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Standard Guide for Deriving Acceptable Levels of Airborne Chemical Contaminants in Aircraft Cabins Based on Health and Comfort Considerations[1]

This standard is issued under the fixed designation D7034; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide provides methodology to assist in interpreting results of air quality measurements conducted in aircraft cabins. In particular, the guide describes methodology for deriving acceptable concentrations for airborne chemical contaminants, based on health and comfort considerations.

1.2 The procedures for deriving acceptable concentrations are based on considerations of comfort and health effects, including odor and irritant effects, of individual chemical contaminants being evaluated. The guide does not provide specific benchmark or guidance values for individual chemicals to compare with results of air quality measurements.

1.3 Chemical contaminant exposures under both routine and episodic conditions for passengers and crew are considered.

1.4 This guide does not address airborne microbiological contaminants, which are also important in consideration of aircraft cabin air quality. This guide also does not address methodologies for investigations of air quality complaints.

1.5 This guide assumes that a list of chemical contaminants of potential concern has been developed based on existing concentration, emission, or material composition data.

1.6 The primary information resources for developing acceptable concentrations are databases and documents maintained or published by cognizant authorities or organizations concerned with health effects of exposure to contaminants.

1.7 Acceptable concentrations developed through this guide may be used as a basis for selecting test methods with adequate reliability and sensitivity to assess the acceptability of aircraft cabin environments.

1.8 Procedures described in this guide should be carried out in consultation with qualified toxicologists and health effects specialists to ensure that acceptable concentrations developed are consistent with the current scientific understanding and knowledge base.

1.9 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.10 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.11 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1356 Terminology Relating to Sampling and Analysis of Atmospheres

D6399 Guide for Selecting Instruments and Methods for Measuring Air Quality in Aircraft Cabins

E609 Terminology Relating to Pesticides

E943 Terminology Relating to Biological Effects and Environmental Fate

2.2 *Other Standards:*[3]

14 CFR 25 Airworthiness Standards

29 CFR 1910 Occupational Safety and Health Standards

40 CFR 50 National Ambient Air Quality Standards

[1] This guide is under the jurisdiction of ASTM Committee D22 on Air Quality and is the direct responsibility of Subcommittee D22.05 on Indoor Air.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from U.S. Government Printing Office, Superintendent of Documents, 732 N. Capitol St., NW, Washington, DC 20401-0001, http://www.access.gpo.gov.

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide, refer to Terminologies D1356, E609, and E943.

4. Summary of Guide

4.1 The purpose of this guide is to provide methodology for interpretation of air quality data obtained by measurements conducted in aircraft cabins. Acceptable concentrations developed through this guide may also be used as a basis for selecting test methods with adequate reliability and sensitivity for measuring cabin air quality.

4.2 To provide a background for assessment of cabin air quality, the guide summarizes information on the concepts of exposure, dose, and related health effects, and makes a distinction between chronic (long-term) and acute (short-term) effects.

4.3 This guide describes data sources and procedures for deriving acceptable concentrations in aircraft passenger cabins. The acceptable concentrations are based on characterization of risk of chronic and acute inhalation exposure. Risk characterization also includes an assessment of potential odor problems.

4.4 An eight-step procedure is described for deriving an acceptable level for an airborne contaminant in aircraft cabins that considers both chronic and acute effects. The steps are:

4.4.1 Select population to be considered;

4.4.2 Choose effects to be considered;

4.4.3 Develop a summary of standards/guidelines and health effects data;

4.4.4 Develop scenarios for exposure;

4.4.5 Select risk levels of concern;

4.4.6 Calculate level of concern for each selected effect;

4.4.7 Determine an acceptable concentration for aircraft cabins; and

4.4.8 Compare acceptable concentration with existing information.

4.5 Guidance also is provided on development of a report that summarizes the methodology and underlying assumptions, and describes implications of results, including limitations.

5. Significance and Use

5.1 Although cabin air quality has been measured on numerous occasions and in many studies, there is very little guidance available for interpreting such data. Guidance for identifying contaminants and associated exposure levels that would cause concern in aircraft cabins is very limited. Federal Aviation Administration (FAA) Airworthiness Standards (14 CFR 25) provide regulatory guidance that explicitly applies to the aircraft cabin environment. The FAA standards, however, define acceptable exposure limits for a limited number of chemical contaminants (ozone, carbon dioxide, and carbon monoxide). Another limitation of the FAA standards is that these are design standards only and are not operational standards; thus, once an aircraft is put in service these standards are not strictly applicable.

5.2 Measurements of aircraft cabin air quality often lead to a much larger list of volatile and semi-volatile organic chemicals of potential concern. Exposures to these chemicals, however, are largely unregulated outside of the industrial workplace.

5.3 An important feature of the aircraft cabin environment is that both passengers (public) and flight attendants (worker population) occupy it simultaneously. Therefore, workplace exposure guidelines cannot simply be extended to address exposures in aircraft cabin environment. Also, the length of flights and work shifts can vary considerably for flight attendants.

5.4 Contaminant levels of concern for the general public must account for the non-homogeneity of the population (for example, address sensitive individuals, the differences between passenger and crew activity levels, location, health status, personal microenvironment). Levels of concern associated with industrial workplace exposures typically consider a population of healthy adults exposed for 40 h per week (**1**).[4] Consequently, exposure criteria developed to protect public health typically are more stringent than those for workers.

5.4.1 Given that the aircraft cabin environment must meet the needs of passengers as well as crew, a more stringent concentration level based upon the general population would protect both.

5.4.2 Aircraft cabin air quality must be addressed both during flight and on the ground because the conditions during flight are much different than when the aircraft is on the ground.

6. Exposure and Effects

6.1 *Concepts of Exposure and Dose:*

6.1.1 Exposure is defined as human contact with a chemical or physical agent (see Terminology E943). Exposure via the inhalation route, of interest in this guide, can be expressed as the product of airborne concentration times the duration of exposure, provided that the concentration remains constant during the time period of interest. If the airborne concentration varies over time, then exposure is defined as the area under the curve (integral of all the finite or momentary concentrations) obtained when concentration values are plotted against time. Exposure is expressed as concentration multiplied by time with resultant units such as ppm-h or mg/m^3-h. The relevant exposure measure depends on the type of biological effect. Some effects, for example, allergic sensitization, may depend more on frequency of peak exposure above a certain limit than on the exposure measures described here.

6.1.2 Dose is the quantity of chemical or physical agent that enters an organism or target organ (see Terminology E609), with units such as mg. Dose also can be expressed as a rate, with mass/time units such as mg/day. The dose rate can be normalized in relation to body mass, with units such as mg/kg-day. A specific term that often is used in risk characterization is potential inhaled dose—the product of average concentration in an environment (mg/m^3) times the duration in

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

the environment (h) times the average breathing rate while in the environment (m^3/h), commonly expressed in mass units such as mg.

6.1.3 Chronic exposure generally refers to a long-term perspective such as repeated exposures or the cumulative exposure for more than 3 months.

6.1.4 Acute exposure refers to a short-term exposure to a substance occurring from a single incident or over a period less than 24 h. In the case of occupational exposures, exposure limits have been defined for certain chemicals for 8-h workday periods and short-term, 15-min periods.

6.2 *Chronic Effects:*

6.2.1 The risk of cancer, due to lifetime exposure to a contaminant, typically is calculated using the slope for the low-dose linear portion of the dose-response curve for the contaminant. For cancer, a threshold for dose-response may not be known or, if one does exist, it may be very low and cannot be reliably identified. If the slope for the low-dose linear portion of the dose-response curve for the contaminant is unknown or uncharacterized, methodologies are available in the peer-reviewed literature to approximate the dose-response curve (**2**).

6.2.2 For chronic toxic effects other than cancer, one generally accepted procedure used for evaluating health effects involves identifying the highest exposure among all experimental studies at which no toxic effect has been observed, that is, the "no observed adverse effect level" or NOAEL. The U.S. Environmental Protection Agency (USEPA) has developed chronic and non-chronic inhalation reference concentrations (RfCs) for some contaminants for comparison with the average concentration to which an individual has been exposed over a relatively long period; the sub-chronic RfCs pertain to exposures of less than 7 years (**3**). Minimum risk levels (MRLs) have been derived by the Agency for Toxic Substances and Disease Registry (ATSDR) for chronic exposure periods of 365 days and longer (**4**).

6.3 *Acute Effects:*

6.3.1 Specific guidelines available for considering acute effects of exposure to contaminants in air are quite limited. Minimum risk levels (MRLs) have been derived for acute exposures of one day to 14 days (**4**). Other guidelines such as Acute Exposure Guidelines Levels (AEGLs) developed by the National Advisory Committee Acute Exposure Guideline Levels for Hazardous Substances (NAC/AEGL Committee) are applicable only for one-time, short-term hazardous exposures during chemical emergency situations (**5**). For occupational settings, the National Institute for Occupational Safety and Health (NIOSH) develops and recommends criteria for preventing disease or hazardous conditions. NIOSH recommended exposure limits (NIOSH RELs) are expressed as a time-weighted average for up to 10 h/day during a 40-h workweek. The NIOSH RELs are also expressed as a short-term exposure limit (STEL) that should never be exceeded over a specified time—usually 15 min or as ceiling limit that should never be exceeded even instantaneously (**6**). In conjunction with recommendations from NIOSH, the Occupational Safety & Health Administration (OSHA) has promulgated permissible exposure limits (PELs) for certain chemicals that relate to an 8-h work period (**7**). The American Conference of Governmental Industrial Hygienists (ACGIH) has defined threshold limit values (TLVs) for 8-h work periods as well as STELs for 15-min work periods (**8**). Guidelines or data on irritation effects are not available in a single database and need to be gleaned from multiple databases (**2-5**).

6.4 *Odor Thresholds:*

6.4.1 Data relating to odor thresholds are available for the general population (**9**) or for workers (**10**).

6.5 *Consideration of Uncertainty Factors:*

6.5.1 To account for the known and unknown variations in the toxicological response of organisms, including the variability across species and among individuals within the same species, uncertainty factors are used. Such factors are applied by adjusting a value derived from experimental data by a multiplier or divisor that reflects the degree of uncertainty.

6.5.2 The National Research Council, NRC (**11, 12**), provides guidance on uncertainty factors. For example, an uncertainty factor of 10 is applied to NOAEL values derived from animal testing if the most sensitive species is not used in toxicological studies, if the mechanism or mode of physiologic or metabolic response is unknown, or if the data are inadequate. An uncertainty factor of 3 applies if the most appropriate species is used in laboratory studies, or if the mechanism or mode of action does not differ between humans and the species studied in the laboratory. An uncertainty factor of 1 may be applied when there is a high degree of confidence that the animal model tested is a sensitive surrogate for humans or more sensitive than humans. The magnitude of uncertainty factors can also depend on the type of effect under consideration. For example, the uncertainty factor could range from 3 for local tissue irritation to 10 or more for serious systemic effects.

6.5.3 In addition to the uncertainty factors mentioned above, additional modifying factors may be used to account for uncertainties or for known differences in toxicity among structurally similar chemicals. For further extrapolation from the reported exposure duration and chemical concentration of a toxic endpoint to an equivalent concentration for a specified period such as one hour, a time-scaling method has been used by the AEGL committee (**11**) and by California Office of Environmental Health Hazard Assessment (**13**).

6.6 *Effects of Mixture of Chemicals:*

6.6.1 There generally is a paucity of information on effects of mixtures, except for selected types of mixtures such as jet engine oil (**14**). Whenever health-effects data on mixtures are available, such data should be considered in conjunction with the toxicity of individual chemicals.

6.6.2 In the absence of health-effects information on mixtures, the effects of chemicals affecting the same target organ should be considered additive. For example, the following expression is used for deriving a combined TLV from TLVs for individual compounds (**8**).

$$\text{TLV of mixture} = 1/\{C_1/TLV_1 + C_2/TLV_2 + \ldots + C_n/TLV_n\} \quad (1)$$

where:

C_1 and TLV_1 = concentration and TLV of compound 1,

C_2 and TLV_2 = concentration and TLV of compound 2, and
C_n and TLV_n = concentration and TLV of compound *n*.

6.7 *No Health Effects Data:*

6.7.1 If some chemical has no health guideline values or toxicity data available, then guideline values for compounds of similar type and structure should be considered. However, given the uncertainty in extrapolating from other substances, steps should be considered to reduce the concentration of that compound to as low a level as possible.

6.8 *Effects of Altitude:*

6.8.1 It should be recognized that most toxicity data for chemicals are for ground-based environments and the cabin pressure regulation (14 CFR 25) is not to be less than pressure at 2438 m. Two types of effects need to be considered with respect to cabin pressures: (*1*) the reduced pressure would tend to increase the inhalation rate in persons that are not acclimatized to such pressures; and (*2*) the lower pressure could cause adverse effects or could exacerbate effect(s) of chemicals. These effects of pressure should be considered for chemicals for which such data are available.

6.8.2 There is a possibility that the flow rate of sampling pumps under reduced pressures may vary from a value pre-set and calibrated under different pressure conditions (for example, at sea-level). The manufacturer should be consulted to determine whether a specific pump type is affected, or preferably, the pumps should be calibrated under the conditions of use. Certain types of flow meters (for example, rotometers) are strongly affected by pressure differences, and should either not be used, or should be calibrated under the conditions of use. (It may also be possible to calculate the magnitude of the effect for a specific pressure and apply a correction to the reading.) Rotometers provided with certain types of pumps are for flow indication purposes only and cannot be used for accurate measurement of flow rate.

7. Procedure

7.1 *Select Population to be Considered:*

7.1.1 A first step in deriving an acceptable level for an airborne contaminant in aircraft cabins is to select the population to which such levels will apply. Two major population groups in aircraft cabins are the cabin crew and the passengers. If the selected population were the cabin crew, then occupational guidelines would be influential in determining the acceptable level. However, occupational guidelines need to take into account the atmosphere at cruise conditions rather than ground-level environments. On the other hand, if only the passenger population is of interest, then public health guidelines will have stronger influence in determining the acceptable level. Further, if a highly sensitive subset of passengers (for example, those with a pre-existing condition that may make them more sensitive to chemical exposures) is considered, then the selected level will be need to address the higher level of protection that may need to be provided for such individuals.

7.2 *Choose Effects to be Considered:*

7.2.1 One of the primary considerations in choosing the type of effect(s) is the frequency/duration of exposure. The two major types of exposures to be considered are *(1)* repeated exposures to the routine or typical cabin environment and *(2)* infrequent exposures to episodic conditions in the cabin. The first type can contribute to long-term exposure, whereas the second can result in elevated short-term exposure.

7.2.2 The types of effects to be considered include *(1)* cancer and other chronic endpoints for long-term exposure (see 6.2) and *(2)* acute effects, including exceedance of irritation/odor thresholds (see 6.3 and 6.4), for short-term exposure. While all possible effects should at least be considered, the final choice may be dictated in part by availability of appropriate data.

7.3 *Develop a Summary of Standards/Guidelines and Health Effects Data:*

7.3.1 The first step in developing a summary involves compiling standards, guidelines, and health-effects data that pertain to the contaminant under consideration, based on the type of effect(s) considered (see 7.2). Table 1 presents an example format for summarizing human regulatory standards or guidelines for chronic and sub-chronic effects. Table 2 presents a similar format for information on acute effects, including acute inhalation MRLs and immediately dangerous to life or health (IDLH) concentrations (**15**). The "Notes" column in the table can be used to record information on data sources or references or for details such as the duration of exposure on which the value is based.

7.3.2 In addition to the chronic, sub-chronic and acute guidelines, it is useful to develop a summary of the data reported for laboratory animals or humans on NOAELs or LOAELs (see Table 3).

7.3.3 Leading examples of information resources that compile and summarize such data appear in Appendix X1.

7.4 *Develop Scenarios for Exposure:*

7.4.1 Development of a realistic and reasonable scenario is necessary for an accurate estimation of exposure. Short-term exposure scenarios often are straightforward, requiring only specification of an exposure duration (for example, 30 min or 1 h). Long-term exposure scenarios commonly require a number of assumptions, as described below.

7.4.2 Long-term exposure scenarios involve time periods that span a lifetime or a substantial portion thereof. A bounding estimate for passengers and crew on commercial flights can be based on the assumption that such an individual might log an

TABLE 1 Example Format for Summarizing Standards/Guidelines for Chronic and Subchronic Health Effects Data

Chemical Name:	CASRN:	
Parameter	Value[A]	Notes
EPA IRIS Chronic Inhalation RfC		
EPA HEAST Chronic RfC		
EPA HEAST Sub-Chronic RfC		
Intermediate Inhalation MRL		
Chronic Inhalation MRL		
Chronic REL (California)		
NIOSH REL		
SMAC 180 days		
ACGIH TLV		
OSHA PEL		
Inhalation unit risk		

[A] Include units when completing this portion of the table.