Designation: D7034 – 11

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 and health practices and determine the applicability of regulatory requirements prior to use.*

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

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

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

Current edition approved March 1, 2011. Published March 2011. Originally approved in 2004. Last previous edition approved in 2005 as D7034 - 05. DOI: 10.1520/D7034-11.

[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, Mail Stop: SDE, Washington, DC 20401.

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. FAA Airworthiness Standards (14 CFR 25) constitute the only source of 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 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

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

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 mixtures 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 8000 ft [2438 m]. Two types of effects need to be considered with respect to cabin pressures: (*i*) the reduced pressure would tend to increase the inhalation rate in persons that are not acclimatized to such pressures; and (*ii*) 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 exceedence 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 average of 40 h per month, or 480 h per year, over 30 years **(16)**. This assumption corresponds to an estimated upper limit of 14 400 lifetime hours of exposure (equivalent to 1.64 years).

7.4.3 For a less extreme scenario, but one that is still at the upper end of the distribution for frequency and duration of flying, it is appropriate to consider a subgroup of passengers who travel fairly frequently (for example, 10 h of flight time every two weeks). Over a 30-year period, members of this subgroup would travel 10 h × 26 biweekly periods per year × 30 years, for a lifetime total of 7800 h or about one year.

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.

TABLE 2 Example Format for Summarizing Standards/Guidelines for Acute Health Effects and Odor Thresholds

Chemical Name:	CASRN:	
Parameter	Value	Notes
Acute Inhalation MRL		
Odor Threshold		
Detection		
Recognition		
Acute REL (California)		
NIOSH STEL/Ceiling Limit		
SMAC 1-h		
OSHA STEL		
NIOSH IDLH		

TABLE 3 Example Format for Summarizing LOAELs and NOAELs for Humans and Laboratory Animals

Chemical Name:	CASRN:	
Data Reported for Laboratory Animals		
Parameter	Value	Notes
No-adverse-effect level (NOAEL)		
Low-adverse-effect level (LOAEL)		
Data Reported for Humans		
Parameter	Value	Notes
NOAEL		
LOAEL		

7.4.4 The durations for these long-term exposure scenarios are, thus, 12 to 24 % of the customary OSHA exposure duration of 40 h per week over 30 years.

7.5 *Select Risk Levels of Concern (where appropriate):*

7.5.1 For some effects the exposure level of concern may be directly defined in a standard or guideline, as in the case of an RfC (**2, 3**) or an MRL (**4**). For cancer effects, however, the exposure level of concern depends on the choice for a lifetime risk of cancer that should not be exceeded. Common choices for a lifetime cancer risk of concern are 1 in 100 000 and 1 in 1 000 000 (**2**).

7.6 *Calculate Level of Concern for Each Selected Effect:*

7.6.1 *Carcinogenic Effects*—For some contaminants an inhalation unit risk for cancer has been defined in units of $(\text{mg m}^{-3})^{-1}$. The unit risk is defined by the USEPA as the upper-bound estimate of the probability of cancer due to continuous lifetime exposure to a unit concentration (that is, 1 mg m^{-3}) of a carcinogen, assuming a 70-year life span and an average inhalation rate of 20 m^3 day^{-1}. Multiplication of the lifetime average concentration to which one is exposed by the unit risk yields an estimate of lifetime cancer risk. The lifetime cancer risk of concern and lifetime average daily dose (LADD) are related as follows (**2**) :

$$\text{Lifetime Cancer Risk of Concern} = \text{LADD} \times \text{Slope of Dose} - \text{Response Curve} \quad (2)$$

where:

$$\text{LADD}(\text{mg kg}^{-1}\text{day}^{-1}) = \frac{\text{Concentration}(\text{mg m}^{-3}) \times \text{Exposure Duration}(\text{h}) \times \text{Inhalation Rate}(\text{m}^3\text{h}^{-1})}{\text{Body Weight}(\text{kg}) \times \text{Lifespan}(\text{days})} \quad (3)$$

The concentration equated to the lifetime excess risk can be determined from Eq 2 and 3 as:

$$\text{Concentration} = \frac{\text{Lifetime Excess Risk}}{\text{Slope of Dose Response Curve}} \times \frac{\text{Body Weight} \times \text{Lifespan}}{\text{Duration of Exposure} \times \text{Inhalation Rate}} \quad (4)$$

7.6.1.1 *Discussion*—As an example of applying Eq 2-4, consider a contaminant with a slope of 0.01 mg kg^{-1} day^{-1}. For a lifetime risk of concern of 1 in 100 000, an average body weight of 70 kg, a life span of 25 550 days (70 years), an exposure duration of 7800 h, and an inhalation rate of 0.5 m^3h^{-1} (appropriate for a seated population such as airline passengers), the calculated concentration is 0.66 mg m^{-3}. This value can be considered an acceptable concentration for the contaminant in the cabin environment, from the standpoint of minimizing the risk of carcinogenic effects for frequent flyers.

7.6.2 *Long-term Non-carcinogenic Effects*—An exposure duration equivalent to about one year, similar to the duration used in the above example, can be considered for sub-chronic or intermediate-level exposure. Thus, in cases where they exist, sub-chronic reference concentrations or intermediate exposure Minimal Risk Levels (MRLs) could be used as a basis for defining an acceptable concentration from the standpoint of minimizing long-term non-carcinogenic effects.

7.6.3 *Acute Effects*—The acute minimal risk levels (MRLs) developed by ATSDR (**4**) provide a very useful basis for considering acute effects for the general population. An alternative approach for considering irritation and other acute effects is to define exposure limits for sensitive subgroups such as children, elderly people, and asthmatics. One approach (**17**) that can be used for sensitive subgroups is to take 1/40 of a time-weighted-average (TWA) occupational exposure limit such as the ACGIH TLV (**8**). If, for example, the TLV were 50 mg m^{-3}, then the acceptable concentration by this procedure would be 1.25 mg m^{-3} (that is, 50 mg m^{-3} ÷ 40). A similar divisor currently is not available for equating occupational STEL values to an appropriate value for episodic exposures. In such cases, the more stringent AEGL value could be considered, as AEGL values relate to once-in-a-lifetime exposures.

7.6.4 *Odor Threshold*—The odor thresholds, where such data exist, may lie within a range of odor-recognition values that span several orders of magnitude (**9, 10**). No safety factor is necessary for odor thresholds. However, odor thresholds should not be considered indicators of acute effects and by themselves do not provide a sufficient basis for determining an acceptable concentration. Given the wide range and types of odor response, an acceptable limit above the odor threshold may be reasonable, provided that such a limit is at or below other thresholds of concern.

7.7 *Determine an Acceptable Concentration for Aircraft Cabins*—The choice of acceptable concentration level is based on an examination of the outcomes from calculations and choices described in 7.6.

7.7.1 In deriving an acceptable concentration, the population of concern and the effects of concern should be considered. In general, an acceptable concentration is one below the highest concentration at which the effect is known not to occur

for the population under consideration. A possible exception is the case where the lowest level is an odor threshold (see 7.6.4).

7.8 *Compare Acceptable Concentration with Existing Information:*

7.8.1 Once a proposal for an acceptable concentration has been determined, it should be compared with existing guidelines and with reported aircraft cabin concentrations (if such data are available).

7.8.2 Based on such information, a conclusion can be made as to whether there is a potential problem in aircraft cabins for the contaminant under investigation. Such a conclusion would be warranted in cases where monitoring data indicate that the acceptable concentration has been approached or exceeded on multiple occasions.

7.8.3 In cases where monitoring data are nonexistent or inadequate, preliminary conclusions can be reached by reviewing data collection methodologies and evaluating materials and processes expected to occur in the aircraft cabin environment for any propensity to release the chemical of concern **(18-21)**.

8. Report

8.1 The report on acceptable concentration for aircraft cabins should contain the components listed below.

8.1.1 *Hazard Assessment*—Provide a list of chemicals of potential concern. For each chemical, include a compilation of toxicity, irritancy and odor threshold data and data sources consulted in compiling reference values.

8.1.2 *Summary of Exposure Assessment*—Describe the methodology and assumptions used in conducting exposure assessment. Include brief descriptions of exposure scenarios that were used. Present results of the exposure assessment and discuss associated uncertainties.

8.1.3 *Derivation of Acceptable Concentration*—Describe the methodology, assumptions, and analysis of existing data used in the calculation of the acceptable concentration, and discuss associated uncertainties.

8.1.4 *Conclusions*—State conclusions associated with the derivation of the acceptable concentration and summarize limitations of the data and methodology.

APPENDIX

(Nonmandatory Information)

X1. SUMMARY OF DATA SOURCES FOR EVALUATING HEALTH EFFECTS AND TOXICITY OF CHEMICAL SUBSTANCES

X1.1 There are numerous chemicals in widespread industrial and commercial use that are of potential concern for occupants of the airliner cabin environment. As noted in Guide D6399, there is very little direct guidance for identifying contaminants and the exposure levels that would cause concern. FAA Airworthiness Standards (14 CFR 25) constitute the only source of regulatory guidance that explicitly applies to the cabin environment. The FAA standards, however, cover only a handful of contaminants, specifying acceptable exposure levels for O_3, CO_2, CO, and cabin pressure and are design standards.

X1.2 The temptation exists to make direct use of standards and guidance developed for other purposes. Exposure standards such as regulations promulgated by the Occupational Health and Safety Administration (OSHA) under the Occupational Safety and Health Act of 1970 (29 CFR 1910), and guidance devised by the American Conference of Governmental Industrial Hygienists (ACGIH) to define acceptable limits for workplace exposure are sometimes used to define exposure limits for the general population. Simply extending standards and guidance developed for application in the workplace to the protection of the general population, however, ignores many underlying public health principles. The American Industrial Hygiene Association summarizes accepted application of Permissible Exposure Limits (PELs), Threshold Limit Values (TLVs), and Workplace Environmental Exposure Levels (WEELs) **(1)**:

X1.2.1 "PELs are derived for use by occupational health professionals to protect the health of workers in their environments. To accomplish this certain assumptions are made. The population at risk is assumed to be healthy and ranging in age from 16 to 72 years. Exposures are usually periodic averaging forty hours per week. There may be susceptible or hypersensitive individuals for which the PEL will not prevent adverse effects."

X1.2.2 "PELs, TLVs and WEELs at times have been inappropriately applied in other public health situations (for example, control of air pollution exposures for the general public). Vast differences in general population exposure conditions and protection goals rule out the application of occupational limits to the control of environmental exposures for the general public. Most often the goal of public health is the elimination of all risk to a population of all ages and varying degrees of health which may be involuntarily and continuously exposed to an agent. In the occupational environment susceptible individuals can be protected by use of additional exposure controls with the guidance of an occupational health professional. These options are not usually available within a community. It is therefore inappropriate and scientifically unjustifiable to use these limits in nonoccupational applications."

X1.3 Similar arguments could be launched against direct use of other guidance for the airliner cabin environment. The Clean Air Act (40 CFR Part 50), specifies acceptable limits for the general population for designated Criteria Pollutants (O_3, CO, NO_x, SO_2, particulate matter, and Pb), and also regulates population exposure to emissions of nearly 200 hazardous air pollutants. Guidance is also available through the Spacecraft Maximum Allowable Concentrations (SMACs), developed by The National Aeronautic and Space Administration (NASA)

and the National Research Council of the National Academy of Sciences (NRC) (22).

X1.4 The NAAQS are concerned with the general population, but are predicated on ground-level conditions. The SMACs, on the other hand, were developed for personnel operating the Space Shuttle, the International Space Station, and other manned missions within the Space Program. Thus, while chemicals could be identified through review of past studies and assessment of materials and processes that constitute potential sources, the establishment of exposure levels of concern requires additional input from toxicologists and other health-effects specialists as addressed in the main body of this document.

X1.5 A significant body of information is available in the form of electronic databases and hardcopy publications to support such reviews. TOXNET, operated by the National Library of Medicine (NLM), for example, allows users to select and search among literature sources as well as specially prepared databases. Many of the databases within TOXNET, such as EPA's Integrated Risk Information System (IRIS) (3), can be accessed directly.

X1.6 Leading examples of these resources, which include guidelines and standards are summarized on subsequent pages of this appendix; highlights of the different resources are as follows:

X1.6.1 *Integrated Risk Information System (IRIS)*—Official EPA repository of information on carcinogenic and noncarcinogenic risk assessment values for oral and inhalation routes of exposure, currently for about 500 chemicals (3);

X1.6.2 *Minimal Risk Levels for Hazardous Substances (MRLs)*—A list of acute, intermediate and chronic inhalation/oral MRLs developed by the Agency for Toxic Substances and Disease Registry (ATSDR) for about 300 chemicals, used in screening contaminants and potential health effects of concern at hazardous waste sites (4);

X1.6.3 *National Ambient Air Quality Standards (NAAQS)*—Standards tied to the Clean Air Act, intended to protect public health and welfare, for carbon monoxide, lead, nitrogen dioxide, ozone, sulfur dioxide, and particulate matter (40 CFR 50);

X1.6.4 *Airworthiness Standards*—FAA-acceptable exposure limits for passengers and flight crew for ozone, carbon dioxide and carbon monoxide, and acceptable limits for cabin pressure (14 CFR 25);

X1.6.5 *Spacecraft Maximum Allowable Concentrations (SMACs)*—NASA/NRC guidelines (short-term and long-term SMACs) and toxicological profiles for 35 chemicals or compounds, published in three volumes (22);

X1.6.6 *NIOSH-Recommended Exposure Limits (NIOSH REL)*—NIOSH RELs are occupational exposure limits expressed as time-weighted average (TWA) exposure for up to 10 h/day during a 40-h workweek, as a short-term exposure limit (STEL), or as a ceiling limit, or both. Currently, there are RELs for over 700 substances (6);

X1.6.7 *Threshold Limit Values (TLVs)*—ACGIH publication providing 8-h-average occupational TLVs and 15-min short-term exposure limits (STELs) for over 700 substances (8);

X1.6.8 *Odor Thresholds for Chemicals with Established Occupational Health Standards*—AIHA publication that includes tabular summaries on the best estimate and range of detection and recognition odor threshold for chemicals with occupational TLVs (10);

X1.6.9 *Permissible Exposure Limits (PELs)*—OSHA publication on 8-h-average occupational exposure limits for about 700 hazardous substances and physical/biological agents (29 CFR 1910);

X1.6.10 *Acute Exposure Guideline Levels*—Guidelines for once-in-a-lifetime, short exposures to airborne concentrations of acutely toxic chemicals applicable to different federal agency programs (11, 12); and

X1.6.11 *Reference Exposure Levels (RELs California)*—California EPA Office of Environmental Health Hazard Assessments (OHHEA) has developed acute and chronic Reference Exposure Levels (RELs California) for non-cancer effects (23).

X1.7 Each summary table that follows describes the kind of record housed within the database or publication and identifies key parameters relating to critical dose and/or exposure along with the type of population (public versus occupational) involved. Where appropriate, available documentation and the degree of critical review are described, along with the intended user community. While most of theses resources can be accessed through the Internet, additional contact information for telephone and facsimile is provided. Printed editions of reports and manuals are available for review at most academic and government libraries.

TABLE X1.1 Integrated Risk Information System (IRIS)

IRIS is an electronic database, created by the U.S. Environmental Protection Agency, that serves as the official repository of consensus information on potential adverse human health effects from chronic or lifetime exposure to approximately 500 environmental contaminants. It contains information on carcinogenic and noncarcinogenic risk assessment values for oral and inhalation routes of exposure.	
Organization	USEPA National Center for Environmental Assessment
Contents	Chemical-specific files (Searchable) for ~500 chemicals
Searchable	By CASRN, Chemical Name
Key Parameters	RfD, RfC, NOAEL, LOAEL
Target Population	Public Health
Level of Scientific Review	Consensus of scientific panel; EPA approved
Specific Documentation	Users Guide
General Documentation	Glossary, Acronyms, Rationale, Methods, Limitations
Revision history	1988- Present
User Community	Toxicology, Environmental Health
Internet Access	http://www.atsdr.cdc.gov/mrls/index.asp
Email	RIH.IRIS@epamail.epa.gov
Voice	513-569-7254
Fax	513-569-7159
Basis	Cost-Free via Internet, Published

TABLE X1.2 Minimal Risk Levels For Hazardous Substances (MRLs)

Minimal Risk Levels (MRLs) are estimates of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure. Substance-specific estimates are developed by the Agency for Toxic Substances and Disease Registry (ATSDR) to serve as screening levels for identifying contaminants and potential health effects that may be of concern at hazardous waste sites. MRLs are not intended to define clean-up or action levels.	
Organization	ATSDR
Contents	Toxicological profiles for ~300 chemicals
Searchable	Single Text File, Tabular Format
Key Parameters	Inhalation MRL, Oral MRL; Acute, Intermediate, Chronic
Target Population	Public (Including Sensitized Populations)
Level of Scientific Review	Scientific Peer-Review Panel
Specific Documentation	Users Guide
General Documentation	Glossary, Acronyms, Rationale, Methods, Limitations
Revision history	Regular Updates
User Community	Toxicology, Environmental Health, Physicians, Public Health Specialists
Internet Access	http://www.atsdr.cdc.gov/mrls.html
Email	cjc3@cdc.gov
Voice	404-639-6308; Toll-free: 888-422-8737
Fax	404-639-6315
Basis	Cost-Free Via Internet, Published

TABLE X1.3 National Ambient Air Quality Standards (NAAQS)

The NAAQS are established as Primary Standards to set limits related to protection of public health (including the health of “sensitive” populations such as asthmatics, children, and the elderly), and as Secondary Standards to set limits related to protection of public welfare (including visibility, damage to animals, crops, vegetation, and buildings). Primary ambient air quality standards exist for Carbon Monoxide (CO), Lead (Pb), Nitrogen Dioxide (NO_2), Ozone (O_3), Sulfur Dioxide (SO_2), and Particulate Matter (PM10, PM2.5).	
Organization	EPA Office of Air and Radiation
Contents	Ambient Air Quality Standards
Searchable	Hardcopy Publication, Tabular Format
Key Parameters	1 h, 8 h, 24-h, Annual Average Concentration
Target Population	Public
Level of Scientific Review	Extensive Scientific and Public Review
Specific Documentation	Pollutant-Specific Criteria Documents
General Documentation	The Plain English Guide To The Clean Air Act 40 CFR 50 (Clean Air Act)
Revision history	Every 5 Years
User Community	Public, Scientific, Regulatory
Internet Access	www.epa.gov/air/criteria.html
Email	
Voice	
Fax	
Basis	Cost-Free Via Internet, Published

TABLE X1.4 Airworthiness Standards

Airworthiness Standards are promulgated by the Federal Aviation Administration (FAA) to specify, among other things, acceptable exposure levels for O_3, CO_2, CO, and acceptable limits on cabin pressure.	
Organization	FAA
Contents	Acceptable Air Concentrations for O_3, CO_2, CO; Cabin Pressure
Searchable	Hardcopy Publication
Key Parameters	Allowable Levels
Target Population	Passengers, Flight Crew
Level of Scientific Review	Extensive Scientific and Public Review
Specific Documentation	14 CFR 25 Airworthiness Standards: Transport Category Airplanes
General Documentation	
Revision history	February 1999
User Community	Regulatory
Internet Access	www.faa.gov
Email	
Voice	
Fax	
Basis	Cost-Free Via Internet, Published

TABLE X1.5 Spacecraft Maximum Allowable Concentrations (SMACs)

SMACs are developed from the toxicological literature to ensure the health and well-being of astronauts traveling and working in the spacecraft environment. SMACs have been published in final form by the National Academy of Sciences in three volumes.	
Organization	National Academy of Sciences, National Research Council
Contents	Toxicological Profiles for 35 Chemicals
Searchable	Hardcopy Publication, Contaminant-Specific Summaries
Key Parameters	Short-term (1-24 h), Long Term (7-180 day) SMACs
Target Population	Astronauts
Level of Scientific Review	Extensive Scientific and Public Review
Specific Documentation	Spacecraft Maximum Allowable Concentrations for Selected Airborne Contaminants, V1 (1994), V2 (1996), V3 (1997)
General Documentation	
Revision history	
User Community	Toxicology
Internet Access	http://www.nap.edu/ (Read-Only)
Email	customer_service@nap.edu
Voice	202-334-3313; Toll Free: 888-624-8373
Fax	202-334-2451
Basis	Purchase

TABLE X1.6 NIOSH Recommended Exposure Limits (NIOSH RELs)

The National Institute for Occupational Safety and Health (NIOSH) develops and recommends criteria for preventing disease or hazardous conditions. These are referred to as recommended exposure limits (NIOSH RELs)	
Organization	National Institute for Occupational Safety and Health
Contents	Exposure limits for over 700 substances
Searchable	Hardcopy Publication, Contaminant-Specific Summaries
Key Parameters	TWA for up to 10 h/day during 40-h workweek. Also 15-min STEL and ceiling limit
Target Population	Workplace
Level of Scientific Review	A tripartite (government, labor, industry) external review before publication
Specific Documentation	A compendium of the sources of the NIOSH RELs and the publication numbers of those sources is available on the website at: http://www.cdc.gov/niosh/92-100.html
General Documentation	
Revision history	Periodic
User Community	Industrial Hygienists
Internet Access	http://www.cdc.gov/niosh/homepage.html
Email	http://www.cdc.gov/niosh/nioshmail.html
Voice	1-800-356-4674
Fax	
Basis	Cost-Free by way of internet

TABLE X1.7 Threshold Limit Values (TLVs)

Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Values, published by ACGIH, gives 8-h time-weighted-average occupational threshold limit values (TLVs) and 15-min short-term exposure limits (STELs) for a large number of industrial chemicals.	
Organization	ACGIH
Contents	Over 700 substances
Searchable	Hardcopy Publication, Tabular Format
Key Parameters	8-h TWA, 15-min STEL, Ceiling limit
Target Population	Occupational
Level of Scientific Review	Peer Review
Specific Documentation	Documentation of the Threshold Limit Values and Biological Exposure Indices
General Documentation	TLVs® and BEIs® TLVs® and Other Occupational Exposure Values
Revision history	Annual
User Community	Industrial Hygiene
Internet Access	www.acgih.org (No Online Queries)
Email	customerservice@acgih.org
Voice	513-742-2020
Fax	513-742-3355
Basis	Purchase

TABLE X1.8 Odor Thresholds For Chemicals With Established Occupational Health Standards

Odor Thresholds For Chemicals With Established Occupational Health Standards was commissioned by the American Industrial Hygiene Association (AIHA) to eliminate wide variations in odor threshold data reported in existing literature. The critique provides important reference information for chemicals with threshold limit values. The publication presents a review of the main topic of odor perception, and presents chemical-specific findings in three major tables. The first table in the AIHA report presents the best estimate and range of detection and recognition odor threshold; along with qualitative descriptions of odor character, threshold limit values, chemical formula, and molecular weight. The second table compares and critiques the primary experimental odor threshold determinations reported by each investigator. The third table summarizes the results of the literature review and critique.	
Organization	AIHA
Contents	Tabular Summaries
Searchable	Hardcopy Publication, Tabular Format
Key Parameters	Odor Thresholds; Odor Character
Target Population	Occupational
Level of Scientific Review	Peer-Reviewed Critique
Specific Documentation	AIHA Publication SKU# 108-EA-89
General Documentation	
Revision history	None
User Community	Industrial Hygiene; Toxicology
Internet Access	www.aiha.org (No Online Queries)
Email	
Voice	703-849-8888
Fax	703-207-3561
Basis	Purchase

TABLE X1.9 OSHA Permissible Exposure Limits (PELs)

OSHA sets PELs to define enforceable exposure limits (8-h time TWA) for about 700 hazardous substances and physical/biological agents.	
Organization	OSHA
Contents	~500 Chemicals
Searchable	Hardcopy Publication, Tabular Format
Key Parameters	8-h TWA
Target Population	Occupational
Level of Scientific Review	Peer Review
Specific Documentation	OSHA Regulations (29 CFR Part 1910)
General Documentation	Occupational Health Guidelines to Chemical Hazards. (NIOSH Publication No. 81-123, 1987)
Revision history	Annual
User Community	Industrial Hygiene
Internet Access	www.osha.gov/SLTC/pel/
Email	
Voice	202-693-1999
Fax	
Basis	Cost-Free Via Internet

TABLE X1.10 Acute Exposure Guidelines Levels (AEGL)

The primary purpose of the AEGL program is to develop guideline levels for once-in-a-lifetime, short-term exposures to airborne concentrations of acutely toxic, high-priority chemicals. Among the applications of AEGL include EPA's emergency planning program, U.S. CAAA's accident prevention program, and DOE's and DOD's environmental restoration programs and waste management programs	
Organization	National Research Council
Contents	Chemical-specific guidelines and files for<100 chemicals
Searchable	
Key Parameters	AEGL 1, AEGL 2, and AEGL 3
Target Population	Public
Level of Scientific Review	Scientific Review Panel
Specific Documentation	Standing operating procedures
General Documentation	Overview of AEGL program, derivation of AEGL values, priority list of chemicals, glossary, and technical support documents
Revision history	Intermittent
User Community	Toxicology, Environmental Health
Internet Access	http://www.nap.edu/
Email	
Voice	
Fax	
Basis	National Academy Publications and web access

TABLE X1.11 Reference Exposure Levels (RELs California)

The concentration level at or below which no adverse health effects are anticipated for a specified exposure duration is termed the reference exposure level (REL). RELs are based on the most sensitive, relevant, adverse health effects reported in the medical and toxicological literature. RELs are designed to protect the most sensitive individuals in the population by the inclusion of margins of safety. Since margins of safety are incorporated to address data gaps and uncertainties, exceeding the REL does not automatically indicate an adverse health impact.	
Organization	California Office of Environmental Health Hazard Assessment
Contents	Chemical-specific guidelines and files for 100+ chemicals
Searchable	
Key Parameters	Acute REL; chronic REL
Target Population	Public
Level of Scientific Review	Formalized peer review process
Specific Documentation	Standing operating procedures
General Documentation	Legislative mandate, overview of REL development process, derivation of acute and chronic REL values, list of chemicals, priorities for evaluation of chemicals, and technical support documents
Revision history	Intermittent
User Community	Toxicology, environmental health
Internet Access	http://www.oehha.ca.gov/air/allrels.html
Email	
Voice	
Fax	
Basis	Web access

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