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A review of leak detection for fuel storage sites

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EXECUTIVE SUMMARY

Objectives

To review detectors (principally gas but also liquid hydrocarbon) for potential use at fuel storage sites such as Buncefield.

Main Findings

General

Various types of hydrocarbon spill and leak detection techniques for potential use at fuel storage sites such as Buncefield have been reviewed. These are mitigative devices compared with preventative devices such as liquid level detectors.

Gas detectors are widely used to monitor leaks of flammable vapour, particularly offshore where evacuation of the site is obviously much more difficult than onshore. They are employed onshore on petroleum refineries but tend not to be used at UK fuel storage sites. Indeed, currently, there are no gas detectors used for petrol vapour applications on UK fuel storage sites.

Gas and liquid detectors are not covered in the API 334 (1996) guide on leak detection for aboveground storage tanks.

Functional safety

With respect to functional safety systems, the use of performance-based design methodologies associated with *mitigative* Safety Instrumented Functions eg provided by gas detection, is not currently normal practice within the process industries. However, mitigative Safety Instrumented Functions could be within the scope of standards such as BS EN 61511.

There are various standards specifically relating to flammable gas detection including performance requirements, guide for use and functional safety. The current functional safety standards are, however, concerned with the instruments themselves (hardware) and do not consider their coverage. The current UK standard (BS EN 60079-29-2) relating to the location of flammable detectors is very general.

At present, there are no UK/EN performance standards relating to liquid hydrocarbon detectors.

There are useful principles in ISA TR84.00.07 which could be adopted (possibly by IEC) so that the degree of risk reduction from the use of leak detection techniques can be quantified. The major points to consider are as follows:

- Risk-based concepts, as in ISA 84.00.07 and BS EN 61511, including designing to a targeted performance level with an associated integrity and an acceptably low probability of failure on demand.
- Undertake a comprehensive screening analysis to determine if Fire & Gas Systems (FGS) are desirable for the process under consideration.
- The assessment of detector coverage is an important concept in determining how effective that proposed array of detectors with a given voting arrangement would be in detecting an incipient hazard at a level that will initiate a specified safety action.
- Detector placement and coverage issues require study with the same quantitative rigour as average Probability of Failure on Demand (PFD).

- Use of an event tree model similar to that used in Quantitative Risk Assessment (QRA) which quantifies detector coverage, FGS safety availability and mitigation effectiveness to calculate the mitigated risk.

Gas detectors

Infrared point and open-path detectors tend to have lower PFDs than catalytic detectors and are therefore preferred for fixed monitoring applications for spills.

For open areas, open-path gas detectors are typically preferred to point detectors because of their greater coverage. However, point detectors can play a role if the point detector is very close to the potential leak (based on a quantitative risk assessment) and where the point detector coverage is expected to be very high, eg through use of traps, enclosures.

Gas imaging systems, while still under development, hold promise for portable, sensitive leak detection and repair systems and possibly as fixed site monitors.

Ultrasonic detection could be considered for leaks from high pressure gas systems, but not liquids or mixed phase leaks, should these occur at a fuel storage site. Again, as for concentration-based detectors, care is needed in placement, even though gas does not need to disperse to the detector.

Gas dispersion and detector coverage

The range of conditions of interest, both when a hazard could occur and what should be detected, need to be specified.

There is a lack of information on the flow and concentration of vapour in the near field. This would affect the ability to specify detector coverage in the near field and a source term for the far field.

If models are used their capabilities would need to be demonstrated and the conditions used would need to be justified. Until more measurements have been performed and models have been developed any solutions are likely to be heuristic.

Optimal location of detectors is likely to be in the bund and use of traps, enclosures will improve coverage. Alarm levels should be set sufficiently high such that only a significant spill will generate sufficient vapour concentration to alarm.

Liquid hydrocarbon detectors

Liquid hydrocarbon detectors, while not as widespread in petroleum applications as gas detectors, offer significant advantages as a mitigative spill/leak detection technique. Liquid flow is easier to predict and therefore the coverage of the detector is likely to be higher than for a gas detector. Moreover, the use of a cable monitoring system also improves coverage when a large area is required to be covered. Again, the use of traps, enclosures will improve coverage, as for gas detectors

A disadvantage is the requirement for some types to reset the detectors when they have been exposed to fuel (depending on its volatility) after removing them from the spillage.

More information is required on their reliability.

Recommendations

1. Developments in the ISA report TR84.00.07, which is being written by the ISA Standard Panel 84 (SP84), should be monitored to determine whether it can be adapted for UK/European use, eg through the IEC 60079-29 committee on gas detectors.

2. Review the application/relevance of a published ISA TR84.00.07 Technical Report for fuel storage sites with dutyholders, particularly regarding whether the quantitative methodology of risk mitigation assessment in the document can be applied whenever gas/liquid spill detection systems, but not leak detection and repair (LDAR) systems, are being put forward by dutyholders.

3. Liquid hydrocarbon detection may be preferable to gas detection as it is more likely to have greater detector coverage because predicting liquid flow is less uncertain than gas dispersion, although liquid detection is not a true measure of the hazard (ie LEL-related). Further investigation into their use at fuel storage sites is required.

4. If gas detection is used for petroleum vapour then infrared detection is preferable.

5. More data on gas/liquid dispersion at fuel storage sites is required.

6. Detector coverage estimation techniques require further investigation and validation as they are just as important, if not more, than hardware reliability for assessing the risk mitigation effectiveness of Fire & Gas Systems.

1 INTRODUCTION

In the UK, there are approximately 50-60 petrol storage depots similar to Buncefield operated in Great Britain, based on HSE's view of the factors that led to the overfill of the tank with petrol supplied through a pipeline, and subsequent generation of the vapour cloud (HSE, 2007a). These depots are characterised by the Buncefield Standards Task Group (BSTG, 2007) as limited to tanks containing material and operating under similar regimes that existed at Buncefield, namely:

- COMAH top- and lower-tier sites, storing:
- gasoline (petrol) as defined in Directive 94/63/EC [European Parliament and Council Directive 94/63/EC of 20 December 1994 on the control of volatile organic compound (VOC) emissions resulting from the storage of petrol and its distribution from terminals to service stations], in:
- vertical, cylindrical, non-refrigerated, above-ground storage tanks typically designed to standards BS 2654, BS EN 14015:2004, API 620, API 650 (or equivalent codes at the time of construction); with
- side walls greater than 5 metres in height; and at
- filling rates greater than 100 m^3/hour (this is approximately 75 tonnes/hour of gasoline).

The sites are operated by a variety of dutyholders and comprise both terminals (approx 50) and refineries (approx 5) (HSE, 2007b). These terminals can either be attended or unattended.

Following the Buncefield incident in 2005, the Buncefield Major Incident Investigation Board (MIIB) reported on ‘Recommendations on the design and operation of fuel storage sites’ (Buncefield MIIB, 2007). Amongst the recommendations were those relating to *prevention* and *mitigation* of flammable and explosion hazards. Prevention is defined as an action that reduces the frequency of occurrence of a hazardous event, while mitigation is defined as an action that reduces the consequence(s) of a hazardous event (BS EN 61511-1). An example of a *prevention* layer is an overfill prevention system and Recommendation 3 (part of the section on Protecting against loss of primary containment using high integrity systems) of the MIIB Report states that:

“Operators of Buncefield-type sites should protect against loss of containment of petrol and other highly flammable liquids by fitting a high integrity, automatic operating overfill prevention system (or a number of such systems, as appropriate) that is physically and electrically separate and independent from the tank gauging system. Such systems should meet the requirements of Part 1 of BS EN 61511 for the required safety integrity level, as determined by the agreed methodology (see Recommendation 1).”

Examples of *mitigation* layers are fire and gas systems (FGS) and liquid hydrocarbon detection systems which may then actuate, for example, a shutdown system. Recommendation 13 of Clause 28 (‘Engineering against loss of primary containment’) of the MIIB Report states that:

“Operators of Buncefield-type sites should employ measures to detect hazardous conditions arising from the loss of primary containment, including the presence of high levels of flammable vapours in secondary containment. Operators should without delay undertake an evaluation to identify suitable and appropriate measures. This evaluation should include, but not be limited to, consideration of the following:

- Installing flammable gas detection in bunds containing vessels or tanks into which large quantities of highly flammable liquids or vapour may be released;
- The relationship between the gas detection system and the overfill prevention system. Detecting high levels of vapour in secondary containment is an early indication of loss of containment and so should initiate action, for example through the overfill prevention system, to limit the extent of any further loss…"

Gas detectors are widely used to monitor leaks of flammable vapour, particularly offshore where evacuation of the site is obviously much more difficult than onshore. They are employed onshore on petroleum refineries but tend not to be used at UK fuel storage sites. Indeed, currently, there are no gas detectors used for petrol vapour applications on UK fuel storage sites although, apparently, one major company has specified gas detectors for a major installation. Gas detectors are used however on some European fuel storage sites, eg France.

The main reasons put forward for the absence of gas detection at fuel storage sites are:

1. gas detection is a hazard mitigation system rather than a prevention system;
2. doubts about their effectiveness – will they detect gas and give adequate warning without false alarms? Effectiveness depends critically on the detector location, reliability of detector hardware and software, and human factors (eg regular maintenance and calibration, manual actions upon alarm activation); and
3. will any mitigation initiated by a detection system be effective?
4. their cost-effectiveness - the cost of installing gas detection is estimated to be around £30k per tank, dependent on existing infrastructure – is this a worthwhile investment for the required level of risk reduction?

An alternative leak detection system is based on monitoring liquid hydrocarbon; these are mitigative techniques like gas detection, and are relatively new technology compared to gas detection systems.

The effectiveness of mitigation systems, eg shut-off valves, which may be actuated by gas/liquid hydrocarbon detection, are not considered here.

The overall objective of this project is to review the use of gas detectors for petrol vapour (and to briefly consider liquid hydrocarbon detectors) at UK fuel storage sites such as Buncefield.

The methodology adopted for this review was:

- Literature review using various search terms
- Internet searching
- Face to face meetings with
  - HSE staff
  - HSL staff
  - Dutyholders
  - Gas detector manufacturers
- LASTFIRE[1] meeting attendance

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[1] *LASTFIRE is a consortium of international oil companies reviewing the risks associated with fires in storage tanks and developing the best industry practice to mitigate the risks. http://www.resprotint.co.uk/lastfire.htm*

2 LEAK DETECTION AT FUEL STORAGE SITES

There are various sources of fuel leakage at fuel storage sites which can be classified as major hazard, ie major spills, and leaks which are minor, whose detection is classified by the industry as LDAR – leak detection and repair.

Overfill of the primary containment, at atmospheric pressure, as occurred at Buncefield, is a major hazard although its frequency is extremely low. Leaks occur at greater frequencies and arise from:

- Holes, eg from corrosion, in tanks and pipes, usually at low pressure
- Faulty valves and flanges, which may be under high pressure
- Fugitive emissions from the tank at atmospheric pressure

The API guide to leak detection for aboveground storage tanks (API, 1996) considers the following classes:

- Volumetric/mass: measurement of changes in the amount of liquid in terms of level or mass (ie prevention);
- Acoustic: measurement of acoustic energy generated by fluid as it passes through an orifice;
- Soil-vapour monitoring: use of a chemical marker compound in the tank that can contact the bottom and migrate through the backfill; and
- Inventory control: detailed records of additions and withdrawals and compare with the liquid level or mass.

There are, however, alternative methods subsequently put forward for spill/leak detection at fuel storage sites are based on two other principles, which form the basis of this review:

- Gas (vapour) detection; and
- Liquid hydrocarbon detection

Gas detection systems, discussed further in Section 6, can be deployed to detect the vapour from spillage of liquid arising from overfill, holes, valves and flanges when operated at the appropriate sensitivity in the optimal location. This could be in the bund, beyond the bund and specifically in areas on the site where there are ignition sources. The bund area is designed to retain liquid from spillage and therefore the probability that the detector will ‘see’ the gas from a spill is highest there.

Locating the gas detector(s) in the right place is not an easy task and, currently, there is no guidance specifically relating to gas/liquid detection at fuel storage sites. However, the Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AIChE) together with the American Industrial Hygiene Association (AIHA) is to publish a book on "Continuous Monitoring for Hazardous Material Releases" (AIChE, 2009) due for release in March 2009. An advance copy has been kindly made available in advance of publication. This book contains more specific guidance, mainly relating to flammable and toxic gas detection from accidental releases from chemical facilities, including fuel storage sites.

For high pressure leaks (typically > 10 bar) then ultrasound detectors could be employed. These detect the ultrasonic emission from a high pressure gas/vapour leak but do not quantify the concentration of gas (eg %LEL) or the release rate. Currently, they are unsuitable for liquid leak detection. These are also discussed in Section 6.

Liquid hydrocarbon detection systems are also used for leak detection at fuel storage sites. They can be deployed to detect leaks of liquid fuel from overfill, holes, valves and flanges when operated at the appropriate sensitivity in the optimal location. Usually, this will be in the bund for tank overfill and tank hole and flange/valve leakage. They are discussed further in Section 7.

Gas detection systems (including ultrasonic detectors) and liquid hydrocarbon and must be designed, located and operated so that they do not alarm under normal operating conditions when, for example, minor spillages occur or the result of normal transfer operations.

Currently, there are no gas detection systems installed at UK fuel storage sites. Risk prevention techniques (eg tank level monitoring) rather than mitigation techniques, are receiving more attention than spill/leak detection by some dutyholders. Nevertheless, one approach being considered, based on a risk analysis of each site, involves lower cost point flammable gas detectors and liquid hydrocarbon detectors (conductance principle) in the bund. The detectors sample the denser than air vapour and liquid from below a container surrounding identified potential leak sources. This reduces the uncertainty associated with dispersion of the gas/liquid and improves coverage. The setup is principally designed to detect small leaks from valves/flanges but would also respond to a large-scale spillage which spread into the bund. The detectors also have three alarm levels where the first level is a low level alarm followed by two high alarms.

Some dutyholders have installed liquid hydrocarbon detectors (conductivity principle) at their storage tank sites.

3 STANDARDS AND GUIDES

3.1 GENERAL

National and international standards are primary sources of good design and practice relating to the performance, selection, installation, use, maintenance and functional safety of instrumentation including gas detection. Functional safety standards BS EN 61508[1], for the equipment supplier, and particularly BS EN 61511[2] for the user, (and ISA 84.00.01-2004[3]) are well-known and increasingly applied to safety instrumented systems. However, major issues arise in the application of these standards to Fire & Gas Systems (FGS), including those potentially used at fuel storage sites, and include:

- the use of performance-based design methodologies associated with *mitigative* Safety Instrumented Functions eg provided by gas detection, is not currently normal practice within the process industries. However, mitigative Safety Instrumented Functions could be within the scope of standards such as BS EN 61511 (and ISA 84.00.01-2004) as is discussed further in Section 4.
- the precise definition of the safety function. If the safety function is 'detect release of gas' then all the difficulties associated with detection coverage have to be included and these are likely to dominate over the hardware and software integrity of the FGS, so diluting the value of the SIL concept with regard to the system hardware and software integrity. This is discussed in Section 4.
- the FGS may only be one of the inputs into the mitigation system, ie the emergency shutdown (ESD) system. It is usually the ESD system that implements the logic and 'final actuation' e.g. shut down or partial shut down. This is not discussed further in this report.

Additionally, there is US guidance on leak detection for aboveground storage tanks produced by the American Petroleum Institute (API, 1996), see Section 2.

There are various standards relating to gas detection including performance requirements, guide for use and functional safety. Current, previous and draft replacement standards for functional safety and all aspects of gas detection are listed in Table 3.1. These standards and the functional safety standards previously mentioned are discussed further below. The current functional safety standards are, however, concerned with the instruments themselves (hardware) and do not consider their coverage. This is discussed in Section 4.

At present, there are no UK/EN performance standards relating to liquid hydrocarbon detectors.

Additionally, industry guidance from industry associations or specific companies, eg Design Engineering Practice, tends to refer to the above standards as overarching documents but incorporates experience of technologies, procedures etc, specific to the industry.

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[1] *BS EN 61508 series: Functional safety – safety instrumented systems for the process sector*

[2] *BS EN 61511 series: Functional safety of electrical/electronic/programmable electronic safety related systems*

[3] *ANSI/ISA 84.00.01-2004 (IEC 61511 Mod), Functional Safety: Safety Instrumented Systems for the Process Industry Sector, Parts 1, 2 & 3)., Instrumentation, Systems, and Automation Society, Research Triangle Park, NC, 2004.*

Table 3.1. UK (BS/EN) standards relating to flammable gas detectors

Subject	Current standard name	Current standard number	Previous standard	Comments
Flammable gas detector performance (product) specification	Explosive atmospheres atmospheres – Part 29-1: Gas detectors – Performance requirements	BS EN 60079-29-1:2007	BS EN 61779-1:2000 BS EN 61779-2:2000 BS EN 61779-3:2000 BS EN 61779-4:2000 BS EN 61779-5:2000 Withdrawal date: Apr 2010	BS EN 60079-29-1 is an IEC derived standard based on BS EN 61779 but with more emphasis on tests relevant to IR detectors. The various parts of BS EN 61779 (mines, non-mines, 0-100%LEL, 0-100%v/v) are combined into one document.
Flammable gas detector guide for use etc	Explosive atmospheres – Part 29-2: Gas detectors – Selection, installation, use and maintenance of detectors for flammable gases and oxygen	BS EN 60079-29-2	BS EN 50073:1999 Withdrawal date: Apr 2010	Based on BS EN 50073 to some extent, more information but more repetitive.
Functional safety of fixed gas detection systems	Electrical apparatus for the detection and measurement of combustible or toxic gases or vapours or of oxygen – Requirements on the functional safety of fixed gas detection systems	BS EN 50402:2005 (BS EN 60079-29-3 as draft)		BS EN 60079-29-3 under development by IEC, using BS EN 50402 as basis. HSE input to IEC committee.
EMC gas detectors performance specification	Electromagnetic compatability – Electrical apparatus for the detection and measurement of combustible gases, toxic gases or oxygen	BS EN 50270:1999		Gas detector specific version of generic EMC standard.
Software and digital gas detectors performance specification	Electrical apparatus for the detection and measurement of combustible gases, toxic gases or oxygen – Requirements and tests for apparatus using software and/or digital technologies.	BS EN 50271:2002		Uncertain status in relation to 'more robust' BS EN 50402. However, detectors have been certified to this standard.
Open-path flammable gas detectors: general requirements	Specification for open path apparatus for the detection of combustible or toxic gases and vapours: Part 1 - General requirements and test methods	BS EN 50241-1:1999		Not used by industry. Parts 1 and 2 revised by IEC as 60079-29-4.
Open-path flammable gas detectors: combustible	Specification for open path apparatus for the detection of	BS EN 50241-2:1999		Not used by industry. Parts 1 and 2 revised by IEC as 60079-29-4.

Subject	Current standard name	Current standard number	Previous standard	Comments
gas performance	combustible or toxic gases and vapours: Part 2 – Performance requirements for apparatus for the detection of combustible gases			
Open-path flammable gas detectors: guide for use		(BS EN 60079-29-2 as draft modification)		To be developed by IEC as part of 60079-29-2 to accompany performance specification 60079-29-4.

3.2 BS EN 50402 FUNCTIONAL SAFETY GAS DETECTORS

BS EN 50402 is a product standard based on BS EN 61508 and includes additional requirements of EN ISO 13849-1 (Safety of machinery – Safety related parts of control systems Part 1: General principles of design). It covers part of the phase 9 "realisation" of the overall safety life cycle defined in BS EN 61508. It does not specify requirements for the installation and maintenance of gas detection systems. It also does not specify the physical positioning of sensors. It focuses on the effectiveness of the fire & gas system hardware alone and uses the term Safety Integrity Level (SIL) as in IEC 61508 and 61511.

3.3 IEC 60079-29-3 FUNCTIONAL SAFETY GAS DETECTORS (DRAFT)

At present, this standard is in the early drafting stages. The current draft (dated 16/07/2007) is essentially based on EN 50402 and has the same Scope as in Section 3.2 above. The proposal was approved by IEC (USA was the only negative vote) on 09/05/2008 and has been introduced in the IEC programme of work under the following title: IEC 60079-29-3 Ed. 1.0: Explosive atmospheres – Part 29-3: Gas detectors – Requirements on the functional safety of fixed gas detection systems.

The US objection was "Overall we do not see any justification as to why this document should be adopted as an IEC standard as it does not add anything over what is already defined within IEC 61508/61511. Current development work within ISA SP84 supports the use of the principles in IEC 61508 (adopted in the US as ISA 84.00.01)". The points raised are discussed in Section 4.

It was expressed that the document as presented requires major change. The Australia/New Zealand committee was charged with developing ideas and concepts based upon IEC 60079-29-3 (Draft 1) and ISA SP84 to produce a revised document including considerations of, for example, probability of failure on demand (PFD), safe failure fraction (SFF), and possible exclusions such as coverage (location and voting) systematic (common mode) failures such as poisoning in catalytic detectors (see Section 6), Installation and Maintenance.

3.4 BS EN 60079-29-2 GUIDE FOR USE

The guidance relating to the location of detectors is very general. The key points identified in Clause 8 of the standard relating to location of detectors are:

1. the principal objective is that sensors and sampling points should be placed such that gas accumulations are detected before they create a significant hazard.
2. sensors and sampling points should be located in positions determined in consultation with those who have a knowledge of gas dispersion, those who have a knowledge of the process plant system and equipment involved, and safety and engineering personnel. This determination should consider:
    a. The combination of sources of release with propagation effects (clause 7);
    b. Whether the sources of release can be inside our outside confining structures, buildings etc.;
    c. What can happen at access points such as doorways, windows, tunnels, trenches etc.;
    d. Local environmental conditions;
    e. Occupational Health and Safety;
    f. Access for maintenance including calibration and verification, and protection of the system against operational hazards of the plant.

3. The decisions reached on the locations of sensors and sampling points should be recorded in a safety dossier for the plant.
4. Where it is necessary only to detect the escape of gas from within a given area, then sensors or sample points may be placed at intervals around the perimeter of the site. However, such an arrangement may not provide an early warning of a release. This arrangement should not be used alone if a release could cause a significant hazard to personnel or property within the perimeter itself.
5. Sensors or sample points should be located close to any potential sources of major release of gas, although to avoid nuisance alarms, detection points should generally not be located immediately adjacent to equipment which may produce inconsequential minor leakage in normal operation. In general, on open sites minor leaks may be dispersed without causing a hazardous accumulation.
6. Sensors should also be located in all areas where hazardous accumulations of gas may occur. Such areas may not necessarily be close to potential sources of release but might, for instance, be areas with restricted air movement. Heavier than air gases are particularly likely to flow like a liquid and to accumulate in cellars, pits and trenches if these are present.
7. Similarly, lighter than air gases may accumulate in overhead cavities.
8. If there is significant ambient air movement, or if the gas is released into enclosed spaces, then the behaviour of gas is modified. The behaviour of gases following a release is complex and depends on many parameters. However, knowledge of the influence of these parameters is not sufficient, in practice, to predict the extent and/or build-up speed of a flammable atmosphere. The prediction may be improved by:
    a. the application of generally accepted empirical rules developed by experts, based on their past experience;
    b. on-site experimentation to simulate and describe precisely the behaviour of the gases. This includes the use of smoke tube tests, anemometer readings or more detailed techniques such as tracer gas analysis;
    c. numerical simulation of gas dispersion.
9. In general, sensors should be sited above the level of ventilation openings and close to the ceiling for the detection of gases lighter than air, and below the ventilation openings and close to the floor for the detection of gases heavier than air.
10. Where it is required to detect the possible ingress of gas or vapour into a building or enclosure from an external source, sensors should be sited adjacent to the ventilation openings. These sensors should be in addition to any required for the detection of releases within the building or enclosure.

Further aspects of Point 8 above are explored in Section 5.

3.5 NORWEGIAN OIL INDUSTRY ASSOCIATION GUIDE TO EN 61508 & 61511

This document, published by the Norwegian Oil Industry Association in 2004 and funded by OLF, is a guideline to adapt and simplify the application of IEC 61508 and IEC 61511 in the Norwegian petroleum industry (OLF, 2004). IEC 61508 describes a fully risk based approach for determining SIL (Safety Integrity Level) requirements, while the OLF guidance provides minimum SIL requirements for the most common instrumented safety functions on a petroleum production installation. Although it is primarily intended for offshore applications there are various aspects of the guide which could be of use for onshore systems.

The guide also refers to the Norwegian produced PDS Method Handbook, generally referred to as the ‘PDS, document (SINTEF, 2003a) and compares it with IEC 61508. Key aspects of the OLF ‘standard’ relating to gas detection are:

- **Development of SIL requirements**. Section *7.6 Minimum SIL requirements.* Table 7.1 Minimum SIL requirements - local safety functions. The SIL-requirement applies to the sub-function needed for gas detection, given exposure of one detector, i.e. gas detector, F&G node.
- **Systematic failures**. Section 8.5.1 SIL requirements. Avoidance and control of systematic faults. Even if systematic failures are difficult to quantify, the PDS data handbook (“Reliability Data for Control and Safety Systems – 2003 Edition”) provides generic values, and also a method for obtaining plant specific values for gas detectors. Thus, leaving out systematic failures from the analysis would seem as a “step backwards” as compared to what was obtained in the PDS projects. Furthermore, since the PFD figures for the safety functions will be used as input to the QRA, it is important that these figures are as realistic as possible. i.e. in the QRA systematic failures must be added in order to give a realistic figure of the SIS performance (refers to Appendix A and Appendix D in PDS).
- **SIL requirements**. Appendix A Background for minimum SIL requirements**,** Section A9 Gas detection, Quantification of safety function. Data are given in Table A14 Table A.14 PFD and PSF results for gas detection sub-function (i.e. single detector).From the table it is deduced that a SIL 2 requirement is achievable.
- **SIL requirements.** Appendix A Background for minimum SIL requirements**,** Section A9 Gas detection, ‘Basic Assumptions’: the standard states that it should be noted that considerations related to number of and layout of detectors must be covered by separate studies (e.g. simulation studies and QRA).
- **QRA and IEC 61508** Appendix C Handling of deviations – use of QRA. C.4 QRA and IEC 61508. When stating SIL requirements as given in Table 7.1 in this document, and when performing verifications of these requirements according to IEC 61508, there will be a number of “risk elements” that may not be explicitly addressed. These elements therefore need to be addressed in other analyses such as the overall QRA, and some examples may include:
    - The gas detectors are not exposed as assumed and the safety function is therefore not activated (wind direction, detector layout, size of release, etc.)
    - Several of the safety functions described in Table 7.1 and in Appendix A are incomplete, i.e. in order to provide input to the QRA, some additional (installation specific) considerations need to be done. E.g. for the gas detection function (ref. section A.9) the actual detector voting and the likelihood of exposing the detectors need to be reflected…
    - It should be noted that some of the “additional risk elements” listed above will typically fall into the category of systematic failures. This underlines an important point; when performing calculations according to IEC 61508, the standard explicitly states that systematic failures shall not be quantified but shall be controlled and reduced by the use of qualitative checklists. However, when performing QRA, the goal should be to obtain a “correct” estimate of the risk, and in this respect it will be important to also include the PSF (Probability of Systematic Failure) contributions towards failure of the considered safety functions.
- **Voting.** Appendix D.8, some example calculations have been performed for different types of gas detection voting configurations (MooN). The treatment is at variance with that in IEC 61508.

3.6 DUTYHOLDER CODES OF PRACTICE

Dutyholders have their own Engineering Best Practice documents which refer to the above standards but incorporates their own field knowledge of their installations and their experiences, both in the laboratory and field, of detection systems.

4 GAS DETECTION & FUNCTIONAL SAFETY

4.1 INTRODUCTION

The standards BS EN 50402 and IEC draft 60079-29-3 on gas detection and functional safety, described in Section 3, focus on the effectiveness of the gas detection system hardware alone and use the term SIL as in IEC 61508 and 61511. Moreover, IEC 61511 focuses on those safety instrumented systems which are prevention layers. The assumption with prevention layers is that:

- they will always be able to respond to the hazardous condition, and
- if they respond correctly their action will prevent the hazardous event from occurring.

Using a SIL 2 rated detector, a SIL 2 rated logic solver, and a SIL 2 rated final element should result in a SIL 2 rated function that should provide a Risk Reduction Factor (RRF) of >100, (see Table 4.1) assuming all the other requirements in the standard are met. If a properly functioning sensor is unable to respond to the hazardous condition it was designed to detect, and if a properly functioning final element does not eliminate the hazard, then the system was not designed properly.

Table 4.1 SIL levels

SIL	Probability of Failure on Demand	Risk Reduction Factor [1/(PFD)]
3	≥10-4 – <10-3	>1000 – ≤10000
2	≥10-3 – <10-2	>100 – ≤1000
1	≥10-2 – <10-1	>10 – ≤100

However, gas (and fire) systems, which are mitigation layers, are different. Detectors may be working properly but they may never see the gas release, for example, sensors may be placed improperly, there may not be enough sensors, wind may dilute the gas before it can be detected, obstructions may divert the release, a release may be too small to be detected. The system may respond properly, but there is no guarantee that the consequences of the hazardous event will actually be eliminated or mitigated. Consequently, *if the safety function is to 'detect release of gas'*, using a SIL 2 rated sensor, a SIL 2 rated logic solver, and a SIL 2 rated final element may *not* result in a SIL 2 rated function that may *not* provide a Risk Reduction Factor of >100. This is illustrated by Table 4.2 where risk reduction factors are calculated for various values for detection coverage, hardware and mitigation safety availability.

Table 4.2. Gas detection Risk Reduction Factors

Hazard	Detection Coverage Safety availability	Hardware/software Safety availability	Mitigation Effectiveness Safety availability	Risk Reduction Factor*
1	1.00	0.991 (SIL2 min)	1.00	111
1	0.90	0.91 (SIL1 min)	0.90	3.8
1	0.90	0.991 (SIL2 min)	0.90	5.1
1	0.90	0.9991 (SIL3 min)	0.90	5.2
1	0.90	1	0.90	5.3
1	0.90	0.991 (SIL2 min)	1.00	9.3

*RRF = 1/PFD = [1/(1-SA)]; SA is the product of the safety availabilities for coverage, hardware and mitigation.

Typically, detection coverage at sites is less than 90%, for example HSE data for *offshore* installations (Hydrocarbons releases database) indicates a minimum of 60%, (HSE, 2008); the mitigation effectiveness is typically less than 90%, therefore the overall risk reduction will never be greater than 10. The overall system will thus not even reach the SIL 1 rating. The level of performance of the gas detection system hardware is therefore of secondary importance. Further calculations showing RRFs for various combinations can be found in General Monitors Information (Choo, 2008). Nevertheless, despite this, the use of SIL 1 or SIL2 rated hardware gives the user more confidence in the reliability of the detector itself, and these ratings are the accepted norms for FGS. Nevertheless, to be an effective detection system then knowledge of the coverage (and mitigation) availability should be known. Details on SIL ratings for commercially available gas detectors are given in Section 6.

The Instrumentation, Systems, and Automation Society ISA Standard Panel 84 (SP84) has recently determined that it was appropriate to provide supplemental information in the application of hazard and risk analysis to Fire & Gas Systems (FGS), addressing such issues as those above. This panel has published a draft technical report, not a standard, which is discussed below.

4.2 ISA dTR 84.00.07 TECHNICAL REPORT (DRAFT)

4.2.1 Scope

The purpose of ISA-TR84.00.07 “The Application of ANSI/ISA 84.00.01-2004 Parts 1-3 (IEC 61511 Parts 1-3 Modified) for Safety Instrumented Functions (SIFs) in Fire & Gas Systems. Technical Report (draft) Version C, March 2008” (ISA, 2008) is to provide guidance to owners, operators and manufacturers of FGS on how to determine when a function in the FGS is a Safety Instrumented Function (SIF). It demonstrates how the principles of ISA-84.01-2004 (or IEC 61511 Pts 1-3) can be applied to establish the performance requirements for identified FGS safety functions, FGS safety functions that are identified as SIFs should be implemented according to the requirements of ISA-84.01-2004 in addition to relevant application specific practices. ISA-TR84.00.07 illustrates how these prescriptive good engineering practices work in conjunction with ISA 84.01-2004 to define the FGS safety requirements.

4.2.2 Rationale

Risk-based concepts associated with ISA 84.00.01-2004, including the concept of designing to a targeted performance level, with an associated integrity and an acceptably-low probability of failure on demand were adopted. However, it concluded that it is difficult to apply the ISA 84.0.01 lifecycle in practice for reasons including the following:

- Traditional techniques are suited for specific hazards that can be adequately defined using process hazards analysis for the risk assessment process.

- FGS are mitigation not preventative systems which limits the use of ISA 84.00.01-2004 and BS EN 61511 for FGS analysis.

- a significant cause of FGS ineffectiveness is due to inadequate location of FGS detectors to detect the hazard, ie flammable gas.

It was considered that the existing tools, techniques and guidance (e.g., LOPA) were inappropriate or incomplete for FGS. Also the performance criterion of Safety Integrity Level

(SIL) is insufficient to define the FGS safety function; therefore additional performance criteria were introduced: detector coverage and mitigation effectiveness (not considered here).

4.2.3 Performance-based FGS Analysis Procedure

The report states that the safety lifecycle presented in the standard should form the basis for fire and gas detection system design process and that consideration should be given to the functional separation of independent mitigation and prevention layers. Eleven steps are identified that should be taken in the implementation of an FGS; these steps supplement the ISA 84.00.01/BS EN 61511 lifecycle:

1. Screen to determine if FGS function is required
2. Identify risk scenarios
3. Analyse consequences
4. Analyse hazard frequency
5. Unmitigated risk assessment
6. Identify equirements for risk reduction
7. Initial FGS design
8. Assess detector coverage
9. Assess FGS safety availability
10. Mitigated risk assessment
11. Modify FGS design

Further details are provided in the technical report (ISA, 2008).

4.2.4 Detector coverage

Assessing detector coverage (Step 8 of the analysis) determines how effective the proposed array of detectors, with a given voting arrangement, will be in detecting a hazard at a level that will initiate a specified safety action. An assessment of detector coverage involves analysis of the potential sources of gas within a given monitored process area. Two possible methods are identified:

- geographic coverage assessment, and
- detector (scenario) coverage assessment.

Detector geometric coverage is defined as the fraction of the geometric area (at a given elevation of analysis) of a defined monitored process area which, if a release were to occur in a given geographic location, would be detected by the release detection equipment with the defined voting arrangement. Detector scenario coverage is defined as the the fraction of the release scenarios that would occur as a result of the loss of containment in a defined and monitored process area that can be detected by the detectors considering the frequency and magnitude of the release scenarios and the defined voting arrangement. Section 5 in this report discusses various coverage estimation techniques in more detail. Further, more detailed information is given in Appendix B of the TR 84 report (ISA, 2008).

Detector coverage factors can then be applied to the mitigated risk analysis to determine the risk reduction factor from the FGS design.

4.2.5 Unmitigated/mitigated risk assessment model

The risk model adopted is a simple one that addresses the analysis of FGS safety availability and detector coverage. This model is an event tree model similar to that used in QRA which quantifies detector coverage, FGS safety availability and mitigation effectiveness to calculate the unmitigated and mitigated risk. An example is shown in Fig. 4.1.

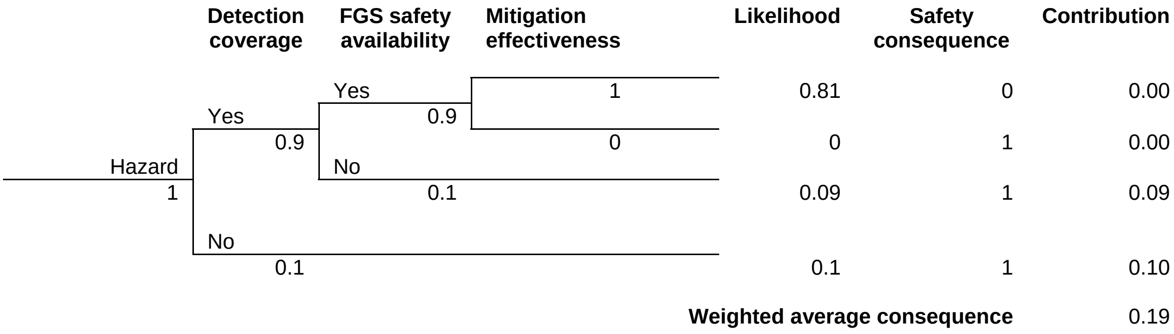

Fig. 4.1 Example risk model for a gas detection system

This design therefore reduces the risk by a factor of 1/0.19, ie approximately 5. Further details on the calculation of risk from the weighted average consequence, frequency of hazard and PFD can be found in the ISA draft Technical Report TR 84 (ISA, 2008).

4.2.6 Discussion

The ISA TR document is generally applicable to the use of FGS in process industries, including fuel storage sites. The worked example relating to risk mitigation by gas detection given in Appendix B of the ISA TR is an offshore application. For this example, in Step 3 - Analyze Consequences it is stated that “a gas dispersion model was selected to analyze the size of the flammable envelope and its possible location with respect to proposed location of gas detection equipment.” However, it may not be possible to employ a gas dispersion model, see Section 5. Models for heavy gas dispersion at atmospheric pressure at fuel storage sites are not as well developed as those for high pressure leaks in offshore/onshore installations (see Section 5). Alternative methods may have to be used ie qualitative estimates, simplified hazard correlation tables. This is discussed further in Section 5.

It would therefore be instructive to include a worked example of risk mitigation by gas detection based on an onshore application.

Also, only 2D coverage of gas detectors is considered – ‘at a given elevation’ for the example in Appendix B of ISA TR. 3D is also needed, as gas can go over or under detectors and therefore analysis of detector location over a volume rather than in a plane is necessary.

Nevertheless, there are useful principles in the ISA TR which could be adopted (possibly by IEC) so that the degree of risk reduction from the use of leak detection techniques can be quantified (or semi-quantified) as it may be difficult to specify exactly the levels of risk reduction from coverage estimations. This appears to be taken up by the IEC committee for 60079-29-3 (see Section 3).

The following section discusses various tools and techniques currently available for estimating coverage, ie the effectiveness of the gas (liquid hydrocarbon) detector in seeing gas.

5 TECHNIQUES FOR ESTIMATION OF GAS DETECTOR COVERAGE

5.1 INTRODUCTION

Fugitive vapour emissions from fuel storage tanks occur in normal operation, ie during filling of tanks and due to evaporation while in storage. Dispersion of fugitive emissions from storage tanks have been studied as they are a major source of toxic releases to the atmosphere (Hort and Robins, 2000), but the concentrations involved are small.

Accidental releases from storage tanks, for example, tank overfilling, can also generate vapour. Tank overfilling at Buncefield produced a high volume, low momentum liquid release forming a flammable vapour cloud. This type of release does not appear to have been studied before the investigation of the Buncefield incident (Atkinson et al., 2008). Experimental and modelling work, performed as part of the Buncefield investigation, has been reported (Atkinson et al., 2008).

Fugitive emissions from fuel storage tanks are a normal occurence and usually do not lead to hazard due to formation of flammable clouds. Overfilling of fuel storage tanks does however lead to the formation of flammable clouds. Techniques to determine the gas detector coverage detection needed for such clouds are discussed below.

5.1.1 Formation of vapour clouds from overfilling of fuel storage tanks

Vapour clouds formed from liquid releases from storage tanks due to overfilling can be considered in two regions. In the near field region, where liquid is present, vapour is produced. The near field is also the vapour source for dispersion in the far field: the vapour produced in the near field disperses as a dense cloud in the far field. Different processes, with different time and length scales, dominate in the near and far field. Due to these differences it is unlikely that both regions could be treated in the same simulation.

The near field is within and close to the bund and the near field flow would need to be resolved in order to examine gas detection coverage using modelling in or close to the bund. The far field is outside the bund with the near field forming the source term for the dispersion occurring in the far field.

Near and far fields may also be distinguished by the fact that the near field continues to the point where a simple source could be used in far field dispersion calculations. Specifying where the transition from near to far field occurs and hence specifying a simple source may, in practice, be difficult. Momentum due to the initial release may have an effect over longer distances than those over which vapour production is significant, making specification of a simple source difficult.

5.1.2 Uncertainty

The Buncefield incident occurred during very stable, very low wind speed atmospheric conditions and the fuel released was a winter fuel, with a high butane content. A large amount of vapour was formed by liquid spilling from the top of a fuel storage tank due to overfilling. This, then, dispersed as a dense gas cloud, forming a large flammable cloud. Other than information from Buncefield and from subsequent investigations there is little data available either for the type of release or for these conditions. There is also a lack of data to examine the range of conditions under which a flammable cloud could form: fuel type, ambient temperature, wind speed and atmospheric conditions. The lack of data also limits the ability to test model predictions for the type of release and conditions.

A consequence of the lack of data and models is that it is difficult, at present, to predict either the range of conditions that would allow the formation of hazardous clouds from overfilling or the type and size of clouds that would be formed.

5.2 MODELLING DETECTOR COVERAGE

Different approaches to deciding detector positions are possible depending on the coverage required and the information and tools available.

5.2.1 Heuristics

As described above, vapour arising from overfilling storage tanks can be considered to be produced in the near field and dispersed in the far field. Heuristics for detector placements in these regions can be developed for individual storage sites based on knowledge of a site's layout and and its operation. Observations from Buncefield can also be used to inform detector placement:

- Near field: Point or open-path detectors in the bund, below the height of the bund (see Section 6).
- Far field: Open-path (IR) detectors on the perimeter of sites. The dispersion of the vapour cloud at Buncefield was influenced by site topography and affected by obstacles, such as hedges. The detection height of the infrared beam would also have to be high enough to avoid interference due to flora and fauna but low enough to sample dense gas clouds.

5.2.2 Mapping

The heuristics, as stated, indicate factors that should be considered when deciding on detector placement but not what exactly should be detected. Examining detector coverage by mapping (see for example, Shell, 2008) does not require data or modelling for individual releases and associated conditions. It does, however, require information of what clouds should be detected and the coverage required. The coverage can be estimated for various numbers and combinations of detectors, ie nooN where n is the number of detectors capable of detecting the leak out of a total of N. For Buncefield type occurrences, ie a dense cloud, it is the size of flammable cloud that should be detected, probably described by cloud widths and heights, and is required to map out the release scenario. The coverage depends both on the frequency of detection required and the clouds that should be considered.

The size of flammable cloud that should be detected can be based on limited consequences if a cloud ignited, or from the size of cloud that could occur due to tank overfilling. The approaches require information about both the release and dispersion behaviour and consequences of flammable cloud ignitition.

5.2.3 Dispersion modelling

The processes occurring in the near and far field are different. Production of vapour in the near field and dispersion in the far field and their modelling treatments would also be different. These processes also have different time and length scales. The near and far field, therefore, need to be treated separately in any model.

Different types of modelling can be used to examine the dispersion of dense gas or vapour. Modelling of vapour dispersion has recently been reviewed in the context of Liquefied Natural Gas (LNG) by Ivings et al (2007). While there are particular issues related to dispersion of LNG, much of the modelling and information in that report is relevant to dense vapour dispersion. The report lists software available and describes a model evaluation protocol. The two main approaches available would be Integral Models and Computational Fluid Dynamics (CFD).

A particular issue at low wind speeds, is the influence that topography and obstacles would have on the dense vapour dispersion and, hence, on detector placement.

5.2.3.1 Integral dispersion models

Integral models attempt to describe flows using simplified descriptions that can be justified based on sound scientific derivation and assumptions.

The near field would not be resolved in a dense gas dispersion model. When more information becomes available it may be possible to develop a simple model of the vapour production from overfilling that could be used to inform detector placement. However, it would be more complex than a model that was only used to specify a source term for far field dispersion calculations.

5.2.3.2 CFD

CFD involves numerical solution of three-dimensional time-dependent fluid flow equations. While CFD simulations can represent the different processes in near and far field they have different time and length scales. Therefore it is likely that in CFD simulations these would be treated separately.

At present the vapour production in the near field could not be modelled with any confidence across the range of possible conditions. CFD should be able to represent the processes that occur in the near field, but the interaction of processes is complex and has not been described. As noted above there is not a large amount of information available and little work has been performed to identify important processes and mechanisms.

More work has been performed modelling dense gas dispersion than for the source term from overfilling. Hence there would be more confidence in the ability of CFD to simulate these flow. Though as with the integral models a source term for the far field dispersion simulations would need to be specified.

6 GAS DETECTOR INSTRUMENTATION

6.1 TYPES OF DETECTOR

Three types of flammable gas detector are commonly used for detection of higher hydrocarbons such as petrol vapour: catalytic, point infrared and open-path infrared. Recently, however, a new type of flammable gas detector has emerged based on infrared gas imaging. Acoustic (ultrasound) detectors are increasingly used both onshore and offshore for detection of high pressure gas leaks but will not detect atmospheric leaks or high pressure liquid leaks (Royle et al, 2006). These detectors are discussed below. Some characteristics for various types of catalytic and infrared detector are given in Appendix 10.1; the list of detectors is not exhaustive.

6.1.1 Catalytic gas detectors (point)

Catalytic detectors are based on measuring the heat generated by the catalytic oxidation of the flammable gas on a heated bead using platinum resistance thermometry with a Wheatsone bridge. An advantage of the catalytic detector is that the low-mid-range hydrocarbons (excluding methane but including the fractions in petrol) have similar LEL responses (methane has a higher LEL response). Variations in the fuel composition, eg seasonal, will therefore be expected to have a small effect on the response and hence the alarm level; this, however will need to be verified.

Any small variation in the resistance of the sensor elements or drift in the measurement electronics may generate a false gas indication. This leads to a requirement for frequent periodic calibration (zero and span – sensitivity) of the gas detectors. These tests can also indicate whether there is a loss in sensitivity, eventually leading to complete failure of the detector because of poisoning of the catalyst by certain compounds eg silicones, hydrogen sulphide, lead compounds, chlorinated hydrocarbons, resulting in an unrevealed failure. This requirement adds significantly to their cost of ownership, although their initial cost per detector is cheaper than infrared detectors.

A further drawback of catalytic detectors is that they become non-linear and under-read in low oxygen atmospheres, which exist with gas rich releases, as the oxidation process requires excess oxygen in the atmosphere. The response peaks with concentration at around 150% LEL and then decreases. Furthermore, catalytic gas detectors have a response time of typically 20 to 30 seconds; if they fail to respond while the release is dispersing, they may well be unable to respond subsequently if the release is large and gas-rich.

HSE OSD guidance (HSE, 2006) also mentions the above deficiencies and the general superiority of infrared instruments (see below).

6.1.2 Point infra-red gas detectors

Infra-red (IR) gas detectors are growing in popularity because they address many of the deficiencies of catalytic detectors, while offering the potential to reduce numbers and life-cycle costs. Infra-red gas detectors are typically preferred to catalytic detectors because they provide rapid response to gas, and they do not under-read in oxygen reduced atmospheres. They are also currently robust with respect to unrevealed failures, eg they do not poison. Also, later models have self-diagnostics, auto-zeroing and auto-spanning.

IR detectors using different types of optics and measurement wavelengths show a varied response to hydrocarbons: greater response (ie greater sensitivity) to higher hydrocarbons or relatively constant LEL responses over the range of hydrocarbons. As with catalytic detectors, the response of the detector to variations in the fuel composition, eg seasonal, will therefore need to be checked.

Point IR gas detectors are generally chosen to safeguard against heavy gas released at low pressure, or for gas migrating from evaporating pools. For such applications, they should be sited to make best use of prevailing wind direction or ventilation movement. If they are employed in open areas, then an appropriate weather baffle is necessary, although this may affect the response time. The majority of detectors are also orientation sensitive, as is their weather protection. Detector spacing is related to risk, however the 5 metre spacing typical employed in uncongested areas on offshore platforms may be relaxed onshore to less than 10 metre.

6.1.3 Open-path gas detectors

Open-path detectors are also known as line of sight or beam detectors. Their increasing use arises from their ability to detect gas more reliably in open spaces, providing greater coverage and their ability to provide boundary monitoring for migrating gas. While manufacturers claim ranges in excess of 100 m, typical ranges onshore are up to 60 m depending on conditions. The maximum working range or optical path length must always reflect local weather conditions, eg heavy rain. In general, keeping the working range fairly short is beneficial in that it minimises any mis-alignment caused by support flexing, and reducing the demands on detector rigidity.

Point IR gas detectors and some open-path detectors make use of the absorption region around 3.4 µm because hydrocarbons absorb strongly in this spectral region. Many open-path detectors however measure absorption at 2.3 µm, where many of the light hydrocarbons have absorption coefficients which are approximately in inverse proportion to their lower explosive limits (LELs) which is a useful feature because they produce similar LEL responses.

Current instruments are mainly double-ended systems comprising a transmitter and receiver. Open-path detectors (and point) use a flash lamp as their radiation source – flash repetition is typically 1 to 4 Hz. The short duration flash allows extensive filtering and signal processing to be carried out and minimises vibration effects.

Great care is required when siting open-path gas detectors. Sites must be unobstructed and supports rigid. Poorly engineered supports and unsuitable sites account for the vast majority of problems associated with open-path detectors and can lead to false indications of gas and unwanted shutdowns. Care needs to be taken to ensure detector/receiver mis-alignment is kept to a minimum, because this has been shown, in exceptional circumstances, to result in false indications of gas. Open-path detectors operating onshore have the potential of more rigid supports and, generally, preferential weather conditions.

All open-path detectors need an unobstructed path when viewed from both sending and receiving ends, and a minimum safe working radius (a cylinder) of 0.5 metres is necessary to ensure no modulation of sending/receiving signals from obstacles along the optical path. A typical mounting height of 2.5 to 3 metre from ground level is typically adopted where practical to minimize beam interruption from humans, animals and vegetation, and for ease of maintenance.

Open-path gas detection versus point gas detection

Open-path and point IR gas detectors have their individual strengths and weakness, neither being suited to all applications. But general guidance can be given to cover open and closed areas, and dispersion resulting from momentum or wind driven evaporation.

Dispersion in open areas resulting from momentum, evaporation or a combination of both, may be subject to mixing from collisions and wind turbulence. For open areas, open-path gas detectors are typically better than point detectors. They maximise the probability of detection, ie high coverage, and produce integrated measurements (ie measurement units of LEL.m) which is a better measure of risk for dispersed clouds. They also offer the benefits of detecting gas anywhere along the line-of-sight, rather than relying on air movement to carry the gas cloud to the detector, as is the case with point gas detectors. Moreover, open-path detectors are the only practical option if boundary detection is required. Point gas detectors can be considered for open areas where heavy gas or liquids are likely to be released under low (less than 2 bar) pressure, however optimising coverage is more difficult than with open-path detectors.

Detecting gas in closed areas is reasonably straightforward because gas dispersing from a leak source is a fairly rapid mechanism and accumulation will result for significant leaks. Gas or liquid fractions that result will be momentum driven for high pressure releases, or reside as evaporating liquid pools and vapour subject to gravity, ie heavier fractions will tend to accumulate at lower levels. For Buncefield type releases, inside the bund may approximate to a closed area and detectors could be located there. Higher pressure releases will entrain significant quantities of air, become neutrally buoyant and migrate under natural ventilation, if present.

6.1.4 Gas imaging

Gas imaging technology is the latest type of area detection and has been developing since the 1990s. They have usually been designed for leak detection (LDAR – leak detection and repair) and are therefore highly sensitivity but operate over quite short ranges, eg 20 m. However, the correlation gas imager from Gasoptic (see below) can operate over much larger distances (eg 200 m) but is not as sensitive; its measurement range is more akin to the open-path flammable detectors described in section 6.1.3.

Two modes of operation are possible:

- Passive – where the background radiation is used as the IR source, but there must be a temperature differential between the background and the intervening gas to generate a signal; and
- Active – where the backscattered light, eg from a laser beam, arising from an object or surface behind the inspection region, is used to image the gas.

Examples of passive systems include:

- Image multi-spectral sensing - IMSS - (Hinnrich et al, 2006) is based on the principle of diffractive optics to disperse light. It is a combination of a diffractive imaging spectrometer and an adaptive tunable filter. IMSS performs both imaging and dispersion using a single lens.
- Gas correlation (Sandsten et al, 1996) is a non-dispersive spectroscopic technique (the incoming light is not split into its component wavelengths); it uses a sample of the gas itself to act as a filter. Currently the system is optimised for methane and not for higher

hydrocarbons such as those in petrol. Mechanical optical shutters, ie moving parts, on current systems can present a reliability issue.
- Non-dispersive imaging using filters (Naranjo, 2008) based on microbolometer (IR detector/imager) operating in the 8-14 micron region of the IR spectrum.

The sensitivity of passive systems is particularly susceptible to variations in background temperature, which at certain time during the daily cycle may reduce the sensitivity of the instrument considerably. Also, rain can severely impair sensitivity because the temperature of the background (ie rain) and the gas are very similar. Moreover, it is not always clear that the detector is responding to gas and not just to a temperature change between the gas and the background. If the background temperature and that of the gas are the same then it is not possible to see the gas, as there will be no net absorption (or emission) of IR radiation by the gas.

Active systems, known as backscatter absorption gas imaging (BAGI), use laser sources of various types to image the gas (Sandia, 2007). The detectors are not as portable as the passive systems, however they are relatively insensitive to background variations.

Detectors that are being considered by petrochemical companies for leak detection include, but are not exclusive to, the following organisations:

- Gasoptics (gas correlation)
- Pacific Advanced Technologies/Gas Imaging Technology (IMSS)
- Bertin (microbolometers)
- Sandia Laboratories (BAGI)

6.2 RELIABILITY

A summary of failure and deterioration modes for point and open-path detectors is given in Table 6.1. Gas imagers have only recently been applied and information is still relatively scarce; trials of various models and prototypes are ongoing.

Some PFD data for IR point and open-path detectors is quoted in the OLF guidance (OLF, 2004), discussed in Section 3.5, which itself is derived from the PDS Data Handbook (SINTEF, 2003b). The PFDs are for one gas detector of type:

- catalytic - 3.9×10^{-3},
- IR point and IR open-path - 1.5×10^{-3},

The above values are combined with a PFD for the logic of 4.4×10^{-3}, which indicates that SIL 2 is achievable for catalytic, IR point and IR open-path (PFDs for the function of 0.008, 0.006 and 0.006 respectively). It can be seen that the IR detectors are more reliable (by a factor of at least 2) than catalytic detectors with respect to random errors. This data is obtained prior to 2003 and therefore does not reflect further improvements in technology, particularly for IR detectors.

Some examples of current detectors and their SIL ratings where provided by the manufacturer are given in the table in Section 10.1 of the Appendix.

Table 6.1. Modes of failure and deterioration of flammable gas detectors (typical characteristics).

Modes of failure/deterioration	**Point detectors**		**Openpath detectors**
	Catalytic	**Infrared**	
Systematic			
Wrong location	+	+	+
Dispersion effects (eg high air flow/wind)	+	+	+ but not as much as point
Wrong model ie insensitive to gas	+	+	+
Wrong set up (eg too much attenuation)	+	+	+
Wrong calibration (eg methane versus other hydrocarbons)	+	+	+
Sinter/filter blockage	+	-	-
Poisoning	+	-	-
Drift in detector response	+	+ but much less than catalytic due to self-checking	+ but much less than catalytic due to self-checking
Beam blockage, poor alignment	-	-	+
Blinding by sunlight, fires, black body radiation, lamps	-	-	+ but improved on later models
Fog, snow, ice	+ (with sinters which are required for Ex d certification)	- except where sinters used	+ but revealed on later models
Random hardware			
Aging and stress (failure rates of electronics typically much less than those for the sensor itself)	+	+	+

KEY: + possesses this failure/deterioration mode; – does not possess this mode.

NOTES:
Catalytic sensors are prone to poisoning by contaminants in the environment (which may therefore affect all such sensors in a given area), and the sintered metal screen is prone to blockage, once again by features of the area such as painting operations. These devices have no effective self-check and therefore have a major unrevealed failure mode. Sensitivity varies for different hydrocarbons, particularly methane versus higher hydrocarbons (more sensitive to methane by a factor of approximately 2).

All point detectors are limited to detecting gas at a specific location, and can be rendered ineffective e.g. if placed in a dead spot in the local airflows where air stagnates and gas does not migrate, or if blockages of covers can prevent gas from reaching the detector mechanism. These problems cannot be revealed by any internal test or external calibration.

Open path detectors can have the beam path blocked by obstructions such as scaffolding, long grass, and a second wavelength reference IR is used to detect the blocked beam condition and enunciate the fault as well as to self-calibrate the instrument. Sensitivity varies for different hydrocarbons. Latest models use two or three (on latest models) wavelength references to reduce effects of fog, snow, ice etc.

6.3 CHECK/PROOF TEST INTERVAL

The check period or proof test interval is an important component of the PFD calculation for the system. Proof test intervals of 3 months and a repair time of 3 hours are values quoted by one manufacturer having gas detection instruments rated with SIL suitability levels. The limits of the application of the SIL rating are dependent on a maintenance schedule. For example, a typical maintenance period is at least every 90 days.

Additionally, the competence of maintenance engineer can affect reliability. As sytems become more complicated to test then errors can occur possibly resulting in the detector being desensitised to the gas or even not responding at all. Open-path detectors require more care and attention than point detectors, for example.

6.4 FIBRE-OPTIC CHEMICAL SENSOR

The fibre-optic sensors are typically used to detect and measure hydrocarbon concentrations arising from leaks, ie comparatively low concentrations compared to the IR detectors above (Sensfelder et al., 1998). Fibre-optic detectors operate in air to detect the vapour, but also hydrocarbons dissolved in water and in soil. They are non-specific detectors for total petroleum hydrocarbons and semi-volatile hydrocarbons (e.g., diesel fuel, heating fuels, etc.). The sensors are unaffected by high humidity, or by naturally occurring methane, as they are sensitive to C6 and above hydrocarbons.

The principle behind the fibre-optic vapour sensor, termed FOCS – fiber optic chemical sensor, is the modulation of light guided along an optical fiber based upon total internal reflection (Saini et al, 1994). The amount of internally reflected light can be optimized by cladding the fibre optic core with a material with a certain refractive index which is also sensitive to the presence of hydrocarbon. Examples of such materials are metal oxides, etc. When hydrocarbons adsorb *reversibly* on the surface of the cladding, the resultant change in the cladding refractive index alters the amount of transmitted light; some of the light travelling through the optical fibre escapes. A reference detector at one end and a sense detector (PD) at the other end of the fiber measure that loss of light. Very small changes in the refractive index generate relatively large changes in transmitted light; these changes can be measured and calibrated to represent concentrations of species (e.g., TPH – total petroleum hydrocarbon) present in the surrounding medium.

The device is configured as a probe several centimeters long which is supplied by a protected optical fibre cable of around 40 m long. Some characteristics of the detector (probe) are shown in Table 6.2.

Table 6.2. Typical fibre optic vapour sensor characteristics

Parameter	Value
Operating Range	0 – 20, 000 ppm as TPH
Lower Limit of Detection	<10 ppm as xylene (a C8 hydrocarbon)
Hydrocarbons Detected	C6 and higher petroleum hydrocarbons
Accuracy/Precision	±15% of reading
Response Time (initial)	12 s
Response Time (to 95%)	<1 minute
Operating Temperature	0 – 50 C

One manufacturer of fibre-optic hydrocarbon detectors used in the petroleum industry is Petrosense (www.petrosense.com), marketed through FCI Environmental Inc., where the FOCS is used for portable detection and continuous monitoring systems. The original FOCS was introduced in 1994 and is used around above ground storage tanks, particularly in the USA.

6.5 ULTRASONIC

This is a non-concentration based detector used to detect leaks from high pressure gas systems. The operating principle is based on the emission of ultrasound from the escape of gas from a high pressure pipeline or other pressurised system (Little et al, 1999). They measure sound frequencies above around 25 kHz (audible extends to 18 k Hz). The detection limit is of the order of 0.1 kg/s leak rate and typical minimum leak pressure is of the order of 10 bar, although lower pressures can be detected background noise can interfere therefore requiring increased coverage of detectors over the operating site.

The ultrasonic detector has the advantage over the concentration-based detectors above in that it does not require transport of the gas to the sensor. Theoretically it provides 360º coverage, however an ultrasound survey is conducted before installation in order to optimise its location because there may be reflections or interferences which reduce the coverage. Again, as for concentration-based detectors, care is needed in placement. Typically they can be installed up to 20 m from a suitable potential source, however this depends on the leak size, pressure and ultrasound background. Steam releases can generate false alarms, although steam tends to be at lower pressures than hydrocarbons, but if the two sources are close together then problems can occur.

The latest models are self-testing (using a bottle of nitrogen gas) and can be calibrated with a portable test unit.

Current ultrasonic detectors are not sensitive to liquid or mixed phase releases (Royle et al, 2006).

Ultrasound detectors are increasingly being used on petroleum sites, however, because they do not measure the concentration of gas (either as LEL or LEL.m), they are typically used in conjunction with point or open-path concentration-based detectors.

Gassonic quote a MTBF of the order of 25 years in sheltered areas.

Manufacturers of ultrasonic detectors include Gassonic (www.gassonic.com) and Groveley (http://detection.groveley.co.uk/).

7 LIQUID HYDROCARBON DETECTION

7.1 INTRODUCTION

An alternative to gas detection at fuel storage sites is liquid hydrocarbon spill measurement, particularly where the released material has a low vapour pressure and its vapour is heavier than air. It may be a more effective to detect a liquid release because it is easier to predict where the liquid will collect and travel: it will always be gravity driven, in contrast to predicting where a gas will disperse. There are various types of liquid hydrocarbon detection system including very sensitive sensors for measuring oil on water (based on absorption of electromagnetic radiation) and detectors for measuring the fraction of hydrocarbon in a water stream (based on microwave absorption or fibre-optic vapour sensing, see section 6.5). However, the most common for use in fuel storage sites are those based on conductivity change although the detection technique based on capacitance can also be employed in certain circumstances. Such detection systems have been briefly reviewed for use in the USA for aboveground tanks (ASTs), underground tanks (USTs) and underground pipelines (Hogg, 2000; Groves, 2002).

7.2 CONDUCTIVITY

The principle is based on the swelling of a carbon-enriched polymer which can induce a resistance change when it absorbs liquid hydrocarbon. The swelling time is dependent on the temperature and the type of fuel. The polymer detector can be implemented as a cable sensor which senses along its length or a fast reaction probe on a thin film. An example of a manufacturer of this type of detector is Tyco TraceTek (www.tycothermal.com).

7.2.1 Cable sensor

The core of the cable is composed of a spiral wire bundle. Two of the wires are electrodes which have a metal conductor core and a jacket of conductive polymer. The other wires form part of the general current-carrying and measurement/display functions. A tubular jacket of conducting, rubber polymer is extruded around the wire bundle enclosing the spiral wires in a sheath. The electrode wires are on opposite sides of the spiral and do not normally touch each other, neither do they normally touch the inner wall of the tubular jacket. There is thus an open circuit. However, when liquid hydrocarbon comes in contact with the sheath, the sheath swells and eventually contacts the two electrodes in the core and a current flows between the two electrodes. This resistance drop is monitored and the circuitry can also measure the distance along the sensor cable to the point of leak detection from the resistance between the electrodes, typically to an accuracy of ±1 m.

The disadvantage of this system is that the cable must be either replaced, for heavier hydrocarbons, or left for a period for the lighter hydrocarbons to desorb from the polymer.

The sensor does not respond to vapour concentrations around the LEL but does eventually alarm when vapour concentrations are around the saturated vapour concentration, ie approximately 5-10 % v/v. While the sensor does not respond to low levels of hydrocarbon in water, above a certain level then it is anticipated that the alarm would activate after a period (months?) when exposed to hydrocarbon contaminated water above several hundred ppm.

Typically, the cable sensor is used for buried applications, positioned in a slotted PVC conduit, and for small leaks.

Hogg (2000) describes the use of the cable detector operated as a stand-alone, battery-operated flasher unit (as opposed to a network of detectors in a SCADA system, which is also possible) and lists their experiences and problems at various US tank farms.

7.2.2 Probe sensor

Here the carbon particles are deposited as a thin film using a polymer base onto a dual electrode probe. The use of a thin film probe provides a faster responding device than the cable but not as large coverage. When liquid hydrocarbon comes into contact with the probe the liquid is absorbed into the carbon-enriched polymer causing swelling which increases the resistance of the polymer, measured by the electrodes. The response time is of the order of a few seconds for light or middle-weight fuels such as petrol, jet fuel and diesel. The time taken to reset and the ability of the sensor to repeatably reset after being exposed to fuel depends on the volatility of the fuel, light fuels such as petrol which evaporate more quickly result in a shorter turn-round time.

This detector can be used to detect overfill by detecting hydrocarbon in the bund. It can also be used to detect leaks from valves etc by use of a small stainless steel sump below such leak sources.

7.2.3 Reliability

Various instruments are described as being SIL 2 suitable. Furthermore third party test reports and evaluations are quoted, mainly on the sensitivity and selectivity against water.

7.2.4 Location

The correct installation and positioning of the detector, which takes into account the local site conditions, is crucial to the reliable detection of leaks whether they be liquid or gas. Liquid hydrocarbon detection is likely to have better coverage than gas detection because liquid motion is much easier to predict being gravity led.

The strategy for location of the sensor should consider soil, water and backfill conditions and that a leak will migrate toward the sensor, using gravity on a microscale by channelling the leak into a small sump located below a potential leak, eg valve or on a macroscale by locating the sensor at the lowest point of the bund, for example. The water table should also be taken into account.

7.3 CAPACITANCE

Capacitance change monitoring for electrically non-conductive liquids such as fuels (and electrically conductive) can be used for the detection of low-viscosity liquids for such tasks as indicating the presence of fluid on the base of a collector. The technique is sensitive to all organic and inorganic liquids with specific dielectric constants between approximately 2 and 100. The sensors need to be sufficiently wetted and appear to be less rugged than the above conductivity detectors, although there is not as much information readily available.

An example of a manufacturer of this type of equipment is Jola (www.jola-info.de).

8 CONCLUSIONS

General

Various types of hydrocarbon spill and leak detection techniques for potential use at fuel storage sites such as Buncefield have been reviewed. These are mitigative devices compared with preventative devices such as liquid level detectors.

Gas detectors are widely used to monitor leaks of flammable vapour, particularly offshore where evacuation of the site is obviously much more difficult than onshore. They are employed onshore on petroleum refineries but tend not to be used at UK fuel storage sites. Indeed, currently, there are no gas detectors used for petrol vapour applications on UK fuel storage sites.

Gas and liquid detectors are not covered in the API 334 (1996) guide on leak detection for aboveground storage tanks.

Functional safety

With respect to functional safety systems, the use of performance-based design methodologies associated with *mitigative* Safety Instrumented Functions eg provided by gas detection, is not currently normal practice within the process industries. However, mitigative Safety Instrumented Functions could be within the scope of standards such as BS EN 61511.

There are various standards specifically relating to gas detection including performance requirements, guide for use and functional safety. The current functional safety standards are, however, concerned with the instruments themselves (hardware) and do not consider their coverage. The current UK standard (BS EN 60079-29-2) relating to the location of detectors is very general.

At present, there are no UK/EN performance standards relating to liquid hydrocarbon detectors.

There are useful principles in ISA TR84.00.07 which could be adopted (by IEC?) so that the degree of risk reduction from the use of leak detection techniques can be quantified. The major points to consider are as follows:

- Risk-based concepts, as in ISA 84.00.07 and BS EN 61511, including designing to a targeted performance level with an associated integrity and an acceptably-low probability of failure on demand.
- Undertake a comprehensive screening analysis to determine if FGS is desirable for the process under consideration.
- The assessment of detector coverage is an important concept in determining how effective that proposed array of detectors with a given voting arrangement will be in detecting an incipient hazard at a level that will initiate a specified safety action.
- Detector placement and coverage problem requires study with the same quantitative rigour as average PFD.
- Use of an event tree model similar to that used in QRA which quantifies detector coverage, FGS safety availability and mitigation effectiveness to calculate the mitigated risk.

Gas detectors

IR point and open-path detectors tend to have lower PFDs than catalytic detectors and are therefore preferred for fixed monitoring applications for spills.

For open areas, open-path gas detectors are typically preferred to point detectors because of their greater coverage. However, point detectors can play a role if the point detector is very close to the potential leak (based on a quantitative risk assessment) and where the point detector coverage is expected to be very high, eg through use of traps, enclosures.

Gas imaging systems, while still under development, hold promise for portable, sensitive leak detection and repair systems and possibly as fixed site monitors.

Ultrasonic detection could be considered for leaks from high pressure gas systems, but not liquids or mixed phase leaks, should these occur at a FSS. Again, as for concentration-based detectors, care is needed in placement, even though gas does not need to disperse to the detector.

Gas dispersion and detector coverage

The range of conditions of interest, both when a hazard could occur and what should be detected, need to be specified.

There is a lack of information on the flow and concentration of vapour in the near field. This would affect the ability to specify detector coverage in the near field and a source term for the far field.

If models are used their capabilities would need to be demonstrated and the conditions used would need to be justified. Until more measurements have been performed and models have been developed any solutions are likely to be heuristic.

Optimal location of detectors is likely to be in the bund and alarm levels set sufficiently high such that only a major spill will generate sufficient vapour concentration to alarm.

Liquid hydrocarbon detectors

Liquid hydrocarbon detectors, while not as widespread in petroleum applications as gas detectors, offer significant advantages as a mitigative spill/leak detection technique. Liquid flow is easier to predict and therefore the coverage of the detector is likely to be higher than for a gas detector. Moreover, the use of a cable monitoring system also improves coverage when a large area is required to be covered.

A disadvantage is the requirement to reset the detectors when they have been exposed to fuel after removing them from the spillage.

More information is required on their reliability.

9 RECOMMENDATIONS

The following recommendations are made following this review:

1. Developments in the ISA report TR84.00.07, which is being written by the ISA Standard Panel 84 (SP84), should be monitored to determine whether it can be adapted for UK/European use, eg through the IEC 60079-29 committee on gas detectors.
2. Review the application/relevance of a published ISA TR84.00.07 Technical Report for fuel storage sites with dutyholders, particularly regarding whether the quantitative methodology of risk mitigation assessment in the document can be applied whenever gas/liquid spill detection systems (but not LDAR systems) are being put forward by dutyholders.
3. Liquid hydrocarbon detection may be preferable to gas detection as it is more likely to have greater detector coverage because predicting liquid flow is less uncertain than gas dispersion, although liquid detection is not a true measure of the hazard (ie LEL-related). Further investigation into their use at FSS is required.
4. If gas detection is used for petroleum vapour monitoring then infrared detection is preferable.
5. More data on gas/liquid dispersion at fuel storage sites is required.
6. Detector coverage estimation techniques require further investigation/validation as they are just as important, if not more, than hardware reliability for assessing the risk mitigation effectiveness of FGS.

10 APPENDIX

10.1 GAS DETECTOR CHARACTERISTICS (POINT & OPEN-PATH) - EXAMPLES

Manufacturer	Type	Inst Model	Detectable hydrocarbons	Concentration Range	Operating distance metres	Response Time (s)	SIL
Spectrex Inc http://www.spectrex-inc.com/	Infrared beam (Open path)	SafEye200	C1 to C8 flammables Ethylene/LPG	0 to 5 LEL m	From 3m to 140 m depending on model	2 to 5 depending on model	No mention.
MSA http://www.msabritain.co.uk/	Infrared beam (Open path)	SafEye Xenon 700 series	C1 to C8 flammables Ethylene/LPG	0 to 5 LEL m	From 4 m to 140 m depending on model		No mention
	Infrared (Point)	Ultima XI	C1 to C7 hydrocarbons	0 – 100 % LEL		T90 < 2	No mention
	Catalytic	Series 47K sensors	Combustible gases	0 – 100 % LEL		T90 <30	No mention
Groveley http://detection.groveley.co.uk/index.asp	Infrared beam (Open path)	GD10L	Combustible gases	5 LEL/m CH4 Other ranges optional	2 – 20 m or 2 – 30 m		Suitable for use in SIL 2 & SIL 3 systems
	Infrared (Point)	GD10P	Methane, propane, butane, ethylene, methanol	0 – 100 % LEL 0 – 100 % vol methane	NA		Suitable for use in SIL 2 & SIL 3 systems
Draeger http://www.draeger.com/STms/internet/site/MS/internet/UK-en/ms/index.jsp	Infrared beam (Open path)	Polytron Pulsar 2	Alkanes to C6 propylene, methanol & ethanol	0 to 4 LEL m 0 to 8 LEL m	4 – 60 m 30 – 120 m 100 – 200 m	T95 < 2	No mention
	Infrared (Point)	PIR 7000	Methane, propane, ethylene	0 to 20…100% LEL 0 – 100% vol CH4	NA	T90 <4	SIL 2
Crowcon http://www.crowcon.com/	Infrared (Point)	Xgard IR	Combustible gases	0 – 100 % LEL	NA		No mention
	Infrared (Point)	Nimbus	C1 to C6 hydrocarbons + ethanol, ethylene & LPG	0 – 100 % LEL		T90 < 7	SIL 2 compliant

Manufacturer	Type	Inst Model	Detectable hydrocarbons	Concentration Range	Operating distance metres	Response Time (s)	SIL
	Catalytic	Xgard Type 3 Type 4 Type 5	Alkanes to C5, H2 LPG Petrol Vinyl chloride	0 – 100 % LEL	NA	T90 <15	SIL compliant
	Catalytic	Flamgard Plus	Alkanes to C6 H2 LPG Petrol NH3	0 – 100 % LEL	NA	T90 <15	No mention
	Catalytic	GasPoint WD	Combustible gases	0 – 100 % LEL	NA		No mention
	Infrared (Point)	GasPoint IR WD	Combustible gases	0 – 100 % LEL	NA		No mention
Honeywell http://honeywellanalytics.com/Home.aspx	Catalytic	Sensepoint RFD	Combustible gases	0 – 20 % LEL 0 – 100 % LEL	NA		No mention
	Catalytic	Sensepoint Pro	Combustible gases	0 – 100 % LEL	NA		No mention
	Catalytic	Sensepoint Plus	Combustible gases	0 – 100 % LEL	NA		No mention
	Infrared beam (Open path)	Searchline Excel	Methane, ethane, propane, butane, pentane, ethylene, propylene, ethanol, methanol.	0 to 5 LEL m	5 – 40 40 – 120 120 - 200	T90 <3	No mention
	Infrared (Point)	Searchpoint Optima Plus	Combustible gases	0 – 100 % LEL	NA	T90 <6.5	No mention
General Monitors http://www.generalmonitors.com/	Infrared (Point)	IR2100	Alkanes, benzene	0 – 100 % LEL	NA	T90 <10	SIL 2 suitable
	IR Point, Single or Multi	IR4000S or M	Combustible gases		NA		2/3*
	Catalytic	S4000CH	Combustible gases	0 – 100 % LEL	NA	T90 <30	2/3*
	Catalytic	S4100C	Combustible gases	0 – 100 % LEL	NA	T50 <10	3
Detcon Inc http://www.detcon.com/	Catalytic	FP-700	Combustible gases	0 – 100 % LEL	NA	T90 <30	SIL 2

Manufacturer	**Type**	**Inst Model**	**Detectable hydrocarbons**	**Concentration Range**	**Operating distance metres**	**Response Time (s)**	**SIL**
Det-tronics http://www.detronics.com/	Infrared (Point)	PointWatch PIRECL	Combustible gases	0 – 100 % LEL	NA		SIL 2
	Infrared beam (Open path)	Open Path Eclipse OPECL	Methane	0 to 5 LEL m	5 - 120	T90 <5	
Sierra Monitor Corporation (SMC) http://www.sierramonitor.com/	Catalytic	5100-02-IT	Combustible gases	0 – 100 % LEL	NA	T60 <12	SIL 1
	Infrared (Point)	5100-28-IT	Methane, propane	0 – 100 % LEL	NA	T60 <10	SIL 1

* SIL 2 rating for typical environment; SIL 3 rating for clean environment

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12 GLOSSARY

FGS	Fire and gas system
LDAR	Leak detection and repair
LEL or LFL	Lower explosive limit or Lower flammable or flammability limit
PFD	Probability of failure on demand
QRA	Quantitative risk assessment
RRF	Risk reduction factor
SFF	Safe failure fraction
SIL	Safety integrity level