

OSHA Method 1027, Carbon Dioxide

Carbon Dioxide

CAS number:	124-38-9
OSHA PEL:	5000 ppm (9000 mg/m ³) 8-Hour TWA, General Industry, Construction, Shipyard
ACGIH TLV:	30,000 ppm (54,000 mg/m ³) 15-Minute STEL
IDLH:	40,000 ppm (72,000 mg/m ³)
Procedure:	Expose a personal gas monitor using a carbon dioxide (CO ₂) non-dispersive infrared (NDIR) sensor to workplace air.
Recommended sampling time:	Full shift (up to approximately 8 hours with new batteries)
Reporting limit:	900 ppm
Working range:	900-50,000 ppm
Uncertainty (<i>u</i>):	9.4% (8-Hour TWA) 9.9% (15-Minute STEL) 9.6% (IDLH)
Special requirements:	The IDLH is only measurable under certain combined conditions of temperature and pressure as shown in Table 1 due to the limitation of the working range.
Author:	Yalun Cui & Michael Simmons

Method Development Team
OSHA Technical Center
Sandy UT 84070-6406

OSHA Method 1027, Carbon Dioxide

1 Introduction

The methodologies described in this method replace OSHA's use of OSHA Method ID-172.¹ That method requires the collection of CO₂ samples using gas sampling bags, and analysis by gas chromatography using a thermal conductivity detector. This method uses a direct-reading monitor with an NDIR sensor for on-site monitoring of CO₂.

2 Monitoring Procedure

Follow all safety practices that apply to the work area where monitoring occurs.

2.1 Apparatus

- A multiple-gas personal gas monitor with a one-second or less datalogging interval and a ten-hour operating time (i.e., Dräger X-am 5600 Multi-Gas Detector with a firmware version of 7.8 or equivalent), synchronized to the OSHA Technical Center's time zone, and safety alarms set to the maximum value
- CO₂ NDIR sensor with a manufacturer-listed working range of 0-50,000 ppm (i.e., DrägerSensor IR CO₂ ES or equivalent)
- Calibration adapter with chemically compatible tubing
- Calibration gas cylinders of CO₂ at 200, 5000, and 10,000 ppm with a manufacturer-listed accuracy of $\leq \pm 5\%$
- Compatible calibration gas regulators with a fixed gas flow of 0.5 L/min
- Data communication adapter and cable
- Battery packs with rechargeable or non-rechargeable batteries
- NIST traceable temperature and barometric pressure monitor (i.e., Extech SD700 or equivalent)
- Monitor-specific software (i.e., Dräger CC-Vision Basic)

2.2 Technique

2.2.1 Calibration

Equilibrate the monitor to the ambient temperature of the monitoring site for at least 15 minutes. Power on the monitor and wait for completion of warm-up. Place the monitor into a calibration adapter supplied with 200-ppm CO₂ calibration gas and wait until the reading is stabilized before zero calibration. Place the monitor into a calibration adapter supplied with 10,000-ppm CO₂ calibration gas and wait until the reading is stabilized before span calibration.

Immediately following the span calibration, verify the monitor calibration using a 5000-ppm CO₂ calibration gas as a continuous calibration verification (CCV). Re-calibrate the monitor if the stabilized reading is not within 5000 ± 500 ppm.

2.2.2 Monitoring

Position the monitor securely in the worker's breathing zone. Record the time, atmospheric pressure, and temperature at the start and end of monitoring on the Form OSHA-91A.

At the end of monitoring, re-verify the monitor calibration using a 5000-ppm CO₂ calibration gas.

Turn off the monitor and return the monitoring equipment to the OSHA Technical Center with the Form OSHA-91A.

OSHA Method 1027, Carbon Dioxide

3 Data Processing Procedure

3.1 Data Examination

Examine the downloaded monitoring data and identify all possible events including powering on and off, time synchronization, calibration, CCVs, monitoring duration, abnormal monitor readings, etc. Identify any responses over the IDLH.

3.2 Determination of TWA

Calculate the time-weighted average (TWA) air concentration (C_S) in terms of parts of analyte per million parts of air (ppm) at the monitoring site temperature and pressure by summing all data points and dividing by the number of data points collected over the monitoring period. For example, divide by 14,400 when monitoring with a data collection rate of one second for 240 minutes. Use 50,000 ppm for any response over the maximum indication value of 50,000 ppm.

3.3 Determination of IDLH

Identify the highest air concentration (C_S) value in terms of parts of analyte per million parts of air (ppm) at the monitoring site temperature and pressure.

Due to the limitation of the monitor working range, the IDLH can only be determined with the corresponding uncertainty as shown in Table 21 under certain combined conditions of temperature and pressure as listed in Table 1.

Table 1. Minimum required atmospheric pressures at given temperatures for IDLH determination.

temperature (°C)	minimum required atmospheric pressure (mmHg)
5	684
7	689
9	694
11	699
13	704
15	709
17	714
19	719
21	724
23	729
25	734
27	738
29	743
31	748
33	753
35	758

OSHA Method 1027, Carbon Dioxide

3.4 Calculation

Calculate the air concentration (C) in terms of ppm at 760 mmHg and 25 °C using Equation 1, where C_s is the measured monitoring site air concentration (ppm), P is the monitoring site atmospheric pressure (mmHg), and T is the monitoring site temperature (°C).

$$C = C_s \times \frac{P}{760 \text{ mmHg}} \times \frac{298.15 \text{ K}}{T + 273.15 \text{ K}} \quad (1)$$

The OSHA Integrated Management Information System (IMIS) number for CO₂ is 0530.

OSHA Method 1027, Carbon Dioxide

4 Method Validation

The procedures used to develop the method validation data are described in OSHA Technical Center’s Guideline 2 *Direct-Reading Methods*.² The target concentration (T_C) for method evaluation was the OSHA 8-hour TWA permissible exposure limit (PEL) and the IDLH value for carbon dioxide.

Dynamically generated controlled test atmospheres were created in a walk-in hood for all validation tests. House air was regulated using a flow-temperature-humidity control system. A measured flow of 99% carbon dioxide was introduced near the entrance of the test atmosphere, where it was mixed into a measured flow of dilution air from the flow-temperature-humidity control system. The carbon dioxide and dilution air flowed into a mixing chamber, and then into a testing chamber. Monitors were placed into the testing chamber. Temperature and humidity measurements were obtained near the exit of the testing chamber.

4.1 Time of Response

The time needed for the response to reach 63% of the final steady-state measured value (t_{63}) was determined by sampling dynamically generated controlled test atmospheres containing carbon dioxide at 10,028 and 24,984 ppm. The relative humidity and temperature of the air sampled were 46% and 21 °C. The t_{63} value was determined from signal rise of three monitors quickly placed into the test atmosphere, and signal decay of three monitors quickly removed after signal stabilization. Tests were performed six times at each concentration for each monitor. Results were calculated as described in *Direct-Reading Methods*.² Results obtained are provided in Table 2. The t_{63} value was determined to be 3 seconds.

Table 2. Time of response for carbon dioxide (ppm values listed at 647 mmHg and 21 °C).

monitor no.	10,028 ppm rise in sec (%CV)	10,028 ppm decay in sec (%CV)	24,984 ppm rise in sec (%CV)	24,984 ppm decay in sec (%CV)	mean t_{63} in sec
monitor 1	2.3 (5.72%)	3.3 (6.63%)	2.9 (8.15%)	3.5 (10.6%)	3.0
monitor 2	2.4 (12.2%)	3.0 (14.6%)	2.4 (13.4%)	3.8 (8.12%)	2.9
monitor 3	2.5 (13.8%)	2.7 (12.2%)	2.5 (9.45%)	3.3 (7.38%)	2.8

4.2 Limit of Detection and Reporting Limit

The limit of detection (LOD) was determined by sampling dynamically generated controlled test atmospheres where the relative humidity and temperature of the air sampled were 81% and 21 °C. The LOD is the concentration that produces a response greater than 3.3x the standard error of estimate ($S_{y/x}$) divided by the slope of the line produced from three monitors used at six evenly spaced levels across a concentration range of 0 to 6 times the monitor resolution. Monitor response was determined after exposure to the test atmosphere for 30 seconds (i.e., $t = 10 \times t_{63}$). The reporting limit (RL) is designated to be 900 ppm to result in a recovery $\leq \pm 25\%$ and meet the requirements of method precision as described in Section 2.5 of *Direct-Reading Methods*.² Results obtained are provided in Table 3 and plotted in Figure 1.

OSHA Method 1027, Carbon Dioxide

Table 3. LOD and RL data for carbon dioxide (ppm values listed at 650 mmHg and 21 °C).

concn (ppm)	monitor no.	response (ppm)
0.00	monitor 1	0
0.00	monitor 2	0
0.00	monitor 3	0
200	monitor 1	0
200	monitor 2	0
200	monitor 3	0
299	monitor 1	200
299	monitor 2	200
299	monitor 3	200
400	monitor 1	300
400	monitor 2	300
400	monitor 3	300
498	monitor 1	400
498	monitor 2	400
498	monitor 3	400
598	monitor 1	500
598	monitor 2	500
598	monitor 3	500

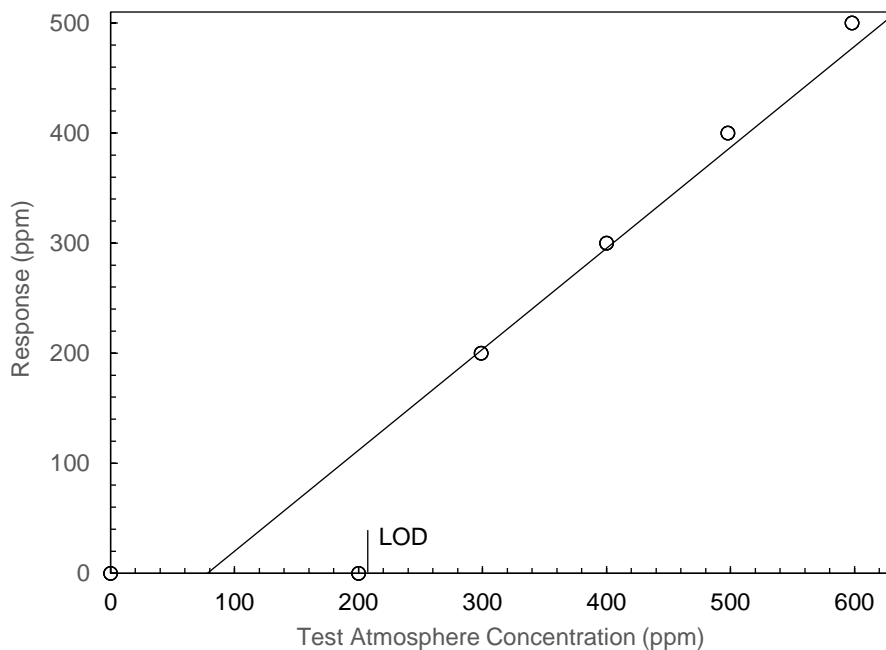


Figure 1. Plot of data used to determine the LOD and RL for carbon dioxide ($y = 0.917x - 71.7$, $S_{y/x} = 58.8$, LOD = 211 ppm, RL = 900 ppm).

4.3 Working Range

The working range was tested by sampling dynamically generated controlled test atmospheres where the relative humidity and temperature of the air sampled were 81% and 22 °C. Three monitors were used at ten evenly spaced

OSHA Method 1027, Carbon Dioxide

levels across a concentration range of the RL to 90% of the maximum indication value of 50,000 ppm. To evaluate the necessity of user-level adjustment, a 200-ppm CO₂ calibration gas was used as a zero-calibration gas compared with 100% nitrogen gas. Monitor response was determined after exposure to the test atmosphere for 30 seconds (i.e., $t = 10 \times t_{63}$). Results obtained are provided in Table 4 and 5, respectively. As shown below, the 200-ppm CO₂ calibration gas was chosen to be used as a zero-calibration gas due to the improved recoveries through the working range.

Table 4. Working range data for carbon dioxide using 200 ppm CO₂ as the zero-calibration gas (ppm values listed at 650 mmHg and 22 °C).

concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
894	89.5	89.5	89.5	89.5
5017	105.6	105.6	105.6	105.6
9916	102.9	102.9	102.9	102.9
14,925	101.8	100.5	101.8	101.4
19,977	99.1	100.1	98.1	99.1
24,841	98.2	95.8	99.0	97.7
29,902	97.0	93.6	98.7	96.4
34,830	94.7	90.4	96.2	93.8
39,866	94.1	87.8	95.3	92.4
47,933	92.8	86.6	94.9	91.4

Table 5. Working range data for carbon dioxide using 100% nitrogen as the zero-calibration gas (ppm values listed at 653 mmHg and 21 °C).

concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
895	122.9	122.9	122.9	122.9
4876	108.7	110.7	108.7	109.4
9756	104.6	104.6	102.5	103.9
14,565	100.2	98.9	100.2	99.8
19,458	98.7	95.6	97.6	97.3
24,459	96.5	94.0	97.3	95.9
29,413	95.2	90.1	95.2	93.5
34,212	93.5	87.7	93.5	91.6
39,094	93.4	85.7	93.4	90.8
44,825	91.5	83.7	91.5	88.9

4.4 Method Precision and Bias

The 8-hour TWA method precision and bias was determined by monitoring dynamically generated controlled test atmospheres for 240 minutes. Three monitors were used at five levels across a concentration range of 0.16 to 5x the 8-hour TWA T_c. The results of these tests are provided in Table 6, along with the concentration, temperature, and relative humidity of each test atmosphere. The coefficient of variation of the means of the five levels tested (CV_{m_TWA}) was 4.6%, and the pooled coefficient of variation of each of the five levels tested (CV_{pl_TWA}) was 1.9%. The resulting 8-hour TWA method precision (u_{mp_TWA}) for carbon dioxide was determined to be 4.9%. The mean recovery of all fifteen results was 99.6%, resulting in a method bias (B_{mp_TWA}) of 0.40% and a percent coefficient of variation (CV_{mb_TWA}) of 4.5%.

OSHA Method 1027, Carbon Dioxide

Table 6. Method precision data for carbon dioxide (8-hour TWA, ppm values listed at 760 mmHg and 25 °C).

concn (ppm)	temp (°C)	RH (%)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
802	21	81	90.8	95.0	95.4	93.7
2488	22	81	99.8	100.4	99.2	99.8
4992	21	81	105.4	105.9	103.9	105.1
9972	22	82	103.1	102.5	102.9	102.8
25,112	21	81	98.4	93.2	98.1	96.6

The STEL method precision and bias was determined by monitoring dynamically generated controlled test atmospheres for 15 minutes. Three monitors were used at five levels across a concentration range of 0.25 to 1.25x the STEL T_c. The results of these tests are provided in Table 7, along with the concentration, temperature, and relative humidity of each test atmosphere. The coefficient of variation of the means of the five levels tested (CV_{m_STEL}) was 5.3%, and the pooled coefficient of variation of each of the five levels tested (CV_{pl_STEL}) was 3.0%. The resulting 8-hour TWA method precision (u_{mp_STEL}) for carbon dioxide was determined to be 6.0%. The mean recovery of all fifteen results was 96.1%, resulting in a method bias (B_{mp_STEL}) of 3.9% and a percent coefficient of variation (CV_{mb_STEL}) of 5.5%.

Table 7. Method precision data for carbon dioxide (15-minute STEL, ppm values listed at 760 mmHg and 25 °C).

concn (ppm)	temp (°C)	RH (%)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
7459	22	80	103.7	104.8	104.0	104.2
14,991	22	80	97.3	95.6	98.3	97.1
22,508	22	79	96.1	92.8	97.3	95.4
30,039	22	80	94.5	88.8	95.3	92.9
37,480	22	79	93.0	86.1	94.0	91.0

The IDLH method precision and bias was determined by monitoring dynamically generated controlled test atmospheres for 30 minutes. Three monitors were used at five levels across a concentration range of 0.6 to 1.0x the IDLH T_c. The results of these tests are provided in Table 8, along with the concentration, temperature, and relative humidity of each test atmosphere. The coefficient of variation of the means of the five levels tested (CV_{m_IDLH}) was 2.9%, and the pooled coefficient of variation of each of the five levels tested (CV_{pl_IDLH}) was 4.3%. The resulting IDLH method precision (u_{mp_IDLH}) for carbon dioxide was determined to be 4.9%. The mean recovery of all fifteen results was 93.2%, resulting in a method bias (B_{mp_IDLH}) of 6.8% and a percent coefficient of variation (CV_{mb_IDLH}) of 4.5%.

Table 8. Method precision data for carbon dioxide (IDLH, ppm values listed at 760 mmHg and 25 °C).

concn (ppm)	temp (°C)	RH (%)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
24,108	21	81	97.8	93.7	99.2	96.9
28,088	21	81	95.7	91.0	97.2	94.6
32,236	21	81	94.6	88.8	96.0	93.1
36,142	22	81	92.9	85.4	93.7	90.7
40,113	21	82	93.2	84.9	93.7	90.6

4.5 Effect of Face Velocity

The 8-hour TWA effect of face velocity was tested by monitoring a dynamically generated controlled test atmosphere containing carbon dioxide nominally at the 8-hour TWA T_c. The relative humidity and temperature of the air monitored were 80% and 22 °C. Three monitors were used at five levels across a velocity range of 0.1 to 1.0 m/s. Monitor response was determined after exposure to the test atmosphere for 30 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 9, along with the concentration of each test atmosphere. The effect of face velocity (Δ_{v_TWA}),

OSHA Method 1027, Carbon Dioxide

calculated as the absolute difference between the maximum mean recovery and the minimum mean recovery through all tested face velocities was 3.3%.

Table 9. Face velocity data for carbon dioxide (8-hour TWA, ppm values listed at 760 mmHg and 25 °C).

face velocity (m/s)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0.1	5007	105.3	107.1	107.1	106.5
0.3	5032	103.2	103.2	103.2	103.2
0.5	4989	104.1	104.1	104.1	104.1
0.7	4965	104.4	104.4	104.4	104.4
1.0	4973	104.0	104.0	104.0	104.0

The STEL effect of face velocity was tested by monitoring a dynamically generated controlled test atmosphere containing carbon dioxide nominally at the STEL T_c . The relative humidity and temperature of the air monitored were 79% and 21 °C. Three monitors were used at five levels across a velocity range of 0.1 to 1.0 m/s. Monitor response was determined after exposure to the test atmosphere for 30 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 10, along with the concentration of each test atmosphere. The effect of face velocity ($\Delta_{v_{STEL}}$), calculated as the absolute difference between the maximum mean recovery and the minimum mean recovery through all tested face velocities was 1.1%.

Table 10. Face velocity data for carbon dioxide (15-minute STEL, ppm values listed at 760 mmHg and 25 °C).

face velocity (m/s)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0.1	30,025	93.9	89.6	95.3	92.9
0.3	29,985	94.0	89.7	95.5	93.1
0.5	29,946	95.6	89.8	95.6	93.7
0.7	30,065	95.2	89.4	95.2	93.2
1.0	30,079	93.6	89.2	95.0	92.6

The IDLH effect of face velocity was tested by monitoring a dynamically generated controlled test atmosphere containing carbon dioxide nominally at the IDLH T_c . The relative humidity and temperature of the air monitored were 80% and 22 °C. Three monitors were used at five levels across a velocity range of 0.1 to 1.0 m/s. Monitor response was determined after exposure to the test atmosphere for 30 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 11, along with the concentration of each test atmosphere. The effect of face velocity ($\Delta_{v_{IDLH}}$), calculated as the absolute difference between the maximum mean recovery and the minimum mean recovery through all tested face velocities was 0.70%.

Table 11. Face velocity data for carbon dioxide (IDLH, ppm values listed at 760 mmHg and 25 °C).

face velocity (m/s)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0.1	39,885	94.3	85.6	95.4	91.8
0.3	40,238	93.6	86.1	94.7	91.5
0.5	40,105	93.9	85.2	94.9	91.3
0.7	40,164	93.6	85.0	94.6	91.1
1.0	40,078	93.6	86.1	94.7	91.5

4.6 Effect of Orientation

The 8-hour TWA effect of orientation was tested by monitoring a dynamically generated controlled test atmosphere containing carbon dioxide nominally at the 8-hour TWA T_c . The relative humidity and temperature of the air monitored were 78% and 22 °C. Three monitors were used to test two flow directions of 0° and 90° relative to the diffusion orifice.

OSHA Method 1027, Carbon Dioxide

The face velocity was 0.5 m/s. Monitor response was determined after exposure to the test atmosphere for 30 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 12, along with the concentration of each test atmosphere. The effect of orientation (Δ_{o_TWA}), calculated as the absolute difference between the two orientations tested was 0.10%.

Table 12. Orientation data for carbon dioxide (8-hour TWA, ppm values listed at 760 mmHg and 25 °C).

flow direction to diffusion orifice (°)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0	4989	104.1	104.1	104.1	104.1
90	4973	104.0	104.0	104.0	104.0

The STEL effect of orientation was tested by monitoring a dynamically generated controlled test atmosphere containing carbon dioxide nominally at the STEL T_c . The relative humidity and temperature of the air monitored were 78% and 21 °C. Three monitors were used to test two flow directions of 0° and 90° relative to the diffusion orifice. The face velocity was 0.5 m/s. Monitor response was determined after exposure to the test atmosphere for 30 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 13, along with the concentration of each test atmosphere. The effect of orientation (Δ_{o_STEL}), calculated as the absolute difference between the two orientations tested was 0.60%.

Table 13. Orientation data for carbon dioxide (15-minute STEL, ppm values listed at 760 mmHg and 25 °C).

flow direction to diffusion orifice (°)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0	29,946	95.6	89.8	95.6	93.7
90	30,079	95.0	89.2	95.0	93.1

The IDLH effect of orientation was tested by monitoring a dynamically generated controlled test atmosphere containing carbon dioxide nominally at the IDLH T_c . The relative humidity and temperature of the air monitored were 78% and 22 °C. Three monitors were used to test two flow directions of 0° and 90° relative to the diffusion orifice. The face velocity was 0.5 m/s. Monitor response was determined after exposure to the test atmosphere for 30 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 14, along with the concentration of each test atmosphere. The effect of orientation (Δ_{o_IDLH}), calculated as the absolute difference between the two orientations tested was 0.20%.

Table 14. Orientation data for carbon dioxide (IDLH, ppm values listed at 760 mmHg and 25 °C).

flow direction to diffusion orifice (°)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0	40,105	93.9	85.2	94.9	91.3
90	40,078	93.6	86.1	94.7	91.5

4.7 Effect of Humidity

The 8-hour TWA effect of low humidity was tested by monitoring a dynamically generated controlled test atmosphere containing carbon dioxide nominally at the 8-hour TWA T_c for 240 min (calculated to be 5023 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 21% and 21 °C. Results for carbon dioxide as a percentage of expected recovery of the three monitors was 103.8%, 105.4%, and 103.9%. The mean percentage of expected recovery was 104.4%. The effect of humidity (Δ_{h_TWA}), calculated as the absolute difference between the mean dry recovery and the mean humid recovery of 105.1% taken from the 4992 ppm method precision test described in Section 4.4, was 0.70%.

The STEL effect of low humidity was tested by monitoring a dynamically generated controlled test atmosphere containing carbon dioxide nominally at the STEL T_c for 15 min (calculated to be 30,333 ppm at 760 mmHg and 25 °C).

OSHA Method 1027, Carbon Dioxide

The relative humidity and temperature of the air sampled were 21% and 21 °C. Results for carbon dioxide as a percentage of expected recovery of the three monitors was 95.7%, 90.1%, and 96.6%. The mean percentage of expected recovery was 94.1%. The effect of humidity (Δ_{h_STEL}), calculated as the absolute difference between the mean dry recovery and the mean humid recovery of 92.9% taken from the 30,039 ppm method precision test described in Section 4.4, was 1.2%.

The IDLH effect of low humidity was tested by monitoring a dynamically generated controlled test atmosphere containing carbon dioxide nominally at the IDLH T_C for 30 min (calculated to be 40,740 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 22% and 21 °C. Results for carbon dioxide as a percentage of expected recovery of the three monitors was 92.4%, 85.3%, and 93.3%. The mean percentage of expected recovery was 90.3%. The effect of humidity (Δ_{h_IDLH}), calculated as the absolute difference between the mean dry recovery and the mean humid recovery of 90.6% taken from the 40,113 ppm method precision test described in Section 4.4, was 0.30%.

4.8 Effect of Interferents

No interferents were observed in this validation due to the high specificity of the carbon dioxide NDIR sensors. However, any substance that has strong optical absorption at a wavelength of 4.26 μm can potentially interfere with the carbon dioxide NDIR sensors. The presence of such a substance should be confirmed when the interference is suspected.

4.9 Effect of Intermittent Exposure

The effect of intermittent exposure was tested by monitoring a dynamically generated controlled test atmosphere containing carbon dioxide nominally at the 8-hour TWA T_C (calculated to be 4985 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 42% and 21 °C. All monitors were exposed to the test atmosphere for 7 seconds (i.e., $t = 2.3 \times t_{63}$) followed by zero air recovery, where the exposure cycle was repeated ten times for a 70-second intermittent exposure. Subsequently, the monitors were exposed to the test atmosphere for a 70-second steady exposure. Results as a percentage of expected recovery of the three monitors are provided in Table 15. The effect of intermittent exposure (Δ_{ie_TWA}), calculated as the absolute difference between the mean intermittent exposure recovery and the mean steady exposure recovery, was 3.6%.

Table 15. Intermittent exposure data for carbon dioxide (8-hour TWA, ppm values listed at 760 mmHg and 25 °C).

total exposure time (s)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
160 (intermittent)	109.4	112.0	105.5	109.0
160 (steady)	103.7	106.5	105.9	105.4

The effect of intermittent exposure was tested by monitoring a dynamically generated controlled test atmosphere containing carbon dioxide nominally at the STEL T_C (calculated to be 29,882 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 39% and 21 °C. All monitors were intermittently exposed to the test atmosphere for 7 seconds (i.e., $t = 2.3 \times t_{63}$) followed by clean air recovery with the same period for ten cycles and subsequently exposed to the test atmosphere for a 70-second steady exposure. Results as a percentage of expected recovery of the three monitors are provided in Table 16. The effect of intermittent exposure (Δ_{ie_STEL}), calculated as the absolute difference between the mean intermittent exposure recovery and the mean steady exposure recovery, was 3.1%.

OSHA Method 1027, Carbon Dioxide

Table 16. Intermittent exposure data for carbon dioxide (15-minute STEL, ppm values listed at 760 mmHg and 25 °C).

total exposure time (s)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
70 (intermittent)	99.1	98.4	98.1	98.5
70 (steady)	97.0	92.6	96.6	95.4

4.10 Effect of Temperature

The effect of temperature was tested by monitoring a dynamically generated controlled test atmosphere containing carbon dioxide nominally at the 8-hour TWA T_C (calculated at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 81% and 21 °C. Prior to obtaining readings, all monitors were equilibrated at 5 °C, 22 °C, and 50 °C for one hour. Monitor response was determined after exposure to the test atmosphere for 30 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 17, along with the concentration of each test atmosphere. The effect of temperature ($\Delta_{T,TWA}$), calculated as the absolute difference between the minimum mean recovery and the maximum mean recovery through all tested temperatures, was 3.4%.

Table 17. Temperature data for carbon dioxide (8-hour TWA, ppm values listed at 760 mmHg and 25 °C).

temperature (°C)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
5	4984	105.7	107.4	103.9	105.7
22	5000	105.2	106.9	105.2	105.8
50	5007	98.3	103.5	105.3	102.4

The STEL effect of temperature was tested by monitoring a dynamically generated controlled test atmosphere containing carbon dioxide nominally at the STEL T_C (calculated at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 81% and 21 °C. Prior to obtaining readings, all monitors were equilibrated at 5 °C, 21 °C, and 50 °C for one hour. Monitor response was determined after exposure to the test atmosphere for 30 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 18, along with the concentration of each test atmosphere. The effect of temperature ($\Delta_{T,STEL}$), calculated as the absolute difference between the minimum mean recovery and the maximum mean recovery through all tested temperatures, was 0.50%.

Table 18. Temperature data for carbon dioxide (15-minute STEL, ppm values listed at 760 mmHg and 25 °C).

temperature (°C)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
5	30,062	95.2	89.4	96.6	93.7
22	29,970	94.2	89.9	95.7	93.3
50	30,071	95.1	89.4	95.1	93.2

The IDLH effect of temperature was tested by monitoring a dynamically generated controlled test atmosphere containing carbon dioxide nominally at the IDLH T_C (calculated at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 81% and 21 °C. Prior to obtaining readings, all monitors were equilibrated at 5 °C, 21 °C, and 50 °C for one hour. Monitor response was determined after exposure to the test atmosphere for 30 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 19, along with the concentration of each test atmosphere. The effect of temperature ($\Delta_{T,IDLH}$), calculated as the absolute difference between the minimum mean recovery and the maximum mean recovery through all tested temperatures, was 0.40%.

OSHA Method 1027, Carbon Dioxide

Table 19. Temperature data for carbon dioxide (IDLH, ppm values listed at 760 mmHg and 25 °C).

temperature (°C)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
5	40,011	93.8	86.3	93.8	91.3
22	40,104	94.6	86.0	94.6	91.7
50	40,176	94.6	86.0	93.5	91.4

4.11 Effect of Oversaturation

The effect of oversaturation was tested by monitoring a dynamically generated controlled test atmosphere containing carbon dioxide nominally at two times the maximum indication value of 50,000 ppm for 10 minutes (calculated to be 101,000 ppm at 651 mmHg and 21 °C). The relative humidity and temperature of the air sampled were 80% and 21 °C. After oversaturation for 10 minutes, followed by recovery with clean air for 60 minutes, no monitor response drift was observed.

4.12 Reproducibility

A dynamically controlled test atmosphere was generated, containing carbon dioxide nominally at the 8-hour TWA T_C (calculated to be 5008 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air monitored were 79% and 22 °C. The test atmosphere was monitored by Production Team for 240 min using the monitoring procedure described in Section 2 of this method. The monitor results were then submitted to the OSHA Technical Center for analysis using the data processing procedure described in Section 3 of this method. The monitoring results are provided in Table 20. No sample result for carbon dioxide fell outside the permissible bounds set by the expanded uncertainty determined in Section 4.13.

Table 20. Reproducibility data for carbon dioxide (8-hour TWA, ppm values listed at 760 mmHg and 25 °C).

monitored (ppm)	recovery (%)	deviation (%)
5307	106.0	+6.0
5354	106.9	+6.9
5327	106.4	+6.4

4.13 Estimation of Uncertainty

Carbon dioxide relative standard uncertainty components (u_i) are provided in Table 21 for the 8-hour TWA, 15-minute STEL, and IDLH levels. The combined percent relative standard uncertainty of the monitoring procedure (u) was determined to be 9.4% for the 8-hour TWA, 9.9% for 15-minute STEL, and 9.6% for the IDLH. The expanded uncertainty (U) was determined to be 19% for the 8-hour TWA, 20% for 15-minute STEL, and 19% for the IDLH.

OSHA Method 1027, Carbon Dioxide

Table 21. Uncertainty.

uncertainty component (u_i)	8-hour TWA (%)	STEL (%)	IDLH (%)	notes
calibration standards (u_{cs})	2.9	2.9	2.9	$u_{cs} = 5\%/\sqrt{3}$, assumes an accuracy of $\pm 5\%$
method precision (u_{mp})	4.9	6.0	4.9	$u_{mp} = \sqrt{(CV_m)^2 + (1 - 1/n) \times (CV_{pl})^2}$, where $CV_{m_TWA} = 4.6\%$, $CV_{pl_TWA} = 1.9\%$, $CV_{m_STEL} = 5.3\%$, $CV_{pl_STEL} = 3.0\%$, $CV_{m_IDLH} = 2.9\%$, $CV_{pl_IDLH} = 4.3\%$, and $n = 3$, see Section 4.4
method bias (u_{mb})	3.2	4.0	5.1	$u_{mb} = \sqrt{(B_{mb}/\sqrt{3})^2 + (CV_{mb}/\sqrt{n})^2 + (u_{rc})^2}$, where $B_{mb_TWA} = 0.40\%$, $CV_{mb_TWA} = 4.5\%$, $B_{mb_STEL} = 3.9\%$, $CV_{mb_STEL} = 5.5\%$, $B_{mb_IDLH} = 6.8\%$, $CV_{mb_IDLH} = 4.5\%$, and $n = 15$, see Section 4.4; $u_{rc} = 3\%$ see Reference 3
effect of face velocity (u_v)	1.9	0.64	0.40	$u_v = \Delta_v/\sqrt{3}$, where $\Delta_{v_TWA} = 3.3\%$, $\Delta_{v_STEL} = 1.1\%$, and $\Delta_{v_IDLH} = 0.70\%$, see Section 4.5
effect of orientation (u_o)	0.058	0.35	0.12	$u_o = \Delta_o/\sqrt{3}$, where $\Delta_{o_TWA} = 0.10\%$, $\Delta_{o_STEL} = 0.60\%$, and $\Delta_{o_IDLH} = 0.20\%$, see Section 4.6
effect of humidity (u_h)	0.40	0.69	0.17	$u_h = \Delta_h/\sqrt{3}$, where $\Delta_{h_TWA} = 0.70\%$, $\Delta_{h_STEL} = 1.2\%$, and $\Delta_{h_IDLH} = 0.30\%$, see Section 4.7
effect of intermittent exposure (u_{ie})	2.1	1.8	N/A	$u_{ie} = \Delta_{ie}/\sqrt{3}$, where $\Delta_{ie_TWA} = 3.6\%$ and $\Delta_{ie_STEL} = 3.1\%$, see Section 4.9
effect of temperature (u_T)	2.0	0.29	0.23	$u_T = \Delta_T/\sqrt{3}$, where $\Delta_{T_TWA} = 3.4\%$, $\Delta_{T_STEL} = 0.50\%$, and $\Delta_{T_IDLH} = 0.40\%$, see Section 4.10
resolution (u_r)	0.58	0.48	0.36	$u_r = [Res/(2 \times \sqrt{3} \times T_C)] \times 100\%$, where $Res_{TWA} = 100$ ppm, $T_{C_TWA} = 5000$ ppm, $Res_{STEL} = 500$ ppm, $T_{C_STEL} = 30,000$ ppm, $Res_{IDLH} = 500$ ppm, $T_{C_IDLH} = 40,000$ ppm
monitor response drift (u_{dr})	5.8	5.8	5.8	$u_{dr} = 10\%/\sqrt{3}$, assumes a maximum monitor response drift of $\pm 10\%$
temperature measurement (u_{AT})	0.16	0.16	0.16	$u_{AT} = 0.27\%/\sqrt{3}$, assumes a measured accuracy of ± 0.8 °C at 25 °C
pressure measurement (u_{bp})	0.12	0.12	0.12	$u_{bp} = 0.20\%/\sqrt{3}$, assumes a measured accuracy of ± 1.5 mmHg at 760 mmHg
standard uncertainty (u)	9.4	9.9	9.6	$u = \sqrt{\sum(u_i^2)}$, where u_i represents each uncertainty component as shown above

OSHA Method 1027, Carbon Dioxide

uncertainty component (u_i)	8-hour TWA (%)	STEL (%)	IDLH (%)	notes
expanded uncertainty (U)	19	20	19	$U = k \times u$, where $k = 2$

OSHA Method 1027, Carbon Dioxide

References

1. Cee, R. Carbon Dioxide in Workplace Atmospheres (OSHA Method ID-172), 1987. United States Department of Labor, Occupational Safety & Health Administration website. <https://www.osha.gov> (accessed March 2024).
2. Direct-Reading Methods, 2024. United States Department of Labor, Occupational Safety & Health Administration website. <https://www.osha.gov> (accessed March 2024).
3. ISO/DIS 22065:2018, Workplace air - Procedures for measuring gases and vapours using pumped samplers - Requirements and test methods.