



BSI Standards Publication

**Explosive and toxic atmospheres —
Hazard detection mapping — Guidance
on the placement of permanently
installed flame and gas detection
devices using software tools and
other techniques**

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Foreword

Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 30 September 2020. It was prepared by subcommittee EXL/31/1, *Gas detectors*, under the authority of Technical Committee EXL/31, *Equipment for explosive atmospheres*. A list of organizations represented on these committees can be obtained on request to their committee managers.

Information about this document

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Where websites and webpages have been cited, they are provided for ease of reference and are correct at the time of publication. The location of a webpage or website, or its contents, cannot be guaranteed.

Use of this document

As a guide, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification or a code of practice and claims of compliance cannot be made to it.

Presentation conventions

The provisions of this standard are presented in roman (i.e. upright) type. Its requirements are expressed in sentences in which the principal auxiliary verb is “shall”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Where words have alternative spellings, the preferred spelling of the Shorter Oxford English Dictionary is used (e.g. “organization” rather than “organisation”).

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

0 Introduction

0.1 General

This British Standard is written in the form of guidance and supports flame and gas (F&G) detection standards across the industry.

One of the most challenging activities faced by a design engineer is deciding the quantity and location of gas detectors and/or flame detectors.

This British Standard refers to F&G coverage factors but does not specify target coverage factors for different applications. Coverage factors are only broad targets and are easily manipulated by changing device sensitivities, alarm trip levels, voting configurations, target gas concentrations, target flame size and other factors.

This British Standard also provides guidance on sensing technologies and the physical format of detectors which could greatly affect coverage (quantity and position). Irrespective of the quantity and positioning of detectors by a manual or software-related activity, the selection of incorrect sensing technologies leads to incidents not being detected or an increase in spurious trips.

This British Standard provides guidance on the full life cycle of a gas detection or flame detection system, emphasizing that mapping and/or modelling is an ongoing activity and not simply an activity that is carried out once in the design of a new facility. Routine surveillance of detector coverage during the full life cycle of a facility ensures that facility modification, changes in hazards, etc., are all addressed, and the management of change highlights any deficiencies or opportunities for improvement.

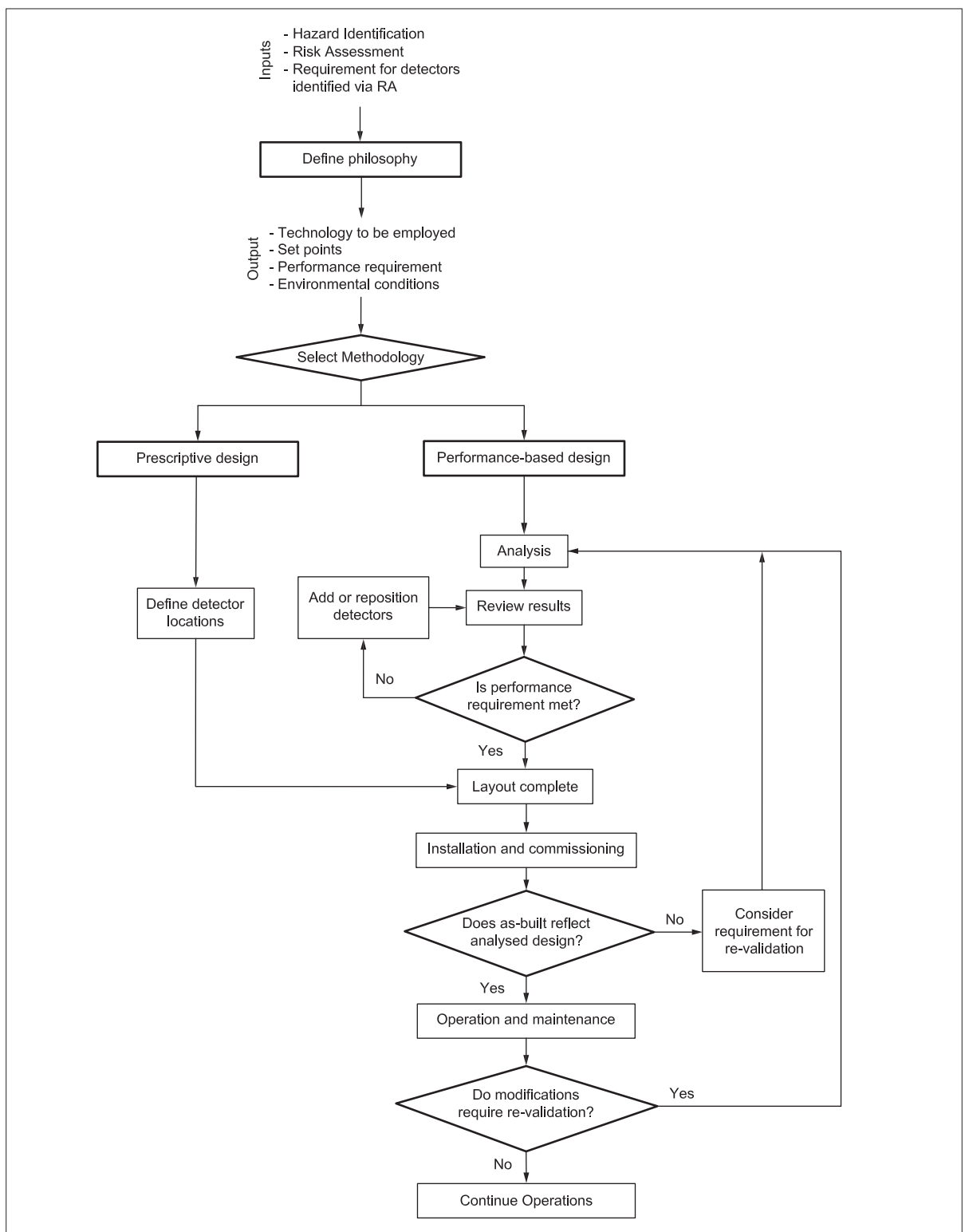
Detector coverage within this British Standard means permanently-installed devices, which are the only devices for which guidance is provided. The use of additional personal monitors, e.g. portable gas detectors, does theoretically increase the density of “detecting devices” when persons are actively working within a plant area or location.

This British Standard is based on existing and established sensing and detector technologies and configurations. It is also based on many years of industrial experiences and lessons learned. This British Standard does not exclude emerging technologies or innovative ideas; however unless there is reasonable and practical evidence that these technologies or methodologies offer equal benefits, caution is advised.

This British Standard provides informative guidance on detection symbols (see [Annex E](#)), however this guidance does not preclude continued application of any established symbols applied by an operator or designer.

0.2 Document structure

The structure of the document and the process for F&G mapping is illustrated in [Figure 1](#), with detail provided in [Clause 4](#) to [Clause 12](#).

Figure 1 — Document structure

1 Scope

This British Standard provides guidance on the placement of permanently-installed F&G detectors, including coverage and technology selection.

NOTE 1 "Permanently-installed detection systems" include optical flame detection (including ultraviolet, infrared and imaging/visual), flammable gas/vapour detection and toxic gas detection.

This British Standard provides guidance on the most commonly used methods of mapping and/or modelling: prescriptive, volumetric-based and scenario-based.

This British Standard is applicable to applications where:

- a) optical flame detection is used as a means of detecting flaming fires in internal and external environments;
- b) a gas detection system is used as a method of explosion protection;
- c) the hazard arises from the release or accumulation of explosive gases and vapours; and
- d) the hazard arises from the release or accumulation of toxic gases.

This British Standard also provides guidance on operations, maintenance and the availability/reliability of the system to complement relevant standards.

This British Standard does not provide guidance for:

- 1) addressing hazards that are a product of vehicle exhaust fumes;
- 2) applications in the domestic and general public environment;
- 3) applications in mining and tunnelling, heating ventilation and air conditioning (HVAC), medical applications or environments;
- 4) smoke detection; or
- 5) toxic gas detection with regard to business continuity, e.g. food tainting.

Mitigation effectiveness is an important aspect of F&G detection design but is out of scope of this British Standard.

NOTE 2 Oxygen detection is typically biased towards prescriptive methods for detector coverage and is generally excluded from this British Standard, considerations regarding typical oxygen detection are described in [Annex A](#).

2 Normative references

There are no normative references in this British Standard.

3 Terms and definitions

For the purposes of this British Standard, the following terms and definitions apply.

3.1 baseline sensitivity

sensitivity or performance capability of a device in controlled test conditions, i.e. before site specific performance influencing factors are applied

3.2 beam path absorption

absorption of the detection beam in the presence of gas (IR, UV and laser)

3.3 consequence

qualification/quantification of the harm caused by a hazard

NOTE Examples include death, injury, escalation.

3.4 coverage

criteria by which the volume/scenario is monitored or unmonitored with respect to detection success

NOTE Coverage can be represented as a percentage calculation, visual representation or both.

3.5 coverage factor

percentage coverage of the mapping zone

3.6 detection criticality factors

individual importance of a single detector, if known

3.7 escalation potential

potential consequence where no mitigating measures are implemented

3.8 emerging technology

devices with little proven in-use justification

NOTE The method by which detection occurs or how detection coverage is analysed can differ dependent upon the nature of the technology.

3.9 fire size

representation of fire as a function of geometric volume or radiant heat output

3.10 flame and gas detector modelling

application of software tools to generate a quantitative coverage of F&G detection in a specific space

NOTE Results of this modelling are often a valuable input to the F&G mapping process when applying volumetric-based and scenario-based methods.

3.11 flame and gas (F&G) mapping

process by which flame or gas detection layout is determined

NOTE This can include a combination of prescriptive adherence to facility philosophies, detection engineering knowledge, experience and software modelling tools.

3.12 fire and gas (F&G) philosophy

project document covering philosophy/strategy of the fixed F&G system

NOTE For the purposes of this British Standard, this is assumed to be different to a particular company's F&G philosophy/strategy that provides generic guidance for all installations/sites.

3.13 graded volume

volume within the mapping zone where specific detection performance targets are specified

3.14 hazard

source that has the potential to cause harm to someone or something

3.15 inverse square law

specified intensity inversely proportional to the square of the distance from the source of that physical quantity

NOTE Inverse square law is the determining factor in flame detection performance.

3.16 judgement-based placement

consensus between competent persons from different disciplines who holistically apply best judgement and experience to locate a detector

3.17 lower explosive limit (LEL)

volume fraction of flammable gas or vapour in air below which an explosive gas atmosphere does not form, expressed as a percentage

NOTE LEL can be used interchangeably with lower flammable limit (LFL) in this context.

3.18 mapping zone

boundary of the volume to be assessed as a single voting grouping

3.19 open-path detector (gas)

detector which measures the concentration of gas in a straight line between two points

NOTE 1 Concentration measured is displayed as metres (m), e.g. ppm/m or LEL/m.

NOTE 2 The concentration of gas is typically from >0 m to 250 m.

3.20 performance target

set of detection goals against which success of detection can be measured

NOTE Examples include a target maximum fire size or gas cloud volume.

3.21 point detector (gas)

single detector to measure a gas concentration at its location

3.22 prescriptive method

method of detector placement based on preset rules which can be followed by applying “pass/fail” criteria

3.23 radiant heat output (RHO)

energy (in kW) emitted from a flame in the radiant region of a fire

NOTE This is not to be confused with radiant heat flux (kW/m²).

3.24 risk

combination of the frequency/likelihood of harm occurring and the consequence severity

3.25 scenario-based method

method of detector placement taking into account a number of probabilistic scenarios which might result in detection

3.26 volumetric-based method

method of detector placement which measures a geographic volume where a hazard can occur which might result in detection

NOTE This is often referred to as geographic.

4 Hazard identification and risk assessment

Once a hazard has been identified employers need to conduct a risk assessment.

NOTE 1 Attention is drawn to The Health and Safety at Work Act 1974 [1].

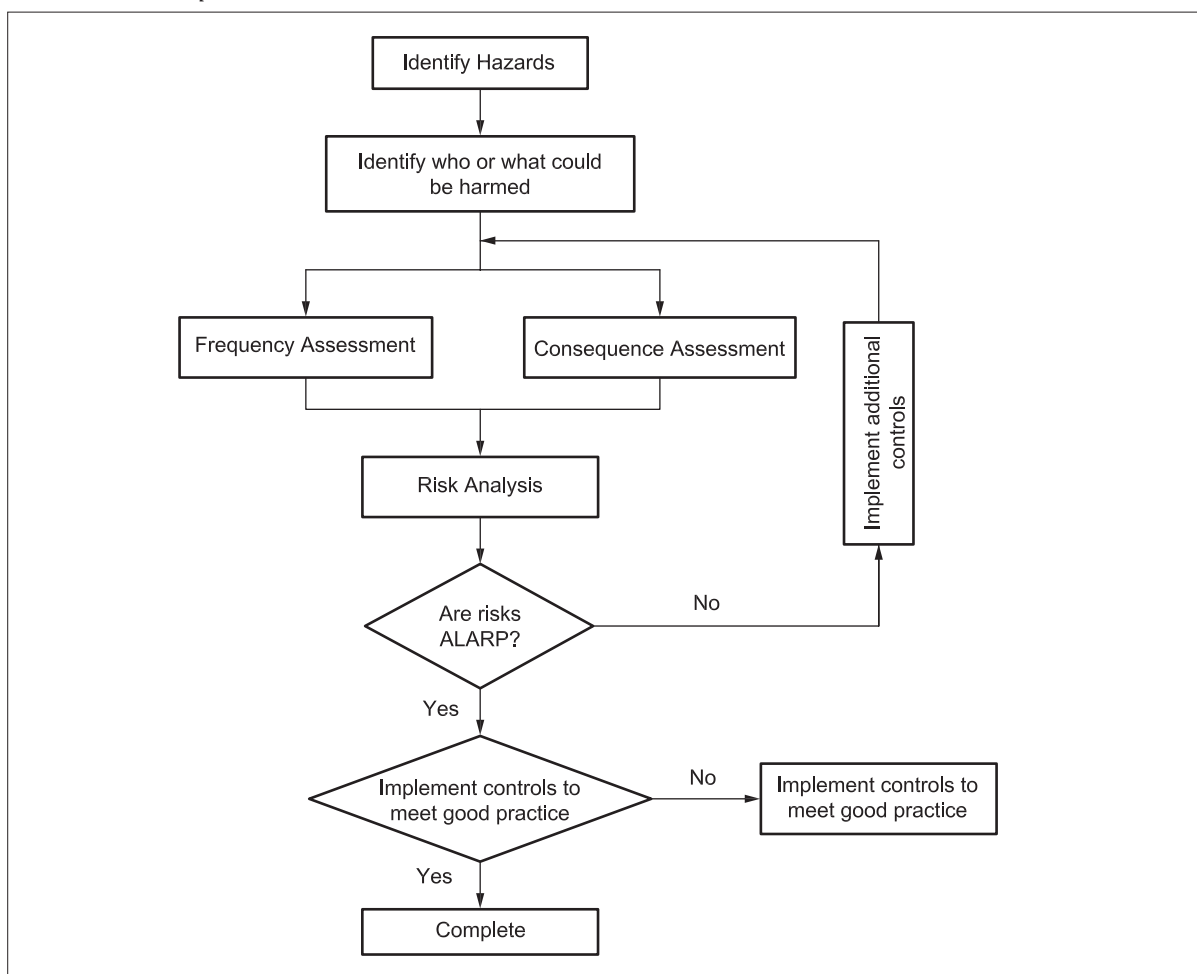
A typical risk assessment process is shown in [Figure 2](#) with the objective of determining if adequate control measures are in place so that risks can be deemed As Low As Reasonably Practicable (ALARP). For flammable gases and vapours, this process is typically conducted as part of a Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR) [2] assessment. For toxic gases

and vapours this is often carried out as part of a the Control of Substances Hazardous to Health Regulations 2002 (COSHH) [3] assessment.

One control measure is flame and/or gas (flammable and toxic) detection. In most cases F&G detection only detects the hazard rather than preventing the hazard and offers limited benefit in terms of reducing the potential for immediate fatalities. It is when combined with additional risk reduction measures (e.g. blowdown, deluge, alarms) that consequence and hence risk is lowered by reducing the potential for escalation. The F&G detection system is classed as mitigation when the centre of the bowtie is the release of flammable/toxic materials, or a fire.

NOTE 2 For further information on bowtie, see <https://www.gov.uk/government/news/bowtie-a-visual-tool-to-keep-an-overview-of-risk-management-practices>.

Figure 2 — Risk assessment process



The risk assessment process can range from qualitative to fully quantitative and the level of effort should be proportional to the risk; a concept known as proportionality. For example, it is not necessary to conduct a fully quantitative study if determining the flammable risk arising from an isolated single flammable source (e.g. propane bottle) in an unmanned room. This British Standard assumes that a risk assessment has been conducted with the output being that flame and/or gas detection is required to demonstrate that risks are ALARP. This British Standard provides guidance on the process to justify the number of detectors to employ and where to put them.

Toxic gas detection introduces different layers of complexity compared to flame and flammable gas. For flame and flammable gas, the risk assessment process identifies any requirement for fixed flame/gas detection and the detector location requirement is based on the required control measures in place to mitigate the event of a fire/flammable gas release. For toxic gas, the risk assessment

identifies the requirement for fixed detection and informs the decision on how many detectors are required and their location. It is therefore necessary to take account of the other control measures that are in place, along with the desired outcome of detection with respect to toxicity, when making the decision on positioning requirements for toxics. Further guidance on other control measures and how they affect decisions on the location and number of detectors is given in [7.6](#).

5 Fire and gas (F&G) philosophy

5.1 General

The fixed detection philosophy or strategy with respect to F&G detection should be defined at the outset of the project to allow for a consistent approach to be taken for the long-term maintenance and upgrading of the system, i.e. if new equipment is installed or changes are made to the plant, additional detectors can be installed or be relocated in a manner consistent with the philosophy (see [Clause 11](#) for further guidance on operation and maintenance of F&G detection systems).

In some instances, larger companies might have internal guidance (also sometimes referred to as a philosophy) on F&G detection that outlines preferred methodologies and metrics to ensure consistency across sites/installations. Where this is the case, a philosophy document should still be developed for the site in question, but the internal guidance can be referenced within the philosophy to avoid duplication.

The philosophy should include, as a minimum:

- a) the metrics to use to assess a system, e.g. percentage coverage, target fire size, gas cloud of a certain size, gas cloud/fire that could lead to escalation of a certain frequency of occurrence (see [7.3.6](#), [7.5.6](#), [7.6.6](#));
- b) whether separate criteria are set for the environment, personnel, asset and business continuity. If multiple criteria are applied, the system should be designed based on the most onerous criteria. Further, toxic gas detection is typically required only to protect personnel;
NOTE Toxic gas detection can be applied solely for business continuity protection (i.e. food tainting by ammonia, use in the semi-conductor industry), however, this is outside the scope of this British Standard.
- c) the mapping zones, including the methodology used to define them, if not included within the company's internal guidance document;
- d) area grading rules (if applicable) that define the performance criteria based on different assessed risk categories (see [7.3.2](#), [7.5.2](#), [7.6.2](#));
- e) what technologies are appropriate for the environment and hazard;
- f) set points and voting requirements for detectors; and
- g) whether there are multiple design authorities/certification bodies/stakeholders for a particular installation/site, e.g. for a floating production storage and offloading (FPSO) installation the certification body would differ between the hull and topsides. Ideally a single consistent philosophy should be developed for the installation but if this is not possible it might be necessary to include details of how the philosophy differs across the installation/site and how the interfaces are managed.

The mapping methods to be applied could differ as the design progresses. More detailed methods might not be appropriate early on in a design as sufficient information might not be available.

5.2 Detector location – practical considerations

5.2.1 General

An important element of mapping involves taking account of engineering practicalities when deciding where to locate detectors. The positioning of detectors should be determined during the mapping exercise and not left until detailed engineering.

5.2.2 Mounting

Once positioning has been determined by a mapping study, correct mounting becomes important for the correct operation of devices. Detector mounts should be permanently secured to structural steelwork, where practicable. Where mounting posts are to be used, consultation with the civil engineer might be necessary to determine the suitability of locations, e.g. taking account of drainage channels where mounting foundations might not be possible.

5.2.3 Maintenance access

Detectors should be accessible from ground or a platform without the need for specialized equipment or temporary construction, such as scaffolding, or lifting devices, or fall protection, where practicable. This includes the orientation of mountings so that displays and important written information are visible from an accessible location.

For line of sight (LOS) detectors, this includes the ability to align the optical beam from an accessible location.

Access for testing and maintenance should be confirmed during the design.

In some cases, it might be necessary to mount point gas detectors at locations inaccessible without scaffolding; in such cases test gas tubing up to the detectors should be specified to enable function testing. For locations where this is not possible, e.g. on brownfield sites, rope access can be provided and used by fully trained and properly equipped personnel.

5.2.4 Impact of normal operational activities

Detectors should be located so that the potential for damage during normal plant maintenance is minimal.

The location of LOS-type gas detectors or optical flame detectors should allow for normal activities in the region of the detection that could block the sensor. This can include regular maintenance activities such as those requiring scaffold.

5.3 Brownfield versus greenfield considerations

The mapping method for a new greenfield project might be different from an existing operational (brownfield) site.

For a greenfield project it should be possible to optimize the detection performance close to the theoretical limit of the modelling, as there is usually a lot of flexibility in mounting locations and system configuration. A typical optimization aim is to achieve a detection target with the minimum number of detectors.

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

NOTE The cost of a "small" move (e.g. within the cable slack already provided) or re-orientation might be trivial.

An apparent “optimum” mapping result which requires multiple detectors in a zone to be moved is typically more expensive to engineer than purchase and installation of an additional detector, so an alternative solution involving the addition of a new detector to improve coverage might be more cost-efficient and practical.

Where this could present an issue, it is beneficial to agree an optimization policy prior to starting the mapping exercise, typically based on overall cost efficiency and effectiveness rather than a simple metric of total detector numbers, to achieve the desired coverage or risk reduction target.

An example would be a brownfield policy for flame detection optimization making changes to the layout, where necessary to close gaps or meet targets, in the following order of preference.

- a) Change angles/orientations of flame detectors.
- b) Consider making one or two small moves (preferably within the cable slack).
- c) If target still not met, consider adding new detectors in new locations rather than multiple relocations of existing detectors.

Consideration of risk reduction to ALARP is particularly relevant when justifying addition of new detection in brownfield studies, as practicability of implementation is a significant issue.

6 Detection technology

6.1 General

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

- a) if there is a risk of a unique fuel (i.e. hydrogen), it is important to be aware of the fire detector types and capability; and
- b) certain flammable vapours, such as benzene, are not detected by standard infrared line of sight (IR LOS) detection.

Interoperability between device and system could have an impact on device selection. This should be taken into account as early as possible in the design philosophy. If this information is not available, conservative assumptions should be made with respect to coverage and updated as the project evolves.

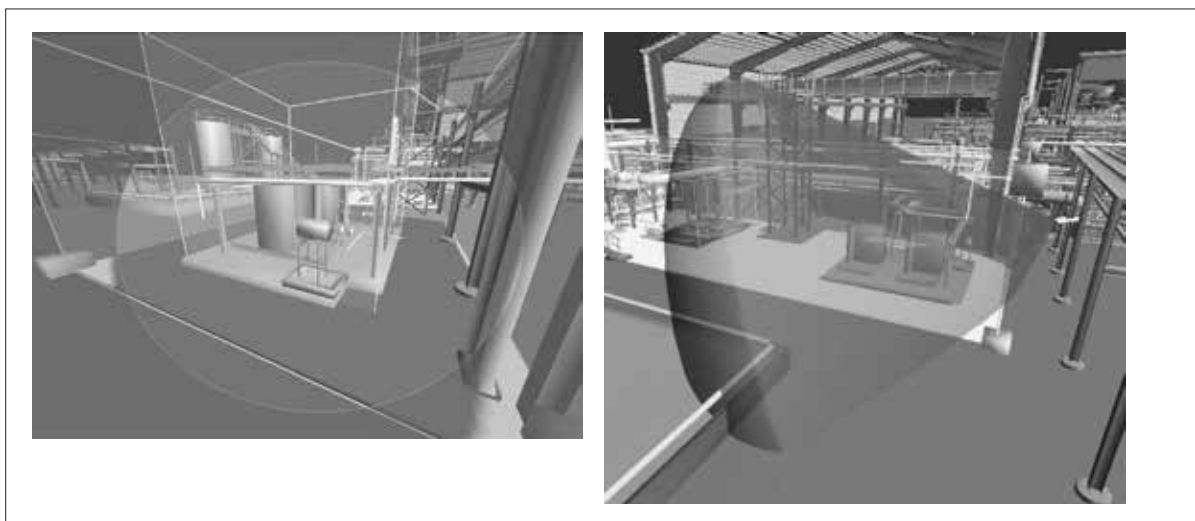
6.2 Flame detection

6.2.1 General

For all detector types the manufacturer's and third-party performance testing of detector performance for different fire types should be taken into account and guidance on installation followed.

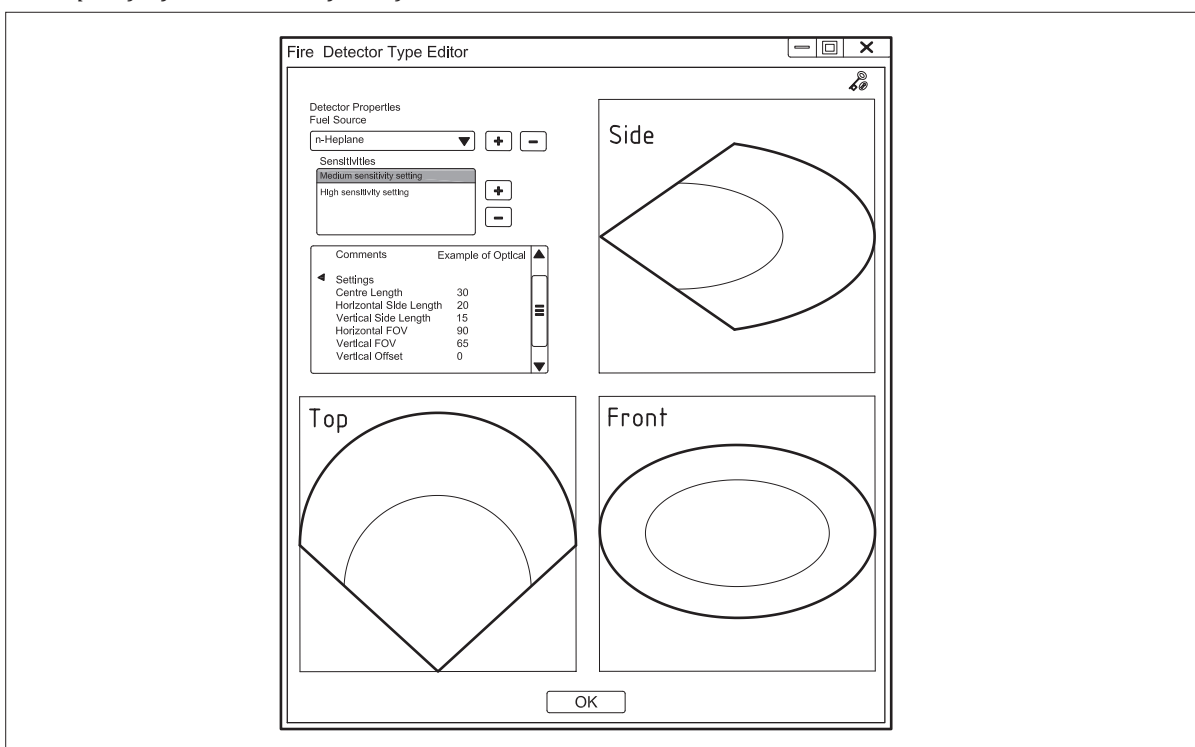
6.2.2 Mapping of optical flame detection

Optical flame detectors operate on a “detection envelope” principle which is characteristic of the model type. The detection envelope depends on the “field of view” (detection distance and angles defining the cone of vision), the centre length distance (distance of detection for the specified flame), and the fall-off in sensitivity around the periphery of the cone of vision (see [Figure 3](#) for an example from one software package).

Figure 3 — Typical point of view (POV) alongside external view of the same envelope

This information is typically included in the detector technical manual and should be used, if possible, to define the volume of coverage in the mapping software.

An example of how this is characterized in one software package is shown in [Figure 4](#). In this case, the inner and outer envelopes represent the detection ranges for two sensitivity settings, as set by detector hardware switches.

Figure 4 — Example of a flame detector field of view

As each detector model has a different detection envelope, it is important to model the correct detector type. Optical flame detector mapping should include the following information to model the coverage characteristic:

- detector make and model;
- detector sensitivity setting; and
- fuel (for the fire hazard being modelled).

The mapping methodology should also take account of degraded performance in operational conditions, e.g. by factoring in a reduced detection distance to allow for dirty optics. Where the detector manufacturer does not publish sensitivity distances for the precise fuel type, the nearest one should be selected (see [7.2.4](#) for guidance on spectral characteristics).

Detector sensitivity is not a standardized parameter with flame detection. Flame detector manufacturers publish performance claims to a set of tested fires. Performance of the device in the field is determined against these, typically using the inverse square law. This means a fixed detection cone is rarely an acceptable way of modelling coverage as the device might be able to see a fire at a much greater distance if the radiant heat output (RHO) of the flame is sufficiently high.

For example, a square foot n-Heptane pan fire is widely accepted to generate an RHO of approximately 40 kW. If the data sheet claims detection of this fire at 30 m, it can be modelled that the flame detector detects a 160 kW fire at 60 m (see [7.3.7.1](#) for guidance on the inverse square law).

6.2.3 Fire detection

The main fire detection technologies in general industrial use are:

- a) optical flame detection;
- b) heat detection; and
- c) smoke detection.

Mapping assessment methodologies are typically applied for optical flame detectors in order to optimize numbers and ensure coverage targets are met. Heat detection is currently not regarded as suitable for mapping optimization but its contribution to fire detection coverage can be taken into account during mapping, assuming adequate risk assessment has been carried out.

NOTE Smoke detection is outside the scope of this British Standard.

6.2.4 Optical flame detection

Optical flame detection consists of the following types of sensor:

- a) infrared (IR) sensors;
- b) ultraviolet (UV) sensors; and
- c) imaging/visual (camera-type) sensors.

IR and UV are further categorized as:

- 1) Single IR (see [6.2.5](#));
- 2) Multi-spectrum IR (see [6.2.5](#));
- 3) UV/IR combined (see [6.2.7](#)); and
- 4) UV (see [6.2.6](#)).

6.2.5 Infrared (IR) and multi-spectrum (MSIR)

IR flame detectors can be “single IR” or “multi-spectrum IR”. Single IR devices use a single IR channel filter to “look” for the IR signal emitted when a hydrocarbon fire burns. Signal processing is used to reduce the response from other IR sources (such as hot compressor or engine exhausts and sunlight). Multi-spectrum IR devices “split” the IR signal into channels to monitor different frequency ranges. In so doing, they attempt to look at the IR signal due to hot CO₂ (or in some cases water) and therefore attempt to further reduce false alarms from hot surfaces and background radiation.

6.2.6 Ultraviolet (UV) flame detectors

UV flame detectors respond to the UV radiation emitted from a fire. UV flame detectors are typically fast responding devices. Their location should be carefully planned as they are susceptible to false alarms from electrical arcing and lightning and also lose sensitivity if their lenses become coated in a film of hydrocarbons. It is more common for UV detectors to be used indoors where the surrounding environment is controlled.

6.2.7 Combination ultraviolet/infrared (UV/IR)

These devices combine the detection principles of a single IR and UV detector with the aim of reducing false alarms. They do this by applying an AND gate; both sensors need to detect a presence of their respected radiation in order to output the fire event. These combined devices can be an advantage in some specific applications to reduce false alarms; however, the UV channel can lose sensitivity if the lens is covered by a thin film of hydrocarbon, and IR detectors can be desensitized by multiple environmental factors, so their use is often restricted.

6.2.8 Visual flame/CCTV

Visual flame detectors are designed to respond to the visual footprint of a flame within the visual/near IR region of the electromagnetic spectrum. This region allows the devices to distinguish between real flames and other, non-visual, background radiative sources (i.e. flare radiation, turbine exhausts). This also means the detectors are unable to see fires which burn invisible to the naked eye, i.e. methanol, hydrogen. Some units can provide live CCTV images, and video recording of fire events. These devices are typically applied on facilities with/near a flare, or where the environment can be challenging (i.e. offshore oil and gas, onshore external exposed environments with hot processing equipment/background radiation, etc.).

6.3 Heat detection

COMMENTARY ON 6.3

Within this British Standard, the term heat detectors include fusible plug, linear wire, frangible bulb, pneumatic systems, bimetallic strip, IR heat sensor and thermistors.

Heat detection devices are generally considered as point detectors and respond when exposed to an elevated temperature at a predetermined set point.

6.4 Flammable gas detection

6.4.1 General

For all detector types the manufacturer's and third-party performance testing of detector performance for different gases and vapours should be taken into account and guidance on installation followed.

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

6.4.2 Pellistor

The pellistor sensor works on a Wheatstone bridge principle where one of the four resistors react to the target gas. This chemical reaction results in a rising temperature that causes an electrical

change across the bridge. Certain airborne contaminants can affect the chemical reaction on a temporary or permanent basis, so regular maintenance is a supporting requirement when using pellistor technology.

NOTE Pellistor is also referred to as catalytic.

6.4.3 Thermal conductivity sensor

The operation of a thermal conductivity sensor depends upon the change of heat loss by conduction of an electrically-heated element referenced against another electrically-heated element which is not exposed to the measurement gas or vapour.

6.4.4 Infrared (IR) point

The principle operation of an infrared sensor is IR absorption at specific frequencies referenced to non-absorbent frequencies. A point detector detects gas at the point of its sensing element. IR devices need to be selected to detect all hazardous gases within the target zone and the alarm set point selected to ensure adequate response to the least sensitive gas likely to be encountered in a hazardous situation.

6.4.5 Line of sight (open-path)

6.4.5.1 IR based

IR LOS detectors transmit an IR beam between a transmitter and a receiver. LOS detectors can have a path length between 0 m and 250 m and the maximum allowable path length should be taken into account.

IR devices might show a differing response to lower explosive limit (LEL) levels of different gases and devices need to be selected to detect all hazardous gases within the target zone and the alarm set point selected to ensure adequate response to the least sensitive gas likely to be encountered in a hazardous situation.

LOS detectors measure the integrated gas concentration within the beam path (beam path absorption), e.g. if a well-mixed gas/air accumulation of 10% LEL concentration was enclosed and fully distributed throughout a module in which the following LOS detectors were installed, the following signals would be recorded from each device:

- a) LOS 1: 10 m long would record $10 \text{ m} \times 10\% \text{ LEL} = 100\% \text{ LEL m}$ or 1 LEL m; and
- b) LOS 2: 30 m long would record $30 \text{ m} \times 10\% \text{ LEL} = 300\% \text{ LEL m}$ or 3 LEL m.

6.4.5.2 Laser based

Laser LOS detectors are very similar to IR LOS detectors in respect to mounting arrangement and path lengths. However a key difference between laser and IR technology is that laser technology is gas-specific, therefore it is essential that the target gas is matched to the laser device. Alongside the gas-specific characteristics of laser-based technologies lies greater sensitivity in the ppm/metre range, however overall path lengths might need to be reduced to gain this extra sensitivity.

6.5 Toxic gas detection

6.5.1 General

For all detector types, the manufacturer's and third-party performance testing of detector performance for different toxic gases, including cross sensitivities, should be taken into account and guidance on installation followed.

6.5.2 Electrochemical sensors

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

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

6.5.3 Semiconductor sensors

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

6.6 Ultrasonic (acoustic) gas leak detectors

Ultrasonic gas leak detectors (UGLD) "listen" for the characteristic sound of gas under pressure being released through an orifice.

UGLD can be considered as a "first line of defence" device as they do not measure the concentration of a potential hazard but do respond quickly to pressurized gas leaks, depending upon the built-in time delays to guard against spurious trips. While UGLDs can be used to detect the release of gas, mapping of UGLD is outside the scope of this British Standard.

7 F&G mapping techniques

7.1 General

Three different mapping methods are available:

- a) prescriptive method;
- b) volumetric-based method; and
- c) scenario-based method.

Prescriptive methods are the most simplistic, with the level of complexity and effort increasing progressively towards the employment of scenario-based methods. The mapping methods can be considered analogous to qualitative (prescriptive), semi-quantitative (volumetric-based) and fully-quantitative (scenario-based method) methods applied to risk assessment. The concept of proportionality should be applied with the methodology chosen being appropriate to the level of risk. Further detail on these approaches is provided in [7.3](#), [7.5](#) and [7.6](#).

7.2 Flame properties

7.2.1 General

Where the potential for a flaming fire exists and traditional fire detection technologies cannot be relied upon for detection (e.g. in an external area/an area where [BS 5839-1](#) is not applicable), the use

of optical-based flame detection should be determined. In determining the risk posed by such flaming hazards, a number of factors should be taken into account, including, but not limited to, the:

- a) nature of the anticipated fire (gas jet, liquid spray, pool fire, etc.) (see [7.2.2](#) and [7.2.3](#));
- b) burning characteristics of the material in the area (whether the processed material contains materials which burn with a unique characteristic making detection through optical means difficult, e.g. hydrogen) (see [7.2.4](#));
- c) escalation potential of a secondary fire, such as escalation potential associated with a particular piece of equipment or area, e.g. if a 100 kW RHO flame impinges a particular vessel, is there potential for escalation which would be unacceptable against the organization's risk philosophy, e.g. boiling liquid expanding vapour explosion (BLEVE);
- d) dimensions of the graded volume for a piece of equipment [e.g. at what distance from a vessel would the target fire (e.g. 100 kW) not lead to escalation]; and
- e) fire load/inventory size, e.g. fire duration.

Accounting for the factors in a) to e) allows the designer to apply escalation grades/performance targets (see [7.3.2](#)) when prescriptive measures are not applied.

7.2.2 Pool fire

Where an ignition occurs after the leak has accumulated as a liquid pool, a pool fire can occur. Pool fires either spread under gravity and reach an equilibrium pool size (where the burn rate of the fuel equals the spill rate) or are limited by geometric features local to the release (e.g. contained within a bund or the walls of a room).

Detectors should be placed to take account of the location of liquid inventories and the likely areas where leaks would accumulate, e.g. bunds, sumps, ditches, below grated decks.

7.2.3 Momentum driven jet/spray fire

Pressurized releases that ignite result in a momentum driven jet/spray fire. The jet can be either gas or liquid or a mixed phase resulting in a jet/spray fire. Secondary pool fires should also be taken into account.

Jet/spray fires can be in any direction as they typically occur due to the failure of flanges or instrumentation. Their momentum also means they are more susceptible to impingement on equipment and walls than pool fires. If conducting volumetric mapping, this should be taken into account when specifying the volume over which the detector coverage is assessed.

7.2.4 Spectral characteristics

Dependent upon the characteristics of the material burning, flame characteristics vary. Pool fires and jet/spray fires (gas, liquid, mixed) generate radiation to varying extents. The carbon content of the flame also has an impact on the capability of differing technologies to respond, and also impacts the response time of detection. Certain fuels that are free from impurities (e.g. methanol and hydrogen) burn "cleanly" with a flame colour with limited luminosity. The flames from these fuels might appear "invisible" to some technologies, so the detection characteristics for the expected fuel (including purity) should be determined and the technology selection (UV, IR or visual) should be suitable for the anticipated burning characteristics of the fuels of concern.

7.2.5 Environment

The environment in which optical flame detectors are to be applied should be taken into account, including seasonal weather conditions, e.g. will the detector operate in warm/cold temperatures, when there is fog/mist, when the sun is shining/modulating?

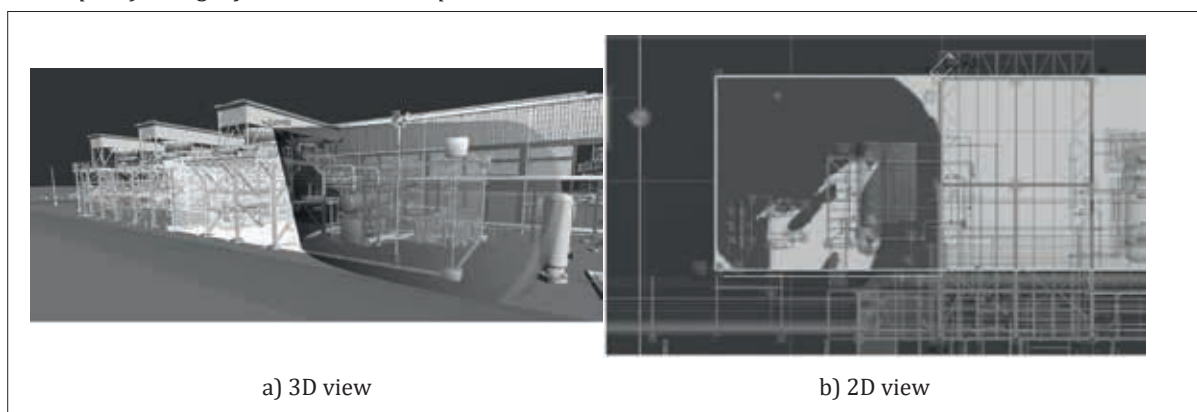
7.3 Flame detection

COMMENTARY ON 7.3

This subclause primarily addresses optical flame detection, however this does not repudiate taking credit for heat detection within the process area. Heat detection can be mapped in process areas, typically giving credit for coverage of the area in close proximity to the location of the sensors (see 6.2.3). This method of design needs to be reviewed against the risk assessment process and facility approach to risk (see Clause 4 and Clause 5), taking into account the reduced sensitivity and detection capability of heat detection in external areas.

An example detection envelope of a flame detector is shown in [Figure 5](#).

Figure 5 — Example of a single flame detector map shown in 3D and 2D views



7.3.1 Set points and voting

Flame detectors do not have set points and are binary in their response, i.e. they either generate an alarm or they do not. They do not respond to different RHO levels of a flame (in the way a gas detector provides different responses to %LEL). The differing level of RHO, however, allows detectors to be positioned closer to/further from the source depending on the target fire size. The multiples of RHO commonly seen (10 kW – 500 kW) should be calculated from a baseline sensitivity, e.g. the 1 ft² n-Heptane pan fire. This detection distance should then be extrapolated to larger or smaller fires using the inverse square law (see [7.3.7.1](#)) to provide an accurate measure of detection capability to the fire size of concern.

To minimize the potential for spurious trips within a mapping zone, detector voting can be employed. As an example, an alarm would be generated if gas was detected by one detector (100N, where N is the number of devices in the voting group) followed by an executive/control action on two detectors detecting the gas (200N).

NOTE Voting can also be applied when using multiple detectors at a specific point, e.g. 3 × smoke detectors located within a vent duct.

7.3.2 Graded volumes and performance standards

When conducting flame detection mapping it is typically necessary to define a target fire size. This can be based on protecting personnel, avoiding escalation, ensuring business continuity or protecting the environment. This fire should be justified based on the flammable materials handled in the area, the conditions of the process and the corporate approach to risk.

When selecting a target fire size, it should be noted that the geographic volume of a flame is not the only determinant of the escalation potential posed by a fire. A jet fire with the same base area as a pool fire provides significantly different consequences. The surface emissive power is, typically, higher for jet fires. For this reason, where the hazard is a flaming fire, a fire hazard can be defined by its RHO, specified in kW, which is verified by third-party certification testing (i.e. BS EN 54-10

and FM 3260 [4]). RHO provides a good indication of the potential damage and likelihood of escalation and loss.

NOTE 1 When applying RHO as a metric, the designer is required to implement an RHO value for the type of fire specified. There is no industry consensus or standard which specifies how to do this, but methods include extracting values from test burns, fire models, traditional fire dynamics calculations, etc.

Grades and performance standards should avoid using target fires which flame detectors have not been certified to detect (i.e. large fires which result in sensor saturation/blinding). The target fire sizes used in the placement of flame detectors are typically smaller than those associated with escalation, i.e. the intention is to detect the fire before escalation occurs, not to detect the fire which could credibly occur in a worst-case scenario. Care should be taken if determining the placement of flame detectors based on worst-case fires calculated as part of the predictive aspects of a *Control of Major Accident Hazards Regulations 1999 (COMAH)* [5] assessment or a fire risk assessment/quantitative risk assessment (QRA) conducted to support an offshore safety case. If detectors are located on this basis, smaller fires that could potentially cause escalation might not be detected, and the design could be based on fires the detectors are not certified or capable of detecting.

Multiple target fire sizes are often taken into account, including:

- a) target fire size for alarm (where the fire is not significant enough to result in automated actions and can be dealt with manually); and
- b) target fire size for executive action (when an operator can no longer be relied upon to initiate the mitigating action manually to reduce/prevent escalation, i.e. the fire has grown to a level where automated action is required).

These fire sizes have different values (based on RHO), e.g. an alarm is generated at 50 kW RHO fire and executive action at 100 kW RHO.

Where the escalation potential and methodology warrant it, graded volumes can be defined within the mapping zone. The size of the fire to be detected within the graded volume can be based on the escalation potential, if that fire occurs within that volume, allowing optimization of the layout, i.e. smaller fires can be targeted for high escalation areas.

Where the escalation potential and method warrant the application of graded volumes, representation should allow for presentation of coverage beyond a binary “coverage” or “no coverage” (e.g. a fixed XX m detection cone is rarely a suitable metric of coverage). To design a performance-based flame detection system based on a review of escalation potential there are multiple factors to take into account, including but not limited to percentage coverage of:

- 1) alarm only;
- 2) control action;
- 3) late alarm; and
- 4) minimal coverage to all target fire sizes.

NOTE 2 “Late alarm” represents a location where the target fire size for control action will be detected by two devices, however any smaller target fire size for alarm will not be detected to provide a fast response alarm without executive actions.

NOTE 3 “Minimal” coverage represents a location where the target fire size is not within range, but if it grows beyond the specified target, it will be detected by a single device (100N) as a clear line of sight exists to that point.

7.3.3 Prescriptive

Prescriptive flame detector mapping refers to the use of qualitative evaluation and judgement-based placement in the locating of flame detectors. Examples include:

- a) proven design that is reused for similar applications; in many instances this would not require a full modelling activity;
- b) prescriptive ruleset provided by the operator; compliance can be verified using a checkbox type review to ensure the rules are met; and
- c) for open facilities with minimal obstruction to the field of view, it might be sufficient to place detectors at the extremities of the area where fires could exist, taking account of the detector range.

Software flame and gas modelling tools and metrics (e.g. fire size/percentage coverage) are not required when using the prescriptive approach and compliance can often be checked using a checkbox-type approach against the rule set that has been employed.

7.3.4 Volumetric-based method

Volumetric-based mapping assesses the capability of a system to detect a fire of a certain size and presents the results in terms of the coverage of a given volume. The size of fire can be based on different methods, including effective viewing distance to the flame of specified size, or RHO of a fire.

Volumetric-based flame mapping is performed using software packages which verify the coverage achieved by the system.

The advantages of volumetric-based flame mapping include:

- a) 3D model can be applied for visualization purposes;
- b) information on process incorporated, e.g. heat and mass balance data, can be used to show stream pressure and composition which influences the potential for escalation and therefore the selected target fire size;
- c) no modelling of specific scenarios is required;
- d) analysis is relatively quick;
- e) consistent designs;
- f) easily audited;
- g) coverage can be validated against certified detection capability; and
- h) it is less subjective than scenario-based type approaches.

A disadvantage of volumetric-based mapping is that results can be influenced by the size of volume assessed, i.e. the designer can expand the graded volume into open space to increase the resulting percentage coverage achieved. [7.3.6](#) gives guidance on assessing adequacy and the issues surrounding the using percentage coverage as the sole metric of adequacy.

NOTE An example of volumetric-based flame mapping is given in [Annex B](#).

7.3.5 Scenario-based method

Scenario-based methods in the analysis of flame detection coverage are not commonly used due to a perceived lack of benefit for the additional complexity. Guidance on their application is therefore omitted.

7.3.6 Assessing adequacy of coverage for volumetric mapping

Where modelling is carried out, the resultant coverage should be reviewed for adequacy. The designer should assess the percentage coverage (if applicable) of each volume and determine if the coverage is acceptable.

Any predetermined target for coverage should not be used as a definitive pass/fail criterion. Percentage coverage alone might not be a suitable measurement against which to determine acceptable coverage in isolation.

It is important that each modelled volume is reviewed both in isolation and in the greater context of the facility to determine if the coverage is acceptable. This review process should have input from all relevant disciplines.

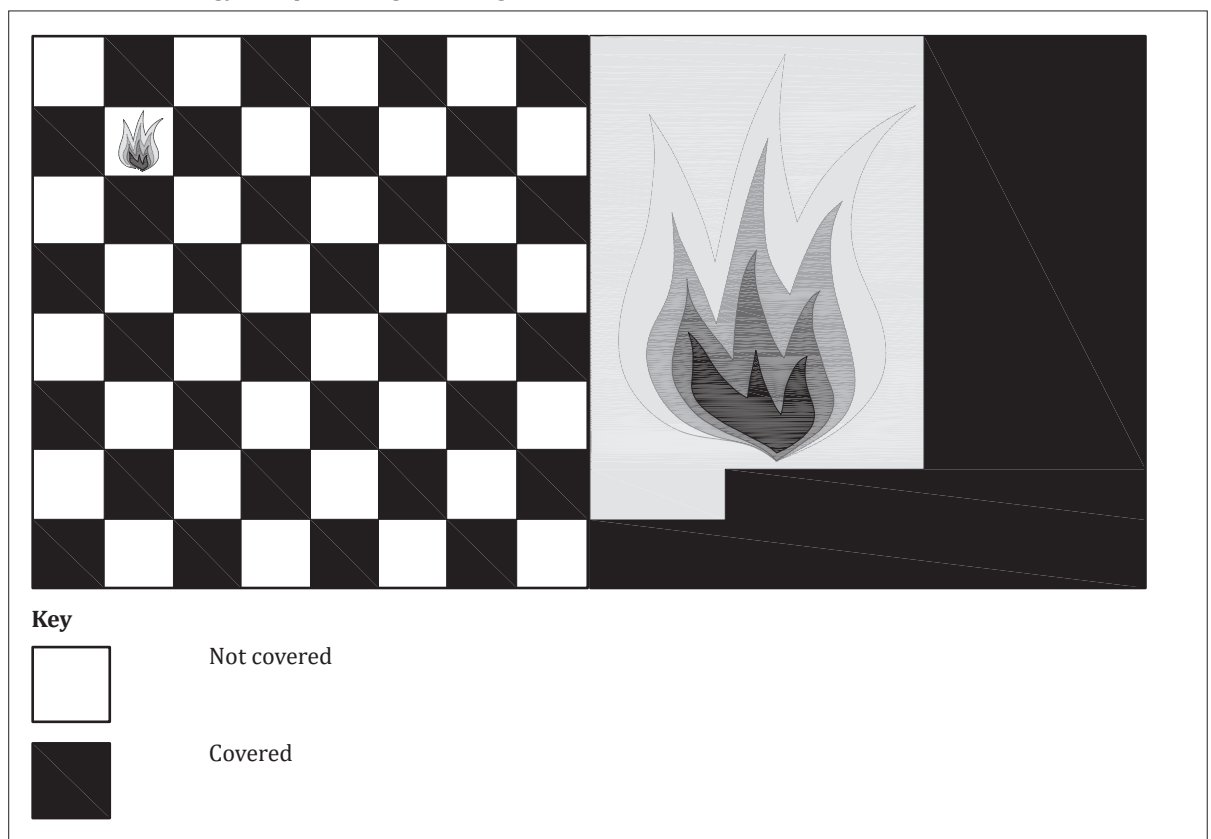
This approach ensures that:

- a) the project team are fully aware of any potential gaps in coverage, or areas where the system could be over-engineered; and
- b) the resultant design is appropriately optimized by reviewing areas of suitable coverage, blind spots where fires might remain undetected, and how each detector contributes to coverage.

Reviewing detector contributions allows the designer to identify when the point of diminishing returns is reached with respect to the addition of more detectors.

Alongside the concept of reducing the risk to ALARP, the addition of detectors should take into account the benefit in coverage provided for each additional device proposed. Percentage coverage alone is not a suitable metric for this (however it can be used as a guide), as the designer needs to review the nature of the area covered to determine if the cost of additional detectors is suitably offset by the reduced risk of a hidden fire at that specific location. This assessment of acceptability can change throughout the same volume, for varying degrees of percentage coverage achieved. For example, a device which provides only a 5% increase in coverage for an area where numerous fires can originate with significant escalation potential would be preferable over a detector which would provide an additional 10% coverage of an open area with limited escalation potential.

The deficiencies of analysing solely on percentage coverage are illustrated in two dimensions using the analogy of a chess board in [Figure 6](#). [Figure 6](#) shows that in both instances there is a 50% coverage. The example on the right, however, has much larger “gaps” and therefore a significant fire could go undetected. Percentage coverage can give an indicative metric for the effectiveness of fire detection systems but should not be used in isolation. The designer should review gaps in the detector layout, as these are the weak points, and assess if a fire could remain undetected at those locations.

Figure 6 — Chessboard analogy and percentage coverage

7.3.7 General considerations

7.3.7.1 Inverse square law

The inverse square law provides an approach that can be used to represent detection capability for a range of fire sizes. This allows multiple fire sizes to be included in a single assessment, if required, in accordance with 7.3.2. If multiple fire sizes are to be modelled, it is necessary to select tools/methods capable of calculating this, for example where a piece of equipment is assigned a graded volume to detect 10 kW for alarm (100N) and 100 kW for control action (200N). For a performance-based flame detection assessment, coverage should be calculated based on the inverse square law, not an assessment of a binary closed cone of vision.

7.3.7.2 Flame detection response time

Desired response time from the flame detector should be based upon the hazard intended to be detected and the escalation potential. Designers should ensure the response time is acceptable in allowing effective mitigation measures to be applied.

Designers should verify that the response time across the full claimed field of view is suitable. Any reduction in detection distance to meet the desired response time should be accounted for in the mapping where software modelling is carried out.

7.3.7.3 Point/volume source modelling

When mapping is carried out, flame detection can be modelled by mapping points in space, verifying if a clear line of sight exists to that point (point source modelling), or by representing the fire as a 3-dimensional shape (volume source modelling) and verifying that there is a line of sight between the detector and that volume or a portion of that volume.

Coverage represented using the point source approach requires a clear line of sight to the location of the targeted fire to be represented as successful detection. Engineering judgement is then applied to analyse adequacy of the layout and subsequent coverage (see 7.3.6).

Care should be taken when using volume source modelling as the result could differ depending upon flame detection technologies and/or models (e.g. the region of the electromagnetic spectrum the device operates, specific filters applied, signal processing firmware, burning fuel).

EXAMPLE Two “triple IR” flame detectors, despite being the same technology, might use different filters along the mid IR range (impacting solar blindness, sensitivity, false alarm immunity, etc.), analysing the signals received in a unique way. Where the flame volume is partially obscured by geometry, the features of the specific flame detector being modelled (including sensitivity to the portion of the flame visible, the environmental conditions of the facility and any desensitization the flame detector might be subjected to) should be taken into account.

NOTE These data are often protected by the flame detector manufacturer.

7.3.7.4 Detector sensitivity

The viewing characteristics of a flame detector typically presented by its manufacturer are those under ideal test conditions.

Each flame detection technology and model are desensitized in a unique way and, to a varying degree of severity, dependent upon the technology, model, facility and environment.

Calculation of the “in-field” viewing distance to a target fire (i.e. the 1ft² n-Heptane pan fire) should be taken into account. This is not the maximum viewing distance at which the detector detects a fire. The in-field detection distance should be a facility-tailored baseline sensitivity. If using a flame detector modelling tool, this value should be extrapolated to suit the grade on any given piece of process equipment/volume and its subsequent target fire size applying the inverse square law.

The following factors should be determined, as a minimum.

- a) Reduction in sensitivity to genuine flame in the presence of unwanted/false alarm stimuli. Values for this can be taken from the manufacturer or detector manual, if disclosed. Unwanted stimuli can include sunlight (direct, modulated, unmodulated, reflected), welding activities, blackbody radiation (modulated/unmodulated), florescent/incandescent lamps, shielded and unshielded quartz halogen lamps.
- b) Dirty optics. Optical fault occurs at a manufacturer-set degradation in field of view. The impact of dirty optics should be taken into account in the calculation of flame detection effectiveness. The maintenance periods and detection technology’s susceptibility to dirty optics can be taken into account in the value applied.
- c) The filter edge effect represents the reduction in sensitivity across the claimed field of view from the maximum at the centre line. This value should be justified from an analysis of the flame detector’s specific detection cone of vision as this differs between devices. If modelling is applied, this should account for the shape of the detector field of view. The filter edge effect can also have an impact on detection response time and affects devices in a unique way, dependent upon the filters and sensors used. The device manual and third-party certification data (i.e. FM approvals test report) should be consulted to review the impact of the filter edge effect on devices.

7.4 Fluid states and dispersion

7.4.1 General

Fluids vary in their nature dependent on their state, pressure and temperature. The nature of the fluid being released influences how the gas/vapour disperses and has a direct effect on where

gas/vapour accumulates and hence where detectors are placed. This is equally applicable to both flammables and toxic gasses. The different physical states are:

- a) a gas, which might be at an elevated temperature or pressure;
- b) a gas liquefied by the application of pressure, e.g. LPG, CO₂;
- c) a gas which can only be liquefied by refrigeration, e.g. methane; and
- d) a liquid with an associated release of flammable or toxic vapour.

In addition to fluid state, ventilation also affects where gas accumulates and how gas/vapour disperses to a safe limit (i.e. below the flammable or toxic limits). The different types of ventilation are:

- 1) local extract ventilation;

NOTE 1 This is generally installed local to a release point to remove gas/vapour and exhaust it to a safe location.

- 2) bulk mechanical ventilation;

NOTE 2 This is typically installed to ventilate rooms or enclosures and, if designed correctly, prevents dead spots (areas of low ventilation or recirculation) where clouds could accumulate, dilutes gas to a safe limit and/or exhausts it to a safe place. Bulk mechanical ventilation can influence detector placement as gas/vapours are likely to be carried by the flow, hence detectors need to be placed taking this into account.

- 3) natural ventilation;

NOTE 3 For enclosed plants, natural ventilation is provided by either flow-through louvres or advantageous openings around doors, windows or penetrations.

For open plants, the degree of natural ventilation depends on external buildings (if significant), large items of equipment, cladding and prevailing wind conditions.

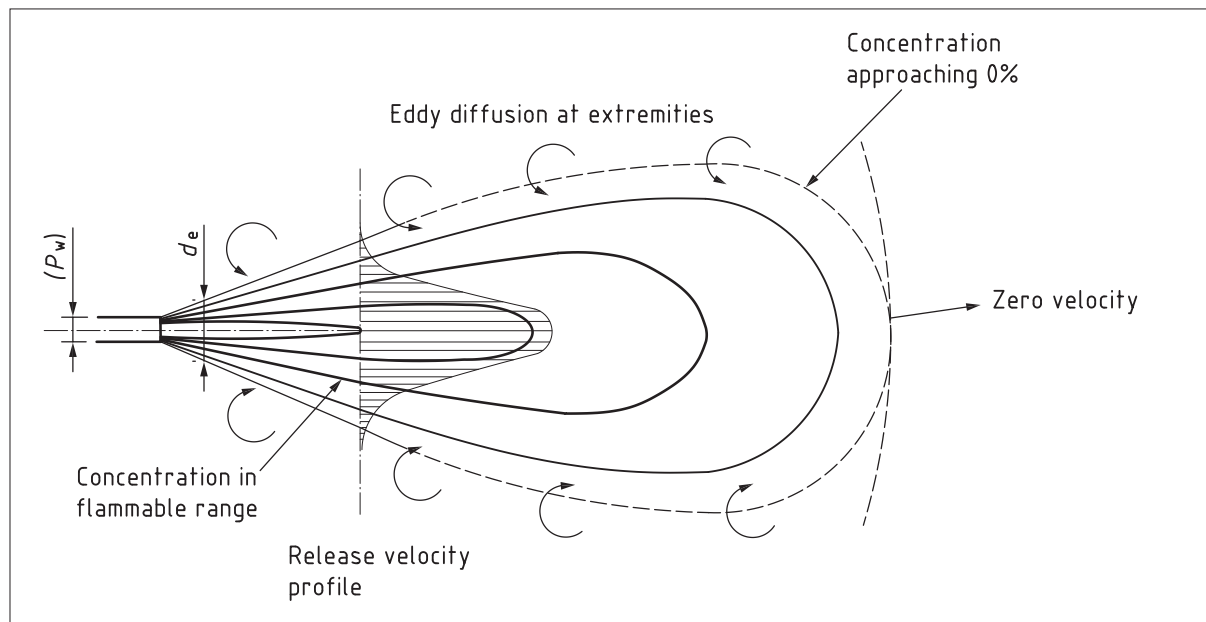
With respect to natural ventilation and the placement of detectors, the greater the natural ventilation, the more dilute the cloud and the "harder" it is to detect. Conversely, for a given release, the lower the consequence as the flammable cloud is smaller. Therefore, for a plant that has significant ventilation, detection might be impractical as it is unlikely to detect releases unless they are catastrophic.

Prior to detector mapping being carried out the nature of the release, ventilation and hazard range should be determined. The hazard range can be used to inform the maximum distance from any release point that detectors should be considered.

Accounting for the factors in 7.4.2 to 7.4.6 allows the designer to apply escalation grades/performance targets where prescriptive measures are not applied.

7.4.2 Gaseous releases

Gaseous releases result in a jet or plume, dependent on the storage pressure. Above the critical pressure the release is choked and a sonic jet forms; below the critical pressure the release forms a plume with the velocity dependent on the storage pressure. For unobstructed, external jet releases in the near field (i.e. close to the release) the dispersion is driven by the entrainment of air into the jet caused by the differential velocity between the jet and the surrounding air (see [Figure 7](#)).

Figure 7 — *Jet entrainment*

For plumes, velocities are lower and therefore entrainment due to differential velocity is lower and dispersion is governed by the bulk air flow (provided either naturally or via forced ventilation).

If releases impinge on geometry this reduces the momentum, and hence the velocity, leading to less entrainment of air, larger cloud sizes and a break-up of the jet/plume type structure. If releases are inside buildings, and the gas is not removed, there is the potential for gas to build up, leading to a background concentration of gas; this leads to larger cloud sizes as air that is entrained into the plume or jet already contains gas. Detectors should be placed in areas where gas is likely to accumulate based on the geometry and/or room. The buoyancy of the gas also affects the size, shape and location of where gas accumulates. Buoyancy tends to have more of an effect for plumes, obstructed or internal releases. For unobstructed jets, the momentum and direction of the release tends to dominate over any buoyancy affects.

7.4.3 Location of detectors near pressurized leak sources

Point detectors which are placed with the purpose of monitoring specific leak sources of pressurized gas should not be located too close to those leak sources.

A pressurized gas plume is narrow near the initial release point and expands with distance due to the air entrainment (see [Figure 7](#)).

Therefore, gas detectors (particularly if point detectors are used) are best placed some distance from the leak source – typically, detectors should be placed away from a collection of sources such as a skid with multiple flanges and instrument fittings (the distance to be agreed by the project team and justification documented). This is less applicable when a volumetric-based approach is applied in an area where there are leak sources across the mapping zone.

If pellistor point detection is used, the gas plume is oxygen-deficient prior to air entrainment. Pellistor detectors require the presence of oxygen to function and have poor performance in the gas-rich zone close to the leak point.

7.4.4 Gases liquefied by the application of pressure

For gases liquefied by pressure (e.g. propane and butane), an aerosol is formed on release. The aerosol is made up of droplets of varying sizes. Small droplets might vaporize, forming a flammable cloud, whereas larger droplets might coalesce and rain out onto the ground, forming a pool. The pool