Guidance on fire, combustible gas and toxic gas detection system philosophy

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This paper provides a summary of the forthcoming guidance by the Energy Institute for the development of fire, combustible gas and toxic gas detection philosophies.

A well-conceived fire and gas system enables the early detection of loss of containment incidents, and the resultant actions can significantly reduce the magnitude and duration of potential consequences. While there is a wealth of vendor documentation available for the components of fire and gas detection systems, there is no independent industry guidance to assist with the overall implementation of such systems. The guidance document is intended to address this shortfall and provides a reference to industry for the development of an effective and fit-for-purpose fire and gas detection philosophy.

The guidance is aimed to provide an adaptable and consistent approach that is applicable to both onshore and offshore environments. Emphasis is placed on the importance of hazard assessment to gain understanding of the release fluid behaviour and how this can used to select, place and manage detectors. The guidance goes beyond what may be included in a typical fire and gas philosophy document and covers detector layout strategies, describes methods to assess detector coverage, and provides approaches for the management of ongoing inspection and testing of the fire and gas detection system.

Introduction

Implementing a fire and gas detection system across a process facility is a significant challenge. In an ideal world there would be a solution that could detect all potential releases as soon as they occur, the reality however is that the diversity of release outcomes does not make this practicable. The range of influencing factors that affect hazard behaviour, such as release direction, wind speed, wind direction, obstructions and ignition sources leads to a seemingly unlimited number of potential outcomes.

The problem is not simplified by the wealth of fire and gas detection equipment available on the market, each with their own supporting guidance, data sheets and manuals. Rather than helping, the wealth of options and information can serve to hinder the designer, leaving the fire and gas design exposed to judgement, multiple iterations and potential compromises to safety.

Recognising the above challenges, in 2017 the Energy Institute (EI) commissioned Risktec to develop guidance for fire, combustible gas and toxic gas detection system philosophies (Energy Institute, 2020) under the supervision of its Process Safety Committee. The guidance is to be published in 2020. The purpose of the guidance is to provide an overview of the detection of acute releases resulting from loss of primary containment from process plant which have the potential to result in major accidents such as fires, explosions and toxic releases. Covering the necessary considerations for development of a fire and gas philosophy, and subsequent detector implementation, the guidance is intended to offer an adaptable approach to develop a robust fire and gas system. It is primarily aimed at operators of sites handling flammable or toxic fluids and is intended to be equally relevant for upstream and downstream facilities, both onshore and offshore. With this wide-ranging target audience, the guidance document adopts a flexible high-level approach, based on defining fire and gas detection requirements through facility-specific hazard and risk assessment.

The intent of this paper is to provide a short summary of the proposed methodology and present the key points identified during its development.

What role does fire and gas detection play?

To understand the general objectives of a fire and gas detection system, it is necessary to first understand its role in fulfilling a safety function. A safety function is intended to achieve or maintain a safe state, and it typically constitutes the following stages:

1. Detecting the deviation from normal operations (e.g. loss of containment).
2. Decision making (automatic and/or manual response).
3. Intervention / action to prevent or mitigate consequences.

The fire and gas detection system fulfils only the first of these points and therefore it must successfully interface with the subsequent step for the overall safety function to be achieved. In other words, when a response is not triggered, the fire and gas detection system does not provide risk reduction benefits.

The "Swiss cheese" (Reason, 2000) model in Figure 1 below is an effective way of visualising the role of fire and gas detection. In the event of failure of process containment, reliance is placed on a means of detecting the release, following which a decision needs to be made (by an operator or automatically) to initiate the appropriate response. Failure of any one of these parts can compromise the integrity of the safety system.

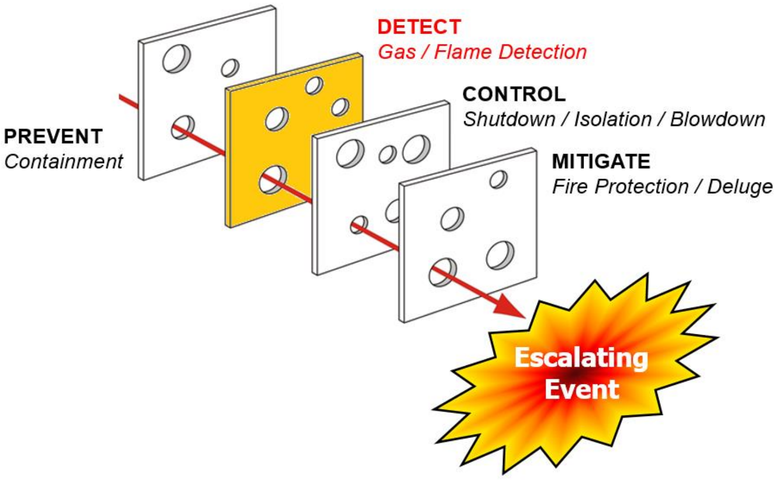

Figure 1: Position of Fire and Gas Detection in Barriers of Defence

It is also important to note the mitigative role that fire and gas detection supports. In accordance with the hierarchy of risk reduction, effort should first be targeted toward elimination and prevention measures, both of which generally tend to have a direct and measurable impact on risk reduction. The risk reduction benefits of mitigation measures, of which fire and gas detection forms a part, is difficult to demonstrate, again due to the uncertainty of release behaviour. In some cases, elimination and prevention measures may reduce risk sufficiently to make the cost of a fire and gas detection (and the subsequent actions) grossly disproportionate to the risk benefits. For most facilities however, a lack of fire and gas detection would fail the as low as reasonably practicable (ALARP) test and its necessity is widely accepted without such assessment.

A typical set of objectives for the fire and gas detection system is:

- To provide continuous automatic monitoring functions and to alarm to alert personnel of the presence of a hazardous fire or a flammable/toxic gas condition.
- To allow control actions to be initiated manually or automatically in order to mitigate the consequences, minimise escalation and reduce overall loss.

The above objectives could be used as a starting point and then tailored to the particular requirements of the facility.

Fire and gas system scope and interfaces

The fire and gas detection system is typically made up of an array of suitable and appropriately positioned detectors located throughout the facility, together with junction boxes, local area control panels and a main control panel / human machine interface (HMI). The size and complexity of the system is very much dependent on the size of the facility, the hazards and the intended response.

A schematic of a fire and gas detection system is presented in Figure 2. While this is not exhaustive, it conceptually shows the flow of information, from inputs via detectors, through the control system through to initiation of responses. Some responses may be executed automatically via the fire and gas control system logic, or manually by the operator based on information gained from alarm and indication at the control panel. It is also possible to have a hybrid approach where there is a short delay of automatic response activation to allow for operator assessment and intervention.

Some examples of potential responses following fire or gas detection include:

- Initiate alarms at manned locations.
- Actuation of emergency shutdown valves and blowdown systems to minimise the inventory of hazardous materials.
- Shutdown equipment such as pumps and compressors.
- Remove potential ignition sources by electrical isolation of non-essential equipment or non-certified equipment.
- Activate warning systems such as helideck wave off lighting.
- Initiate active fire protection systems.
- Adjust area ventilation, for example, to minimise the ingress and spread of smoke or gas in non-hazardous areas and ensure effective operation of any fire suppressant systems.

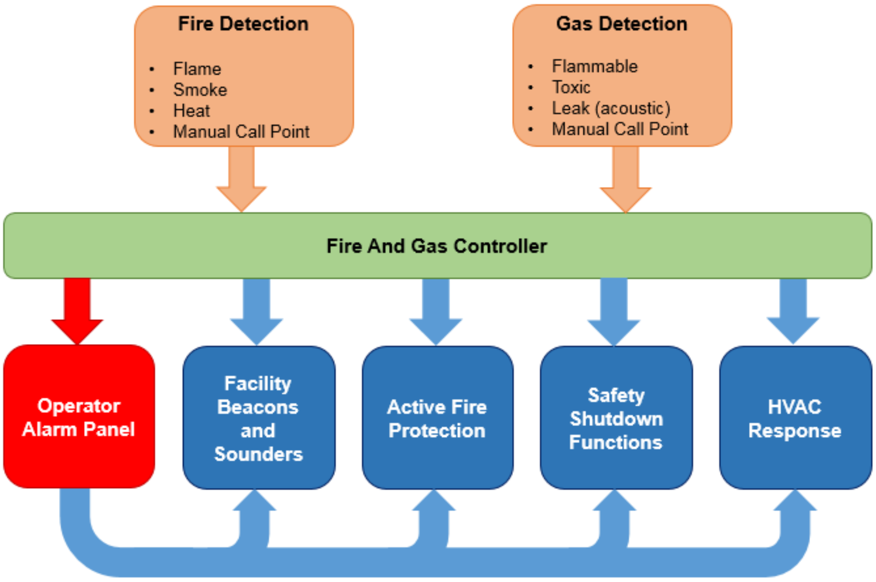

Figure 2: Typical Fire & Gas System Interfaces

An overview of the guidance

The underlying theme of the EI guidance document is that the fire and gas detection philosophy should be developed using information obtained from hazard and risk analysis. This analysis can then be used as a basis for detector selection, positioning, performance assessment and ongoing review.

The structure of the guidance document and proposed approach is outlined in Figure 3.

The first step of the fire and gas detection design process should be to review all applicable legal requirements, approved codes of practice, standards and industry practice/guidance applicable to the area of operation. NFPA 72 (NFPA 72, 2019) for example, provides comprehensive positioning guidance for heat and smoke detectors indoors and at air intakes.

Whilst prescriptive standards have success when applied indoors where hazard behaviour is relatively predictable, process and storage facilities present a more complex challenge due to the greater number of influencing factors. For such cases a predictive / hazard analysis approach must be applied to understand the behaviour of a release.

Hazard and risk analysis requires an understanding of:

- Fluids being handled, including pressure, temperature, flammability, toxicity.
- The likelihood of a release.
- The potential consequences following a release.
- Size and duration of these consequences.
- The potential impact on personnel, assets, environment and business of the consequences.

The level to which such analysis is completed may vary:

- A qualitative review of each area, identifying what is being handled and its likely behaviour (e.g. dense gas, buoyant gas, jet fire, pool fire, etc.). This may take the form of a hazard identification (HAZID) exercise.
- A coarse hazard assessment identifying what size of hazard could credibly lead to escalation.
- A detailed quantitative risk assessment (QRA) or fire and explosion assessment (FEA), identifying potential hazardous scenarios, and quantifying their frequency, consequences and associated risks.

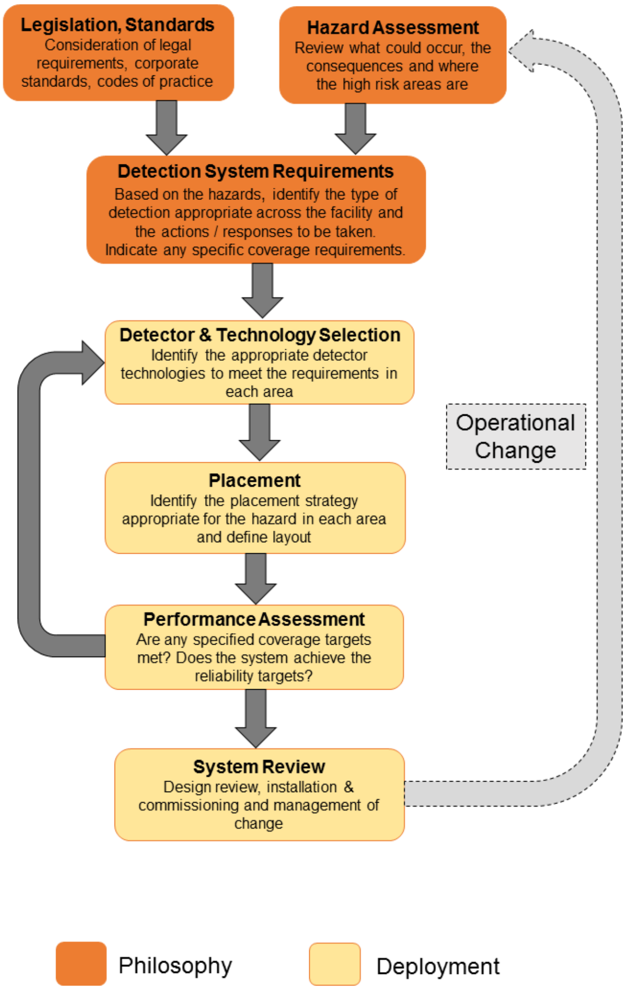

Figure 3: Typical Fire & Gas System Development Process

QRA studies may well be conducted as a matter of course for the facility or project. A QRA or FEA can provide invaluable information regarding the extent of hazards and main contributors to risks. A specific review of these studies for the purposes of fire and gas detection philosophy / design can ensure that the main hazards are mitigated and the system is implemented in a manner that is commensurate with the risks.

Where these studies are not available, application of a simple event tree may assist with understanding the potential hazardous outcomes. Figure 4 shows an example event tree for a gas release illustrating the potential sequences and outcomes that may occur in the event of a release.

The hazards, along with their outcomes and risks should inform the detection requirements and layout strategy. For example, in a highly congested volume an approach may be to provide a detector density that triggers action prior to a flammable gas cloud reaching a size, which, if ignited, could result in damaging explosions. Following on from the Health and Safety Executive (HSE) research (HSE, Offshore Technology Report OTO 93 002, 1993), a detector spacing of 5m diameter is often adopted for highly congested volumes. However, a different detector type and layout will be required for an open facility where the main hazard is migration of a gas cloud to a public area.

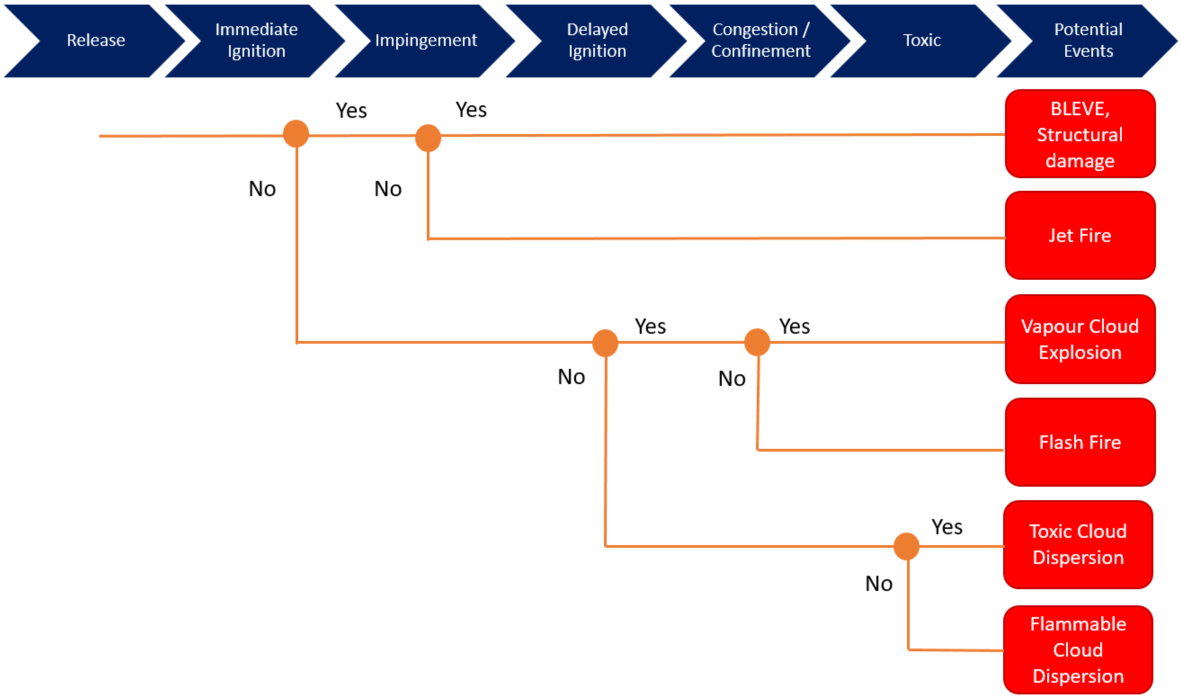

Figure 2: Simple Event Tree for a Gas Release

Detection requirements

Typical detection requirements that may arise from the hazard analysis can include:

- Response time.
- Alarm level / sensitivity setting.
- Scenario or volume coverage requirements.
- Voting logic arrangements.

The speed with which the consequences of a release could escalate can be a factor when determining detector response times. For example, an offshore congested area may require a fast response to trigger emergency shutdown and isolation of ignition sources. Similarly, detectors in a ventilation inlet may require very rapid detection to initiate damper closure and prevent hazardous concentrations reaching occupied areas.

In ensuring the required response time is achieved, it is necessary to select the appropriate detection technology. Factors such as the hazard medium to be detected (e.g. smoke, thermal radiation, gas concentration, etc.) and environmental influences (e.g. temperature, wind, terrain) will need to be considered in the hazard assessment. In addition, potential contaminants (e.g. dust, oil, seawater spray), operational factors (e.g. flaring) and many other factors must also be considered. An annex to the guidance document provides an overview of commonly used detector types including their applicability and associated advantages and disadvantages.

Once the detector technology, response time and set points have been determined, it is necessary look at performance of the system as a whole, including the layout of detectors. Too few or poorly positioned detectors and the hazard may not be effectively detected, while too many has cost and maintenance implications.

Detector placement strategies and positioning

The first step of identifying suitable detector locations is to identify a placement strategy that effectively manages the hazards and risks. Gas detector placement strategies include:

- Gas volumetric monitoring - this approach uses a three-dimensional array of detectors (point, beam, or a combination thereof) to ensure that a 'design basis' gas cloud cannot exist in the monitored space without contacting a sensor.
- Gas source monitoring - source monitoring involves positioning detectors around release points with the intent of detecting the gas as quickly as possible as it migrates away from the source. It can be used for positioning of toxic or flammable gas detectors in low congestion environments.
- Path of travel monitoring - the objective of path of travel detection is to place detectors where personnel are expected to travel or congregate on a regular basis. Example of such areas include points of entry to a process area, confined or partially enclosed areas, below grade locations at risk of gas slumping and accumulating in the area, stairways, ladders or routes of access to the site.

- Perimeter monitoring - perimeter gas detection is best achieved by placing open path detectors around the boundary of an area where there is potential for gas migration and subsequent escalation or human impact.

As previously mentioned, smoke and heat detectors indoors achieve success by being installed in accordance with standards. For outside areas however, transport of smoke and heat products from a fire is much less predictable and detection of the characteristic flame radiation (using flame detectors) can be a much more reliable and rapid solution. Flame detector positioning is dependent on several factors, including:

- Dimensions of the fire that is to be detected.
- Sensitivity of the detector to the type of fire.
- Sensitivity of vulnerable equipment to the fire.
- Field of view of the detector and potential obscuration of the fire by equipment.
- Presence of extraneous sources of radiant emissions (including flares).
- Consequences of failure to respond to a fire in that location.

Assessments of flame detector visibility and positioning are well suited to computational modelling, particularly given the wide availability of detailed 3D CAD models of facilities and can significantly assist with detector placement in congested environments (see also coverage assessment below).

Once the placement strategy is selected, the final position must be identified. Final position influences may include:

- Clashes with routine operations, such as lifting operations.
- Liquid spills.
- Access for periodic maintenance, testing and calibration.
- Appropriate mounting position to ensure sufficient rigidity such that vibration does not affect performance.
- Environmental conditions that may affect detector performance (rain, snow, sand, oil mist, water spray, etc.).
- Multiple detector array voting requirements.
- Application of inhibits to voted systems and consequences to emergency response adequacy.
- Area blockage.

Fire and gas mapping provides one method of assessing detector coverage thereby assisting with final positioning and optimisation of detectors.

Detector performance assessment

If the area being monitored is sufficiently high risk, then it may be necessary to verify fire and gas detection performance for reliability, availability and maintainability, and also for detector coverage.

Detector coverage assessment (more commonly known as fire and gas mapping) is undertaken to quantify the coverage provided by the fire and gas detector layout, thereby enabling verification of performance against pre-defined targets. Two definitions of detector coverage are generally adopted, as follows:

- Geographic coverage – this is the fraction of a volume covered by detectors that is calculated by consideration of geometrical features (i.e. equipment blockage) and design basis hazard sizes (e.g. fire dimension, spherical cloud). The method involves moving the design basis hazard throughout the volume and identifying where detectors will be triggered by the hazard. Flame detection mapping considers equipment blockage that may obscure flame visibility in the field of view by performing a ray tracing calculation, thereby enabling optimisation of both orientation and location.
- Scenario coverage - this coverage can be defined as the fraction of all the assessed hazardous scenarios that a detector array can detect. Uncertainty in the calculation is reduced by analysing more release cases, and for an accurate result a very large number and wide-ranging set of release scenarios must be considered. This method is very much specific to gas release scenarios, where the predicted size and location of the gas cloud is determined based on its release location, release direction, process conditions, wind direction and any other parameters which may influence the dispersion.

The chosen technique must be able to appropriately verify the adopted detection strategy. Geographic coverage assessment is particularly suited to assessing detector layouts incorporated based on a volumetric detection strategy, for example in a congested volume where one wishes to prevent an accumulation of an explosive volume. Scenario based mapping is more appropriate to gas source / path of travel monitoring where detector placement is optimised based on dispersion characteristics and location probability across a larger, less congested volume.

With the rise of 3D modelling in recent years (and computational power), fire and gas mapping is becoming a prevalent method for coverage verification. When appropriately applied, the benefits of performing such studies are significant, with detector quantity, position and angle optimised throughout the facility. These studies serve to ensure that coverage performance is achieved with minimum detectors, thereby ensuring safety objectives of the fire and gas system are achieved in the most cost-effective manner.

System Review

Regular review and assurance of the fire and gas detection system, both during design and operation, is essential if it is to be successfully implemented and operated. This becomes even more crucial if the system is considered safety critical.

The fire and gas detection philosophy should stipulate the documentation requirements for each stage of the design. A staged approach will minimise design risks, particularly for complex facilities where corrective actions may be costly.

Examples of design documentation pertinent to the fire and gas detection system include:

- Fire and gas detection philosophy.
- Fire and gas detection performance standards.
- Detector layout drawings.
- Cause and Effects Matrices.
- Design calculation and analysis reports.
- Design deviations.
- Application of inhibits.
- Maintenance, calibration and trip test.

When the fire and gas detection system enters its operational life, its performance should be continually demonstrated. Specific maintenance routines should be developed and validated in accordance with manufacturer, company or more specific recommendations. These should then form part of the maintenance management system for the facility. The frequency and nature of such testing will be dictated by the required reliability of the system.

If a modification to the fire and gas detection system is required, the performance of the fire and gas detection system should be reviewed as part of an established change control process.

Conclusions

In 2020, the Energy Institute (EI) is to publish guidance for the development of fire, combustible gas and toxic gas detection system philosophies (Energy Institute, 2020). This paper has presented a summary of the methods proposed in the guidance document, along with the key findings identified during its development.

The guidance provides a common approach for fire and gas detector implementation for a range of facilities to ensure a comprehensive and suitable detection system is installed. It is argued in the guidance that prescriptive standards are unsuitable for most process facilities due to the range of release behaviours, and to address facility-specific hazards a fire and gas philosophy should be developed. The fire and gas philosophy document should be developed during the initial stages of a project, and, using hazard and / or risk analysis (e.g. via the QRA or FEA), the performance requirements of the detection system should be defined. If hazard and risk analysis is not available as input to the philosophy, then it should include, as a minimum, a qualitative assessment. The forthcoming guidance proposes a number of methods to effectively assess the risks where more detailed analysis is not available.

Once the hazards and risks are known, the fire and gas detection solution should cover the following topics:

1. Detection requirements to mitigate the hazards.
2. Appropriate technology to detect the hazard.
3. Placement (including layout strategy).
4. Rigour of verification methods to assess performance.
5. System review and management.

The process the guidance document promotes can be summarised as follows. First assess or review the hazards and risks in order to identify the necessary performance requirements of the detection system (e.g. response time). Then select an appropriate technology that can both detect the hazard medium and fulfil the performance requirements. In tandem with detector selection, a layout strategy should be identified to manage the main risks, including potential escalation scenarios (e.g. vapour cloud explosion). Once the preliminary detector layout has been determined that both satisfies the strategy and any other constraints, the performance of the system can be verified using established reliability, availability and maintainability methods, as well as fire and gas mapping techniques to assess coverage. Finally, throughout the subsequent commissioning and operational phases, system reviews and re-assessment of performance should be undertaken on a routine basis and / or when there is a change to the design or operational parameters of the facility.

References

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