

# Breathing Air Quality, Sampling and Testing

Environmental Health Laboratory  
Department of Environmental and Occupational Health Sciences  
School of Public Health  
University of Washington



Funding and support from  
The State of Washington Department of Labor & Industries  
Safety & Health Investment Projects  
Medical Aid and Accident Fund

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# Overview

In response to queries on alternatives to high-pressure sampling of breathing air and lack of independent information on the accuracy, functionality, durability, and safety of commercially available breathing air quality assessment kits, the Environmental Health Laboratory (EHL) at the University of Washington evaluated six representative breathing air sampling kits. Kits were tested in the laboratory and by personnel at three fire departments and one commercial diving company.

# Background

Statutes and codes for breathing air quality parameters are shown in Table 1. In Washington state, regulated components for commercial diving breathing air are listed in Washington Administrative Code (WAC) 296-37-570(2)(C), while those for firefighting breathing air are given in WAC 296-305-04001(21); some fire agencies choose to follow specifications in the more restrictive self-contained breathing apparatus (SCBA) Breathing Air Quality Specification in the National Fire Protection Code (NFPA).

## Typical Problems in Breathing Air

When the regulatory level of water in fire-fighting (SCBA) breathing air was lowered to 24 ppm in 1997, the number of breathing air quality failures due to excessive water vapor increased. Excessive water vapor continued to be the most frequent cause of failed testing for SCBA air (Table 2).

Combustion gases, carbon dioxide and carbon monoxide, each had a failure rate of 1% in self-contained underwater breathing apparatus (SCUBA) breathing air samples. Exhaust from nearby engines is likely the cause. Oxygen in submitted samples has only failed when elevated levels are present due to oxygen enrichment (Nitrox).

One percent of SCBA air samples tested failed due to a pronounced odor. Ten percent had a slight odor, which

was typically described as stale. One percent of diving samples failed due to a pronounced odor. The odors were musty, vegetable, rubber, exhaust, and moldy. Thirty-three percent of the SCUBA samples had a slight odor. Air from compressors operating in marine or outdoor environments appears to have more odors than air from a dry, indoor fire department setting.

## Why is water a problem in collecting a SCBA breathing air sample?

Water is a “sticky” molecule and easily forms an invisible molecular film on surfaces. The absence of visible water does not mean the surface is dry enough to avoid contamination of a dry air sample. Thus, sample containers and fill lines must be thoroughly purged prior to sampling, regardless of appearance. Water has an affinity for surfaces unless they have been specially treated to make them water-repellent. More water is retained on rougher surfaces.

Sample container leaks are another possible source of water contamination. Given that room air contains around 30,000 ppm (3%) water, a small leak will alter a dry air sample with a water concentration of 10–30 ppm. Samples at low pressure are more affected by water contamination problems because at high pressures any water contamination from the container surface is in essence diluted.

Table 1. Breathing Air Quality Specifications

	Washington Fire Fighting	Washington Commercial Diving	CGA Grade D	CGA Grade E	OSHA	NFPA 1989
Citation	WAC 296-305-04001	WAC 296-37-570	ANSI G 7.1 5 <sup>th</sup> ed.	ANSI G 7.1 5 <sup>th</sup> ed.	29 CFR 1910.134	2008 edition
Date effective	3/1/05	11/1/04	8/27/04	8/27/04	1/8/98	12/31/07
Frequency of testing	3 months	6 months	—	—	—	3 months*
Oxygen (%)	19.5–23.5	—	19.5–23.5	20–22	19.5–23.5	19.5–23.5
Carbon dioxide (ppm)	≤ 1,000	≤ 1,000	≤ 1,000	≤ 1,000	≤ 1,000	≤ 1,000 <sup>§§</sup>
Carbon monoxide (ppm)	≤ 10	≤ 10	≤ 10	≤ 10	≤ 10	≤ 5
Hydrocarbon content (ppm)	—	—	—	≤ 25 <sup>§</sup>	—	≤ 25 <sup>‡</sup>
Nitrogen (%)	—	—	—	—	—	75–81
Water (ppm)	≤ 24	—	A	A	≤ 67	≤ 24
Water (dew point °F)	-65°	—	—	—	-50°	-65°
Particulate & Oil (mg/m <sup>3</sup> )	≤ 5 <sup>¶¶</sup>	≤ 5 <sup>#</sup>	≤ 5 <sup>¶¶</sup>	≤ 5 <sup>¶¶</sup>	≤ 5 <sup>¶¶</sup>	≤ 2
Odor <sup>**</sup>	None	None	None	None	None	None

\* Additional requirements: test after alterations, maintenance, repairs, or relocation of any breathing air system or system part; within one week prior to filter replacement; when contamination of system, storage, or SCBA cylinder is suspected.

‡ Non-methane volatile organic compounds expressed as methane.

§ Total expressed as methane.

¶ Oil (condensed) only.

# Oil mist only.

\*\* The standards and regulations are worded slightly differently but essentially all require that the air shall be free of any pronounced, objectionable, or noxious odor.

§§ Levels > 500 ppm should be investigated.

A For SCBA operations, a dew point ≤ -65° F or 10° F lower than the coldest temperature expected in the area is required.

Table 2. Typical Failure Rates for Air Quality Tests

SCBA	
Water Vapor	12%
Carbon Dioxide	0%
Carbon Monoxide	0%
Total Hydrocarbons	0%
Oil	0%
Odor	1%
Oxygen	0%
SCUBA	
Carbon Dioxide	1%
Carbon Monoxide	1%
Oil Mist	1%
Odor	1%

# Regulated Components of Breathing Air

**Oxygen (O<sub>2</sub>)** is an odorless, colorless gas, essential for life, with an atmospheric concentration of 21% by volume. OSHA and NIOSH define an oxygen-deficient atmosphere as any atmosphere containing oxygen at a concentration below 19.5% at sea level, which includes a safety factor.<sup>1</sup> At concentrations below 16%, decreased mental effectiveness, visual acuity, and muscular coordination occur. Below 10%, loss of consciousness may occur; below 6%, death results. Individuals exposed to low concentrations of oxygen are often unaware of the growing danger because only mild perceptual changes are initially experienced.

Oxygen toxicity may result from exposure to elevated concentrations of oxygen (> 50%) at normal pressures; delayed symptoms begin with inflammation of the upper airways and can progress to acute respiratory distress syndrome.<sup>2</sup> Hyperbaric oxygen exposure can lead to central nervous system toxicity in divers; symptoms can include visual disturbance, ear problems, dizziness, confusion, nausea, and seizures. Safety procedures have been developed for divers using high percentages of oxygen or hyperbaric oxygen.<sup>3,4</sup>

There is also an increased danger of ignition and combustion at oxygen concentrations higher than atmospheric. Equipment for elevated oxygen levels must be rated for oxygen service and cleaned prior to initial use to remove combustible contamination.<sup>5,6,7</sup> An air compressor may leave hydrocarbon residues, such as oil or grease, on internal components. Fire or explosion can occur if an elevated oxygen atmosphere, especially pressurized oxygen, comes in contact with these residues.<sup>8</sup> Thus, oxygen service is not compatible with standard compressed air systems.

**Carbon dioxide (CO<sub>2</sub>)** is an odorless, tasteless gas produced by combustion and metabolism in cells. Atmospheric concentration is approximately 390 ppm. CO<sub>2</sub> is a simple asphyxiant, with an OSHA permissible exposure limit of 5,000 ppm. Drowsiness may occur at 10,000 ppm; symptoms can progress to headaches, dizziness, restlessness, lack of sensation, labored

breathing, discomfort, increased heart rate, and even coma and death as the concentration increases.

In diving operations, CO<sub>2</sub> retention (hypercapnia) is generally caused by excessive carbon dioxide in the breathing supply or inadequate lung ventilation in relation to exercise levels.<sup>9</sup> Symptoms are listed above.

**Carbon monoxide (CO)** is a colorless, odorless, tasteless, and highly toxic gas produced by incomplete combustion of carbon or fuels. Normal atmospheric levels are around 0.1 ppm but will likely be higher in locations with combustion sources.

CO combines with hemoglobin in blood to form carboxyhemoglobin, which does not bind oxygen and thus diminishes the body's ability to deliver oxygen to tissues. Symptoms include headache, nausea, vomiting, dizziness, fatigue, weakness, confusion, disorientation, visual disturbance, fainting, and seizures. Short duration exposure can lead to permanent neurological damage and death. Cardiac dysfunction, including arrhythmias, has often been reported in carbon monoxide poisoning.<sup>10</sup>

The OSHA permissible exposure limit to CO is 50 ppm, averaged over an eight-hour period. NFPA reduced its breathing air specification for carbon monoxide from 10 to 5 ppm in 2008. Carboxyhemoglobin will rise to 3.5% in individuals doing heavy work while breathing air with 5 ppm carbon monoxide. The American Conference of Governmental Industrial Hygienists (ACGIH) feels that this level of carboxyhemoglobin reflects a CO concentration to which nearly all workers may be repeatedly exposed without adverse health effects.

**Hydrocarbon content** is a catch-all term for volatile organic chemicals present in breathing air. (Methane, the simplest volatile organic compound, is the principal component of natural gas and is excluded in the NFPA definition of hydrocarbon content. Its concentration in the atmosphere is approximately 1–2 ppm.) The presence of volatile organic compounds indicates that something is wrong with breathing air production or storage. Besides being potentially toxic and flammable, the compounds can also deteriorate breathing air gear.

**Nitrogen (N<sub>2</sub>)** is an odorless, colorless, tasteless gas that makes up most of the earth's atmosphere (78%). It is inert, nonflammable, and non-toxic. If the oxygen content of breathing air were reduced below 19.5%, say by blending in nitrogen, nitrogen would be considered an asphyxiant. NFPA does not explain the reason for an acceptability range for nitrogen concentration. If breathing air is generated through compression of the atmosphere, oxygen and nitrogen ratios do not change.

**Water (H<sub>2</sub>O)** vapor saturation in the air changes with temperature; less water can be held in the air as the temperature decreases. The formation of dew or fog is an example of this phenomenon. The dew point is the temperature to which humid air must be cooled for water vapor to condense into water. A dew point temperature can also be expressed as a water vapor concentration; for SCBA breathing air, this is regulated at the ppm level.

While water vapor and liquid water are not directly harmful to users of breathing air, excessive amounts can cause hazards. Moisture can corrode breathing air systems and reduce the efficacy of gas purifiers. A greater hazard is ice blockage of regulators in cold temperature conditions, whether on land or during extreme cold

water diving. As gas expands from the breathing air tank, it cools. If the dew point is reached, moisture will condense and then freeze if the surrounding temperature is low, thus blocking the air supply.

**Oil Mist** is a generic term for an aerosol of oil such as that produced by a leaking compressor or contaminated fill line. Oil mist has an odor similar to burned lubricating oil, with an odor threshold of 1 ppm. Oil mist is not a natural component of the atmosphere and is not formed by evaporation.

Chemical pneumonia, with initial symptoms of shortness of breath, decreased exercise tolerance, and respiratory distress, is a serious toxic response to inhaled oil mist and may continue to worsen after removal from exposure. Other effects include eye and skin irritation. The Occupational Safety and Health Administration (OSHA) permissible exposure limit is 5 mg/m<sup>3</sup>.

**Particulate** refers to any matter with size characteristics that allow collection by a filter during air testing. This would include oil mist. NFPA specifies that the filter retain particulate 0.3 micron and higher in size. Particles of 10 microns (0.0004") can penetrate deep into the lungs. Particulate may cause irritation of eyes, skin, throat, and upper respiratory system.



# Performance of Breathing Air Testing Kits

Six commercial breathing air testing kits were chosen for evaluation as representative of the diverse designs and approaches for measurement of breathing air quality. Table 3 provides information on kit features and regulated components in breathing air. For those interested, patents (Table 3) can be viewed online for detailed information on design and function: <http://patft.uspto.gov/netahtml/PTO/search-bool.html>.

Kits A, B, C, D-S, and E include a sample container in the sample kit. In these kits, a breathing air sample is collected in the container and then submitted to an analytical chemistry laboratory associated with the kit for measurement of breathing air components. Kits D-T and E are designed to measure most breathing air components at the compressor site using indicator tubes. Kits A and E assess water vapor in the laboratory from the collected sample, while kits B, C, D-S, D-T, and E use indicator tubes at the compressor location for this purpose.

## Evaluation of usability

Potential hazards encountered during use in the laboratory and at the compressor sites are presented in Table 4. Predictions on durability and operability after exposure to oil mist and particulate are also presented in Table 4.

Each kit was field tested by personnel at three fire departments and one commercial diving company. The most significant parameters evaluated are presented in Table 5.

## Evaluation of sample collection

The ability of the kits to collect uncompromised samples was evaluated, with the reference for comparison being a high pressure sample collected in a SCUBA bottle at the dive facility or SCBA bottles at fire departments. Samples were collected following kit instructions.

Carbon monoxide was not detected at any site, either in samples collected by kits or in the reference samples. Carbon dioxide and methane concentrations in kit

Table 3. Description of Kits Tested

Kit Code	A	B	C	D-S*	D-T	E	F
Flow control	Critical orifice	Critical orifice	Critical orifice	Valves	Valves	Regulators and valve	None
Sample container	Plastic syringe	Glass vial	Glass vial	Aluminum cylinder	None	None	Aluminum cylinder
Gas analysis done by	Lab	Lab	Lab	Lab	Indicator tube	Indicator tube	Lab
Location of filter	External in cassette	Internal, upstream of sample container	External in cassette	External in cassette	—	—	Internal
Oil mist done by	Lab using Filter	Lab using Filter	Lab using Filter	Lab using Filter	Indicator tube	Indicator tube	Unknown
Water vapor done by	Lab	Indicator tube	Indicator tube	Indicator tube	Indicator tube	Indicator tube	Lab
US Patent	Unknown	4,014,216	Unknown	5,101,671		Unknown	7,183,115

\* Kit D comes in two versions, with a common airflow regulating component; one version (D-S) has a sample container attachment and the other (D-T) has a indicator tube manifold.

Table 4. Observations of Safety and Durability

Kit Code	A	B	C	D-S	D-T	E	F
Hazard due to equipment malfunction or design	Plunger ejection,* filter cassette came apart*	—	—	—	—	Indicator tube ejected*	—
Hazard due to operator error	Syringe not completely attached	Indicator tube broke <sup>§</sup>	Indicator tube ejection <sup>‡</sup>	—	—	—	—
Damage due to operator error	Luer <sup>¶</sup> fitting striping	—	Luer fittings on cassette	—	—	—	—
Impact of oil mist or particulate	None	None	None	None	None	Irreversibly contaminate regulator	None
Cleaning	Return	Instructions	Instructions	Instructions	Instructions	Not possible	Return

\* Occurred during laboratory and field testing

§ Can occur with any kit using tubes

¶ Standard medical syringe fitting with 6% taper, lock style

‡ Not inserted fully in holder

Table 5. Tester's Opinions on Kits

Kit Code	A	B	C	D*	E	F
Durable	50%	100%	50%	100%	100%	100%
Easy to use	100%	100%	50%	25%	100%	100%
Safe to use	75%	100%	100%	100%	75%	100%
Had confidence in sample collection	75%	100%	75%	100%	—	75%
Able to set flow and pressure per instructions	75%	100%	75%	100%	50%	100%

\* Evaluation included both breathing air sample collection and indicator tube measurements  
Kits were tested at four sites with one tester per site.

samples were similar to the reference (Figure 1); carbon dioxide in kits was 1–22% different from the reference. Methane was 2–30% different from the reference. In contrast, the concentration of water vapor in the kit samples was vastly greater (29–790-fold) than the reference (Figure 2).

Only with kits A and F are the collected samples used for determination of water vapor concentration by the vendor. Samples from kits A and F would fail both the NFPA and WAC-FF criteria for water vapor because of the added water.

Kits B, C, and D use on-site measurements with

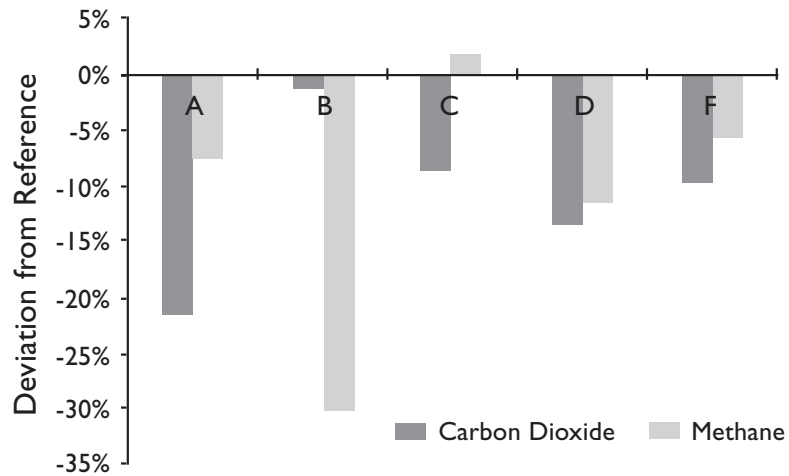


Figure 1. Comparison of kit samples to the reference sample: carbon dioxide and methane concentrations

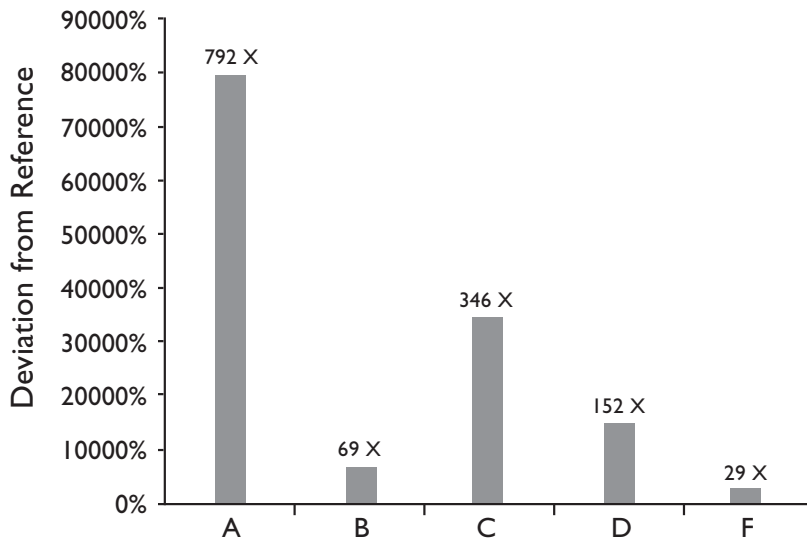


Figure 2. Comparison of kit samples to the reference sample: water vapor concentration

indicator tubes for water vapor, and their vendors do not claim that the kits can successfully collect an air sample for water vapor—nor do they offer this analysis. We examined these kits to gather data on suitability of materials and approaches for collection of air samples for water vapor analysis. Analysis of air samples from all kits with containers supports the assertion that low pressure sampling for water vapor is problematic regardless of the container material.

### Comparison of laboratory testing results

For those kits designed to collect breathing air samples for laboratory analysis, different gas mixtures of known composition were sampled according to vendors' instructions and then submitted to the laboratory associated with the kit. Samples were submitted blind, with coded identities so that the contents were not distinguishable by the laboratories before analysis. Samples were submitted for testing to NFPA or Compressed Gas Association (CGA) E standards.

Some samples contained very little oxygen (< 0.5%) and would not support life. Laboratories testing samples from kits B, C, D, and F correctly identified the samples with low oxygen content. Labs testing for kits C and D called to inform us of this hazard. The oxygen level results from the lab associated with kit A were close to normal for all samples (Figure 3). While this may be

additional evidence that the kit A sample container was leaking, the possibility of measurement error cannot be discounted.

Gas concentrations in samples submitted to laboratories were chosen so that they represented “passing low” and “failing high” concentrations of contaminants. Vendor analysis of samples from kits B, C, D, and F showed a good correspondence between submitted sample concentration and laboratory results for carbon dioxide (Figure 4), carbon monoxide (Figure 5), and methane (Figure 6).

In contrast, results from vendor laboratory analyses of Kit A samples were substantially different from the expected concentrations. The bias was mostly toward lower concentrations of contaminants.

Water vapor was not part of the vendor laboratory analyses for kits B, C, and D. Regardless of the submitted sample value, the results for kit A were all approximately 20 ppm (Figure 7). The same was observed for kit F (Figure 8). Thus, both vendor analyses underestimated the water vapor concentration in samples with “failing” levels of water vapor, erroneously passing the sample.

### General information on indicator tubes

Indicator tubes, also known as stain or detector tubes, are one approach used for measuring some, but not all, regulated components of breathing air. Carbon dioxide,

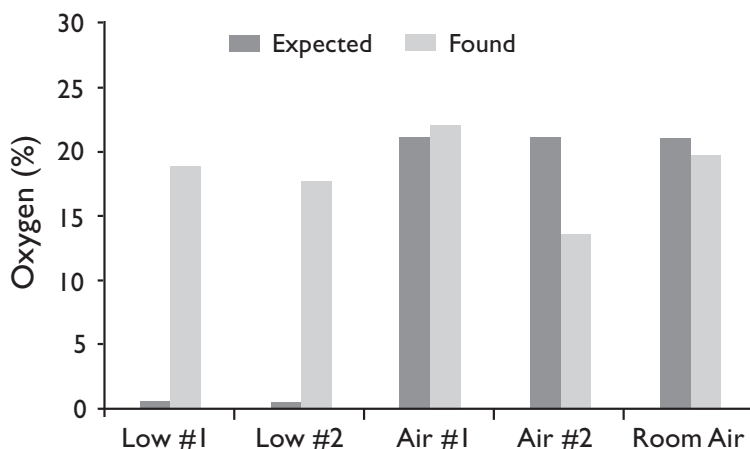


Figure 3. Kit A results for oxygen

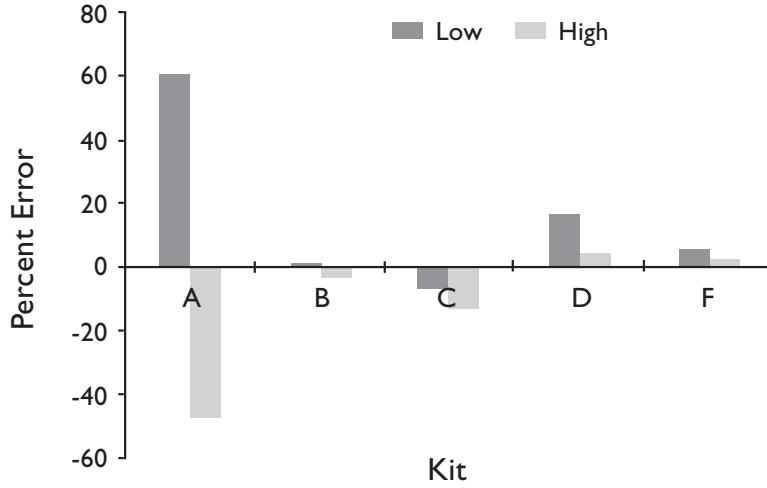


Figure 4. Percent error in laboratory analyses for carbon dioxide in kit samples

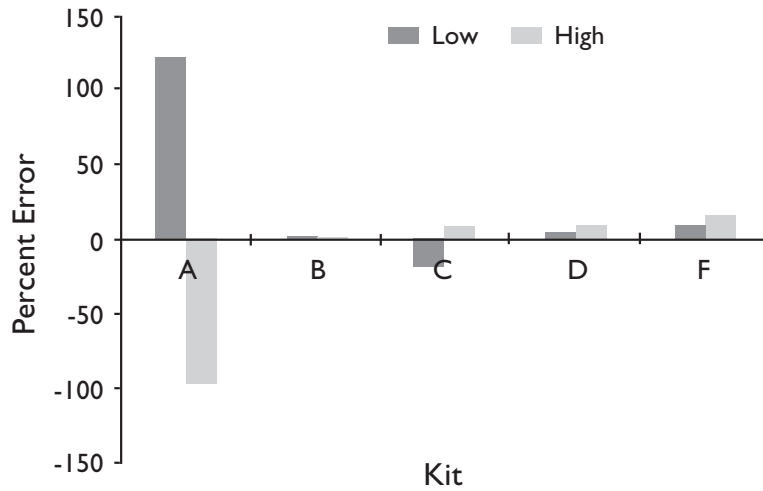


Figure 5. Percent error in laboratory analyses for carbon monoxide in kit samples

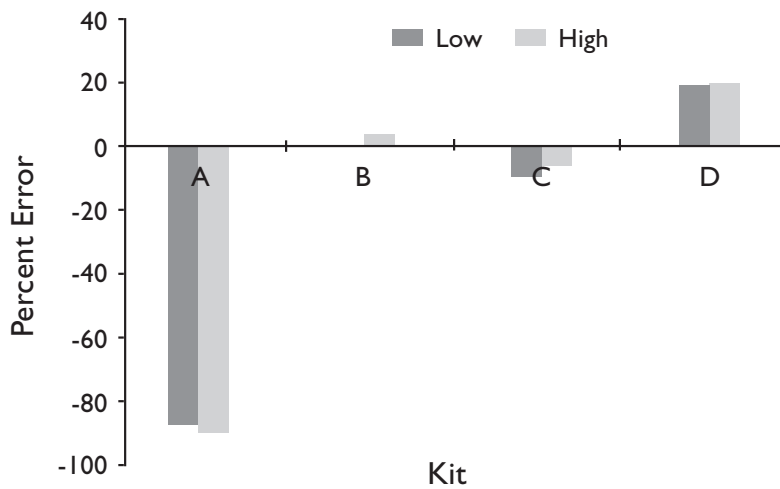


Figure 6. Percent error in laboratory analyses for methane in kit samples

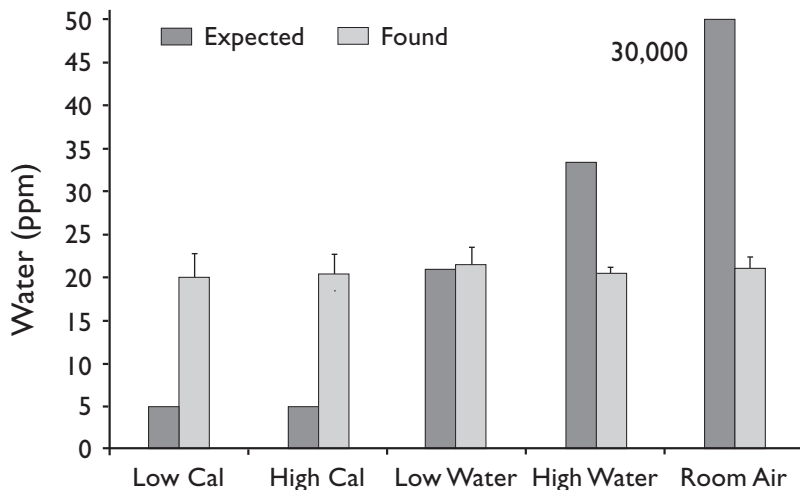


Figure 7. Vendor laboratory kit A results for water

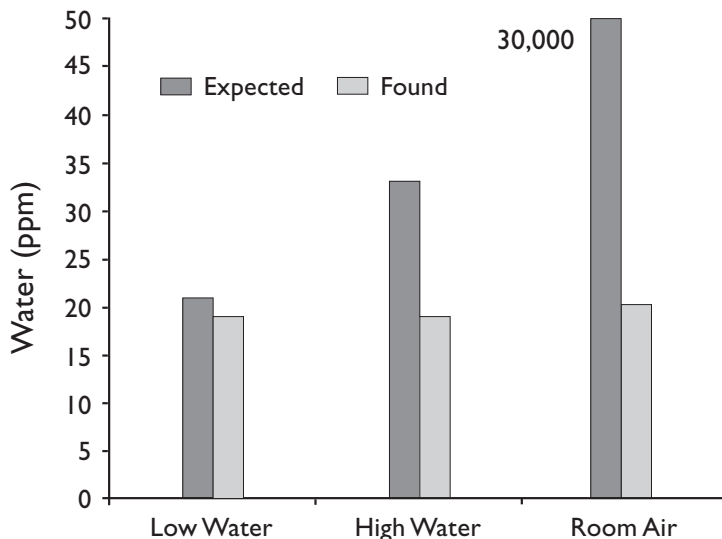


Figure 8. Vendor laboratory kit F results for water

carbon monoxide, water vapor, and oil mist can be measured with indicator tubes, but oxygen and particulate cannot.

When exposed to the test contaminant by passage of air through the tube, a chemical reaction causes the packing in the tube to change color. The amount of packing that changes color is proportional to the mass of contaminant entering the tube, which is equal to the concentration of contaminant in the air times the volume of air passing through the tube. Tube manufacturers

have established optimum air flow rates to allow time for the contaminant to react with the packing. The scale on the tubes is for flow rates specified by the manufacturer. Departure from those rates means that values from the scale on the tube cannot be directly used.

Substituting one brand of detector tube for another is not recommended because differing flow characteristics between brands will cause errors.<sup>11</sup> However, obtaining the same brand and model of tube from a third-party source is perfectly satisfactory and may provide cost savings.

The accuracy—that is, how close the reading is to the true value—of concentrations determined by tubes was found to be in the range of 25% to 35% by National Institute for Occupational Safety and Health (NIOSH) when measured at values 0.5 to 5.0 times the Threshold Limit Value (TLV).<sup>12</sup> No tube meets the NFPA requirements for accuracy in breathing air measurements. We could not find any studies on accuracy at the low concentrations of contaminants typically found in breathing air, even though accuracy is generally poorer at lower concentrations. Shorter stains are harder to read and if the procedure allows, a longer sampling time is preferred. The greatest source of error using indicator tubes for testing is in reading them.<sup>12</sup> Figure 9 shows how to read tubes when the stain front is not perpendicular to the tube.

### Suggestions for better accuracy in reading indicator tubes

- Measure at indicated flow or pressure.
- Accurately conform to the sampling time.
- If the procedure allows, run for a longer time.
- Use at room temperature.

Stains may continue to lengthen after airflow stops because of diffusion of the atmosphere into the tube. Thus, a later reading of the tube may be inaccurate.

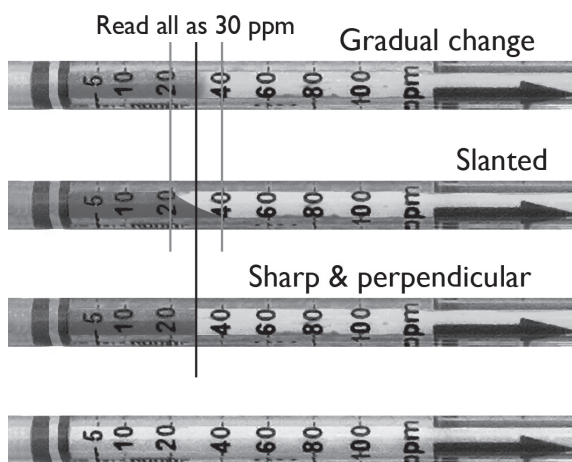


Figure 9. Reading indicator tubes

### Evaluation of kit measurements using indicator tubes

Kits B, C, and D measure water vapor using indicator tubes. Kit E is used solely for field-testing breathing air with indicator tubes. Kit D in one format (D-T) can also be used for field-testing. Kits B, C, and D control flow indirectly through pressure, and hence pressure must be closely controlled in those three kits, which was sometimes a challenge for the testers.

Oil mist and carbon monoxide were not detected at any site, either by indicator or reference measurement in the lab, and so performance for these two contaminants could not be gauged. At four of five sites, Kit E gave significantly higher readings of carbon dioxide—close to four-fold in one case—than the reference value (Figure 10). In three cases, air quality would have falsely failed based on the measurement. Kit D had three occurrences of higher carbon dioxide than reference; one would have falsely failed the air standard.

Kit E gave substantially elevated water concentration measurements at each site (Figure 11); each would have falsely failed the air quality standard. This problem is likely due to the lengthy path the air sample must travel to reach the tube, which obviously was not sufficiently dried in the time called for by the instructions. The reference measurement at Site 5 gave a value higher than the WAC standard of 24 ppm, yet tube measurements with kits B, C, and D were significantly lower and would have resulted in falsely passing measurements for water concentration.

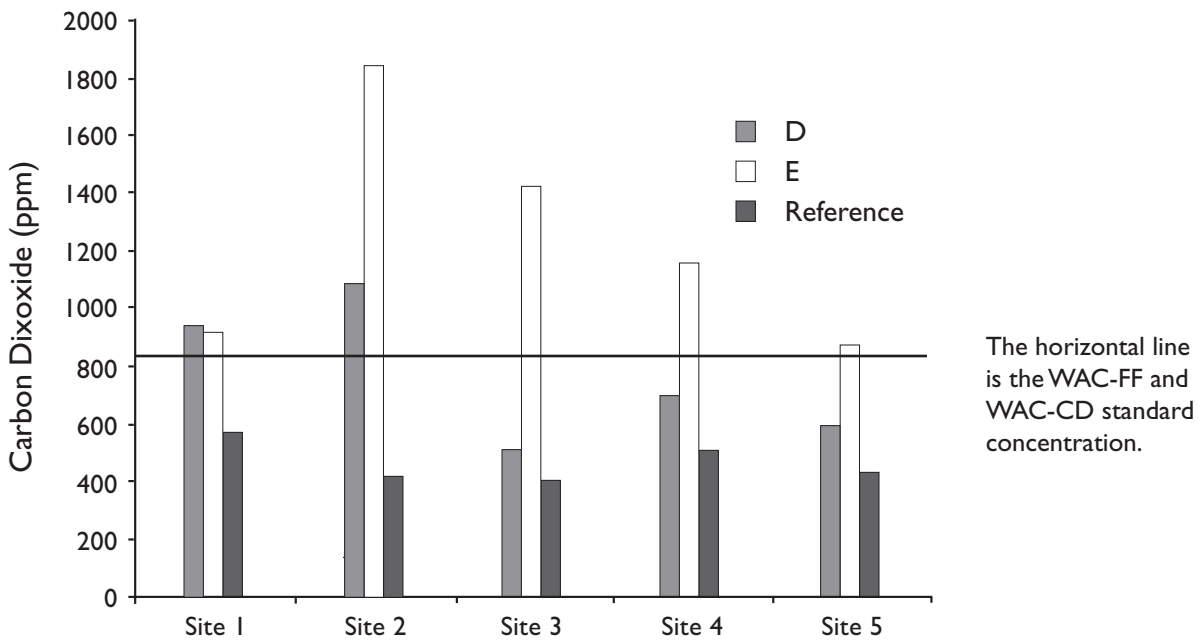


Figure 10. Evaluation of carbon dioxide testing by indicator tube

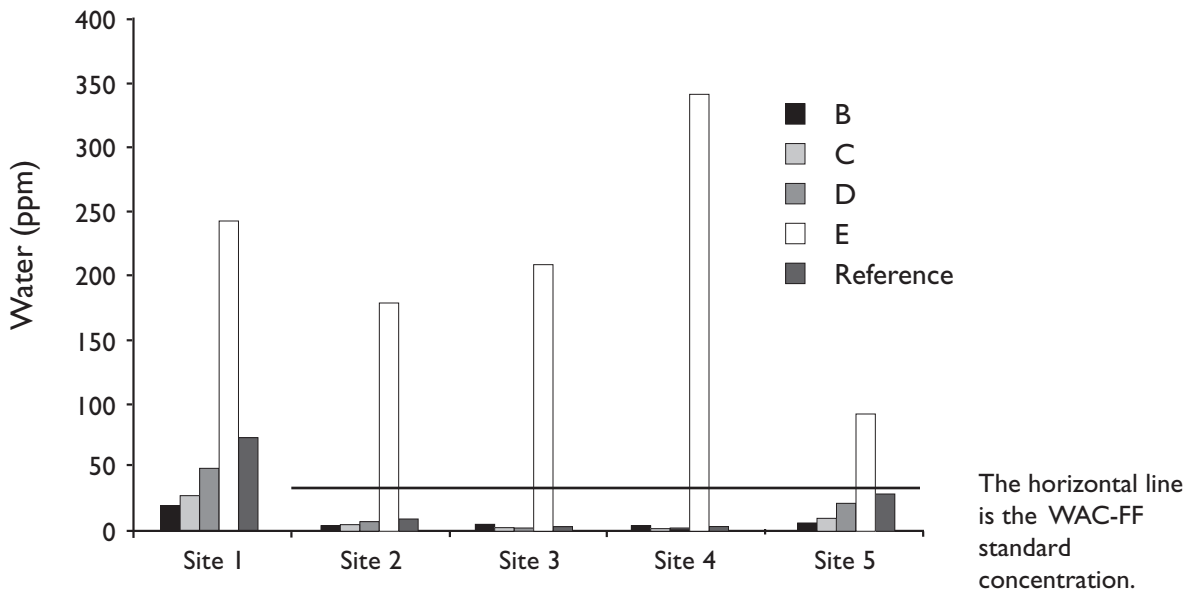


Figure 11. Evaluation of water testing by indicator tube



# Laboratory Accreditation

You can greatly increase the likelihood of accurate results by using a laboratory that is specifically accredited for the analysis being performed. In the accreditation process, inspectors from an accreditation organization evaluate the laboratory for competence using the following criteria:<sup>13</sup>

- Technical competency of staff
- Validity and appropriateness of the methods
- Traceability of chemical standards
- Appropriate application of measurement uncertainty
- Suitability, calibration, and maintenance of test equipment
- Testing environment
- Sampling, handling, and transportation of test items
- Quality assurance of tests

Advantages in using an accredited laboratory include:

- Minimizing the risk of unknowingly using bad air from false passes
- Avoiding lost time and money due to false failures
- Having proper documentation for site inspections
- Complying with NFPA guidelines, which require the use of a lab accredited to ISO/IEC 17025 standards.

One important method of evaluating technical competency is proficiency testing of independently created samples at regular intervals. The Compressed Air Proficiency Testing (CAPT) program specifically evaluates a lab's proficiency in testing breathing air samples and to our knowledge is the only program in the United States to do so. The CAPT program is administered by volunteer labs and is endorsed by the American Industrial Hygiene Association (AIHA). Details on the program can be found on the AIHA website.<sup>14</sup> A lab does not have to be accredited to participate in the CAPT program.

The main standard used by testing and calibration laboratories is ISO/IEC 17025, which incorporates the ISO 9001 quality management system. Accreditation bodies that use these standards check the laboratory for conformity to the standards. Accredited laboratories usually issue test reports bearing a symbol or endorsement indicating their accreditation. You should also check with the laboratory on specific tests or measurements for which they have accreditation.

# Guidance Summary

## Selection of laboratories and kits

- Use a lab accredited through ISO/IEC 17025 standardization.
- Use a lab certified for analytical methods employed in their breathing air analyses.
- Use a lab with demonstrated proficiency in the CAPT program.
- Avoid kits based on a syringe sampling system.
- Avoid kits that have a pressure regulator as a component; pressure gauges are acceptable.

## Collection and measurement of breathing air samples for water

- Try further purging of fill lines and sampler when water is out of specification.
- Note that laboratory analysis of high-pressure samples is superior to any indicator tube measurement.
- Note that the use of indicator tubes is acceptable for regulatory (OSHA and Division of Occupational Safety and Health [DOSH]) purposes but does not meet NFPA requirements for accuracy or sensitivity.
- We cannot recommend any low pressure (< 500 psi) sample container for use with water vapor measurements.

## Indicator tube measurements

- Follow time and flow requirements exactly.
- Use a longer duration for tube exposure if this is an option.
- Follow instructions on reading the stain on tubes.
- Note that *your* reading of the tube determines the concentration, not the laboratory's.

## Recurrent problems for breathing air

- Firefighting: water
- Diving: carbon monoxide and odor

## Prevention of problems

- See guidance in WAC 296-842-20010.
- See guidance in WAC 296-842-20015.
- Change purifiers according to manufacturer schedule.

- Use a shorter replacement cycle for purifiers when pre-maintenance samples (a NFPA requirement) regularly fail or when the air source is impure and the contamination is not due to compressor malfunction.
- Position exhaust away from or downwind of compressor intake and fill point.
- Consider oil-less compressors when replacing equipment.
- Monitor oil level and compressor temperature; overheating can form carbon monoxide.
- Maintain calibration on carbon monoxide alarm as required.<sup>15</sup>
- Keep fill lines clean; dirty lines are a source of particulate and oil.
- Keep compressors clean.
- Don't overfill oil compressors.

## Troubleshooting suggestions

### Oil mist

- Keep fill lines clean; dirty lines are a source of particulate and oil.
- Repair oil leaks.
- Replace and maintain oil separation element and filters as scheduled by manufacturer.

### High CO and CO<sub>2</sub> levels

- Isolate intake or sample point from combustion source.
- Replace failed purifiers.

### High CO levels

- Check for overheating of compressor.
- Replace failed purifiers.
- Check oil level (levels that are too high or too low cause problems).

### High water vapor levels

- Increase purge time of fill lines.
- Increase purge time of sample container or kit.
- Check condensate traps.
- Replace failed or undersized compressed air dryer.

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