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Standard Guide for Selecting Instruments and Methods for Measuring Air Quality In Aircraft Cabins[1]

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1. Scope

1.1 This guide covers information and guidance for the selection of instrumentation and test methods for measuring air quality in aircraft passenger cabins as well as in areas limited to flightcrew access.

1.2 This guide assumes that a list of pollutants to be measured, or analytes of interest, which are present, or may be present, in aircraft cabins is available.

1.3 This guide provides information and guidance to identify levels of concern pertaining to public and occupational exposures to relevant air pollutants. This guide does not address levels of concern, if any, related to degradation of materials or aircraft components because of the presence of air pollutants.

1.4 Based on levels of concern for public and occupational exposures for each pollutant of interest, this guide provides recommendations for developing three aspects of data quality objectives (*a*) detection limit; (*b*) precision; and (*c*) bias.

1.5 This guide summarizes information on technologies for measurement of different groups or classes of air pollutants to provide a basis for selection of instruments and methods. The guide also identifies information resources on types of available measurement systems.

1.6 This guide provides general recommendations for selection of instruments and methods. These recommendations are based on concepts associated with data quality objectives discussed in this guide and the information on available instruments and methods summarized in this guide.

1.7 This guide is specific to chemical contaminants and does not address bioaerosols, which may be present in the cabin environment.

1.8 This guide does not provide details on use or operation of instruments or methods for the measurement of cabin air quality.

1.9 This guide does not provide information on the design of a monitoring strategy, including issues such as frequency of measurement or placement of samplers.

1.10 Users of this guide should be familiar with, or have access to, individuals who have a background in (*a*) use of instruments and methods for measurement of air pollutants and (*b*) principles of toxicology and health-effects of environmental exposure to air pollutants.

1.11 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1356 Terminology Relating to Sampling and Analysis of Atmospheres[2]

D 1914 Practice for Conversion Units and Factors Relating to Atmospheric Analysis[2]

D 3162 Test Method for Carbon Monoxide in the Atmosphere (Continuous Measurement by Nondispersive Infrared Spectrometry)[2]

D 3631 Test Methods for Measuring Atmospheric Pressure[2]

D 4023 Terminology Relating to Humidity Measurements[2]

D 4490 Practice for Measuring the Concentration of Toxic Gases or Vapors Using Detector Tubes[2]

D 4861 Practice for Sampling and Selection of Analytical Techniques for Pesticides and Polychlorinated Biphenyls in Air[2]

D 5149 Test Method for Ozone in the Atmosphere: Continuous Measurement by Ethylene Chemiluminescence[2]

D 5156 Test Methods for Continuous Measurement of Ozone in Ambient, Workplace, and Indoor Atmospheres (Ultraviolet Absorption)[2]

D 5197 Test Method for Determination of Formaldehyde and Other Carbonyl Compounds in Air (Active Sampler Methodology)[2]

D 5466 Test Method for Determination of Volatile Organic Chemicals in Atmospheres (Canister Sampling Methodology)[2]

D 6196 Practice for Selection of Sorbents and Pumped

[1] This standard is under the jurisdiction of Committee D-22 on Sampling and Analysis of Atmospheres and is the direct responsibility of D22.05 on Indoor Air.

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[2] *Annual Book of ASTM Standards*, Vol 11.03.

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Sampling/Thermal Desorption Analysis Procedures for Volatile Organic Compounds in Air[2]

D 6245 Guide for Using Indoor Carbon Dioxide Concentrations to Evaluate Indoor Air Quality and Ventilation[2]

2.2 *Other Standards:*

14 CFR 25 Airworthiness Standards

29 CFR 1910.1450 Occupational Exposure to Hazardous Chemicals in Laboratories

40 CFR 50 National Ambient Air Quality Standards

40 CFR 53 Ambient Air Monitoring Reference and Equivalent Methods

40 CFR 60 Standards of Performance for New Stationary Sources—Appendix A: Test Methods

RTCA/DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide, refer to Terminology D 1356.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *analyte*, *n*—designated chemical species to be measured by a monitor or to be identified and quantitated by an analyzer.

3.2.2 *bioaerosol*, *n*—airborne material of biological origin, including viable microorganisms, pollens, spores, bacteria, viruses, allergens, and biological debris.

3.2.3 *ceiling limit*, *n*—a maximum allowable air concentration, established by the Occupational Safety and Health Administration (OSHA), that must not be exceeded during any part of the workday.

3.2.4 *concentration range*, *n*—a semiquantitative term referring to the extreme uppermost portion of the distribution of anticipated measurements. This term (and the dose or risk analogues) traditionally refers to the portion of the distribution that conceptually falls above about the 98th percentile of the distribution, but is not higher than the highest individual measurement.

3.2.5 *data quality objectives (DQOs)*, *n*—qualitative and quantitative statements of the overall level of uncertainty that a decision-maker is willing to accept in results or decisions derived from environmental data. Minimum DQOs include method detection limit, precision, and bias.

3.2.6 *level of concern*, *n*—an exposure level or concentration that is not to be exceeded by regulation or, for unregulated pollutants, an exposure level or concentration that is believed to be associated with odor, sensory irritation, and other adverse health or toxic effects.

3.2.7 *lowest-observed-adverse-effect level (LOAEL)*, *n*—the lowest exposure at which there is a significant increase in an observable effect.

3.2.8 *no-observed-adverse-effect level (NOAEL)*, *n*—the highest exposure among all the available experimental studies at which no adverse health or toxic effect is observed.

3.2.9 *overall uncertainty (OU)*, *n*—quantity used to characterize, as a whole, the statistical uncertainty of a measurement result compared to a true or accepted value. The overall uncertainty is expressed as a percentage that combines bias and precision. At the 99 % (3σ) statistical confidence level, the overall uncertainty may be calculated using the following formula:

$$OU = \frac{|\bar{X} - X_{ref}| + 3\sigma}{X_{ref}} \times 100 \quad (1)$$

where:

$\bar{X}$ = mean value of results of a number (n) of repeated measurements,

X_{ref} = true or accepted reference value of measurement result, and

σ = standard deviation of a number (n) of repeated measurements.

3.2.10 *permissible exposure limit (PEL)*, *n*—the OSHA-mandated time-weighted-average (TWA) concentration of a chemical in air that must not be exceeded during any 8-h workshift or 40-h work week.

3.2.11 *safety factor*, *n*—a dimensionless number, greater than unity, to account for incomplete understanding of errors encountered in extrapolating exposure or health effects derived for one set of conditions or basis to another.

3.2.12 *spacecraft maximum allowable concentrations (SMACs)*, *n*—developed by the National Aeronautics and Space Administration and the Committee on Toxicology from the National Research Council, based on exposure duration of 1 h to 180 days.

3.2.13 *short-term-exposure limit (STEL)*, *n*—American Conference of Governmental Industrial Hygienists (ACGIH)-recommended 15-min TWA air concentration for a chemical which should not be exceeded at any time during a workday, even if the 8-h TWA concentration is within the threshold limit value (TLV).

3.2.14 *threshold limit value (TLV)*, *n*—ACGIH-recommended TWA air concentration of a chemical for a normal 8-h workday and a 40-h workweek, to which nearly all workers may be repeatedly exposed without adverse effects.

4. Summary of Guide

4.1 This guide provides procedures and recommendations for the selection of test methods and equipment suited to measuring air quality in aircraft cabins.

4.2 Major steps in the selection process include identifying one or more levels of concern for each analyte to be monitored, selecting the most appropriate level of concern for each analyte, defining minimum data quality objectives that are compatible with the level of concern, defining desirable operating characteristics that are compatible with the aircraft cabin environment, and selecting instruments and test methods that meet these objectives.

5. Significance and Use

5.1 This guide may be used to identify instruments and methods for measuring air quality in aircraft cabins. Such measurements may be undertaken to:

5.1.1 Conduct monitoring surveys to characterize the aircraft cabin environment and to assess environmental conditions. Results of such measurements could then be compared with relevant standards or guidelines for assessment of health and comfort of passengers and flight attendants.

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5.1.2 Investigate passenger and flight attendant complaints; or

5.1.3 Measure and compare the performance of new materials and systems for the aircraft cabin environment.

6. Identify and Select Levels of Concern

6.1 Identification and selection of the level of concern for each analyte of interest is the most important basis for defining data quality objectives. The level of concern for each analyte is defined from review of applicable regulations, standards, and guidelines using procedures described below in 6.2 and 6.3.

6.2 Use the following sources to compile levels of concerns for each analyte[3] identified for monitoring:

6.2.1 FAA Airworthiness Standards (14 CFR 21), which specify acceptable exposure levels for ozone, carbon dioxide, carbon monoxide, and cabin pressure that explicitly apply to the aircraft cabin environment;

6.2.2 Spacecraft Maximum Allowable Concentrations (SMACs), which have been defined for chemicals under exposure conditions ranging from 1 h to 180 days for the space program;

6.2.3 The Clean Air Act (40 CFR Part 50), which specifies acceptable limits for general population exposure to criteria pollutants (ozone, carbon monoxide, oxides of nitrogen, sulfur dioxide, particulate matter, and lead), and also regulates population exposure to emissions of nearly 200 hazardous air pollutants;

6.2.4 The Occupational Safety and Health Act of 1970 (29 CFR 1910), which establishes PELs and ceiling concentrations to protect workers against the health effects of exposure to approximately 200 hazardous substances;

6.2.5 ACGIH Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Values, which gives TLVs and STELs to define acceptable limits for workplace exposure.

6.2.6 AIHA *Odor Thresholds for Chemicals with Established Occupational Health Standards* is a peer-reviewed document that contains odor thresholds for a wide variety of chemicals.

6.2.7 For analytes not covered by items 6.2.1-6.2.6, specialized databases may be consulted to develop levels of concern. Such resources include the Agency for Toxic Substances and Disease Registry (ATSDR), the Health Effects Assessment Summary Tables (HEAST), the Integrated Risk Information System (IRIS), and the Registry of Toxic Effects of Chemical Substances (RTECS) **(1)**[4]. Interpretation of these information resources requires input from a qualified toxicologist.

6.2.8 Table 1 gives an example of compilation of levels of concern for selected contaminants.

6.3 Use the following approach to prioritize and select levels of concern for each analyte[5] identified from the above sources of data:

6.3.1 Since regulations applicable to the aircraft cabin environment are developed based on the knowledge and data specific to that environment, give the highest priority to levels of concern that are part of such regulations (for example, FAA Airworthiness Standards). Similarly, available consensus-developed guidelines for cabin air quality should be also given high priority because these are developed considering the effects of air pollutants on passengers and flight attendants in the aircraft cabin environment.

6.3.2 Guidelines developed for the spacecraft environment such as the SMACs developed for long-term exposures, such as the 180-day exposure period, should be considered at the next level of priority. The 180-day SMACs are based on health-effect considerations over such extended periods of time and are applicable to astronauts. These are considered as the next best alternative to cabin air quality standards or guidelines for passengers and flight attendants because the relative susceptibility of passengers (that is, general public) as compared to astronauts (that is, healthy worker population) is balanced against the duration of exposure (that is, 180-day continuous exposure for astronauts versus intermittent exposure over much shorter periods of time for passengers or even flight attendants).

6.3.3 The next level of priority is for environmental standards such as ambient air quality standards that are developed considering health effects of exposures to air contaminants by the public.

6.3.4 The next level of priority is for standards or guidelines for occupational exposures. It should be pointed out that, while the aircraft cabin environment includes exposure of the general public (passengers) and occupational exposure (flight attendants) in the same airspace, the limits of exposure for the public should be used, as those are more stringent. The reason for stringency is that the public includes segments of more susceptible populations such as children, as compared to healthy workers that are included in considerations for occupational exposures.

6.3.5 If a workplace standard is the only basis for defining a level of concern associated with passenger exposure, then a safety factor should be considered to account for uncertainties. Sources of uncertainty include (*a*) extrapolating toxicological data from controlled animal testing to estimated health effects in humans, (*b*) extrapolating lowest-observed-adverse-effect levels (LOAEL) to a no-observed-adverse-effect level (NOAEL), and (*c*) variations in individual responses. Regulatory agencies usually require safety factor values of 10, 100, or 1000 in different situations. If the NOAEL has been derived from high-quality data in humans, then a factor less than 10 may be appropriate provided test conditions are similar to conditions under investigation. If the NOAEL is derived from

[3] Preparing a list of analytes of interest, if not available, requires considerable effort such as review of results of past studies on cabin air quality, assessment of sources of air contaminants, and consultation with toxicologists and health effects specialists (for example, physicians and epidemiologists) to assess potential causes of suspected or actual health effects or symptoms. As stated in the scope, the development of a list of analytes is not within the scope of this guide.

[4] The bold face numbers in parentheses refer to the list of references at the end of this standard.

[5] Although the approach given here is for individual analytes, as the understanding of health effects and the technology for instrumentation improve in the future, consideration may also need to be given to contaminants acting in toxicological groups.

TABLE 1 Compilation Table of Levels of Concern for Various Air Pollutants and Parameters

Parameters Measured	Level of Concern	Comment
CO_2	30 000 ppmv	ACGIH STEL[A]
	30 000 ppmv	FAA Airworthiness Standards (Title 14 CFR 25)
	13 000 ppmv	1-24 h to SMACs[B]
	7 000 ppmv	7-180 d SMACs[B]
	5 000 ppmv	ACGIH TLV[A], OSHA PEL (Title 29 CFR 1910)
	1 000 ppmv	Guide 6245
CO	50 ppmv	OSHA PEL (Title 29 CFR 1910)
	35 ppmv	1-h NAAQS (Title 40 CFR 50)
	25 ppmv	ACGIH TWA[A]
	9 ppmv	8-h NAAQS (Title 40 CFR 50)
O_2	20.95 % at 2.4 km (8000 ft) cabin altitude equivalent to partial pressure of 16 kPa	FAA Airworthiness Standards (Title 14 CFR 25)
O_3	0.25 ppmv	FAA Airworthiness Standards (Title 14 CFR 25)
	0.1 ppmv	FAA Airworthiness Standards
	0.12 ppmv	1-h NAAQS (Title 40 CFR 50)
	0.1 ppmv	OSHA PEL (Title 29 CFR 1910)
	0.08 ppmv	8-h NAAQS (Title 40 CFR 50)
Particulate matter		
PM_{10}	150 μg m^{-3}	24-h NAAQS (Title 40 CFR 50)
	50 μg m^{-3}	Annual NAAQS (Title 40 CFR 50)
$PM_{2.5}$	65 μg m^{-3}	24-h NAAQS (Title 40 CFR 50)
	15 μg m^{-3}	Annual NAAQS (Title 40 CFR 50)
Organic compounds	Chemical-specific	
	~1-100 ppmv	OSHA PEL (Title 29 CFR 1910)
	to < 0.01 ppmv	SMACs[B]
	to < 0.01 ppmv	ATSDR[C]
	to < 0.01 ppmv	AIHA odor thresholds[D]
Cabin air pressure		FAA Airworthiness Standards (Title 14 CFR 25)
	75.1 kPa	2.4 km pressure altitude
	37.6 kPa	7.6 km pressure altitude

[A]Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure, American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 1997.

[B]Spacecraft Maximum Allowable Concentrations for Selected Airborne Contaminants. Vols. 1-3, Committee on Toxicology, National Research Council, National Academy of Sciences, Washington, DC, 1994-96.

[C]Agency for Toxic Substances and Disease Registry (ATSDR), Minimal Risk Levels for Hazardous Substances, U.S. Public Health Service, Atlanta, GA. 1997.

[D]Odor Thresholds for Chemicals with Established Occupational Health Standards, American Industrial Hygiene Assoc., 1993.

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less similar or less reliable studies, then a factor such as 100 or 1000 may be required **(2)**. The selection and use of a safety factor should be done by a qualified toxicologist or health-effects specialist and the scientific rationale for the selected safety factor(s) must be documented.

6.4 Table 2 illustrates levels of concern selected based on the above approach.

7. Define Minimum Data Quality Objectives

7.1 For each analyte, specify minimum data quality objectives in terms of concentration range, method detection limit, precision, and bias.

7.1.1 Specify an upper limit of the concentration range that is at least twice the level of concern.

7.1.2 Specify the precision and bias necessary to achieve acceptable statistical confidence when comparing a measured value with the level of concern. The 99 % confidence level is commonly used as a basis for comparison. For example, given a level of concern of 100 ppmv and considering a measurement system having 10 % precision, the 99 % confidence interval (that is, 3 standard deviations) extends from 70 ppmv to 130 ppmv. Thus, a measured value of 69 ppmv would be interpreted with 99 % confidence as being below the level of concern. On the other hand, a value of 71 ppmv would be interpreted with 99 % confidence as being indistinguishable from the level of concern.

7.1.3 Specify the method detection limit such that the level of concern minus the overall uncertainty is at least a factor of ten greater than the method detection limit:

$$MDL \leq \frac{LOC \times (1 - OU)}{10} \quad (2)$$

where:

MDL = method detection limit;
LOC = level of concern;
OU = overall uncertainty (Eq 1)

TABLE 2 Levels of Concern Selected for Various Pollutants and Parameters

Parameters Measured	Level of Concern	Comment
CO_2	7 000 ppmv	upper
	1 000 ppmv	lower
CO	35 ppmv	upper
	9 ppmv	lower
O_2	20.9 % at 7.6 km altitude or 8 kPa partial pressure	upper
	20.9 % at 2.4 km altitude or 6 kPa partial pressure	lower
O_3	0.25 ppmv	upper
	0.08 ppmv	lower
PM_{10}	150 µg m^{-3}	upper
	50 µg m^{-3}	lower
$PM_{2.5}$	65 µg m^{-3}	upper
	15 µg m^{-3}	lower
Organic compounds	Chemical-specific	
	~100 ppmv	upper
	< 0.01 ppmv	lower
Cabin air pressure	101.3 kPa	upper
	37.6 kPa	lower

Given a level of concern at 100 ppmv and precision and bias objectives of ± 10 %, for example, the lower limit of the level of concern minus the overall uncertainty would be at 60 ppmv, and the method detection limit should be no larger than about 6 ppmv.

7.1.4 When considering multiple levels of concern for a particular analyte (as could occur when interest is focused on odor threshold effects as well as compliance with regulatory criteria), use the smaller value to define the MDL, and use the larger value to define the upper limit of the concentration range.

8. Define Desirable Operating Characteristics

8.1 Define desirable operating characteristics for equipment based on practical details of the monitoring objectives as well as the level of experience, resources, and facilities available to the performing organization. Consider the following factors in making final decisions regarding selection of instrumentation and methods:

8.1.1 Mode–active (requiring a pump or aspirator to convey sample) or passive (relying on diffusion),

8.1.2 Output–continuous, point-in-time, or time-weighted average,

8.1.3 Record–electronic signal, field observation, or laboratory report,

8.1.4 Mobility–handheld (< 1kg), portable (< 5kg), or stationary (>5kg),

8.1.5 Power–battery, standard alternating current, or mechanical,

8.1.6 Calibration–standard atmospheres, co-located references, laboratory procedures or factory procedures, or both, and

8.1.7 Ancillary Data–temperature, relative humidity, and air pressure may be required to adjust data to a common basis (for example, sea-level equivalent).

8.2 All electronic equipment operated in the aircraft cabin must be certified for electromagnetic compatibility with avionic systems (see, for example, RTCA/DO-160).

8.3 Instrumentation selected for aircraft cabin monitoring must be sufficiently stable to allow for acceptable operation for 8 or more h. Calibrations and zero/span checks may be conducted in a ground facility before and after a flight. Calibrations generally are not performed aboard the aircraft because the use of pressurized gases and the handling of toxic materials is prohibited in the aircraft cabin.

8.4 All electronic equipment taken aboard the aircraft must be sufficiently stable to be turned off during ascent and descent without loss of calibration.

8.5 At a minimum, cabin pressure should be monitored to permit correcting data for reduced air density at altitude. Special equipment and procedures may be required to verify correction factors for some technologies. It should be noted that simple pressure-altitude corrections are not sufficient since monitoring technologies such as non-dispersive infra red (NDIR) have a systematic error caused by pressure differences which need to be addressed.

9. Select Instruments and Test Methods

9.1 For each analyte, identify available instruments and test methods using data quality objectives and operating characteristics, as described below.

9.2 For commonly monitored pollutants, select from the technologies listed in Tables 3-11 which give examples of technologies for each pollutant or pollutant group. These tables include a wide range of technologies to give readers a feel for what is available. Several of these technologies are appropriate for use in measuring cabin air quality. Those that are clearly not appropriate are so indicated in these tables. A set of recommendations are offered in a later section.

9.3 For analytes not covered by Tables 3-11, consult ASTM standard test methods as well as compilations published by organizations such as USEPA **(3, 4)**, NIOSH **(5)**, and other publications **(6, 7, 8, 9, 10)** to identify instruments and test methods.

9.4 If available equipment does not meet one or more data quality objectives, then select technologies of lesser capabilities provided that changes to the affected data quality objectives do not increase statistical uncertainty to unacceptable levels.

9.4.1 It should be recognized that relationships defined in 7.1.2 and 7.1.3 using the level of concern to determine instrument performance represents an ideal that practical instrumentation sometimes cannot meet.

9.4.2 Less-than-ideal performance can be accommodated by accepting reduced statistical confidence or by reappraising measurement objectives. Given a level of concern at 100 ppmv, for example, the 99 % confidence interval for an instrument or method characterized by ±20 % precision and bias would extend from 40 ppmv to 160 ppmv while the 90 % confidence interval would extend from 66 ppmv to 134 ppmv. Such a method or instrument would be acceptable for objectives

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TABLE 3 Operating Characteristics of Instrumentation and Methods for Monitoring Aldehydes and Ketones

Technology	Guidance	Comments
Sorbent Tube – sample gases are collected using a cartridge with DNPH-coated sorbent that is returned to the laboratory for analysis of individual compounds by HPLC.	Test Method D 5197 EPA Methods[A,B] Range: 0.01-5 ppmv Bias: ± 10 % Precision: ± 10 % MDL: 0.0005 ppmv	Field apparatus is compact. Requires external pump. Requires sophisticated laboratory. O_3 at high concentrations interferes negatively. Approximate costs: <$15 per tube plus pump (~$500) and laboratory analysis ($100 to $1000).
Liquid Impingement - sample is absorbed in DNPH solution and returned to the laboratory for analysis of individual compounds by HPLC.	EPA Methods[B] Range: 0.01-5 ppmv Bias: ± 10 % Precision: ± 10 % MDL: 0.0005 ppmv	Field apparatus is compact, but requires liquid-filled impinger. Requires external pump. Requires sophisticated laboratory. O_3 at high concentrations interferes negatively. Approximate costs: ~$50 for impinger plus pump (~$500) and laboratory analysis (~ $100). Impractical for use in aircraft passenger cabins.
Colorimetric Tube - - sample gases are drawn through a chemically treated sorbent bed that changes color in the presence of a specific aldehyde or ketone; length of color stain is correlated with concentration.	Practice D 4490 Range: 0.2-100 ppmv Bias: ± 25 % Precision: - - MDL: - -	Requires external air pump (may be hand-powered). Disposable system (single use) that relies on factory calibration. Resolution is generally lower than other technologies. Separate type of tube required for each aldehyde and ketone of interest. Approximate costs: $10 per tube plus pump (~$300). Inappropriate for quantitative measurements of cabin air quality.

[A] *Compendium of Methods for the Determination of Air Pollutants in Indoor Air*, Report No. EPA/600/4-90/010. U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC, 1990.

[B] *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1988.

TABLE 4 Operating Characteristics of Instrumentation and Methods for Monitoring Carbon Dioxide

Technology	Guidance	Comments
Non-dispersive infrared (NDIR) spectrometry – absorption of infrared radiation by CO_2 in a sample cell is compared to that of a reference (CO_2-free) absorption cell	OSHA ID-172 Woebkenberg[A] Range: 20-20,000 ppmv Bias: ± 50 ppm Precision: ± 50 ppm MDL: 200 ppmv	Very specific for CO_2; portable units are available. Some units require an external pump. Approximate costs: $500 (handheld) $5 000 to $ 10 000 (portable or stationary).
Colorimetric Tube – sample gases are drawn through a chemically treated sorbent bed that changes color in the presence of CO_2; length of color stain is correlated with concentration	Practice D 4490 Range: 100-200,000 ppmv Bias: ± 25 % Precision: - - MDL: - -	Requires external air pump (may be hand-powered). Disposable system (single use) that relies on factory calibration. Resolution is generally lower than other technologies. Approximate costs: $10 per tube plus pump (~$300). Inappropriate for quantitative measurements of cabin air quality.

[A] Woebkenberg, M.L., and McCammon, C.S., "Direct-Reading Gas and Vapor Instruments." *Air Sampling Instruments,* B.S. Cohen and S.V. Hering, eds., American Conference of Governmental Industrial Hygienists, Inc., Cincinnati, OH, 1995, pp. 439-510.

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focused on determining whether or not environmental concentrations exceed the level of concern, but results may be unacceptable if objectives seek definitive statements regarding low concentrations.

9.4.3 Collecting replicate samples and averaging results can reduce statistical uncertainty associated with time-weighted-average samples.

9.5 For each monitoring technology identified as meeting data quality objectives, evaluate operating characteristics compared to desirable characteristics listed under Section 8.

9.5.1 Portable and handheld monitoring systems featuring battery-power are generally preferred over larger and heavier stationary systems that require alternating current.

9.5.2 Monitoring systems featuring continuous output are generally preferred for monitoring objectives that involve examining the impacts of short-term and episodic sources.

9.5.3 Monitoring systems designed to collect samples for subsequent analysis in the laboratory are generally preferred for monitoring objectives that involve examining time-weighted average concentrations.

9.5.4 Not withstanding the considerations given in 9.5.1-9.5.3 related to operating characteristics, the first and foremost consideration should be toward meeting the primary requirements of detection limit, precision and accuracy. Thus, a heavier or nonportable equipment that meets these requirements would be preferred to a portable, battery powered instrument that does not satisfy the primary requirements.

9.6 Evaluate appropriateness of the measurement instruments and methods for suitability of their use in commercial aircraft cabins. For example, instruments requiring continuous gas supply are not appropriate as pressurized gas cylinders are not permitted on aircraft. For conducting measurements on