

OSHA Method 1030, Chlorine

Chlorine

CAS number:	7782-50-5
OSHA PEL:	1 ppm (3 mg/m ³) Ceiling, General Industry 1 ppm (3 mg/m ³) 8-Hour TWA, Construction, Shipyard
IDLH:	10 ppm (30 mg/m ³)
Procedure:	Expose a personal gas monitor using a chlorine (Cl ₂) electrochemical sensor to workplace air.
Recommended sampling time:	Full shift (up to 16 hours due to monitor datalogger capacity)
Reporting limit:	0.2 ppm
Working range:	0.2-20 ppm
Uncertainty (<i>u</i>):	31% (8-Hour TWA) 10% (Ceiling) 9.4% (IDLH)
Special requirements:	Do not use this method when bromine, fluorine, chlorine dioxide or hydrogen sulfide are present.
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1 Introduction

This method describes alternative methodologies to OSHA's use of OSHA Method ID-101.¹ That method requires the collection of Cl₂ using a midjet fritted glass bubbler containing a 0.1% sulfamic acid solution. This method uses a direct-reading monitor with an electrochemical sensor for on-site monitoring of chlorine.

2 Monitoring Procedure

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

2.1 Apparatus

- Personal gas monitor with a one-second or less datalogging interval and a sixteen-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
- Cl₂ electrochemical sensor with a manufacturer-listed working range of 0-20 ppm (i.e., Dräger XXS Cl₂ or equivalent)
- Monitor-specific mountable external pump with a fixed sampling flow rate and chemically compatible tubing (i.e., Dräger X-am pump with 3/16-inch i.d. Tygon SE200 tubing or equivalent)
- Calibration gas cylinders of Cl₂ at 2 and 5 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 batteries
- NIST traceable temperature and barometric pressure monitor (i.e., Extech SD700 or equivalent)
- Monitor-specific software

2.2 Technique

2.2.1 Calibration

To avoid being exposed to Cl₂, perform calibration and monitoring checks in a well-ventilated area and keep the monitor-pump assembly as far away from the personal breathing zone as possible.

Equilibrate the monitor-pump assembly at the ambient temperature for at least 15 minutes. Power on the monitor-pump assembly and ensure that the pump operates properly. Wait for completion of warm-up. Zero-calibrate the monitor by directly exposing it to clean air. Next, supply the monitor-pump assembly with 5-ppm Cl₂ calibration gas for 3 minutes and then perform span calibration. Record the time, temperature and atmospheric pressure.

Immediately following the span calibration, verify the monitor calibration using a 2-ppm Cl₂ calibration gas as pre-monitoring check. If the stabilized reading is not within 2 ± 0.2 ppm, then re-perform zero and span calibrations.

2.2.2 Monitoring

Position the inlet of the monitor tubing securely in the worker's breathing zone. Measure and record the time, temperature, and atmospheric pressure at the monitoring location at the start and end of each monitoring period.

At the end of monitoring, re-verify the monitor calibration using the 2-ppm Cl₂ calibration gas as post-monitoring check. Record the time, temperature and atmospheric pressure.

Turn off the monitor-pump assembly and return the monitoring equipment to the OSHA Technical Center with all recorded monitoring information.

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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, checks, monitoring duration, abnormal monitor readings, etc. Identify any responses over the immediately dangerous to life or health (IDLH) value. Report the potential of sensor saturation if any reading is over the maximum indication value of 20 ppm.

3.2 Determination of the TWA

Calculate the time-weighted average (TWA) air concentration (C_s) in terms of 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 20 ppm for any response over the maximum indication value of 20 ppm.

3.3 Determination of the Ceiling and IDLH

Identify air concentration (C_s) of each response above the ceiling or IDLH value in terms of ppm at the monitoring site temperature and atmospheric pressure.

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 Cl₂ is 0640.

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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) values for method evaluation were the OSHA 8-hour TWA permissible exposure limit (PEL), ceiling, and the IDLH value for chlorine.

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 3000 or 250-ppm chlorine 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 chlorine 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 chlorine at 4.94 and 10.2 ppm. The relative humidity and temperature of the air sampled were 45% 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 1. The t_{63} value was determined to be 3 seconds.

Table 1. Time of response for chlorine (ppm values listed at 649 mmHg and 21 °C).

monitor no.	4.94 ppm rise in sec (%CV)	4.94 ppm decay in sec (%CV)	10.2 ppm rise in sec (%CV)	10.2 ppm decay in sec (%CV)	mean t_{63} in sec
monitor 1	2.9 (10.9%)	2.8 (11.9%)	2.7 (11.0%)	2.9 (9.75%)	2.8
monitor 2	2.8 (14.2%)	2.9 (10.6%)	2.8 (9.51%)	3.0 (5.72%)	2.9
monitor 3	2.8 (11.2%)	3.0 (11.5%)	2.6 (9.71%)	3.0 (6.89%)	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 43% and 21 °C. The LOD is the concentration that produces a response greater than $3.3 \times$ 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 3 minutes. The reporting limit (RL) is designated to be 0.20 ppm, the nearest reading above the LOD resulting in a recovery $\leq \pm 25\%$. Results obtained are provided in Table 2 and plotted in Figure 1.

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Table 2. LOD and RL data for chlorine (ppm values listed at 652 mmHg and 21 °C).

concn (ppm)	monitor no.	response (ppm)
0.00	monitor 1	0.0
0.00	monitor 2	0.0
0.00	monitor 3	0.0
0.050	monitor 1	0.05
0.050	monitor 2	0.00
0.050	monitor 3	0.05
0.100	monitor 1	0.10
0.100	monitor 2	0.10
0.100	monitor 3	0.10
0.151	monitor 1	0.15
0.151	monitor 2	0.15
0.151	monitor 3	0.15
0.201	monitor 1	0.20
0.201	monitor 2	0.20
0.201	monitor 3	0.20
0.254	monitor 1	0.30
0.254	monitor 2	0.25
0.254	monitor 3	0.30

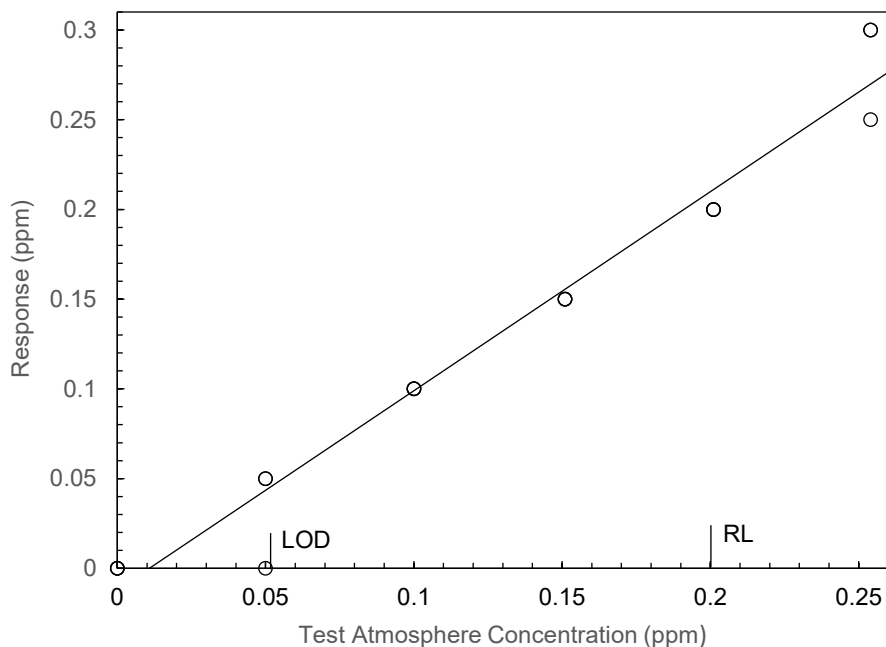


Figure 1. Plot of data used to determine the LOD and RL for chlorine ($y = 1.11x - 0.0120$, $S_{y/x} = 0.0178$, LOD = 0.0530 ppm, RL = 0.20 ppm).

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 48% and 21 °C. Three monitors were used at ten evenly spaced

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levels across a concentration range of the RL to 90% of the maximum indication value of 20 ppm. Monitor response was determined after exposure to the test atmosphere for 3 minutes. Results obtained are provided in Table 3.

Table 3. Working range data for chlorine (ppm values listed at 652 mmHg and 21 °C).

concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0.201	99.5	99.5	99.5	99.5
1.99	95.5	103.0	105.5	101.3
3.99	96.5	102.8	105.3	101.5
6.03	97.0	104.5	107.0	102.8
8.03	97.1	104.0	106.5	102.5
9.90	95.4	101.9	104.9	100.7
12.0	99.2	105.8	108.3	104.4
13.9	98.6	105.0	107.9	103.8
16.0	98.1	105.0	107.5	103.5
18.0	98.3	105.0	107.8	103.7

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 0.2 to 5× the 8-hour TWA T_c . The results of these tests are provided in Table 4, 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 4.9%, and the pooled coefficient of variation of each of the five levels tested (CV_{pL_TWA}) was 3.0%. The resulting 8-hour TWA method precision (u_{mp_TWA}) for chlorine was determined to be 5.4%. The mean recovery of all fifteen results was 105.2%, resulting in a method bias (B_{mp_TWA}) of 5.2% and a percent coefficient of variation (CV_{mb_TWA}) of 5.2%.

Table 4. Method precision data for chlorine (8-hour TWA, ppm values listed at 760 mmHg and 25 °C).

concn (ppm)	temp (°C)	RH (%)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0.202	21	52	107.0	107.0	107.0	107.0
0.505	21	59	103.0	94.5	94.3	97.3
0.992	21	49	101.0	109.0	108.0	106.0
1.91	21	45	112.0	112.0	110.0	111.3
5.05	21	56	106.0	103.0	104.0	104.3

The ceiling method precision and bias was determined by monitoring dynamically generated controlled test atmospheres for 3 minutes. Three monitors were used at five levels across a concentration range of 0.75 to 1.25× the ceiling T_c . The results of these tests are provided in Table 5, 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_CLG}) was 1.9%, and the pooled coefficient of variation of each of the five levels tested (CV_{pL_CLG}) was 5.3%. The resulting ceiling method precision (u_{mp_CLG}) for chlorine was determined to be 4.7%. The mean recovery of all fifteen results was 98.2%, resulting in a method bias (B_{mp_CLG}) of 1.8% and a percent coefficient of variation (CV_{mb_CLG}) of 4.8%.

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Table 5. Method precision data for chlorine (ceiling, ppm values listed at 760 mmHg and 25 °C).

concn (ppm)	temp (°C)	RH (%)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0.757	21	48	91.9	97.6	97.6	95.7
0.908	21	48	91.0	100.6	100.6	97.4
1.00	21	48	91.3	100.0	104.0	98.4
1.09	21	48	95.4	103.7	103.7	100.9
1.26	21	48	92.9	100.0	103.2	98.7

The IDLH method precision and bias was determined by monitoring dynamically generated controlled test atmospheres for 3 minutes. Three monitors were used at five levels across a concentration range of 0.75 to 1.25× the IDLH 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_IDLH}) was 1.4%, and the pooled coefficient of variation of each of the five levels tested (CV_{pl_IDLH}) was 4.8%. The resulting IDLH method precision (u_{mp_IDLH}) for chlorine was determined to be 4.2%. The mean recovery of all fifteen results was 103.4%, resulting in a method bias (B_{mp_IDLH}) of 3.4% and a percent coefficient of variation (CV_{mb_IDLH}) of 4.3%.

Table 6. Method precision data for chlorine (IDLH, ppm values listed at 760 mmHg and 25 °C).

concn (ppm)	temp (°C)	RH (%)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
7.42	21	48	96.1	102.6	105.5	101.4
8.97	21	48	97.0	103.8	106.7	102.5
9.94	21	48	98.9	105.6	109.7	104.7
11.0	21	48	99.1	106.4	108.2	104.6
12.4	21	48	98.4	104.8	108.1	103.8

4.5 Effect of Face Velocity

The determination of the effect of face velocity was not performed due to the fixed gas flow rate provided by the external pump during monitoring.

4.6 Effect of Orientation

The determination of the effect of orientation was not performed due to the fixed gas flow direction provided by the external pump during monitoring.

4.7 Effect of Humidity

The 8-hour TWA effects of low and high humidity were tested by monitoring dynamically generated controlled dry and humid test atmosphere containing chlorine nominally at the 8-hour TWA T_C for 240 minutes, respectively. The results of these tests are provided in Table 7, along with the concentration of each test atmosphere. The effect of humidity (Δ_{h_TWA}), calculated as the absolute difference between the mean humid recovery and the mean dry recovery was 1.7%.

Table 7. Humidity data for chlorine (8-hour TWA, ppm values listed at 760 mmHg and 25 °C).

relative humidity (%)	temp (°C)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
21	21	0.964	98.7	98.8	99.6	99.0
81	21	0.984	102.6	101.4	98.1	100.7

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The ceiling effects of low and high humidity were tested by monitoring dynamically generated controlled dry and humid test atmosphere containing chlorine nominally at the ceiling T_C for 3 minutes, respectively. The results of these tests are provided in Table 8, along with the concentration of each test atmosphere. The effect of humidity (Δ_{h_CLG}), calculated as the absolute difference between the mean humid recovery and the mean dry recovery was 5.3%.

Table 8. Humidity data for chlorine (Ceiling, ppm values listed at 760 mmHg and 25 °C).

relative humidity (%)	temp (°C)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
21	21	0.964	98.8	98.8	98.8	98.8
81	21	0.984	105.7	105.7	101.0	104.1

The IDLH effects of low and high humidity were tested by monitoring dynamically generated controlled dry and humid test atmosphere containing chlorine nominally at the IDLH T_C for 3 minutes, respectively. The results of these tests are provided in Table 9, along with the concentration of each test atmosphere. The effect of humidity (Δ_{h_IDLH}), calculated as the absolute difference between the mean humid recovery and the mean dry recovery was 3.4%.

Table 9. Humidity data for chlorine (IDLH, ppm values listed at 760 mmHg and 25 °C).

relative humidity (%)	temp (°C)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
21	21	9.96	100.4	101.4	103.4	101.7
81	21	9.99	106.1	107.1	102.1	105.1

4.8 Effect of Interferents

Any substances that interact with the working electrode of the Cl_2 electrochemical sensor can potentially interfere with measurements during Cl_2 monitoring. Due to high cross-sensitivities of the sensor to bromine, fluorine, chlorine dioxide (positive) and hydrogen sulfide (negative), it is necessary to confirm the presence of these substances in the contaminated air if suspected. For Dräger XXS sensors, see *DrägerSensor & Portable Instruments Handbook* for information on cross-sensitivities of selected substances.³

4.9 Effect of Intermittent Exposure

The 8-hour TWA effect of intermittent exposure was tested by monitoring a dynamically generated controlled test atmosphere containing chlorine nominally at the 8-hour TWA T_C (calculated to be 0.998 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 46% and 22 °C. All monitors were exposed to the test atmosphere for 7 seconds (i.e., $t = 2.3 \times t_{63}$) followed by 7 seconds of clean 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 10. 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 50%.

Table 10. Intermittent exposure data for chlorine (8-hour TWA, ppm values listed at 760 mmHg and 25 °C).

total exposure time (s)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
70 (intermittent)	153.1	149.1	149.5	150.6
70 (steady)	103.1	99.2	100.6	101.0

4.10 Effect of Temperature

The 8-hour TWA and ceiling effects of temperature were tested by monitoring a dynamically generated controlled test atmosphere containing chlorine nominally at the 8-hour TWA and ceiling T_C (calculated at 760 mmHg and 25 °C). The

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relative humidity and temperature of the air sampled were 43% and 21 °C. Prior to obtaining readings, all monitors and external pumps were equilibrated at 4 °C, 22 °C, and 50 °C for one hour. Monitor response was determined after exposure to the test atmosphere for 3 minutes. The results of these tests are provided in Table 11, along with the concentration of each test atmosphere. The effect of temperature (Δ_{T_TWA} and Δ_{T_CLG}), calculated as the absolute difference between the minimum mean recovery and the maximum mean recovery through all tested temperatures, was 6.3%.

Table 11. Temperature data for chlorine (8-hour TWA and ceiling, ppm values listed at 760 mmHg and 25 °C).

temperature (°C)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
4	1.01	103.0	94.8	94.8	97.5
22	1.02	102.0	102.0	102.0	102.0
50	1.03	97.1	93.0	97.1	95.7

The IDLH effect of temperature was tested by monitoring a dynamically generated controlled test atmosphere containing chlorine nominally at the IDLH T_c (calculated at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 43% and 21 °C. Prior to obtaining readings, all monitors and external pumps were equilibrated at 4 °C, 22 °C, and 50 °C for one hour. Monitor response was determined after exposure to the test atmosphere for 3 minutes. The results of these tests are provided in Table 12, along with the concentration of each test atmosphere. The effect of temperature (Δ_{T_IDLH}), calculated as the absolute difference between the minimum mean recovery and the maximum mean recovery through all tested temperatures, was 5.3%.

Table 12. Temperature data for chlorine (IDLH, ppm values listed at 760 mmHg and 25 °C).

temperature (°C)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
4	10.0	107.0	104.0	104.0	105.0
22	9.97	106.3	107.3	107.3	107.0
50	10.1	101.0	101.0	103.0	101.7

4.11 Effect of Oversaturation

The effect of oversaturation was tested by monitoring a dynamically generated controlled test atmosphere containing chlorine nominally at 2× the maximum indication value of 20 ppm for 10 minutes (calculated to be 40.4 ppm at 652 mmHg and 21 °C). The relative humidity and temperature of the air sampled were 52% and 21 °C. After oversaturation for 10 minutes, followed by recovery with clean air for 60 minutes, the monitor response drift between pre-monitoring check and post-monitoring check described in Section 2.2 was observed to be +2.5%.

4.12 Reproducibility

A dynamically controlled test atmosphere was generated, containing chlorine nominally at the 8-hour TWA T_c (calculated to be 0.969 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air monitored were 48% and 20 °C. The test atmosphere was monitored by the Production Team for 240 minutes 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 13. No sample result for chlorine fell outside the permissible bounds set by the expanded uncertainty determined in Section 4.13.

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Table 13. Reproducibility data for chlorine (8-hour TWA, ppm values listed at 760 mmHg and 25 °C).

monitored (ppm)	recovery (%)	deviation (%)
0.96	99.1	-0.9
0.94	97.0	-3.0
0.94	97.0	-3.0

A dynamically controlled test atmosphere was generated, containing chlorine nominally at the ceiling T_C (calculated to be 0.969 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air monitored were 48% and 20 °C. The test atmosphere was monitored by the staff of OSHA Technical Center 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 14. No sample result for chlorine fell outside the permissible bounds set by the expanded uncertainty determined in Section 4.13.

Table 14. Reproducibility data for chlorine (8-hour TWA, ppm values listed at 760 mmHg and 25 °C).

monitored (ppm)	recovery (%)	deviation (%)
0.96	99.1	-0.9
0.96	99.1	-0.9
0.96	99.1	-0.9

4.13 Estimation of Uncertainty

Chlorine relative standard uncertainty components (u_i) are provided in Table 15 for both the 8-hour TWA, ceiling and IDLH levels. The combined percent relative standard uncertainty of the monitoring procedure (u) was determined to be 31% for the 8-hour TWA, 10% for the ceiling and 9.4% for the IDLH. The expanded uncertainty (U) was determined to be 62% for the 8-hour TWA, 10% for the ceiling and 19% for the IDLH.

Table 15. Uncertainty.

uncertainty component (u_i)	8-hour TWA (%)	Ceiling (%)	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})	5.4	4.7	4.2	$u_{mp} = \sqrt{(CV_m)^2 + (1 - 1/n) \times (CV_{pl})^2}$, where $CV_{m_TWA} = 4.9\%$, $CV_{pl_TWA} = 3.0\%$, $CV_{m_CLG} = 1.9\%$, $CV_{pl_CLG} = 5.3\%$, $CV_{m_IDLH} = 1.4\%$, $CV_{pl_IDLH} = 4.8\%$, and $n = 3$, see Section 4.4
method bias (u_{mb})	4.4	3.4	3.8	$u_{mb} = \sqrt{(B_{mb}/\sqrt{3})^2 + (CV_{mb}/\sqrt{n})^2 + (u_{rc})^2}$, where $B_{mb_TWA} = 5.2\%$, $CV_{mb_TWA} = 5.2\%$, $B_{mb_CLG} = 1.8\%$, $CV_{mb_CLG} = 4.8\%$, $B_{mb_IDLH} = 3.4\%$, $CV_{mb_IDLH} = 4.3\%$, and $n = 15$, see Section 4.4; $u_{rc} = 3\%$, see Reference 4

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uncertainty component (u_i)	8-hour TWA (%)	Ceiling (%)	IDLH (%)	notes
effect of humidity (u_h)	1.0	3.1	2.0	$u_h = \Delta_h / \sqrt{3}$, where $\Delta_{h_TWA} = 1.7\%$, $\Delta_{h_CLG} = 5.3\%$, and $\Delta_{h_IDLH} = 3.4\%$, see Section 4.7
effect of intermittent exposure (u_{ie})	29	N/A	N/A	$u_{ie} = \Delta_{ie} / \sqrt{3}$, where $\Delta_{ie_TWA} = 50\%$, see Section 4.9
effect of temperature (u_T)	3.6	3.6	3.1	$u_T = \Delta_T / \sqrt{3}$, where $\Delta_{T_TWA} = 6.3\%$, $\Delta_{T_CLG} = 6.3\%$, and $\Delta_{T_IDLH} = 5.3\%$, see Section 4.10
resolution (u_r)	1.4	1.4	0.29	$u_r = [Res / (2 \times \sqrt{3} \times T_C)] \times 100\%$, where $Res_{TWA} = 0.05$ ppm, $T_{C_TWA} = 1$ ppm, $Res_{CLG} = 0.05$ ppm, $T_{C_CLG} = 1$ ppm, and $Res_{IDLH} = 0.1$ ppm, $T_{C_IDLH} = 10$ 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})	0.17	0.17	0.17	$u_{bp} = 0.30\% / \sqrt{3}$, assumes a measured accuracy of ± 2.25 mmHg at 760 mmHg
standard uncertainty (u)	31	10	9.4	$u = \sqrt{\sum(u_i^2)}$, where u_i represents each uncertainty component as shown above
expanded uncertainty (U)	62	20	19	$U = k \times u$, where $k = 2$

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References

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