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 from the many available. Kits were tested in the laboratory and by personnel at three fire departments and one commercial diving company. In addition to the results from testing, generalized guidance for breathing air quality assessment, avoidance of problems, and problem solving is provided. Information on regulated contaminants is presented for better appreciation of breathing air quality regulations.

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 SCBA Breathing Air Quality Specification in the National Fire Protection Code (NFPA).

Water in Firefighter Air

When the regulatory level of water in breathing air was lowered to 24 ppm in 1997, the number of breathing air quality failures due to excessive water vapor increased, even though breathing air systems were being maintained to manufacturer recommendations. This frustrating and confusing situation was aggravated when tests using some commercial kits always passed and misinformation circulated that water content was not important for SCBA air.

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 5th ed.	ANSI G 7.1 5th 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[§§]
Carbon monoxide (ppm)	≤ 10	≤ 10	≤ 10	≤ 10	≤ 10	≤ 5
Hydrocarbon content (ppm)	—	—	—	≤ 25[§]	—	≤ 25[‡]
Nitrogen (%)	—	—	—	—	—	75–81
Water (ppm) Water (dew point °F)	≤ 24 -65°	—	[A]	[A]	≤ 67 -50°	≤ 24 -65°
Particulate & Oil (mg/m^3)	≤ 5[¶]	≤ 5[#]	≤ 5[¶]	≤ 5[¶]	≤ 5[¶]	≤ 2
Odor**	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 when 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.

After working with fire department clients, EHL determined that the main cause of higher than expected water concentrations was water contamination of the sample containers, which in this case were SCBA bottles. When extensively dried through repeated flushing with dry breathing air, contribution to water concentration from the bottles became negligible; those breathing air samples were then able to meet the water vapor concentration specification in the statute.

EHL examined a commercial breathing air test kit and found that the kit's sample container leaked. When a leak-free sample container containing room air with a water concentration of approximately 30,000 ppm was submitted to the commercial lab associated with the kit for testing, water vapor concentration passed the 24 ppm specification. Inappropriate laboratory methodology was likely the cause of this erroneous result.

Most submissions of breathing air samples to the EHL pass the water vapor specification (solid line in Figure 1). The dashed line represents the standard with the NFPA measurement tolerance added; values to the left of this line would pass. The highest values were obtained from samples knowingly submitted in wet bottles.

Gases in Firefighter Air

Seldom are any regulated gases found to be over the regulatory limit in a properly maintained breathing air generation system. During 2009–2010 no samples of breathing air had gas contaminants above regulatory limits (Figure 2). Oxygen in submitted samples has always been within regulatory limits.

Gases in Diving Air

Carbon dioxide and carbon monoxide each had a failure rate of 1% in tested breathing air samples (Figure 3). The majority of breathing air samples from commercial diving came from air compressors powered by an engine, exhaust from which was likely the cause of elevated values. Oxygen in submitted samples has only failed when elevated levels are present in oxygen enriched gas mixtures such as Nitrox.

Odor in Firefighter Air

One percent of firefighting samples tested failed due to a pronounced odor (Figure 4). Ten percent had a slight odor, which was typically described as stale.

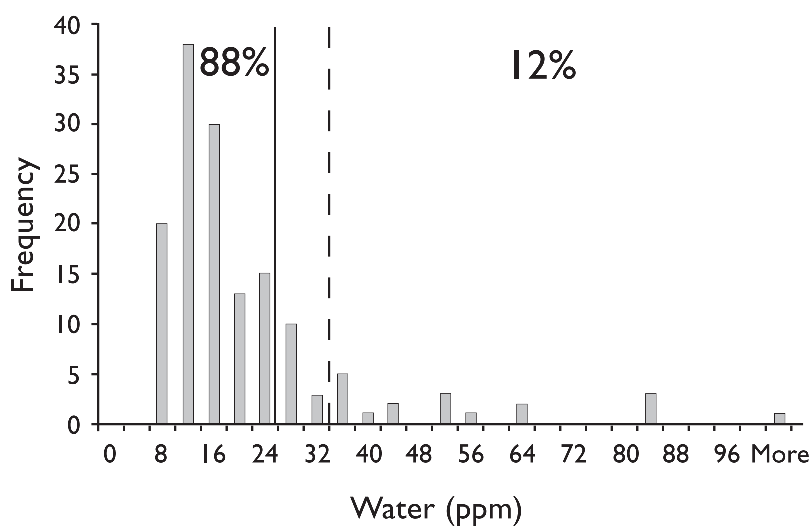

Figure 1. Water vapor results, 2009-2010 SCBA

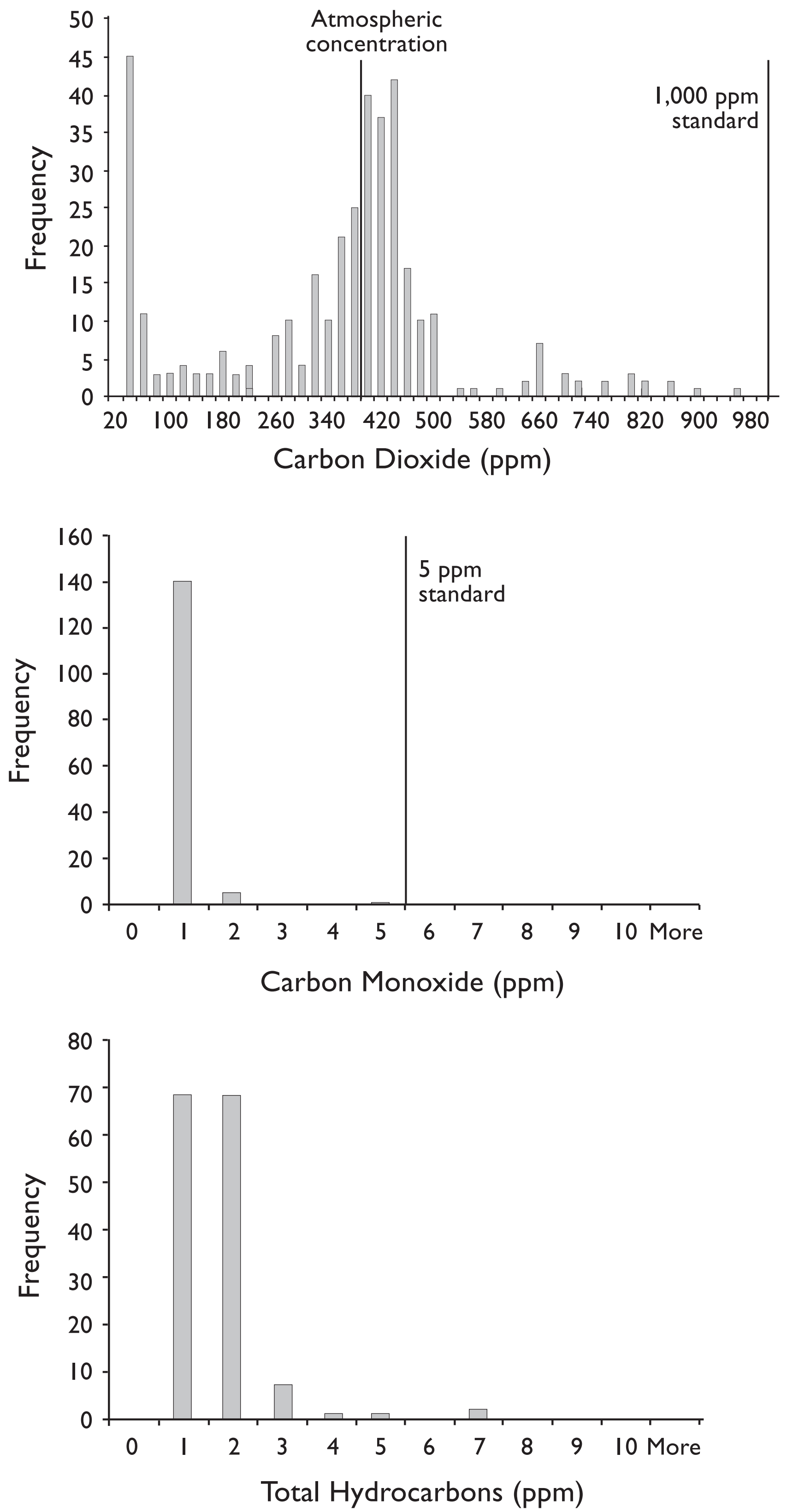

Figure 2. Gas analyses, 2009–2010 SCBA

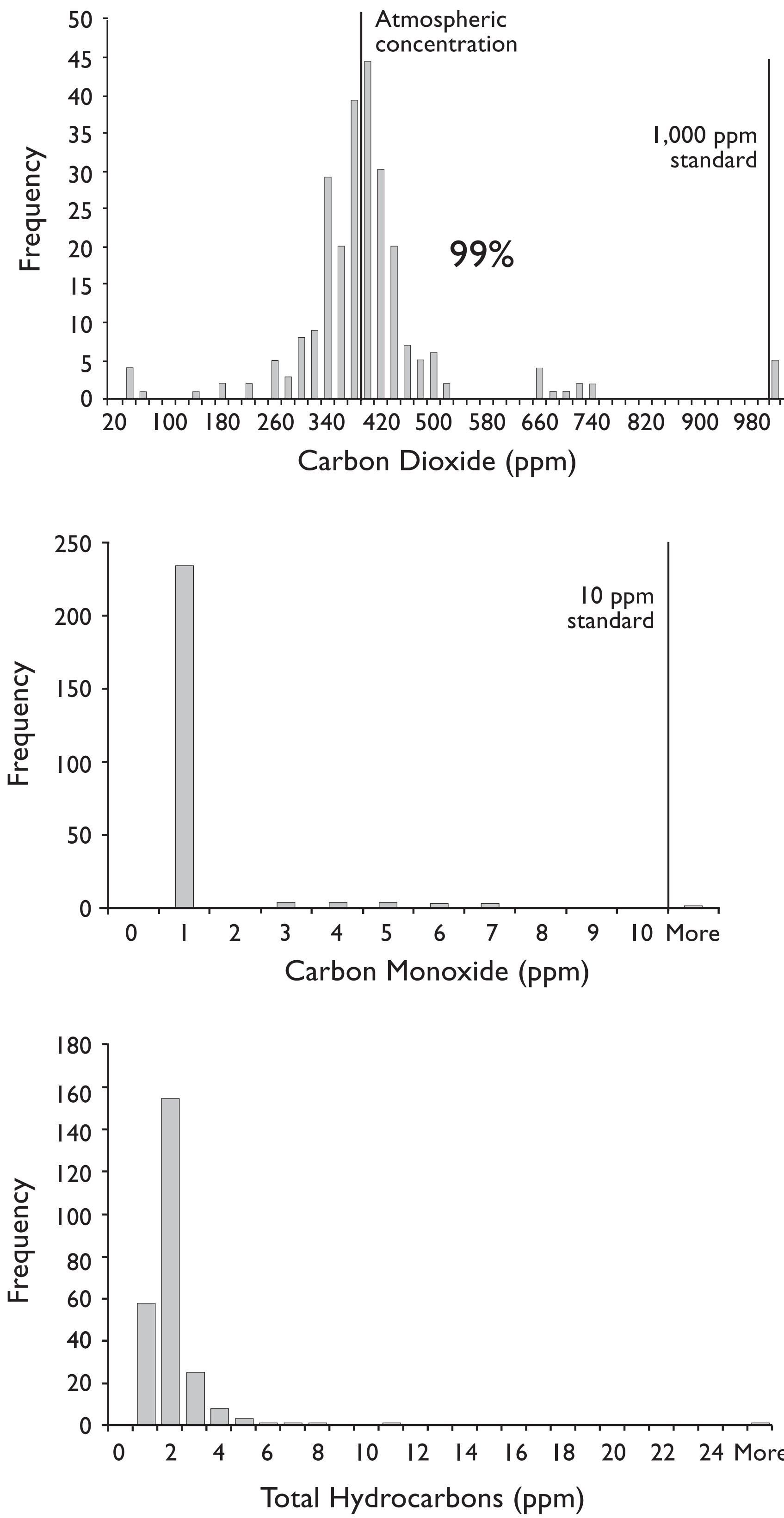

Figure 3. Gas analyses, 2009–2010 Diving

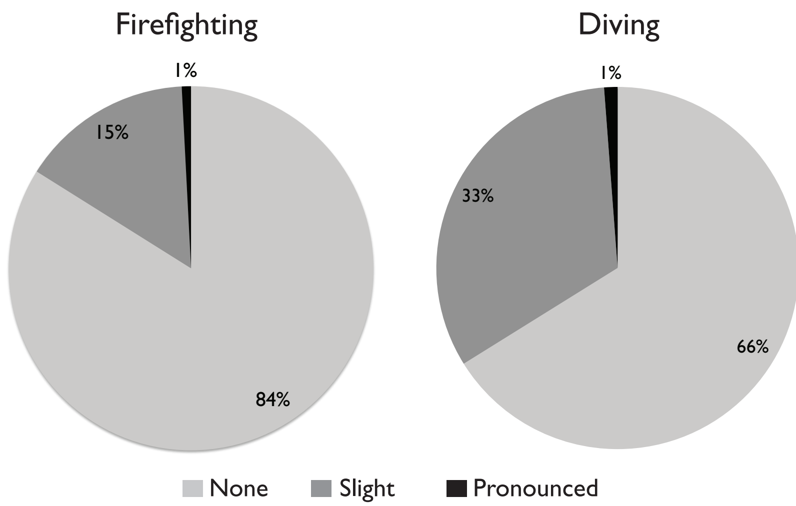

Figure 4. Odor results, 2009–2010

Odor in Diving Air

One percent of diving samples failed due to a pronounced odor (Figure 4). The odors were described as musty, vegetable, rubber, exhaust, and moldy. Thirty-three percent of the diving 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 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. Aluminum and fluorocarbon plastics such as Teflon do not perform as well as stainless steel, and glass is one of the worst materials for water contamination. Also, 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. Others have made the same observation.[1]

Regulated Components of Breathing Air

Oxygen (O_2) 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.[2] 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 perceptional 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.[3] 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.[4, 5]

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.[6, 7, 8] 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.[9] Thus, oxygen service is not compatible with standard compressed air systems.

Carbon dioxide (CO_2) is an odorless, tasteless gas produced by combustion and metabolism in cells. Atmospheric concentration is approximately 390 ppm. CO_2 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_2 retention (hypercapnia) is generally caused by excessive carbon dioxide in the breathing supply or inadequate lung ventilation in relation to exercise levels.[10] 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.[11]

The OSHA permissible exposure limit to CO is 50 ppm, averaged over an 8-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 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.) Volatile organic chemicals, such as solvents, may have anesthetic properties, generally at concentrations greater than 1%, and at lower concentrations may have significant short-term or long-term toxicity. Volatile organic compounds, with the exception of those compounds containing substantial numbers of fluorine or chlorine atoms, such as

Freon or perchlorethylene, are flammable. 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_2) 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. If breathing air is generated through compression of the atmosphere, oxygen and nitrogen ratios do not change. NFPA does not indicate why it is necessary to provide a specific acceptability range for nitrogen concentration.

Water (H_2O) 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 cold water diving, e.g., ice diving. As gas expands from the breathing air tank, it cools. If the dew point is reached, moisture will condense and then freeze when 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 OSHA permissible exposure limit is 5 mg/m^3.

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 lung. Particulate alone 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 2 provides basic information on distinguishing features of the kits and each vendor's approach to measurement of regulated components in breathing air. Our purpose was to evaluate designs and approaches and not specific vendors, because multiple vendors offer similar kits. Patents (Table 2) can be examined 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. Which components are measured depends on the laboratory and kit. Kits D-T and E are designed to make measurements of most breathing air components at the compressor site using indicator tubes. 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. 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 customer's location for this purpose.

Evaluation of usability

Potential hazards encountered during use in the laboratory and at the compressor sites are presented in Table 3. Predictions on durability and operability after exposure to oil mist and particulate are also presented in Table 3.

Each kit was field tested by personnel at three fire departments and one commercial diving company. A compilation of their opinions on the most significant and distinctive parameters is presented in Table 4.

Evaluation of sample collection

The ability of the kits to collect uncompromised samples was evaluated, with the reference for comparison being a

Table 2. 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 with Filter	Lab with Filter	Lab with Filter	Lab with Filter	Indicator tube	Indicator tube	Unknown
Moisture done by	Lab	Indicator tube	Indicator tube	Indicator tube	Indicator tube	Indicator tube	Lab
Patent	Unknown	4,014,216	Unknown	5,101,671		Unknown	7,183,115

Table 3. 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§	Indicator tube ejection‡	—	—	—	—
Damage due to operator error	Luer¶ 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 4. 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 indictor tube measurements
Kits were tested at four sites with one tester per site.

high pressure sample collected in a SCUBA bottle (Site 1) or SCBA bottle (Sites 2–5) which was then analyzed in the EHL. Samples were collected following kit instructions. Kit sample containers used at Site 5 were shipped from Yakima in eastern Washington to the EHL in Seattle to test for sample container integrity during shipping. No differences in breathing air composition were found between shipped containers and those driven directly back to the lab.

Carbon monoxide was not detected at any site, either in samples collected by kits or in the reference samples. No clear trends in deviation from reference values were seen in the samples for carbon dioxide (Figure 5) or methane (Figure 6) among the various kits.

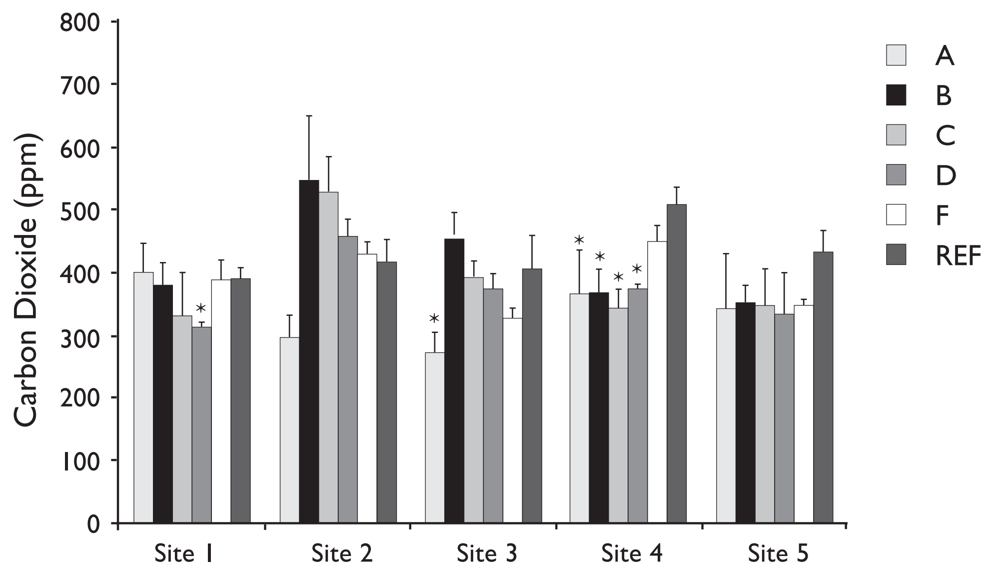

Figure 5. Evaluation of samplers for carbon dioxide measurement

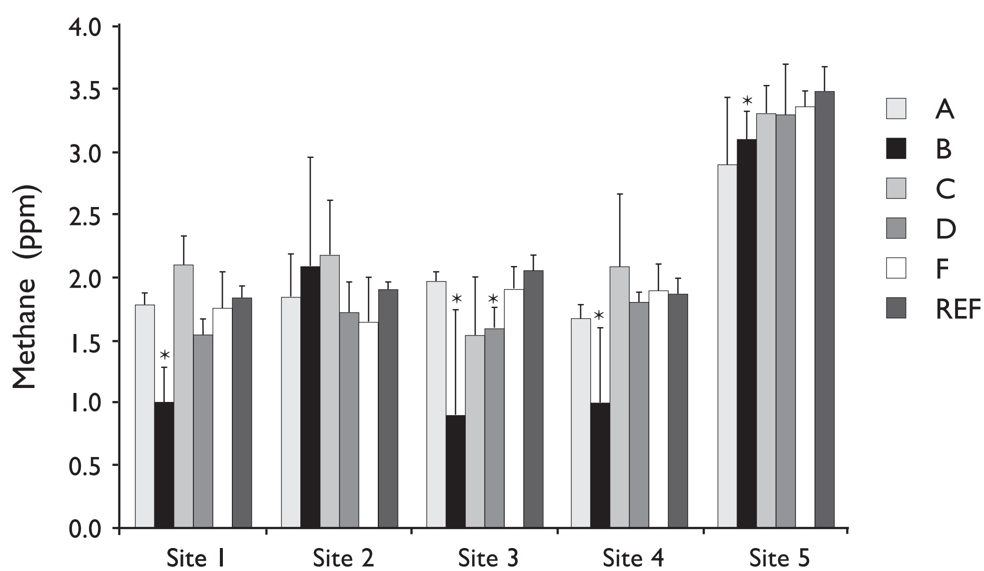

Figure 6. Evaluation of samplers for methane measurement

An asterisk in the figures indicates statistically significant deviations from reference values. The lines above the bars indicate variability.

In contrast, every air sample collected in any kit had excess water (Figure 7) compared to the reference. Only with kits A and F are collected samples analyzed for water vapor by the vendor's laboratory. The samples collected from kit A had, on average, 800 fold excess water compared to the reference value. Kit F was the better performer, with 29 fold excess water on average in the samples. 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 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 were sampled according to vendors' instructions and then submitted to the laboratory associated with the kit. Three kinds of samples were submitted: certified calibration gas mixtures, previously analyzed compressed breathing air, and room air. Calibration gas mixtures contained regulated breathing air components with the balance of the mixture being either dry air or purified nitrogen gas. 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 CGA-E standards.

Purified nitrogen gas contained very little oxygen (< 0.5%). 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, thinking this was for human use. The results from the lab associated with kit A gave close to normal oxygen levels for all samples, even those with just a very small concentration of oxygen (Figure 8). While this may be additional evidence that the kit A

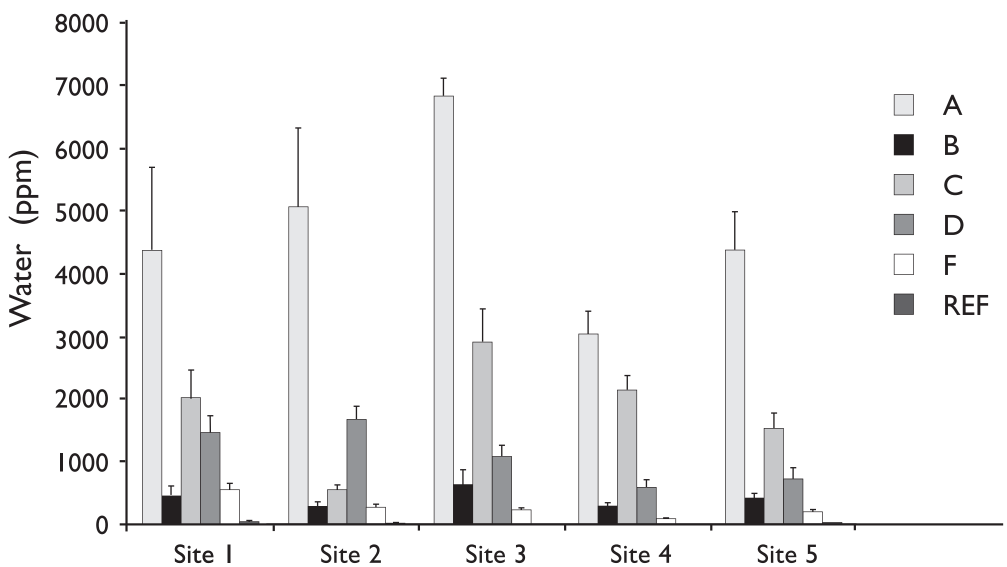

Figure 7. Evaluation of samplers for water measurement

sample container was leaking, the possibility of measurement error cannot be discounted.

Analysis of samples from kits B, C, D, and F for carbon dioxide by their respective labs showed a good correspondence between submitted sample concentration and laboratory results (Figure 9). However, results for kit A were about 550 ppm carbon dioxide for both high (1015 ppm) and low (347 ppm) concentration reference gas.

Similarly, analysis of samples from kits B, C, D, and F for carbon monoxide had a close match between reference concentrations and laboratory results (Figure 10). Results from kit A were again troubling; the results for the low reference standard matched on average the high

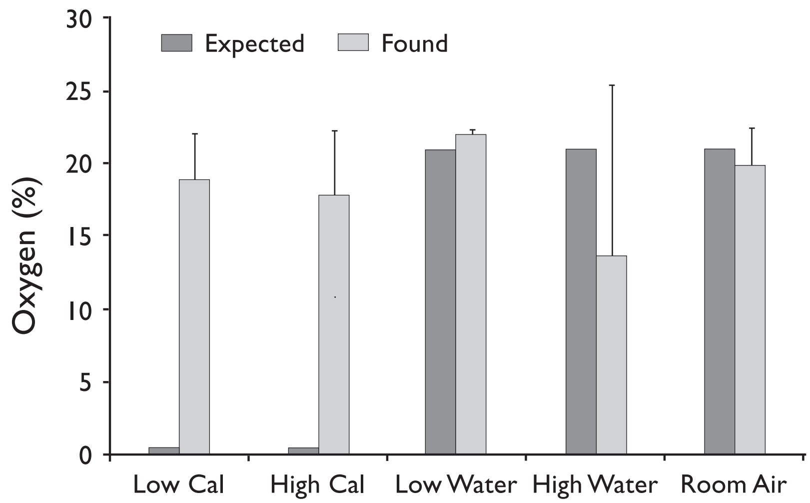

Figure 8. Kit A results for oxygen

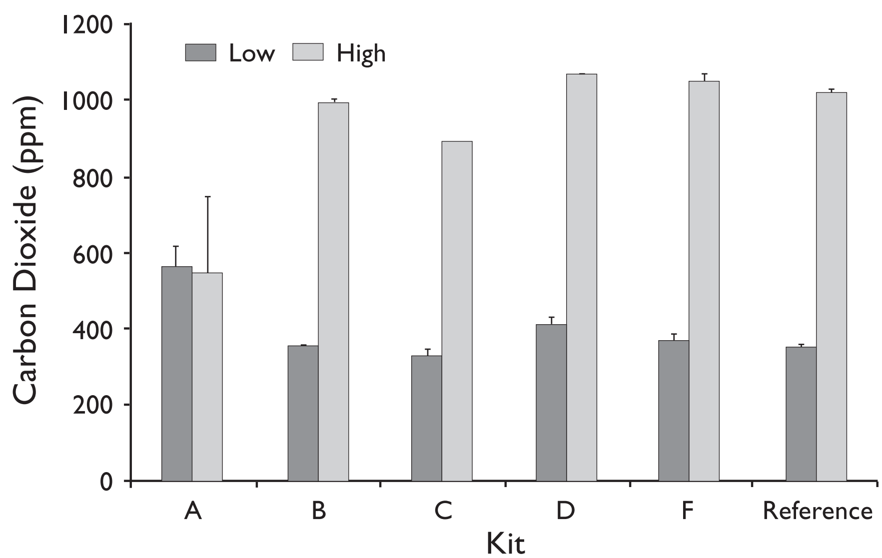

Figure 9. Laboratory results for carbon dioxide

reference standard, and carbon monoxide was reported as not detected in the high reference sample.

Methane was not part of the analysis suite for kit F. Results for kits B, C, and D closely matched the submitted reference gases (10 and 20 ppm), while kit A results were both less than 2 ppm (Figure 11).

Water was not part of the analysis for kits B, C, and D. Regardless of the submitted sample value, the results for kit A were all approximately 20 ppm (Figure 12). The same was observed for kit F (Figure 13).

General information on indicator tubes

Indicator tubes, also known as stain or detector tubes, are one approach used for measuring some, but not all,

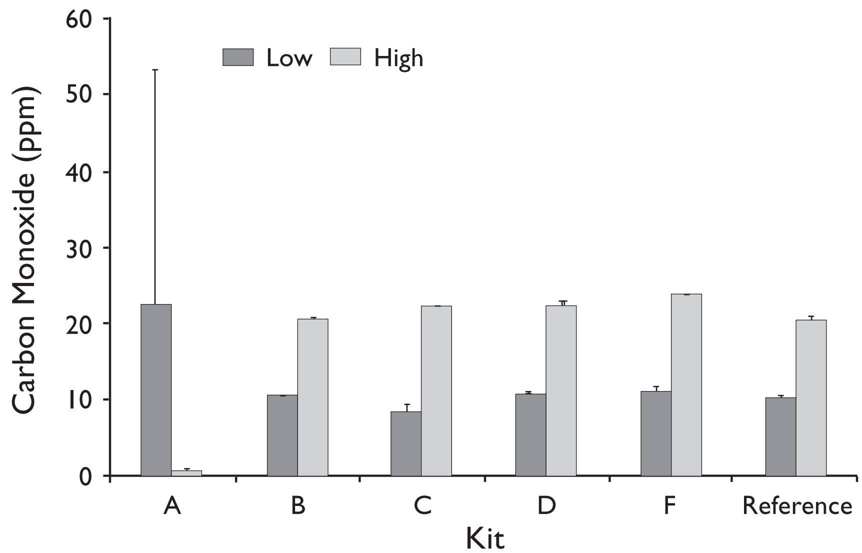

Figure 10. Laboratory results for carbon monoxide

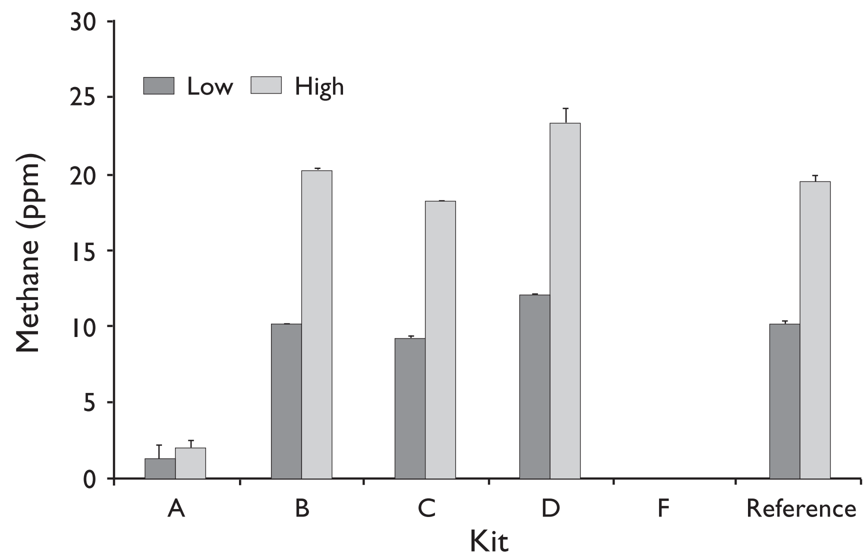

Figure 11. Laboratory results for methane

regulated components of breathing air. Carbon dioxide, 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.

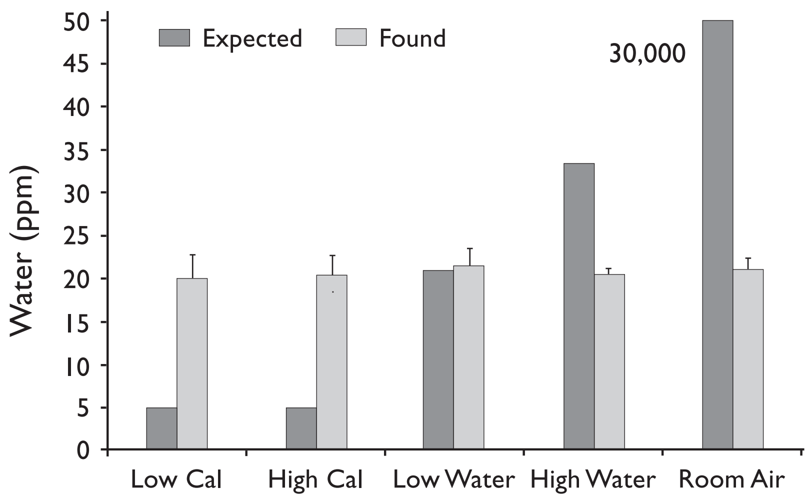

Figure 12. Kit A results for water

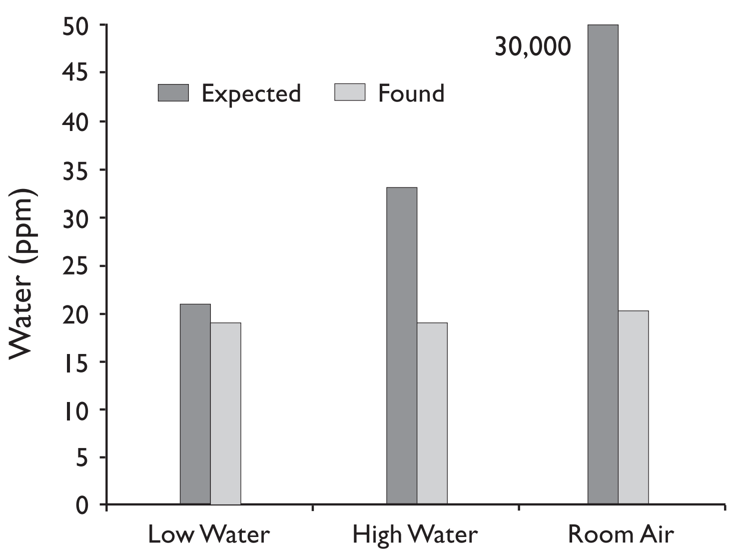

Figure 13. Kit F results for water

Departure from those rates means that values from the scale on the tube cannot be directly used. The scales are not linear, because stain length is proportional to the logarithm of the product of gas concentration and sample volume.[12]

Substituting one brand of detector tube for another is not recommended, because differing flow characteristics in different brands will cause errors.[13] 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 NIOSH when measured at values 0.5 to 5.0 times the Threshold Limit Value (TLV).[14] We could not find any studies on accuracy at the low concentrations of contaminants typically found in breathing air, even though accuracy is 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.[15] Figure 14 shows how to read tubes when the stain front is not perpendicular to the tube.

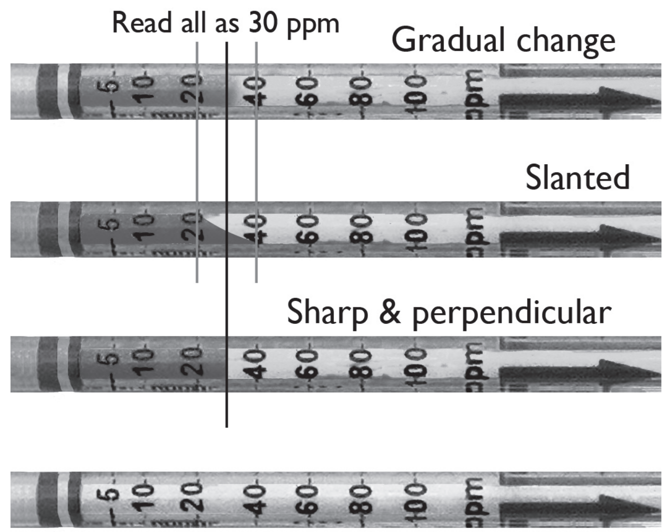

Figure 14. Reading indicator tubes

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.

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 using tubes usually require that the duration of flow through the tube be exactly as specified. Kit D provides data so that the correct concentrations for different flow rates can be determined. Kits B and C do not provide flow rates and the stain length is interpreted by the vendor. Flow in the tube is directly controlled in Kit E. 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 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 15). (The reference value in all cases is for samples collected at high pressure and measured in the EHL.) 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 16); 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.

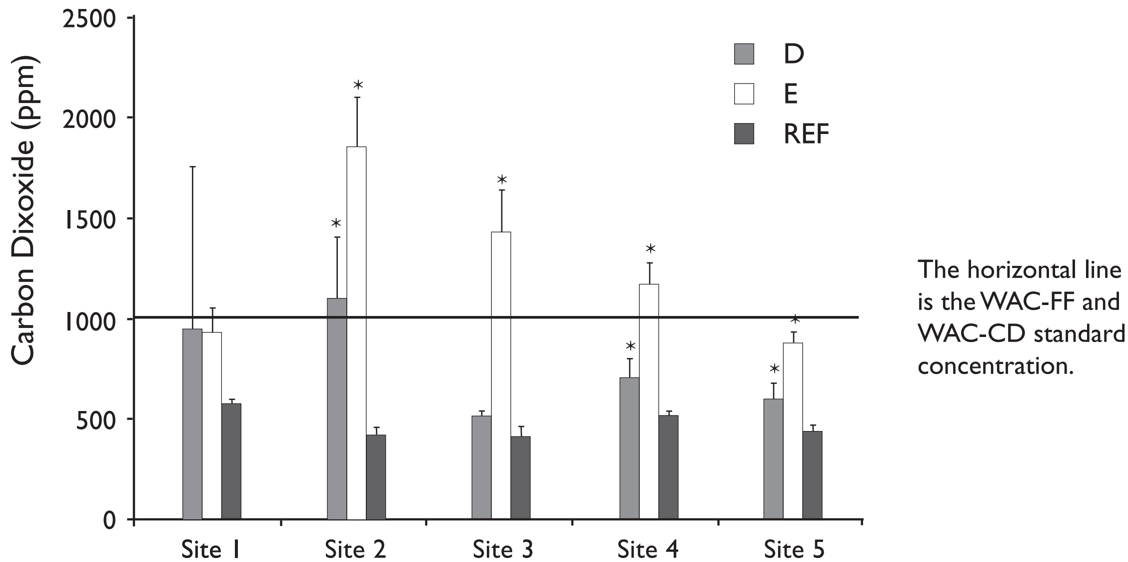

Figure 15. Evaluation of carbon dioxide testing by indicator tube

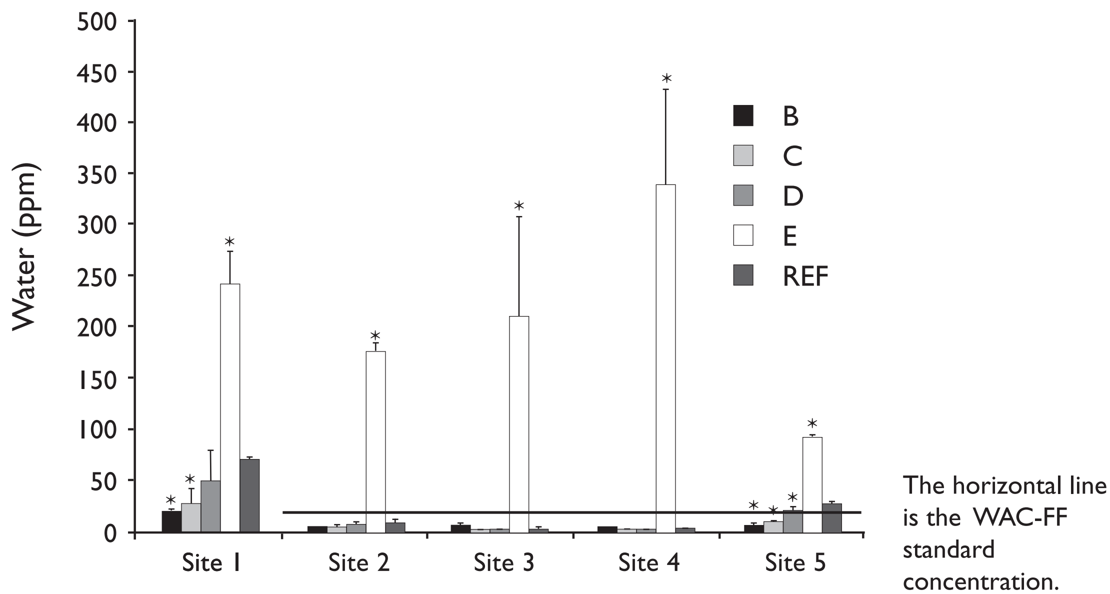

Figure 16. Evaluation of water testing by indicator tube

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:[16]

- 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; and complying with NFPA guidelines, which require the use of a lab accredited to ISO 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 AIHA. (Details on the program can be found on the AIHA website.[17]) 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 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

- Avoid kits that use laboratory analysis for water in a sample collected at less than 500 psi.
- 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 DOSH) purposes but does not meet NFPA requirements for accuracy or sensitivity.

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 source air 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.[18]
- 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_2 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.

Glossary

AAUS The American Academy of Underwater Sciences is a non-profit organization that develops standards for scientific diving. Scientific diving programs allow research diving teams to operate under the exemption from OSHA commercial diving regulations. *http://www.aaus.org*

ACGIH The American Conference of Governmental Industrial Hygienists is a non-profit, member-based organization that advances occupational and environmental health. They produce annual editions of the Threshold Limit Values and Biological Exposure Indexes. *http://www.acgih.org*

AHIA The American Industrial Hygiene Association is a non-profit organization serving the needs of occupational and environmental health and safety professionals and operating several highly recognized laboratory accreditation programs based on the highest international standards. *http://www.aiha.org*

ANSI The American National Standards Institute is a private non-profit organization that administers and coordinates a voluntary consensus standardization system in the United States. *http://www.ansi.org*

BEI Biological Exposure Indices were developed by ACGIH as guidelines to assist in the control of health hazards. BEIs represent a biological measure that relates to an exposure without adverse health effects. BEIs represent conditions to which ACGIH believes that nearly all workers may be repeatedly exposed without adverse health effects.

CAPT Compressed Air Proficiency Testing is a program under AIHA to certify proficiency in testing of breathing air. Participant laboratories test the same set of air samples to demonstrate that accurate analytical results can be generated by independent analysts following their own documented procedures. CAPT is open to participation by all analytical laboratories.

CFR The Code of Federal Regulations is the codification of the general and permanent rules published in the Federal Register by the executive departments and agencies of the Federal Government. *http://www.gpoaccess.gov/cfr*

CGA The Compressed Gas Association is a trade association that develops and promotes safety standards and safe practices in the industrial gas industry. These standards are often cited by agencies regulating safety. *http://www.cganet.com*

DOSH The Division of Occupational Safety and Health in the Washington State Department of Labor and Industries administers requirements under WISHA. *http://www.lni.wa.gov/safety*

EHL The Environmental Health Laboratory, a service group in the Department of Environmental and Occupational Health Sciences, School of Public Health, University of Washington, provides no-cost industrial hygiene analytical chemistry services to employers and employees in the state of Washington. *http://depts.washington.edu/ehlab*

FOT Fields of Testing refers to techniques for which specific accreditation is allowed.

IEC The International Electrotechnical Commission is the international standards and conformity assessment body for all fields of electrical, electronic, and related technologies. *http://www.iec.ch/*

ISO The International Organization for Standardization is a voluntary non-governmental organization whose members are recognized standard authorities, each representing a single country. The American National Standards Institute (ANSI) is the United States representative to ISO. *http://www.iso.org*

NFPA The National Fire Protection Association is a non-profit organization that creates and advocates consensus codes and standards for fire safety and provides research, training, and education. *http://www.nfpa.org*

NIOSH The National Institute of Occupational Safety and Health is a federal agency that conducts research on improving the health and safety of workers. *http://www.cdc.gov/niosh*

OSHA The Occupational Safety and Health Administration is a federal agency in the US Department of Labor established in 1970 to ensure safe and healthful working conditions by setting and enforcing standards. Regulations may be administered under an OSHA-approved state program such as WISHA. *http://www.osha.gov/*

PPM Parts per million is a measure of concentration, often in terms of a volume to volume ratio. For example, 1 milliliter of water vapor in 1,000 liters of air would have a concentration of 1 ppm.

SCBA Self-Contained Breathing Apparatus provides breathable air in hazardous atmospheres and is not dependent on a remote supply. Standards are provided by NFPA (1981, 2007 ed.) for fire and emergency services.

SCUBA A Self-Contained Breathing Underwater Apparatus provides breathable air for diving, generally using demand valve regulators. CGA-E or better air is recommended by dive organizations (AAUS Standards For Scientific Diving, 11/2006; U.S. Navy Diving Manual).

TLV The Threshold Limit Value (TLV) of a chemical is a concentration to which a worker can be exposed daily for a working lifetime without adverse health effects as determined by ACGIH. TLVs are guidelines—not regulatory levels.

WAC Washington Administrative Code. *http://apps.leg.wa.gov/wac/*

WISHA The Washington Industrial Safety and Health Act was established in 1973 to require employers to provide safe and healthful workplaces for all employees. *http://www.lni.wa.gov/safety*

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