Review of alarm setting for toxic gas and oxygen detectors

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Toxic gas and oxygen deficiency detectors are commonly used throughout the workplace to warn of potentially harmful exposure to personnel, and of dangerous gas leaks. The detectors employed to perform these tasks are personal (worn in the breathing zone, eg on the upper lapel), portable (typically hand-held or worn on a belt) and fixed (typically connected to a control and warning system). Carbon monoxide alarms are also employed in domestic premises to warn of carbon monoxide leaks.

Current knowledge on alarm setting for toxic gas detectors was reviewed by a literature survey and consultation with stakeholders (eg HSE, various industries, gas detector manufacturers). The purpose of this review was to develop a framework for guidance on alarm setting for toxic gas detectors as information is lacking on the rationale behind setting alarm levels. The available guidance was summarised, the factors which influence the alarm setting process identified, and recommendations made on how this process should be conducted.

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Acknowledgements

I would like to thank my HSE colleagues and various representatives of the industry, including various companies and gas detector manufacturers - both individuals and their trade organisation, CoGDEM, for their help.
KEY MESSAGES

Toxic gas detectors are commonly used throughout the workplace to warn of potentially harmful exposure to personnel and dangerous gas leaks; they play a valuable role in risk mitigation. They are also employed in a domestic environment, principally for the detection of carbon monoxide.

Some specific guidance exists in HSE publications and British/European standards for certain gases and industries. However, information is lacking on the rationale behind setting alarm levels.

Various factors relating to the characteristics of a toxic gas release and the detector itself should be considered when setting alarm levels for toxic gas detectors to minimise risk of potentially dangerous exposure levels to personnel in a particular area of the workplace (or domestic environment). In many situations, however, discussion of these factors either does not occur at all or is extremely brief, and “default” alarm set-points are typical used. These values may be appropriate for the task required, i.e. to satisfy the risk assessment or safety case; indeed some are specified in guidance or standards for certain gases and applications. However, a more thorough analysis of requirements and the actual circumstances would prove beneficial and is likely to lead to more robust risk assessment and mitigation. This analysis should be documented as part of the risk assessment.

An occupational exposure level (OEL), e.g. Workplace Exposure Limit (WEL) listed in EH40, a company specified value, should be the starting point for setting alarm levels for a particular individual gas or gas mixture, assuming one exists. The characteristics of the toxic gas risk, which the detection system (the levels may be different whether fixed or portable toxic gas detection is used) is there to mitigate, should then be considered. The factors which may influence the decision to change the alarm levels are as follows:

- The source(s) characteristics and potential rate of toxic gas build-up.
- Whether egress is difficult and/or takes an especially long time or emergency conditions;
- Background variations and events from the process and instrumental effects, which may trigger “spurious” alarms;

This assessment may influence any initial (default) alarm set-points: the values could remain the same, decrease or possibly increase, especially for fixed gas detectors.

Setting alarm points should not be “fit and forget”. Initial alarm set-points may be adjusted either up or down in the light of experience in the environment, i.e. process-related events and instrument characteristics. This requires analysis of the data over a suitable period.

The information in this report should form a basis for updated HSE guidance, and be proffered for discussion at the appropriate European standards committees updating the guide for use of toxic gas detectors in the workplace (BS EN 45544-4 : 2000).
EXECUTIVE SUMMARY

Toxic gas and oxygen deficiency detectors are commonly used throughout the workplace to warn of potentially harmful exposure to personnel and dangerous gas leaks. The detectors employed to perform these tasks are personal (worn in the breathing zone, e.g. on the upper lapel), portable (typically hand-held or worn on a belt) and fixed (typically connected to a control and warning system). They are also employed in a domestic environment, principally for the detection of carbon monoxide.

The objective of this study was to review current knowledge on alarm setting for toxic gas detectors by a literature survey and consultation with stakeholders (e.g. HSE, various industries, gas detector manufacturers) in order to develop a framework for guidance. The approach adopted was to summarise currently available guidance, identify and discuss the factors which influence the alarm setting process and then summarise the findings leading to various recommendations on how this process should be conducted.

Guidance currently exists on the HSE website for setting alarm levels for predominantly flammable gas detectors. Similar guidance does not exist, however, for toxic gas detectors, although alarm levels are specified for a limited number of gases in specific industries, e.g. chlorine plants, hydrogen sulphide offshore. There is a need, therefore, to produce a framework by which the actual intended function of the toxic gas detection system can be established and, following on from that, which factors need to be considered to set appropriate alarm levels in order to carry out detection and warning.

Specific levels for setting alarms for toxic gas detectors are referred to in a few British/European standards relating to refrigerants, hydrogen sulphide offshore and various toxic gases and oxygen encountered in tunnels. However, guidance in standards, e.g. BS EN 45544-4 relating to toxic gas detectors, is not comprehensive enough. While each application of toxic gas detector is usually different from the others, general background information and guiding principles would assist HSE inspectors and safety practitioners. This study reviews previous guidance and then identifies the factors which need to be considered when setting alarm levels for toxic gases.

Various factors relating to the characteristics of a toxic gas release and the detector itself should be considered when setting alarm levels on toxic gas detectors to minimise risk of potentially dangerous exposure levels to personnel in a particular area of the workplace. In many situations, however, discussion of these factors either does not occur at all or is extremely brief, and “default” values are typical used. While these values may well be adequate for the task required, i.e. to satisfy the risk assessment or safety case, a more thorough analysis of requirements and the actual circumstances would prove beneficial and is likely to lead to more robust risk assessment and mitigation.

The following factors relating to setting an alarm should be considered when installing and using any type of gas detector:

1. Whether detectors should be fixed and/or whether personnel should be issued with portable, which includes personal, detectors;

2. The location of the fixed detector and whether the work area is occupied or unoccupied;

3. Whether the fixed detector is a point or open-path (also known as beam or line of sight detectors) detector;
4. Whether egress is difficult and/or time-consuming or there is an emergency;
5. Whether Workplace Exposure Limit (WELs), other Exposure Limit values or other health-based levels (e.g. Immediate Danger to Life and Health - IDLH) exist;
6. Instantaneous or time-weighted average (TWA) alarm;
7. Background variations and events from the process, which may trigger “spurious” alarms;
8. Effects of interferents;
9. False alarms caused by instrumental effects;
10. The potential rate of gas build up (considering short-term peaks in point 7);
11. Time to alarm of the detection system;
12. Number of alarm levels (e.g. high and low levels);

Additionally, two vital requirements also need to be fulfilled: maintenance of gas detectors (including function checks/bump tests and calibration), to help ensure they alarm when they should and don’t alarm when they shouldn’t; and training of operatives to help ensure that they know how to use the detector correctly and act appropriately in the event of alarm activation.

The OEL, either official or a company specified value, should be the starting point for setting alarm levels for a particular individual gas or gas mixture. The characteristics of the toxic gas risk, which the detection system (the levels may be different whether fixed or portable toxic gas detection is used) is there to mitigate, should then be considered. The factors which may influence the decision to change the alarm levels are summarised thus:

- The source(s) characteristics and potential rate of toxic gas build-up.
- Whether egress is difficult and/or takes an especially long time or emergency conditions;
- Background variations and events from the process and instrumental effects, which may trigger “spurious” alarms;

This assessment may influence any initial (default) alarm set-points: the values could remain the same, decrease or possibly increase, especially for fixed gas detection.

Setting alarm points should not be “fit and forget”. Initial alarm set-points may be adjusted either up or down in the light of experience in the environment, i.e. process-related events and instrument characteristics. This requires analysis of the data over a suitable period.

The information in this report should form the basis for updated HSE guidance, and be put forward for discussion at the appropriate European standards committees updating the guide for use of toxic gas detectors in the workplace (BS EN 45544-4).
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1. INTRODUCTION

1.1 BACKGROUND

Toxic gas detectors are commonly used throughout the workplace to warn of (a) potentially harmful exposure to personnel and (b) gas leaks. The detectors employed to perform these tasks are personal (worn in the breathing zone, e.g. on the upper lapel), portable (typically hand-held or worn on a belt) and fixed (typically connected to a control and warning system). They can be used for a variety of purposes, including the following where alarms are incorporated into the detector:

- providing warning of a situation which is potentially hazardous;
- measurements in confined spaces;
- testing the effectiveness of health-risk control measures;
- fixed (also known as area or static) monitoring;
- boundary fence monitoring;

Further information on their characteristics and use can be found, for example, in the BS EN 45544 (2000) series, BOHS (2011), Chou (2000), CCPS (2009).

Toxic gas detectors are also used in domestic premises, where they are usually known as CO alarms, to warn of carbon monoxide leaks, for example, from fuel burning appliances.

Flammable gas detectors, which are often used in conjunction with toxic gas detectors, provide a safety warning based on the lower flammable limit (LFL also known as the LEL - lower explosive limit, usually expressed as a percentage), typically around 10-30% LFL (HSE, 2001a). This type of alarm is a simple volume ratio (“concentration”) threshold. Toxic gas detector alarms can be more complex: in addition to a simple threshold for warning of potentially dangerous gas leaks, there is also the facility, for use when providing a health warning, to employ time-weighted average (TWA) alarms which are related to the workplace exposure limits (WELs) defined in COSHH and EH40 (HSE, 2005). Fixed and portable (including personal) toxic gas monitors have somewhat different roles relating to their use as leak detectors and personal monitors respectively.

Guidance currently exists on the HSE website for setting alarm levels for predominantly flammable gas detectors (HSE, 2001a; HSE, 2001b; HSE, 2004). Similar guidance does not exist, however, for toxic gas detectors, although alarm levels are specified for a limited number of gases in specific industries. HSE guidance on monitoring strategies for toxic substances (HSE, 2006a) relates to occupational hygiene measurements. Here, alarms are mentioned in the context of fixed place monitoring: the guidance advises that fixed place sampling can be taken when continuous monitoring alarm systems are installed.

There is a need, therefore, to produce a framework by which the actual intended function of the toxic gas detection system can be established and, following on from that, which factors need to be considered to set appropriate alarm levels in order to carry out that function. Guidance in standards, eg BS EN 45544-4 (BSI, 2000), tends to be very general and not very practical for the average user. While each application of toxic gas detector is usually different from the others, general background information and guiding principles would assist HSE inspectors and safety practitioners.
1.2 SCOPE

The scope of this review is setting alarm levels for toxic gas detectors used in the workplace for protection of personnel. It does not include discussion of the location of toxic gas detectors and handling of such alarms. Toxic gas detector placement is generally discussed, for example, in BSI (2000) and CCPS (2009), while alarm handling is addressed in guidance such as HSE (2000) and EEMUA (1999).

1.3 OBJECTIVES

The objective of this review is to review current knowledge on alarm setting for toxic gas detectors by a literature survey and consultation with stakeholders (eg HSE, various industries, gas detector manufacturers) in order develop a framework for guidance.
2. IMPLICATIONS

Some specific guidance on alarm setting for toxic gas detectors exists in HSE publications and British/European standards for certain gases and industries. However, information is lacking on the rationale behind setting an alarm level or levels which could then be applied to many other situations. This has implications for assessing the effectiveness of alarm levels: are they adequate, are the instruments capable of reliable alarming at these levels, will they provide protection for the specific circumstances of their environment, and can the risks be reduced further by a more thorough analysis of the factors involved in alarm setting.

Various factors listed in this report should be considered when setting alarm levels on toxic gas detectors to minimise risk of potentially dangerous exposure levels to personnel in a particular area of the workplace. In many situations, however, discussion of these factors either does not occur at all or is extremely brief, and “default” values are typical used. While these values may well be adequate for the task required, i.e. as part of the risk assessment or safety case, a more thorough analysis of requirements and the actual circumstances should prove beneficial and is likely to lead to more robust risk assessment and mitigation.

This report has identified gaps in HSE guidance and also in British/European standards such as BS EN 45544-4 (Guide for use of toxic detectors in the workplace). It would be of benefit if the information in this report was used as the basis for the revision of these guidance documents.
3. METHODOLOGY

This report was compiled using references obtained from a literature search conducted by HSE’s Information Centre, which included internet searches on Google and Google Scholar. Further information was obtained from discussions with HSE Inspectors, and industry representatives – process control experts, occupational hygienists; gas detector manufacturers - both individuals and their trade organisation CoGDEM.
4. CURRENT GUIDANCE ON ALARM SETTING

4.1 GENERAL

The use of toxic gas detectors including their alarms for workplace safety is subject either directly or, more usually, indirectly to legislation augmented by codes of practice; British, European or worldwide standards; industry guidance which can be produced by industry trade associations or expert groups and individual companies. The current regulations and corresponding guidance is reviewed, though not exhaustively, in 4.2 and 4.3.

Toxic gas detectors, specifically for carbon monoxide (CO), are also used extensively in the domestic environment, for example in houses, flats, residential homes, caravans, boats. This aspect is covered in 4.4.

4.2 WORKPLACE REGULATIONS

There are several principal regulations that are concerned, either solely or in part, with preventing, controlling or mitigating the effects of exposure to toxic gases/vapours. Gas detectors and their associated alarms play a role in controlling exposure. The relevant regulations with their approved codes of practice include:

- COSHH Regulations and Approved Code of Practice. The central requirements are:
  - regulation 6(1) - carry out a suitable and sufficient assessment of the risks to the health of your employees and any other person who may be affected by your work, if they are exposed to substances hazardous to health;
  - regulation 7(1) - ensure that exposure is prevented or, when this is not reasonably practicable, adequately controlled;
  - COSHH Approved Code of Practice states that monitoring is required when:
    - failure or deterioration of the control measures could result in a serious health effect;
    - when measurement is needed to ensure a WEL or any self-imposed (in-house) working standard is not exceeded; or
    - as an additional check on the effectiveness of any control measures provided in accordance with regulation 7, and always in the case of the substances or processes specified in Schedule 5 to the Regulations;
    - when any change occurs in the conditions affecting employees’ exposure which could mean that adequate control is no longer being maintained.

- Confined Spaces Regulations (CSR) and Safe Work in Confined Spaces ACOP - In the Approved Code of Practice, Regulations and Guidance, testing/monitoring the atmosphere is included in the elements to consider when designing a safe system of work which may form the basis of a permit to work. For those people who must work within a confined space, this section of the ACOP covers the procedures that must be followed prior to and during entry and includes paragraphs on testing and monitoring the atmosphere. Following the risk assessment, the atmosphere may need to be tested
for the presence of hazardous gas or deficiency of oxygen. Regular monitoring of the atmosphere may be necessary, especially where forced ventilation is being used or where the work activity could give rise to changes in the atmosphere. Guidance is given on the techniques which can be used to test the atmosphere and specific mention is made of portable atmospheric monitoring equipment (gas detectors) and that these will need to be approved for use in flammable atmospheres.

- COMAH - Safety reports must specify details of measures to limit the consequences of any major accident that may occur. Such mitigation methods may include gas detection. The HSE COMAH Technical Measures Document on Leak Detection (HSE, 2012) briefly refers to issues surrounding the detection of leaks and gases. The contributory factors for an assessor to consider concerning leak/gas detection include the types of protective devices linked to the detection systems including alarms. Also mentioned under Major Hazards, is that the Safety Report should address, amongst other items, whether the detector fails to detect in time (i.e. response time of instrument and/or response to high reading/alarm failing to prevent a major accident), and whether alarms, warning devices and protective devices fail to operate on demand.

- Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations 1995 (PFEER) and the associated Approved Code and Practice and Guidance, (HSE, 1997) - Regulation 10 Detection of incidents. The duty holder shall take appropriate measures with a view to detecting fire and other events which may require emergency response, including the provision of means for detecting and recording accumulations of flammable or toxic gases.

4.3 WORKPLACE GUIDANCE

4.3.1 HSE

HSE guidance on alarms for specific toxic gases is summarised in Table 1; it relates to fixed detectors for chlorine and offshore hydrogen sulphide.

As stated in the Background, there is no HSE general guidance on setting toxic gas alarms, however HSE guidance (HSE, 2004) on alarm setting for flammable gas detectors contains general principles, which can be applied to toxic gas detectors. For example, the gas detector should be set to alarm at a level low enough to ensure the health and safety of people but high enough to prevent false alarms. False alarms are most likely to be caused by fluctuations in sensor output due to environmental changes (e.g. ambient temperature, pressure or humidity), sensitivity to other gases or vapours, or sensor drift. In determining the required alarm levels for fixed gas detection systems, the following should be taken into account:

- any industry standards and recommendations;
- the lower explosion limit of the gas or vapour;
- the size of the potential leak and the time to reach a hazardous situation;
- whether the area is occupied;
- the time required to respond to the alarm;
- the actions to be taken following the alarm;
- the toxicity of the gas or vapour.
Relating to fixed detectors, “a suitable safety margin should also be incorporated to account for ventilation dead spots, where vapours could accumulate, and the variability of natural ventilation.”
### Table 1 Specific HSE guidance on alarm setting for toxic gases and oxygen deficiency

<table>
<thead>
<tr>
<th>Gas</th>
<th>Use/Occurrence</th>
<th>Guidance document</th>
<th>Alarm level</th>
<th>Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorine</td>
<td>Bulk chlorine installations</td>
<td>HSG28</td>
<td>Low: 1-5 ppm</td>
<td>The detector system should activate the low level alarm at a chlorine concentration of 1-5 ppm. Lower settings are liable to activate the system at every tank-filling operation, unless a duration requirement is also imposed. For example, some companies set the low level alarm at 0.5 ppm, but require the sensor to register this concentration for at least 30 seconds, to avoid spurious trips of the alarm system during filling operations. For indoor installations, the low alarm level should activate the ventilation fan, open the intake louvers, and activate local audio alarms and any remote telemetry alarm. Multi-stage detector systems are sometimes used to give an indication of the severity of the malfunction to personnel outside a chlorine room. It is suggested that the high level alarm operates at about three times the level of the first-stage alarm, ie 3-15 ppm, depending on the duration that the sensor needs to register this level. However, some companies set the high level alarm at 2 ppm with a 30 second duration requirement.</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Chlorine in cylinders (ie receptacles of 33 kg to 73 kg capacity) and drums (ie receptacles of about 870 kg to 1 tonne capacity). It does not deal with the bulk handling of chlorine,1 or with the smaller cylinders used mainly in laboratories.</td>
<td>HSG40</td>
<td>Low: 1-5 ppm, High: 3-15 ppm</td>
<td>The detector system should activate the low level alarm at a chlorine concentration of 1-5 ppm. Lower settings are liable to activate the system at every drum/cylinder change, unless a duration requirement is also imposed. For example, some companies set the low-level alarm at 0.5 ppm, but require the sensor to register this concentration for at least 30 seconds, to avoid spurious trips of the alarm system during the changing of containers. The low alarm level should activate the ventilation fan, open the intake louvres, and activate the local audio and visual alarms and any remote telemetry alarm. Multi-stage detector systems are sometimes used to give an indication of the severity of the malfunction to personnel outside the chlorine room. These systems are recommended at larger</td>
</tr>
</tbody>
</table>
Table 1 Specific HSE guidance on alarm setting for toxic gases and oxygen deficiency

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<tr>
<th>Gas</th>
<th>Use/Occurrence</th>
<th>Guidance document</th>
<th>Alarm level</th>
<th>Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen sulphide</td>
<td>Sour production on offshore platforms</td>
<td>HSE Offshore Information Sheet No. 6/2009 (Issued April 2009) Managing hydrogen sulphide detection offshore</td>
<td>Low: 10 ppm High: 15 ppm</td>
<td>installations. It is suggested that the high-level alarm operates at about three times the level of the first-stage alarm, ie 3-15 ppm, depending on the duration that the sensor needs to register this level. Some companies set the high-level alarm at 2 ppm with a 30 second duration requirement. See BS EN ISO 10418 Offshore process safety in Table 2.</td>
</tr>
</tbody>
</table>

If \( \text{H}_2\text{S} \) concentrations in the process stream are known to be less than 500 ppm fixed flammable-gas detection can be used to indicate a potential toxic gas hazard. Flammable-gas detectors are normally set to alarm at 20 % methane LFL (i.e. 1 % methane in air). If a hydrocarbon gas containing 500 ppm of \( \text{H}_2\text{S} \) is diluted to 1 % in air, the corresponding \( \text{H}_2\text{S} \) concentration in the atmosphere will be 5 ppm. Therefore, the flammable-gas detector will signal alarm before the \( \text{H}_2\text{S} \) concentration in the atmosphere reaches the OEL.

For \( \text{H}_2\text{S} \) concentrations in the production streams exceeding 500 ppm, fixed \( \text{H}_2\text{S} \) detectors should be installed. Detection of 10 ppm of \( \text{H}_2\text{S} \) gas in the atmosphere should initiate audible and visual alarms in the area where the gas has been detected, any adjacent areas where personnel may need to take executive action on detection of \( \text{H}_2\text{S} \) and the facility's control room. Detection of 15 ppm of \( \text{H}_2\text{S} \) gas in the atmosphere should initiate an audible general platform alarm and a visual alarm, as most appropriate for the area where in which the gas has been detected. |
HSE (2004) also states that setting two alarm levels may be an advantage in some cases. The procedure at the lower-level alarm could be for personnel to stop their work, put on respiratory protective equipment (RPE), and investigate the problem to determine if it can be easily rectified. The procedure at the higher-level alarm could be to initiate emergency procedures such as shutting the plant down and/or evacuating the building or site.

HSE guidance for portable gas detectors (HSE, 2001a) covers similar ground. It lists various examples of situations where portable toxic gas detectors are used:

- “To routinely check levels of toxic gas/ vapour over a wider area from a known source, e.g. landfill gas from a landfill cell gas extraction vent.

- In emergency situations to locate a suspected toxic gas/ vapour leak from pipework and equipment, e.g. natural gas pipework. In such a situation, and in confined spaces (see below), a risk assessment should be carried out to determine whether gas monitoring is the correct method of leak detection and any precautions that should be taken, e.g. the instrument user may need to wear breathing apparatus.

- In emergency situations to check levels of toxic gas/ vapour over a wider area from a known leak. An example would be to check concentrations in a plant area when a known leak has occurred on a pressurised liquid or gas pipeline in order to determine exclusion zones.

- To check the atmosphere in confined spaces both prior to entry into the confined space and at intervals specified on the entry permit. Initial monitoring should be done, where possible, from outside the space with the sample tube inside”.

Additionally, the guidance states:

“In determining the required alarm level for oxygen concentration the following should be taken into account: For oxygen deficient atmospheres: health effects of reduced oxygen concentration, possible cause of reduced concentration (e.g. leak of another gas), time and method of response to the alarm (e.g. time taken to make the area safe and/or evacuate), and any industry standards…”

In all cases alarm levels should be set with sufficient safety factors included to account for poor mixing of gases. This should ensure that a hazardous atmosphere does not exist anywhere in the area being monitored…

Fixed detector systems can be designed to trigger automatic shutdown of plant and equipment or to increase mechanical ventilation rates…

The response time should also be considered in conjunction with the alarm level. For example, a longer response time may be acceptable, if the system alarms to evacuate at 10% LEL rather than 25% LEL, for the same gas leakage rate and detector position.”

The above guidance is echoed in HSE guidance (HSE, 2001b) for fixed flammable gas detectors.

Note that in underground coalmines, fixed carbon monoxide detectors (i.e. monitoring in the general body of the mine) are used for fire detection, including spontaneous combustion purposes. Fixed point CO detectors have warning and alarm levels set on a site by site basis within the mine to shadow the background reading. For hand held portable monitors, the alarm
would generally be set at 10 ppm to avoid the alarm continuously sounding, which is below the 8-hr WEL of 30 ppm in order to provide a more advanced warning of fire.

4.3.2 Standards

Specific levels for setting alarms for toxic gas detectors are referred to in various British/European standards. A non-exhaustive list of gases for which alarm levels have been specified but including some of the principal gases used in major industries, is shown in Table 2.

The most relevant standard for toxic gas detectors is the BS EN 45544 (2000) series “Workplace atmospheres - Electrical apparatus used for the direct detection and direct concentration measurement of toxic gases and vapours.”

In Part 1: General requirements and test methods, tests are specified for checking that the alarms activate at a test gas mixture equivalent to 120 ± 10% of the volume ratio corresponding to the alarm set point.

In Part 4: Guide for selection, installation, use and maintenance, the standard states “For operation of fixed apparatus: Alarm set points should be as low as possible taking into consideration the need to avoid false alarms. Adjustments should be carried out in accordance with the manufacturer’s instructions”. And “Many types of electrical apparatus are fitted with visual and audible alarms to warn the operator of high concentrations of toxic gases and vapours. Industrial processes vary widely and there are also widely different lighting and noise environments. It is important that the operator checks that the warning indicators can be seen and/or heard in the actual working conditions”.

There is no guidance, however, on setting alarm levels because, as stated earlier, the general view was that it was not possible to give any more specific advice due to the differing circumstances of operation.
### Table 2 BSI standards guidance on alarm setting for toxic gases and oxygen deficiency

<table>
<thead>
<tr>
<th>Gas</th>
<th>Use/Occurrence</th>
<th>Guidance document</th>
<th>Alarm level</th>
<th>Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia (Refrigerant R717)</td>
<td>Refrigerant</td>
<td>BS EN 378-1:2008</td>
<td>N/A</td>
<td>In the case of refrigerants with a characteristic odour at concentrations below the ATEL/ODL e.g. ammonia, detectors are not required for toxicity.</td>
</tr>
<tr>
<td>Refrigerants (without a characteristic odour at concentrations below the ATEL/ODL)</td>
<td>Refrigerant</td>
<td>BS EN 378-1:2008</td>
<td>50% ATEL/ODL (Values for refrigerants given in BS EN 378-1 Annex E)</td>
<td>Refrigerant detection systems shall be fitted in machinery rooms for any refrigerants in order to raise alarms and initiate ventilation if the levels rise to 25 % of the LFL or 50 % of the ATEL/ODL. ATEL (Acute toxicity exposure limit) is defined in BS EN 378-1 F.3.2.2.</td>
</tr>
<tr>
<td>Hydrogen sulphide (H₂S)</td>
<td>Sour production on offshore platforms</td>
<td>BS EN ISO 10418 Offshore process safety</td>
<td>Low: 10 ppm High: 15 ppm</td>
<td>If H₂S concentrations in the process stream are known to be less than 500 ppm fixed flammable-gas detection can be used to indicate a potential toxic gas hazard Flammable-gas detectors are normally set to alarm at 20 % methane LFL (i.e. 1 % methane in air). If a hydrocarbon gas containing 500 ppm of H₂S is diluted to 1 % in air, the corresponding H₂S concentration in the atmosphere will be 5 ppm. Therefore, the flammable-gas detector will signal alarm before the H₂S concentration in the atmosphere reaches the OEL. For H₂S concentrations in the production streams exceeding 500 ppm, fixed H₂S detectors should be installed. Detection of 10 ppm of H₂S gas in the atmosphere should initiate audible and visual alarms in the area where the gas has been detected, any adjacent areas where personnel may need to take executive action on detection of H₂S and the facility's control room. Detection of 15 ppm of H₂S gas in the atmosphere should initiate an audible general platform alarm and a visual alarm, as most appropriate for the area where in which the gas has been detected. Where the atmospheric monitoring equipment does not have the capability for multiple level alarms the alarm settings and response should be as for Level 2 Alarms. In tunnels where the risk assessment shows that sudden change in levels of atmospheric contamination are unlikely to occur, a 2-stage</td>
</tr>
<tr>
<td>Toxic gas (typically CO, H₂S, oxides of nitrogen)</td>
<td>Tunnelling</td>
<td>BS 6164 : 2011</td>
<td>Low: 50% STEL High: 100% STEL</td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>Use/Occurrence</td>
<td>Guidance document</td>
<td>Alarm level</td>
<td>Guidance</td>
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<tr>
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<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Oxygen (deficiency)</td>
<td>Tunnelling</td>
<td>BS 6164 : 2011</td>
<td>Low: 19.5%</td>
<td>Low alarm: there is a threat to safety from the atmosphere but it remains safe without donning a self-rescuer and evacuating. Action should be taken to ascertain the cause of the threat and put mitigating measures in place.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>High: 19%</td>
<td>High alarm: there is an atmospheric problem. The tunnel should be evacuated in accordance with the emergency plan. Self-rescuers should be worn immediately.</td>
</tr>
</tbody>
</table>
4.3.3 Learned bodies

Gas detection alarm set points are covered to some extent in the joint CCPS (Centre for Process Chemical Safety of the American Institute of Chemical Engineers) and AIHA (American Industrial Hygiene Association) publication on continuous monitoring for hazardous material release (CCPS, 2009). For continuous monitoring of toxic gases in the semiconductor industry, it states that the alarm level should be based on the IDLH (Immediately Dangerous to Life and Health) which is a volume ratio defined by NIOSH in the USA relating to use in assigning respiratory protection equipment and the effects which might occur as a consequence of a 30 min exposure i.e. providing the time to don RPE and escape (NIOSH, 1995). Specific alarm levels are listed in CCPS (2009): The maximum low level alarm shall be set based on half of the IDLH. The maximum high level alarm shall be set at the IDLH for toxic gases, depending on the detection range constraints. Some values of IDLH for commonly encountered gases are listed in Table 4 in Section 5.

4.3.4 Industry

4.3.4.1 Petrochemicals offshore and onshore: hydrocarbon narcosis

Most VOCs or hydrocarbons are harmful long before they are at a combustible concentration; typically 10% LEL is the alarm point, potentially giving rise to a number of health effects on inhalation including nausea, headache, dizziness, and narcosis up to asphyxiation at higher concentrations. Such exposures could also lead to functionality impairment (intoxication), which could compromise the individual and others’ safety. The reciprocal calculation procedure (RCP) for estimating exposure limits for mixtures of hydrocarbon solvents is given in EH40 (HSE, 2005). Hydrocarbons are grouped into normal and branched chain alkanes, cycloalkanes and aromatics, but these groups exclude certain specific compounds. This allows calculation of an occupational exposure limit in units of mg/m$^3$ if the percentages of each group in the mixture and the WELs of individual compounds are known. While quantitation of the mixture and comparison with the RCP-derived exposure limit is possible using a sampling device, it is, however, much more difficult to specify an alarm level based on this exposure limit for a fixed or portable gas detector, calibrated in ppm or %LEL for a particular gas.

A detailed analysis of hydrocarbon toxicity (Energy Institute, 2010) recommended that alarms could be set at approximately 10% LEL for individual hydrocarbons (alkanes, cycloalkanes, aromatics), or their mixtures. This would then provide a window of around 15 min in which to don RPE and subsequently escape or investigate the cause. Compared with health-based IDLHs, this is probably a conservative alarm threshold for most hydrocarbons.

4.3.4.2 Brewing and beverages: carbon dioxide

In the brewing and drinks industries, typical values used for fixed carbon dioxide detector alarms are 0.5% for a low level alarm and 1.5% for a high level alarm, i.e. at the WEL values for long-term exposure limit (LTEL) and short-term exposure limit (STEL) respectively. However, alarms in cellars can be set at 4% as the high level to warn that the worker should exit the cellar while the low alarm can be set at 1.5% as 0.5% can result in “spurious” alarms.
4.3.5 Gas detector manufacturers

Some publicly available guidance on setting alarm levels is proffered by gas detection manufacturers although, typically, the levels used in practice for specific applications are the result of discussions between the manufacturer and the user. The levels are typically based on fractions of the WELs, if available, or on another country’s values, eg TLVs in the USA.

Guidance on setting alarm levels can be found on the USA-based Interscan website (Interscan, 2012). Suggested values for individual gases, based on OSHA, ACGIH and NIOSH 8-hr TWA, STEL and ceiling limits, are summarised in table 3. However, they conclude that there is no simple answer to alarm setting, as individual applications will vary. Also, in the USA, while OSHA standards have the force of law, the other learned institutions may disagree on allowable levels.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Alarm Level 1 (ppm)</th>
<th>Alarm Level 2 (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>Chlorine</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Ethylene oxide</td>
<td>2 or 2.5</td>
<td>5</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Hydrogen chloride</td>
<td>1.9</td>
<td>4 or 4.5</td>
</tr>
<tr>
<td>Hydrogen sulphide</td>
<td>10 or 20</td>
<td>20 or 50</td>
</tr>
<tr>
<td>Sulphur dioxide</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

Alarm levels suggested by other manufacturers no doubt exist as generally available documents and in manuals.

4.4 CARBON MONOXIDE IN DOMESTIC PREMISES

4.4.1 General

Carbon monoxide detectors used in a domestic environment comprise CO alarms which are typically mounted on the wall or ceiling of the premises (BS EN 50292, 2002; HSE, 2011), and electronic portable combustion gas analysers (also known as flue gas analysers) used for measuring CO (and possibly other gases) in flues and/or the general indoor environment (BS 7967-1, 2005).

4.4.2 Regulations

There are no regulations governing the general use of CO alarms in existing buildings. However, for new buildings, there is now in Part J (Combustion Appliances and Fuel Storage Systems) of the Building Regulations a legal requirement to make appropriate provision for detection and warning of carbon monoxide release, i.e. installing a CO detector. This requirement applies whenever a fixed combustion appliance is provided, as a new installation or a replacement, in a dwelling.
4.4.3 Standards and Guidance

4.4.3.1 CO alarms

The performance standard BS EN 50291-1 (2010) specifies the CO concentrations and exposure times at which domestic CO alarms shall activate; these are summarised in Table 4.

<table>
<thead>
<tr>
<th>CO alarm level (ppm)</th>
<th>Must alarm before (min)</th>
<th>Must not alarm before (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>-</td>
<td>120</td>
</tr>
<tr>
<td>50</td>
<td>90</td>
<td>60</td>
</tr>
<tr>
<td>100</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>300</td>
<td>3</td>
<td>-</td>
</tr>
</tbody>
</table>

Times before which the alarm must not activate are specified (in addition to alarm activation times) to prevent spurious alarms, e.g. from fuel appliances starting up. Guidance on alarm setting for CO alarms can be found in BS EN 50292 (2002). Here, the principle of alarm setting is outlined: CO health effects are related to % carboxyhaemoglobin (COHb) in the blood, which is primarily dependent on the CO concentration and the exposure time. Consequently, the alarm set points in Table 4 are designed to approximate to the COHb curve around 2.5% COHb, which is the guideline value set by the World Health Organisation (WHO, 2000) for protection of vulnerable groups such as the elderly and pregnant women. This is illustrated in Fig. 1.
Fig. 1 - CO alarm activation regions based on the requirements of BS EN 50291-1. The dashed transition lines at the ends of the three alarm set point ranges (at 50, 100 and 300 ppm CO) are not defined by the standard, they are shown for diagrammatic purposes only. The CO concentration-exposure time curves for 2.5% and 5% COHb are shown.

The WHO guideline values (given in rounded ppm values) and periods of time-weighted average exposures, which ensure that the COHb level of 2.5% is not exceeded even when a normal subject engages in light or moderate exercise, are:

- 90 ppm for 15 min
- 50 ppm for 30 min
- 25 ppm for 1 hr
- 10 ppm for 8 hr

4.4.3.2 **Electronic portable combustion gas analysers**

BS 7967-1 (2005) gives guidance for gas operatives engaged in the activity of identifying and managing sources of fumes, smells, spillage/leakage of combustion products and CO alarm activation in dwellings, and is for use with appliances using 1st, 2nd or 3rd family gases. Various action levels are given in BS 7967-3 (2005), which is the guide for responding to measurements obtained from electronic portable combustion gas analysers. BS 7967-2 (2005) is the guide for using electronic portable combustion gas analysers in the measurement of carbon monoxide and the determination of combustion performance.
In BS 7967-3 (2005), the following CO action levels, measured in accordance with BS 7967-2 (2005) and taken to be increases above outdoor background conditions, are specified. The actions have been paraphrased somewhat from the standard for the sake of brevity:

- CO levels from 10 ppm to 30 ppm: If the source of CO cannot be determined, notify the emergency services such as fire and/or police. If the source of the CO is associated with a gas appliance other than a cooker, remedial work should be carried out and assessed. If the source of CO is associated with a gas cooker and it conforms to BS 7967-2, the cooker is satisfactory. If it does not conform to BS 7967-2, the installation should be treated in accordance with actions for CO levels greater than 30 ppm.

- For CO levels greater than 30 ppm: For gas cookers which do not conform to BS 7967-2, and for all other CO sources with levels greater than 30 ppm, advise the occupants to leave the dwelling immediately. Turn off or extinguish all appliances and open windows and doors to ventilate the dwellings, before leaving. On re-entry, check the atmosphere in the dwelling continually from the point of access inwards. Do not consider the dwelling is safe to fully re-enter to carry out any further investigation until CO concentrations are below 10 ppm and preferably down to outdoor background levels.

Another standard in the BS 7967 series, BS 7967-5 (2010) provides guidance for using electronic portable combustion gas analysers in non-domestic premises for the measurement of carbon monoxide and carbon dioxide levels (and the determination of combustion performance). Non-domestic premises include schools, hotels, guest houses, restaurants, kitchens, canteens, laundries, laundrettes, shops, offices, leisure centres/facilities, churches, meeting halls, factories, waiting rooms and agricultural premises.

The action levels specified in BS 7967-5 (2010) are 10 ppm for CO or 2800 ppm for CO₂ in ambient air, which should trigger the following actions:

- A risk assessment should be carried out.
- Gas and fuel burning appliances should be turned off, wherever practicable, and non-essential appliances isolated.
- Occupants should be evacuated from the affected space.
- Windows, shutters and doors should be opened to the outside air, wherever practicable, to ventilate the occupied space.
5. FACTORS INFLUENCING ALARM SETTING

5.1 GENERAL

The use of toxic gas detection, assuming it is required, will follow from the requirements of the risk assessment. There are various factors that should be considered when setting alarm levels on toxic gas detectors to minimise risk of potentially dangerous exposure levels to personnel in a particular area of the workplace. In many situations, however, discussion of these factors either does not occur at all or is extremely brief, and “default” values are typically used. While these values may well be adequate for the task required, i.e. to satisfy the risk assessment or safety case, a more thorough analysis of requirements and the actual circumstances would prove beneficial and is likely to lead to more robust risk mitigation.

The following factors relating to setting an alarm should be considered when installing any type of gas detector:

1. Whether detectors should be fixed and/or whether personnel should be issued with portable, which includes personal, detectors;
2. The location of the fixed detector and whether the work area is occupied or unoccupied;
3. Whether the fixed detector is a point or open-path (also known as beam or line of sight detectors) detector;
4. Whether egress is difficult and/or time-consuming or there is an emergency;
5. Whether WELs, other Exposure Limit values or other health-based levels (e.g. IDLH) exist;
6. Instantaneous or TWA alarm;
7. Background variations and events from the process, which may trigger “spurious” alarms
8. False alarms caused by instrumental effects and interferent gases, which may also be classified as spurious;
9. The characteristics of the source(s) and the potential rate of gas build up;
10. Time to alarm of the detection system;
11. Number of alarm levels (e.g. high and low levels);
12. Mixture of gases/vapours.

These factors and the related issues of maintenance and training are discussed below.

5.2 FIXED AND PORTABLE DETECTORS

5.2.1 Fixed detectors

The role of fixed detectors is to warn of a leak to prevent entry into a monitored area if an event has occurred; to alert personnel in the area, especially if they are not carrying portable detectors; and to warn personnel in adjacent areas to leave. Fixed detectors also includes transportable detectors which are not intended to be portable detectors but which can readily be moved from one place to another but serve the (temporary) purpose of a fixed detector.
Fixed detector alarms should be instantaneous and not TWA as they do not measure workers’ exposure in the breathing zone. There is typically only a weak correlation or even none at all between the gas concentration as measured by a fixed detector and that by a personal/portable monitor worn by personnel in the general area covered by the fixed monitor. This is stated in HSE Guidance HSG 173: “Most WELs refer to personal exposures. You can also use fixed place or static monitoring to obtain information on the likely sources contributing to the exposure. However, fixed place monitoring does not usually reflect the amount that one of your employees could breathe in, which determines the risk to health”. Nevertheless, conducting a survey on the degree to which fixed alarm activation events correlate with exposure peaks from workers’ datalogged portable monitors may help to assess whether the fixed detectors are performing adequately.

Fixed detectors may have different alarms to portable detectors. This is because they are usually connected to a control system which activates the alarm and may initiate executive action to mitigate the effects of a gas release, e.g. isolate, ventilate, system shut-down. It is desirable that this should only occur when there is a serious leak. Consequently the levels may be set higher than those for a portable detector. However, these action levels should still enable any workers present in the area, to safely exit the area and initiate effective mitigation. For example, a H$_2$S fixed point detector might be set to alarm at 10 and 40 ppm for low and high levels, while for a portable detector, the equivalents might be 5 and 10 ppm.

It is possible that when fixed detector alarms are set higher than the LTEL or STEL for example, in order to minimise spurious alarms, workers may be exposed to concentrations greater than the limit, if they are not employing portable detectors to warn of this situation. This has been known to occur when a company decides to use fixed detector(s) as a surrogate because of the additional cost of portable detectors.

Open-path detectors do not directly measure concentration (volume ratio) as point detectors do. They measure the average concentration of gas over the path length of the detector, which is typically over a range of tens of metres; the measurement unit for toxic gases is ppm.m (volume ratio times a length). If the path length is known, then dividing the ppm.m reading by the path length gives the path-averaged concentration (ppm). A cloud of toxic gas in the detector beam having a high concentration distributed over a short length could give the same reading as a lower concentration distributed over a longer length. As the measurement unit cannot be directly related to a concentration-based health limit, alarms for open-path toxic detectors are based on practical experience of the likely nature of the gas release in the location of the detector, the path length and performance of the detector and any exposure limit. For example, some open-path detector alarms for H$_2$S, which are increasingly used for monitoring in the onshore and offshore petrochemical industries are set at 100 ppm.m.

### 5.2.2 Location of fixed detector

The location of a fixed detector is important as this will affect the time for any gas release to reach the gas sensor and then, if the concentration is high enough, activate the alarm. Consideration of the likely sources and type of gas leaks should be undertaken in order to ensure the optimal position for the detector(s) which then minimises the time to alarm.

Alarm set points may be dependent on whether the detector is situated inside or outside a building. Indoors, releases will tend to accumulate and the consideration here is predominantly related to occupational exposure. Outdoors, and assuming there is rapid dispersion, smaller releases are more difficult to detect and may not be necessary to detect. The consideration here is likely to be that of detecting large releases e.g. during tanker operations transferring bulk chlorine, organic liquids, and alarm levels may be set higher.
5.2.3 Portable detectors

Portable detectors include hand-held and personal detectors, the latter for use in the breathing zone. The role of portable detectors is for identifying events and removing personnel from adjacent areas but not for preventing entry, which is the role of fixed detectors. Portable detectors are used for testing for gas free areas, particularly in confined spaces, and personal protection. The alarm limits for such detectors are therefore more directly related to exposure limits and are typically set at lower levels than instantaneous alarms for fixed detectors.

The use of portable detectors to test for entry in confined space can introduce more stringent requirements than those for more open environments. Working in confined spaces requires an entry procedure: initial testing for entry may require alarm levels to be lower than non-confined spaces. Moreover, if testing allows entry, egress may be difficult if hazardous levels are encountered later on which would again suggest setting alarm levels lower than for non-confined spaces.

5.3 DIFFICULT EGRESS AND EMERGENCIES

Consideration must be taken of setting appropriate alarm levels when egress from a working environment is difficult and/or time-consuming, for example working in tunnels, offshore platform legs, marine environments. Also, there may be emergency situations where RPE, including breathing apparatus, is required to be donned upon alarm activation. This time may be very short e.g. minutes, therefore the alarm must give sufficient time for this to occur yet allow the emergency operations still to be carried out. The IDLH values (see Section 5.5) reflect this situation.

If escape times are greater than a certain period, e.g. 15 min, then the alarm levels may have to be reduced compared to a shorter evacuation time.

5.4 INSTANTANEOUS AND TWA ALARMS

Instantaneous alarms activate when the instantaneous concentration (or instantaneous path averaged concentration for an open-path detector) of toxic gas exceeds a threshold. Some toxic gas detectors, typically portable detectors, in addition to the instantaneous concentration-based alarm, have time-weighted average (TWA) alarms which trigger when the average concentration over the measurement period exceeds a threshold. As the cumulative exposure has to be recorded some form of logging is required. The alarm thresholds are usually related to the workplace exposure limits (WELs) listed in EH40 (HSE, 2005), assuming they exist for the gas in question (see Section 5.5). These can be 8-hr TWAs and 15-min TWA STELs.

Instantaneous alarms are typically the only type employed on fixed detectors, as mentioned in Section 5.2.1. Many portable detectors offer both instantaneous and TWA alarms where the averaging period can be specified, but typically the 15-min and 8-hr averaging periods are used. Instantaneous alarms have the advantage of simplicity and, provided the alarm levels are set appropriately, can help to ensure personnel quickly evacuate the area where the atmosphere may rapidly deteriorate. TWA alarms are not so useful in emergencies, however, for more controlled and predictable environments, they can help to ensure that exposures do not exceed WELs. Moreover, they together with the logged data can provide detailed information on the exposure of workers and are a useful tool for assessing exposure and modifying work practices, particularly when TWA alarms are found to be activated when instantaneous alarms are set at LTELs and STELs. The workplace culture should not be “working up” to an alarm set at a LTEL or STEL but rather encouraging the philosophy of “working down” from a limit.
Where the exposure profile is understood and consists of short peak exposures associated with specific tasks in a low background concentration, then the combination of a TWA alarm and an instantaneous alarm, can provide protection. If the instantaneous alarm is set at a higher level than the TWA (8-hr) then this can avoid spurious peaks, providing they do not alarm at the STEL and warn against unforeseeable events.

In some detectors, the TWA alarm is the lowest priority alarm and as such will be over-ridden by any instantaneous gas alarms triggered by a short-term increase in gas levels.

In general, instantaneous alarms for low and high levels are usually set to the EH40-listed 8-hr and 15-min WEL values, where these exist. Alarm settings, however, should be selected to reflect the level of risk such that when an instantaneous alarm is triggered the user of the monitor is able to exit to a safe environment without risk of receiving a TWA exposure exceeding the WEL (STEL and LTEL). A decision based on such an analysis requires considerable more judgement than current practice, and the reality is that it is much easier to maintain the traditional alarm levels.

5.5 LIMIT VALUES

Limit values form the basis of both instantaneous and TWA alarm levels. For COSHH-related monitoring then the WELs are appropriate. For emergency situations, which may, for example, occur offshore, then alarm levels based on IDLH may be appropriate. Table 4 lists values for some commonly occurring gases.
Table 4 Limit values for various gases (ppm)

<table>
<thead>
<tr>
<th>Gas</th>
<th>LTEL</th>
<th>STEL 1,2,3</th>
<th>50% STEL 4</th>
<th>IDLH 5,6</th>
<th>50% IDLH 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia</td>
<td>25</td>
<td>35</td>
<td>17</td>
<td>300</td>
<td>150</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>5000</td>
<td>15000</td>
<td>7500</td>
<td>40000</td>
<td>20000</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>30</td>
<td>200</td>
<td>100</td>
<td>1200</td>
<td>600</td>
</tr>
<tr>
<td>Chlorine</td>
<td></td>
<td>0.5</td>
<td>0.25</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Hydrogen sulphide</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Nitrogen monoxide</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Sulphur dioxide</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>

1. LTEL – Long term exposure limit, averaged over 8 hr. Values listed in EH40 Workplace exposure limits (HSE, 2005 with amendments 2007)
2. STEL – Short term exposure limit, averaged over 15 min. Values listed in EH40 Workplace exposure limits (HSE, 2005 with amendments 2007)
3. 100% STEL advised as high level alarm by BS 6164 (2011)
4. 50% STEL advised as low level alarm by BS 6164 (2011)
5. IDLHs listed in NIOSH Documentation for Immediately Dangerous To Life or Health Concentrations (IDLHs). Chemical Listing and Documentation of Revised IDLH Values (as of 3/1/95) May 1994. http://www.cdc.gov/niosh/idlh/intridl4.html. IDLH is defined as the maximum exposure concentration in the workplace from which one could escape within 30 min without any escape-impairing symptoms or any irreversible health effects.
6. 100% IDLH advised as maximum high level alarm by CCPS (2009)
7. 50% IDLH advised as maximum low level alarm by CCPS (2009)

Many gases, however, have no current WELs (e.g. nitric oxide, nitrogen dioxide, sulphur dioxide) or only partial WELs (e.g. chlorine and ozone) with, for example, a 15-min WEL (STEL) but not an 8-hr WEL (LTEL). When there is no WEL, it is advisable to use other countries’ limits, particularly from North America and the European Union, see for example the updated list from GESTIS (2012); or suppliers’ recommendations and available literature, as stated in CCPS (2009). When there is only a STEL, then options are to use 50% STEL as the low alarm and 100% STEL as the high alarm as advocated in BS 6164 (see Table 4). Alternatively, another percentage of the STEL could be used, for example, a rule of thumb is that the STEL tends to be around three times the LTEL, therefore choosing the low alarm at 33% STEL could be an option. The occurrence of spurious alarms should also be considered (see 5.6 and 5.7).

Reductions in exposure limits, which occur from time to time, with the implication that alarm levels may also be reduced, can impact on the accuracy and reliability of the detector (Hemingway et al, 2012). This is especially true when large changes occur. For example, the TLV for hydrogen sulphide was lowered by ACGIH from 10 ppm (8-hr TWA) and 15 ppm (15-min STEL) to 1 and 5 ppm respectively. Also, the TLVs for sulphur dioxide were lowered from 2 ppm (8-hr TWA) and 5 ppm (15-min STEL) to 0.25 ppm (15-min STEL only). However, using an instantaneous concentration threshold at the old, higher TLV to activate the alarm rather than a TWA alarm at the new, lower TLV, which could cause detectability problems, may also reduce the TWA exposure at the new TLVs (CAPP, 2009). CAPP (2009) reported that personal exposure measurements of hydrogen sulphide exposure associated with specific tasks related to various oil and gas production operations was highly variable, with short peak exposures exceeding 10 ppm. The combination of low background levels, and use of PPE to
protect against exposure to hydrogen sulphide when personal monitors alarmed at 10 ppm, resulted in a very low average concentration over the whole shift.

5.6 SHORT DURATION PEAKS

Typically, in a workspace, the gas concentration and therefore the exposure will vary both spatially and temporally. One source of this variation is short term peaks which can result from equipment automatically depressurising or personnel conducting short tasks involving transfer/manipulation of product which results in a short duration release of gas/vapour, e.g. tank filling, valve cracking. If not managed properly, this can lead to excessive alarm activation which can impact on effectiveness and efficiency, while not significantly lowering the risk. Indeed, in the extreme, too many false alarms can and have led to operators turning off the alarms, sometimes with catastrophic results.

A balance needs to be struck between effective protection from exposure to toxic gas and maintaining productivity. The setting of appropriate alarm levels is usually achieved through experience, which is itself based on monitoring the process over a suitable period. This situation usually applies to instantaneous alarms on fixed detectors. Portable detectors can use TWA alarms to avoid this problem.

The prime aim is to set the alarm level such that it controls the risk but minimises spurious alarms. There are, however, various ways in which peaks can be dealt with in order to minimise spurious alarms on fixed detectors, for example:

- imposing a time delay to activate, e.g. tens of seconds, which must, however, exceed the time to alarm;
- averaging the response over a short period, e.g. tens of seconds, which must, however, exceed the time to alarm;
- use a voting system, e.g. two detectors must activate.

In all the above cases, no special processing is required at the sensor head, the central control system should activate the alarm.

HSE guidance for chlorine operations (HSE, 1999a; HSE, 1999b) discusses the use of a time delay on the alarm: “Lower settings are liable to activate the system at every tank-filling operation, unless a duration requirement is also imposed. For example, some companies set the low level alarm at 0.5 ppm, but require the sensor to register this concentration for at least 30 seconds, to avoid spurious trips of the alarm system during filling operations”.

5.7 FALSE ALARMS CAUSED BY INSTRUMENT FACTORS

In addition to the potential for spurious alarms generated by the process itself (described in Section 5.6), which is, however, the result of actual exposure to gas, alarm levels must also take into account variations in the instrument response not caused by gas. Such false alarms are caused by an increase in the baseline (zero level) and/or sensitivity. The opposite of this condition, i.e. a decrease in the zero level and/or sensitivity will lead to a “fail to danger” – the alarm will not activate when it should. These adverse effects include instrument drift (e.g. ageing of the detector); changes in the ambient environment which the gas detector is sensitive to, e.g. temperature, humidity; interferent gases (i.e. gases other than the target gas) to which the gas sensor is cross-sensitive.
As with spurious peaks described in 5.6, if false alarms are not managed properly, this can lead to excessive alarm activation which can impact on effectiveness and efficiency. This has resulted in operators turning off the alarms, sometimes with dangerous consequences. The prime aim, as in 5.6, is to set the alarm level such that it controls the risk but minimises spurious alarms. The setting of appropriate alarm levels is usually achieved through experience, which is itself based on monitoring the process over a suitable period. The particular environment affects the detector; the user and detector manufacturer should discuss appropriate intervals.

The occurrence of false alarms caused by instrument variations is reduced by regular maintenance programme involving both function check (bump test, not involving adjustment) and calibration (which may involve adjustment and carried out by a specialist in a workshop not field environment). A background instrument “noise” level analysis can also be performed on portable detectors immediately prior to operation to check whether the zero level is satisfactory or whether there is a fault.

5.8 POTENTIAL RATE OF GAS BUILD UP

Firstly, if there is a catastrophic failure leading to an extremely rapid build-up of gas, then it may not be possible for any detector to alarm in time. It is therefore important to explain to users the events for which the detector can and cannot provide an adequate alarm.

Knowledge of the rate of gas build up for potential leak scenarios, which can vary in complexity from simple heuristics, knowledge from previous events to Computational Fluid Dynamics (CFD), will assist in setting an appropriate alarm level to allow action to be taken, especially for evacuation of the area.

5.9 RESPONSE TIME

It is critical that alarm activation allows enough time for appropriate action to be taken. This overlaps with both the previous and next section as knowledge of gas build up rates and use of multiple alarms levels can allow sufficient time for action, i.e. evacuation, checking and possible rectification of the event which has led to a gas release. Setting a lower alarm threshold allows longer time to take executive action, and should be considered when egress is more difficult (e.g. tunnels, confined spaces). Although the increased chance of spurious and false alarms should be taken into account.

The time to alarm of the detector should be considered. When sensing heads are employed which sample the gas immediately surrounding the sensor, this will depend on the intrinsic response time of the instrument and the gas concentration – the higher the gas concentration (provided it is above the particular alarm threshold), the shorter the time to activate at the threshold, for both instantaneous and TWA alarms.

When a sampling system is used, which aspirates the sample from the sampling point(s) to a central detector or analyser, there are additional considerations to take into account:

- number of sampling points on the loop, decreasing the number will decrease the effective response time but coverage of the area may be impaired;
- sampling all points simultaneously by mixing the gas from each line which will give the average concentration for the space. However the analyser may require enhanced sensitivity because of increased dilution and the location of the leak will be more difficult to identify;
• arranging the sequence of samplers on the loop to minimize the cycle time for the more hazardous areas;

• use of an additional bypass pump in a sequential sampling manifold to flush the next sample line out in readiness for analysis while the previous sample is being analysed;

• sample line length;

• sample line flow rate;

• central detector/analyser response time.

5.10 NUMBER OF ALARM LEVELS

It is common to employ two alarm levels – low and high, although just one and more than two alarm levels are also used. Two alarm levels typically require that on the first, low level activation, an investigation be conducted to check the cause of the alarm and place the personnel nearby on alert. If, subsequently, the second, high level alarm activates then this usually instigates more drastic action such as evacuation or donning breathing apparatus for portable and fixed gas detectors or activation of mitigation measures for fixed detectors, e.g. increased ventilation, isolating and/or turning off plant. It is important that where there are two alarms, the first alarm activation should actually trigger an action and not be ignored or automatically cancelled. If the latter situation prevails, however, then the role of the low level should be reviewed and the threshold either increased, e.g. to avoid spurious trips, or possibly removed, leaving just one alarm where action is immediately taken.

Single alarms are acceptable in certain circumstances where it is not possible to protect against the release other than by evacuating the area. For example, there may be a rapid increase in toxic gas concentration in the vicinity and the presence of a low alarm would only delay evacuation, as may be the case for protection against, for example, hydrogen sulphide in certain petrochemical environments.

Some detectors have provision for setting more than two alarms, typically three. However, it is difficult to envisage a situation where this confers additional benefits to having fewer alarms. Indeed, it may be viewed as complicating matters and simplicity is invariably the best policy when dealing with safety.

5.11 ALARM LIMITS FOR MIXTURES

As stated in 4.3.4.1, a method for estimating exposure limits for mixtures of hydrocarbon solvents is given in EH40 (HSE, 2005). This allows calculation of an occupational exposure limit in units of mg/m$^3$ if the weight fractions of each group in the mixture and the WELs of individual compounds are known. The method is the reciprocal calculation procedure (RCP), see also 4.3.4.1. It is, however, difficult to specify an alarm level based on this exposure limit for a fixed or portable gas detector, calibrated in ppm for a particular gas; the average molecular weight of the mixture must be known to convert from mg/m$^3$ into a volume fraction-related unit such as ppm. Nevertheless, it may be possible to achieve this for some well-characterised hydrocarbon mixtures.

Only a few complex mixtures have occupational exposure limits, e.g. gasoline TLV in the USA. For the other complex mixtures, the exposure limit of the mixture must be calculated from the exposure limits of the individual components or groups of hydrocarbons (HSE, 2005). Guidance on setting alarm levels for mixtures is given in Rae (1997), which is also based on RCP. The mixture exposure limit ($EL_{mix}$) is given by:
where $EL_i$ is the exposure limit of the individual gas/vapour component $i$ and $x_i$ is volume (mole) fraction of the component in the vapour phase of the mixture, $n$ being the total number of components.

Ideally, the detector is then calibrated with a known volume fraction (concentration) of mixture, derived from individual standard test gases, and the alarm limits set as a fraction of the mixture exposure limit. However, when such standards are unavailable or inconvenient/time-consuming to generate, as is the case for many mixtures, then it is possible to calculate a calibration factor for the mixture based on the individual calibration factors, again using RCP method, thus:

$$CF_{mix} = \frac{1}{\sum_{i=1}^{n} \frac{x_i}{CF_i}}$$

where $CF_i$ is the calibration factor for the individual gas/vapour component with respect to a standard calibration gas, e.g. isobutylene, which is commonly used for calibration of photo-ionisation detectors (PIDs). The response ($R_{mix}^{EL}$) of the instrument at the mixture exposure limit, after applying the calibration factor, is given by:

$$R_{mix}^{EL} = \frac{EL_{mix}}{CF_{mix}}$$

In the USA, it is common practice, stated by Rae (1997), to set the lower alarm limit to 50% TLV (i.e. 50% $EL_{mix}$) and the upper limit to 100% TLV (i.e. 100% $EL_{mix}$).

### 5.12 RELATED ISSUES

#### 5.12.1 Maintenance

The maintenance of gas detectors is extremely important, including regular function checks (bump tests) and calibration for both fixed and portable monitors, as is stressed in the toxic gas detector standard (BS EN 45544-4) and flammable gas detector (BS EN 60079-29-2) and in HSE guidance for flammable gas detectors (HSE, 2001a; HSE, 2001b; HSE, 2004). This will help to ensure that the alarm activates at the right concentration or TWA level and does not fail-to-danger, and that spurious alarms are minimised. Bump tests are carried out in between calibrations; the periodicity of bump tests varies from days upwards while calibrations tend to be 6 monthly or annually. Both the bump test and calibration periods will, however, depend on the particular application. Depending on the type of sensor, fault alarms can warn the user that the instrument is no longer functional. Ideally, the fault warning should provide adequate warning of an imminent failure, although some failures occur suddenly. Obtaining a suitable and accurate diagnostic is, however, not always straightforward and typically depends on the environment the detector is working in.

On certain sites, there is a significant risk in sending personnel to an area where there may be potential for exposure to very high toxic gas concentrations arising from a major leak. The frequency of maintenance operations involving checking the operation of gas detectors should therefore be kept to a minimum commensurate with ensuring that the detectors are fit for
purpose. The more reliable the detector the less frequently checks are necessary and the risk of exposure is reduced.

5.12.2 Training

Another important factor in risk management involving the use of gas detectors and alarms is that operators who use gas detectors or carry out maintenance on them are properly trained in their use and know what actions to take in the event of an alarm activation. The use of subcontractors can make it harder to ensure that the necessary training has been undertaken. Again, reference to training is mentioned in gas detector guidance previously cited (HSE, 2004; BS EN 45544-4; BS EN 60079-29-2). This guidance needs to be transmitted in a suitably effective form by the dutyholder to the user.

An important point is that any procedures and instructions for alarm setting and actions should be kept as simple as possible.

5.13 USE OF ALARMS - PRACTICAL EXAMPLES

Examples of issues raised from use of toxic gas/oxygen alarms involved in incident investigations or highlighted as part of routine inspection include:

- Switching off fixed systems or portable monitors because of spurious alarms, which has led to a fatality in at least one brewery. The conclusion was that either the spurious alarms should have been dealt with or the alarm level increased to reduce the number of spurious alarms but still ensuring that the system could function effectively. This would have obviated the need to turn the system off, thereby creating a dangerous situation.

- Disabling a fixed oxygen alarm and then not using a portable alarm in an engineering works using argon welding, also lack of adequate knowledge and maintenance of the gas monitoring equipment. This was not so much an alarm setting issue as inadequacies in safety management and risk awareness.

- Lack of awareness of the extended response time of an aspirated, multi-sample point monitoring system in a brewery.

- Use of the wrong type of detector when entering a confined space on a ship: a hydrogen sulphide monitor erroneously supplied instead of an oxygen monitor.

5.14 CONCLUSIONS & RECOMMENDATIONS

It can be seen that there are many factors that can influence the setting of alarm levels for toxic gases. While each exposure scenario has its own particular characteristics, it is possible to draw together the above information and outline some general recommendations.

The first considerations, which are not directly related to alarm setting, are the type of detector (fixed, portable, point, open-path, suitability for the task, maintenance) and the location of fixed detectors for the intended task. This will follow on from the risk assessment. Then, when considering what alarm levels to set, the user may already have default values set by the detector manufacturer, which, in some models, may be capable of being reprogrammed by the user. These values may be general, default levels selected by the manufacturer/supplier or arrived at through discussion with the user, the latter is the ideal methodology. Consultation with the user following the recommendations below would help to guide that discussion. If there has been no consultation with the manufacturer/supplier then users should satisfy themselves
that the default values are appropriate for their application. Ideally this should take place through consultation with the manufacturer or another expert, using these recommendations.

The generic values will typically be derived from consideration of the occupational exposure limits (OELs), if there are any. In the UK, these are denoted WELs, and ideally should be used as the basis, although not necessarily the actual values (see later), for setting levels for monitors in the UK. In the absence of a WEL, then values from other countries may be used, e.g. TLVs from the USA which are more numerous than WELs, other EU countries - see GESTIS (2012) for a list of OELs. For other gases where no limit exists, suitable alarm set-points should be set based on discussion with experts. Certain gases, although there are not many, have alarm set-points specified in standards or guidance (see Sections 4.3 and 4.4). These should be adhered to unless there are special circumstances which require the levels to be altered. The reasoning for any deviations should be documented.

The OEL, either official or a company specified value, should be the starting point for setting alarm levels for a particular individual gas or gas mixture. The characteristics of the toxic gas risk, which the detection system (the levels may be different whether fixed or portable gas detection is used) is there to mitigate, should then be considered. The factors discussed in Section 5 relating to the risk may influence the decision to change the alarm levels, these are summarised:

- The source(s) characteristics and potential rate of gas build-up.
- Whether egress is difficult and/or takes an especially long time or emergency conditions;
- Background variations and events from the process and instrumental effects, which may trigger “spurious” alarms;

This assessment should mediate the initial (default) alarm set-points: the values can remain the same, decrease or possibly increase, the latter especially for fixed gas detection.

The facility for both instantaneous and TWA alarms on personal/portable monitors (TWA alarms are not appropriate for fixed monitors) is useful for some situations, however, the overriding need may be to keep it simple, in which case the priority is to set the instantaneous alarms. TWA alarms are more suitable for non-critical environments, e.g. not confined spaces, where the risk does not escalate rapidly and egress does not present difficulties.

Typically, two alarm levels (low and high) are chosen – any more tends to complicate matters, which should be avoided. The first alarm level should provide an initial warning to conduct an investigation and assess the situation. The low alarm level should be set such that this is not a spurious alarm, warranting an investigation, which should carried out, and not ignored. The high alarm level should initiate a mitigating action. It should be noted that in certain cases, the use of a single alarm is appropriate where an emergency could quickly follow and any delay could be dangerous. The setting of this alarm level requires especially careful consideration.

Setting alarm points should not be “fit and forget”. Initial alarm set-points may be adjusted either up or down in the light of experience in the environment, i.e. process-related events and instrument characteristics. This requires analysis of the data over a suitable period. Minimising the risk by lowering the alarm levels has to be balanced by minimising spurious alarms, which reduce efficiency. Nevertheless, it is good practice to try to drive down alarm levels. On the other hand, alarm levels may have to be increased from their initial values. In this case, the reasons need to be recorded and the risk assessment reviewed to ensure that the new risk is tolerable.
This report has identified gaps in HSE guidance and also in British/European standards such as BS EN 45544-4 (Guide for use of toxic detectors in the workplace). It would be of benefit if the information in this report was used as a basis for the revision of these guidance documents.
6. REFERENCES


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7. GLOSSARY

ACGIH American Conference of Government Industrial Hygienists
ACOP Approved Code of Practice
AIHA American Industrial Hygiene Association
ATEL Acute toxicity exposure limit (BS EN 378-1)
BSI British Standards Institute
CAPP Canadian Association of Petroleum Producers
CCPS Centre for Process Chemical Safety of the American Institute of Chemical Engineers
CFD Computation Fluid Dynamics
CoGDEM Council of Gas Detection & Environmental Monitoring
COMAH Control of Major Accident Hazards
COSHH Control of Substances Hazardous to Health
CSR Confined Spaces Regulations
EEMUA Engineering Equipment and Materials Users Association
HSE Health and Safety Executive (UK)
HSL Health and Safety Laboratory (UK)
IDLH Immediately Dangerous to Life & Health
LEL Lower Explosive Limit
LFL Lower Flammable/Flammability Limit
LTEL Long Term Exposure Limit
NIOSH National Institute For Occupational Safety And Health (USA)
ODL Oxygen Deprivation Limit (BS EN 378-1)
OEL Occupational Exposure Limit
OSHA Occupational Safety And Health Administration (USA)
PFEER Prevention of Fire and Explosion, and Emergency Response (Offshore Installations)
RPE Respiratory Protection Equipment
STEL Short Term Exposure Limit
TLV Threshold Limit value
TWA Time Weighted Average
VOC Volatile Organic Compound
WEL Workplace Exposure Limit
WHO World Health Organization
Review of alarm setting for toxic gas and oxygen detectors

Toxic gas and oxygen deficiency detectors are commonly used throughout the workplace to warn of potentially harmful exposure to personnel, and of dangerous gas leaks. The detectors employed to perform these tasks are personal (worn in the breathing zone, eg on the upper lapel), portable (typically hand-held or worn on a belt) and fixed (typically connected to a control and warning system). Carbon monoxide alarms are also employed in domestic premises to warn of carbon monoxide leaks.

Current knowledge on alarm setting for toxic gas detectors was reviewed by a literature survey and consultation with stakeholders (eg HSE, various industries, gas detector manufacturers). The purpose of this review was to develop a framework for guidance on alarm setting for toxic gas detectors as information is lacking on the rationale behind setting alarm levels. The available guidance was summarised, the factors which influence the alarm setting process identified, and recommendations made on how this process should be conducted.

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