FIRE AND GAS MAPPING GUIDELINE

EGPC-PSM-GL-017

PSM GUIDELINES

The Egyptian Process Safety Management Steering Committee (PSMSC Egypt)
PSM TECHNICAL SUBCOMMITTEE (PSMTC)

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PSM Technical Subcommittee team members during the project comprised:

Amr Moawad Hassan	**PSM Senior Consultant – Methanex Egypt**	**Team leader**
Mohamed Mesbah	Operations Department Head – KPC	Member
Ahmed Mostafa	Operations Section Head – ELAB	Member
Ahmed Roustom	Risk Management and Loss Prevention Studies Assistant General Manager – GASCO	Member
Hany Tawfik	OHS & PS General Manager – ETHYDCO	Member
Mohamed Ashraf Aboul-Dahb	Safety Section Head for Upstream – EGPC	Member
Mohamed Hamouda	HSE Department Head – Pharaonic Pet. Co.	Member
Mohammed Sabry	Risk Management and Loss Prevention Studies Executive General Manager – GASCO	Member
Sayed Eid	HSE A. General Manager – Agiba Pet. Co.	Member
Tamer Abdel Fatah	QHSE Senior – UGDC	Member

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Process Safety Consultant (in alphabetical order):

- Bell Energy Services - By: Amey Kulkarni,Technical Director.
- DNV - By: Cees de Regt, Senior Principal Consultant.
- Risktec Solutions - TÜV Rheinland.
- Aladdin Elsonbati, HSE & Process Safety Manager (ENI).

Major IOCs & EPCs (in alphabetical order):

- ENPPI - By: Ahmed Mousa, Process Technology | GM Assistant, Safety & Loss Prevention Engineering.
- ENPPI - By: Essam Mohsen, Process Technology | Safety & Loss Prevention Principal Engineer.

It should be noted that the above have not all been directly involved in developing this document, nor do they necessarily fully endorse its content.

Egypt PSM Steering Committee team members during the project comprised:

Gamal Fathy	EGPC CEO Consultant for HSE – EGPC	Member
Mohamed Mahmoud Zaki	Executive Vice President – ECHEM	Member
Salah El Din Riad	Q&HSE Chairman Assistance – ECHEM	Member
Dr. Ashraf Ramadan	Assistant Chairman for HSE – EGAS	Member
Emad Kilany	OHS & Fire Fighting Technical Studies GM - EGAS	Member
Mohamed Sayed Suliman	HSE General Manager – GANOPE	Member
Mohamed Mostafa	Inspection & External Audit GM – ECHEM	Member
Mohamed Shindy	Managing Director – Methanex Egypt	Member
Manal El Jesri	Public Affairs Manager – Methanex Egypt	Member
Mohamed Hanno	RC Manager – Methanex Egypt	Member
Amr Moawad Hassan	PSM Senior Consultant – Methanex Egypt	Member
Mourad Hassan	PSM Consultant – Methanex Egypt	Member

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NAME	TITLE	DATE	SIGNATURE
Amr Moawad Hassan	PSM Senior Consultant - Methanex Egypt PSM Technical Subcommittee TL	DEC-2022	Amr Hassan Digitally signed by Amr Hassan Date: 2022.12.29 09:03:40 -06'00'
Gamal Fathy	EGPC CEO Consultant for HSE	DEC-2022	Gamal Fathy

Endorsement

NAME	TITLE	DATE	SIGNATURE
Alaa El Batal	CEO - Egyptian General Petroleum Corporation (EGPC)	DEC-2022	A. ElBatal

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All administrative queries must be directed to the Egyptian Process Safety Technical Subcommittee.

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1. Introduction

Fire and gas detection systems minimize the potential for escalation and loss of life due to flammable or toxic accident events. To achieve this objective, the fire and gas (F&G) system should reliably and quickly alert personnel of a flammable or fire event and initiate control and mitigation systems via the ESD system. To achieve this objective, the F&G detection system should:

- Monitor all areas where fires may occur.
- Monitor all areas where flammable/toxic gases may be present.
- Monitor all areas where flammable gas may accumulate, leading to the potential for vapor cloud explosion.

F&G mapping is a study utilized to identify the adequate placement of fire and gas detectors (Location, elevation, and orientation) to provide the optimum coverage in case of accidental fires or flammable or toxic gas releases.

2. Purpose

The purpose of this document is to provide a guideline on the placement of permanently installed fire and gas detectors, including coverage, technology selection, and the minimum performance targets that the fire and gas detection should achieve. It also guides the most commonly used mapping methods: prescriptive, volumetric-based, and scenario-based. The guideline also identifies the expected deliverables from acceptable fire and gas mapping studies

This guideline applies to the Egyptian General Petroleum Corporation (EGPC) and Oil and Gas Holding Companies, including the Egyptian Natural Gas Holding Company (EGAS), the Egyptian Petrochemical Holding Company (ECHEM), and the South Valley Petroleum Holding Company (GANOPE) covering all their operational subsidiaries, state-owned companies, affiliates, and joint ventures.

ENTITIES, COMPANIES, and contractors should ensure that all requirements listed herein are fully understood, implemented, complied with, and always monitored, including current operations and existing and future projects during the whole project's life cycle from feasibility to decommissioning.

3. Scope

While the whole fire and gas system effectiveness relies on three factors which are coverage, availability, and mitigation effectiveness, the scope of this document covers the fire and gas mapping (coverage) for the permanently installed detection systems, including optical flame detection (including ultraviolet, infrared and imaging/visual), flammable gas/vapor detection and toxic gas detection. Fire and gas availability and mitigation effectiveness are excluded from the scope of this document. The details of fire and gas technology are not within the scope of this document. However, annex A comprises information about common detectors in the oil and gas industry.

4. Definitions

COMPANY: Refers to any operating company, subsidiary, affiliated, or joint venture companies belonging to an ENTITY.

COVERAGE: criteria by which the volume/scenario is monitored or unmonitored concerning detection success. Note: Coverage can be represented as a percentage calculation, visual representation, or both.

CONFIRMED FIRE: Typically, two or more detectors within a zone report fire or a single detector plus confirmation by Operations.

ENTITIES: Refers to the Egyptian General Petroleum Corporation (EGPC) and Oil and Gas Holding Companies, including the Egyptian Natural Gas Holding Company (EGAS), the Egyptian Petrochemical Holding Company (ECHEM), and the South Valley Petroleum Holding Company (GANOPE).

FIRE SIZE: Representation of fire as a function of geometric volume or radiant heat output.

FIRE AND GAS SYSTEM (FGS) SAFETY AVAILABILITY: The availability of the fire and gas function designed to mitigate the consequences of hazards automatically. FGS Availability is equal to one minus the FGS function's probability of failure on demand (PFDavg).

FIRE AND GAS SYSTEM (FGS) EFFECTIVENESS: The ability of the FGS to perform its intended safety actions in a demand condition. It depends on several factors associated with design, installation, site-specific operating conditions, and maintenance. FGS effectiveness is the product of detector coverage, FGS safety availability, and mitigation effectiveness.

FLAME AND GAS (F&G) MAPPING: Process by which flame or gas detection layout is determined. Note: This can include a combination of prescriptive adherence to facility philosophies, detection engineering knowledge, experience, and software modeling tools.

FIRE AND GAS (F&G) PHILOSOPHY: Project document covering the philosophy/strategy of the fixed F&G system.

GRADED VOLUME: Volume within the mapping zone where specific detection performance targets are specified.

GEOGRAPHIC (VOLUMETRIC-BASED) COVERAGE: The fraction of the geometric area or volume of a defined, monitored process area that, if a hazard were to occur in a given geographic location, would be detected considering the defined voting arrangement.

JUDGEMENT-BASED PLACEMENT: Consensus between competent persons from different disciplines who holistically apply the best judgment and experience to locate a detector.

LOWER EXPLOSIVE LIMIT (LEL): The volume fraction of flammable gas or vapour in air below which an explosive gas atmosphere does not form is expressed as a percentage.

MAPPING ZONE: Boundary of the volume is to be assessed as a single voting grouping.

OPEN-PATH DETECTOR (GAS): The detector measures the gas concentration in a straight line between two points.

PERFORMANCE TARGET: Set detection goals against which detection success can be measured**.** Note: Examples include a target maximum fire size or gas cloud volume.

POINT DETECTOR (GAS): Single detector to measure a gas concentration at its location.

PRESCRIPTIVE METHOD: Method of detector placement based on preset rules, which can be followed by applying "pass/ fail" criteria.

RADIANT HEAT OUTPUT (RHO): Energy (in kW) emitted from a flame in the radiant region of fire.

SCENARIO COVERAGE: The fraction of the hazard scenarios from process equipment within a defined and monitored process area that can be detected considering the frequency and magnitude of the hazard scenarios and the defined voting arrangement.

5. Abbreviations

1ooN	One out of N voting
3D	Three dimensional
CCPS	Centre for Chemical Process Safety
CCTV	Closed Circuit Television
EGPC	Egyptian General Petroleum Corporation
ESD	Emergency Shutdown
FERA	Fire and Explosion Risk Assessment
F&G	Fire and Gas
FGS	Fire and Gas System
HVAC	Heating, Ventilation, and Air Conditioning

IEC	International Electrotechnical Commission
IR	Infrared
LEL	Lower Explosive Limit
LEL.m	Lower Explosive Limit. meter
LOS	line Of Sight
LTEL	Long-term exposure limit (LTEL – 8 hours)
MOC	Management of Change
MOP	Ministry of Petroleum and Mineral Resources
OPGD	Open Path Gas Detector
PFD	Probability of Failure on Demand
PPM	Parts Per Million
PSM	Process Safety Management
QRA	Quantitative Risk Assessment
RA	Risk Assessment
RHO	Radiant Heat Output
SDS	Safety Data Sheets
STEL	Short-Term Exposure Limit (STEL- 15 min.)
TOR	Terms of Reference
TR	Temporary Refugee
TWA	Time Weighted Average
UGLD	Ultrasonic Gas Leak Detectors
UV	Ultraviolet

For other definitions and abbreviations, refer to the PSM Glossary of Definitions and Abbreviations Guideline (EGPC-PSM-GL-011).

6. Fire and Gas Mapping Design

Fire and gas mapping starts with the proper identification and assessment of the potential hazards that could lead to fire, flammable or toxic gas releases. The next step is to define the fire and gas philosophy that will form the baseline for the detection technology and mapping methodology. Figure 1 illustrates the whole process for the fire and gas mapping from the initial Hazard Identification until a smooth and running operation.

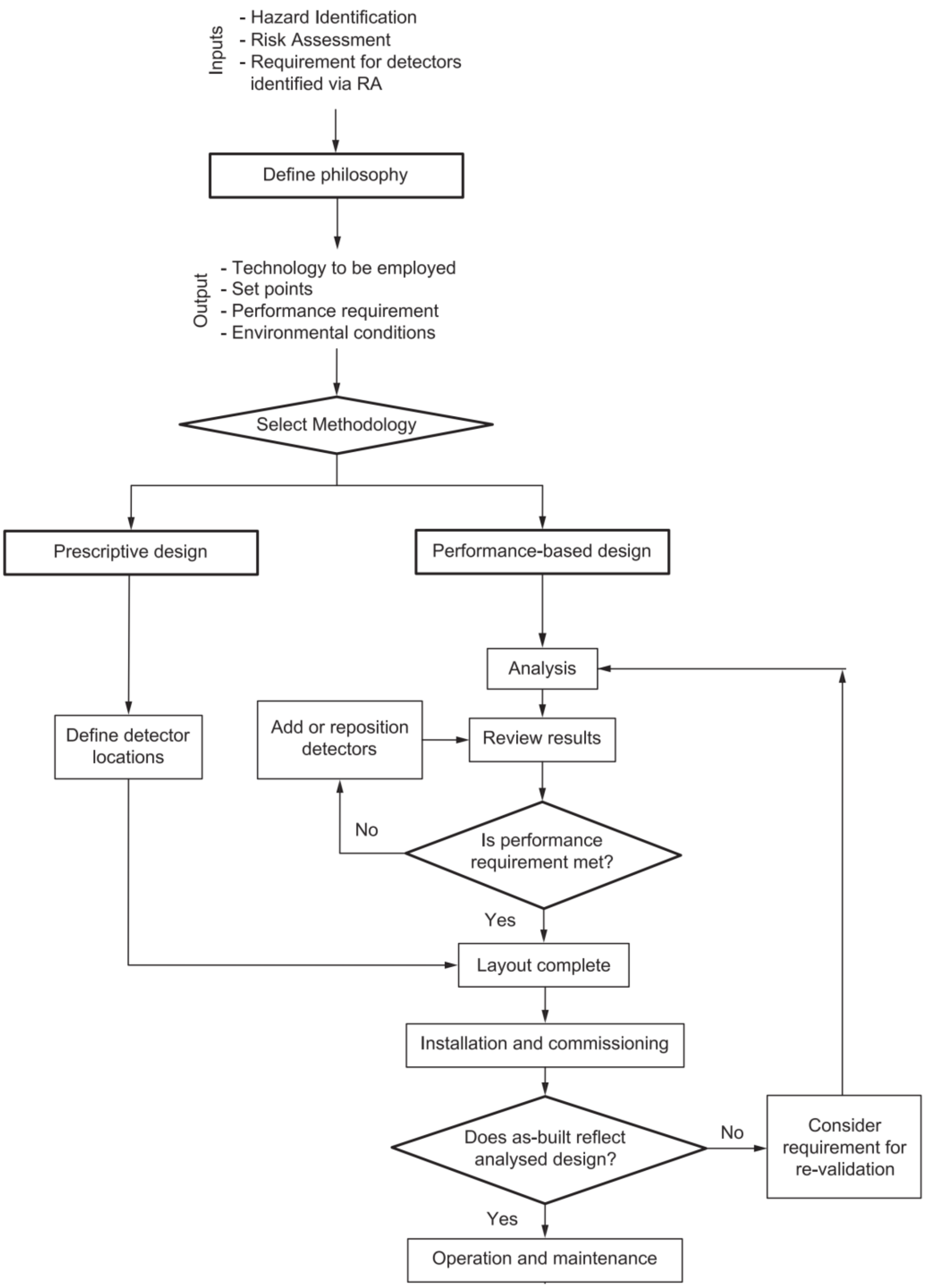


Figure 1. *Fire and gas mapping design [1].*

7. Fire and Gas (F&G) Philosophy

7.1 General

A fire and gas philosophy should be in place for new projects or physical changes in facilities to assure the consistency of installation of the F&G detection system. The fire and gas detection philosophy should include the following:

- The metrics to use to assess the system, e.g., percentage coverage, target fire size, the gas cloud of a certain size, and gas cloud/fire that could lead to escalation of a certain frequency of occurrence.
- The mapping zones, including the methodology used to define them.
- Area grading rules (if applicable) that define the performance criteria based on different assessed risk categories.
- Appropriate applied technologies for the environment and the hazard.
- Set points and voting requirements for detectors.

The mapping methods to be applied could differ as the design progresses. More detailed methods might not be appropriate in early design as sufficient information might not be available. Annex B shows an example of fire and gas detection philosophies.

7.2 New Projects versus Existing Facility Considerations

The mapping method for a new project might be different from an existing operational site. Optimizing the detection performance close to the theoretical limit of the modeling for a new project should be possible, as there is usually a lot of flexibility in mounting locations and system configuration. A typical optimization aim is to achieve a detection target with the minimum number of detectors.

There are likely to be other significant constraints for an existing site that is already operating with an existing F&G system. For example, relocating a detector could be disruptive and require significant engineering effort. The cost of installing new cabling, cable trenches, mounts, and modifying drawings typically outweighs the purchase cost of a detector. The relative cost of moving a detector versus installing a new one should be determined (this varies from site to site).

Existing facility detection optimization could take the following order:

a) Change angles/orientations of flame detectors.

b) Consider making one or two small moves (preferably within the cable slack).

c) If the target is still not met, consider adding new detectors in new locations rather than multiple relocations of existing detectors.

For existing facilities that have already adopted the prescriptive approach, and to assure that over/under engineering does not represent an issue, it is recommended to select a highly hazardous location (use Annex C for hazard ranking) and apply the geographic-based or scenario-based approach to it. This will help to check whether the current detector placement provides an acceptable level of coverage.

8. Fire and Gas Mapping Methods

8.1 Flame Detection

Flame detectors allocation analysis is performed without CFD simulations. A criterion shall be used to allocate the detectors taking into account the sight view of the detector and the vertical and horizontal range of the detector angle of view to define the maximum coverage of equipment/area. Each detector has a cone of coverage/detection, calculated based on the orientation. A geometric approach could be used to identify the most recommended spots for flame detector placement. The approach shall aim to guarantee that the equipment is covered by fire detectors avoiding any obstacles by analyzing the real geometry model. The availability of a 3D model will support the flame detectors' proper allocation

8.2 Gas Detection

There are three gas mapping methods currently in use in the oil and gas industry:

a) Prescriptive method.

b) Volumetric-based (geographic) method.

c) Scenario-based method.

Prescriptive methods are the most simplistic, with the complexity and effort increasing progressively toward employing scenario-based methods.

The volumetric-based method seeks to determine the degree of coverage of a monitored area, which contains a process with potential gas hazards. The goal is to determine the fraction of geometric area within a monitored process area covered if a release occurs in a given geographic location. Geographic coverage is a function of the release detection equipment in the monitored process area, considering obstacles that prevent/inhibit detection and the defined voting arrangement for the safety action of interest. Detector geographic coverage does not require a specific risk scenario to determine coverage. The method assumes a hazard could occur anywhere within a monitored area and seeks to determine how well-covered that area is. Detector geographic coverage does require general information about the magnitude of a gas hazard that requires detection in a monitored area.

Scenario-based method mapping models individual scenarios using a range of different parameters such as: release location, release direction, wind speed and direction, and hole size. It quantifies the potential for releases to be detected in terms of either percentage of scenarios detected or the frequency of releases that remain undetected.

The volumetric and scenario-based methods are performance-based and hence require specific performance targets for acceptance. Annex C contains an example of a semi-quantitative approach for selecting fire and gas system (FGS) performance targets for the volumetric and scenario-based approaches. The mapping methods can be considered analogous to qualitative (prescriptive), semi-quantitative (volumetric-based), and fully quantitative (scenario-based method) methods applied to risk assessment.

8.2.1 The Prescriptive Method

Prescriptive gas mapping use qualitative evaluation and judgment-based placement to locate flammable gas or toxic gas detectors. Examples include:

- A proven design that is reused for similar applications; in many instances, this would not require a full modeling activity.
- Prescriptive ruleset provided by the operator; compliance can be verified using a checkbox type review to ensure the rules are met.
- Ruleset-based approach, e.g., detectors at a spacing of X m.
- Evaluation of the factors and detectors placed at locations where gas is likely to accumulate; this is most appropriate for applications that do not contain many potential leak sources and releases likely to behave predictably, e.g., no areas of recirculation.

Software modeling tools and metrics (e.g., cloud size/percentage coverage) are not required when using the prescriptive approach, and compliance can often be checked using a checkbox-type approach against the rule set that has been employed. This could lead to one or two kinds of problems:

- Due to the lack of coverage percentage that the prescriptive approach can provide, it is recommended to use this approach only in the initial design. Then the design engineers should follow a more detailed performance-based approach (geographic or scenario-based).
- For existing facilities that have already adopted the prescriptive approach, and to assure that over/under engineering does not represent an issue, selecting a highly hazardous location and applying the geographic- or scenario-based approach is recommended. This will help to check whether the current detector placement provides an acceptable level of coverage. The area hazard ranking and required target coverage are explained in detail in Annex C.

8.2.2 The Volumetric-Based (Geographic) Method

8.2.2.1 Flammable Gas Detection

Volumetric-based mapping assesses the capability of a system to detect a target gas cloud of a certain size and presents the results in terms of the percentage coverage of a given volume. Volumetric-based mapping is typically performed using software packages that verify the coverage achieved.The target gas cloud size can be based on different methods. The shape of the cloud is typically assumed to be of uniform concentration.

In its simplest form, volumetric-based mapping assumes a gas cloud size can be present at any point within the analyzed three-dimensional space. The total volume to be assessed should encompass all potential release locations, but subdivision might be appropriate where release locations are not evenly distributed. More complex applications can include a dilution factor to account for a central high-concentration point, diluting to low concentration the further it moves from the center.

When conducting volumetric-based mapping, detector set points can be accounted for by scaling the target gas cloud by the dilution factor (e.g., low-level alarm based on cloud size of 15 m and high-level alarm based on cloud size of 5 m); if consequence analysis has not been conducted this factor has to be set based on designer judgment.

The following advantages and disadvantages are generated based on common applications where the method is selected. The critical factor is the use of the most appropriate methodology for the specific application, e.g., the exclusion of subjective factors such as wind direction, leak orientation, and gas release rate is a strength in the volumetric-based approach as it aims to detect dangerous accumulations which could result in explosion, rather than calculate how this occurs. If the application is a controlled environment, however, where variables are reduced (i.e., an internal volume with few sources of release), excluding those factors could be considered a disadvantage. The advantages of volumetric-based mapping include the following:

- A 3D model can be applied for visualization purposes.
- Detailed information on the process is not always required, e.g., heat and mass balance data.
- Subjective features of analysis are reduced by comparison with scenario-based mapping, i.e., where leaks originate, the likelihood of pipe rupture, etc.
- No complex modeling of specific scenarios is required.
- The analysis is relatively quick.
- Consistent designs.
- Easily audited.

- Coverage detects the "dangerous" accumulation of gas, concerning explosion potential, with a higher degree of certainty than alternative methods as it assumes accumulation has occurred and aims to detect the critical cloud volume.
- Change management is easily incorporated (i.e., the detailed analysis does not need to be rerun due to minor alterations in the process area).

The disadvantages of volumetric-based mapping include the following:

- Results can be influenced by the size of the volume assessed.
- There is no clear way of determining where the graded volume is to extend to (to compensate for this, it is recommended to extend at least 2m around each major equipment item).
- Subjective features of analysis are increased compared to prescriptive methods, i.e., various cloud sizes, coverage adequacy interpretation, etc.
- The behavior of releases might not be taken into account.

8.2.2.2 Toxic Gas Detection

Volumetric-based mapping assesses a system's capability to detect a certain size of a toxic cloud and presents the results in terms of the coverage of a given volume. The toxic cloud size can be based on the cloud size and gas detection risk assessment.

Volumetric-based toxic mapping considers where personnel requiring protection are normally present, without falling under a specific permit to work system and associated safe working practices (e.g., restricted access, breathing apparatus, and portable detection).

Focusing on where personnel is present, volumetric-based mapping, therefore, typically concentrates on regularly used walkways and escape routes through the process area and entrances/exits. Control measures to restrict occupancy of areas not normally occupied (outside the assessed volumes) can include a permit to work, removing the risk of gas, portable protection, etc.

Volumetric-based mapping is typically performed using software packages that verify the coverage achieved.

The following advantages and disadvantages are generated based on common applications where the method is selected. The critical factor is the use of the most appropriate methodology for the specific application, e.g., the exclusion of subjective factors such as wind direction or leak orientation, is a strength in the volumetric-based approach, but if the application is a controlled environment where variables are reduced (i.e., an internal volume with few sources of release), the exclusion of those factors could be considered a disadvantage.

The advantages of volumetric-based mapping include the following:

- A 3D model can be applied for visualization purposes.
- Incorporates information on the process, e.g., heat and mass balance data, to determine constituents of a potential cloud (e.g., pressure, molecular weight, and temperature) to set elevation/location of the graded volume.
- No detailed knowledge of where leaks originate is required.
- Subjective features of analysis are reduced compared to scenario-based mapping, i.e., where leaks originate, the likelihood of pipe rupture, etc.
- Relatively quick to design.
- Consistent designs.
- Easily audited.

The disadvantages of volumetric-based mapping include the following:

- The size of the volume assessed can influence results.
- No clear way of determining where the graded volume should extend to.
- Subjective features of analysis are increased compared to prescriptive, i.e., various cloud sizes, coverage adequacy interpretation, etc.

8.2.3 The Scenario-based method

8.2.3.1 Flammable gas detection

Scenario-based mapping requires information specific to the process and is analogous to the approach taken in a QRA, i.e. it considers both the frequency and consequence of quantifying risk. For this reason, scenario-based mapping is often carried out where QRA has been conducted previously. The QRA can be used to provide the frequency of individual scenarios. Dispersion modeling might have been completed as part of a QRA, but this might not be at the required resolution for scenario-based mapping, so additional dispersion modeling is often required.

Scenario-based method mapping models individual scenarios using a range of different parameters, such as:

- Release location.
- Release direction.
- Wind speed and direction.
- Hole size.

It quantifies the potential for releases to be detected in terms of either percentage of scenarios detected or the frequency of releases that remain undetected. If conducting scenario-based mapping, event trees can be used to calculate the frequency of each discrete scenario. Event trees consider the initiating frequency of a release and the probability of each branch (e.g., release direction, wind speed, and direction). The probability of ignition should be accounted for when calculating the frequency of each scenario.

It should be noted that fire safety engineering applications often assume a probability of the central initiating event (i.e., the fire) being 1.0 to avoid dilution of the holistic risk (across the prevention and mitigation spectrum) of the facility, thereby potentially reducing the emphasis on an effective and critical mitigation system.

The scenarios are modeled using dispersion analysis which calculates the gas concentration in 3D space. Dispersion analysis can be conducted using either phenomenological models or CFD. Phenomenological models are faster to run but generally do not account for obstructions that can influence the size and shape of a cloud following a release. CFD offers a more rigorous modeling approach with the geometry being imported into the modeling software and both impingement and the influence of geometry on upstream wind conditions being captured. The dispersion analysis also gives more detailed information on each scenario modeled, such as:

- Time of detection.
- Cloud size versus time, i.e., this can highlight the importance of ensuring a fast system response.
- Number of gas detectors that alarm for a given scenario highlighting redundancy in a system, e.g., this information could be used to justify continued operation if a given detector is in a fault condition.

The following advantages and disadvantages are generated based on common applications where the method is selected. The critical factor is the use of the most appropriate methodology for the specific application, e.g., the more thorough consideration of release scenarios is a strength in the scenario-based approach, but if the application is a standard application (i.e., a tank storage facility), expending resources on a more thorough assessment of risks could be classed as a disadvantage.

The advantages of scenario-based mapping include the following:

- A 3D models can be applied for visualization purposes.
- If dispersion analysis has been conducted, this can be used directly to account for different set points of detectors as the concentration in 3D space is calculated, i.e., judgment is not required in terms of the difference in the size of a cloud at low and high set points.

- More thorough consideration of different release scenarios by considering specific release conditions, including wind direction, release orientation, gas release rate, etc.

The disadvantages of scenario-based mapping include the following:

- It can depend on the number of scenarios considered; the designer should ensure that results are independent of the number of scenarios. The result is based on the number of identified conditions and a range of assumptions (inputs). The number of inputs is open and variable and changing the input causes inconsistency of results due to the higher degree of inputs, creating greater uncertainty than alternative methods. For example, the impact of inaccurate assumptions should be determined (e.g., the frosting of the release source making release trajectory unreliable, wind gusts rather than a modeled steady prevailing wind direction, etc.).
- More time-consuming than volumetric-based mapping.
- Minor changes in the area (i.e., the addition of scaffolding/ temporary habitat) can affect the gas detection design. The engineer should assess whether the design is adequate or requires a revalidation process. Each change determined to impact the detection layout requires the engineer to undergo the assessment and revalidation process (including additional detection or relocating existing detection if required). Designs based solely on dispersion can be more susceptible to additional/altered obstructions in the area. Updating assessments, revalidation, and modification can be onerous, depending on the risk philosophy.

8.2.3.2 Toxic Gas Detection

Scenario-based mapping requires information specific to the process. It is analogous to the approach taken in a QRA, i.e. it takes account of both frequency and consequence to quantify risk. For this reason, scenario-based mapping is often carried out where QRA has been conducted previously.

The QRA can be used to provide the frequency of individual scenarios. Dispersion modeling might have been completed as part of a QRA, but this might not be at the required resolution for scenario-based mapping, so additional dispersion modeling is required.

The following advantages and disadvantages are generated based on common applications where the method is selected. The critical factor is the use of the most appropriate methodology for the specific application, e.g., the more thorough assessment of risks is a strength in the scenario-based approach, but if the application is a standard application (i.e., a tank storage facility), expending resources on a more thorough assessment of risks could be classed as a disadvantage.

The advantages of scenario-based mapping include the following:

- A 3D model can be applied for visualization purposes.

- If dispersion analysis has been conducted, this can be used directly to account for different set points of detectors as the concentration in 3D space is calculated.
- A more thorough review of different release scenarios by considering specific conditions, including wind direction, release orientation, gas release rate, etc.

The disadvantages of scenario-based mapping include the following:

- It can be dependent on the number of scenarios considered; the designer should ensure that results are independent of the number of scenarios.
- The result is based on the number of identified conditions and a range of assumptions (inputs). The number of inputs is open and variable and changing the input causes inconsistency of results due to the higher degree of inputs creating greater uncertainty than alternative methods. The impact of inaccurate assumptions, for example, should be determined (e.g., the frosting of the release source making release trajectory unreliable, wind gusts rather than steady prevailing wind direction, etc.).
- More time-consuming than volumetric-based mapping.
- Minor changes in the area (i.e., the addition of scaffolding/ temporary habitat) can impact the toxic detection design. The engineer must assess whether the design is adequate or requires a revalidation process. Each change determined to impact the detection layout requires the engineer to undergo the assessment and revalidation process (including additional detection or relocating existing detection, if required). Designs based solely on dispersion can be more susceptible to additional/ altered obstructions in the area. Update of assessments, revalidation, and modification can be onerous, dependent upon the risk philosophy.

8.3 Set Points and Voting

8.3.1 Fire Scenarios

Fire detectors normally either generate an alarm or do not. They do not have set points and are binary in their response. They do not respond to a flame's different Radiant Heat Output (RHO) levels.

However, the differing level of RHO allows detectors to be positioned closer to/ further from the source, depending on the target fire size. The multiples of RHO commonly seen (10 kW – 500 kW) should be calculated from a baseline sensitivity, e.g., the 1ft^2 n-Heptane pan fire.

Detector voting can be employed to minimize the potential for spurious trips within a mapping zone. For example, an alarm would be generated if the fire was detected by one detector (1ooN, where N is the number of devices in the voting group) followed by an executive/ control action on two detectors detecting the fire (2ooN).

8.3.2 Flammable Gas Releases

1. Point detectors:

Set points for flammable gas detectors are below the targeted gas LEL (0%- 100% LEL). In the event of a gas release, the lower the set point, the earlier the detection system responds. For point flammable gas detectors, it is recommended to have set points as low as possible but avoid false alarms. Below are specific values not to go to avoid potential false alarms:

- 5% LEL for methane.
- 10% LEL for propane.
- 20% LEL for gasoline vapors.

2. Open-Path Detector :

Open-path detector set points are in LEL/m, i.e., concentration (LEL) is integrated across the path length (m). The same principles apply to point detectors in setting set points as low as practical without encountering false alarms. Guidance given for low- and high-level set points for open-path detectors is [4]:

- low-level – 1 LEL m.
- high-level – 2 LEL m.

8.3.3 Toxic Gas Releases

1. Point Detectors:

Lower set points generally result in a faster response and greater protection for personnel. Fixed detectors should measure instantaneous concentrations and typically have higher set points than personal detectors as they initiate executive action. Defining the set points at the long-term exposure limit (LTEL – 8 hours) and short-term exposure limit (STEL- 15 min.) can be impractical due to the following reasons:

1. The technology might not be capable of reliably alarming at low concentrations.
2. Spurious trips.
3. The detector can be triggered during normal operation, e.g., filling/unloading.
4. Background concentration of the target gas.

Therefore, the practicalities of setting the low and high levels at the STEL and LTEL should be reviewed, and it might be more appropriate to use immediately dangerous to life or health (IDLH) values. To guard against spurious trips due to short-lived peak concentrations, a time delay could be incorporated into the alarm (e.g., if the set point has to be maintained for X seconds, the time would be dependent on the particular operation), or voting could be employed, e.g., 2ooN detectors required to alarm.

The set points for toxic gas detectors should also be reviewed against the criteria used to justify the number of detectors for a particular area or operation, e.g., areas where egress is difficult and/or takes an especially long time might require lower set points than those where egress is unimpeded.

The set points should be monitored over time to ensure they are appropriate for the operation. If detectors are continuously alarming, there is the potential that they will be inhibited by operators and hence not provide the intended function.

Unlike set points for flammable detectors, toxic set points could change as more research and data are collected on the physiological effects of different materials. Therefore, toxic set points should be reviewed periodically to meet current guidelines.

Where only STEL data are provided, the low set point can be set based on 33% of the STEL.

2. Open-Path Detectors:

The set points for open-path detectors are measured in ppm/meter and hence do not measure the concentration directly. The concentration for detectors should be based on practical experience, or modeling can be used to calculate the potential size and concentration of clouds to inform the set point.

8.4 Area Grading

8.4.1 General

Area grading could be defined qualitatively (based on the fire and gas specialist's judgment or quantitatively), as illustrated in Table 1. Annex C comprises a semi-quantitative approach to identify the area grading and the required target coverage. Each of the grades defines a relative level of fire or gas risk, with grade A* being the highest risk area and grade C being the lowest risk area requiring detection

***Table 1**. Area grading exposure definitions.*

Grade	Exposure Definition
A*	High Hydrocarbon processing with high sensitivity
A	High hazard potential
B	Moderate hazard potential
C	Low or very low hazard potential
No FGS	Risk is tolerable without benefit of FGS

8.4.2 Fire Area Grading

Fire grade A is typically assigned to areas with higher fire risk levels. These areas are characterized by hydrocarbon handling areas where small fires could cause significant damage quickly or rapidly escalate. Such fires might be due to the potential for a higher consequence severity (e.g., high-pressure gas from a compressor) or a higher likelihood of fire (e.g., small bore pipework and pump seals).

Fire grade B is assigned to most hydrocarbon processing areas throughout the facility. "normal" risk processing areas categorize these areas. They typically contain fixed equipment with a moderate to low likelihood of fire.

Fire grade C is assigned to areas where the risk of a fire is relatively low. Low potential for severe consequences characterizes Grade C areas (for example, due to high flash point fuel).

8.4.3 Flammable Gas Grading

Flammable gas grade A is typically assigned to FGS 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.

Flammable gas grade B is typically assigned to areas subject to a moderate degree of confinement of a burning gas cloud.

Flammable gas grade C is typically assigned to open hydrocarbon-processing areas with fixed equipment, relatively low operating pressure, and well-controlled ignition sources.

8.4.4 Toxic Gas Grading

Toxic gas grade A is typically assigned to FGS zones where a life-threatening toxic hazard could occur from a 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 of an injury-level toxic hazard that 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.

8.5 Typical Fire and Gas Mapping Workflow

Whether the fire and gas mapping utilizes the volumetric-based or the scenario-based approach, the following workflow can be followed:

1. Define the facility/unit that requires fire and gas detection mapping.

2. Define the hazard ranking for each area and the required coverage percentage (Annex C and Annex D) .
3. Input data to the fire and gas modeling software (3D model, plot plans).
4. Split the model into hazard zones.
5. Input detectors into the model.
6. Adjust detector capabilities using project detector specifications.
7. Obtain the intended performance target.
8. Detectors optimization.
9. Report generation.

Note: Although the hazard grade calculations may require 90% or higher detection coverage, achieving those values is practically and economically difficult. For this reason, it is acceptable for A* and A grades to achieve at least 80% detection coverage.

9. F&G Mapping Studies Inputs / Deliverables

9.1 Required Documents for Fire and Gas Mapping

To conduct an adequate fire and gas mapping study, the following documents should be available:

1. Target coverage.
2. Hazardous area layout drawings.
3. Equipment layout drawings / plot plans.
4. Process flow diagrams.
5. Process description.
6. Heat & material balance sheets/stream compositions and corresponding to process flow diagrams (PFDs).
7. Msds for all existing chemicals (flash points required).
8. Any relevant safety studies (fera, dispersion models, and consequence modeling).
9. Previous performance targets, if available.
10. Fire and gas philosophy.
11. A 3D model in recognized formatting such as .nwd or DWG format.
12. Environmental conditions.

9.2 Expected Deliverables in the Fire and Gas Mapping Reports

Fire and gas mapping report should comprise the following:

1. The general fire and gas detection philosophy.
2. Detection areas.
3. Mapping methodology.
4. F&G performance targets.
5. Coverage maps and levels.
6. Hazard zone layouts.
7. Fire and gas detection layout drawings.
8. Detectors tables (types, numbers, location, orientation, elevation).
9. List of any approved assumptions.
10. Information about the software utilized or calculations used in the study.
11. References.

10. References

[1] British Standards (BS), Hazard detection mapping - Guidance on the placement of permanently installed flame and gas detection devices using software tools and other techniques (BS 60080), 2020.

[2] UK Health & Safety Executive (UK-HSE), Fixed flammable gas detector systems on offshore installations: optimisation and assessment of effectiveness, (HSE RR1123), 2017.

[3] American Petroleum Institute (API), Recommended Practice for Fire Prevention and Control on Fixed Open-type Offshore Production Platforms (API RP 14G), 2019.

[4] American Petroleum Institute (API), Analysis, Design, Installation, and Testing of Safety Systems for Offshore Production Facilities, (API RP 14C), 2018.

[5] International Organization for Standardization (ISO), Petroleum and natural gas industries — Control and mitigation of fires and explosions on offshore production installations — Requirements and guidelines, (ISO 13702), 2015.

[6] International Society of Automation (ISA), Guidance on the Evaluation of Fire, Combustible Gas and Toxic Gas system effectiveness,(ISA TR84.00.07), 2010.

[7] J. McNay, A Guide to Fire and Gas Detection Design in Hazardous Industries, CRC Press, 2023.

[8] UK Health & Safety Executive (UK-HSE), Fire and Gas Detection, https://www.hse.gov.uk/offshore/strategy/fgdetect.htm, HSE.

11. List of Annexes

- **Annex A -** Detection Technology.
- **Annex B -** Examples of Fire and Gas Detection Philosophies.
- **Annex C -** Hazard Ranking and Target Coverage Determination.
- **Annex D -** An Application Example – Fire Target Coverage Determination.
- **Annex E -** Examples of Optimized Design.
- **Annex F -** Sample for Sensing Device Symbols.

Annex A – Detection Technology

A.1. General

For all types of detection, the detector technology selected needs to be suitable for the hazard types which might be present in the particular location, e.g.:

- If there is a risk of a unique fuel (i.e., hydrogen), it is important to be aware of the fire detector types and capability.
- Certain flammable vapors, such as benzene, are not detected by the standard infrared Line of site (IR LOS) detection.

Interoperability between the device and system could have an impact on device selection. This should be considered as early as possible in the design philosophy. If this information is unavailable, conservative assumptions should be made concerning coverage and updated as the project evolves.

There are three main categories of detectors in the oil and gas industry:

- Fire detectors.
- Flammable gas detectors.
- Toxic gas detectors.

A.2. Fire Detectors

The main fire detection technologies in general industrial use are:

- Flame detection.
- Heat detection.
- Products of Combustion Detectors.

The operating principle of each type is illustrated in Table A1. Note that flame detection is the only one to be mapped in the ways mentioned in this guideline. Heat and smoke are mapped prescriptively per appropriate standards/guidance.

Table A1. *Fire detectors types and operating principles [3].*

Classification of Detectors	Type of Detector	Operating Principle	Remarks
Flame Detectors	(a) Infrared (IR) Detectors	Responds to radiant energy from a flame	Used when a very rapid response to a fire is desired. Generally used in conjunction with an extinguisher system
	(b) Ultraviolet (UV) Flame Detectors	Responds to the wavelength of light emitted from the flame	
	(c) Combination IR/UV	Responds to both UV and IR	Eliminate some of the false alarm problems of the individual IR or UV flame detectors
Heat Detectors	(a) Fusible Plugs or links	Melts at a predetermined temperature	Used in compressor and equipment buildings and areas around production equipment and wellheads
	(b) Heat-pneumatic or Theronistor sensors	Detect a high temperature along a length of tubing	
	(c) Rate of Rising Detectors	Detect a rapid rate of temperature rise	Not recommended for use near outside doorways in heated or air-conditioned buildings
	(d) Fixed Temperature Detectors	Detect temperature above a predetermined value	
Products of Combustion Detectors	(a) Ionization Detector	Products of combustion activate an ionization chamber	Normally used in living quarters and control rooms
	(b) Photoelectric Detector	Activated by interruption of a beam of light by smoke particles	

A.3 Flammable Gas Detectors, Capabilities, and Recommended Set Points

1. Point Detectors

Point flammable gas detectors can be pellistor or IR. It should be noted that, unlike IR point detectors, pellistor detectors rely on both gas and air to be present to detect the gas component and might not therefore respond in situations where large gas releases rapidly displace the air. IR detectors operate in 100% v/v gas environments. Relative sensitivities for pellistors and IR detectors change significantly across the broad range of hydrocarbons, e.g. pellistors are more sensitive towards lighter hydrocarbons than heavier hydrocarbons which is the inverse for IR detectors. IR detectors cannot detect hydrogen.

2. Line of Sight (Open Path) Detectors

There are two types of Line of sight (LOS) or open path detectors: IR based and Laser based. IR LOS detectors transmit an IR beam between a transmitter and a receiver. LOS detectors can have a path length between 0 m and 250 m, and the maximum allowable path length should be considered. Laser LOS detectors are very similar to IR LOS detectors concerning mounting arrangement and path lengths. However, a key difference between laser and IR technology is that laser technology is gas-specific. Therefore the target gas must be matched to the laser device.

3. Ultrasonic/Acoustic Detectors

Ultrasonic gas leak detectors (UGLD) "listen" for the characteristic sound of gas under pressure being released through an orifice. UGLD can be considered a "first line of defence" device as they do not measure the concentration of a potential hazard but respond quickly to pressurized gas leaks, depending upon the built-in time delays to guard against spurious trips. While UGLDs can be used to detect the release of gas, mapping of UGLD is outside the scope of this guideline. Table A2 illustrates the types of flammable gas detectors and their capabilities and recommended set points

Table A2. *Flammable gas detectors capabilities and recommended set points [4].*

Combustible Gas Detector Type	Capabilities	Recommended Set Points
Point	Detect combustible gas specifically at the sensor head.	An audible alarm should be activated at a gas concentration no greater than 25 % LEL. Under confirmed gas detection, automatic corrective action should be initiated at no greater than 60 % LEL.
Open path/Line of sight	Detect combustible gas along a continuous path between an infrared energy transmitter and an infrared receiver. It can provide greater coverage than a single-point combustible gas detector.	An audible alarm should be activated at a gas concentration no greater than 1.25 LEL-m. Under confirmed gas detection, automatic corrective action should be initiated at no greater than 3.00 LEL-m. Note that these set points are equivalent to the point gas detector set points based on a 5 m gas cloud.
Ultrasonic/acoustic	Detects pressurized gas leaks by measuring the ultrasonic energy generated by the leak. This technology offers a complementary method to point and open path combustible gas detectors. NOTE: Ultrasonic gas detectors can pick up leaks of nonhazardous gases (e.g., air leaks). As such, consider voting ultrasonic detectors with point or open path detectors when initiating automatic corrective action.	An audible alarm should be activated at a level greater than 6 dB above the background ultrasonic noise level.

A.4 Toxic Gas Detectors

1. Electrochemical Sensors

Electrochemical sensors consist of two or more electrodes, sensing, reference, and measuring electrodes. This type of sensor works on the diffusion of the target gas into the sensor resulting in a change of electrical current proportional to the gas concentration.

The operation of an electrochemical sensor depends upon the electrical parameters of electrodes placed in an electrolyte due to redox reactions of the gas on the surface of the electrodes. As with all types of sensors, the cross-sensitivity towards other gases needs to be known before use, and this information can be found in the manufacturer's supporting data.

2. Semiconductor Sensors

The operation of a semiconductor sensor depends upon changes in the electrical conductance of a semiconductor due to the chemisorption of the gas being detected at its surface. Many semiconductor sensors require higher gas concentrations to initiate a response due to the "sleep effect" of semiconductor materials.

3. Ultrasonic (Acoustic) Gas Leak Detectors

Ultrasonic gas leak detectors (UGLD) "listen" for the characteristic sound of gas under pressure being released through an orifice. UGLD can be considered a "first line of defense" device as they do not measure the concentration of a potential hazard but respond quickly to pressurized gas leaks, depending upon the built-in time delays to guard against spurious trips. While UGLDs can be used to detect the release of gas, mapping of UGLD is outside the scope of this guideline.

A.5 Typical Application of Fire and Gas Detectors

Typical application of fire and gas detectors and the typical correspsponding actionas are illustrated in Table A3.

Table A3. Typical application of fire and gas detectors *[3].*

<table>
<tr><th colspan="5">Fire and gas system</th></tr>
<tr><th>Hazard</th><th colspan="2">Type of detector</th><th>Typical application</th><th>Typical actions</th></tr>
<tr><td rowspan="4">Fire</td><td rowspan="2">Heat</td><td>pneumatic</td><td>Process, wellhead, utilities</td><td>Alarm, ESD, EDP, closure of the SSSV, active fire protection</td></tr>
<tr><td>electric</td><td>Turbine hoods, workshops, stores, engine rooms, process, wellhead,
utilities</td><td>Alarm, ESD, EDP, active fire protection</td></tr>
<tr><td colspan="2">Flame</td><td>Process, wellhead utilities, generators, turbine hoods</td><td>Alarm, ESD, EDP, active fire protection</td></tr>
<tr><td colspan="2">Smoke</td><td>Control rooms, electrical rooms, computer rooms, accommodation</td><td>Alarm, isolate power, active fire protection (if present)</td></tr>
<tr><td colspan="3" rowspan="3">Flammable gas</td><td>Air intakes to TR and control stations</td><td>Alarm, isolate ventilation</td></tr>
<tr><td>Process, wellhead, utility areas
engine rooms</td><td>Alarm, ESD, EDP, isolate power</td></tr>
<tr><td>Air intakes</td><td>Alarm, ESD, EDP, isolate power, ESD
ventilation system</td></tr>
<tr><td colspan="5">Notes:
Process areas include drilling areas.
For rooms containing safety systems that might be operating during the emergency.</td></tr>
</table>

Annex B - Examples of Fire and Gas Detection Philosophies

Tables B1, B2, and B3 illustrate examples of fire, flammable gas, and toxic gas dection philosophies, respectively [5].

Table B1. *Example of fire detection philosophies.*

Fire Detection Philosophy	Elements of Philosophy Decision	Typical Application
The goal is to detect fire as early as practical to reduce the possibility of escalation, minimize the impact on the asset, and allow personnel to take appropriate protective actions.	Within a monitored process area: Detection: Incipient fire. Successful FGS mitigation: • prompt evacuation or shelter-in-place response to alarm notification • isolate fuel source • depressurize the process • initiate fixed fire suppression of affected equipment and surrounding equipment	Occupied offshore facilities High-value assets Onshore process plants with significant occupancy
	Migration beyond the monitored process area: Detection: Smoke at building air intakes. Successful FGS mitigation: • prompt evacuation or shelter-in-place response to alarm notification • shutdown ventilation	Occupied offshore facilities
The goal is to detect fire that has the potential to produce major damage beyond the area of origin to mitigate against total asset loss.	Within a monitored process area: Detection: Fully developed fire Successful FGS mitigation: • isolate fuel source and allow it to extinguish by depletion of fuel	Normally unmanned installations, onshore or offshore, with limited firefighting capability
	Migration beyond the monitored process area: Detection: (none)	

Table B2. *Example of flammable gas detection philosophies.*

Flammable Gas Detection Philosophy	Elements of Philosophy Decision	Typical Application
Detect credible gas releases by strategically placing detection equipment near release sources to minimize the potential for extended gas release that could ignite with severe consequences.	Within a monitored area: Detection: Leak/release sources and size should be identified, and detectors located in proximity to leaking sources to provide incipient (early) indication of a hazard before gas migrates to a location where the ignition and escalation are likely. Successful FGS mitigation: • alarm to evacuate personnel to safety and allow controlled operator shutdown (or automatic ESD)	Onshore process plants
	Migration beyond a monitored area: Detection: Variation in gas cloud size and direction makes it difficult to specify detector layout and spacing within a monitored area to address all possible leak scenarios. Because ignition sources and occupancy are well controlled within a process area, detection within a monitored area should be supplemented with perimeter gas detection to improve confidence that the release will be detected before migrating to a strong ignition source or area with higher occupancy and a more severe impact. Successful FGS mitigation: alarm to evacuate personnel to safety and allow a controlled operator shutdown (or automatic ESD)	
Detect gas accumulations in hazardous quantities that, if ignited, could cause significant impairment to life, safety, and the asset.	Within a monitored area: Detection: Gas dispersion patterns might not be predictable, and gas hazards are most severe in areas where gas can accumulate within confined and congested process areas. Detectors should be placed where gas can accumulate to mitigate a threshold accumulation volume that can result in a more severe blast,	Offshore facilities

Flammable Gas Detection Philosophy	Elements of Philosophy Decision	Typical Application
	which could impair structural integrity or evacuation/egress. Successful FGS mitigation: • isolate fuel source and depressurize • de-energize electrical apparatus • evacuate personnel to safety	
	Migration beyond a monitored area: Detection: Reliable detection cannot be assured in areas where gas does not accumulate (absence of confinement/ congestion), nor is the severity of an ignited gas cloud of high concern due to the lower severity of a vapor cloud fire (no VCE). Credible leak scenarios should be identified, and detection of gas migration should be provided at receptors of concern (detection at HVAC air intakes, etc.). Successful FGS mitigation: • alarm to shelter/evacuate personnel • de-energize electrical apparatus	

Table B3. *Example of toxic gas detection philosophies.*

Toxic Gas Detection Philosophy	Elements of Philosophy Decision	Typical Application
Detect credible gas releases by strategically placing detection equipment near release sources to minimize the potential for extended-duration gas hazards that could result in severe consequences.	Within a monitored area: Detection: Leak/release sources and size should be identified, and detectors should be located near leak sources to provide an early indication of a hazard before gas migrates to a location where exposure is likely. Successful FGS mitigation: • alarm to evacuate personnel to safety or shelter and allow controlled operator shutdown (or automatic ESD)	Onshore process plants and offshore facilities
	Migration beyond a monitored area: Detection: Variation in gas cloud size and direction results in difficulty. Specifying the detector layout and spacing within a monitored area to address all possible leak scenarios. Because occupancy is well controlled within a process area, detection within a monitored area should be supplemented with perimeter gas detection or gas detection along egress paths to improve confidence that the release will be detected before migrating to an area with higher occupancy and more severe impact. Successful FGS mitigation: • alarm to evacuate personnel to safety or shelter and allow controlled operator shutdown (or automatic ESD)	

Annex C - Hazard Ranking and Target Coverage Determination

Hazard ranking is a function of the equipment, hazards, consequences, frequency, occupancy, and special factors. Ranking requires an equipment-by-equipment assessment of factors, including:

a) Identifying hydrocarbon processing equipment:

- Identify credible sources of hydrocarbon gas or liquid release.
- Identify the amount and type of processing equipment in the FGS zone.
- Identify process conditions that could aggravate/mitigate consequence severity.

b) Assessing consequence severity:

- Identify equipment that the FGS is intended to safeguard.
- Assess the magnitude of safety consequences (injury versus life-threatening).
- Identify confinement and congestion in process areas that could aggravate combustible gas hazards.

c) Assessing hazard frequency:

- Determine the frequency of release from all identified release sources.
- Identify credible ignition sources (continuous and intermittent).
- Identify the effective response action to prevent safety impacts.

d) Assessing level occupancy in the FGS zone:

- Identify normal/routine occupancy (operations, maintenance, contract).
- Identify non-routine occupancy (operations, maintenance, contract).

If an FGS zone is not easily characterized by one or more of the factors that comprise the FGS zone hazard rank, quantitative risk analysis should be considered. Figure 2 illustrates the hazard ranking procedures.

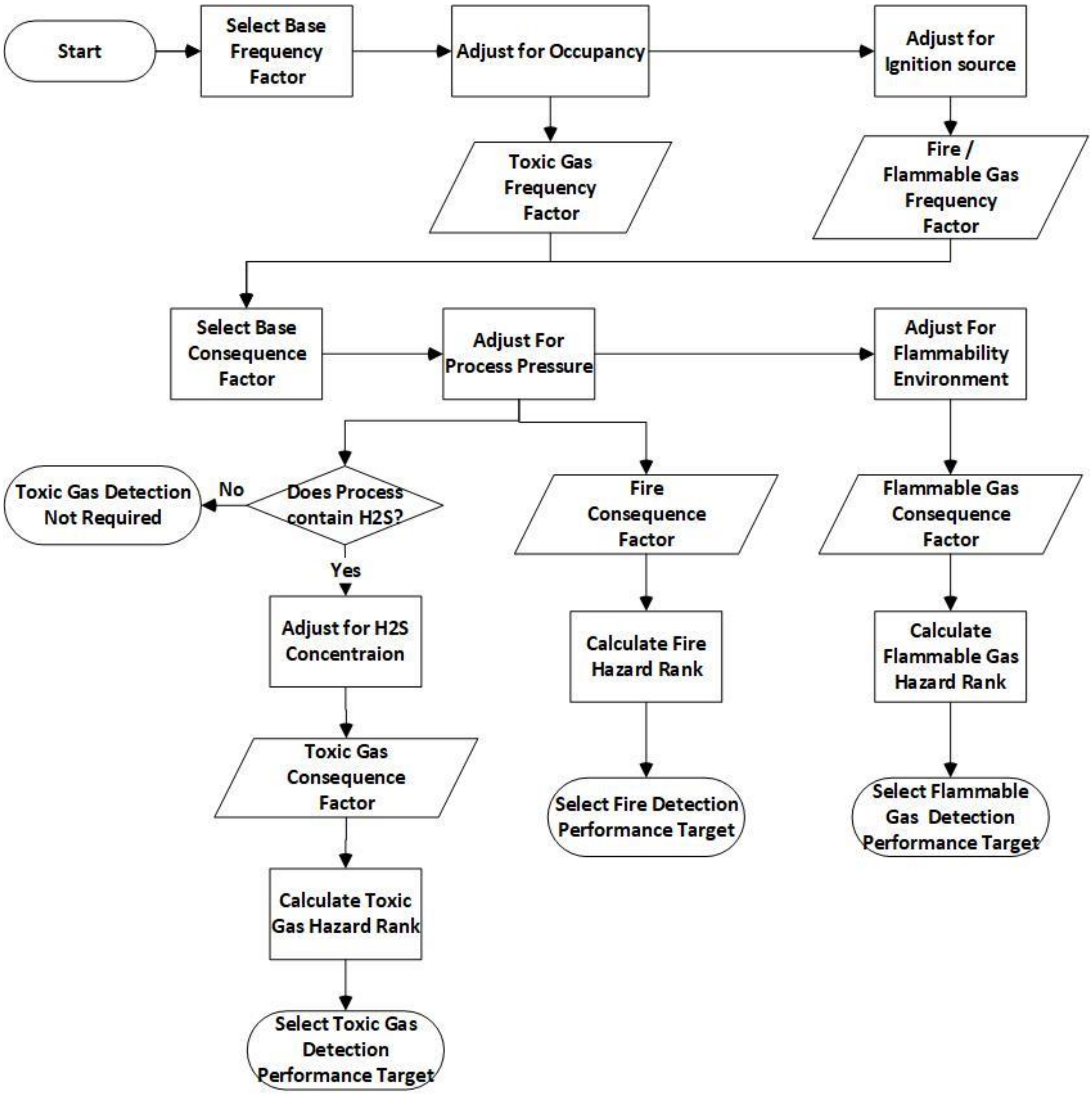


Figure 2. *Hazard ranking procedures [6].*

Step 1: Base Frequency Factor for Major Process Equipment Item:

Equipment Item	Base Frequency Factor
Shell & tube heat exchanger	2
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
A single welded pipe segment	1
Production wellheads	2

Step 2: Occupancy Adjustment:

FGS Protection from Area of Immediate Impact	FGS Protection from Escalation Using Evacuation, Escape, Rescue Model	Adjustment
Rare occupancy (less than 15 min per day) = 1%	Rapid escape likely from area of impact of escalated hazard (1 to 3 minutes).	-2
Moderate occupancy (routine operator rounds) = 10%)	Egress is possible using designated routes. Short-duration protection required from the escalated hazard (3 to 10 minutes)	-1
High occupancy (near continuous occupancy) > 30%	Muster using designated routes + evacuation from temporary safety refuge. Extended protection required from the escalated hazard (10 to 30 minutes).	0

Step 3: Ignition Adjustment:

Description	Adjustment
Low ignition probability (3%)	-1.5
Average ignition probability (10%)	-1
Moderate ignition probability (30%)	-0.5
High ignition probability (near 100%)	0

Step 4: Consequence Score for Process Conditions:

Process Material Phase	Base Consequence Score
Stable liquids	1
Volatile liquid	2
Gas	3

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

Step 5: Consequence Score for Flammability Environment:

Environment Type	Adjustment	Notes (Confinement & Obstacle Density)
No confinement/low congestion	-1	3D Low
Some confinement/ moderate congestion	0	2D Med"
Confinement/high congestion	2	2D High

Step 6: Toxic Gas Concentration Adjustment:

Concentration (v/v)	Adjustment
< 100 ppm	No H2S analysis Required
100 ppm to 1000 ppm	-1
1000 ppm to 1%	0
1% to 3%	1
3% to 10%	2
> 10%	3

Step 7: Hazard Rank Determination (Fire, Flammable Gas, Toxic Gas):

- **Adjusted Hazard Rank (Fire)** = base frequency factor+ occupancy adjustment+ ignition adjustment+ consequence score for process conditions+ base consequence factor.
- **Adjusted Hazard Rank (Flammable gas)** = base frequency factor+ occupancy adjustment + consequence score for process conditions+ base consequence factor+ consequence score for flammability environment.
- **Adjusted Hazard Rank (Toxic gas)** = base frequency factor+ occupancy adjustment + consequence score for process conditions+ base consequence factor+ toxic gas concentration adjustment.

Step 8: Performance Grade and Coverage Determination (Fire, Flammable Gas, Toxic Gas):

Grade	Exposure Definition
A	High hazard potential
B	Moderate hazard potential
C	Low or very low hazard potential
No FGS	Risk is tolerable w/o benefit of FGS

Hazard Rank Grade Fire Detection Coverage		
Adjusted Hazard Rank	**Grade**	**Fire Detection Coverage**
≥ 7	A*	> 0.90
5 to < 7	A	0.9
2 to < 5	B	0.8
0.5 to < 2	C	0.6
< 0.5	N/A	No target coverage

Hazard Rank Grade Flammable Gas Detection Coverage		
Adjusted Hazard Rank	**Grade**	**Gas Detection Coverage**
≥ 7	A*	> 0.90
5 to < 7	A	0.9
2 to < 5	B	0.8
0.5 to < 2	C	0.6
< 0.5	N/A	No target coverage

Hazard Rank Grade Toxic Gas Detection Coverage		
Adjusted Hazard Rank	**Grade**	**Gas Detection Coverage**
≥ 7.5	A*	> 0.90
5.5 to < 7.5	A	0.9
3.5 to < 5.5	B	0.8
1.5 to < 3.5	C	0.6
< 1.5	N/A	No target coverage

Although the hazard grade calculations may require 90% or higher detection coverage, achieving those values is practically and economically difficult. For this reason, it is acceptable for A* and A grades to achieve at least 80% detection coverage.

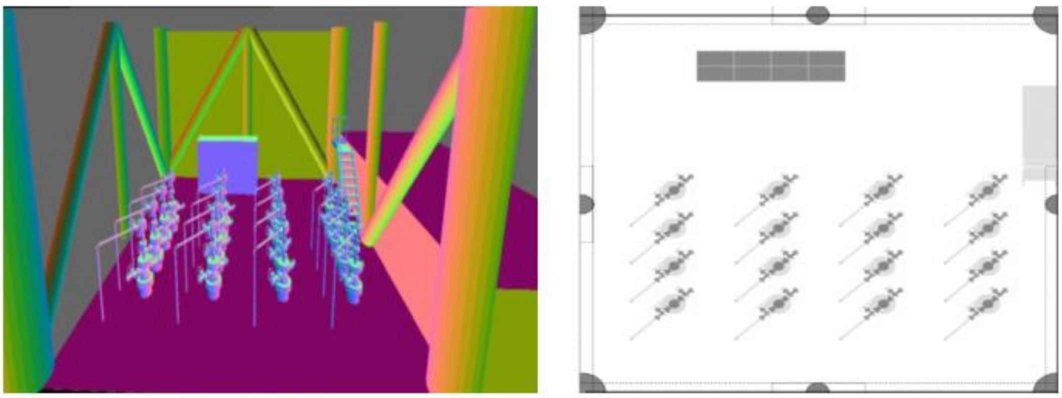
Annex D - An Application Example – Fire Target Coverage Determination

1. Facility Information

The example is a module on an offshore oil and gas production platform. The module is fully enclosed on two sides, partially enclosed on another, and open on one side. The area is rectangular and 20 meters in length on each side. The module contains 16 wellhead assemblies (i.e., wellhead plus Christmas tree) and a wellhead control panel (instrumentation and control cabinet) located on the north side of the module. A 3D visualization and plot view of the module are shown in Figure 3.

Other Details:

- Wellhead pressure is 1500 psig.
- The process temperature is 100°F.
- Process fluid has a flash point of -10°F.
- Personnel is in the area of the well bay approximately 2 hours per day.



(a) (b)

Figure 3. *Offshore module (a) 3D visualization and (b) plot plan [6].*

2. Fire and Gas Hazard Assessment

The fire hazard analysis includes an evaluation of the process that includes the following factors:

- Material processed.
- Process pressure and temperature.
- Equipment potentially involved in a fire.
- Occupancy of the facility.
- Electrical area classification.

Because this is a process module containing flammable hydrocarbon processed at high pressure with the potential presence of personnel on the platform, the external fire hazard/risk analysis determined the need for fire detection. The detection philosophy is for incipient (early-stage) fire detection, automatic shutoff of the process, and initiating firewater deluge by activating the fire water pump and opening the deluge valve.

3. Hazard/Risk Scenarios Identification

The hazard analysis identified the potential for leaks from the wellhead, and a range of release sizes was considered credible scenarios. Those scenarios could involve a pinhole leak from the wellhead, a flange failure, or a rupture of a process connection to the wellhead resulting in a potential turbulent jet fire in the module. Although no strong ignition sources are located in the module (open flames, unclassified electrical equipment, etc.), the possibility of ignition cannot be discounted.

4. FGS Performance Target Identification

FGS performance target identification would according to steps stipulated in Annex C.

Step 1: Base Frequency Factor for Major Process Equipment Item:

Equipment Item	Base Frequency Factor
Production wellheads	2

Step 2: Occupancy Adjustment:

FGS Protection from Area of Immediate Impact	FGS Protection from Escalation Using Evacuation, Escape, Rescue Model	Adjustment
Moderate occupancy (routine operator rounds) = 10%)	Egress is possible using designated routes. Short-duration protection required from the escalated hazard (3 to 10 minutes)	-1

Step 3: Ignition Adjustment:

Description	Adjustment
Low ignition probability (3%)	-1.5

Step 4: Consequence Score for Process Conditions:

Process Material Phase	Base Consequence Score
Volatile liquid	2

Pressure	Adjustment
> 1,000 psig	1.5

Step 5: Consequence Score for Flammability Environment:

- Not applicable in this example.

Step 6: Toxic Gas Concentration Adjustment:

- Not applicable in this example.

Step 7: Hazard Rank Determination:

$$\begin{aligned}&Adjusted\ Fire\ Frequency\ Score\\&\qquad = Base\ Frequency\ Factor + Occupancy\ Adjustment\\&\qquad + Ignition\ evnironment\\&\qquad = 2 - 1 - 1.5\\&\qquad = \ -0.5\end{aligned}$$

$$\begin{aligned}&Adjusted\ Fire\ Consequence\ Score\\&\qquad = Base\ Consequence\ Factor + Process\ Pressure\ Adjustment\\&\qquad = 2 + 1.5\\&\qquad = 3.5\end{aligned}$$

$$\begin{aligned}&Fire\ Ajusted\ Hazard\ Rank\\&\qquad = Adjused\ Fire\ Frequency\ Score + Adjusted\ Fire\ Consequence\ Score\\&\qquad = -0.5 + 3.5\\&\qquad = 3.0\end{aligned}$$

Step 8: Performance Grade and Coverage Determination

The fire-adjusted hazard rank of 3.0 results in the Grade B fire detection requirement. The performance target for Grade B fire hazards is **80%** detector coverage.

Hazard Rank Grade Fire Detection Coverage		
Adjusted Hazard Rank	**Grade**	**Fire Detection Coverage**
≥ 7	A*	> 0.90
5 to < 7	A	0.9
2 to < 5	**B**	**0.8**
0.5 to < 2	C	0.6
< 0.5	N/A	No target coverage

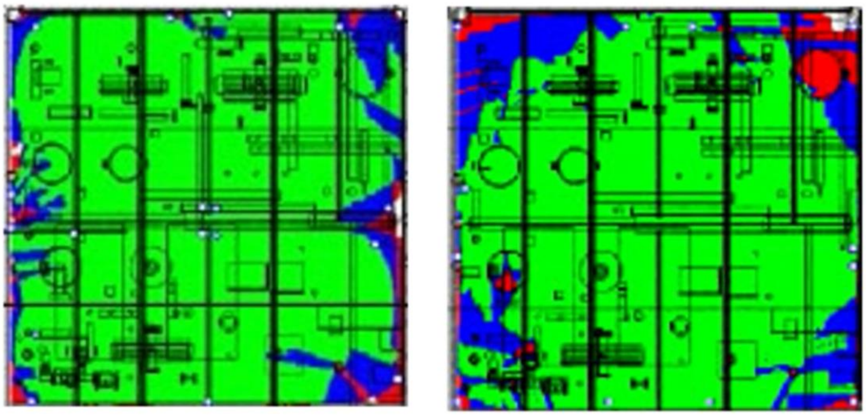
Grade	Exposure Definition
A	High hazard potential
B	**Moderate hazard potential**
C	Low or very low hazard potential
No FGS	Risk is tolerable w/o benefit of FGS

Based on the detection philosophy, 80% coverage for 2ooN is required for action.

Annex E - Examples of Optimized Design

1. Optimizing Over-Engineering Design

The following example illustrates that original design comprised 18 detectors based on detecting 25 kW pool fire. However, the optimized design comprised 12 detectors based on 25 kW pool fire at almost the same coverages.



1ooN	2ooN	>2ooN
94 %	90 %	82 %

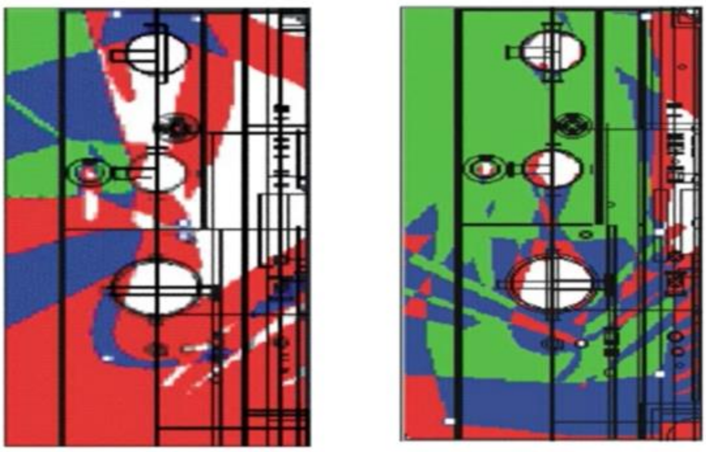
1ooN	2ooN	>2ooN
93 %	89 %	76 %

(a) **(b)**

Figure 4. *Example of over-engineering design (a) vs. optimized design (b).*

2. Optimizing Under-Engineering Design

The following example illustrates that original design comprised 5 detectors based on detecting 25 kW pool fire. However, the optimized design comprised also of 5 detectors based on 25 kW pool fire but with higher coverage of the detectors.



1ooN	2ooN	>2ooN
80 %	33 %	15 %

1ooN	2ooN	>2ooN
98 %	85 %	57 %

(a) **(b)**

Figure 5. *Example of under-engineering design (a) vs. optimized design (b).*

Annex F - Sample for Sensing Device Symbols

A sample for sensing devises symbols is illustrated in table F.1 [6].

Table F2. *Sample of sensing device symbols.*

Variable	Safety Device Designation		Symbol
	Common	ISA	Single Device
Flame	Flame arrestor	None	FA
	Stack arrestor	None	SA
Fire	Flame detector (ultraviolet/infrared)		USH
	Heat detector (thermal)	Temperature safety high	TSH
	Smoke detector (ionization)		YSH
	Fusible material	Temperature safety high	TSE
Combustible gas concentration	Combustible gas detector	Analyzer safety high	ASH
Toxic gas concentration	Toxic gas detector		OSH