ADOPTED APPENDICES

APPENDIX A: Carcinogenicity

ACGIH® has been aware of the increasing public concern over chemicals or industrial processes that cause or contribute to increased risk of cancer in workers. More sophisticated methods of bioassay, as well as the use of sophisticated mathematical models that extrapolate the levels of risk among workers, have led to differing interpretations as to which chemicals or processes should be categorized as human carcinogens and what the maximum exposure levels should be. The goal of the Chemical Substances TLV® Committee has been to synthesize the available information in a manner that will be useful to practicing industrial hygienists, without overburdening them with needless details. The categories for carcinogenicity are:

A1 — *Confirmed Human Carcinogen:* The agent is carcinogenic to humans based on the weight of evidence from epidemiologic studies.

A2 — *Suspected Human Carcinogen:* Human data are accepted as adequate in quality but are conflicting or insufficient to classify the agent as a confirmed human carcinogen; OR, the agent is carcinogenic in experimental animals at dose(s), by route(s) of exposure, at site(s), of histologic type(s), or by mechanism(s) considered relevant to worker exposure. The A2 is used primarily when there is limited evidence of carcinogenicity in humans and sufficient evidence of carcinogenicity in experimental animals with relevance to humans.

A3 — *Confirmed Animal Carcinogen with Unknown Relevance to Humans:* The agent is carcinogenic in experimental animals at a relatively high dose, by route(s) of administration, at site(s), of histologic type(s), or by mechanism(s) that may not be relevant to worker exposure. Available epidemiologic studies do not confirm an increased risk of cancer in exposed humans. Available evidence does not suggest that the agent is likely to cause cancer in humans except under uncommon or unlikely routes or levels of exposure.

A4 — *Not Classifiable as a Human Carcinogen:* Agents which cause concern that they could be carcinogenic for humans but which cannot be assessed conclusively because of a lack of data. *In vitro* or animal studies do not provide indications of carcinogenicity which are sufficient to classify the agent into one of the other categories.

A5 — *Not Suspected as a Human Carcinogen:* The agent is not suspected to be a human carcinogen on the basis of properly conducted epidemiologic studies in humans. These studies have sufficiently long follow-up, reliable exposure histories, sufficiently high dose, and adequate statistical power to conclude that exposure to the agent does not convey a significant risk of cancer to humans; OR, the evidence suggesting a lack of carcinogenicity in experimental animals is supported by mechanistic data.

Substances for which no human or experimental animal carcinogenic data have been reported are assigned no carcinogenicity designation.

Exposures to carcinogens must be kept to a minimum. Workers exposed to A1 carcinogens without a TLV® should be properly equipped to eliminate to the fullest extent possible all exposure to the carcinogen. For A1 carcinogens

with a TLV® and for A2 and A3 carcinogens, worker exposure by all routes should be carefully controlled to levels as low as possible below the TLV®. Refer to the "Guidelines for the Classification of Occupational Carcinogens" in the Introduction to the Chemical Substances in the *Documentation of the Threshold Limit Values and Biological Exposure Indices* for a complete description and derivation of these designations.

APPENDIX B: Particles (insoluble or poorly soluble) Not Otherwise Specified [PNOS]

The goal of the TLV®-CS Committee is to recommend TLVs® for all substances for which there is evidence of health effects at airborne concentrations encountered in the workplace. When a sufficient body of evidence exists for a particular substance, a TLV® is established. Thus, by definition the substances covered by this recommendation are those for which little data exist. The recommendation at the end of this Appendix is supplied as a guideline rather than a TLV® because it is not possible to meet the standard level of evidence used to assign a TLV®. In addition, the PNOS TLV® and its predecessors have been misused in the past and applied to any unlisted particles rather than those meeting the criteria listed below. The recommendations in this Appendix apply to particles that:

- Do not have an applicable TLV®;
- Are insoluble or poorly soluble in water (or, preferably, in aqueous lung fluid if data are available); and
- Have low toxicity (i.e., are not cytotoxic, genotoxic, or otherwise chemically reactive with lung tissue, and do not emit ionizing radiation, cause immune sensitization, or cause toxic effects other than by inflammation or the mechanism of "lung overload").

ACGIH® believes that even biologically inert, insoluble, or poorly soluble particles may have adverse effects and recommends that airborne concentrations should be kept below 3 mg/m^3, respirable particles, and 10 mg/m^3, inhalable particles, until such time as a TLV® is set for a particular substance.

APPENDIX C: Particle Size-Selective Sampling Criteria for Airborne Particulate Matter

For chemical substances present in inhaled air as suspensions of solid particles or droplets, the potential hazard depends on particle size as well as mass concentration because of 1) effects of particle size on the deposition site within the respiratory tract and 2) the tendency for many occupational diseases to be associated with material deposited in particular regions of the respiratory tract.

ACGIH® has recommended particle size-selective TLVs® for crystalline silica for many years in recognition of the well-established association between

silicosis and respirable mass concentrations. The TLV®-CS Committee is now re-examining other chemical substances encountered in particle form in occupational environments with the objective of defining: 1) the size-fraction most closely associated for each substance with the health effect of concern and 2) the mass concentration within that size fraction which should represent the TLV®.

The Particle Size-Selective TLVs® (PSS–TLVs) are expressed in three forms:

1. *Inhalable Particulate Matter TLVs®* (IPM–TLVs) for those materials that are hazardous when deposited anywhere in the respiratory tract.
2. *Thoracic Particulate Matter TLVs®* (TPM–TLVs) for those materials that are hazardous when deposited anywhere within the lung airways and the gas-exchange region.
3. *Respirable Particulate Matter TLVs®* (RPM–TLVs) for those materials that are hazardous when deposited in the gas-exchange region.

The three particulate matter fractions described above are defined in quantitative terms in accordance with the following equations:[1–3]

A. IPM fraction consists of those particles that are captured according to the following collection efficiency regardless of sampler orientation with respect to wind direction:

$$IPM\ (d_{ae}) = 0.5\ [1 + \exp(-0.06\ d_{ae})]$$
$$\text{for } 0 < d_{ae} \leq 100\ \mu m$$

where: $IPM\ (d_{ae})$ = the collection efficiency
d_{ae} = aerodynamic diameter of particle in μm

B. TPM fraction consists of those particles that are captured according to the following collection efficiency:

$$TPM\ (d_{ae}) = IPM\ (d_{ae})\ [1 - F(x)]$$

where: $F(x)$ = cumulative probability function of the standardized normal variable, x

$$x = \frac{\ln(d_{ae}/\Gamma)}{\ln(\Sigma)}$$

$\ln$ = natural logarithm
Γ = 11.64 μm
Σ = 1.5

C. RPM fraction consists of those particles that are captured according to the following collection efficiency:

$$RPM\ (d_{ae}) = IPM\ (d_{ae})\ [1 - F(x)]$$

where $F(x)$ = same as above, but with Γ = 4.25 μm and Σ = 1.5

The most significant difference from previous definitions is the increase in the median cut point for a respirable particulate matter sampler from 3.5 μm to

4.0 μm; this is in accord with the International Organization for Standardization/ European Standardization Committee (ISO/CEN) protocol.[4,5] At this time, no change is recommended for the measurement of respirable particles using a 10-mm nylon cyclone at a flow rate of 1.7 liters per minute. Two analyses of available data indicate that the flow rate of 1.7 liters per minute allows the 10-mm nylon cyclone to approximate the particulate matter concentration which would be measured by an ideal respirable particulate sampler as defined herein.[6,7]

Collection efficiencies representative of several sizes of particles in each of the respective mass fractions are shown in Tables 1, 2, and 3. *Documentation* for the respective algorithms representative of the three mass fractions is found in the literature.[2–4]

TABLE 1. Inhalable Fraction

Particle Aerodynamic Diameter (μm)	Inhalable Particulate Matter (IPM) Fraction Collected (%)
0	100
1	97
2	94
5	87
10	77
20	65
30	58
40	54.5
50	52.5
100	50

TABLE 2. Thoracic Fraction

Particle Aerodynamic Diameter (μm)	Thoracic Particulate Matter (TPM) Fraction Collected (%)
0	100
2	94
4	89
6	80.5
8	67
10	50
12	35
14	23
16	15
18	9.5
20	6
25	2

TABLE 3. Respirable Fraction

Particle Aerodynamic Diameter (µm)	Respirable Particulate Matter (RPM) Fraction Collected (%)
0	100
1	97
2	91
3	74
4	50
5	30
6	17
7	9
8	5
10	1

References

1. American Conference of Governmental Industrial Hygienists: Particle Size-Selective Sampling in the Workplace. ACGIH®, Cincinnati, OH (1985).
2. American Conference of Governmental Industrial Hygienists: Particle Size-Selective Sampling for Particulate Air Contaminants. JH Vincent, Ed. ACGIH®, Cincinnati, OH (1999).
3. Soderholm, SC: Proposed International Conventions for Particle Size-Selective Sampling. Ann. Occup. Hyg. 33:301–320 (1989).
4. International Organization for Standardization (ISO): Air Quality—Particle Size Fraction Definitions for Health-Related Sampling. ISO 7708:1995. ISO, Geneva (1995).
5. European Standardization Committee (CEN): Size Fraction Definitions for Measurement of Airborne Particles. CEN EN481:1993. CEN, Brussels (1993).
6. Bartley, DL: Letter to J. Doull, TLV® Committee, July 9, 1991.
7. Lidén, G; Kenny, LC: Optimization of the Performance of Existing Respirable Dust Samplers. Appl. Occup. Environ. Hyg. 8(4):386–391 (1993).

APPENDIX D: Commercially Important Tree Species Suspected of Inducing Sensitization

Common	*Latin*
SOFTWOODS	
California redwood	*Sequoia sempervirens*
Eastern white cedar	*Thuja occidentalis*
Pine	*Pinus*
Western red cedar	*Thuja plicata*
HARDWOOD	
Ash	*Fraxinus spp.*
Aspen/Poplar/Cottonwood	*Populus*
Beech	*Fagus*
Oak	*Quercus*

TROPICAL WOODS	
Abirucana	*Pouteria*
African zebra	*Microberlinia*
Antiaris	*Antiaris africana, Antiaris toxicara*
Cabreuva	*Myrocarpus fastigiatus*
Cedar of Lebanon	*Cedra libani*
Central American walnut	*Juglans olanchana*
Cocabolla	*Dalbergia retusa*
African ebony	*Diospryos crassiflora*
Fernam bouc	*Caesalpinia*
Honduras rosewood	*Dalbergia stevensonii*
Iroko or kambala	*Chlorophora excelsa*
Kejaat	*Pterocarpus angolensis*
Kotibe	*Nesorgordonia papaverifera*
Limba	*Terminalia superba*
Mahogany (African)	*Khaya spp.*
Makore	*Tieghemella heckelii*
Mansonia/Beté	*Mansonia altissima*
Nara	*Pterocarpus indicus*
Obeche/African maple/Samba	*Triplochiton scleroxylon*
Okume	*Aucoumea klaineana*
Palisander/Brazilian rosewood/ Tulip wood/Jakaranda	*Dalbergia nigra*
Pau marfim	*Balfourodendron riedelianum*
Ramin	*Gonystylus bancanus*
Soapbark dust	*Quillaja saponaria*
Spindle tree wood	*Euonymus europaeus*
Tanganyike aningre	

APPENDIX E: Threshold Limit Values for Mixtures

Most threshold limit values are developed for a single chemical substance. However, the work environment is often composed of multiple chemical exposures both simultaneously and sequentially. It is recommended that multiple exposures that comprise such work environments be examined to assure that workers do not experience harmful effects.

There are several possible modes of chemical mixture interaction. Additivity occurs when the combined biological effect of the components is equal to the sum of each of the agents given alone. Synergy occurs where the combined effect is greater than the sum of each agent. Antagonism occurs when the combined effect is less.

The general ACGIH® mixture formula applies to the additive model. It is utilized when additional protection is needed to account for this combined effect.

The guidance contained in this Appendix does not apply to substances in mixed phases.

Application of the Additive Mixture Formula

The "TLV® Basis" column found in the table of Adopted Values lists the adverse effect(s) upon which the TLV® is based. This column is a resource that may help alert the reader to the additive possibilities in a chemical mixture and the need to reduce the combined TLV® of the individual components. Note that the column does not list the deleterious effects of the agent, but rather, lists only the adverse effect(s) upon which the threshold limit was based. The current *Documentation of the TLVs® and BEIs®* should be consulted for toxic effects information, which may be of use when assessing mixture exposures.

When two or more hazardous substances have a similar toxicological effect on the same target organ or system, their combined effect, rather than that of either individually, should be given primary consideration. In the absence of information to the contrary, different substances should be considered as additive where the health effect and target organ or system is the same.

That is, if the sum of

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \ldots \frac{C_n}{T_n}$$

exceeds unity, the threshold limit of the mixture should be considered as being exceeded (where C_1 indicates the observed atmospheric concentration and T_1 is the corresponding threshold limit; see example). It is essential that the atmosphere is analyzed both qualitatively and quantitatively for each component present in order to evaluate the threshold limit of the mixture.

The additive formula applies to simultaneous exposure for hazardous agents with TWA, STEL, and Ceiling values. The threshold limit value time interval base (TWA, STEL, and Ceiling) should be consistent where possible. When agents with the same toxicological effect do not have a corresponding TLV® type, use of mixed threshold limit value types may be warranted. Table E-1 lists possible combinations of threshold limits for the additive mixture formula. Multiple calculations may be necessary.

Where a substance with a STEL or Ceiling limit is mixed with a substance with a TLV–TWA but no STEL, comparison of the short-term limit with the applicable excursion limit may be appropriate. Excursion limits are defined as a value five times the TLV–TWA limit. The amended formula would be:

TABLE E-1. Possible Combinations of Threshold Limits When Applying the Additive Mixture Formula

Full Shift or Short Term	Agent A	Agent B
Full Shift	TLV–TWA	TLV–TWA
Full Shift	TLV–TWA	TLV–Ceiling
Short Term	TLV–STEL	TLV–STEL
Short Term	TLV–Ceiling	TLV–Ceiling
Short Term	Excursion limits where there is no STEL (5 times TLV–TWA value)	TLV–Ceiling or TLV–STEL
Short Term	TLV–STEL	TLV–Ceiling

$$\frac{C_1}{T_{1STEL}} + \frac{C_2}{(T_2)(5)} \leq 1$$

where: T_{1STEL} = the TLV–STEL
T_2 = the TLV–TWA of the agent with no STEL.

The additive model also applies to consecutive exposures of agents that occur during a single work shift. Those substances that have TLV–TWAs (and STELs or excursion limits) should generally be handled the same as if they were the same substance, including attention to the recovery periods for STELs and excursion limits as indicated in the "Introduction to Chemical Substances." The formula does not apply to consecutive exposures of TLV–Ceilings.

Limitations and Special Cases

Exceptions to the above rule may be made when there is a good reason to believe that the chief effects of the different harmful agents are not additive. This can occur when neither the toxicological effect is similar nor the target organ is the same for the components. This can also occur when the mixture interaction causes inhibition of the toxic effect. In such cases, the threshold limit ordinarily is exceeded only when at least one member of the series (C_1/T_1 or C_2/T_2, etc.) itself has a value exceeding unity.

Another exception occurs when mixtures are suspected to have a synergistic effect. The use of the general additive formula may not provide sufficient protection. Such cases at present must be determined individually. Potentiating effects of exposure to such agents by routes other than that of inhalation are also possible. Potentiation is characteristically exhibited at high concentrations, less probably at low. For situations involving synergistic effects, it may be possible to use a modified additive formula that provides additional protection by incorporating a synergy factor. Such treatment of the TLVs® should be used with caution, as the quantitative information concerning synergistic effects is sparse.

Care must be considered for mixtures containing carcinogens in categories A1, A2, or A3. Regardless of application of the mixture formula, exposure to mixtures containing carcinogens should be avoided or maintained as low as possible. See Appendix A.

The additive formula applies to mixtures with a reasonable number of agents. It is not applicable to complex mixtures with many components (e.g., gasoline, diesel exhaust, thermal decomposition products, fly ash, etc.).

Example

A worker's airborne exposure to solvents was monitored for a full shift as well as one short-term exposure. The results are presented in Table E-2.

TABLE E-2. Example Results

Agent	Full-Shift Results (*TLV–TWA)*	Short-Term Results (*TLV–STEL)*
1) Acetone	160 ppm *(500 ppm)*	490 ppm *(750 ppm)*
2) sec-Butyl acetate	20 ppm *(200 ppm)*	150 ppm (N/A)
3) Methyl ethyl ketone	90 ppm *(200 ppm)*	220 ppm *(300 ppm)*

According to the *Documentation of the TLVs® and BEIs®*, all three substances indicate irritation effects on the respiratory system and thus would be considered additive. Acetone and methyl ethyl ketone exhibit central nervous system effects.

Full shift analysis would utilize the formula:

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \frac{C_3}{T_3} \leq 1$$

thus,

$$\frac{160}{500} + \frac{20}{200} + \frac{90}{200} = 0.32 + 0.10 + 0.45 = 0.87$$

The full-shift mixture limit is not exceeded.

Short-term analysis would utilize the formula:

$$\frac{C_1}{T_{1STEL}} + \frac{C_2}{(T_2)(5)} + \frac{C_3}{T_{3STEL}} \leq 1$$

thus,

$$\frac{490}{750} + \frac{150}{1000} + \frac{220}{300} = 0.65 + 0.15 + 0.73 = 1.53$$

The short-term mixture limit is exceeded.

APPENDIX F: Minimal Oxygen Content

Adequate oxygen delivery to the tissues is necessary for sustaining life and depends on 1) the level of oxygen in inspired air, 2) the presence or absence of lung disease, 3) the level of hemoglobin in the blood, 4) the kinetics of oxygen binding to hemoglobin (oxy-hemoglobin dissociation curve), 5) the cardiac output, and 6) local tissue blood flow. For the purpose of the present discussion, only the effects of decreasing the amount of oxygen in inspired air is considered.

The brain and myocardium are the most sensitive tissues to oxygen deficiency. The initial symptoms of oxygen deficiency are increased ventilation, increased cardiac output, and fatigue. Other symptoms that may develop

include headache, impaired attention and thought processes, decreased coordination, impaired vision, nausea, unconsciousness, seizures, and death. However, there may be no apparent symptoms prior to unconsciousness. The onset and severity of symptoms depend on many factors such as the magnitude of the oxygen deficiency, duration of exposure, work rate, breathing rate, temperature, health status, age, and pulmonary acclimatization. The initial symptoms of increased breathing and increased heart rate become evident when hemoglobin oxygen saturation is reduced below 90%. At hemoglobin oxygen saturations between 80% and 90%, physiological adjustments occur in healthy adults to resist hypoxia, but in compromised individuals, such as emphysema patients, oxygen therapy would be prescribed for hemoglobin oxygen saturations below 90%. As long as the partial pressure of oxygen (ρO_2) in pulmonary capillaries stays above 60 torr, hemoglobin will be more than 90% saturated and normal levels of oxygen transport will be maintained in healthy adults. The alveolar ρO_2 level of 60 torr corresponds to 120 torr ρO_2 in the ambient air, due to anatomic dead space, carbon dioxide, and water vapor. For additional information on gas exchange and pulmonary physiology see Silverthorn[1] and Guyton.[2]

The U.S. National Institute for Occupational Safety and Health[3] used 60 torr alveolar ρO_2 as the physiological limit that establishes an oxygen-deficient atmosphere and has defined an oxygen-deficient atmosphere as one with an ambient ρO_2 less than 132 torr.[4] The minimum requirement of 19.5% oxygen at sea level (148 torr ρO_2, dry air) provides an adequate amount of oxygen for most work assignments and includes a margin of safety.[5] However, the margin of safety significantly diminishes as the O_2 partial pressure of the atmosphere decreases with increasing altitude, decreases with the passage of low pressure weather events, and decreases with increasing water vapor,[6] such that, at 5000 feet, the ρO_2 of the atmosphere may approach 120 torr because of water vapor and the passage of fronts and at elevations greater than 8000 feet, the ρO_2 of the atmosphere may be expected to be less than 120 torr.

The physiological effects of oxygen deficiency and oxygen partial pressure variation with altitude for dry air containing 20.948% oxygen are given in Table F-1. No physiological effects due to oxygen deficiency are expected in healthy adults at oxygen partial pressures greater than 132 torr or at elevations less than 5000 feet. Some loss of dark adaptation is reported to occur at elevations greater than 5000 feet. At oxygen partial pressures less than 120 torr (equivalent to an elevation of about 7000 feet or about 5000 feet accounting for water vapor and the passage of low pressure weather events) symptoms in unacclimatized workers include increased pulmonary ventilation and cardiac output, incoordination, and impaired attention and thinking. These symptoms are recognized as being incompatible with safe performance of duties.

Accordingly, ACGIH® recommends a minimal ambient oxygen partial pressure of 132 torr, which is protective against inert oxygen-displacing gases and oxygen-consuming processes for altitudes up to 5000 feet. Figure F-1 is a plot of ρO_2 with increasing altitude, showing the recommended minimal value of 132 torr. If the partial pressure of oxygen is less than 132 torr or if it is less than the expected value for that altitude, given in Table F-1, then additional work practices are recommended such as thorough evaluation of the confined space to identify the cause of the low oxygen concentration; use of continuous monitors integrated with warning devices; acclimating workers to the altitude of

the work, as adaptation to altitude can increase an individuals work capacity by 70%; use of rest–work cycles with reduced work rates and increased rest periods; training, observation, and monitoring of workers; and easy, rapid access to oxygen-supplying respirators that are properly maintained.

Oxygen-displacing gases may have flammable properties or may produce physiological effects, so that their identity and source should be thoroughly investigated. Some gases and vapors, when present in high concentrations in air, act primarily as simple asphyxiants without other significant physiologic effects. A TLV® may not be recommended for each simple asphyxiant because the limiting factor is the available oxygen. Atmospheres deficient in O_2 do not provide adequate warning and most simple asphyxiants are odorless. Account should be taken of this factor in limiting the concentration of the asphyxiant particularly at elevations greater than 5000 feet where the ρO_2 of the atmosphere may be less than 120 torr.

References

1. Silverthorn DE: Human Physiology: An Integrated Approach, 2nd ed. Prentice-Hall, New Jersey (2001).
2. Guyton AC: Textbook of Medical Physiology, 8th ed. W.B. Saunders Co., Philadelphia (1991).
3. U.S. National Institute for Occupational Safety and Health: A Guide to Industrial Respiratory Protection, DHEW (NIOSH) Pub. No. 76-198. NIOSH, Cincinnati, OH (1976).
4. U.S. National Institute for Occupational Safety and Health: Working in Confined Spaces. DHHS (NIOSH) Pub. No. 80-106. NIOSH, Cincinnati, OH (1979).
5. NIOSH U.S. National Institute for Occupational Safety and Health: NIOSH Respirator Decision Logic. DHHS Pub. No. 87-108. NIOSH, Cincinnati, OH (1987).
6. McManus N: Safety and Health in Confined Spaces. Lewis Publishers, Boca Raton, FL (1999).

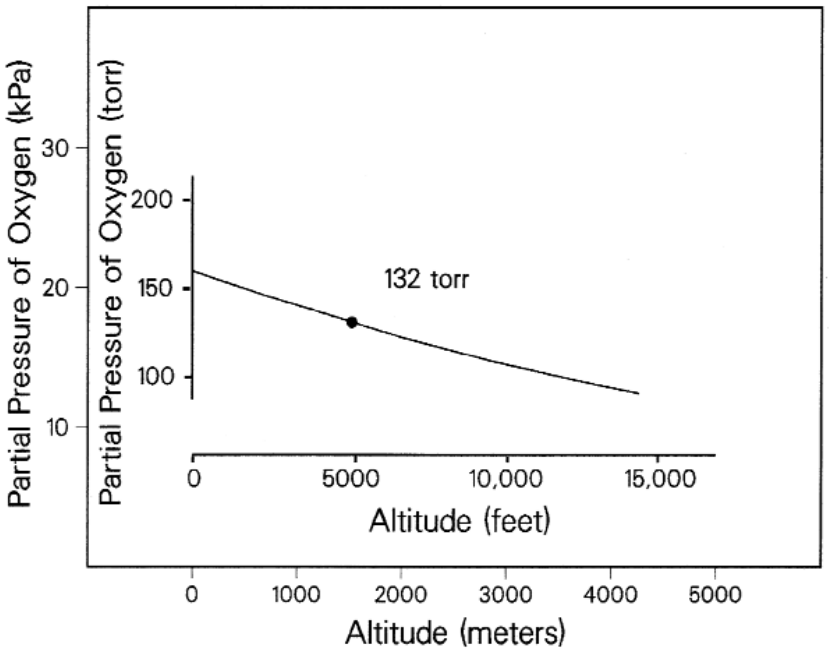

FIGURE F-1. Plot of oxygen partial pressure (ρO_2) (expressed in torr and kPa) with increasing altitude (expressed in feet and meters), showing the recommended oxygen partial pressure of 132 torr.

TABLE F-1. Barometric Pressure, Oxygen Partial Pressure, and Percent Oxygen Concentration Variation with Altitude and Physiological Effect [adapted from McManus[6]]

Altitude Feet (meters)	Barometric Pressure torr, Dry Air[A] (kilopascals)	ρO_2 Equivalent, torr dry air at 20.948% O_2[B] (kilopascals)	$\%O_2$ Equivalent, Dry Air at Sea Level[C] (percent)	Physiological Effect of ρO_2 Levels[D]
0 (0)	760 (101)	159 (21.2)	20.9	
1000 (305)	731 (97.4)	153 (20.4)	20.1	
2000 (610)	704 (93.8)	147 (19.6)	19.3	
3000 (914)	677 (90.3)	142 (18.9)	18.7	
4000 (1219)	652 (86.9)	137 (18.3)	18.0	
5000 (1524)	627 (83.6)	131 (17.5)	17.2	None in healthy adults
6000 (1829)	603 (80.4)	126 (16.8)	16.6	Loss of dark adaptation can occur at elevations above 5000 feet
7000 (2134)	580 (77.3)	121 (16.1)	16.0	Increased pulmonary ventilation and cardiac output, incoordination, and impaired attention and thinking

8000 (2438)	559 (74.5)	117 (15.6)	15.4	Rapid exposure to altitudes over 8000 feet may cause high altitude sickness (respiratory alkalosis, headache, nausea, and vomiting) in unacclimatized individuals. Rapid ascent increases the risk of high altitude pulmonary edema and cerebral edema
9000 (2743)	537 (71.6)	112 (14.9)	14.7	
10000 (3048)	517 (68.9)	108 (14.4)	14.2	
11000 (3353)	498 (66.4)	104 (13.9)	13.7	Abnormal fatigue on exertion, faulty coordination, impaired judgment, emotional upset
12000 (3658)	479 (63.8)	100 (13.3)	13.2	
13000 (3962)	461 (61.5)	98 (12.9)	12.8	
14000 (4267)	443 (59.1)	93 (12.4)	12.2	Impaired respiration, very poor judgment and coordination, tunnel vision

[A]Calculated from $P_{re:\ sea\ level} = 760 \times e^{-(altitude\ in\ feet/25970)}$

[B]Calculated from $\rho O_2 = 0.20948 \times 760 \times e^{-(altitude\ in\ feet/25970)}$

[C]Calculated from: $P_{\%O_2} = 20.948 \times e^{-(altitude\ in\ feet/25970)}$

[D]The approximate physiological effect in healthy adults is influenced by duration of the oxygen deficiency, work rate, breathing rate, temperature, health status, age and pulmonary acclimatization.

APPENDIX G: Substances Whose Adopted *Documentation* and TLVs® Were Withdrawn For a Variety of Reasons, Including Insufficient Data, Regrouping, Etc.

[Individual entries will remain for a 10-year period, commencing with the year of withdrawal]

Substance [CRN]	Year Withdrawn	Reason
Acetylene tetrabromide	2006	Withdrawn in favor of its IUPAC name; *see* 1,1,2,2-Tetrabromoethane
Aluminum [7429-90-5] and compounds, as Al	2008	Combined into Aluminum metal and Insoluble compounds
Aluminum oxide [1344-28-1]	2008	Combined into Aluminum metal and Insoluble compounds
Aluminum welding fumes	2004	TLV® withdrawn as a result of Appendix B removal
APPENDIX B: Substances of Variable Composition	2004	Appendix withdrawn, insufficient data
B1: Polytetrafluoroethylene decomposition products		B1: *Documentation* withdrawn as a result of Appendix removal
B2: Welding fumes (not otherwise specified)		B2: *Documentation* and TLV® withdrawn as a result of Appendix removal
Borates, tetra, sodium salts	2005	Combined into Borate compounds, Inorganic
Butane [106-97-8]	2004	Presently covered by Aliphatic hydrocarbon gases: Alkane [C_1-C_4]
Calcium carbonate [471-34-1]	2007	Insufficient data
Dinitolmide	2007	Withdrawn in favor of its synonym 3,5-Dinitro-o-toluamide
Emery [1302-74-5]	2008	Combined into Aluminum metal and Insoluble compounds
Ethane [74-84-0]	2004	Presently covered by Aliphatic hydrocarbon gases: Alkane [C_1-C_4]

APPENDIX G: Substances Whose Adopted *Documentation* and TLVs® Were Withdrawn For a Variety of Reasons, Including Insufficient Data, Regrouping, Etc.

[Individual entries will remain for a 10-year period, commencing with the year of withdrawal] (Con't.)

Substance [CRN]	Year Withdrawn	Reason
Iron oxide (Fe_2O_3) dust & fume, as Fe	2006	Combined into Iron Oxide
Isopropanol	2006	Withdrawn in favor of its IUPAC name, 2-Propanol
Lead arsenate [3687-31-8], as $Pb_3(AsO_4)_2$	2009	Insufficient data
Liquefied petroleum gas (LPG) [68476-85-7]	2004	Insufficient data
Magnesite [546-93-0]	2006	Insufficient data
Methane [74-82-8]	2004	Presently covered by Aliphatic hydrocarbon gases: Alkane [C_1-C_4]
Particulates (Insoluble) Not Otherwise Specified	2003	Insufficient data; *see* Appendix B
Perlite [93763-70-3]	2006	Insufficient data
Propane [74-98-6]	2004	Presently covered by Aliphatic hydrocarbon gases: Alkane [C_1-C_4]
Rouge	2006	Combined into Iron Oxide
Rubber solvent (Naphtha) [8030-30-6]	2009	Refer to Appendix H: Reciprocal Calculation Method for Certain Refined Hydrocarbon Solvent Vapor Mixtures
Silica, Amorphous — Diatomaceous earth [61790-53-2]	2006	Insufficient data on single-substance exposure, most are co-exposures with crystalline silica
Silica, Amorphous — Fume [69012-64-2]	2006	Insufficient data

APPENDIX G: Substances Whose Adopted *Documentation* and TLVs® Were Withdrawn For a Variety of Reasons, Including Insufficient Data, Regrouping, Etc.

[Individual entries will remain for a 10-year period, commencing with the year of withdrawal] (Con't.)

Substance [CRN]	Year Withdrawn	Reason
Silica, Amorphous — Fused [60676-86-0]	2006	Insufficient data
Silica Amorphous — Precipitated silica and silica gel [112926-00-8]	2006	Insufficient data
Silica, Crystalline — Cristobalite [14464-46-1]	2006	Combined into one TLV® and *Documentation*, i.e., Silica, Crystalline
Silica, Crystalline — Quartz [14808-60-7]	2006	Combined into one TLV® and *Documentation*, i.e., Silica, Crystalline
Silica, Crystalline — Tridymite [15468-32-3]	2005	Insufficient data
Silica, Crystalline — Tripoli [1317-95-9]	2006	Insufficient data and unlikely single-substance exposure. Combined into one TLV® and *Documentation*, i.e., Silica, Crystalline
Silicon [7440-21-3]	2006	Insufficient data
Tetrasodium pyrophosphate [7722-88-5]	2006	Insufficient data
Triphenyl amine [603-34-9]	2008	Insufficient data
Vegetable oil mist	2006	Insufficient data
VM & P Naphtha [8032-32-4]	2009	Refer to Appendix H: Reciprocal Calculation Method for Certain Refined Hydrocarbon Solvent Vapor Mixtures

APPENDIX H: Reciprocal Calculation Method for Certain Refined Hydrocarbon Solvent Vapors

The reciprocal calculation procedure (RCP) is a method for deriving occupational exposure limits (OEL) for refined hydrocarbon solvents. Refined hydrocarbon solvents often are found as mixtures created by distillation of petroleum oil over a particular boiling range. These mixtures may consist of up to 200 components consisting of aliphatic (alkane), cycloaliphatic (cycloalkane) and aromatic hydrocarbons ranging from 5 to 15 carbons.

The goal of the TLV®-CS Committee is to recommend TLVs® for all substances where there is evidence of health effects at airborne concentrations encountered in the workplace. When a sufficient body of evidence exists for a particular substance or mixture, a TLV® is established. However, hydrocarbon solvents are often complex and variable in composition. The use of the mixture formula, found in Appendix E: Threshold Limit Values for Mixtures, is difficult in such cases because these petroleum mixtures contain a large number of unique compounds, many of which do not have a TLV® recommendation.

There are two aspects of the RCP — the methodology and the group guidance values (GGVs). The methodology is based on the special case formula found in pre-2004 versions of the Mixture Appendix in *TLVs® and BEIs® Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*. The RCP formula calculates a unique OEL based on the mass composition of the mixture, the GGVs and where applicable, substance-specific TLVs®.

Group guidance values are categorized based on similar chemical and toxicological concerns. Several entities (both trade groups and regulatory authorities) have adopted group guidance values to utilize with the reciprocal mixture formula (RMF) (Farmer, 1995; UK HSE, 2000; McKee et al., 2005). Two examples of published GGVs are found in Table 1. A mixture-specific time-weighted-average limit ($GGV–TWA_{mixture}$) is calculated based on the mass percent make-up of the designated groups utilizing the reciprocal mixture formula and the GGVs from column *B* or *C* and TLV® values in column *D* found in Table 1.

ACGIH® considers this method to be applicable for mixtures if the toxic effects of individual constituents are additive (i.e., similar toxicological effect on the same target organ or system). The principal toxicological effects of hydrocarbon solvent constituents are acute central nervous system (CNS) depression (characterised by effects ranging from dizziness and drowsiness to anaesthesia) and eye and respiratory tract irritation (McKee et al., 2005; ECETOC, 1997).

Application

The RCP is a special use application. It applies only to hydrocarbon solvents containing saturated aliphatics (normal, iso-alkanes and cycloalkanes) and aromatics with a carbon number of C_5 to C_{15} derived from petroleum and boiled in the range of 35–329°C. It does not apply to petroleum derived fuels, lubricating oils, or solvent mixtures for which there exists a unique TLV®. It does not apply to hydrocarbons with a toxicity that is significantly greater than the mixture at large, such as benzene (see limitations).

Where the mixture is comprised entirely of compounds with unique TLVs®, the mixture should be handled according to Appendix E. When the mixture contains an appreciable amount of a component for which there is a TLV® (i.e., when the use of the TLV® results in a lower GGV–$TWA_{mixture)}$, those specific values should be entered into the RCP (see column *D*, Table 1). When the mixture itself has been assigned a unique TLV®, that value should be utilized rather than the procedures found in this appendix.

Exposure excursions above the calculated GGV–$TWA_{mixture}$ should be handled according to the procedures found in the Introduction to the TLVs® (see *Excursion Limits*).

The reciprocal calculation mixture formula is:

$$GGV_{mixture} = \frac{1}{\frac{F_a}{GGV_a} + \ldots + \frac{F_n}{GGV_n}}$$

where:

$GGV_{mixture}$ = the calculated 8-hour TWA–OEL for the mixture

GGV_a = the guidance value (or TLV®) for group (or component) *a*

F_a = the liquid mass fraction of group (or component) *a* in the hydrocarbon mixture (value between 0–1)

GGV_n = the guidance value (or TLV®) for the n^{th} group (or component)

F_n = the liquid mass fraction of the n^{th} group (or component) in the hydrocarbon mixture (value between 0–1)

The resulting $GGV_{mixture}$ should identify the source of GGVs used in the calculation (i.e., column *B* or *C*).

The resulting calculated $GGV_{mixture}$ value should follow established recommendations regarding rounding. For calculated values < 100 mg/m^3, round to the nearest 25. For calculated values between 100 and 600 mg/m^3, round to the nearest 50, and for calculated values > 600 mg/m^3, round to the nearest 200 mg/m^3.

Limitations

1. The reciprocal formula requires that the composition of the mixture be characterized at least to the detail of mass percent of the groups found in Table 1.
2. The reciprocal formula does not apply to solvents containing benzene, or n-hexane, or methylnaphthalene, which have individual TLVs® significantly less than the GGV to which they would belong and have unique toxicological properties. Whenever present in the mixture, these components should be measured individually and evaluated using the methodology found in Appendix E, i.e., independent treatment or use of the additive formula depending on the TLV® basis.
3. Care in the use of GGV/RMF should be observed where the mixture in question is known to have significant toxicokinetic interactions of components that are manifested at or below GGV levels.
4. The use of the reciprocal formula should be restricted to applications where

TABLE 1. Group Guidance Values

A Hydrocarbon Group	B McKee et al. (mg/m^3)	C UK-HSE 40/2000 (mg/m^3)	D ACGIH® Unique TLVs® (mg/m^3)
C5–C6 Alkanes	1500	1800	Pentane, all isomers (1770) Hexane isomers (1760)
C7–C8 Alkanes	1500	1200	Heptane, all isomers (1640) Octane, all isomers (1401)
C5–C6 Cycloalkanes	1500	1800	Cyclopentane (1720) Cyclohexane (350)
C7–C8 Cycloalkanes	1500	800	Methyl cyclohexane (1610)
C7–C8 Aromatics	200	500	Toluene (75) Xylene, all isomers (434) Ethyl benzene (434)
C9–C15 Alkanes	1200	1200	Nonane, all isomers (1050)
C9–C15 Cycloalkanes	1200	800	
C9–C15 Aromatics*	100	500	Trimethyl benzene, isomers (123) Naphthalene (52) Cumen (246)

*N-Hexane (TLV®-176 mg/m^3) and methylnaphthalenes (TLV®-3 mg/m^3) are significantly below the recommended GGV. Whenever present in the mixture, these components should be measured individually and evaluated using the methodology found in Appendix E, i.e., independent treatment or use of the additive formula depending on the critical effect.

the boiling points of the solvents in the mixture are relatively narrow, within a range of less than 45°C (i.e., vapor pressure within approximately one order of magnitude). The procedure should not be used in situations where the liquid composition is significantly different from the vapor composition. If these conditions cannot be met, the reciprocal formula can be utilized by substituting $F_{(n)}$ in the equation with the vapor mass fraction for each group *(n)* in the hydrocarbon mixture, based on situation-specific airborne concentration measurements.

5. The group guidance values apply only to vapors and do not apply to mists or aerosols. The GGV/RMF procedure does not apply to mixtures containing olefins or other unsaturated compounds or polycyclic aromatic hydrocarbons (PAHs).

Example

A solvent containing the following mass composition is matched with the appropriate group guidance value:

Component	Percent by weight	Group Guidance Value (mg/m³)
C7–C8 alkanes cycloalkanes	45%	1500
C9–C10 alkanes cycloalkanes	40%	1200
C7–C8 aromatics	9%	200
Toluene	6%	75
Benzene	< 1%	-NA-

Based on Column *B*, Table 1 (McKee et al., 2005), the $GGV_{mixture}$ would be:

$$GGV_{mixturc} = \frac{1}{\frac{.45}{1500} + \frac{.40}{1200} + \frac{.09}{200} + \frac{.06}{75}} = \frac{1}{.001884}$$

= 531 (rounded to 550 mg/m³)

Toluene (part of the aromatic C7, 8 fraction) is added as a TLV® rather than a GGV since it makes a difference in the resulting $GGV_{mixture}$. Benzene would be evaluated separately at the current TLV® for benzene.

References

European Centre for Ecotoxicology and Toxicology of Chemicals (ECETOC). Occupational exposure limits for hydrocarbon solvents. Special Report No. 13. Brussels, Belgium (1997).

Farmer TH: Occupational hygiene limits for hydrocarbon solvents. Annals of Occupational Hygiene 40: 237-242 (1995).

McKee RH; Medeiros AM; Daughtrey WC: A proposed methodology for setting occupational exposure limits for hydrocarbon solvents. J of Occ and Env Hygiene 2: 524-542 (2005).

UK Health and Safety Executive (UKHSE) EH40/2000. Occupational Exposure Limits (2000).