

## CSRTA Continuing Professional Development Guidance

Confined Space Rescue Trade Association Ltd

# Air Change Calculations, Ventilation, Gas Stratification and Gas Detection in Confined Spaces

*A CPD reference for instructors, rescue operatives, entry controllers, supervisors, assessors and safety professionals working in UK confined space environments.*

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# 1. Version Control

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## 2. Executive Summary

This CPD guidance examines four interlinked technical questions that arise in every planned confined space entry: how the volume of a space is calculated, how air change rates and purge times are determined, how gas stratification affects the atmosphere within the space, and how gas detection is used to confirm what the calculations alone cannot.

The document is written to support confined space instructors, rescue operatives, entry controllers, supervisors, assessors and safety professionals working in UK confined space environments.

It aligns with the Confined Spaces Regulations 1997, the Approved Code of Practice, and guidance in L101; the Management of Health and Safety at Work Regulations 1999; COSHH 2002 (with EH40 workplace exposure limits and L5); DSEAR 2002 (with L138); HSG53; HSG250; and PUWER 1998.

The central message is unambiguous. Air change calculations are a planning tool. They help size a fan, estimate purge time, and demonstrate that ventilation has been considered.

They do not prove that the atmosphere inside the space is safe. Only atmospheric testing carried out at appropriate locations, supported by suitable risk assessment, isolation, a safe system of work, competent supervision and rescue arrangements compliant with regulation 5, can support that decision.

Confined spaces are not well-mixed rooms. They have low points, high points, sumps, baffles, dead spaces and residues that influence gas movement. Ventilation can disturb settled gases, push contamination into other parts of the space, or draw in new contamination from outside.

Gas detectors have sensor-specific limitations, response delays, and cross-sensitivities that alter the meaning of their readings. This guidance addresses each of these factors, with worked examples, common errors and an important safety position that must be communicated to every learner.

### 3. Learning Outcomes

On completion of this CPD study, the learner should be able to:

1. Explain what air change calculations are and why they are used in confined space planning.
2. Calculate the volume of rectangular and cylindrical confined spaces using metric units.
3. Calculate air changes per hour and purge time using the standard formulas.
4. Explain why the advertised free-air rating of a fan may overstate the actual delivered airflow at the work face.
5. Describe how ducting length, bends, restrictions, filters, poor positioning and back pressure reduce ventilation performance.
6. Explain why air change calculations must be treated only as a planning tool and never as proof that the atmosphere is safe.
7. Describe how gas stratification, dead spaces and confined space geometry affect atmospheric distribution.
8. Identify common gas detection errors and the conditions that lead to false reassurance.
9. Justify the need for atmospheric testing at appropriate levels and for ongoing monitoring during work.
10. Explain the implications of ventilation and detection limitations for rescue planning and breathing apparatus selection.

## 4. Introduction

Ventilation, atmospheric testing, and gas detection are among the most frequently discussed and most commonly misunderstood subjects in confined space practice.

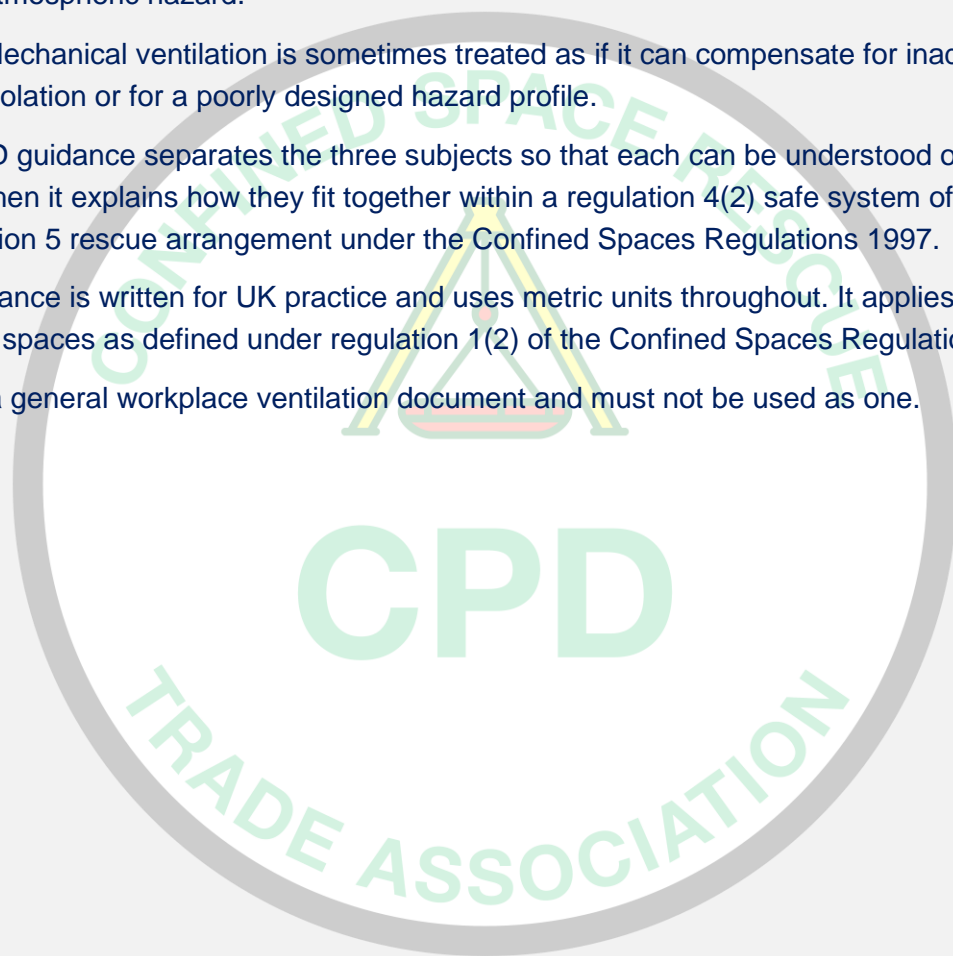
The misunderstanding usually arises from a single error: treating the outputs of one as a substitute for the inputs of another.

- A calculated purge time is often presented as if it confirms that the air in the space is safe to breathe.
- A four-gas detector reading is sometimes treated as a complete assessment of every atmospheric hazard.
- Mechanical ventilation is sometimes treated as if it can compensate for inadequate isolation or for a poorly designed hazard profile.

This CPD guidance separates the three subjects so that each can be understood on its own terms. Then it explains how they fit together within a regulation 4(2) safe system of work and a regulation 5 rescue arrangement under the Confined Spaces Regulations 1997.

The guidance is written for UK practice and uses metric units throughout. It applies only to confined spaces as defined under regulation 1(2) of the Confined Spaces Regulations 1997.

It is not a general workplace ventilation document and must not be used as one.



## 5. Why Ventilation Matters in Confined Spaces

Mechanical ventilation in a confined space serves multiple purposes, and the planning must reflect each of them. As outlined in L101 paragraph 102-105, mechanical ventilation can replace the oxygen consumed by people working in the space. It can dilute and remove gases, fumes, or vapours generated by the work itself. As outlined in L101 paragraph 103, the choice of method depends on the layout of the space, the position of openings and the properties of the pollutants present.

Ventilation cannot, on its own, make a confined space safe. It is one control measure within the hierarchy of controls set out in Regulation 4(2) of the safe system of work. It is selected and configured based on the hazard profile developed during risk assessment. It must be supported by atmospheric testing before entry and by ongoing monitoring, as conditions can change.

### Three things ventilation is asked to do

1. Purge the space of pre-existing contaminants identified by hazard profiling.
2. Maintain breathable air during the period of occupation by replacing consumed oxygen and removing gases, fumes or vapours generated by the work.
3. Control residue-related emissions where sludge, scale or biological deposits may be disturbed during the work.

Each of these purposes places different demands on the ventilation system. A pre-entry purge depends on the space's total volume and the time available before entry. Maintenance ventilation depends on the rate at which contaminants are generated during work. Residue control may require local extraction in addition to general ventilation.

### What ventilation cannot do

- Ventilation cannot substitute for isolation. Where flowing gases, vapours, or liquids could enter the space, the source must be isolated in line with L101 paragraphs 107 to 111.
- Ventilation cannot remove a flammable hazard while the fan itself or the work is providing an ignition source. DSEAR controls remain necessary.
- Ventilation cannot prove the atmosphere is safe. Only atmospheric testing can do that, and only at the location and time the sample is taken.
- Ventilation cannot reach every part of every space. Dead spaces, sumps, baffles, pipe runs, and benching can shelter gas pockets from airflow.

## 6. Air Change Calculations Explained

An air change is the replacement of the air contained within a defined volume with an equivalent volume of fresh air. Air change calculations estimate how long a fan will take to dilute or displace contaminants in a space to acceptable levels, assuming ideal mixing.

The assumption rarely matches reality, which is why the calculation is a planning tool rather than a measurement.

### 6.1 Volume of the confined space

The first step is to calculate the internal volume of the space in cubic metres. Rectangular and cylindrical formulas cover most assets encountered in UK practice.

### 6.2 Air changes per hour

Once the volume is known, the air changes per hour (ACH) for a given fan delivery can be calculated by dividing the airflow per hour by the volume of the space. The result is dimensionless.

### 6.3 Purge time

Purge time is the time required to achieve a specified number of air changes. The number of air changes selected depends on the contaminant, the initial concentration, the target concentration, and the assumed degree of mixing.

Common planning figures of five, seven or ten air changes are used in industry practice but must be justified for each entry. A purge time calculation using 10 air changes is more conservative than one based on 5.

### 6.4 Standard formulas

The following formulas are used throughout this guidance.

Purpose	Formula	Output
Volume of a rectangular space	Length × Width × Height	Volume in cubic metres (m <sup>3</sup> )
Volume of a cylindrical space	$\pi \times \text{radius}^2 \times \text{length}$	Volume in cubic metres (m <sup>3</sup> )
Air changes per hour	Airflow per hour ÷ Space volume	Air changes per hour (ACH)
Purge time	(Required air changes × Space volume) ÷ airflow per minute	Time in minutes

## 6.5 Why the advertised air rating may not represent the delivered airflow

Fan manufacturers publish a free-air rating, which is the volume of air the fan can move when operating against no resistance. In a confined space application, the fan rarely operates under those conditions.

Delivered airflow at the work face is reduced by the static pressure created by the ducting, by every bend or kink in the trunking, by the length of the duct run, by any reduction in duct diameter, by any filter fitted in the air path, by build-up of dirt or moisture, and by back pressure from a space with poor cross-section for return airflow.

The actual delivered airflow can be a small fraction of the free-air rating in a long, bent, or restricted system. Fan manufacturers publish performance data typically generated under standardised test conditions, such as ISO 5801, which defines the test installations and methods used to measure airflow against static pressure for industrial fans.

The free-air rating quoted in product literature is the airflow figure at zero static pressure on the performance curve, measured on the manufacturer's test rig with no duct system attached. In a real confined-space application, the fan operates against the static pressure created by the ducting, bends, restrictions, filters, and the space itself, and the delivered airflow moves down the curve accordingly.

Where the manufacturer publishes a performance curve, the planning calculation must be based on the point on the curve that matches the system's static pressure, not the free-air figure. Where the curve is not available, the free-air rating must not be used as the planning figure.

The competent person on site must rate the figure based on the installed ducting configuration, record the assumptions made, and justify them within the safe system of work. The most reliable check, where it can be carried out safely, is a direct measurement of airflow at the duct outlet using a calibrated anemometer before the entry decision is recorded.

## 6.6 What reduces ventilation performance in real systems

- Long duct runs increase friction loss along the trunking.
- Bends in trunking, particularly sharp 90 degree bends, increase static pressure and reduce throughput.
- Reductions in duct diameter create restriction and turbulence.
- Filters fitted to the inlet or outlet add static pressure that the fan must overcome.
- Poor fan positioning, including ingestion of exhaust air or proximity to engine emissions, contaminates the supply air.
- Make-up air is unavailable where the only opening is occupied by the supply duct, leaving the fan to fight against pressurisation of the space.
- Damaged trunking, kinked lay-flat ducting or loose joints reduce the effective delivery.
- Cold weather, condensation and water ingress increase resistance and may foul motor windings.

## 7. Worked Calculation Examples

Three examples are presented below, using metric units. Each example shows the calculation, the assumptions, the key limitations of the planning figure and the gas detection considerations that must accompany the calculation. The figures used are illustrative; learners must apply the actual dimensions and manufacturer data for each real entry.

### 7.1 Example 1 — Small Inspection Chamber

#### Scenario

A square brick-built inspection chamber forms part of a buried drainage network. Hazard profiling has identified the potential presence of hydrogen sulphide arising from upstream sewerage and the potential for oxygen deficiency. A portable fan is to be used to ventilate the space before entry.

#### Space dimensions

- Length: 1.2 m
- Width: 1.2 m
- Depth (internal height): 2.0 m
- Fan rated free air delivery: 1,800 m<sup>3</sup>/h (30 m<sup>3</sup>/min)
- Planning factor for ducting losses: 50% reduction.

*(Note: The percentage reduction used here is an illustrative teaching figure only.)*

#### Volume calculation

$$\text{Volume} = 1.2 \times 1.2 \times 2.0 = 2.88 \text{ m}^3$$

#### Fan airflow

$$\text{Effective airflow after 50\% reduction} = 30 \times 0.5 = 15 \text{ m}^3/\text{min} = 900 \text{ m}^3/\text{h}$$

#### Air changes per hour

$$\text{ACH} = 900 \div 2.88 = 312.5 \text{ air changes per hour, theoretical, based on ideal mixing.}$$

#### Purge time

Required air changes selected: 7. Purge time =  $(7 \times 2.88) \div 15 = 1.34$  minutes. In practice, this would be rounded up to a minimum purge period that allows for incomplete mixing and post-purge re-test (for example, 5 minutes).

### Key limitations in this space

- The chamber has a single top opening that serves both as a supply route and an exit for displaced air. Short-circuiting of the fan output is likely, leaving the chamber base under-ventilated.
- Heavier than air  $H_2S$  will tend to remain at the base unless the supply duct is extended to the bottom of the chamber, as outlined in L101 paragraph 105.
- Sludge or silt at the base will release  $H_2S$  if disturbed during entry.
- The 50% reduction used here is illustrative; actual losses must be derived from the fan curve and ducting in use.

### Gas detection considerations

- Test from outside via a probe or gas detector on a rope, sampling at 1-metre intervals throughout the chamber.
- Allow full T90 values relevant to the gas detector being used at each depth before recording.
- Continue continuous monitoring throughout the entry, as upstream surges can rapidly change conditions.
- Carry a personal multi-gas detector in the breathing zone of the entrant.

### Why does the calculated purge time not prove the space is safe?

The 1.34-minute calculated purge time only describes how long a perfectly mixed, perfectly delivered volume of air would take to be displaced. The chamber is not perfectly mixed, the fan is not delivering its rated free air, and the production of new  $H_2S$  during the work must be considered. Atmospheric testing at appropriate locations before and during entry is the only basis for the entry decision.

## 7.2 Example 2 — Horizontal Cylindrical Tank

### Scenario

A horizontal cylindrical steel tank is to be entered for internal inspection. The tank previously contained a low-flash-point hydrocarbon residue, which has been identified as heavier than air. It has been emptied, washed and ventilated overnight. A DSEAR risk assessment has been completed, isolation is in place, and hot work is not planned. A blower fan is to be used to maintain ventilation during occupancy.

### Space dimensions

- Internal diameter: 2.0 m (radius 1.0 m)
- Internal length: 6.0 m
- Fan rated free air delivery: 3,600  $m^3/h$  (60  $m^3/min$ )
- Planning factor for 12 m of trunking with two 90° bends: 40% reduction.

(Note: The percentage reduction used here is an illustrative teaching figure only.)

## Volume calculation

Volume =  $\pi \times 1.0^2 \times 6.0 = 18.85 \text{ m}^3$  (using  $\pi \approx 3.1416$ )

## Fan airflow

Effective airflow after 40% reduction =  $60 \times 0.6 = 36 \text{ m}^3/\text{min} = 2,160 \text{ m}^3/\text{h}$

## Air changes per hour

ACH =  $2,160 \div 18.85 = 114.6$  air changes per hour, theoretical, based on ideal mixing.

## Purge time

Required air changes selected: 10 (conservative figure used because of residual hydrocarbon history). Purge time =  $(10 \times 18.85) \div 36 = 5.24$  minutes, theoretical, before adjustment for mixing inefficiency. The safe system of work would specify a longer minimum purge period and a documented post-purge test.

## Key limitations in this space

- Horizontal cylinders have very poor cross-mixing along their length. A single supply duct at a single manhole will create vapour pockets at the opposite end of the tank.
- Hydrocarbon vapour is heavier than air and will tend to remain in the lower curve of the cylinder, unless the supply duct is extended to the bottom of the tank.
- Residual hydrocarbon trapped in sludge, scale or pipe stubs will continue to vapourise during the entry.
- Trunking losses of 40% are illustrative; the actual figure depends on duct diameter, length, bends and fan curve.

## Gas detection considerations

- Test the atmosphere at both manholes and at the lower curve along the length of the tank.
- Use a sensor configuration that includes oxygen, LEL and any specific contaminants identified in the hazard profile.
- Catalytic LEL sensors require oxygen to function; check the sensor type if oxygen deficiency is possible.
- Continue continuous monitoring throughout occupancy because residue disturbance can release new vapour.

## Why does the calculated purge time not prove the space is safe?

A purge time calculated above, of just over 5 minutes, corresponds to the ideal displacement of a perfectly mixed cylinder. The cylinder is not perfectly mixed, residues remain in the tank, and the fan is delivering less than its rated free air. The DSEAR risk assessment, atmospheric testing at appropriate locations, and continuous monitoring during work are required to support the entry decision.

## 7.3 Example 3 — Deep Wet Well with Sump

### Scenario

A wastewater pumping station wet well is to be entered for inspection and minor mechanical work. The well has a deep sump containing sludge and standing effluent. Hazard profiling identifies hydrogen sulphide, methane, oxygen deficiency and the potential for sudden inflow from upstream surges.

A blower fan is to be used to purge before entry and to maintain ventilation during occupancy.

### Space dimensions

- Internal cross section: 2.5 m × 2.5 m (rectangular)
- Depth from cover to sump base: 6.0 m
- Fan rated free air delivery: 4,800 m<sup>3</sup>/h (80 m<sup>3</sup>/min)
- Planning factor for 8 m of trunking with one 90° bend extended to the base of the well: 30% reduction (used for this worked example)

### Volume calculation

$$\text{Volume} = 2.5 \times 2.5 \times 6.0 = 37.5 \text{ m}^3$$

### Fan airflow

$$\text{Effective airflow after 30\% reduction} = 80 \times 0.7 = 56 \text{ m}^3/\text{min} = 3,360 \text{ m}^3/\text{h}$$

### Air changes per hour

$$\text{ACH} = 3,360 \div 37.5 = 89.6 \text{ air changes per hour, theoretical, based on ideal mixing.}$$

### Purge time

Required air changes selected: 10 (a conservative figure for a high-hazard space).

Purge time =  $(10 \times 37.5) \div 56 = 6.70$  minutes, theoretical. The safe system of work would specify a longer minimum purge period and a documented post-purge test.

### Key limitations in this space

- The sump retains sludge that will release H<sub>2</sub>S if disturbed. Ventilation alone will not address the gas held within the sludge.
- Methane is lighter than air and may accumulate beneath the cover. The supply duct positioned at the base must be paired with adequate air return at the top.
- Upstream surges from rainfall can introduce new contaminants in seconds. The space is therefore one in which conditions can change during occupancy.
- A 30% reduction factor is illustrative; the actual delivery must be derived from the fan curve and ducting in use.

## Gas detection considerations

- Sample from outside at multiple depths before any entry, including the air space immediately above the sludge.
- Pause at each depth for at least T90 plus tube delay.
- Use a sensor suite that includes O<sub>2</sub>, LEL, H<sub>2</sub>S, and CH<sub>4</sub> as a minimum; add other specific sensors as required by the hazard profile.
- Continue continuous monitoring with alarms set, and consider a low-point detector in addition to the breathing-zone personal monitor.
- Re-test after any disturbance of the sludge.

## Why does the calculated purge time not prove the space is safe

The 6.70-minute calculated purge time describes ideal mixing of a 37.5 m<sup>3</sup> volume. The wet well is not a mixing chamber. Gas can be held in sludge, gas can re-enter from upstream, and ventilation can disturb settled hydrogen sulphide.

The entry decision must rest on atmospheric testing at appropriate locations, continuous monitoring, isolation where reasonably practicable, and rescue arrangements compliant with regulation 5.

## 8. Limitations of Air Change Calculations

Section 7 demonstrates the limitations of the calculation in three different geometries.

The following points apply across all confined space ventilation planning.

### 8.1 Ideal mixing versus real confined space conditions

The air change formula assumes that fresh air entering the space mixes instantaneously and uniformly with the existing air, so that each cubic metre of supply removes an equal share of contaminant from every cubic metre of the space.

Confined spaces are not perfectly stirred. The cross-section is irregular, openings are limited, residues retain gas, and the geometry of the space creates preferential airflow paths in which most of the fan delivery moves through a small fraction of the volume.

The remainder of the space, including the areas where heavier than air or lighter than air gases collect, may receive little ventilation. Real world tracer gas studies routinely show that achieving the calculated number of air changes can require several times the theoretical purge time, particularly in cylindrical or deep, narrow spaces.

### 8.2 The calculation is a planning tool, not a measurement

An air change calculation supports:

- Selection of an appropriately sized fan and trunking.

- Estimation of the order-of-magnitude purge time so that the pre-entry sequence can be planned.
- Demonstration that ventilation has been considered and that a reasonable basis exists for the chosen approach.

It does not establish:

- That the atmosphere in any specific part of the space has reached a target concentration.
- That all contaminants of concern have been removed.
- Those conditions will remain stable during occupancy.
- That breathing apparatus is not required.

### **8.3 Why atmospheric testing and ongoing monitoring are still required**

As outlined in L101 paragraph 88, the atmosphere in a confined space must be tested before entry where the risk assessment indicates that the air inside may be unsafe. As outlined in L101 paragraph 97, testing from outside through a long probe is normally the first step. Testing must be planned to capture pockets of poor air quality, particularly where there is any doubt about the thoroughness of ventilation.

Where the risk assessment indicates that conditions may change during the work, continuous monitoring is required, as outlined in INDG258. This includes any space where the work itself can introduce contaminants, any space with residues, any space connected to upstream or adjacent processes, and any space where workplace exposure limits may be approached.

## **9. Gas Stratification in Confined Spaces**

Stratification is the formation of layers of different atmospheric composition within a confined space. It arises from differences in gas density relative to air, confined spaces with low airflow and irregular geometry, and residues and biological activity that release gas at specific points within the space.

Stratification is a planning issue and a testing issue. It determines where gas pockets are most likely to form, where the probe or monitor must be placed, and where personal detectors must be positioned during occupancy. It also determines how ventilation must be configured, because misplaced ventilation can disturb stratified layers in ways that increase, rather than reduce, exposure.

### **9.1 Common confined space gases and how they behave**

The table below summarises the behaviour of the most common contaminants encountered in UK confined space work. The relative density figures are nominal and refer to standard conditions. Real behaviour is affected by temperature, airflow, pressure, humidity, chemical reactions, sludge disturbance, biological activity, work activity, and confined-space geometry. Vapour density alone must not be used as a sole basis for testing strategies.

Gas or condition	Relative density	Typical confined space sources	Behaviour and detection notes
Hydrogen sulphide (H <sub>2</sub> S)	Heavier than air (1.19)	Decay of organic matter Sewers, wet wells, and the digestion plant Geological infiltration	Tends to collect at low points and within sludge. Disturbance of sludge or water can release sudden high concentrations. Olfactory fatigue (anosmia) at higher levels means smell is not a reliable indicator. Test at low points and after any disturbance.
Carbon dioxide (CO <sub>2</sub> )	Heavier than air (1.53)	Biological breakdown Acid groundwater on limestone Brewing, fermentation, and dry ice	Collects at low points, sumps and benching. Reduces breathable oxygen and is directly toxic at elevated levels. Easily missed by detectors set only for O <sub>2</sub> , LEL, H <sub>2</sub> S and CO. Use a CO <sub>2</sub> sensor specific to the hazard profile where needed.
Methane (CH <sub>4</sub> )	Lighter than air (0.55)	Decay of organic matter Landfill and geological seepage Sewerage and digestion plant	Rises and can accumulate at the top of a space, in roof voids and beneath covers. Detected as percentage LEL by catalytic sensors; high concentrations can poison some sensors. Test high points and the breathing zone.
Carbon monoxide (CO)	Similar to air (0.97)	Combustion sources Petrol or diesel engines outside the space Hot work and chemical processes	Diffuses fairly evenly but follows airflow paths. It can be drawn into a space by ventilation if intakes are poorly sited. Standard electrochemical sensor; cross-sensitivity to hydrogen and some hydrocarbons.
Oxygen deficiency	Not applicable	Displacement by inert gas or other vapours Biological consumption Rusting steel and chemical reactions	Not uniform; pockets can occur above or below the breathing zone. Even brief exposure below 16% can lead to unconsciousness without warning. Filtering RPE must never be used in oxygen-deficient atmospheres (HSG53 paragraph 11). (I101 para172)

Gas or condition	Relative density	Typical confined space sources	Behaviour and detection notes
Oxygen enrichment	Not applicable	Leaking oxygen supply Inappropriate use of medical or cutting oxygen	Above approximately 23.5%, the flammability of clothing, hair, and other combustible materials increases significantly. Grease and oils can spontaneously ignite.
Flammable vapours	Variable	Petrol, solvents, hydrocarbons Residues, sludges and contaminated water Adjacent processes	Vapour density determines the initial distribution, but airflow, temperature, and disturbances change it. DSEAR risk assessment is required where an explosive atmosphere may be present. Catalytic LEL sensors require oxygen to function; check the sensor type for atmosphere.

## 9.2 How heavier than air gases collect at low points

Hydrogen sulphide, carbon dioxide, and many flammable vapours have densities greater than air at typical confined space temperatures. In a still atmosphere, they will settle towards the base of the space, the sump, the benching or any other low point. They will also remain in pipe stubs that lead downwards and in dead spaces below baffles.

In a sewer, wet well, or digester, low-point accumulation is the most common cause of severe atmospheric exposure incidents. Testing at the breathing zone only, or at the entrance only, can read close to zero while the lower part of the space contains lethal concentrations.

As outlined in L101, paragraph 97, sufficiently representative samples of the space must be tested to detect pockets of poor air quality.

## 9.3 How lighter than air gases collect at high points

Methane, hydrogen, and ammonia have densities lower than that of air. They rise and tend to collect at the roof of a space, beneath domed covers, in the headspace of a partly filled tank or in any high-level recess. In wastewater and biogas environments, methane accumulation beneath covers is a common finding.

Testing must include the high points where lighter than air gases are reasonably foreseeable. A test performed only at the breathing zone of an entrant standing on the floor will not detect a methane layer beneath the cover until the layer is disturbed.

## 9.4 Why oxygen deficiency and enrichment may not be evenly distributed

Oxygen content is not uniform across a stratified atmosphere. Where a denser gas displaces air at the base of the space, the oxygen reading at the base will be lower than at the top. Where biological consumption is occurring at the base, the same pattern emerges. Where an inert gas blanket has been applied at the top of a tank, the oxygen reading at the top will be lower than at the base.

Oxygen readings must therefore be taken at the same locations as the contaminant tests. A single oxygen reading at the entrance does not represent the atmosphere at the work position.

## 9.5 How geometry prevents effective air mixing

Geometry that interferes with air mixing includes:

- Sludge layers and sumps that retain gas and release it when disturbed.
- Benching and shelves that create dead spaces below the main flow.
- Pipe runs and pipe stubs that allow gas to migrate from outside the assessed area.
- Internal tanks, vessels within vessels, and divided chambers that isolate one part of the space from the airflow.
- Ducts and trunking that channel airflow away from the working area.
- Baffles, weirs and internal walls that obstruct cross-section flow.
- Dead-end spaces with no return air path.

Each of these features should be identified during hazard profiling and reflected in the testing plan.

# 10. Ventilation and Gas Movement

The act of ventilating a confined space changes the atmosphere within it. Some of those changes are intended; others are not. The following points must be understood by anyone planning a ventilated entry.

## 10.1 Ventilation may disturb settled gases

Hydrogen sulphide and other heavier than air gases can sit in stable layers above sludge and at the base of a space. The introduction of forced ventilation moves these layers.

If the sample is not taken in the right place at the right time, the disturbance can either appear to remove the gas or, conversely, can spread it through the breathing zone of the entrants.

Ventilation in spaces with significant sludge content should be planned assuming that some H<sub>2</sub>S will be released during the purge. Continued monitoring during the purge is essential before any entry is authorised.

## 10.2 Ventilation may push contamination into another part of the space

In a multi-chambered space, a long horizontal tank, or a sewer network, fresh air supplied at one location can push contaminants into an adjacent location rather than removing them. This is particularly important where the entry team will move through the space, because contamination can be ahead of them as well as behind them.

Extract ventilation, applied at the contaminated area with make-up air drawn from a clean source, is often more effective than blowing fresh air at the base of the space. As outlined in L101 paragraph 104, complicated spaces may need a combined supply and extract arrangement to achieve thorough ventilation.

## 10.3 Ventilation may draw external contamination into the space

Fresh air for a confined space must come from a location free from contamination. As outlined in L101 paragraph 102, the inlet must not draw from used air or other pollutants. Petrol or diesel engine exhausts, generator emissions, traffic fumes, adjacent industrial processes and discharges from other vents can all contaminate the supply air.

Where the fan is petrol- or diesel-driven, the engine should be sited well downwind of and below the inlet, or an electric fan should be used. Carbon monoxide from petrol engines used in confined space ventilation has caused multiple UK fatalities.

## 10.4 Ventilation may create false confidence

A common error is to treat a running fan as evidence that the atmosphere is safe. Several documented incidents have resulted in fatalities in spaces where a ventilation fan was operating. However, the airflow did not reach the casualty, or where the inlet was contaminated, or where the contaminant was generated faster than the fan could remove it. Ventilation must always be combined with atmospheric testing and continuous monitoring.

# 11. Gas Detection and Monitoring Considerations

Gas detection answers the question that ventilation calculations cannot: what is the actual composition of the atmosphere at the point and time of measurement, within the limits of the sensor in use. Every element of that statement matters.

## 11.1 Sensor types and what they detect

Confined space portable detectors typically include one or more of the following sensor technologies. Each has a specific application and a specific set of limitations.

- Electrochemical sensors are used for oxygen, hydrogen sulphide, carbon monoxide and other toxic gases. They have a finite operating life, are temperature and humidity-sensitive and exhibit cross-sensitivity to other gases.
- Catalytic combustion (pellistor) sensors are used for flammable gases at LEL concentrations. They require approximately 12% oxygen to function, can be poisoned

by silicones, sulphur compounds, and certain hydrocarbons, and may give unreliable readings at very high concentrations.

- Infrared sensors are used to detect hydrocarbons, carbon dioxide, and methane. They do not require oxygen, are not poisoned by other compounds and operate at high concentrations. They are gas specific and will not detect gases outside their calibration.
- Photoionisation detectors (PID) are used for volatile organic compounds. The response depends on the ionisation potential of the substance relative to the lamp energy. They are sensitive to humidity and dust.

## 11.2 Sampling position, diffusion and pump tubing

Detectors can be operated in diffusion mode, where ambient gas reaches the sensor by natural movement, or in sample-draw (pumped) mode, where a pump draws gas through tubing into the sensor housing.

Diffusion mode is appropriate for personal monitors worn in the breathing zone. It is not appropriate for pre-entry testing of a closed or remote space, because the detector must be physically present in the atmosphere being tested.

Sample-draw mode allows the atmosphere to be tested from outside the space through a probe and tubing. Each metre of tubing adds a delay that must be accounted for in the sensor response time before a reading can be considered representative. The total wait at each test location is therefore the sensor T90 plus the tube delay, not whichever is larger.

## 11.3 Sensor response time and T90 delay

The response time of a sensor is the time taken for the reading to reach a defined fraction of the true value. T90 is the time to reach 90% of the true value. T100 is not normally specified because the last 10% can take much longer than the first 90%.

Published T90 figures are typically 15 to 60 seconds for common toxic and flammable sensors and can be longer in cold conditions. Sampling on the move or recording readings before T90 has elapsed will yield values that lag the true atmosphere and may understate the hazard.

## 11.4 Humidity, temperature and pressure

Sensor performance varies with humidity, temperature and pressure. Electrochemical sensors can drift when moving between cold and warm environments. Infrared sensors are generally more stable but are not immune. Manufacturers' data sheets state the operating ranges and any required corrections. Where conditions are at the extreme of the operating range, sensor accuracy must be reviewed.

## 11.5 Cross sensitivity

Electrochemical sensors respond to gases other than the target gas. Common examples include CO sensors responding to hydrogen and to some hydrocarbons, and H<sub>2</sub>S sensors

responding to mercaptans. Where cross-sensitivity is likely, the manufacturer's data sheet should be consulted and the readings interpreted accordingly. A high CO reading in the absence of any obvious combustion source should prompt consideration of an alternative gas.

## 11.6 Where to test

Testing must cover the locations where gas is reasonably foreseeable. This normally means:

- At the top of the space, particularly where lighter than air gases are foreseeable.
- Middle of the space, representing the working zone.
- Bottom of the space, particularly where heavier than air gases or sludge are present.
- Known dead spaces, baffles, recesses and pipe stubs.
- Adjacent to any residue, sludge or scale that may release gas if disturbed.

Allow full T90 plus tube delay at each location. Record the result. Where ventilation is required, repeat the testing after the purge and before any entry.

## 11.7 Continuous monitoring during work

Continuous monitoring is required where conditions can change. This includes any space with residues, any space connected to upstream or adjacent processes, any work that disturbs sludge, scale or settled material, any hot work, and any space with biological activity.

Personal detectors must be carried by each entrant and positioned in the breathing zone. Additional fixed or remote detectors may be required to monitor known dead spaces or low points that are not represented by the personal monitor.

## 12. Common Errors and False Reassurance

The following table summarises the most common gas detection and ventilation errors encountered in UK confined space practice, with the reasons each error can lead to false reassurance and the correct practice to address it.

Error	Why it produce false reassurance	Correct practice
Testing only at the entrance	Misses gas pockets at low points, high points or in dead spaces.	Test the top, middle, and bottom, and at known dead spaces, using a probe and tubing.
Failing to test low points	Heavier than air gases such as H <sub>2</sub> S and CO <sub>2</sub> collect at the bottom and in sludge.	Lower the probe to the lowest accessible point and allow full T90 plus tube delay.

Error	Why it produce false reassurance	Correct practice
Moving too quickly with a pumped detector	Readings lag behind the probe's actual position.	Pause at each test depth long enough for the reading to stabilise.
Not allowing for sensor response time	Snap readings are recorded before the sensor has reached the true value.	Wait for at least T90 at each location before recording.
Not allowing for tubing delay	Gas must travel through the sample line before reaching the sensor.	Add a documented tube delay per metre to the T90; never sample on the move.
Not understanding T90	T90 is the time for the sensor to reach 90% of the true value, not 100%.	Train operatives on what T90 means and on the published value for the sensor in use.
Not bump testing before use	A faulty or out-of-calibration sensor can read zero when gas is present.	Bump test before each use against the manufacturer's schedule; record the result.
Using the wrong sensor for the hazard	Common four-gas detectors do not measure CO <sub>2</sub> , ammonia, solvents, VOCs or specific toxics.	Build a hazard profile first, then choose sensors that match the identified contaminants.
Poor detector positioning during work	A detector clipped at the chest may not represent the breathing zone or the lowest point.	Position personal detectors in the breathing zone; consider an additional low-point detector.
Assuming ventilation has removed all contamination	Ventilation can leave pockets, push gas into other parts of the space, or stir up residues.	Re-test after ventilation; continue to monitor during work.

Each of these errors has been documented in incident investigations. Each is preventable. CSRTA recommends that this table is reviewed during pre-job briefings and during refresher training.

## 13. Practical Control Measures

The control measures below bring the calculation, ventilation, and detection together into a single sequence aligned with regulation 4(2) safe system of work and regulation 5 emergency arrangements under the Confined Spaces Regulations 1997.

### 13.1 Before entry

4. Build a hazard profile from the asset history, surrounding installations, residues, work activity, and upstream connections. Do not infer the hazard from the asset name.

5. Confirm that the regulation 4(1) avoidance question has been answered before entry planning begins.
6. Carry out the COSHH assessment for the substances reasonably foreseeable in the air and the DSEAR assessment for any explosive atmosphere that may be present. These are two separate questions and produce two separate control sets.
7. Isolate the space against the ingress of substances that could pose a risk, in line with L101 paragraphs 107 to 111.
8. Calculate the volume of the space and the planning purge time using the formulas in section 6.
9. Select a fan and ducting that can deliver the required airflow at the actual installed configuration, not at free air.
10. Position the supply and extract to address the stratification expected in the space, including any low or high points identified.
11. Run the fan and conduct atmospheric testing from outside at top, middle, bottom and any known dead spaces, allowing full T90 plus tube delay at each location.
12. Bump-test the detector against the manufacturer's schedule and document the results.
13. Document the entry decision against the readings actually obtained, not against the calculated purge time.

### 13.2 During entry

14. Continue ventilation throughout occupancy.
15. Carry personal monitors in the breathing zone of every entrant.
16. Consider an additional low-point or high-point detector where stratification is foreseeable.
17. Re-test the atmosphere after any disturbance of sludge, scale or residue, and after any change in work activity.
18. Stop work and withdraw if any alarm activates, if any reading approaches the relevant action level, or if conditions appear to be changing in a way not predicted by the risk assessment.

### 13.3 RPE and BA selection where the atmosphere cannot be confirmed safe

Where the atmosphere cannot be confirmed as safe through ventilation and testing, or where it may deteriorate during the work, respiratory protective equipment must be selected based on the hazard present.

As outlined in HSG53 paragraph 11, filtering respirators must not be used in oxygen-deficient atmospheres. As outlined in HSG53 paragraph 22, RPE is the last line of protection and is not a substitute for ventilation, isolation or atmospheric control.

A self-contained breathing apparatus or an airline breathing apparatus is required where the hazard is significant, the atmosphere is uncertain, or the work may degrade the atmosphere during entry.

## 14. Rescue Team Considerations

Ventilation and gas detection are not only entry team concerns. They affect every part of the rescue arrangement under Regulation 5.

### 14.1 The atmosphere may have deteriorated by the time of rescue

A rescue is normally triggered by an event that has already changed the conditions in the space. The atmosphere that supported a working entry team may not support a rescue.

Ventilation that was adequate for the work may have been interrupted, disturbed or contaminated. The atmospheric readings recorded during the original entry are historical and may no longer represent the current conditions.

Rescue planning must therefore assume that atmospheric controls in place at the time of the rescue are uncertain, and the rescue team must be equipped to operate on that basis. As a CSRTA position, this normally means SCBA or airline BA for the rescue operatives committed to the space, with a documented escape provision.

### 14.2 Ventilation cannot be relied upon during a rescue

If a casualty has been overcome by an atmosphere, the cause of the incident is unknown until the rescue is complete. The cause may be a failure of ventilation, a disturbance of residue, a sudden upstream inflow, or a contaminant not included in the original assessment. Rescue operatives must not rely on the assumption that ventilation will protect them.

### 14.3 Detection during a rescue

The rescue team must carry their own detectors, with sensors appropriate to the hazard profile, including any specific contaminants identified by the entry team. Bump-test results must be current. The team must understand the readings' meaning in the context of an evolving incident, including the limitations of T90 and the implications of stratification.

### 14.4 Briefing and decision making

The Critical Incident Decision Model and the FATAL and RESCUE Briefing Methods used in CSRTA training are intended to embed atmospheric, ventilation and detection limitations into the operational decision.

The decision to commit a rescue operative to a space whose atmosphere cannot be confirmed safe is a casualty-centred decision made within VRTO1 role limits, supported by appropriate respiratory protection.

## 15. Instructor Discussion Points

The following discussion points are suggested for CSRTA CPD delivery sessions. They can be used as classroom prompts, workshop tasks, or starting points for scenario debriefs.

19. Take a real fan and trunking from your training stores. Estimate the delivered airflow at the end of the trunking and compare it with the free air rating. What does this tell you about the planning purge time you have used in the past?
20. Identify a space at a recent training venue. List the locations where you would place the probe before entry. Justify each one against the hazard profile.
21. Discuss a recent confined space incident with an atmospheric cause. Identify the stratification, ventilation or detection issue that contributed.
22. Compare the T90 figures published by your detector manufacturer with the times your team actually allows in practice.
23. Discuss when SCBA or airline BA is the appropriate respiratory protection for a planned entry and when it is the appropriate provision for a rescue.
24. Discuss the boundary between COSHH and DSEAR atmospheric assessments and why a multi-gas detector reading does not, on its own, complete either.
25. Discuss the role of the entry controller in monitoring the gas readings and recognising change.

## 16. Learner Knowledge Check Questions

The following questions are suitable for written or oral assessment as part of CPD verification. Model answers are provided in section 17. Each question is intended to test understanding rather than recall.

26. Define an air change in the context of confined space ventilation.
27. State the formula for calculating the volume of a rectangular confined space and the formula for a cylindrical confined space.
28. State the formula for purge time.
29. Explain why the advertised free air rating of a fan may overstate the airflow delivered at the work face.
30. List four physical or installation factors that reduce ventilation performance.
31. Explain why the calculated purge time does not prove that the atmosphere is safe.
32. Explain why hydrogen sulphide is particularly hazardous in confined spaces with sludge.
33. Explain why methane can be missed by a test taken only at the entrance to a confined space.
34. Define T90 and explain how it affects pre-entry testing.
35. Explain why a multi-gas detector reading within alarm limits does not, on its own, complete the COSHH and DSEAR atmospheric assessments.

36. State the conditions in which filtering RPE must not be used.
37. Explain why a rescue team should not rely on the ventilation that was in place during the original entry.

## 17. Model Answers

### Question 1 — Define an air change

An air change is the replacement of the air contained within a defined volume with an equivalent volume of fresh air. In confined space planning, the number of air changes per hour is used to estimate the time required to dilute or displace contaminants, assuming ideal mixing.

### Question 2 — Volume formulas

Rectangular space: Length × Width × Height = Volume in m<sup>3</sup>. Cylindrical space:  $\pi \times \text{radius}^2 \times \text{length} = \text{volume in m}^3$ .

### Question 3 — Purge time formula

Purge time in minutes = (Required air changes × Space volume) ÷ airflow per minute.

### Question 4 — Free air rating versus delivered airflow

The free air rating is measured at zero static pressure. In a real installation, the fan must overcome friction in the trunking, pressure drops at every bend, restriction or filter, and back pressure from the space itself. The delivered airflow at the work face can be a small fraction of the free air figure, particularly with long or bent ducting.

### Question 5 — Factors that reduce performance

Acceptable answers include any four of: long duct runs, sharp bends, reductions in duct diameter, filters, poor fan positioning, lack of make-up air, damaged or kinked ducting, dirt accumulation, condensation and the absence of a published fan curve.

### Question 6 — Why does the purge time not prove safety

The calculation assumes ideal mixing, the rated fan output, and a single contaminant uniformly distributed in the space. Real confined spaces are not perfectly mixed; the fan does not deliver its free-air rating; contaminants stratify; residues continue to release gas; and conditions may change during occupancy. Only atmospheric testing carried out at appropriate locations, supported by isolation, a safe system of work and continuous monitoring, can support the entry decision.

### Question 7 — Hydrogen sulphide and sludge

Hydrogen sulphide is heavier than air and is generated by the breakdown of biological material. It is retained in sludge and standing water and is released suddenly when the

sludge is disturbed. Olfactory fatigue means the sense of smell is less reliable at higher concentrations. Pre-entry testing must therefore include the low points and the air space above the sludge, and continuous monitoring is essential during any work that may disturb the residue.

### **Question 8 — Methane missed at the entrance**

Methane is lighter than air and rises to the top of the space, where it can accumulate beneath covers and in roof voids. A test taken only at the entrance, particularly at chest height, may read close to zero while a methane layer is present above. Testing must include the high points where lighter than air gases are reasonably foreseeable.

### **Question 9 — T90**

T90 is the time taken for a gas sensor to reach 90% of the true reading after exposure to the target gas concentration. The remaining 10% takes longer and is not normally specified. Pre-entry testing must allow at least T90 at each test location before recording. Where a sample-draw detector is used through tubing, the total wait is T90 plus the tube delay.

### **Question 10 — Multi-gas detector and the COSHH and DSEAR questions**

A multi-gas detector reading shows whether alarm thresholds for a specific set of gases are exceeded at the point and time of sampling. COSHH 2002, supported by L5 and EH40, addresses the health effects of breathing air against workplace exposure limits expressed as time-weighted concentrations.

DSEAR 2002, supported by L138, addresses the ignition and explosion hazards posed by explosive atmospheres. A snapshot detector reading does not, on its own, complete either assessment, and RPE selection based on the snapshot alone may breach HSG53 paragraph 11.

### **Question 11 — When filtering, RPE must not be used**

Filtering RPE must not be used in oxygen-deficient atmospheres or where the contaminant is outside the filter's protection range, as outlined in HSG53 paragraph 11. Where the atmosphere cannot be confirmed safe, SCBA or airline BA is required.

### **Question 12 — Rescue and the original ventilation**

A rescue is normally triggered by an event that changes conditions within the space. Ventilation may have been interrupted, disturbed or contaminated, residues may have been disturbed, and contaminants not in the original assessment may now be present.

The atmospheric readings recorded during the original entry are historical. Rescue operatives must therefore use SCBA or airline BA appropriate to the hazard, with a documented escape provision, regardless of the original entry arrangement.

## 18. Practical Exercise

The following exercise is suitable for delivery at a CSRTA centre with appropriate training assets. The exercise can be run as a single workshop or distributed across multiple CPD sessions.

### 18.1 Aim

To consolidate the learner's understanding of air change calculations, ventilation limitations, stratification and gas detection by carrying out a planned pre-entry sequence on a representative training asset.

### 18.2 Materials

- A representative confined space training facility with known dimensions (such as an inspection chamber or a tank simulator).
- A portable ventilation fan with manufacturer's data sheet, including the fan curve where available, and lay-flat or rigid trunking of known length.
- A multi-gas detector with a sampling pump and tubing of known length.
- Bump test the gas appropriate to the detector.
- A copy of this CPD document and the relevant manufacturer's instructions.

### 18.3 Steps

38. Measure the internal dimensions of the training space and calculate its volume in m<sup>3</sup>.
39. Identify the foreseeable hazard profile for an equivalent operational space, including likely contaminants and their density relative to air.
40. Read the fan data sheet and estimate the delivered airflow at the actual ducting configuration. Show your reasoning.
41. Calculate the air changes per hour and the purge time for a defined number of air changes.
42. Bump-test the detector, record the results, and confirm the sensor configuration matches the hazard profile.
43. Plan the pre-entry sampling locations and the expected wait at each (T90 plus tube delay).
44. Run the fan, conduct the sampling and record the readings against the plan.
45. Discuss with the instructor the difference between the calculated purge time and the observed atmospheric behaviour.
46. Identify at least one decision in the planned entry that should not be taken based on the calculation alone, and explain why.

## 18.4 Outcome

The learner should be able to justify each step of the planned entry against regulation 4(2) safe system of work, with the calculation, ventilation arrangement, and detection plan presented as separate but interlinked controls. The instructor should record the outcome on the CPD record sheet.

## 19. Important Safety Position

### **Air change calculations alone do not make a confined space safe.**

They support planning. They help size a fan, estimate purge time, and demonstrate that ventilation has been considered. They are a tool and nothing more.

A confined space entry is supported by all of the following, applied together:

- A suitable and sufficient risk assessment under the Management of Health and Safety at Work Regulations 1999 and the Confined Spaces Regulations 1997.
- A regulation 4(2) safe system of work covering isolation, ventilation, atmospheric testing, communication, supervision and emergency arrangements.
- Isolation of the space against the ingress of substances that could pose a risk.
- Ventilation appropriate to the hazard profile and the geometry of the space.
- Atmospheric testing carried out at appropriate locations, at appropriate times, with appropriate sensors and with allowance for T90 and tube delay.
- Continuous monitoring where conditions can change during occupancy.
- Competent supervision under regulation 4(2).
- Emergency arrangements compliant with regulation 5, including suitable equipment, communications, training and casualty management.
- Appropriate respiratory protection is required where the atmosphere cannot be confirmed safe or may deteriorate during the work.

None of these is optional. The calculation is one input to a planning sequence that ends each time with a competent person making an entry decision based on the actual atmospheric readings, the actual ventilation arrangement, and the actual rescue provision.

## 20. Summary

This CPD guidance has set out the four interlinked technical questions in confined space atmospheric control: volume and air change calculations, ventilation planning, stratification, and gas detection.

It has shown how each contributes to the regulation 4(2) safe system of work and the regulation 5 emergency arrangement, and how each is limited.

The key learning points are:

- Air change calculations are a planning tool only. They never confirm that the atmosphere is safe.
- Fans deliver less air in real installations than their free air ratings suggest. Ducting losses must be accounted for in the planning calculation.
- Confined spaces are not well-mixed. Stratification, dead spaces, residues, and geometry mean that contaminants can be present in pockets not represented by a single sample.
- Ventilation can disturb settled gases, push contamination into another part of the space or draw in contamination from outside. It can also create false confidence if testing is not done correctly.
- Gas detection answers a different question from ventilation and a different question from calculation. It must be carried out with the right sensors, at the right locations, with the right wait times, and with allowance for cross-sensitivity.
- Rescue teams operate in conditions that the original entry assessment cannot describe. SCBA or airline BA appropriate to the hazard is normally required.

Treated together, these points support the central CSRTA position that confined space competence is evidence-based, professional and defensible. Calculation and detection are technical disciplines. They must be taught accurately, applied honestly and reviewed regularly.

## 21. References and Guidance Sources

- Confined Spaces Regulations 1997 (SI 1997/1713).
- Health and Safety Executive (2014). Safe work in confined spaces: Approved Code of Practice, Regulations and guidance. L101 (Third edition).
- Management of Health and Safety at Work Regulations 1999 (SI 1999/3242).
- Control of Substances Hazardous to Health Regulations 2002 (COSHH), with Approved Code of Practice and guidance L5 (Sixth edition).
- Health and Safety Executive. EH40/2005 Workplace exposure limits, as amended.
- Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR), with Approved Code of Practice and guidance L138 (Second edition).
- Health and Safety Executive. HSG53 Respiratory protective equipment at work: A practical guide (Fourth edition).
- Health and Safety Executive. HSG250 Guidance on permit-to-work systems.
- Provision and Use of Work Equipment Regulations 1998 (PUWER).
- Health and Safety Executive. INDG258 Confined spaces: A brief guide to working safely.
- Water UK (2019). Classification and Management of Confined Space Entries — Guidance for the Water and Wastewater Industry.
- Manufacturer instructions for portable ventilation fans, trunking and gas detection equipment in use at the centre.

End of document.