

OSHA Method 1029, Nitric Oxide

Nitric Oxide

CAS number:	10102-43-9
OSHA PEL:	25 ppm (30 mg/m ³) 8-Hour TWA, General Industry, Construction, Shipyard
IDLH:	100 ppm (120 mg/m ³)
Procedure:	Expose a personal gas monitor using a nitric oxide (NO) electrochemical sensor to workplace air.
Recommended sampling time:	Full shift (up to 16 hours due to monitor datalogger capacity)
Reporting limit:	0.6 ppm
Working range:	0.6-200 ppm
Uncertainty (u):	19% (8-Hour TWA) 9.1% (IDLH)
Special requirements:	None
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1 Introduction

This method describes alternative methodologies to OSHA's use of OSHA Method ID-190.¹ That method requires the collection of NO using a three-tube sampling train consisting of two tubes containing molecular sieve coated with triethanolamine, interconnected by a chromate oxidizer tube. This method uses a direct-reading monitor with an electrochemical sensor for on-site monitoring of nitric oxide.

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
- NO electrochemical sensor with a manufacturer-listed working range of 0-200 ppm (i.e., Dräger XXS NO or equivalent)
- Calibration adapter with chemically compatible tubing
- Calibration gas cylinders of NO at 25 and 50 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

Equilibrate the monitor at the ambient temperature for at least 15 minutes. Power on the monitor and wait for completion of warm-up. Zero-calibrate the monitor by directly exposing it to clean air. Next, place the monitor into a calibration adapter supplied with 50-ppm NO calibration gas and wait until the reading is stabilized before span calibration. Record the time, temperature, and atmospheric pressure.

Immediately following the span calibration, verify the monitor calibration using a 25-ppm NO calibration gas as pre-monitoring check. If the stabilized reading is not within 25 ± 2.5 ppm, then re-perform zero and span calibrations.

2.2.2 Monitoring

Position the monitor 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 25-ppm NO calibration gas as post-monitoring check. Record the time, temperature, and atmospheric pressure.

Turn off the monitor 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, monitoring 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 200 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 200 ppm for any response over the maximum indication value of 200 ppm.

3.3 Determination of the IDLH

Identify air concentration (C_s) of each response above the 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 NO is 1890.

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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) and the IDLH value for nitric oxide.

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 2% or 450-ppm nitric oxide 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 nitric oxide 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 nitric oxide at 50.6 and 101 ppm. The relative humidity and temperature of the air sampled were 19% and 21 °C. The t_{63} value was determined from the signal rise of three monitors quickly placed into the test atmosphere, and the 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 4 seconds.

Table 1. Time of response for nitric oxide (ppm values listed at 646 mmHg and 21 °C).

monitor no.	50.6 ppm rise in sec (%CV)	50.6 ppm decay in sec (%CV)	101 ppm rise in sec (%CV)	101 ppm decay in sec (%CV)	mean t_{63} in sec
monitor 1	4.1 (10.3%)	4.0 (10.2%)	4.2 (9.06%)	4.1 (7.58%)	4.1
monitor 2	4.2 (7.40%)	3.9 (9.28%)	4.1 (5.53%)	4.2 (5.78%)	4.1
monitor 3	3.9 (8.48%)	3.9 (9.10%)	3.8 (11.5%)	3.8 (8.82%)	3.8

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 79% 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 20 times the monitor resolution. Monitor response was determined after exposure to the test atmosphere for 40 seconds (i.e., $t = 10 \times t_{63}$). The reporting limit (RL) is designated to be 0.6 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 nitric oxide (ppm values listed at 644 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
0.399	monitor 1	0.5
0.399	monitor 2	0.4
0.399	monitor 3	0.4
0.805	monitor 1	0.9
0.805	monitor 2	0.8
0.805	monitor 3	0.9
1.20	monitor 1	1.3
1.20	monitor 2	1.2
1.20	monitor 3	1.2
1.59	monitor 1	1.7
1.59	monitor 2	1.6
1.59	monitor 3	1.6
2.00	monitor 1	2.0
2.00	monitor 2	1.9
2.00	monitor 3	1.9

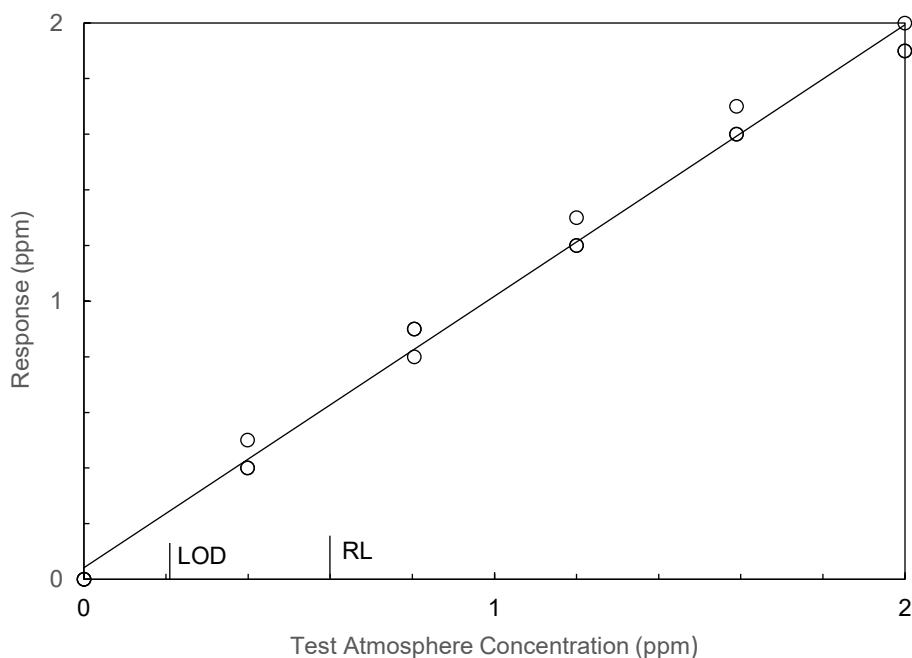


Figure 1. Plot of data used to determine the LOD and RL for nitric oxide ($y = 0.976x + 0.0417$, $S_{y/x} = 0.0613$, LOD = 0.207 ppm, RL = 0.6 ppm).

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 78% and 22 °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 200 ppm. Monitor response was determined after exposure to the test atmosphere for 40 seconds (i.e., $t = 10 \times t_{63}$). Results obtained are provided in Table 3.

Table 3. Working range data for nitric oxide (ppm values listed at 659 mmHg and 22 °C).

concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
0.604	115.9	99.3	115.9	110.4
20.1	99.0	99.5	98.5	99.0
40.2	102.0	102.0	101.7	101.9
59.9	103.5	104.3	102.7	103.5
80.3	104.0	104.0	104.0	104.0
100	105.0	105.0	104.0	104.7
120	105.0	105.8	105.8	105.5
140	105.7	105.0	105.0	105.2
160	105.0	105.0	105.0	105.0
180	105.0	105.0	104.4	104.8

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 0.1 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 4.2%, and the pooled coefficient of variation of each of the five levels tested (CV_{pl_TWA}) was 1.1%. The resulting 8-hour TWA method precision (u_{mp_TWA}) for nitric oxide was determined to be 4.3%. The mean recovery of all fifteen results was 104.3%, resulting in a method bias (B_{mp_TWA}) of 4.3% and a percent coefficient of variation (CV_{mb_TWA}) of 4.0%.

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

concn (ppm)	temp (°C)	RH (%)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
2.49	21	79	110.4	110.4	107.2	109.3
12.9	21	80	100.0	98.4	98.4	98.9
24.9	21	80	106.4	108.8	106.8	107.3
51.7	20	79	100.6	101.4	99.8	100.6
125	21	80	105.6	105.6	105.6	105.6

The IDLH method precision and bias was determined by monitoring dynamically generated controlled test atmospheres for 40 seconds (i.e., $t = 10 \times t_{63}$). 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 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_IDLH}) was 0.49%, and the pooled coefficient of variation of each of the five levels tested (CV_{pl_IDLH}) was 0.54%. The resulting IDLH method precision (u_{mp_IDLH}) for nitric oxide was determined to be 0.66%. The mean recovery of all fifteen results was 104.2%, resulting in a method bias (B_{mp_IDLH}) of 4.2% and a percent coefficient of variation (CV_{mb_IDLH}) of 0.64%.

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

concn (ppm)	temp (°C)	RH (%)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
74.7	21	79	104.7	105.9	104.0	104.9
89.7	21	79	103.8	104.8	103.8	104.1
99.7	21	79	104.3	105.3	104.3	104.6
110	21	79	103.6	103.6	103.6	103.6
125	21	79	104.0	104.0	104.0	104.0

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 nitric oxide nominally at the 8-hour TWA T_c . The relative humidity and temperature of the air monitored were 80% and 20 °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 40 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 6, along with the concentration of each test atmosphere. The effect of face velocity ($\Delta_{v,TWA}$), calculated as the absolute difference between the maximum mean recovery and the minimum mean recovery through all tested face velocities was 3.9%.

Table 6. Face velocity data for nitric oxide (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	25.1	100.7	100.7	100.7	100.7
0.3	25.0	99.7	99.0	99.0	99.2
0.5	25.1	102.0	102.0	100.7	101.6
0.7	25.0	98.9	99.6	99.6	99.4
1.0	25.8	104.0	103.4	102.0	103.1

The IDLH effect of face velocity was tested by monitoring a dynamically generated controlled test atmosphere containing nitric oxide nominally at the IDLH T_c . The relative humidity and temperature of the air monitored were 80% and 20 °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 40 seconds (i.e., $t = 10 \times t_{63}$). The results of these tests are provided in Table 7, 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 2.0%.

Table 7. Face velocity data for nitric oxide (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	100	104.5	104.5	105.4	104.8
0.3	101	104.4	104.4	104.4	104.4
0.5	99.4	106.9	106.1	106.1	106.4
0.7	100	108.0	105.4	105.4	106.3
1.0	101	107.0	106.1	106.1	106.4

4.6 Effect of Orientation

The 8-hour TWA effect of orientation was tested by monitoring a dynamically generated controlled test atmosphere containing nitric oxide nominally at the 8-hour TWA T_c . The relative humidity and temperature of the air monitored were 80% and 20 °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 40 seconds (i.e.,

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$t = 10 \times t_{63}$). The results of these tests are provided in Table 8, 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 2.6%.

Table 8. Orientation data for nitric oxide (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	24.8	101.1	102.5	103.9	102.5
90	24.8	103.9	106.1	105.4	105.1

The IDLH effect of orientation was tested by monitoring a dynamically generated controlled test atmosphere containing nitric oxide nominally at the IDLH T_c . The relative humidity and temperature of the air monitored were 80% and 20 °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 40 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 orientation (Δ_{o_IDLH}), calculated as the absolute difference between the two orientations tested was 5.0%.

Table 9. Orientation data for nitric oxide (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	101	105.0	105.0	105.0	105.0
90	101	109.4	111.1	109.4	110.0

4.7 Effect of Humidity

The 8-hour TWA effect of low humidity was tested by monitoring a dynamically generated controlled test atmosphere containing nitric oxide nominally at the 8-hour TWA T_c for 240 min (calculated to be 25.7 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 21% and 20 °C. Results for nitric oxide as a percentage of expected recovery of the three monitors were 99.2%, 99.6%, and 99.2%. The mean percentage of expected recovery was 99.3%. The effect of humidity (Δ_{h_TWA}), calculated as the absolute difference between the mean dry recovery and the mean humid recovery of 107.3% taken from the 24.9 ppm method precision test described in Section 4.4, was 8.0%.

The IDLH effect of low humidity was tested by monitoring a dynamically generated controlled test atmosphere containing nitric oxide nominally at the IDLH T_c for 40 seconds (i.e., $t = 10 \times t_{63}$) (calculated to be 100 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 20% and 20 °C. Results for nitric oxide as a percentage of expected recovery of the three monitors were 104.0%, 102.0%, and 103.0%. The mean percentage of expected recovery was 103.0%. The effect of humidity (Δ_{h_IDLH}), calculated as the absolute difference between the mean dry recovery and the mean humid recovery of 104.6% taken from the 99.7 ppm method precision test described in Section 4.4, was 1.6%.

4.8 Effect of Interferents

Any substances that interact with the working electrode of the NO electrochemical sensor can potentially interfere with measurements during NO monitoring. 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 nitric oxide nominally at the 8-hour TWA T_c (calculated to be 26.2 ppm at 760 mmHg and 25

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°C). The relative humidity and temperature of the air sampled were 14% and 21 °C. All monitors were exposed to the test atmosphere for 9 seconds (i.e., $t = 2.3 \times t_{63}$) followed by 9 seconds of clean air recovery, where the exposure cycle was repeated ten times for a 90-second intermittent exposure. Subsequently, the monitors were exposed to the test atmosphere for a 90-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 17%.

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

total exposure time (s)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
90 (intermittent)	116.8	116.7	115.4	116.3
90 (steady)	99.6	99.6	99.5	99.6

4.10 Effect of Temperature

The 8-hour TWA effect of temperature was tested by monitoring a dynamically generated controlled test atmosphere containing nitric oxide 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 80% and 21 °C. Prior to obtaining readings, all monitors were equilibrated at 4 °C, 22 °C, and 48 °C for one hour. Monitor response was determined after exposure to the test atmosphere for 40 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 temperature (Δ_{T_TWA}), calculated as the absolute difference between the minimum mean recovery and the maximum mean recovery through all tested temperatures, was 21%.

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

temperature (°C)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
4	24.8	105.6	105.6	118.5	109.9
22	25.1	101.6	101.6	101.6	101.6
48	25.0	132.0	123.2	112.0	122.4

The IDLH effect of temperature was tested by monitoring a dynamically generated controlled test atmosphere containing nitric oxide nominally at the IDLH T_C (calculated at 760 mmHg and 25 °C). The relative humidity and temperature of the air sampled were 80% and 21 °C. Prior to obtaining readings, all monitors were equilibrated at 4 °C, 22 °C, and 48 °C for one hour, respectively. Monitor response was determined after exposure to the test atmosphere for 40 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 temperature (Δ_{T_IDLH}), calculated as the absolute difference between the minimum mean recovery and the maximum mean recovery through all tested temperatures, was 6.4%.

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

temperature (°C)	concn (ppm)	monitor 1 (%)	monitor 2 (%)	monitor 3 (%)	mean (%)
4	100	114.0	113.0	115.0	114.0
22	100	109.0	108.0	108.0	108.3
48	100	124.0	111.0	109.0	114.7

4.11 Effect of Oversaturation

The effect of oversaturation was tested by monitoring a dynamically generated controlled test atmosphere containing nitric oxide nominally at 2× the maximum indication value of 200 ppm for 10 minutes (calculated to be 400 ppm at 655 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.

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4.12 Reproducibility

A dynamically controlled test atmosphere was generated, containing nitric oxide nominally at the 8-hour TWA T_c (calculated to be 25.3 ppm at 760 mmHg and 25 °C). The relative humidity and temperature of the air monitored were 81% and 21 °C. The test atmosphere was monitored by the staff of OSHA Technical Center 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 13. No sample result for nitric oxide fell outside the permissible bounds set by the expanded uncertainty determined in Section 4.13.

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

monitored (ppm)	recovery (%)	deviation (%)
27.0	106.7	+6.7
26.8	105.9	+5.9
26.7	105.5	+5.5

4.13 Estimation of Uncertainty

Nitric oxide relative standard uncertainty components (u_i) are provided in Table 14 for both the 8-hour TWA and IDLH levels. The combined percent relative standard uncertainty of the monitoring procedure (u) was determined to be 19% for the 8-hour TWA and 9.1% for the IDLH. The expanded uncertainty (U) was determined to be 38% for the 8-hour TWA and 18% for the IDLH.

Table 14. Uncertainty.

uncertainty component (u_i)	8-hour TWA (%)	IDLH (%)	notes
calibration standards (u_{cs})	2.9	2.9	$u_{cs} = 5\%/\sqrt{3}$, assumes an accuracy of $\pm 5\%$
method precision (u_{mp})	4.3	0.66	$u_{mp} = \sqrt{(CV_m)^2 + (1 - 1/n) \times (CV_{pl})^2}$, where $CV_{m_TWA} = 4.2\%$, $CV_{pl_TWA} = 1.1\%$, $CV_{m_IDLH} = 0.49\%$, $CV_{pl_IDLH} = 0.54\%$, and $n = 3$, see Section 4.4
method bias (u_{mb})	4.0	3.9	$u_{mb} = \sqrt{(B_{mb}/\sqrt{3})^2 + (CV_{mb}/\sqrt{n})^2 + (u_{rc})^2}$, where $B_{mb_TWA} = 4.3\%$, $CV_{mb_TWA} = 4.0\%$, $B_{mb_IDLH} = 4.2\%$, $CV_{mb_IDLH} = 0.64\%$, and $n = 15$, see Section 4.4; $u_{rc} = 3\%$, see Reference 4
effect of face velocity (u_v)	2.3	1.2	$u_v = \Delta_v/\sqrt{3}$, where $\Delta_{v_TWA} = 3.9\%$ and $\Delta_{v_IDLH} = 2.0\%$, see Section 4.5
effect of orientation (u_o)	1.5	2.9	$u_o = \Delta_o/\sqrt{3}$, where $\Delta_{o_TWA} = 2.6\%$ and $\Delta_{o_IDLH} = 5.0\%$, see Section 4.6
effect of humidity (u_h)	4.6	0.92	$u_h = \Delta_h/\sqrt{3}$, where $\Delta_{h_TWA} = 8.0\%$ and $\Delta_{h_IDLH} = 1.6\%$, see Section 4.7

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uncertainty component (u_i)	8-hour TWA (%)	IDLH (%)	notes
effect of intermittent exposure (u_{ie})	9.8	N/A	$u_{ie} = \Delta_{ie}/\sqrt{3}$, where $\Delta_{ie_TWA} = 17\%$, see Section 4.9
effect of temperature (u_T)	12	3.7	$u_T = \Delta_T/\sqrt{3}$, where $\Delta_{T_TWA} = 21\%$, and $\Delta_{T_IDLH} = 6.4\%$, see Section 4.10
resolution (u_r)	0.23	0.29	$u_r = [Res/(2 \times \sqrt{3} \times T_C)] \times 100\%$, where $Res_{TWA} = 0.2$ ppm, $T_{C_TWA} = 25$ ppm, and $Res_{IDLH} = 1$ ppm, $T_{C_IDLH} = 100$ ppm
monitor response drift (u_{dr})	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	$u_{AT} = 0.27\%/\sqrt{3}$, assumes a measured accuracy of ± 0.8 °C at 25 °C
pressure measurement (u_{bp})	0.17	0.17	$u_{bp} = 0.30\%/\sqrt{3}$, assumes a measured accuracy of ± 2.25 mmHg at 760 mmHg
standard uncertainty (u)	19	9.1	$u = \sqrt{\sum(u_i^2)}$, where u_i represents each uncertainty component as shown above
expanded uncertainty (U)	38	18	$U = k \times u$, where $k = 2$

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References

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4. ISO/DIS 22065:2018, Workplace air - Procedures for measuring gases and vapours using pumped samplers - Requirements and test methods.