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How Can I Effectively Place My Gas Detectors

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Abstract

Several Recognized and Generally Accepted Good Engineering Practices (RAGAGEPs) exist to help someone make their selection and placement of gas detectors (e.g. ISA-TR84.00.07, NFPA 72, UL-2075). However, there are no real consistent approaches widely used by companies. Historically, gas detection has been selected based on rules of thumb and largely dependent on experience. Over the last several years there has been a growing interest in determining not only the confidence but also the effectiveness of those gas detection systems. In fact, incorrect detector placement far outweighs the probability of failure on demand (of the individual system components) in limiting the effectiveness of the gas detection system.

An effective gas detection system has three elements:

1. A comprehensive Gas Detection Philosophy
2. Appropriate Detector Technology Selection
3. Correct Detector Placement

The Gas Detection Philosophy clearly specifies the chemicals of concern and the intended purposes, i.e. detection of toxic or combustible levels, voting requirements, alarm rationalization, and control actions.

Appropriate Detector Technology Selection includes consideration of the target gas and the required detection concentration levels.

The primary approaches for Detector Placement are geographic and scenario-based coverage. Geographic coverage places detectors on a uniform grid, and sometimes areas risk ranked to reduce the number of detectors required. Scenario-based coverage has a range of leak models and places gas detectors based on the dispersion modeling results.

All three elements for effective gas detection (philosophy, technology, and placement) are interdependent but understanding their relationships is of paramount importance to design an effective gas detection system.

The intention of this paper is to present the main considerations that design engineers and process safety professionals should address for each gas detection system element in order to obtain the best return on your investment when placing your gas detectors.

Keywords: Instrumentation, Reduction of Risk, Risk Assessment, Protection, Detection System, Alarms and Operator Interventions, Detector, Gas Detection/Dispersion Prediction

Introduction

Many plants make use of a gas detection system (GDS) to protect both onsite and offsite personnel, and many plants deal with leaks frequently. Most leaks that occur are small. Being able to distinguish between a nuisance condition and a more serious leak that may cause harm to personnel is an important consideration to make when designing a GDS. On one hand, many plants have had experience with nuisance alarms from either inadequate detector technologies, poor gas detector placements, or in some cases, a design based on a philosophy that does not make appropriate leak distinctions. On the other, many plants also make use of outdated or legacy technology that may have been designed and positioned based on Recognized and Generally Accepted Good Engineering Practices (RAGAGEPs) at the time, but are deficient and unable to detect a significant number of serious leaks, or may have missed an opportunity for updating after a significant process modification or expansion.

While there are standards that exist to support selection and placement of gas detectors (e.g. ISA-TR84.00.07, NFPA 72, UL-2075), the reality is the optimal solution can vary from plant to plant (e.g. a congested offshore platform, a batch chemical plant with multiple recipes, a refinery, a sour well) and inconsistent approaches are oftentimes found. Our understanding of gas dispersion and the ability to model and predict the release behavior has grown significantly. Using this knowledge and expertise, as well as practical plant experience from start-up and testing, much more educated and informed decisions can be made to increase confidence in a system. Ignoring nuisance alarms can degrade the overall effectiveness of the GDS. For example, incorrect detector placement alone can be more detrimental to the overall GDS performance over individual component probability of failure on demand to the point where it cannot be credited as an effective independent protection layer (IPL).

Gas Detection Philosophy

The gas detection philosophy drives the design basis of the entire GDS, and without a good structure, sub-optimal decisions can be made at later stages such as when selecting the right technology or placing detectors. The philosophy should provide general direction and intent on how to implement the GDS. Several philosophy decisions may differ from plant to plant, so it is important to consult a subject matter expert (SME) as well as those experienced and knowledgeable with the operations and design of the plant.

For plants handling flammable and toxic gases, continuous monitoring can be an effective risk management strategy. Some plants may opt for fixed detectors while others may choose personal gas detection. A combination of the two may be best, based on an understanding of the hazardous gases present and the amount of time a person may have until a major injury or life-threatening condition arises from the gas. Likewise, detection of a serious leak should be effectively communicated to alert personnel to the presence of the hazard and to shut down and isolate the section of the process that is having the leak to prevent further escalation. Communication to personnel is often in the form of audible alarms and strobes to signify areas with active hazards and direct personnel to safe locations. Personnel in control rooms or other remote locations should have a good human-machine interface (HMI) that is intuitive and helps the operator to accurately identify the area of the plant were the hazard is present and provide a quick response, such as shutting down specific building air intakes and exhaust fans to not draw toxic or combustible fumes into different rooms if needed.

The philosophy should define specific performance goals for the GDS and effective strategies to achieve these goals, including the selection and location of gas detectors. Among those goals should be a focus on best personnel protection, including both potential toxic and flammable effects. For onsite personnel, monitored toxic effects with established end points should include those with atmospheres that are Immediately Dangerous to Life and Health (IDLH), Emergency Response Planning Guidelines (ERPGs), and probability of fatality where life-threatening conditions could develop after exposure to a toxic atmosphere for over a specific duration. For flammable atmospheres, exceeding the lower flammable limit (LFL) provides the opportunity for combustion should a source of ignition be contacted. In order to not exceed IDLH, ERPG-3, or LFL concentrations, a fraction of these concentrations should be monitored. The specific fraction depends on multiple factors, including the available detector technology, manufacturer recommendations, voting, numbers of installed detectors, an indoor or outdoor location, and detector reliability while avoiding spurious activations or nuisance alarms. For some highly toxic chemicals, continuous monitoring may not be practicable at these levels under certain conditions and alternative RAGAGEPs can be used that will still protect personnel from a potential leak. These action levels can lead to such things as requiring a self-contained breathing apparatus (SCBA) or continuously supplied breathing air in areas where a highly toxic atmosphere could become present.

Each highly hazardous chemical should be thoroughly documented, including:

- Different toxic or combustible levels;
- National Fire Protection Association (NFPA) 704 ratings;
- Basic physical properties;
- Applicable American National Standards Institute (ANSI), National Institute of Occupational Safety & Health (NIOSH), and National Institute of Standards and Technology (NIST) codes and standards;
- Locations of hazards;
- Consequences of deviation; and
- Detection criteria.

With hazard identification, include a cause and effect diagram for each chemical and a list of specific areas that may pose a hazard such as trenches or other areas where hazardous gases that are heavier than air are more likely to accumulate. These areas can be identified through dispersion modeling. Aside from highly hazardous chemicals, there is also the potential for inert gases that are not toxic to personnel to cause an oxygen deficient atmosphere and potential asphyxiation. Some inert gases may have additional hazards that need to be factored in, such as carbon dioxide (CO_2) resulting in sleepiness that can diminish the egress of personnel.

The philosophy should describe in detail the method for detection, alarming, and actions to be taken. Detection should be configured appropriately to focus on hazardous leaks that may harm personnel or the plant instead of small leaks. Occupational health requirements can require toxic concentrations to be reported using time-weighted averages. Detector voting and methods for early detection should be detailed in the philosophy. The philosophy should list the requirements for audible and visual alarms along with strobes and other forms of visual notification including alarm rationalization. The philosophy document should describe what hazardous conditions are being alarmed and ensure each location where hazards and an operator may be present provide alarms that can be seen or heard. Having both visual and audible alarms combined is a best practice. For example, a room with a detected leak should strobe both exterior and interior to the room to show field personnel where the hazard is and provide a safe means of egress. Restricting notifications to where the hazard may be present can avoid unnecessary evacuations from other areas of the plant, which is especially useful for indoor releases. Outdoor releases should consider a worst-case release. Zoning and alarms should help personnel identify the source of the leak so that a safe egress route can be taken to the safest muster point location combined with available windsocks. A windsock should be visible at all outdoor locations with personnel present during operator rounds or from occupied buildings where a toxic or combustible hazard could become present. When covering mitigation, list all methods for response including the instrumented control actions on alarm, room ventilation requirements, and mitigation systems such as fogging or water deluge to ensure the response will mitigate the specific chemical hazard.

Appropriate Detector Technology Selection

Many different gas detection technologies exist, including infra-red (IR), electrochemical, catalytic bead, semiconductor, and laser. Each of these technologies has different strengths and weaknesses. Some technologies allow for lower detection limits. Target gases for different detectors can have cross sensitivities with different chemicals that one should be aware of when making the selection of which detector technology will be selected. Different technologies have specific maintenance requirements or costs to be aware of.

Detectors can either be of the fixed point or open path gas detector (OPGD) variety. OPGDs have the advantage of covering a very wide area, which is especially useful outdoors when it can replace multiple point detectors and reduce overall costs. OPGDs will have limitations on the overall length of the beam. OPGD technology is typically limited to the infra-red and laser types. It should be remembered that an OPGD measures the quantity of the target gas in its beam and it does not measure the concentration. The OPGD reports concentrations by the linear meter or foot, such as in LEL-meters for combustible clouds. 1 LEL-m and action at 2 LEL-m is a common setting for a combustible OPGD. For a toxic OPGD, a major issue is you cannot quantify what an operator who happens to be in that area has been exposed to. In order to better estimate the ppm value of toxic clouds (typically for reporting purposes), sometimes an extra point detector or two are included in the area at higher risk leak locations.

The gas detector technology for the target gas of interest should be stated in the gas detection philosophy. Catalytic bead detectors can pick up any combustible gas. However, they suffer from unrevealed failure modes, need regular maintenance, and require the presence of oxygen to operate. They are commonly the choice for hydrogen since IR cannot detect hydrogen. IR point detectors are good general-purpose detectors able to find any hydrocarbon gas which absorbs at their wavelength, and are able to detect at ppm or LEL% levels. IR OPGDs use the same technology as point IR gas detectors though typically operate at a different wavelength. Electrochemical and semiconductor detectors are a common choice for toxic gases and are for point detection only. Laser based OPGDs are used for toxic gases.

Correct Detector Placement

Industry standards followed for gas detection include ANSI/ISA-TR12.13.02 & 03, ANSI/ISA 84.00.01 & 07, API RP 14C, API RP 500, and NFPA 72. Basic rules of thumb applied for placement include locating detectors at breathing height for toxic gases, 1-2 feet above ground for heavy gases such as propane, and for gases that are lighter than air either above the leak source or as high as possible if those gases may accumulate in specific areas such as hydrogen in a battery room. Additional considerations should also be made for conditions that may cause the gas to behave differently, such as cryogenic conditions, as both liquefied natural gas (LNG) and liquefied ammonia are known to disperse low to the ground while the vapors are cold. Other rules of thumb that are important are to place detectors near air ductwork intakes or room outlets, in areas accessible for maintenance, and away from locations that can be damaged by general maintenance or frequently traveled and not in areas where flooding can disable or damage the equipment.

Two RAGAGEPs for placing gas detectors that are mentioned in these standards include scenario and geographic-based methods. Older plants that have not used either of these methods are oftentimes found to have large gaps in detector coverage.

A commonly employed strategy is to place gas detectors to ensure detection of a 5-meter cloud for combustible hazards. The geographic method is simply applying this strategy globally to where all possible areas that handle a specific hazardous material have a hypothetical leak with a 5-meter diameter cloud covered, resulting in a uniform 5-meter spacing of detectors. Basic rules of thumb discussed earlier are then used. The development of a gas detector placement drawing from this method is very simple and cheap.

While geographic methods are successful at leak detection, it can result in more detectors than are necessary, which in turn leads to higher installation and plant operating expenses. This can especially lead to excessive gas detectors for toxic hazards, as the 5-meter cloud methodology was intended for combustible clouds. As a result, many companies prefer to use scenario-based coverage over geographic methods. Scenario-based methods use dispersion modeling to guide detector placement decisions. Scenario model selection involves identifying a variety of leak points, hole sizes, and leak directions. After performing dispersion modeling, detectors are subsequently put in the optimal locations based on leak point and critical receptors of concern locations to detect the hazardous gas.

Tools used for gas dispersion prediction include Gaussian plume, empirical models, and computational fluid dynamics (CFD) models. Gaussian plume is the most simplistic of them all and utilizes basic equations and constants, empirical models add more resolution by making predictions from experimental observations and include software such as the DNV-GL PHAST unified dispersion model (UDM) in a 2--dimensional field, and CFD models use a full suite of transport equations while maintaining conservation of momentum, mass, and energy in a 3--dimensional field that includes geometric and topographic interactions.

Outdoor leaks are largely found to follow the active wind direction. The reason is that the mass and momentum of the air is far greater than the leak itself and will eventually carry it out of the plant in that direction. However, there are exceptions to this typical behavior. For example, it has been found from dispersion modeling that leaks which are especially large and at high pressures have a very large initial momentum and can travel a good distance on their own, especially if along the ground. Sometimes this can result in toxic lethality and flammable thresholds being primarily dictated by leak direction rather than wind direction. Also, topography plays a very large role in dispersion especially for cryogenic plumes, or heavier than air gases. Trenches and diking as well as buildings and large pieces of equipment in plants very frequently dictate gas dispersion behaviors at ground level. OPGDs are often used around the perimeter of secondary containment of hazardous chemicals due to the ability of the geometry to contain and channel gases. Also, wind currents can interact with large buildings and tanks in such a way that turbulence eddies and recirculation zones influence the dispersion in different ways depending on wind direction. Depending on gas density, outdoor vertical leaks in the air may not be detectable from ground-based detectors and an elevated open path detector beam, as well as point detectors at the air intakes of potentially affected buildings, may be needed. All these behaviors can be difficult to predict from simply looking at the geometry, and as such, dispersion modeling that incorporates CFD may be critical to understanding these behaviors and making better decisions in detector placements on a case by case basis.

Indoor leaks are largely found to follow the initial leak direction and are eventually drawn out by room out-take ducts. Room ventilation rates are many times smaller than outdoor areas, but still, influence the dispersion of leaks from the room airflow patterns. When there are many rooms to evaluate, one of the more useful tools for predicting dispersion patterns in a room is a basic airflow model which can be quickly performed using CFD models. Observing these patterns as well as the locations of all equipment handling highly hazardous chemicals, one can make reasonable predictions as to where the vapors of a release will eventually travel as the room exhaust ventilates the air. Incorporating different leak scenarios into these models helps support and confirm these decisions, as well as finding common pathways that multiple vapor clouds may take. Modeling can also expose counter-intuitive behaviors. For example, while typical detector placement practices for lighter than air gas releases is to place the detectors as high as possible, an air supply coming from the ceiling with exhaust ducts along the ground has shown ammonia gas clouds being pushed away from the ceiling and spreading to other areas along the ground. Indoor models can also help in revealing regions with still air (dead zones) where gas clouds may not migrate while dispersing. Finally, heavier than air releases are often found to have the highest concentrations and largest footprint at grade level, suggesting that detectors as low to the ground as possible should typically be used for heavy gases.

Some detector technologies can have additional constraints to be mindful of. For example, electrochemical based detectors contain an electrolytic solution that is directly exposed to the air. Electrochemical detectors must be sheltered from the rain to avoid degradation. If the air that this solution is exposed to has a very high velocity, it can lead to rapid evaporation and depletion of the solution, which can lead to problems such as increased maintenance and inaccurate readings. On the other hand, placement in a dead zone can lead to non-detection of hazardous gases. For these situations, gas dispersion models using CFD are quite useful in finding the right balance with gas detector placement decisions. Considerations for the leak models are numerous, and it can be easy to take different paths. Underspecifying the models can lead to a suboptimal solution with gaps in coverage, which is especially problematic if the GDS is being treated as an IPL and it requires a high amount of coverage. On the other hand, over specifying the models can result in more analysis and computational time than is required. As such, a balanced approach is recommended, and a series of steps can be followed to come up with an effective solution to detector coverage that is not as time intensive, including with CFD based methods. The flow chart in **Figure 1** demonstrates this proposed scenario-based work flow.

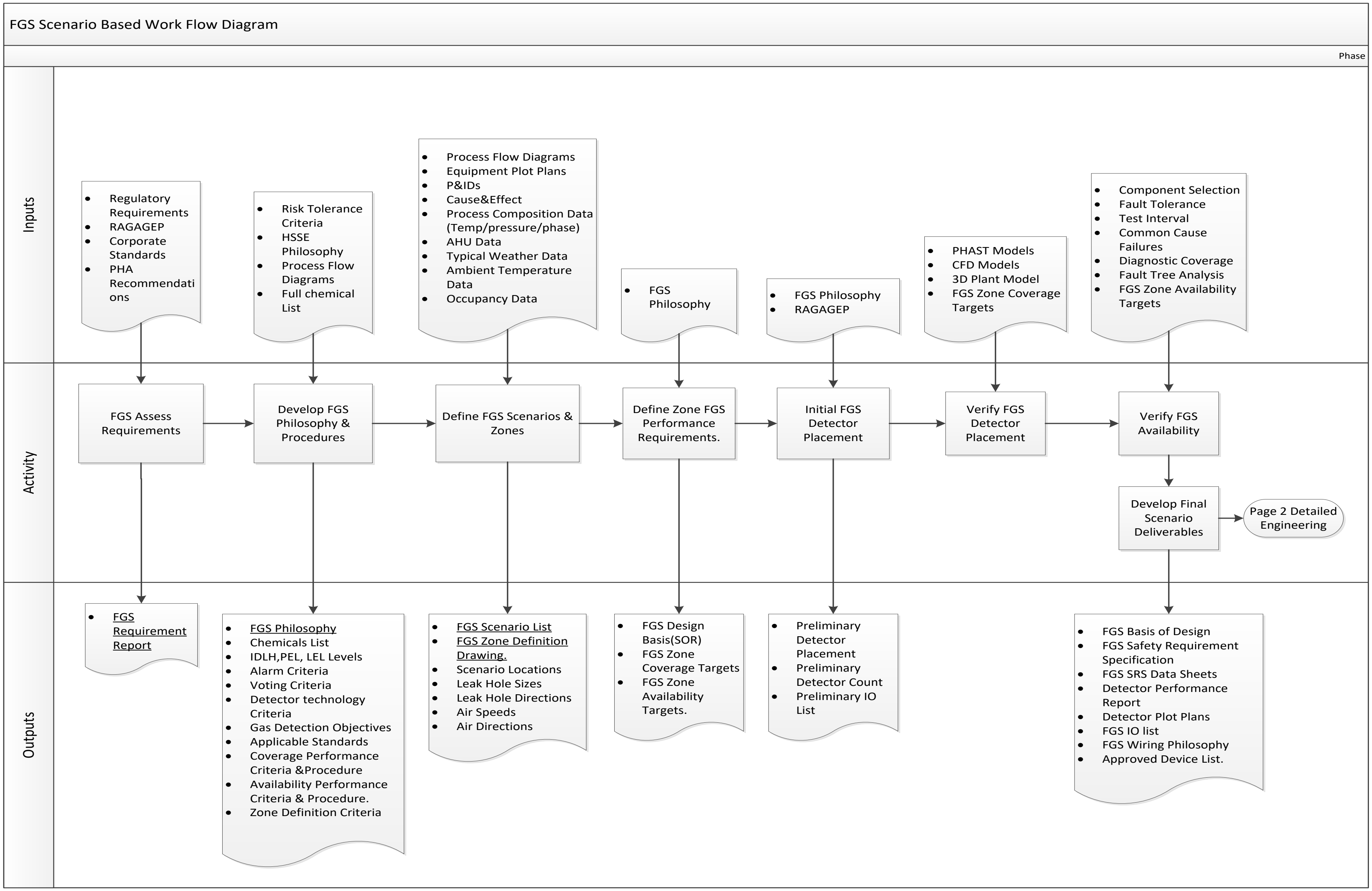
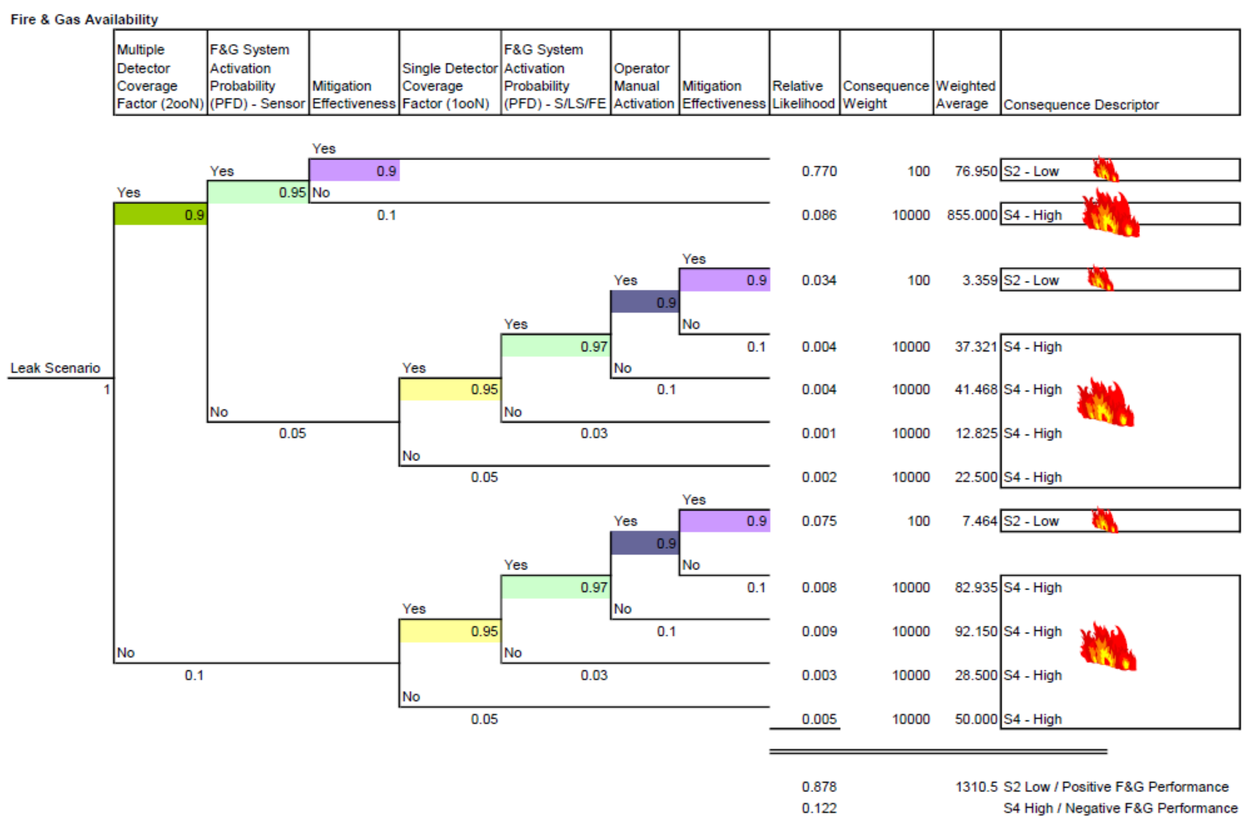


***Figure 1**: FGS Scenario-Based Workflow*

After developing the gas detection philosophy and gathering all process safety information (PSI), a key step to more quickly optimize detector placement is coming up with an initial detector coverage map using RAGAGEP methods. After having the initial design coverages, PHAST or CFD models can be used to assess the initial coverage performance. Some locations that are nearly identical can utilize the same models across numerous areas. For example, multiple trains, multiple similar rooms, etc. This will reduce the number of models that need to be run. Time to alarm can be included in an assessment of maximum available response time (MART). Safety availability performance provides confidence levels in the GDS based on voting requirements, technology reliability, and mean time to failure (MTTF) of different components (e.g. system hardware and mitigation measures). Based on these metrics, the coverages are adjusted based on predicted behaviors from the models until an optimal design is achieved. Then, fire & gas safety (FGS) requirements are specified, and then the GDS can move to detailed engineering.

It is important to note that beyond having a highly effective detector coverage, there are limitations of what a GDS can reasonably do. For example, consider following ISA-TR84.00.07 and employing voting to improve reliability. After the percent coverage is determined, a fault tree may be used to estimate the overall mitigation effectiveness of the GDS system.

***Figure 2**: Fault Tree Analysis on Fire & Gas System Performance*



To achieve an overall risk reduction of SIL-2 or higher, one would need well over 99% coverage and for all components to be SIL-2 capable. Trying to achieve SIL-2 with a GDS would be over specifying performance. Rather, ISA-TR84.00.07 advises that a GDS not be considered as an IPL if the overall effectiveness is less than 90%. One can see in the fault tree example in **Figure 2** how even 90% coverage with 2ooN voting and 95% coverage with 1ooN voting will result in an overall effectiveness under 90% if the entire system is limited by a mitigation effectiveness of 90%. Consequently, both the detector coverage and the mitigation effectiveness should be above 90% to be credited as an IPL, which can necessitate modeling of the mitigation system as well to prove a higher level of effectiveness.

Conclusions

All three elements required for effective gas detection (philosophy, technology, and placement) are interdependent but understanding their relationships is of paramount importance in designing an effective gas detection system. In addition, modeling provides additional details that support other important plant safety decisions. Model driven sensor locations enable informed emergency planning. For example, ground level detectors located between the source of the release and the critical receptors can provide early warning to building occupants to take the specified emergency action. It can also reveal gases that may be drawing into a building air intake that can be a considerable distance from the leak source. 3D modeling that incorporates wake effects from buildings can show the plume reaching areas that may not be immediately intuitive such as air handlers on the back side of a building. Room ventilation patterns may also result in several non-intuitive behaviors. It is therefore essential to understand hazardous chemical properties, potential release sources, release directions, and the ventilation patterns in the room for proper gas detector placement. For some clients, the plant fence line is an important consideration for potential impact to public receptors, and dispersion models provide valuable information on time for emergency response and likely concentration impacts.

Considering the recommended approach of scenario-based coverage through dispersion modeling, although it may increase the initial project cost, over the long term, it typically has a lower overall cost due to reduced detector quantities, reduced maintenance, etc. It also gives confidence and an engineering basis behind detector placement decisions to reduce life cycle costs, overall risk to onsite plant personnel, and overall risk to offsite public receptors.