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Good Practice Guide for CO_2 Leak Detection and Measurement at Component Scale

This guide focuses on the practical use of portable CO_2 leak detectors and room monitors, particularly within Carbon Capture, Utilisation and Storage (CCUS) infrastructures, where fugitive emissions may compromise safety, efficiency, and environmental performance. It outlines fundamental principles and best practices for CO_2 leak detection and quantification, emphasising the importance of clear operational procedures and strict adherence to safety measures. By providing structured guidance and insights into detection and measurement techniques, the guide aims to harmonise practices, minimise human error, and improve the reliability of Leak Detection and Repair (LDAR) campaigns.

The document covers essential topics such as the proper use of portable detectors, recommended safety precautions, the definition of leak thresholds relevant to component-scale monitoring, and specific procedures for CO_2 detection under various site conditions. It also discusses quantification methods, calibration and maintenance requirements, and the training of personnel to ensure consistent and accurate performance. Through this comprehensive guidance, the document provides a reference framework to support safe and effective CO_2 leak monitoring, serving operators, regulators, and other stakeholders involved in emissions management across industrial environments.

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1. Purpose and Scope of the Evaluation

1.1. Scope

This Good Practice Guide addresses the detection and measurement of carbon dioxide (CO_2) leaks at the component scale within Carbon Capture, Utilisation and Storage (CCUS) infrastructures. It covers pipelines, valves, flanges, pressure relief devices, drains, and other fittings where fugitive CO_2 emissions may occur due to imperfect seals, corrosion, fatigue, or assembly defects.

The guide focuses on the use of portable CO_2 leak detectors and room monitors for on-site inspections and for Leak Detection and Repair (LDAR) programmes. Remote sensing technologies such as drones, infrared imaging, or fixed sensor networks are acknowledged but are outside the scope of this document.

1.2. Purpose of this Good Practice Guide

The aim of this guide is to provide practical guidance and harmonised procedures for the detection and measurement of CO_2 leaks in industrial settings. It clarifies the distinction between leak detection (identifying presence) and quantification (measuring emission rates), and aims to minimise operator variability and human error during inspections.

In addition, it outlines good practices for equipment handling, calibration, and data reporting, supporting both internal procedures and external audits. Ultimately, this guide is intended to:

- support effective LDAR campaigns,
- provide a technical basis for future standardisation activities,
- and promote consistency across CCUS operators, service providers, and regulators.

The guidance builds upon previous work on CO_2 leak detection and benchmarking of portable detectors under the MetCCUS project.

2. Before Starting Leak Detection

2.1. Safety Precautions

Although CO_2 is a naturally occurring, non-flammable gas present in the atmosphere at typical background levels around 400–420 ppm, it presents significant safety risks at elevated concentrations. Carbon dioxide is a normal by-product of human respiration and of the combustion of fuels, and is commonly encountered in both indoor and outdoor environments at low levels with no associated hazard.

However, under specific conditions — such as leaks in confined or poorly ventilated areas — CO_2 can accumulate to dangerous levels. Being heavier than air, it tends to settle in low-lying zones, displacing oxygen and increasing the risk of asphyxiation. Exposure to concentrations above 1.5% (15 000 ppm) can impair motor and cognitive functions, while concentrations above 5% (50 000 ppm) may pose serious acute health risks.

For this reason, operators must wear personal CO_2 or oxygen alarms, particularly when entering confined spaces or enclosed environments. Proper personal protective equipment (PPE) should be used, including protective eyewear and antistatic clothing when required. Adequate ventilation must be ensured before initiating leak detection activities, and all site-specific safety protocols and occupational health guidelines must be strictly followed.

2.2. Leak Thresholds for LDAR Schemes

There is no such thing as a perfectly tight system — all components leak to some extent, depending on the sensitivity of the detection method used. Therefore, setting clear, quantitative thresholds is a fundamental requirement before initiating any Leak Detection and Repair (LDAR) activity. Operators must define:

- What minimum concentration change or flow rate constitutes a reportable leak,
- The practical resolution of the selected equipment, and
- The context of the installation (indoor, enclosed, or open and ventilated).

It is also important to note that most portable detectors measure concentration (in ppm) rather than leak rate (in Std cm^3/min or sccm). As such, the definition of leak thresholds must specify the measurement unit and measured quantity. This distinction is further addressed in a dedicated section later in this guide.

Higher detection sensitivity allows the identification of smaller leaks, but also increases the cost of both detection and repair efforts. For CO_2, unlike methane, no harmonised thresholds currently exist. Results from the MetCCUS project show that portable CO_2 detectors — even without sampling pumps — can reliably identify leaks greater than 10 Std cm^3/min at short distances.

Until formal thresholds are adopted, operators are encouraged to define site-specific criteria based on safety, environmental impact, equipment capability, and operating context. Even leaks below the chosen threshold may be relevant if they are likely to grow or contribute to long-term cumulative emissions.

2.3. Understanding Portable CO_2 Leak Detectors

Most portable CO_2 detectors are based on Non-Dispersive Infrared (NDIR) technology, which measures gas concentration by detecting how infrared radiation is absorbed by CO_2 molecules. These instruments are generally sensitive enough to detect ambient atmospheric CO_2 levels (typically 400–500 ppm), so sensitivity alone is not a limiting factor when selecting equipment for leak detection.

Instead, key performance differences arise from:

- Sampling method: Devices may use passive diffusion or pump-assisted sampling. Pump-assisted detectors typically offer more stable and reproducible measurements, and are less sensitive to airflow disturbances caused by wind or local ventilation. They may also allow better quantification by enabling a correlation between measured concentration and leak rate, provided that the sampling geometry is well characterised.

- Response and recovery time: While most detectors specify a 90% response time of 20 to 30 seconds, pump-assisted devices may exhibit faster and more predictable dynamics, particularly in transient scenarios.

- Mechanical design: Field robustness is essential for mobile LDAR campaigns. Some CO_2 detectors are primarily designed as room monitors or for stationary deployment, and may not be suitable for handheld, field-based operation.

- Measurement range: Typical CO_2 detectors cover from 0 to 10 000 ppm, with extended-range models reaching up to 30 000 ppm or more. However, upper range saturation can occur quickly near concentrated leak sources.

Operators must also be aware that performance is strongly influenced by proximity to the leak, sensor orientation, and ventilation conditions — particularly for diffusion-based devices. The presence of a well-defined gas inlet (as opposed to generic housing vents) improves the interpretability of readings and reproducibility between tests.

2.4. Preparation Before Use of Equipment

Before initiating any leak detection activity, it is essential to verify and prepare the equipment to ensure that all measurements are reliable, reproducible, and traceable. This step is especially important in the context of metrology-driven campaigns, where quantitative confidence in the results is critical.

Calibration is the foundation of any meaningful measurement. No CO_2 concentration or leak rate reading should be interpreted or reported without a clear understanding of the detector's calibration status.

- Calibration types: Instruments may be calibrated either in terms of CO_2 concentration (ppm) using certified gas mixtures, or in terms of leak rate (e.g., Std cm^3/min) using traceable leak artefacts. In both cases, the calibration must be suited to the expected measurement range (e.g., 400–5 000 ppm for ambient CO_2 levels or room monitoring).

- Calibrating against leak rate: It is also possible to calibrate a detector's ppm reading against a reference leak rate, thereby enabling the practical conversion between measured concentration and emission rate. In this case, the numerical reading may not correspond directly to the leak rate value, but the calibration provides a functional relationship between both quantities. This approach is particularly valuable when estimating total CO_2 emissions during LDAR surveys or facility assessments.

- Accreditation and traceability: Calibrations must be performed by accredited laboratories, capable of ensuring traceability to international standards (e.g., SI units). Only such calibrations can guarantee the independence, reproducibility and comparability of results across facilities and campaigns.

- Field verification: For on-site verification, portable reference artefacts — such as pre-calibrated leak sources or certified gas cylinders — may be used to assess sensor performance under realistic conditions. These artefacts must be regularly revalidated against reference standards in the laboratory.

- Functional checks: Prior to field deployment, all detectors should undergo a functional test using either a known calibration gas or a reference leak. This serves to confirm operational status and response behaviour.

- Environmental conditions: Operators should note the ambient temperature, pressure, and humidity, as these may influence sensor behaviour, especially for NDIR and electrochemical technologies. Devices should ideally include automatic environmental compensation or correction factors where necessary.

- Logistical preparation: Batteries must be fully charged, with spares available. Data logging settings should be checked, and memory capacity confirmed. In parallel, site access authorisation and a full risk assessment must be completed prior to deployment.

This level of preparation ensures that subsequent measurements are valid and interpretable, supporting the integrity of Leak Detection and Repair (LDAR) decisions and ensuring compatibility with future standardisation efforts.

3. Locating and Quantifying Leaks

3.1. Difference Between Locating and Quantification

In leak detection, it is essential to distinguish between locating a leak and quantifying it.

- Leak localisation refers to identifying the origin, faulty component or precise point of a CO_2 leak. This is typically achieved when a detector registers a concentration noticeably above background levels at a suspected emission point. The goal is to find "where" the leak is occurring. However, this does not imply knowledge of the leak's magnitude, even if the instrument provides a numerical reading.
- Leak quantification, on the other hand, involves estimating the actual leak rate, usually expressed in mass or volume per unit time (e.g., Std cm^3/min). This process requires specific calibration and procedures to correlate detector readings with real emission rates under defined conditions.

Importantly, many portable detectors provide readings in ppm (concentration), not leak rate. Therefore, unless properly calibrated or used under tightly controlled conditions, the displayed values should not be interpreted directly as leak rates.

In practice, localisation is often sufficient for maintenance and repair operations. Quantification is required when emissions need to be reported or when evaluating their environmental significance.

Operators should clearly define their objective in advance — locating versus quantifying — as each requires different procedures, interpretation criteria, and potentially different instrumentation.

3.2. General Operational Procedures

Procedure for CO_2 leak location (adapted from EN 15446):

- Position the probe inlet directly at the surface of the component or joint where a leak is suspected.
- Move the probe slowly along edges, seals, or interfaces, while continuously observing the instrument reading.
- If a rise in the reading is observed, carefully scan the surrounding area to identify the point of maximum response.
- Hold the probe at this point for approximately twice the instrument's response time, and record the measurement (in gas concentration or leak rate).
- Measure and record the background concentration by positioning the probe away from potential sources of leakage.
- Minimise the influence of air currents, especially when wind speed exceeds 0.5 m/s — a particular concern at elevated or exposed locations.

Operators should be aware that large leaks may mask nearby smaller leaks. It is therefore strongly recommended to repair any major leaks before continuing with further leak location activities.

3.3. Specific Procedures for CO_2 Leak Detection

Unlike hydrogen, CO_2 is denser than air and tends to accumulate in low-lying or poorly ventilated areas. For this reason, inspections should begin near the ground or in confined pits, gradually moving upwards.

Special attention should be paid to enclosed environments, such as valve pits or equipment rooms, where CO_2 can build up quickly. Understanding the stratification of CO_2 is important for interpreting readings, as elevated values may reflect accumulation in the environment rather than active leaks.

3.4. Influence of Local Conditions

Environmental conditions strongly influence CO_2 detection. In well-ventilated areas, gas plumes disperse rapidly, which can make small leaks harder to detect and introduce variability in the readings. In confined spaces, however, CO_2 concentrations may rise steadily, creating high readings that pose additional safety risks. Temperature and humidity can also affect the performance of NDIR sensors, causing signal drift or altering sensitivity. Operators should be aware of these factors and interpret readings accordingly.

3.5. Quantification of Leak Rates

Quantifying CO_2 leak rates requires careful selection of methods suited to the leak magnitude, equipment used, and field conditions. Several practical approaches are available, often relying on the use of a calibrated reference leak.

For small leaks, if the detector is equipped with a sampling pump and the probe can be positioned very close to the source, the leak rate can be estimated by comparing the detector response to that of a calibrated reference leak, provided the actual leak is much smaller than the detector's sampling flow. This method allows a direct, practical estimation of leak rate, assuming repeatable positioning and stable conditions.

For larger leaks, the accumulation method (or "bagging") is often more suitable. This involves enclosing the leaking component in a hood or bag and monitoring the increase in CO_2 concentration over time. By comparing the observed concentration increase with that produced under identical conditions by a reference leak, the emission rate can be inferred. Further details and recommended procedures are described in standard EN 13185.

Another technique used for high leak rates is high-flow sampling, commonly applied in methane LDAR campaigns. In this method, a large flow of air is actively drawn from the area surrounding the leak, and the CO_2 concentration in the sampled air is measured. By combining the measured flow rate and gas concentration, the leak rate can be estimated. However, the availability and validation of high-flow instruments specifically for CO_2 remain limited.

Finally, empirical correlation methods—linking observed concentrations to estimated emission rates through statistical models or field data—may offer rough approximations, but these are not yet standardised or validated for CO_2 and should be used cautiously.

3.6. Relation Between Mass and Volumetric Leak Rates

Leak rates can be expressed either in volumetric terms (e.g., cm^3/min at standard conditions) or in mass terms (e.g., g/h or kg/year). Carbon dioxide can be approximated as an ideal gas, and the conversion between volume and mass is obtained from the ideal gas law.

At standard temperature and pressure (0 °C and 1 atm), one mole of CO_2 occupies approximately 22.4 litres and has a mass of 44 grams. This leads to a conversion factor of 1 Std $cm^3/min \approx 0.001964$ g/min. For example, a leak of 10 Std cm^3/min corresponds to 1.18 g/h or 10.33 kg/year

These conversions are essential for reporting fugitive emissions and for comparing results across different measurement methods and detection campaigns.

3.7. Data Reporting

All leak detection and quantification activities must be documented in a structured and traceable format. The report should include both general information about the test context and specific results for each inspected component.

The report may be organised into two main sections:

- **Section 1: Test context** — site identification, environmental and operational conditions, and instrument setup;
- **Section 2: Results** — findings, readings, interpretation, and recommended actions.

Photos of inspection points may be included to support traceability and repeatability. While CO_2 is not flammable and does not pose an explosion risk, photographic equipment must still comply with the site's safety rules. In some industrial environments, only authorised or intrinsically safe devices (e.g., UL, ATEX, or IECEx certified) may be allowed. Always confirm site-specific requirements before using cameras or mobile phones.

Minimum recommended fields:

1. **General Test Information**
   - Date, time, and site/location of the inspection;
   - Description of the inspection area: indoor/outdoor, ventilation status;
   - Identification of the component inspected: type, tag/ID, physical location;
   - Aim of the inspection: leak location, quantification, or both;
   - Test conditions: temperature, atmospheric pressure, wind (if relevant);
   - Maximum admissible leak rate (threshold) if used under an LDAR scheme.
2. **Equipment and Calibration**
   - Detector model, type, and serial number;
   - Calibration status: date, reference gas concentration, or reference leak flow rate;
   - Accessories used (e.g., sampling probes, accumulation bags);
   - Identification of the operator and certification/training record if applicable.
3. **Measurement Results**
   - Background CO_2 level;
   - Detector reading at suspected leak point;
   - Calculated leak rate (if quantification was performed), including method used and uncertainty if known;
   - Calibration reference used (standard leak or gas mixture), including certificate number;
   - Comments on measurement conditions (e.g., wind interference, access limitations);
   - If required, actions taken or recommended: repair, reinspection, monitoring;
   - Photographs (optional and authorised) of each measurement point, especially where leaks were found.

All records must be stored to ensure **traceability and reproducibility**. Consistent and complete documentation supports quality assurance and facilitates comparison across different campaigns or between operators.

4. Beyond Leak Detection and Quantification

4.1. Need for Periodic Calibration

Calibration is essential for ensuring reliable measurements. Instruments should be calibrated annually using certified CO_2/air mixtures, and their performance should be regularly verified in the field using reference leaks. These reference leaks must themselves be calibrated annually and refilled or replaced as necessary to ensure their stability and traceability. Following the principles of EN 14624, all calibration and verification procedures should be traceable to SI standards whenever possible.

4.2. Maintenance and Cleaning

Proper maintenance extends the life of the instrument and ensures accurate readings. Filters should be replaced, and pumps (if present) should be checked for proper operation. Optical components of NDIR sensors should be cleaned as recommended by the manufacturer to prevent signal drift. Alarm functions, where applicable, should be tested regularly to confirm their functionality.

Rechargeable batteries must be maintained in good condition and charged only with the manufacturer-supplied or approved chargers. Battery health should be periodically verified, and degraded batteries replaced to avoid unexpected power loss during field use. Prolonged storage of the instrument should follow manufacturer guidelines, including partial charging and storage at appropriate temperatures.

4.3. Record Keeping

Operators should maintain detailed logs of calibration, maintenance, and inspection results. Records should include all relevant site data, leak detection results, and follow-up actions. Where possible, digital tools should be used to centralise data and allow for long-term trend analysis.

4.4. Training of Personnel and Equipment Certification

Personnel involved in CO_2 leak detection must be trained in both the technical aspects of operating detectors and the specific hazards of CO_2 exposure. Equipment should be certified for occupational safety applications, and refresher training should be conducted at least every one to two years. Competence in interpreting results is as important as technical skill with the instruments.

4.5. Trends and Further Research

The field of CO_2 leak detection is evolving. Integration of portable detectors with fixed sensor networks offers the possibility of continuous monitoring in addition to spot checks. Further research is needed to define harmonised thresholds for CO_2 LDAR schemes and to improve quantification methods, particularly correlation-based approaches. New technologies, including open-path infrared and laser spectroscopy, show promise for enhancing sensitivity and reducing uncertainty.

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Annex A – Pre-Inspection Checklist for CO2 Leak Detection

1. **Equipment Calibration and Verification**

- ☐ Verify that the CO_2 detector has been calibrated.
- ☐ Record the calibration date and reference gas ID.
- ☐ Perform a functional check using calibration gas or a reference leak.
- ☐ Confirm pump-assisted instruments have proper flow rate (if applicable).

2. Power and Backup

- ☐ Ensure batteries are fully charged.
- ☐ Verify that spare batteries are available on-site.

3. Personal Safety Equipment

- ☐ Confirm personal CO_2 or oxygen monitors are functional.
- ☐ Ensure appropriate PPE is worn (protective eyewear, antistatic clothing where required).

4. Site Preparation and Safety

- ☐ Complete a site-specific risk assessment.
- ☐ Ensure adequate ventilation in inspection areas, particularly confined or low-lying spaces.
- ☐ Note potential hazards (e.g., low-lying CO_2 accumulation, elevated areas, wind conditions).

5. Environmental Baseline Measurements

- ☐ Measure and record background CO_2 concentration in an area away from potential leaks.
- ☐ Note ambient temperature, humidity, and wind speed, as these may affect readings.

6. Documentation and Traceability

- ☐ Prepare forms or digital tools for recording all readings and observations.
- ☐ Confirm that all data will be archived for traceability.

7. Operational Readiness

- ☐ Verify access authorization for the inspection area.
- ☐ Ensure the inspection team is trained and aware of procedures.
- ☐ Confirm that all equipment is operational and ready for immediate use.