection system. If a release scenario is detected by the FGS detection array, it can be removed from the analysis and thus removed from the calculation of the risk profile. Consider the mitigated risk profile shown in *Figure 13*. For the situation represented in this figure, the detection array that was chosen included two open path detectors, one on either side of the metering skid. As a result, the risk has been substantially reduced (although not eliminated).

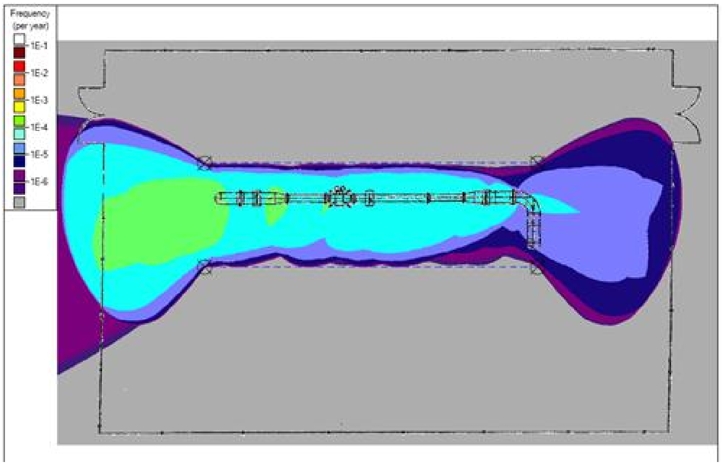
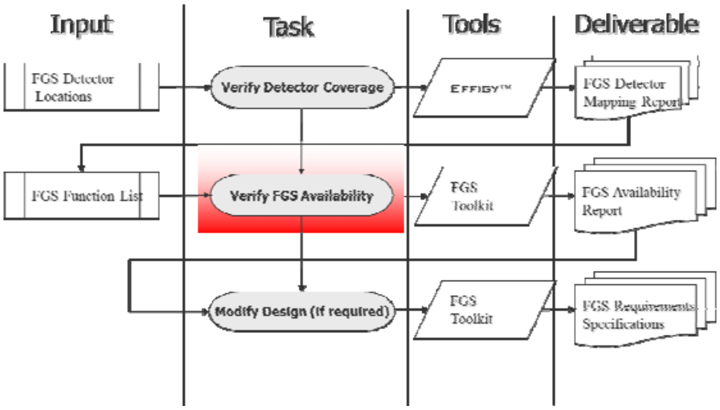


Figure 13 – Mitigated Scenario Based Risk Map

Whereas in the unmitigated geographic risk profile drawing there is a significant amount of yellow (indicating higher risk) and quite a bit of green, in the mitigated geographic risk profile there is no yellow and a limited amount of green, with the cooler colors being more prevalent indicating reduced risk. In addition, the majority of the area has essentially no geographic risk associated with it because any releases that would occur in the direction of the detectors would be detected by the FGS. Ultimately, a scenario-based coverage mapping result includes calculations to determine the fraction of release scenarios (weighted based on the frequencies of the hazard scenarios) that are detected by the fire or gas detector array.

Verifying FGS Safety Availability



After modeling the detector coverage, the next step is to verify the *Safety Availability* of the instrumented FGS function. The goal is to reduce the probability that a FGS component will fail to function as intended, which would inhibit the FGS from activation. This safety availability calculation is very similar to the SIL calculations performed for a traditional safety instrumented system (SIS). The goal during the conceptual design stage, where FGS safety availability is verified, is to select equipment that is appropriate for the performance target. We do this so we can generate a specification for detailed design that addresses the FGS equipment, and how the FGS functions, including the specifics of each individual loop and the general requirements that apply to the overall system. The initial FGS function conceptual design should be defined so that the design will achieve the specified *safety availability* targets defined previously. Parameters which should be considered when creating the initial conceptual design, as they can affect a function's ability to achieve the safety availability target, include: type of components, their characteristic failure rate, fault tolerance (voting), functional test interval, potential for common cause failures, and the capability of self-diagnostic coverage of the devices in the FGS loop.

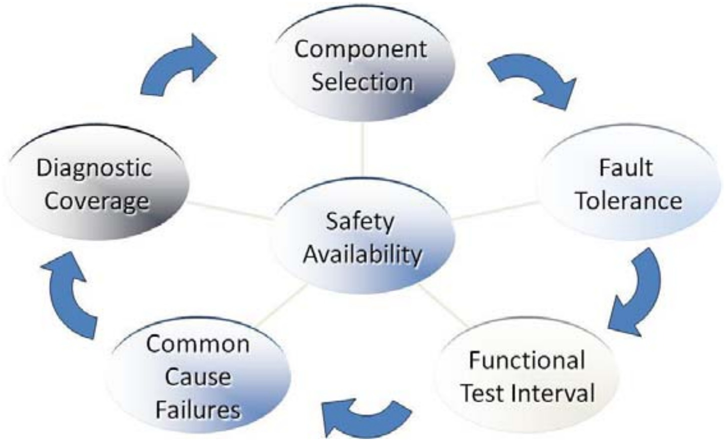


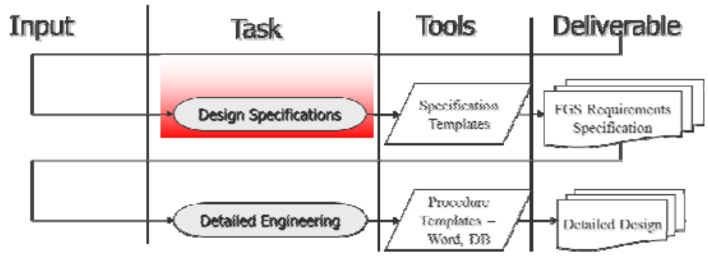
Figure 14 – Parameters Impacting Safety Availability

All of these FGS function parameters are factored into the calculations that verify whether adequate safety availability has been achieved. The verification calculations are typically performed using software tools that calculate probability of failure on demand. These software tools generally employ calculations that are primarily based on the simplified equations that are contained in ISA Technical Report 84.00.02 – *Safety Instrumented Functions (SIF) – Safety Integrity Level (SIL) Evaluation Techniques*, which is a respected source of equations for performing safety availability and probability of failure on demand calculations. Alternatively, calculations can be performed manually using the same equations that are contained in the technical report, or the calculations can be performed using other tools such as fault tree analysis or Markov models. However, most practitioners of performance-based design use simplified equations derived from those that appear in the ISA Technical Report 84.00.02 due to their ease of use compared to more rigorous methods, while still retaining the highest degree of accuracy for the well-defined situations to which the simplified equations apply.

If the proposed FGS design does not achieve the required Safety Availability, several options should be considered. The first is more rigorous or more frequent function testing of FGS sensors, logic solvers, or final control elements. A change in the FGS voting could be contemplated to minimize the possibility that a single fault condition (undetected failure) could inhibit the safety action. In some cases, a change to use IEC 61508 certified detectors or FGS logic solver will provide the necessary safety availability to meet the performance targets.

For a more complete description of SIL verification and Safety Availability calculations, the authors first recommend the Kenexis *SIS Engineering Handbook*. Beyond that overview, there are several authoritative texts that adequately cover the topic in detail.

FGS Requirements Specification



After all of the FGS loops have been verified to achieve their safety availability targets, the conceptual design should be documented in an *FGS Requirements Specification*. This is essentially a design specification that defines the basis for the supply and the detailed engineering of the FGS equipment. As such, the FGS Requirements Specification needs to define how the FGS will function and ensure the detailed designers deliver an FGS that achieves the performance requirements. The FGS Requirement Specification should contain two general types of requirements: the functional specification that defines what the system is required to do and how it will do it, and the integrity specification that defines how well the system should perform, essentially the safety availability targets of the FGS functions along with the coverage targets for the detector arrays.

Good instrumentation and control design dictates that FGS requirement specifications typically are not contained in a single document. Poorly written specifications are not written with the detailed design in mind. They are often nothing more than a safety case designed to facilitate an audit and not a document that is valuable for design purposes. Practitioners that are not familiar with instrumentation and control designs but are very familiar with how standards,\ such as IEC 61511 or ISA 84 are written, will know that the IEC 61511 contains a section (clause 10.3.1) that contains a list of all of the line items that define the considerations that a Safety Specification should include. Unfortunately, many engineers attempt to provide a single specification document in the same format that the standard presents the requirements. This format is a poor way to present a design as it ignores the needs of those who will use the documentation. While this format may be good for presenting a safety case to regulators that the standard was followed, it is difficult for designers who are expected to use the documentation to complete their tasks.

Optimal specification design will use multiple documents with document references indicating the location where the information that is required to be specified exists already, reducing the potential for mismatched information over the course of the life cycle.

Three primary document sections generally comprise FGS Requirement Specification: Logic Description, General Requirements, and Reference Drawings.

Logic Description. The most common method for documenting FGS logic is a cause-and-effect diagram. A typical cause-and-effect diagram for FGS logic description is shown in *Figure 15*. The cause-and-effect diagrams usually contain:

- The inputs and outputs of the system

- The setpoints of the inputs
- Action taken by outputs
- Time delays (if appropriate)
- Instrument ranges
- Logical relationships between the outputs
- Safety criticality of inputs and outputs

The logic description is the core document that describes the extents and actions of the FGS.

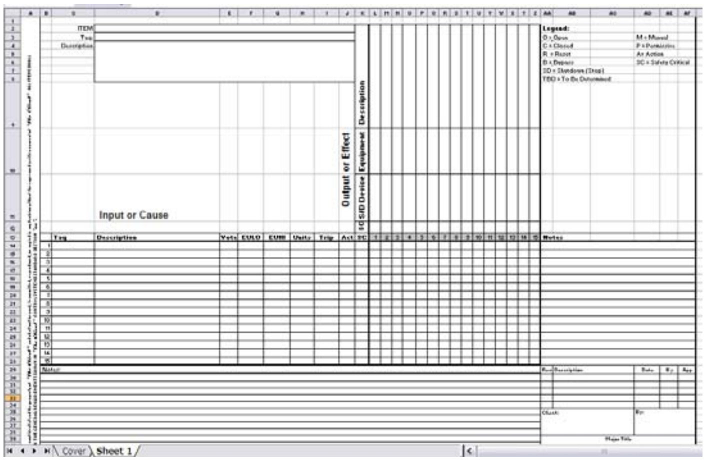


Figure 15 – Typical Cause and Effects Matrix

General Requirements. A set of general requirements is developed that applies to all of the FGS functionality. General requirements are an efficient format for presenting requirements that are common for all FGS loops. Exceptions to general requirements are listed in a separate detailed notes section. The notes section is used when there are special considerations for a specific FGS loop or equipment item or the logic is too complex to simply be represented in the cause-and-effect diagram. In these situations, the notes clarify and supplement the logic diagrams. The general requirements and notes are typically presented as a text document.

Reference Drawings. The following drawings and data tables are typically provided to fully document the conceptual FGS design.

- Zone extents definition diagrams
- Detector summary list
- Detector layout diagram

The zone extents diagram provides a graphical definition of each zone's size and location. The drawing is created by overlaying the zone extents on top of a plan view of the facility. See *Figure 16* for a typical zone extents definitions diagram.

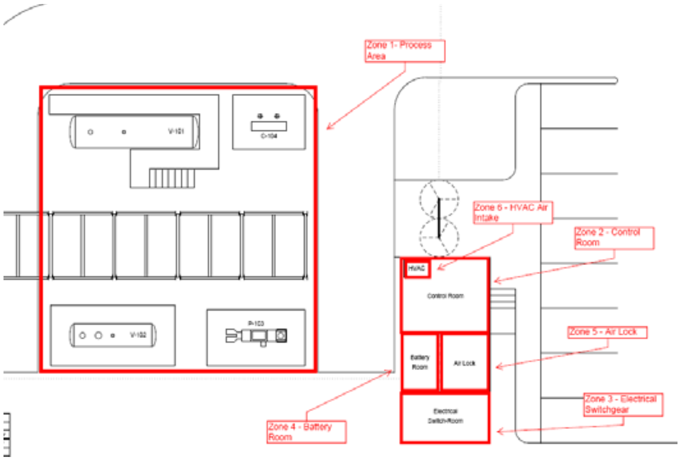


Figure 16 – Zone Extents Diagram

The detector layout summary list provides a listing of all the detectors and relevant information, such as location, elevation, and orientation. The list is normally presented as a table organized by zone, with each detector listed by tag and located according to plant coordinates. For detectors with orientation considerations (such as optical fire detectors), angles of declination and orientation are also included. Additional FGS elements, such as warning beacons / sounders and manual push buttons, may be included in the detector layout summary list. See *Figure 17* for a typical detector layout summary list.

Name	Tag	Num.	Pos. X (ft)	Pos. Y (ft)	Pos. Z (ft)	Det. Dec.	Det. Rot.
OpticalFire Detector	BE-	001	18	47	40	-35	315°
OpticalFire Detector	BE-	002	67	2	45	-40	135°
OpticalFire Detector	BE-	003	68	63	30	-30	220°

Figure 17 – Detector Layout Summary

The detector layout diagrams provide a graphical representation of the locations of each detector. The drawing is typically created by overlaying the detectors on top of a plan view of the facility. Additional FGS elements, such as warning beacons / sounders and manual push buttons, may be included in the detector layout diagram. See *Figure 18* for a typical detector layout diagram.

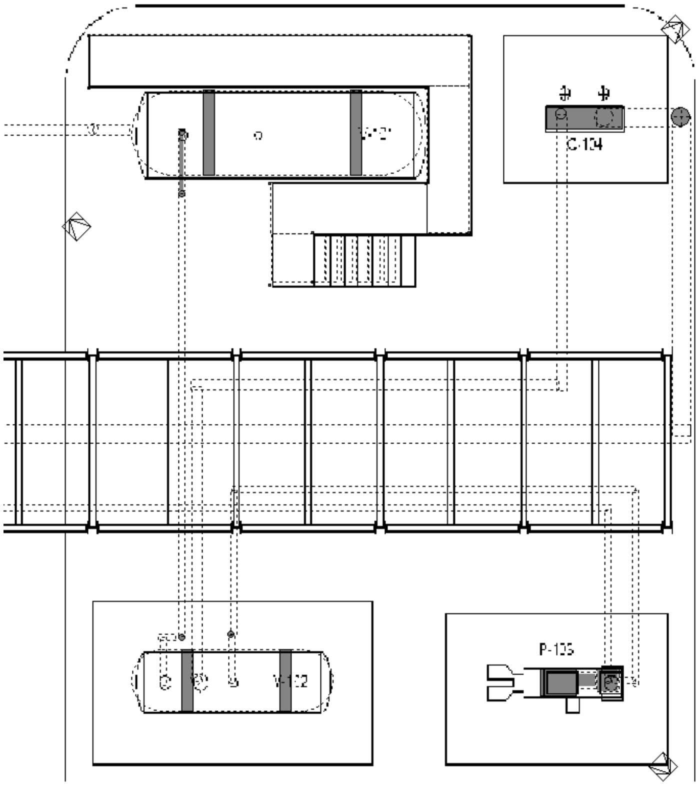
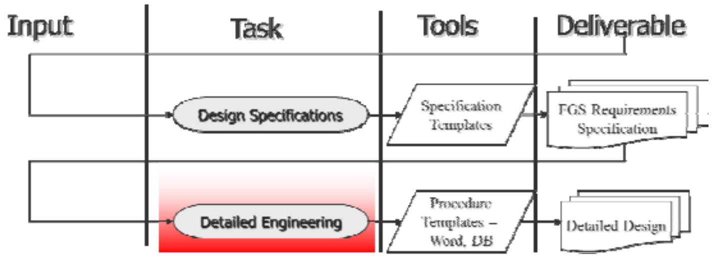


Figure 18 – Detector Layout Diagram

A completed FGS Requirements Specification is the last step in the conceptual design of the FGS. At this point, basic engineering and cost estimates have been completed, which is in line with the completion of Front End Engineering Design (FEED). The FGS project would be submitted for sanctioning and financial authorization to proceed to detailed engineering, construction, installation and commissioning.

Detailed Engineering Design



After the conceptual design phase, the next step is to perform the detailed engineering design of the FGS system. The detailed design phase results in preparation of all the documents required to select, purchase, configure, and install the FGS. This step is not dramatically different from what has traditionally been done for any other general instrumentation and control system project. Detailed design typically includes the following tasks and deliverables:

- FGS Logic Solver Hardware Specification
- FGS Configuration and Application Software
- FGS Loop Diagrams
- FGS Functional Description (Cause & Effect Matrices)
- FGS Instrument Index
- FGS Instrument Data Sheets
- FGS Instrument Installation Details

- FGS Cable Schedules, routing and fireproofing specifications
- FGS Equipment Cabinet Drawings
- FGS Marshalling Cabinet Drawings
- FGS Junction Box Drawings
- FGS Field Panel Drawings
- Control Room, Rack Room, RIE drawings
- Grounding Drawing
- FGS Operations and Maintenance Procedures
- Factory Acceptance Test (FAT) Procedure and Results Report
- Site Acceptance Test (SAT) Procedure, including Functional Test Plans

During detailed design, the procedures by which the FGS system will be operated and maintained are developed. There are multiple procedures that need to be developed in this phase prior to more time-critical steps in the life cycle, such as the commissioning and Site Acceptance Test (SAT). The development of these procedures is an important task because it allows the design team to evaluate how operations and maintenance personnel will interact with the FGS.

Maintenance and testing procedures also need to be created, which should include the following:

- Test procedures for sensors, FGS logic solver, and final control elements

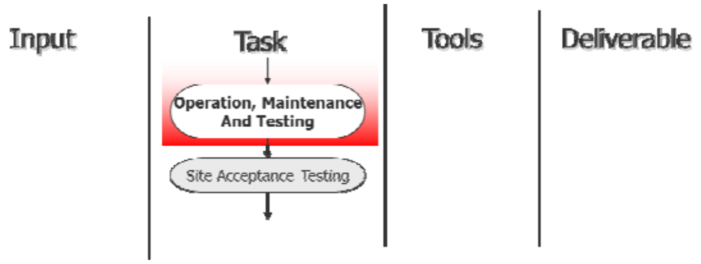
- Preventative Maintenance (PM) tasks

- Corrective maintenance tasks for diagnosed failures

In the development of maintenance procedures, the system response to detected fault conditions should be defined. If a component in an FGS system fails, it is important that the failure is detected quickly and repaired within the mean time to repair (MTTR) that was assumed during the design phase and was used as an assumption in the FGS safety availability calculations. If the repair is not done within the MTTR, the achieved safety availability might be compromised. Developing the procedures is important in order to ensure that all the potential repairs can be done, as it will yield the requirements for spare parts, staffing, degraded voting, and annunciation of fault conditions.

Detailed engineering is usually complete when the FGS is integrated at the factory and subject to a successful Factory Acceptance Test (FAT). The system is now ready to be installed at the end-user facility.

Construction, Installation, and Commissioning

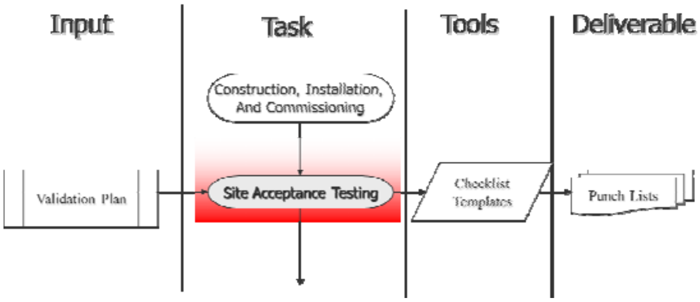


After detailed engineering design, the FGS is delivered to the end-user facility, installed, and commissioned. This task is typically very similar to other instrumentation and control system projects. This task involves the purchasing of the field devices, the fabrication of the cabinets, the assembly of the equipment in the cabinets, and the installation of the cabinets, the field equipment, and all the interconnecting wiring on site.

Installation of the FGS field equipment is critical, possibly more so than other instrument and control systems, because the location and the orientation of the detector array may impact the ability of the system to achieve the specified and verified coverage targets. Thus, it is not enough to simply confirm that the device exists in the field. Each FGS sensor needs to be in the exact location that was specified and also needs to be at the exact orientation that was specified. For example, flame detector's angle of rotation and angle of declination must match the specified values. Furthermore, it is necessary to confirm that the field of view of the detectors is consistent with what was assumed during the design phase and, if not, the coverage models need to be recalculated to confirm that coverage targets have still been achieved. This can be performed by comparing a picture of the actual field of view of the detector with a 3D model of what the detector's expected field of view.

After the installation, all the FGS loops are commissioned to ensure that the instruments are operational and correctly communicating with the FGS logic solver. The system is ready for the critical Site Acceptance Test (SAT).

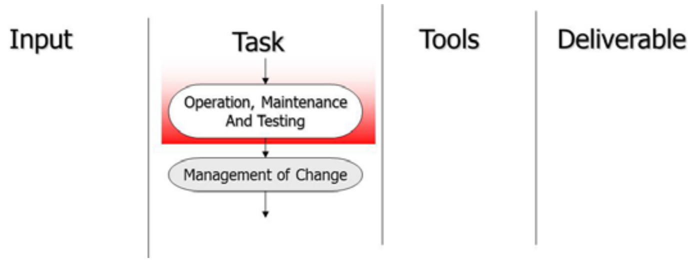
Site Acceptance Test (Validation)



After the FGS commissioning is complete and the construction team is ready to turn the system over to the end-user for operations, a Site Acceptance Test (SAT), also known as a *validation* in the terminology of the IEC 1611 standard, should be performed. During the SAT all of the installed equipment and all of the software is verified to conform to the FGS requirements specifications. It is important to use the FGS Requirements Specification as the basis for the validation to ensure that errors were not generated in the detailed design. If errors were generated, they can be identified and corrected prior to the start up. All of the software and hardware should be reviewed to ensure that everything matches the FGS Requirement Specification and is operational. Subsequently, all of the loops need to be function tested. SAT involves a full test from the detector in the field, to the control room, and back out to the field for any alarm appliance or executive action that the FGS will perform. The test should include activation of field equipment to the greatest degree possible. If any deviations from the FGS Requirements Specifications are noted, they should be documented in a deviation record, often referred to as a punch list. All of the items on the deviation record need to be satisfactorily resolved before the FGS can be considered operational.

In addition to function testing, the SAT should include a verification of positioning of all FGS detectors. Detectors should be verified to determine that they have been installed in the same location and orientation that was assumed in the FGS mapping calculations and documented in the FGS Requirements Specification. Also, a review of the layout of process equipment in comparison to what was assumed during FGS mapping should be undertaken. This ensures that no detectors have been compromised by blockage of line-of-sight, or located in an area that would not receive a representative gas sample.

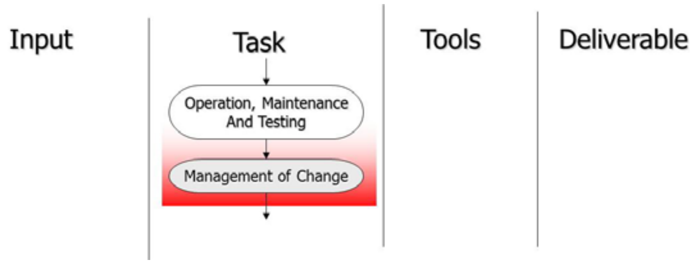
Operation and Maintenance



After Site Acceptance Testing, the FGS is ready for the normal operation and maintenance phase. During the operation and maintenance phase, it will be necessary to perform periodic function testing, inspection, and maintenance to ensure that the FGS is able to achieve its safety availability target and its detector coverage target over its entire lifecycle. During this phase, site personnel need to respond to overt faults in the system with corrective maintenance tasks. The best situation is to invest in a well-designed fire and gas system and have it never activate. Of course, there is still the reassurance that, if fires or gas releases occur, the system will be available to take the mitigative action it was designed to perform.

As with all safety-critical automation systems, a periodic revalidation should occur where the performance of the system is compared against its performance targets. We would want to ensure that any observed failure to detect a hazard or failure to perform adequately on a demand condition were identified and investigated. The ability of the system to achieve the performance targets may need to be re-visited. The authors recommend FGS (as well as SIS for that matter) be subject to design-basis revalidation at a frequency not to exceed 5 years, perhaps coinciding with the normal Process Hazards Analysis (PHA) revalidation.

Management of Change



Management of change is required when any modification to the process occurs. The management of change process is more comprehensive than simply looking at changes to the fire and gas system hardware itself. Things as seemingly benign as adding scaffolding, moving a ladder, or adding a new piece of processing equipment can change the effectiveness of the fire and gas detection. Adding new equipment may increase the number of leak sources, change the definition of the zone and possibly increase performance requirements. At a minimum, the additional equipment creates new obstructions that change the coverage that is achieved by the fire detection arrays.

As a result, the scope of change that will affect the fire and gas detection system's ability to achieve the tolerable risk targets of an organization are affected by a wide range of process changes, some of which do not immediately seem to impact FGS design. It is necessary to ensure that the existing management of change procedures for a facility include steps for review of all changes to determine if fire and gas systems are impacted by those changes. If so, the appropriate level of redesign and return to the appropriate step in the safety life cycle of the FGS are initiated by those changes.

It is also important to remember that a new or separate management of change system that is dedicated to the FGS or to safety instrumentation in general is not appropriate. Having a single unified management of change system that applies to all process changes, while making sure that the system adequately addresses the needs of FGS equipment, ensures that no change which could impact the fire and gas system goes unaddressed.

Appendix A – Abbreviations

FGS	Fire and Gas System
FTA	Fault Tree Analysis
HAZOP	Hazards and Operability Study
HSE	Health, Safety, and Environmental
HSE	Health and Safety Executive (UK)
IDLH	Immediately Dangerous to Life or Health
IEC	International Electrotechnical Commission
ISA	International Society for Automation
IPL	Independent Protection Layer
LOPA	Layer of Protection Analysis
MAC	Manual Alarm Callpoint
NBP	Normal Boiling Point
NFPA	National Fire Protection Association
NRTL	Nationally Recognized Testing Laboratories
PHA	Process Hazards Analysis
PFD	Probability of Failure on Demand
P&ID	Piping and Instrumentation Diagram
PHA	Process Hazards Analysis
PLC	Programmable Logic Controller
PLL	Probable Loss of Life
QRA	Quantitative Risk Assessment

SIL	Safety Integrity Level
SAT	Site Acceptance Test
SIS	Safety Instrumented System
SRS	Safety Requirements Specifications

Appendix B – Definitions

Air Intakes	The location from which a piece of equipment draws its air supply, be it for fresh air supply to an occupied building, combustion, blanket gas or other requirements
Alarm System	Instrumented system designed to alert operators to process deviations
Appurtenances	Accessories or ancillary equipment associated with another larger primary equipment item
Area of Concern	Areas of a facility for which fire or gas hazards exist. This can include both areas with process equipment which handles flammable or toxic material as well as areas that may need detection to prevent migration of gas into them, such as electrical rooms and control rooms
Basis of Safety	A philosophy and methodology that is used to make decisions about the design of the equipment and how it is maintained

Bimetallic Heat Detection	Bimetallic detectors operate on the principal of detecting heat, not flame detection. When temperature increases, the metallic strip deforms as the metal with higher coefficient of expansion lying one side elongates. One end of the strip is fixed and the movement of the free end of the strip closes an electric circuit and generates an alarm condition.
Calibrate	To check, adjust, or standardize a method, usually by comparing it with an accepted model.
Categorization	Selection of an appropriate classification of a system, usually from a fixed list within a limited number of items.
Cone-of-Vision	The extent of an area that a detector (usually an optical fire detector) can monitor, given its location and orientation as well as taking into account traits that are specific to each detector type.
Consequences	Events, effects or outcomes of something that occurred earlier. In chemical process quantitative risk analysis, the measure of the expected effects of an incident outcome case.

Coverage	The extent of an area that a detector can monitor, given its location, declination and orientation while accounting for obstructions that may detract from its ability to monitor an area as well as taking into account traits that are specific to each detector type.
Cyber Security System (Intrusion Detection and Prevention)	A system that monitors computer network traffic and detects abnormal situations. Upon detection alarms can be set and unauthorized traffic can be stopped
Deck Plan	A diagram of an area, including those areas interior to enclosures, that physically shows where equipment is located in relation to the facility as a whole as well as in relation to other equipment defined to a scale.
Design Basis	A set of criteria that describes a situation for which an engineered system is to be specified.
Detector Array	Comprising all detectors monitoring a specific zone, and is inclusive of location, elevation, orientation and setting.

Detector Coverage	Percentage of an area at the elevation of interest where a fire or gas cloud is detectable by the Fire and Gas System. Detector coverage can be defined as either geographic coverage or scenario coverage.
Detector Location	This refers to the placement of fire and gas detectors. This includes the detector's relation to specific equipment or an origin point as well as the elevation.
Detector Orientation	This refers to the direction a detector is facing, in relation to specific equipment or an origin point.
Diagnostics	Functions that detect faults in an instrumented system. Diagnostics can be set to either place a system in its safe state or generate an alarm to inform operations of equipment faults.
Dispersion Modeling	A mathematical model of the movement and diffusion of gas in the atmosphere. The model allows for the estimation of the gas concentration based on the distance from the gas source.
Elevation of Interest	The elevation at which a fire and gas mapping exercise will display the detector coverage results in two dimensions.

Emergency Isolation Valve System	Valve used to isolate process equipment during an incident to prevent continued loss of process inventory.
Extents of Graded Areas	The specified distance from a leak source that is included in a graded area when calculating detector coverage results.
Fault Tree Analysis	A powerful and flexible method for modeling the failure characteristics of complex systems. The purpose of the model is to estimate the failure characteristics of a system based on the characteristics of the individual components of that system and how they are logically related to each other.
FGS Philosophy	A set of documents that define the tools, techniques, polices, performance criteria, and the procedures surrounding fire and gas systems design.
Fire and Gas Detection System	Instrumented system designed to detect fire and/or gas hazards. A FGS is a system composed of any combination of sensor(s), logic solver(s), and final element(s).
Fire Hazards	Any process fluid or gas that can be released or generated which, if a source of ignition is found, can result in a fire.
First Responders	The initial team to respond to a hazardous situation (e.g., fire brigade).

Frangible Bulbs	A liquid-filled glass device for detecting high temperature. At a predetermined temperature, the bulb fractures allowing either the opening of a sprinkler system outlet or a pair of contacts to complete the circuit, initiating the alarm / suppression system.
Frequency	Rate of occurrence, i.e. occurrences per unit of time.
Fully Quantitative Analysis	A risk analysis method that utilizes mathematical calculations to the greatest degree possible, eliminating shortcuts and assumptions employed by other methods.
General Requirements	Section of a systems requirement specifications which includes requirements that are applicable to all functions that are part of the system.
Geographic Coverage	Effectiveness of the proposed array of detectors with a given voting arrangement in detecting an incipient hazard at a level that will initiate a specified safety action.
Geographic Risk	Measure of the probability that a hazardous event will occur at a geographic location.

Grade	a specification that defines the ability of an FGS function to detect, alarm, and if necessary, mitigate the consequence of a fire or gas release upon a demand condition.
Heuristics	a general or approximate principle, procedure, or rule based on experience or practice, as opposed to a specific, scientific calculation or estimate.
Hydrocarbon Processing Area	Any process area with equipment that contains or handles hydrocarbons.
Initiating Event	An event that occurs and is the cause of any subsequent events.
Jet Fire	Jet fires result due to ignition of a release at or close to the point of release resulting in a momentum-driven turbulent jet fire. The consequence is measured by the shape of the flame and the resulting pattern of thermal radiation effects which can be strongly influenced by meteorological conditions and flame impingement.
Layers of Protection Analysis (LOPA)	A fault propagation methodology similar to an event tree method used for determining the potential likelihood of a harmful event when considering potential independent protection layers that could prevent the ultimate consequence.

Leak Rate	mass flow through an orifice per unit time.
Leak Source	A vessel, pump or other type of process equipment that has the potential to release hazardous contents into the process area.
Logic Description	The core document which details the size and actions of a instrumented system. This can be in a form of a cause & effect diagram, a logic narrative, or binary logic diagram.
Machine Safeguarding Systems	Instruments, barriers, etc. that are in place for the purpose of protecting personnel from a piece of equipment's moving parts that are capable of causing personnel injuries were they to come into contact with personnel.
Management of Change	The policies and procedures used to assess changes to a process or facility which could impact systems such as the SIS or FGS.
Manual Alarm Call Point	Designated inputs in process areas that are designed for the purpose of raising an alarm manually once verification of a fire or emergency condition exists. This is typically a push button or break glass alarm that initiates alarms or automated actions.

Markov Model	A fault propagation method used to analyze complex systems, such as a fault tolerant PLC.
Mitigated Geographic Risk Profile	A map showing the geographic risk of an area after removing the risk scenarios that are detected / mitigated by the FGS.
Mitigated Risk Assessment	Determining the risk associated with specific events while including the benefit of systems and tools designed to protect, prevent, or otherwise reduce severity.
Mitigating Factors	Conditional modifiers that do not prevent an event from occurring, but rather lessen the severity of the consequence associated with said event. These include, but are not limited to, ignition probability, occupancy data, and fire and gas systems.
Mitigation	Reduction of severity or seriousness.
Non-Process Area	Areas of a facility which do not include process equipment. These may include areas with electrical equipment or personnel.
Obstruction	An object in modeling that is representative of piping, equipment, or vessels that serves to limit the area which a detector is able to monitor.

Open Path Gas Detection	Gas detector which uses an infrared beam to measure combustible gas concentrations. Open path detectors consist of a transmitter and receiver, measuring the concentration of combustible gas in units of %LFL*m.
Optical Fire Detection	Fire detectors which detect wavelengths of UV/IR light that are emitted during combustion.
Performance Based	Design based on performance requirements developed from risk analysis. Unlike prescriptive standards, which lay out design requirements with no analysis of the current system, performance based design allows the system to be tailored to the requirements of the facility.
Performance Requirements	The required level of availability and detector coverage for a FGS to meet the minimum risk mitigation. Performance requirements are developed and implemented company wide as opposed to a project by project basis and used to determine the minimum effectiveness of a zone's FGS based on the zone categorization and grade.
Personal Monitor	Portable gas detectors carried by personnel. Used to monitor personnel exposure to toxic gasses and warn personnel of hazardous concentrations.

Plot Plan	A diagram which shows the buildings, utilities, and equipment layout in relation to the surrounding area of a project site at a defined scale.
Point Gas Detection	Gas detector (combustible or toxic) which measures gas concentrations (usually in %LFL or ppm) at a single point. These can include a variety of technologies, including IR, Metal Oxide Semiconductor (MOS), and electrochemical type gas detectors.
Pool Fire	Pool fires result due to ignition of spilled hydrocarbon liquids resulting in a turbulent diffusion fire. The consequence is measured by the size of the pool and shape of the flame. Pool Fires emit thermal radiation extending outward from the pool in all directions which dissipates quickly beyond the external limits of the flame.
Prescriptive	An action or behavior based on a norm or standard.
Pressure Relief System	A network than can consist of pipes, valves, vents, and flare for the purpose of limiting the pressure in a system or vessel which can build up to pressures beyond design limits due to process upset (equipment or instrument failure) or fire.

Probable Loss of Life (PLL)	a statistical estimate of the average number of fatalities that might be expected per year for a given hazard.
Process Area	Any area of a facility that includes process equipment that handles process materials.
Process Industries	Industries that process large quantities of liquids or powders.
Quantitative	A term that refers to a type of information that is based on numerical data.
Quantitative Risk Assessment	The process of calculating risk numerically using statistics, chemical properties, and mathematical models.
Risk	The potential that an event will lead to a loss (an undesirable outcome).
Risk Integration	The process by which consequence and likelihood are aggregated for all possible scenario outcomes to calculate the overall risk in a zone.
Risk Scenarios	Events which have a consequence with associated risks. Risk scenarios are used when determining scenario coverage.
Risk-based	Performance based design where performance requirements are based on risk analysis.

Safeguards	Physical devices that can detect that an unwanted or out-of-control situation is occurring in the process plant and take remedial action to move the process to a safe state.
Safety Availability	The calculated probability that a device is operating successfully at a given moment in time. This is a measure of the “uptime”, that considers detectability and reparability of the failure in addition to its failure rate.
Safety Instrumented Function	A safety instrumented function (SIF) is a set of specific actions to be taken under specific circumstances, which will move the process from a potentially unsafe state to a safe state. In order to adequately define a SIF, the following six considerations need to be addressed: i. The hazard that is being prevented or mitigated by the SIF ii. Initiating event(s) or causes of the hazard iii. Inputs, or ways to detect all initiating events iv. Logic connecting inputs and outputs v. Outputs, or actions needed to bring the process into a safe state

Safety Instrumented Systems	Instrumented System is the implementation of one or more Safety Instrumented Functions. A SIS is a system composed of any combination of sensor(s), logic solver(s), and final element(s).
Scenario Coverage	The fraction of release scenarios that would occur as a result of the loss of containment from pieces of equipment of a defined and monitored process area that can be detected by release detection equipment, considering the frequency and magnitude of the release scenarios and the defined voting arrangement of the fire and gas system.
Secondary Graded Areas	The area adjacent to a high risk grade that is defined because of its proximity to a high risk leak source. This is typically a grade rating that is one degree of severity lower than the initial grade defined for a piece of equipment.
Semi-Quantitative	A risk analysis process that uses short-cut order-of-magnitude assessments of risk parameters instead of full quantifications of all parameters.
Source Term	A model used to determine rate of discharge, the total quantity released (or total time) of a discharge of material from a process, and the physical state of the discharged material.

Tolerable Risk	Maximum level of risk which is considered tolerable. Tolerable risk is set by corporation or governmental standards and used during risk analysis to determine if a defined risk has sufficient protections to prevent or mitigate the risk.
Toxic Gas	Of, relating to, or caused by a toxin or poison. A common toxic gas in refining is hydrogen sulfide. Hydrogen sulfide is a broad spectrum toxin, meaning that it damages several different body systems simultaneously. The most pronounced effects are as a pulmanotoxin resulting in pulmonary edema in concentrations in the low 300 ppm range and a neurotoxin resulting in rapid and then sudden loss of breathing at concentrations as low as the 500 ppm range.
Unmitigated Geographic Risk Profile	A map showing the geographic risk of an area prior to removing the risk scenarios that are detected / mitigated by the FGS.
Unmitigated Risk Assessment	Determining the risk associated with specific events without including the benefit of systems and tools designed to protect, prevent, or otherwise reduce severity.

Unrated Electrical Equipment	Electrical equipment that has the potential to initiate a fire or explosion in the event that it is located in an area where flammable gas concentrations could occur.
Validation	In the case of FGS design, to confirm adequacy of intended design through means of hazard assessment, performance verification and FGS modeling and analysis.
Vapor Cloud Fire	Vapor cloud flash fires result due to ignition of a flammable fuel-air mixture away from the point of release resulting in a short-duration, intense flash fire that burns back to the point of release. The consequence is measured by the shape of the flame and the resulting pattern of effects of persons being trapped in the fire. Flash Fires are often followed by residual jet fires if the source of hydrocarbons is not isolated.
Ventilation Intakes	Air intakes for HVAC systems.
Voting	Redundant system (e.g., m out of n, one out of two [1oo2] to trip, two out of three [2oo3] to trip, etc.) which requires at least m of n channels to be in agreement before the FGS can take action.

Voting Arrangement	The logic used in voting (e.g., one out of two [1oo2], two out of two [2oo2], etc.).
Zone	Zones should be defined based on location of processing equipment and the attendant hazards. Fire hazards within a zone should be similar. Gas hazards within each zone should be similar.

Appendix C – FGS Philosophy Considerations

The following sections provide a list of items that should be included in a FGS philosophy document.

1. Criteria for hazard identification
    a. What hazards to design for?
    b. What severity of fire or gas hazard should be detectable?
    c. Major Accident Hazards or Incipient Hazards?
    d. Holistic “QRA” approach to hazard identification
    e. FGS should reduce risk to tolerable level
    f. Selected “Design-Basis” hazard scenarios
    g. Selected Credible Scenarios for design
    h. Objectives of gas detection:
        i. Protect process
        ii. Protect occupants
    i. Threshold volume detection or detection of
    flammable gas regardless of volume?
2. Criteria for FGS Zone Definition and Categorization
    a. What factors should be considered in segregating the facility into zones for purpose of
    b. FGS Performance Analysis
    Hazard and Risk Topics

    c. FGS Design
    Instrumentation and Control Issues
    d. Categorize Zones to apply proper design standards and practices
3. Applicable FGS Standards
    a. Building Fire Detection
    b. Applicable national standard, NFPA 72, EN 54, BS 5839
    c. Process Fire and Gas Detection
    d. Based on Applicable ISA/IEC Standards
    IEC 61511, IEC 61508, ISA TR 84.00.07
    e. Offshore Fire and Gas Detection Requirements
    f. Classification Authority requirements: ABS, DNV, etc.
    g. Reference of associated standards and practices:
    h. Electrical Area Classification Standards
    i. NFPA Standards
4. Criteria for Risk Categorization (Risk Guidelines)
    a. High risk should require high level of performance
    b. FGS Analysis procedures should be developed to conform with corporate risk guidelines
    c. Consider factors related to:
    d. Life safety
    e. Asset protection
    f. Define Analysis Procedure

5. Criteria for Assigning Performance Targets to FGS Equipment
    a. Risk Categories map to Performance Targets
    b. Criteria for Performance Targets that drive requirements for :
        i. Fire and Gas Detector Coverage
            1. Geographic Coverage
            2. Scenario Coverage
        ii. Equipment Probability of Failure
            1. Safety Availability
            2. Safety Integrity Level (SIL)
    c. Protection of Building Occupants via toxic or combustible gas
    d. Protection of Unclassified Electrical Equipment enclosures
    e. Protection of gas ingress into combustion air intakes
    f. Use of fixed toxic detectors versus personal toxic monitors.
    g. When are receptors located sufficiently far away to avoid providing gas detection?
    h. Is there a requirement for a Temporary Safe Refuge?
        i. FGS functions to protect TR occupants
        ii. Combustible Gas Detection
        iii. Toxic Gas Detection
        iv. Fire / Smoke Detection
        v. FGS actions sufficient to protect occupants

            vi. HVAC Damper / Air Handler Shutdown
            vii. Electrical De-energization
            viii. Are FGS actions are needed to ensure safe evacuation / egress to TR?
            ix. Fixed suppression / deluge to ensure evacuation pathways?
6. Criteria for Selecting Appropriate Detector Technologies
    a. Which means of fire and gas detection should we standardize on?
    b. Application specific requirements
    c. What has performed well in prior use?
7. Alarming Requirements
    a. Local Alarms?
    b. Audible, what tones?
    c. Visual, what color scheme?
    d. Alarm at detector location or within zone?
    e. Criteria for how many alarms?
    f. Criteria for types of alarm on fire, combustible, toxic gas
    g. Alarming where complex voting is used for ESD
    h. Central HMI?
    i. What location(s)?
    j. Will it be manned 24x7?
    k. How interface with FGS logic solver?
    l. How interface with site PA system?
    m. Auxiliary Alarm locations, ECC, Fire Brigade?
    n. General FGS actions on any fire alarm?

8. Manual Activation
    a. Do we provide Manual Alarm Call points (MAC)?
    b. In addition to ESD pushbuttons or emergency telephone system?
    c. Spacing and location requirements for MACs
    d. What alarms are raised when MAC is activated?
    e. How to protect against accidental activation?
9. Detector Voting for Automatic Action Requirements
    a. FGS Function:
        i. Alarm Only? (Simplex Voting)
        ii. ESD? (usually Complex Voting)
    b. How many detectors in alarm state are sufficient to command ESD?
    c. Where detectors have multiple alarm set points, which ones should be used in Voting?
    d. How does voting degrade when detectors are unavailable for maintenance / testing?
    e. Are toxic gas detectors used in voting logic?
10. Criteria for Set-point Selection
    a. Fire Detectors
        i. Configuration for Sensitivity?
        ii. Configuration on diagnosed fault?
    b. Combustible Gas Detectors

        i. Low Alarm (HI) 10% LFL to 25% LFL?
        ii. High Alarm (HIHI) 40% LFL to 60% LFL?
        iii. Duct detectors? (usually set lower)
    c. Toxic Gas (H2S) Detection
        i. Low Alarm at 5 ppm?
        ii. High Alarm 10 ppm to 20 ppm?

Appendix D – Zone Definition and Categorization

Fire and Gas Zones are defined by the physical attributes of the location that is being protected by a FGS. Operating areas of process industry plants should be segregated into discrete zones. Each zone should be assessed separately to determine which hazards are present that can be mitigated using FGS: fire, flammable gas, and toxic gas. Performance targets should be established for each zone based on inherent fire and gas risks.

Zones should be defined based on location of processing equipment and the attendant hazards. Fire hazards and gas hazards within a zone should be similar. Each zone will later be segmented into smaller geographic divisions known as “monitored areas” or “graded areas” based on the risk analysis process. Because fire and gas hazards can vary greatly from zone to zone, it is important to use caution when defining zones in an arbitrary or overly-broad manner, as an improperly defined zone could result in inadequate FGS protection.

The process of zone definition should begin with an evaluation of plan drawings for operating areas. Zone boundaries’ should be defined by using the following recommended criteria.

- Similar Equipment. Location of zone boundaries should be defined in such a way as to group equipment with similar process hazards.

- Differentiate by Deck for multi-level structures: Different decks typically require different zones
- FGS system actions: if different FGS actions are required, a separate zone should be defined
- Segregation of hazards. Desire to prevent gas migration from one operating area to adjacent areas may require definition of separate hazard zones.
- Classified Electrical Equipment: the need to protect non-classified electrical equipment within a module or enclosure and segregate from classified areas requires definition of a separate zone.
- Special occupancies: occupied areas of high value equipment (turbine drivers) may require definition of separate / distinct zones to afford additional protection within areas with special occupancies.

Plan drawings showing location of zone boundaries, major equipment within zones, and detector locations should be developed by the detailed engineering contractor in support of the analysis.

Each zone is assigned a category to determine general requirements for fire and gas detection. Further, detailed analysis of performance requirement (including detector coverage mapping) is not required for all categories. *Figure D.1* shows a list of typical fire and gas zone categories.

Zone Category	Area Definition	Examples
H	Hydrocarbon Possessing Area, Fire / Flammable Gas, Toxic Gas Hazard	Production Separation, Gas Compression,
N	Non-Hydrocarbon Fire Hazard	Combustible Liquid Storage, Lubrication Oil System
G	General Occupancy, No Hydrocarbon Fire Hazard	Accommodations Area, Control Building
E	Non-Hydrocarbon Special Equipment Protection	Non-classified Electrical Equipment
T	Gas Turbine or Engine Enclosures	Gas Turbine and Turbine Enclosures
V	Combustion Air Intake / Ventilation Air Intakes	Combustion Air blower, HVAC Fresh Air Intake

Figure D.1 Typical Fire and Gas Zone Categories

Non-Hydrocarbon Fire Categories

Zone Category G is a non-hydrocarbon fire zone. For these zones, proposed designs are recommended to be performed through conformance with good engineering practices. This includes designed to comply with requirements of the local fire detection standards (for example, NFPA72, EN 54, or BSI BS 5839 Part 1).

Zone Categories E, T and V are non-hydrocarbon fire zones that require adequate segregation from hydrocarbon hazards, specifically combustible and/or toxic gas hazards. Zones of these types are analyzed using both general fire detection requirements in conformance with industry standards as well as a consequence based analysis to determine the potential for process related gas hazards to reach these locations.

Hydrocarbon / Non-Hydrocarbon Processing Categories

For each category H or N, zone risk analysis methods are used to evaluate the necessary level of risk reduction provided by FGS function(s) in the zone. For each zone of these types an 'FGS Performance Target Grade' is specified based on the risk reduction requirements for the given zone.

Appendix E – Consequence Tables

Hazard severity is driven by the potential area of impact for any given release. This necessitates the modeling of releases to fully understand their potential consequence and impact area when performing any fully quantitative analysis. Release characteristics are dependent on a number of factors, including:

- Process temperature
- Process pressure
- Hole size
- Properties of process fluids
- Wind speed / direction
- Atmospheric stability
- Release orientation
- Obstacles

Computational fluid dynamic (CFD) models are often necessary to fully model the complex nature of releases; however, source term models for calculation of dispersion can often provide a reasonable estimate for most releases.

Tables E.1-E.12 include release characteristics for releases of methane, ethane, and propane under numerous process pressures and temperatures for several weather conditions. The tables assume the release is oriented downwind and gives both the distance downwind to the stated percent of the lower flammability limit (%LFL) and the maximum width of the release plume which reaches the stated %LFL.

Table E.1: Distance to 50% LFL Under Calm Nighttime Conditions

Distance to 50% LFL (ft); Wind 5 ft/sec Atmosphere Stability Class F													
Pressure (psig)	Temperature (°F)	0		100		200		300		400		500	
		Length	Width	Length	Width	Length	Width	Length	Width	Length	Width	Length	Width
50	Methane	11.3	2.1	10	1.9	8.8	1.7	7.8	1.4	7.2	1.2	6.5	1
	Ethane	11	2	11	1.8	11	1.8	10	1.4	8.8	1.4	8	1.4
	Propane	90	40	11.4	2	11.5	2	11.3	2	10.4	1.6	9.2	1.6
150	Methane	16	3	14.5	2.5	12.6	2.2	11.3	2.1	10.1	1.7	9.2	1.3
	Ethane	22.8	3.2	17.6	2.8	15.6	3	14.4	2.5	12.8	2.4	11.6	2.2
	Propane	117	80	25	5	18.8	3	16.3	2.6	15	2.8	13.5	2.5
300	Methane	21.2	4.4	18.8	3.6	16	3	14	2.4	12.6	2.2	11.1	2
	Ethane	130	120	40	6	24	4.2	18.7	3.8	16.5	3.1	14.4	2.6
	Propane	137	120	135	110	45	7	23.5	4.6	19.4	3.6	17	3.2
1000	Methane	78	14	30.5	6.4	24	4.7	20	3.6	17.5	3.5	14.8	2.8
	Ethane	173	180	207	220	94	32	32.5	6.6	24	4.8	21.5	4
	Propane	182	200	180	180	157	140	105	32	33	7	26	5.2
2000	Methane	160	52	44	10	30.5	6.3	24	4.8	20	4.3	17	3.8
	Ethane	200	240	245	300	155	90	100	12	34.5	6.4	25.5	5.4
	Propane	210	260	207	180	203	130	170	110	77	12	34.5	7.8

Table E.2: Distance to 40% LFL Under Calm Nighttime Conditions

Distance to 40% LFL (ft); Wind 5 ft/sec Atmosphere Stability Class F													
Pressure (psig)	Temperature (°F)	0		100		200		300		400		500	
		Length	Width	Length	Width	Length	Width	Length	Width	Length	Width	Length	Width
50	Methane	12	2.4	10.7	2	9.6	1.8	8.6	1.6	7.8	1.4	7.2	1.5
	Ethane	12	2.4	12	2.2	11.9	2	11.1	1.8	9.7	1.8	8.9	1.6
	Propane	100	54	12.5	2	12.5	2.4	12	2.2	11.3	2	10	1.8
150	Methane	17.5	3.8	15.7	2.8	14.2	2.5	12.4	2.3	11	2.1	10.2	1.7
	Ethane	33	3.6	23.2	3.2	17.3	3.4	15.7	2.8	14.3	2.7	12.8	2.4
	Propane	128	100	36	6	25.5	4	18	3.6	16.1	3.2	14.7	2.8
300	Methane	24	5.4	20	4.2	17.5	3.2	14.5	2.8	13.3	2.6	12.4	2.2
	Ethane	144	150	52	13	30	5	20.5	4.2	17.8	3.4	15.6	2.8
	Propane	150	140	145	130	56	11	28.5	5	21	4.4	18	4.4
1000	Methane	99	20	32	7.2	25.5	5.2	21	4	18	3.7	15.5	3.1
	Ethane	187	200	225	260	108	40	36	8	26.5	5.6	22.5	4.6
	Propane	197	250	190	220	170	160	120	44	37.5	8	27	6
2000	Methane	180	68	48	11	32	6.6	25	5.4	20.5	4.6	18	4
	Ethane	220	300	270	370	175	120	120	14	36	6.8	27	6.2
	Propane	235	320	225	290	223	260	192	140	85	14	37	8.4

Table E.3: Distance to 25 % LFL Under Calm Nighttime Conditions

Distance to 25% LFL (ft); Wind 5 ft/sec Atmosphere Stability Class F													
Pressure (psig)	Temperature (°F)	0		100		200		300		400		500	
		Length	Width	Length	Width	Length	Width	Length	Width	Length	Width	Length	Width
50	Methane	14.4	3.1	13.1	2.8	11.6	2.4	10.4	2.1	9.5	1.8	8.6	1.9
	Ethane	18	3.2	15.5	2.9	14.2	2.8	12.8	2.8	11.7	2.4	10.6	2.2
	Propane	123	90	20	3.2	15.9	3.4	14.5	3	13.4	2.8	12	2.4
150	Methane	22	5.2	19.2	4.4	16.7	3.4	14.3	2.8	13	2.6	11.4	2.1
	Ethane	52	5.4	44.5	5.6	24	5	19.1	4.2	16.8	3.5	14.5	2.8
	Propane	154	155	54	14	48	10	23.5	5.2	19.5	4.4	17.6	3.4
300	Methane	34	7.6	24.5	5.4	21	4	17.5	3.7	15.5	3	13.5	2.8
	Ethane	175	210	72	24	51	7.2	25	5.8	20.7	4.5	17.7	3.6
	Propane	180	200	175	180	78	24	42	7.2	25.5	5.6	21.5	4.6
1000	Methane	146	34	39.5	9	28.5	6.2	23	5	19.5	4.4	17	3.8
	Ethane	232	280	280	340	140	62	45	10.4	31	6.8	25	5.6
	Propane	238	340	235	300	220	230	156	70	45	11	31	6.8
2000	Methane	245	105	60	14	36	8.2	27	6.4	22	5.7	19	4.8
	Ethane	270	360	320	480	235	160	153	19	41	9.8	29.5	7
	Propane	280	440	275	380	275	350	275	180	102	17	39	10

Table E.4: Distance to 20% LFL Under Calm Nighttime Conditions

Distance to 20% LFL (ft); Wind 5 ft/sec Atmosphere Stability Class F													
Pressure (psig)	Temperature (°F)	0		100		200		300		400		500	
		Length	Width	Length	Width	Length	Width	Length	Width	Length	Width	Length	Width
50	Methane	15.8	3.6	14.4	3	12.9	2.8	11.5	2.3	10.4	1.9	9.4	2
	Ethane	25.5	3.6	19	3.8	15.5	3.4	14.4	3	12.9	2.6	11.6	2.4
	Propane	133	106	28	5	20	4	16	3.6	14.7	3	13.5	2.7
150	Methane	25.5	5.8	20.5	4.6	17.8	3.6	15.6	3	13.6	2.8	12.7	2.2
	Ethane	59	6.4	54	7.4	29.8	5.8	20.5	4.6	18	3.6	16.3	3.2
	Propane	173	180	62	20	58	14	28	6	21.2	4.8	19.3	3.6
300	Methane	40.5	8.4	26.5	6.2	22	4.7	18.5	3.9	16.7	3.2	14.5	3
	Ethane	197	220	82	32	64	9	27	6.6	22	4.8	19.2	4
	Propane	195	240	195	210	90	30	49	8.7	27.5	6.4	22.5	5
1000	Methane	173	44	43	10	30.5	6.6	24	5.2	20	4.6	17.5	4
	Ethane	260	320	310	360	160	76	50	12.2	33	7.4	26	5.7
	Propane	265	360	260	340	245	260	180	80	48	12	33	7.4
2000	Methane	315	120	66	15	38	8.7	28	6.8	23	5.8	19.5	5
	Ethane	290	400	370	520	280	190	170	20	44	10.6	31	7.8
	Propane	310	460	300	420	300	380	325	200	110	18	44	10.4

Table E.5: Distance to 10% LFL Under Calm Nighttime Conditions

Distance to 10% LFL (ft); Wind 5 ft/sec Atmosphere Stability Class F													
Pressure (psig)	Temperature (°F)	0		100		200		300		400		500	
		Length	Width	Length	Width	Length	Width	Length	Width	Length	Width	Length	Width
50	Methane	22.9	5.7	19.4	4.8	17	4	15.5	3.2	14.3	2.6	12.9	2.2
	Ethane	51	7.2	45.5	7.6	24.3	5.6	19.1	4.8	17	3.8	14.8	3.4
	Propane	200	174	55	14	48	8	23	5.8	19.4	4.9	17.4	3.7
150	Methane	43	9	28	7	23	5.3	20	4	17.5	3.2	15.5	2.8
	Ethane	96	10.5	98	16.6	54	9.2	28	7.2	24	5.4	20.5	4.2
	Propane	260	260	102	40	100	19	46	9.2	27.5	7	23	5.2
300	Methane	68	12.2	35.5	8.9	28.5	6	23	4.4	20	4	17.5	3.7
	Ethane	320	290	133	54	116	13.2	36	9.4	29	6.3	23.5	4.6
	Propane	280	330	295	300	164	56	71	12.8	35.5	9.2	26.5	6.1
1000	Methane	340	72	57	15	38	8.3	28	7.5	23	5.2	19.5	5
	Ethane	445	420	565	500	290	114	68	16.2	40	9.6	30	6.8
	Propane	380	480	390	450	440	350	337	130	63	17	40	9.6
2000	Methane	700	160	93	21	46	10.6	32	8	26	6.4	21	6
	Ethane	500	530	710	670	555	250	245	27	53	12.4	35	9
	Propane	510	630	480	580	520	530	655	280	145	24	51	13.2

Table E.6: Jet Flame Characteristics Under Calm Nighttime Conditions

Jet Fire Characteristics; Wind 5 ft/sec Atmosphere Stability Class F													
Pressure	Temp. (°F)	0		100		200		300		400		500	
(psig)	Rad. (kW/m2)	12.5	4	12.5	4	12.5	4	12.5	4	12.5	4	12.5	4
50	Methane	-	-	-	-	-	-	-	-	-	-	-	-
	Ethane	-	-	-	-	-	-	-	-	-	-	-	-
	Propane	6	16	-	-	-	-	-	-	-	-	-	-
150	Methane	-	-	-	-	-	-	-	-	-	-	-	-
	Ethane	-	3	-	1	-	-	-	-	-	-	-	-
	Propane	13	21	-	3	-	3	-	-	-	-	-	-
300	Methane	-	6	-	5	-	5	-	3	-	1	-	-
	Ethane	15	24	-	7	-	7	-	6	-	5	-	5
	Propane	16	25	15	24	-	8	-	7	-	7	-	6
1000	Methane	8	18	6	16	3	14	-	12	-	11	-	10
	Ethane	22	39	27	49	10	18	8	16	7	15	5	14
	Propane	22	41	22	40	19	34	11	20	9	17	8	15
2000	Methane	17	28	14	22	13	21	11	19	10	17	8	16
	Ethane	26	48	34	61	18	33	16	27	14	24	13	23
	Propane	27	50	27	49	26	48	20	36	17	30	15	27

Table E.7: Distance to 50% LFL Under Daytime Conditions

Distance to 50% LFL (ft); Wind 16 ft/sec Atmosphere Stability Class D													
Pressure (psig)	Temperature (°F)	0		100		200		300		400		500	
		Length	Width	Length	Width	Length	Width	Length	Width	Length	Width	Length	Width
50	Methane	8	1.1	7.6	1.1	7	1	6.3	1	6	0.9	5.6	0.8
	Ethane	8.4	1.2	8.1	1	7.8	1	7.4	1	6.9	0.9	6.4	0.9
	Propane	31	4	8.8	1.2	8.4	1.2	8	1.1	7.6	1	7.2	1
150	Methane	11.5	1.8	10.5	1.6	9.9	1.6	9	1.4	8.2	1.3	7.8	1.2
	Ethane	12.3	2.1	12	1.8	11.3	1.7	10.3	1.6	9.8	1.5	9.2	1.4
	Propane	59	5	12.6	1.8	12.3	1.7	11.8	1.6	10.9	1.6	10.6	1.5
300	Methane	14.5	2.6	13.8	2.5	13	2.2	11.6	2	10.4	1.8	9.8	1.7
	Ethane	70	10	15.3	2.6	14.7	2.4	13.5	2.2	12.7	2	12.4	2
	Propane	78	14	70	10	15.8	2.4	15.3	2.2	14	2.1	13.3	2.1
1000	Methane	27	4.8	21.5	4.1	19.5	3.8	17.6	3.4	16	3.2	15	3
	Ethane	106	20	132	25	27.5	4.4	21.5	4	19.5	4	18.3	3.8
	Propane	112	26	108	22	90	13	35	5	23	4	20	4
2000	Methane	70	9	38.5	6	28	5.6	22.8	5.2	20.6	4.6	19.1	4.2
	Ethane	129	26	161	36	76	10	46	4.6	29	5.6	24	5
	Propane	135	34	130	30	128	26	90	12	55	7	30	6

Table E.8: Distance to 40% LFL Under Daytime Conditions

Distance to 40% LFL (ft); Wind 16 ft/sec Atmosphere Stability Class D													
Pressure (psig)	Temperature (°F)	0		100		200		300		400		500	
		Length	Width	Length	Width	Length	Width	Length	Width	Length	Width	Length	Width
50	Methane	8.9	1.2	8.2	1.2	7.8	1.1	7.2	1.1	6.6	1	6.2	0.9
	Ethane	9.4	1.4	9	1.2	8.5	1.1	8	1.1	7.6	1	7.2	1
	Propane	40	5	9.7	1.5	9.4	1.2	8.9	1.2	8.2	1.2	8	1.1
150	Methane	12.7	2.2	11.8	2	10.9	2	10	1.6	9.4	1.6	8.6	1.6
	Ethane	13.6	2.4	13.1	2	12.6	2	11.5	1.9	10.7	1.7	10.1	1.7
	Propane	72	6	14.2	2	13.3	2	13	2	12.2	1.7	11.4	1.7
300	Methane	16.3	2.8	15	2.6	14	2.5	13	2.4	12	2	11	2
	Ethane	84	13	16.5	2.8	16	2.6	14.5	2.6	13.9	2.5	13.1	2.4
	Propane	91	17	84	15	16.9	2.9	16.5	2.6	15.2	2.5	14.3	2.5
1000	Methane	34	5.5	25.5	4.8	21.5	4.6	19.7	4.2	18	3.8	16.5	3.4
	Ethane	124	23	153	30	35	5	25	4.6	21.4	4.4	20	4.2
	Propane	128	30	122	26	108	19	45	6	27	5	22	4.5
2000	Methane	86	11	48	7	33.5	6.5	26	5.8	23	5.4	21.1	4.6
	Ethane	148	32	183	44	90	14	58	6.4	35	6.4	27.5	5.6
	Propane	152	40	147	34	145	32	115	14	65	8	38	7

Table E.9: Distance to250% LFL Under Daytime Conditions

Distance to 25% LFL (ft); Wind 16 ft/sec Atmosphere Stability Class D													
Pressure (psig)	Temperature (°F)	0		100		200		300		400		500	
		Length	Width	Length	Width	Length	Width	Length	Width	Length	Width	Length	Width
50	Methane	11.2	1.6	10.3	1.5	9.6	1.5	8.9	1.5	8.2	1.4	7.8	1.3
	Ethane	11.5	1.8	11.4	1.8	10.7	1.5	10.1	1.6	9.6	1.5	9	1.4
	Propane	66	11	11.8	1.8	11.5	1.6	11.2	1.6	10.4	1.6	9.9	1.5
150	Methane	16.5	2.6	15.1	2.5	13.7	2.5	12.5	2.4	11.6	1.9	10.9	1.8
	Ethane	16.8	2.8	15.6	2.6	15	2.6	14.5	2.4	13.6	2.1	13	2.1
	Propane	102	10	16.5	2.8	16.5	2.6	15.5	2.6	14.5	2.5	14	2.3
300	Methane	20.5	3.6	18.7	3.6	17.2	3.4	15.8	3.2	14.5	2.8	13.9	2.5
	Ethane	118	21	20.4	3.8	19.3	3.5	18.2	3.5	16.9	3.1	16	3
	Propane	124	26	119	22	21.7	3.7	20	3.6	19	3.4	17.8	3.3
1000	Methane	54	7.6	41	6.3	30	5.8	24.5	5.2	22.5	5	20.7	4.5
	Ethane	162	34	200	44	55	6.8	39.4	6.4	30	6.2	25.3	5.5
	Propane	168	44	165	36	145	30	65	8	43	7	34	6
2000	Methane	118	16	73	10	53	8.4	39	7.6	31	6.8	27.2	6.4
	Ethane	190	42	235	58	122	19	85	9	54	8.4	40.5	7.4
	Propane	198	52	195	48	191	45	145	22	95	11	60	8

Table E.10: Distance to 20% LFL Under Daytime Conditions

Distance to 20% LFL (ft); Wind 16 ft/sec Atmosphere Stability Class D													
Pressure (psig)	Temperature (°F)	0		100		200		300		400		500	
		Length	Width	Length	Width	Length	Width	Length	Width	Length	Width	Length	Width
50	Methane	12.5	1.8	11.6	1.6	10.7	1.6	10	1.6	9.3	1.5	8.6	1.4
	Ethane	12.6	2	12.7	2	12.1	1.8	11.3	1.8	10.5	1.6	10	1.5
	Propane	79	13	13	2	12.5	1.8	12.5	1.8	11.7	1.8	11	1.7
150	Methane	19.6	3	17.5	2.7	15.7	2.6	14.1	2.5	13	2	12.5	2
	Ethane	19	3.2	17.2	2.8	16.5	2.8	16.5	2.6	15.4	2.4	14	2.4
	Propane	118	11	18.2	3.2	18.5	3	17.1	2.8	16.1	2.7	15.2	2.7
300	Methane	24.2	4	21	3.8	19.4	3.6	17.5	3.4	16.2	3	15.1	2.7
	Ethane	135	25	24.3	4.2	21.5	4	20.5	3.7	18.9	3.3	17.8	3.3
	Propane	148	30	135	26	26.6	4.4	23	4	21.5	3.7	20	3.6
1000	Methane	65	8	50	7.2	38	6.6	29.5	5.8	25	5.4	23	5.1
	Ethane	183	40	225	50	66	7.6	48	7.2	37	6.6	30.5	6.2
	Propane	190	50	185	44	163	34	80	9	54	8	41	7
2000	Methane	135	18	87	11	65	9.5	49	8.3	37.5	7.2	31.5	7
	Ethane	213	50	265	66	138	23	100	10.4	66	9.6	49	8.7
	Propane	223	60	218	52	215	50	162	24	110	12	70	10

Table E11: Distance to 10% LFL Under Daytime Conditions

Distance to 10% LFL (ft); Wind 16 ft/sec Atmosphere Stability Class D													
Pressure (psig)	Temperature (°F)	0		100		200		300		400		500	
		Length	Width	Length	Width	Length	Width	Length	Width	Length	Width	Length	Width
50	Methane	20.5	2.6	18.4	2.5	16.4	2.3	14.5	2	13.3	2	12.2	1.8
	Ethane	18.8	2.6	20.7	2.5	19.2	2.4	17.4	2.3	16	2.2	14.6	2.2
	Propane	122	23	19.5	3	18.5	2.6	20.4	2.5	18.5	2.4	17	2.4
150	Methane	34	4	31	3.7	27	3.6	23.3	3.4	20.5	3	16.5	3
	Ethane	35	4.4	27	4.3	24	4	29	3.6	26	3.6	19.2	3.4
	Propane	175	25	31	4.5	33	4.2	26	4.1	23	4	21.5	3.8
300	Methane	45.5	5.8	39	5.4	33.3	5.2	27.5	4.8	24.3	4.4	22	4.1
	Ethane	195	41	46.5	6	40	5.6	37	5.2	32	5	28.2	4.8
	Propane	205	46	196	42	50	6.4	43	5.9	40	5.6	35	5.4
1000	Methane	110	11.8	87	10	72	9.6	58	8.6	48	7.8	40	7.2
	Ethane	260	60	312	73	110	11.5	86	10.2	70	9.4	60	9
	Propane	275	70	265	64	228	49	125	13	92	11	72	10
2000	Methane	200	28	146	15	103	13.2	86	12	69	10.8	55	10
	Ethane	299	76	360	94	205	34	162	15.4	103	13.4	86	12.5
	Propane	311	85	305	79	299	74	235	36	175	17	107	15

Table E.12: Jet Flame Characteristics Under Daytime Conditions

Jet Fire Characteristics; Wind 16 ft/sec Atmosphere Stability Class D													
Pressure	Temp. (°F)	0		100		200		300		400		500	
(psig)	Rad. (kW/m2)	12.5	4	12.5	4	12.5	4	12.5	4	12.5	4	12.5	4
50	Methane	-	-	-	-	-	-	-	-	-	-	-	-
	Ethane	-	-	-	-	-	-	-	-	-	-	-	-
	Propane	-	14.5	-	-	-	-	-	-	-	-	-	-
150	Methane	-	-	-	-	-	-	-	-	-	-	-	-
	Ethane	-	-	-	-	-	-	-	-	-	-	-	-
	Propane	1	21	-	-	-	-	-	-	-	-	-	-
300	Methane	-	-	-	-	-	-	-	-	-	-	-	-
	Ethane	20	24	-	-	-	-	-	-	-	-	-	-
	Propane	21	25	20	24	-	-	-	-	-	-	-	-
1000	Methane	-	16.5	-	14.5	-	13	-	10.5	-	-	-	-
	Ethane	28	32	34	39	-	17	-	16	-	15	-	14
	Propane	29	33	28	32	24	28	-	19	-	16	-	15
2000	Methane	22	27	19	23	-	21	-	19	-	17	-	16
	Ethane	33	38	42	47	24	28	20	24	16	20	15	21
	Propane	34	39	33	37	33	37	26	30	21	26	19	24

Appendix F – Leak Rate Tables

Determining the estimated frequency for a leak to develop is a crucial step when performing a quantitative risk analysis for a process. When determining the rate at which leaks occur, consideration should be given to numerous factors, including: the age of the equipment, the level of maintenance, the type of equipment, and the size of the release to be studied. All of these can significantly impact the potential frequency of a release. One method of estimating leak rates is to determine the expected frequency of a leak from equipment based on its type, then sum the leak rates over all equipment located in a zone. This can provide an easy starting point for determining leak rates, but consideration should still be given to historical leak data and factors that may result in different leak rates than those given in general tables. The following tables give generic leak rates for a variety of process equipment.

Table F.1 – Sample Leak Rates for Pressure Vessels

Equipment	Leak Type	Release Frequency (yr^{-1})
Pressure Vessel	Small (< 1 in.)	5.00E-05
	Large (> 1 in.)	7.00E-06
	Catastrophic	5.00E-06
Reactor Vessels	Small (< 1 in.)	3.00E-05
	Large (> 1 in.)	5.00E-06
	Catastrophic	5.00E-05

Table F.2 – Sample Leak Rates for Atmospheric Storage

Equipment	Leak Type	Release Frequency (yr^{-1})
Atmospheric Storage	Small (< 1 in. / roof)	5.00E-03
	Large (> 1 in.)	1.00E-04
	catastrophic	5.00E-06

Table F.3 – Sample Leak Rates for Pumps

Equipment	Leak Type	Release Frequency (yr^{-1})
Pump	Seal, single	8.00E-04
	Seal, double	3.00E-04
	Casing	3.00E-05

Table F.4 – Sample Leak Rates for Compressors

Equipment	Leak Type	Release Frequency (yr^{-1})
Compressor (Centrifugal)	Small (< 1in.)	2.00E-02
	Large (> 1in.)	4.00E-04
	Catastrophic	8.00E-06
Compressor (Reciprocating)	Small (< 1in.)	9.00E-02
	Large (> 1in.)	5.00E-03
	Catastrophic	2.00E-04

Table F.5 – Sample Leak Rates for Piping (m^{-1} yr^{-1})

Equipment	Small (< 1in.)	Large (> 1in.)	Catastrophic
Piping (<1 in.)	4.00E-05	N/A	2.00E-06
Piping (>1 in and <6 in.)	1.00E-05	5.00E-06	1.00E-06
Piping (>6 in.)	1.00E-06	5.00E-07	2.00E-07
Pipeline (above ground)	2.00E-07	4.00E-08	7.00E-09

Table F.6 – Sample Leak Rates for Valves / Gaskets / Flanges

Equipment	Release Frequency (yr^{-1})
Valve	2.00E-04
Hose / Coupling	1.00E-07 per transfer
Gasket	5.00E-06
Flange	5.00E-06

Table F.7 – Sample Leak Rates for Miscellaneous

Equipment	Leak Type	Release Frequency (yr^{-1})
Shell/Tube Heat Exchanger		2.00E-04
Plate and Frame		7.00E-03
Fin Fan Cooler		7.00E-03
Condensers		2.00E-04
Filters	Small (< 1in.)	9.00E-04
	Large (> 1 in.)	2.00E-04
	catastrophic	1.00E-05

Appendix G – Example Semi-Quantitative Approach

FGS performance targets specifications define the ability of a FGS function to detect, alarm, and if necessary, take action to mitigate the consequence of a fire or gas release upon a demand condition. In concept, a higher hazard installation should require higher levels of performance; while a lower hazard installation should allow for lower levels of performance, so that FGS resources can be effectively allocated.

The factors used to assess risk of fire and gas hazards in hydrocarbon processing areas are evaluated in a semi-quantitative method using a scoring system. This ranking procedure is used to quantify fire, combustible gas and toxic gas risks for each area into one of three risk categories (high, medium, low) for the purpose of establishing FGS performance requirements.

Hazard ranking is used to assess the risk of fire and gas hazards associated with each Category H or N zone. Hazard ranking is a function of the equipment, hazards, consequences, likelihood, occupancy, and special factors. Ranking requires an equipment-by-equipment assessment of factors, including:

1. Identify Hydrocarbon Processing Equipment
    - Identify credible sources of hydrocarbon gas or liquid release
    - Identify amount and type of processing equipment in zone
    - Identify process conditions that could aggravate / mitigate consequence severity
2. Assessment of Consequence Severity
    - Identify equipment which the FGS is intended to safeguard
    - Consideration of magnitude of safety consequences (injury vs life-threatening)
    - Identify confinement and congestion in process areas that could aggravate combustible gas hazards
3. Assessment of Hazard Likelihood
    - Likelihood of release from all identified release sources.
    - Identify credible ignition sources (continuous and intermittent)
    - Opportunity for effective response action to prevent safety impacts
4. Assessment of Level Occupancy in Zone
    - Normal / Routine Occupancy (operations, maintenance, contract)
    - Non-Routine Occupancy (operations, maintenance, contract)

If a zone is not easily characterized by one or more of the factors that comprise the zone hazard rank, quantitative risk analysis should be considered.

Figure G.1 shows the hazard ranking procedure.

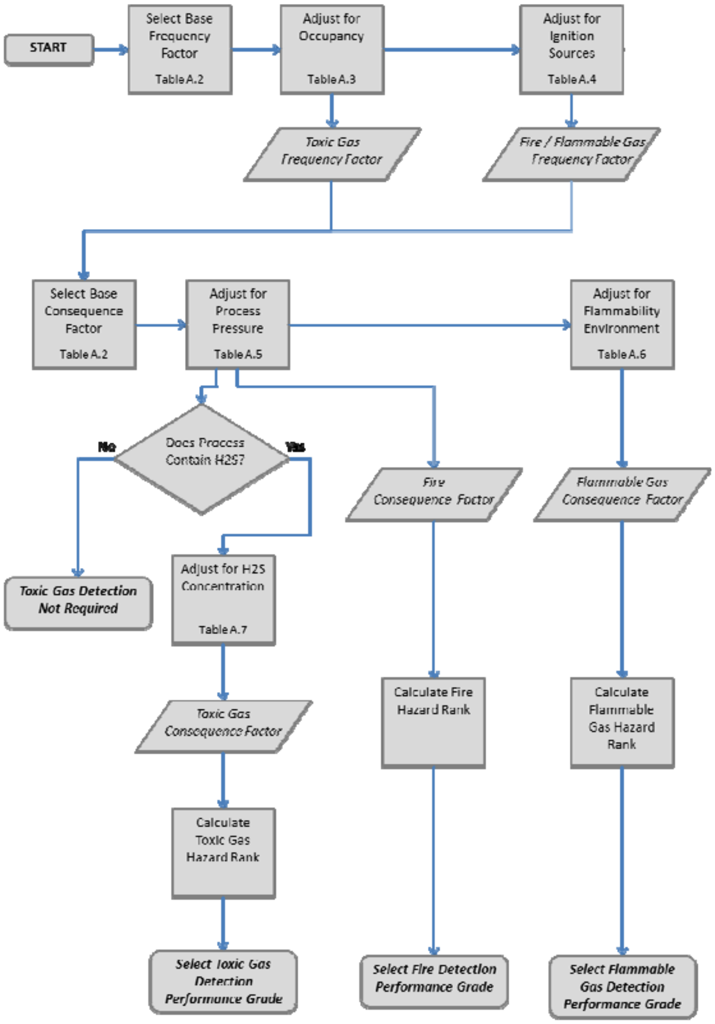


Figure G.1 – Hazard Ranking Procedure

The ranking procedure uses numerical scoring to assess the risk associated with a given area. In step one zones requiring further hazard review have been identified. Category “H” zones are subject to a review of these factors.

Step 1 – Select Major Process Equipment Item

Identify the major process equipment in the zone (or perform the analysis one major equipment item at a time). *Figure G.2* assigns a default likelihood score to each type of processing equipment typically found in a process industry facility and *Figure* G.3 assigns a consequence score based on the phase of material in the process equipment. The scores account for the baseline consequence and baseline likelihood of a release that could result in significant fire, combustible gas, or toxic gas hazard.

Equipment Item	***Base Likelihood Score***
Shell & Tube Heat Exchanger	2.0
Plate & Frame Heat Exchanger	3
Air Cooled Heat Exchanger	2
Column / Tower / Contactor	2.5
Compressor / Expander	3
Pressure Vessel / Reactor	2
Centrifugal Pump	3
Reciprocating Pump	3
Atmospheric Storage Tank	1
LP Storage tank	1
Fired Heater	2
Pig Launcher/Receiver	2
Sump/Sump Pump	1
Piping Manifold	1
Single Welded Pipe Segment	1

Figure G.2 – Major Equipment Item Base Likelihood Scores

Process Material Phase	***Base Consequence Score***
Stable Liquids	1
Volatile Liquid	2
Gas	3
Stable Liquid	T (Process) -< FP (Flash Point) FP and NBP volatile constituent representing > 3 mol% of streams
Volatile Liquid	FP < T (process) < NBP
Gas	T (process) > NPB; Gas also includes cryogenic liquids where T(amb) > NBP

Figure G.3 – Process Material Base Consequence Scores

Step 2 – Adjust Likelihood Score for Occupancy

The base likelihood score should be adjusted as necessary to reflect the occupancy environment within 50 feet of the major equipment item. *Figure G.4* defines occupancy adjustment factors. The result is adjusted likelihood for toxic hazards, if applicable. No further likelihood adjustment is required for toxic hazards. Additional adjustment is required for fire and/or flammable hazard likelihood.

Description	**Adjustment**
Rare (less than 15 min per day) ~1%	-2
Moderate (routine Operator Rounds) ~ 10%	-1
High (near continuous occupancy) > 30%	0

Figure G.4 – Occupancy Adjustment

Step 3 – Adjust Likelihood Score for Ignition Environment Factors

The ignition environment adjustment step is not applicable to toxic hazards. If fire or flammable gas hazards are of concern, then the likelihood score should be further adjusted for ignition probability. *Figure G.5* defines ignition adjustment factors.

Description	**Adjustment**
N/A – Process Does Not Contain Flammables/Combustibles	-10
Low Ignition Probability (3%)	-1.5
Average Ignition Probability (10%)	-1
Moderate Ignition Probability (30%)	-0.5
High Ignition Probability (near 100%)	0

Figure G.5 – Ignition Environment Adjustment

Step 4 – Adjust Consequence Score for Process Conditions

The base consequence score should be adjusted for process pressure. This adjustment applies to Fire, Flammable and Toxic Gas hazards. Higher process pressure is indicative of a higher magnitude of consequence severity if a release were to occur.

Process temperature is already factored into the default consequence score. *Figure G.6* defines Process Pressure adjustment factors.

Pressure	***Adjustment***
Atm to 50 psig	-0.5
50 to 150 psig	0
150 to 300 psig	0.5
300 to 1,000 psig	1
> 1,000 psig	1.5

Figure G.6 – Process Pressure Adjustment

Step 5 – Adjust Consequence Score for Flammability Environment

The base consequence score should be adjusted for factors related to the environment around a burning gas cloud, if it were to occur. This is related to process confinement and congestion factors. A higher degree of confinement and congestion would lead to a more severe consequence. *Figure* G.7 defines the Flammability Environment Adjustment. The flammability environment adjustment should only be applied if flammable gas hazards are being evaluated. Do not adjust the consequence score with this factor if toxic hazards are being evaluated.

Environment Type	***Adjustment***	***Notes (Confinement & Obstacle Density)***
N/A	-10	Material does not have significant vapor pressure at process temperature and atmospheric pressure
No Confinement / Low Congestion	-1	"3D Low"
Some Confinement / Moderate Congestion	0	"2D Med"
Confinement / High Congestion	2	"2D High"

Figure G.7 – Flammability Environment Adjustment

Step 6 – Adjust Consequence Score for Toxic Gas Concentration

The base consequence score should be adjusted for concentration of toxins (e.g., hydrogen sulfide) in the process fluid. This adjustment applies only to toxic gas hazards. Higher toxin concentration is indicative of a higher magnitude of consequence severity if a release were to occur. *Figure G.8* provides a typical H2S concentration adjustment factors.

Concentration (v/v)	***Adjustment***	***Notes***
< 100 ppm	(-5)	No H2S Analysis
100 ppm to 1000 ppm	-1	
1000 ppm to 1%	0	
1% to 3%	1	
3% to 10%	2	
> 10%	3	

Figure G.8 – H2S concentration Adjustment

Step 7 – Determine FGS Hazard Rank

For each hazard (fire, combustible and toxic), each equipment item is assigned an individual adjusted likelihood score and an adjusted consequence score. The hazard rank is the sum of the adjusted likelihood score and the adjusted consequence score. This score is indicative of the degree of the hazard and ultimately the risk of fire, combustible gas or toxic gas hazards.

The calculated value is defined as the adjusted baseline hazard rank. The highest individual value of the baseline hazard rank for all equipment within a given zone is defined as the zone hazard rank.

Step 8 – Determine Need for FGS

Each area receives a performance target for fire, flammable gas and toxic (e.g., H2S) gas hazards which take the form of Grades. These grades are listed in *Figure G.9*.

Grade	Exposure Definition
A	Hydrocarbon processing, with high exposure.
B	Hydrocarbon processing, with moderate exposure.
C	Hydrocarbon processing, with low or very-low exposure.
No FGS	Risk is tolerable w/o benefit of FGS

Figure G.9 – Fire and Gas Performance Grades

Each of the grades serves to define a relative level of fire or gas risk with grade A being the highest risk areas and grade C being the lowest risk areas requiring detection.

Step 8.1 - Fire Detection Performance Targets

Design of fire detection systems is predicated on the principal that sensing a turbulent diffusion fire should be early enough such that automatic control action can be taken, if required, during the incipient stages of the fire to maximize safety and limit commercial losses to a tolerable level. Incipient fire detection requires an adequate number of detectors that are strategically located in a manner to provide adequate coverage.

Fire performance targets are selected based on the results of the semi-quantitative FGS screening procedure described in this appendix. The result of the semi-quantitative method is the fire hazard rank which is representative of the relative fire risk. A higher hazard rank represents a higher level of risk, which subsequently requires a higher performance target on the FGS to mitigate risk. *Figure G.10* details the relationship between the fire hazard rank and the fire grade.

Adjusted Hazard Rank	Grade	Fire Detection Coverage
>=7	A*	0.90
5 to <7	A	0.90
2 to <5	B	0.80
0.5 to < 2	C	0.60
<0.5	N/A	No Detection Required

Figure G.10 – Fire Hazard Rank and Performance Grade

Fire detection performance targets are evaluated in locations where fires could occur with sufficient intensity to result in life-safety and/or commercial impact. In these locations, radiant heat output (RHO) is used as the criterion to specify flame magnitude of the design basis fire that is desired to be detected. The magnitude of a fire hazard is related to its fire size, which is directly correlated to its RHO. Note: this applies to fires that are not expected to produce excessive amounts of smoke before flaming fire. This procedure is written on the principal that optical flame detection in locations with higher fire hazard exposure should be sensitive to lower levels of RHO than fire detection in locations with lower fire hazard exposure.

Fire grade A is typically assigned to areas with higher levels of fire risk. These areas are characterized by hydrocarbon handling areas where small fires could cause significant damage in a short period of time or rapidly escalate. Such fires might be due to the potential for a higher consequence severity (for example, high-pressure gas from a compressor) or from higher likelihood of fire (for example, small bore pipework and pump seals). The performance targets associated with Grade A is such that a minimum of 90% detector coverage is achieved for detection of a 10 kW incipient stage fire.

Fire grade B is assigned to the majority of hydrocarbon processing areas throughout the facility. These areas are categorized by “normal” risk processing areas and typically contain fixed equipment with moderate to low likelihood of fire. The performance targets associated with Grade B is such that a minimum of 80% detector coverage is achieved for detection of a 50 kW incipient stage fire.

Fire grade C is assigned to areas where the risk of a fire is relatively low. Grade C areas are characterized by a low potential for severe consequences (for example, due to high flash point fuel). The performance targets associated with Grade A is such that a minimum of 60% detector coverage is achieved for detection of a 100 kW incipient stage fire.

A zone with a hazard rank of 7.0 or greater should result in a fire grade A*. For zones graded A*, the installed fire detection system should be capable of achieving the Grade A performance targets. In addition, the zone should also be subject to additional risk studies, such as a QRA analysis to verify that fire risk is adequately mitigated with grade A performance targets. If QRA analysis reveals that risks are intolerable, additional risk reduction measures should be considered beyond the fire and gas system, such as a more stringent risk-based inspection program in accordance with API 581.

Step 8.2 - Combustible Gas Detection Performance Targets

Design of combustible gas detection is predicated on having the ability to sense a threshold volume of gas at an incipient stage where action can be taken to prevent significant loss from occurring were that volume of gas to ignite and result in a deflagration. Note: the goal is not to prevent any size flammable cloud from forming, igniting, or deflagrating. The goal is to limit flame front acceleration of such ignited gas clouds to a speed that has been demonstrated to be below the threshold of structural damage in process environments. The degree of hazard and the damage from a combustible gas deflagration is related to the size of the cloud as well as other factors such as confinement, and the presence of turbulence inducing obstacles.

Combustible gas detection performance targets are evaluated in locations where ignited gas clouds could cause damage from explosion overpressure. In these locations, the smallest gas cloud that has the potential to cause such damage, or the smallest gas cloud that can reasonably be developed, is used to define requirements for placing combustible gas detectors.

Combustible gas performance targets are selected based on the results of the semi-quantitative FGS screening procedure described in this appendix. The result of the semi-quantitative method is the combustible gas hazard rank which is representative of the relative combustible gas risk. A higher hazard rank represents a higher level of risk, which subsequently requires a higher performance target on the FGS to mitigate risk. *Figure G.11* details the relationship between the combustible gas hazard rank and the combustible gas grade.

Adjusted Hazard Rank	Grade	Gas Detection Coverage
>=7	A*	0.90
5 to <7	A	0.90
2 to <5	B	0.80
0.5 to < 2	C	0.60
<0.5	N/A	No Detection Required

Figure G.11 –Combustible Hazard Rank and Performance Grade

Combustible gas grade A is typically assigned to zones subject to higher risk, either due to high frequency release sources (such as rotating equipment) or a high degree of confinement of a burning gas cloud that could cause damaging flame acceleration and overpressure when subject to a relatively small gas release. This performance target for grade A is such that the gas detection system should be capable of achieving 90% coverage for detection of a spherical gas cloud 5 meters (16 ft) in diameter anywhere in the zone.

Combustible Gas Grade B is typically assigned to areas subject to a moderate degree of confinement of a burning gas cloud. This performance target for grade A is such that the gas detection system should be capable of achieving 80% coverage for detection of a spherical gas cloud 5 meters (16 ft) in diameter anywhere in the zone.

Combustible gas grade C is typically assigned to open hydrocarbon processing areas with fixed equipment and relatively low operating pressure and well controlled ignition sources. The gas detection system should have 60% detector coverage to detect a spherical gas cloud 10 m (32 ft) in diameter anywhere in the zone. In some cases the primary hazard of concern may be migration of combustible gas to other hydrocarbon processing areas. In these cases, perimeter detection may be considered in lieu of volumetric gas detection.

A zone with a hazard rank of 7.0 or greater should result in a combustible gas grade A*. For zones graded A*, the installed combustible gas detection system should be capable of achieving the Grade A performance targets. In addition, the zone should also be subject to additional risk studies, such as QRA analysis to verify that combustible gas risk is adequately mitigated with grade A performance targets. If QRA analysis reveals that risks are intolerable, additional risk reduction measures should be considered beyond the fire and gas system, such as a more stringent risk-based inspection program in accordance with API 581.

For Combustible Gas Grade A, Grade B, and Grade C, the extent of graded area should be taken as 5 meters from equipment from which a release could result in a combustible gas hazard.

Step 8.3 - Toxic Gas Detection Performance Targets

In this example procedure, toxic gas detection is limited to hydrogen sulfide H2S hazards. A similar approach can be used for other toxins. For not H2S toxic hazards, performance requirements are determined on a case-by-case basis using good engineering practice and conformance to applicable standards and regulations. H2S performance targets are evaluated in locations a gas clouds containing H2S could cause serious injury. Personnel who enter H2S containing areas of the facility are assumed to be wearing personal H2S monitors at all times. This is the primary means of safety once a worker is in an H2S containing area and is nearby equipment containing H2S. Fixed H2S detectors should not be the primary means of safety at these locations since it would require a very large number of detectors to protect every possible exposure. Fixed H2S detectors are the primary means of safety to alert personnel of an H2S hazard who are either: a) not in the area at the time, or b) within the area but not immediate exposed to a hazardous release. The goal is to either prevent personnel from entering the area or evacuating personnel from the area, depending on their initial location.

Performance of H2S gas detection is based on the likelihood and severity of the toxic gas hazards present. Defining performance targets requires definition of the hazard that is being safeguarded against. For H2S, this is the smallest gas cloud that has the potential to cause serious injury. This is descriptive of the magnitude of the hazard that requires detection and is used to define requirements for placing toxic gas detectors.

Toxic gas performance targets are selected based on the results of the semi-quantitative FGS hazard rank procedure described in this Appendix. The result of the semi-quantitative method is the toxic gas hazard rank which is representative of the relative toxic gas risk. A higher hazard rank represents a higher level of risk, which subsequently requires a higher performance target on the FGS to mitigate risk. *Figure G.12* details the relationship between the toxic gas hazard rank and the toxic gas grade.

Adjusted Hazard Rank	**Grade**	**Gas Detection Coverage**
>=7.5	A*	0.90
5.5 or <7.5	A	0.90
3.5 to <5.5	B	0.80
1.5 to < 3.5	C	0.60
<1.5	N/A	No Detection Required

Figure G.12 –Toxic Hazard Rank and Performance Grade

Toxic Gas Grade A is typically assigned to zones where a toxic life-threatening toxic hazard could occur from relatively small gas release at a distance well outside the localized area of the release.

Toxic Gas Grade B is typically used when there is a moderate degree when an injury-level toxic hazard could occur from a small release at a distance well outside the localized area of the release

Toxic Gas Grade C is used when an injury-level toxic hazard could occur only from a large release at a distance beyond the localized area of the release.

A zone with a hazard rank of 7.5 or greater should result in a toxic gas grade A*. For zones graded A*, the installed toxic gas detection system should be capable of achieving the Grade A performance targets. In addition, the zone should also be subject to additional risk studies, such as a QRA analysis to verify that toxic gas risk is adequately mitigated with grade A performance targets. If QRA analysis reveals that risks are intolerable, additional risk reduction measures should be considered beyond the fire and gas system, such as a more stringent risk-based inspection program in accordance with API 581.

Toxic Gas Grade A , Grade B, and Grade C zones should be capable of detecting a spherical gas cloud of size equal to the distance to the acute injury endpoint when analyzed for the design-basis hazard scenario. For toxic gas hazards, the extent of graded area should be taken as the distance to the detection limit for the design-basis hazard scenario. These distances are determined based on the results of Toxic Gas Design Basis Dispersion Modeling.

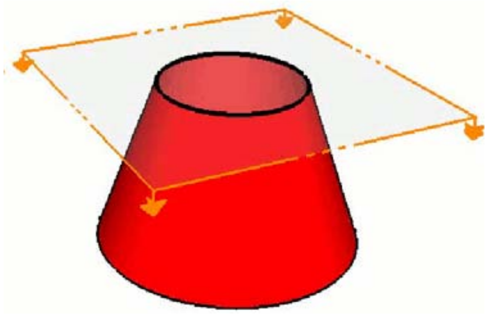
Step 9- Performance Target Acceptance Criteria

The performance targets details in this section for fire, flammable gas and toxic gas detection have been calibrated based on assessment of typical fire scenarios, typical consequences, typical likelihoods and typically target risk reduction for offshore oil and gas production facilities. Suitability to achieve desired level of risk reduction is contingent upon the process conditions and equipment being consistent with the assumptions used to develop the performance targets detailed above. For those situations that do not validate these assumptions calibration based on a specific facilities operating situation may be required.

This procedure is effective for characterizing fire, flammable gas and toxic gas risk for the large majority of offshore environments. However, every facility has unique factors that affect risk such as operating conditions, preventative maintenance programs and facility age. A semi-quantitative procedure cannot account for all variables which contribute to fire and gas risks in a facility and this procedure does not overrule good engineering judgment, standard practices or company policies and procedures. If deemed appropriate by the analysis, a higher grade may have been selected than the grade calculated using this procedure without any additional analysis. If a lower grade is desired than an appropriate risk study should be performed to ensure the company safety / risk goals are being satisfied.

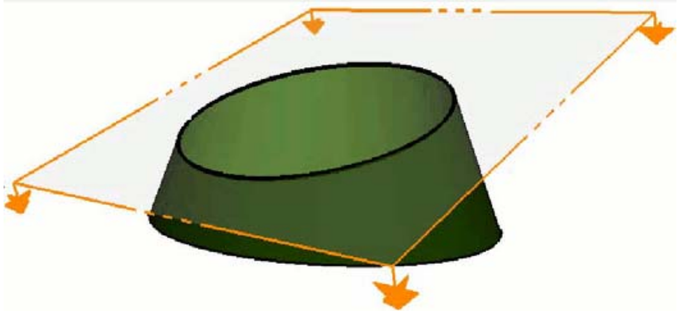
Appendix H – Analytical Geometry Formulae

Circle



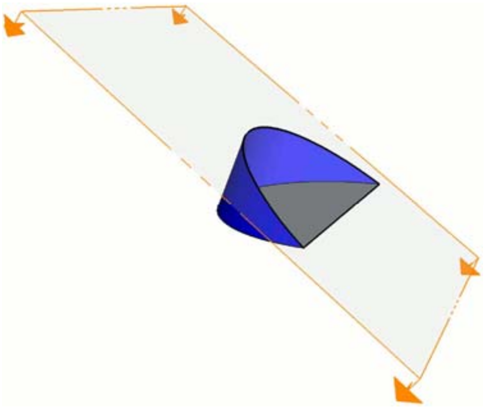
$$X^2 + Y^2 = a^2$$

Ellipse



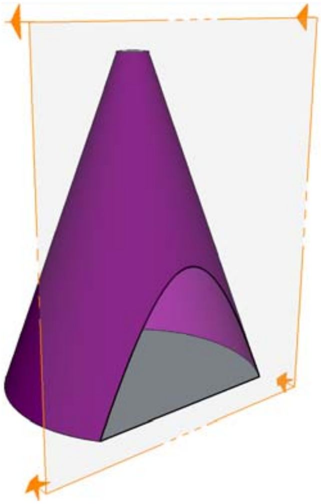
$$\frac{X^2}{a^2} + \frac{Y^2}{b^2} = 1$$

Parabola



$$Y^2 = 4cX$$

Hyperbola



$$\frac{X^2}{a^2} - \frac{Y^2}{b^2} = 1$$

Appendix I – Understanding Fire and Gas Mapping Software

Overview of Fire and Gas Mapping

This appendix delves into the algorithms and techniques that are employed by the various software tools that assist in computer aided fire and gas mapping. This information 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 should be performed fully considering three-dimensional attributes of the space, the cones-of-vision 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.

The “Cone of Vision”

The first consideration to be assessed 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.

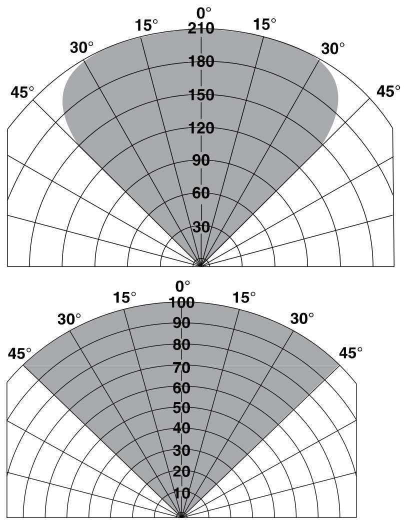


Figure I.1 – Cone of Vision for a Triple IR Optical Fire Detector for n-Heptane Pan Fire (Left) and Methane Jet Fire (Right) at "Very High" Sensitivity

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[1] performance test of the equipment. During this test, the distance (at various

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

angles) where the detector is activated by the test case fire is tracked and recorded.

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 I.2*.

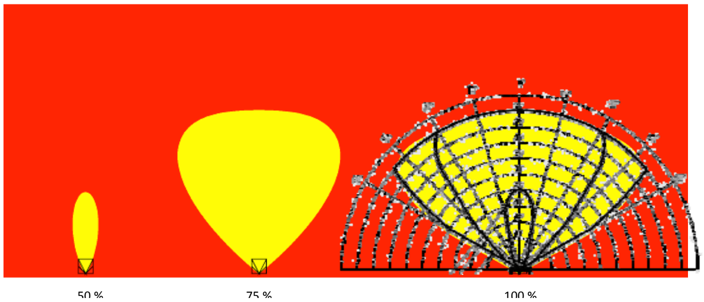

Figure I.2 – Kenexis Effigy Coverage Mapping Output for a Optical Fire Detector for n-Heptane Overlaid with the vendor's Published Coverage Map – Three Sensitivity Settings

Two very important factors should be noted when viewing cones-of-vision, such as the ones presented in *Figure I.1*. 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 I.1*, 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[2]
- "Corona Effect"[3] 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 I.3*.

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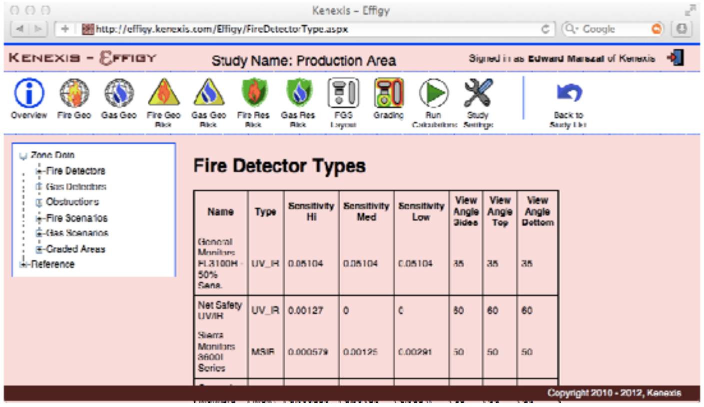
[2] The maximum centerline distance is not sufficient for characterizing performance of a fire detector because it is based on a single design basis fire that may not be consistent with the design basis fire desired to be modeled for any particular project. A means needs to be included to scale the distance 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.

[3] 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.



Study Name: Production Area

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 I.3 – Effigy Screenshot Showing Detector List – Including Sensitivity Settings by Detector and by Species of Interest

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 I.4* presents several three dimensional renderings of what a cone-of-vision would look like if it were visible, rotated through several different angles.

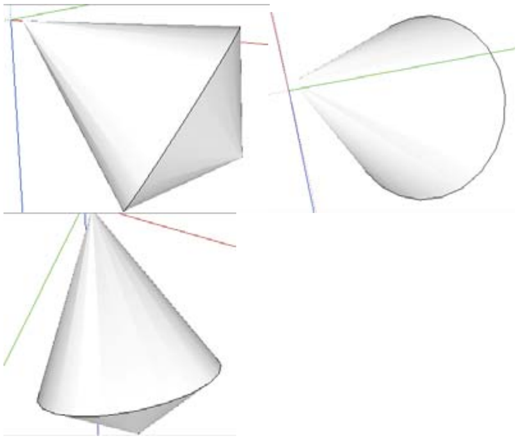


Figure I.4 – Three-Dimensional Drawing of a Typical Cone of Vision from Different Angles

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 I.1*) 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 I.5* presents a graphical representation of taking this slice and rotating it in a 3D model.

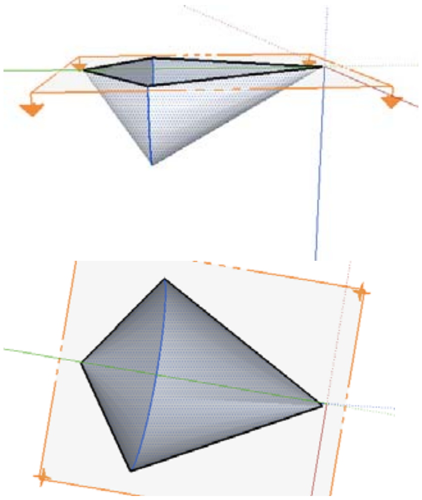


Figure I.5 – Cone of Vision 3D Model with Section Plane through Centerline

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 I.6*, in a 3D model.

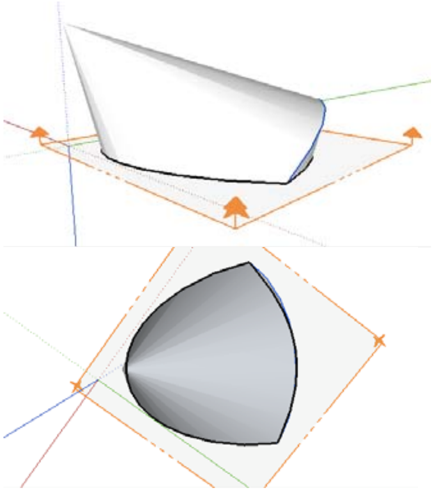


Figure I.6 – Cone of Vision 3D Model with "Off Centerline" Section Plane

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 I.6*). If the detector does not reach the end of its 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 I.7* 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.

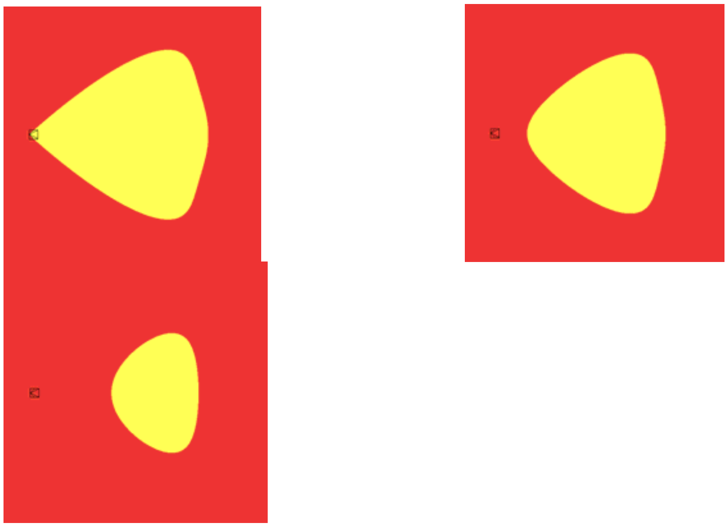


Figure I.7 – Effect of Fire Detector Elevation Change; Elevation of Interest = 1 m, Detector Elevations, 1 m, 3 m, 5 m

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 I.8* presents a progression of angle of declination changes, beginning where the detector left off in *Figure I.7*, 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.

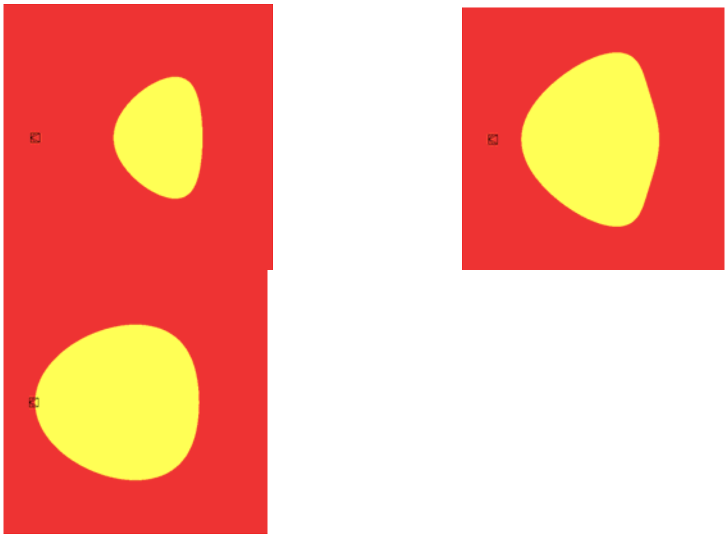
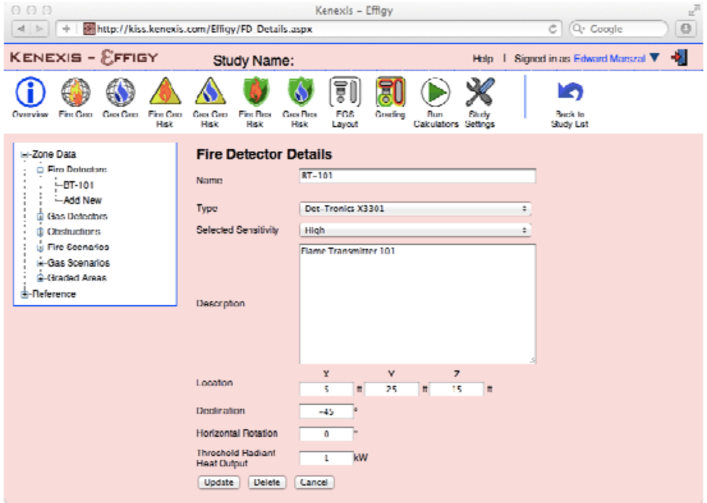


***Figure I.8 – Effect of Fire Detector Declination Angle Change; Elevation of Interest = 1 m, Detector Elevation = 5 m, Detector Declination Angles,* 0° (parallel to grade), 23° and 45°**

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 I.9* 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 I.9 – 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 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[4] 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 and a resultant shock wave of greater than 150 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

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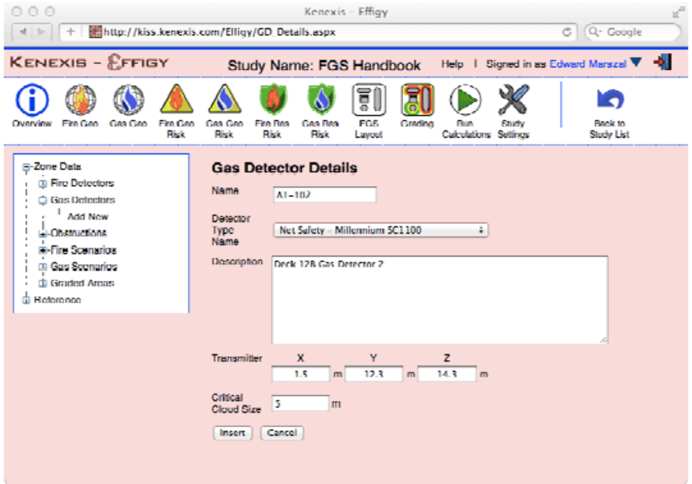
[4] Offshore Technology Report – OTO 93 002 – Offshore Gas Detector Siting Criterion, Investigation of Detector Spacing, United Kingdom, Health and Safety Executive

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 I.10* 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

Gas Detector Details

Name: AI-102

Detector Type Name: Net Safety - Millennium SC1100

Description: Deck 128 Gas Detector 2

	X	Y	Z
Transmitter	1.5 m	12.3 m	14.3 m

Critical Cloud Size: 5 m

Figure I.10 – Effigy Gas Detector Input Page

The gas detector input page shown in *Figure I.10* 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 I.11*.

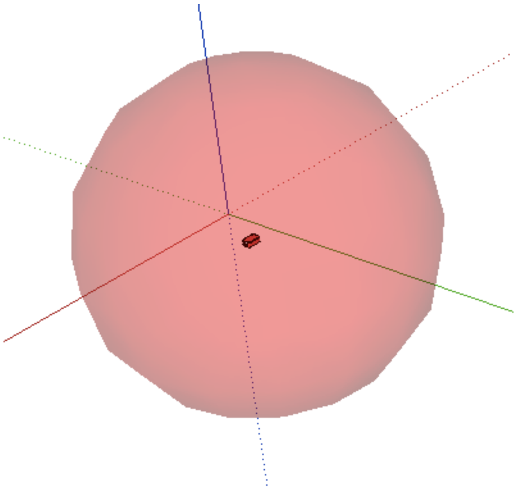


Figure I.11 – 3D Model Representation of Point Gas Detector Coverage

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 cylinder 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 cylinder with spherical ends (for an open path detector) at the elevation of interest. This activity is conceptually shown in *Figure I.12*.

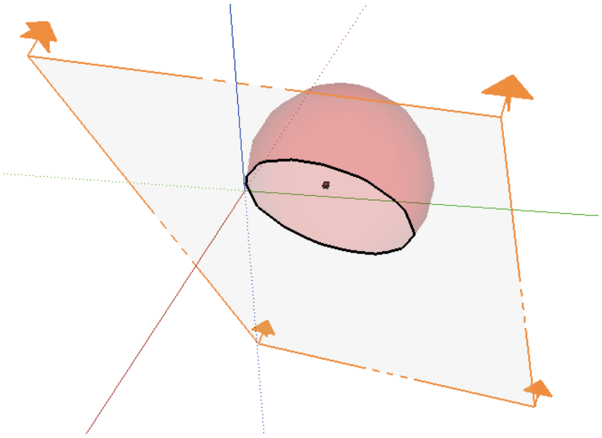
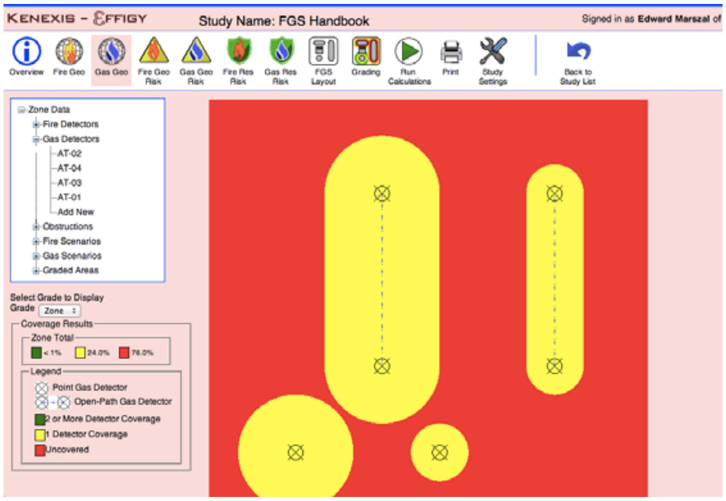


Figure I.12 – Section Plane of a Coverage Sphere of Point Gas Detector Coverage

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 I.12*, 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 I.13* 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 I.13* 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

Grade: Zone

Zone Total: 🟩 < 1% 🟨 24.0% 🟥 76.0%

Figure I.13 – 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.

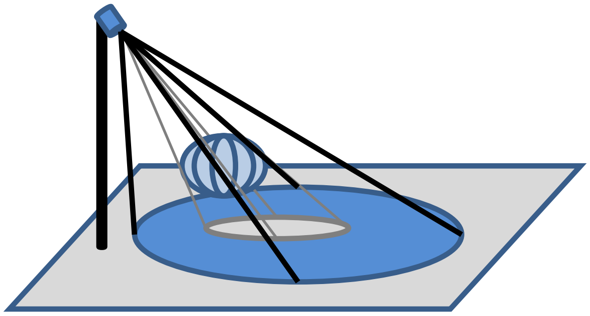


Figure I.14 – The Effect of an Obstruction on Optical Fire Detector Coverage

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 I.14*. 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 I.15*, fully in three dimension using sophisticated analytical geometric techniques.

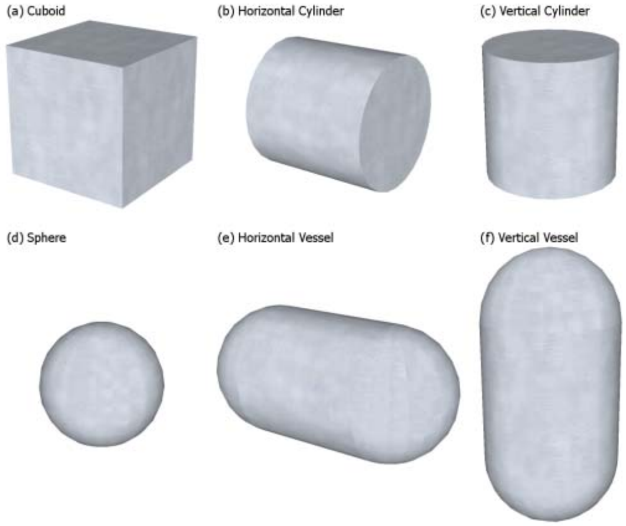
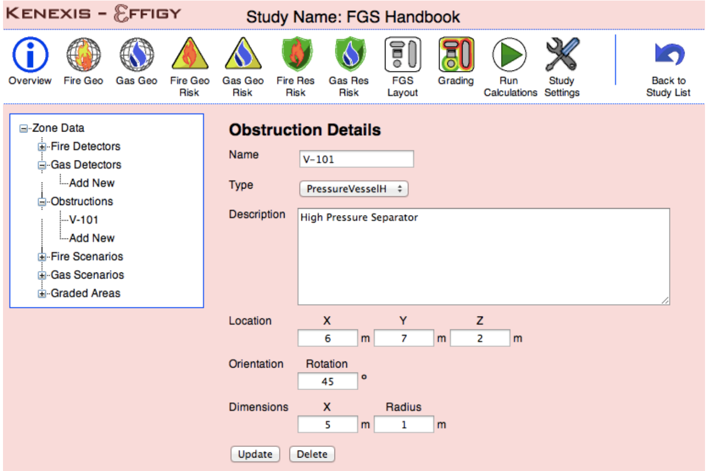


Figure I.15 – Typical Obstruction Geometries Modeled by Effigy

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 I.16*.



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 I.16 – 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 I.16* can be seen in FGS Layout format in *Figure I.17*. 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.

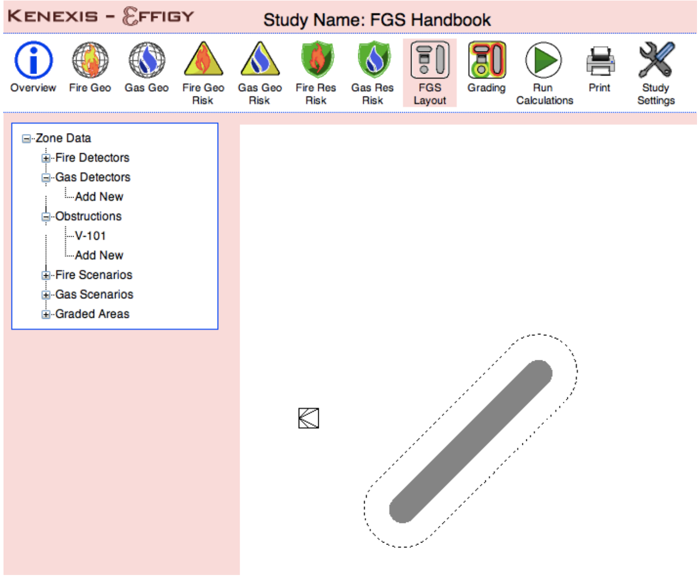


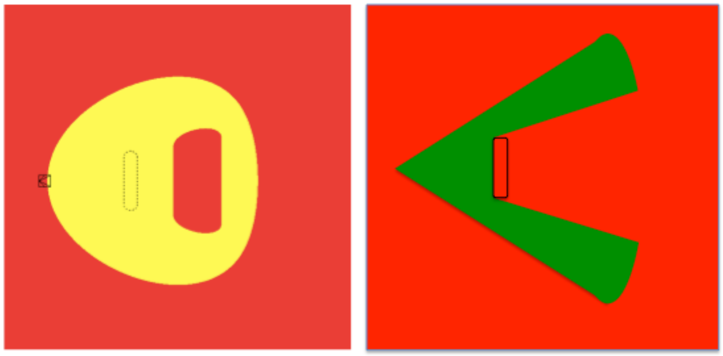
Figure I.17 – Effigy FGS Layout View of a Horizontal Pressure Vessel Obstruction

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 edges 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 I.18*, 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 I.18 – 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 do 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 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 I.19* 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.

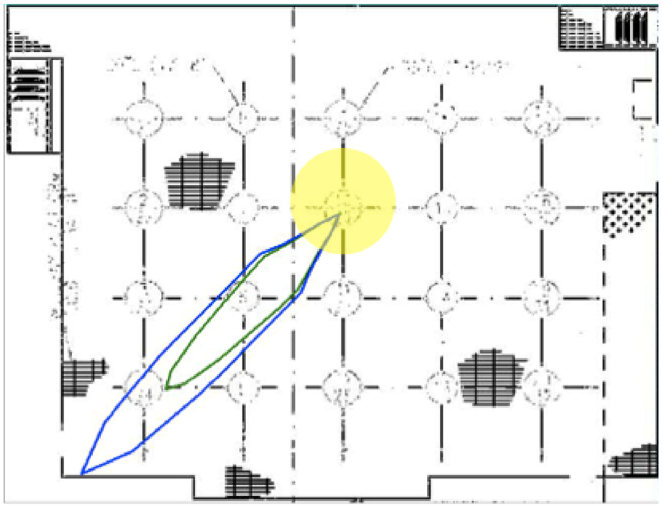


Figure I.19 – Example "Footprint" Depiction of a Gas Release

Kenexis Effigy™ performs internal calculations on a release scenario that consider a full set of potential release orientations (all directions), and also adjusts for wind direction. *Figure I.20* shows a representation of the single release scenario shown in *Figure I.19* as it is rotated in only 8 directions. Effigy™ orients the release in 720 wind-adjusted directions.

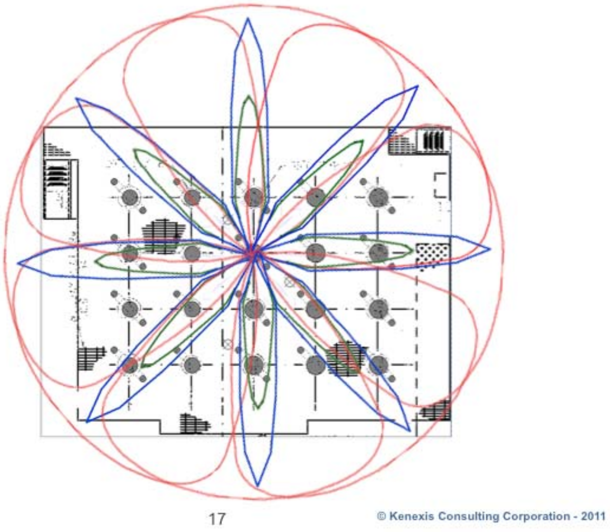


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Figure I.20 – A Gas Release "Footprint" Depiction Rotated in Eight Directions

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 I.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).

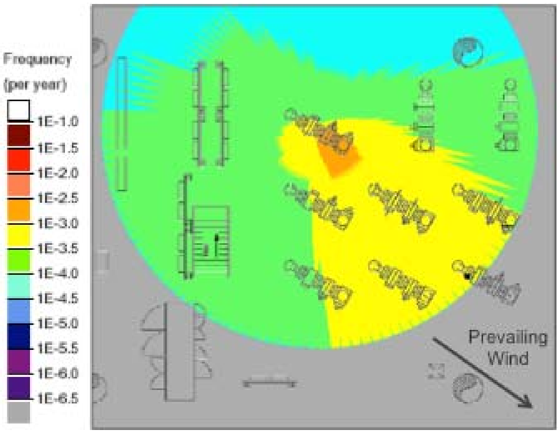
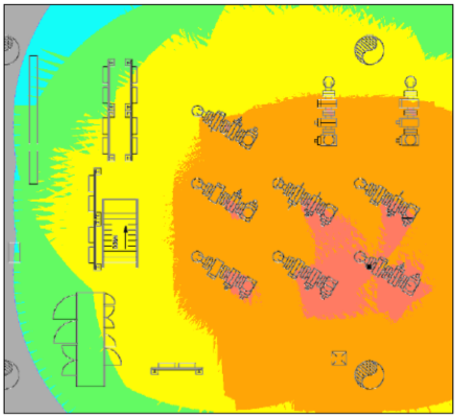


Figure I.21 – Geographic Risk Profile (Scenario Coverage) for One Release Point and No Detectors

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 I.22*.



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

Figure I.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 I.23*.

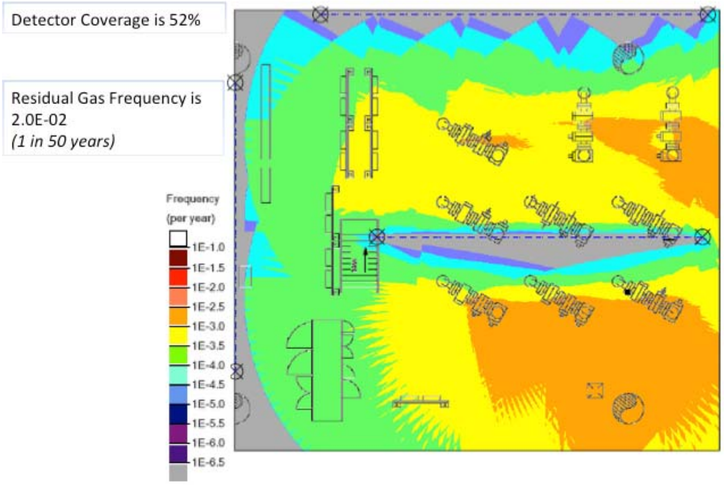


Figure I.23 – Typical Scenario Coverage Results

This figure is the same process as shown in *Figure I.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 I.24*, where each equipment item results in a grade, along with an extents-of-graded-area for which coverage results will be calculated.

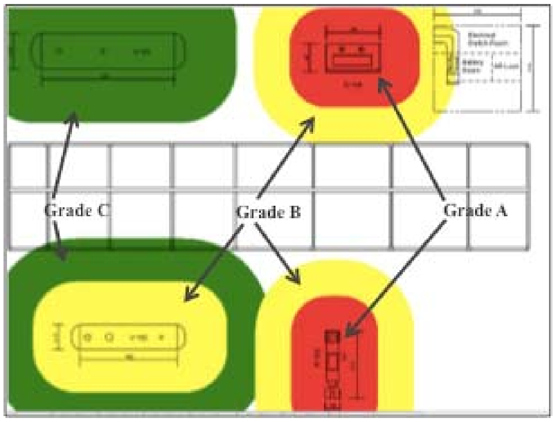


Figure I.24 – Extents of Graded Area Map

Appendix J – References

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