



Standard Practice for Measuring the Concentration of Toxic Gases or Vapors Using Detector Tubes¹

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^{e1} NOTE—Footnote 5 was removed editorially in May 2001.

1. Scope

1.1 This practice covers the detection and measurement of concentrations of toxic gases or vapors using detector tubes (1, 2).² A list of some of the gases and vapors that can be detected by this practice, their 1994–95 TLV values recommended by the ACGIH, and their measurement ranges are provided in Annex A1. This list is given as a guide and should be considered neither absolute nor complete.

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

2. Referenced Documents

2.1 ASTM Standards:

D 1356 Terminology Relating to Sampling and Analysis of Atmospheres³

2.2 Other Document:

29 CFR 1910 Federal Occupational Safety and Health Standard Title 29⁴

3. Terminology

3.1 For definitions of terms used in this method, refer to Terminology D 1356.

4. Summary of Practice (3)

4.1 Detector tubes may be used for either short-term sampling (grab sampling; 1 to 10 min typically) or long term

sampling (actively or passively; 1 to 8 h) of atmospheres containing toxic gases or vapors.

4.1.1 *Short-Term Sampling (Grab Sampling) (4-18)*—A given volume of air is pulled through the tube by a mechanical pump. If the substance for which the detector tube was designed is present, the indicator chemical in the tube will change color (stain). The concentration of the gas or vapor may be estimated by either (a) the length-of-stain compared to a calibration chart, or (b) the intensity of the color change compared to a set of standards.

4.1.2 *Long-Term Active Sampling (Long-Term Tubes) (19-22)*—A sample is pulled through the detector tube at a slow, constant flow rate by an electrical pump. The time-weighted average concentration of the gas or vapor is determined by correlating the time of sampling either with (a) the length-of-stain read directly from the calibration curve imprinted on the tube or (b) the intensity of the color change compared to a set of standards.

4.1.3 *Long-Term Passive Sampling (Diffusion or Dosimeter Tubes) (25)*—The contaminant molecules move into the tube according to Fick's First Law of Diffusion. The driving force is the concentration differential between the ambient air and the inside of the tube. The time-weighted average concentration of the gas or vapor is determined by dividing the indication on the tube by the number of hours sampled (1 to 10 h according to the manufacturers' instructions).

4.2 Instructions are given for the calibration of the sampling pumps required in this practice.

4.3 Information on the correct use of the detector tubes is presented.

5. Significance and Use

5.1 The Federal Occupational Safety and Health Administration, in 29 CFR 1910, designates that certain gases and vapors must not be present in workplace atmospheres at concentrations above specific values.

5.2 This practice will provide a means for the determination of airborne concentrations of certain gases and vapors given in 29 CFR 1910.

¹ This practice is under the jurisdiction of ASTM Committee D22 on Sampling and Analysis of Atmospheres and is the direct responsibility of Subcommittee D22.04 on Workplace Atmospheres.

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² The boldface numbers in parentheses refer to the list of references at the end of this practice.

³ *Annual Book of ASTM Standards*, Vol 11.03.

⁴ *Code of Federal Regulations*, Part 1910.1000 Subpart 2 and Part 1926.55 Subpart D.

5.3 A partial list of chemicals for which this practice is applicable is presented in Annex A1.

5.4 This practice also provides for the sampling of gaseous atmospheres to be used for process control or other purposes (2, 23-25).

6. Interferences (26, 27)

6.1 Some common interferences for the various tubes are listed in the instruction sheets provided by the manufacturers.

7. Apparatus (28-31)

7.1 *Detector Tube*—A detector tube consists of a glass tube containing an inert granular material that has been impregnated with a chemical system which reacts with the gas or vapor of interest. As a result of this reaction, the impregnated chemical changes color. The granular material is held in place within the glass tube by porous plugs of a suitable inert material. The ends of the glass tube are flame-sealed to protect the contents during storage.

7.2 Pump (32):

7.2.1 *Short-Term Sampling*—A mechanical, hand-operated, aspirating pump is used to draw the sample through the detector tube during the short-term sampling. Two types of pumps are commercially available: piston-operated and bellows-operated. The pumps have a capacity of 100 mL for a full pump stroke. By varying the number of pump strokes, the sample volume is controlled. Sampling pumps should be maintained and calibration checked periodically according to the manufacturer's instructions. The pumps shall be accurate to $\pm 5\%$ of the volume stated.

7.2.2 *Long-Term Sampling*—Small electrical pumps having stable low flow rates (2 to 50 mL/min), are required for long-term sampling (2 to 8 h). Flow rates to be used with each detector tube are given by the manufacturers. As with the mechanical pumps, the electrical pumps must be maintained and calibrated regularly. Maintenance and calibration are performed using the instructions supplied by the manufacturer of the pump. The pump flow rate, and, therefore, the sampled volume, shall be accurate to $\pm 5\%$ of the stated flow rate. With this system either area or personal monitoring can be accomplished.

7.3 *Accessories*—Several accessories are provided with detector tubes for special applications:

7.3.1 *Reactor Tubes*—These are tubes that are used in conjunction with detector tubes. Some gases and vapors, because of their low reactivity, are not easily detected by detector tubes alone. The reactor tubes consist of very powerful chemical reactants, which break down the unreactive compound into other more readily detectable substances, which standard detector tubes can detect. Thus, the reactor tube is placed upstream of the detector tube and the combination must be used for certain compounds as a detector tube system.

7.3.2 *Dryer Tubes*—Water vapor interferes with the detection of certain substances; therefore, dryer tubes are used upstream of the detector tube in these cases to remove the water vapor.

7.3.3 *Pyrolyzer*—A pyrolyzer is a hot wire instrument operated by batteries. Instructions for its use and maintenance are given in the manufacturers' instruction manuals. The

purpose of the pyrolyzer, as with reactor tubes, is to break down difficult-to-detect compounds into other compounds more easily detected. The breakdown in this case is caused by heat. The pyrolyzer is particularly useful for organic nitrogen compounds, one of the products of breakdown being nitrogen dioxide, which is easily monitored.

7.3.4 *Remote Sampling Line*—When the sampling point is remote from the pump location, a length of nonreactive tubing can be attached to the pump with the detector tube attached to the other end of the tubing. This is useful for sampling in inaccessible or dangerous places.

7.3.5 *Cooling Unit*—The cooling unit consists of a length of metal tubing through which the sampled gas is pulled. Because of the high thermal conductivity of the metal tubing, the hot sampling gas is cooled sufficiently so that it will not destroy the indicator in the detector tube. The cooling unit must be placed upstream from the detector tube. Cooling units are particularly useful when sampling flue gases.

8. Reagents

8.1 The reagents used are specific for each tube, and, to detect a specific gas, may vary from manufacturer to manufacturer. The instruction sheets supplied by the manufacturers give the principal chemical reaction(s) that occur(s) in the tube, thus showing the reagent that is used to react with the gas or vapor to produce the color change.

9. Sampling with Detector Tubes

9.1 *General*—Detector tubes made by one manufacturer must not be used with pumps made by a different manufacturer (33). Each lot of detector tubes is calibrated at the manufacturer's plant, using their equipment. The pumps of other manufacturers have different flow characteristics that cause different lengths-of-stain resulting in erroneous readings.

9.2 *Procedure (34)*—The detector tube program should be conducted under the supervision of a trained professional such as a chemist or an industrial hygienist. Carefully follow the instruction sheet of the manufacturer for the proper use of each detector tube. In general, the instruction sheet will include the following information.

9.2.1 Storage conditions.

9.2.2 Shelf life.

9.2.3 Chemical reaction and color change.

9.2.4 Test procedure.

9.2.5 Significant interferences.

9.2.6 Temperature and humidity correction factors, if required.

9.2.7 Correction for atmospheric pressure.

9.2.8 Measurement range.

10. Accuracy of Detector Tubes

10.1 The Safety Equipment Institute (SEI) has a certification program for certain detector tubes used in short-term sampling. This program is similar to the NIOSH program for evaluating and certifying detector tube performance (35, 36). Under this program the tubes are required to meet an accuracy (95% confidence level) of $\pm 25\%$ between one and five times the SEI test concentration and $\pm 35\%$ at one half the test

concentration. The SEI test concentration is chosen as the Threshold Limit Value as defined by the American Conference of Governmental Industrial Hygienists for the test gas or vapor (37). The calculation of tube accuracy is based on a set of statistical procedures (38) and provides an estimate of accuracy under actual use conditions. The SEI Certified Equipment List should be consulted for the listing of approved units.

10.2 In general, the accuracy of any detector tube depends on the construction and chemistry of the tube along with the actual composition of the test atmosphere and the conditions under which the tube is read. For gases and vapors not covered by the SEI program, detector tubes may or may not meet the accuracy requirements of the previous paragraph (39, 40). There is also some variation in accuracy between manufacturers tubes designed to detect a specific compound. Therefore the user should verify the accuracy with the tube manufacturer or run his own tests to determine accuracy (41-43). It must be emphasized that a correct estimate of accuracy can only be

done by qualified operators and with careful attention to the generation and verification of test gas or vapor concentrations (44).

10.3 Because the accuracy of a detector tube towards a specific compound depends on the cross-sensitivity of the tube to other gases or vapors present in the test atmosphere, the manufacturer should be consulted for information on cross-sensitivity effects for the specific chemistry employed in their tube. Quite frequently, several different indicating chemistries for a specific compound are available. Proper choice of indicating chemistry can minimize the effect of a co-contaminant in the test atmosphere.

11. Keywords

11.1 air monitoring; detector tubes; dosimeter sampling; grab sampling; sampling and analysis; toxic gases and vapor; workplace atmospheres

ANNEX

(Mandatory Information)

A1. SOME COMPOUNDS THAT CAN BE MEASURED BY DETECTOR TUBES

A1.1 The measurement ranges shown in Table A1.1 are not for a single tube. They are for the lowest and highest concentrations listed in manufacturer's brochures. Values are given in ppm(v) unless otherwise indicated.

TABLE A1.1 Non-Exclusive List of Compounds Measurable by Detector Tubes

Substance	1994-1995 TLV ACGIH, ppm(v)	Measurement Range, ppm(v)	Substance	1994-1995 TLV ACGIH, ppm(v)	Measurement Range, ppm(v)
Acetaldehyde	25 ^A	4-10 000	N,N-Dimethylaniline	5	0.5-10
Acetic acid	10	0.13-100	Dimethyl ether	...	100-12 000
Acetic anhydride	5	Qual.	Dimethyl formamide	10	0.8-90
Acetone	750	50-20 000	1,1-Dimethyl hydrazine	0.5 ^E	0.25-3
Acetonitrile	40	...	N-Dimethyl nitrosamine	^E	...
Acetylene	^{B,C}	50-40 000	Dimethyl sulfate	0.1 ^E	0.005-0.6
Acrolein	0.1	0.1-18 000	Dimethyl sulfide	...	1-100
Acrylonitrile	2 ^E	0.13-35 000	Dioxane	25	13-25 000
Allyl chloride	1	Qual.	Epichlorohydrin	2	5-50
Ammonia	25	0.25-300 000	Ethanol amine	3	0.5-6
Amyl acetate (all isomers)	100-125	10-3000	2-Ethoxyethanol	5	Qual.
Amyl alcohols	...	100-2000	Ethyl acetate	400	20-15 000
Amyl mercaptan	...	...	Ethyl acrylate	5 ^E	2-300
Aniline	2	0.5-60	Ethyl alcohol	1000	25-75 000
Antimony hydride, as Sb	0.5 mg/m ³	0.05-3	Ethyl amine	5	1-60
Arsine	0.05	0.04-160	Ethyl benzene	100	5-1800
Benzene	10 ^E	0.13-500	Ethyl bromide	5 ^E	15-400
Benzyl bromide	...	...	Ethyl chloride	1000	50-8000
Benzyl chloride	1	0.2-8	Ethyl chloroformate	...	...
Bromine	0.1	0.2-30	Ethyl ether	400	20-10 000
Bromobenzene	...	30-720	Ethylene	^{B,C}	0.1-5000
Bromoethane	...	15-400	Ethylenediamine	10	0.5-27
Bromoform	0.5	7-200	Ethyleneimine	0.5	...
1,3-Butadiene	2 ^E	1-1200	Ethylene oxide	1 ^E	0.4-40 000
Butane	800	25-8000	Ethyl glycol acetate	...	50-700
2-Butoxyethanol	25	Qual.	Ethyl mercaptan	0.5	0.5-1000
Butyl acetate (all isomers)	150-200	10-10 000	N-Ethyl morpholine	5	...
Butyl alcohol (all isomers)	50-100 ^A	4-5100	Formaldehyde	0.3 ^{A,E}	0.04-6400
Butyl amine (all isomers)	5 ^A	2-36	Formic acid	5	1-2500
Butyl mercaptan	0.5	0.5-15	Furfuryl alcohol	10	Qual.
Carbon dioxide	5000	100-1 000 000	Heptane	400	20-2600
Carbon disulfide	10	0.65-4000	Hexane (all isomers)	50-500	20-12 000
Carbon monoxide	25	2-400 000	Hydrazine	0.1 ^E	0.05-10
Carbon tetrachloride	5 ^F	0.2-70	Hydrochloric acid	5 ^A	0.1-5000
Carbonyl sulfide	...	0.5-60	Hydrocyanic acid	4,7 ^A	0.2-30 000
Chlorine	0.5	0.05-1000	Hydrogen	^{B,C}	500-20 000
Chlorine dioxide	0.1	0.05-20	Hydrogen fluoride as F	3 ^A	0.25-100
Chlorobenzene	10	5-610	Hydrogen selenide as Se	0.05	1-600
Chlorobromomethane	200	5-180	Hydrogen sulfide	10	0.2-400 000
1-Chloro-1,1-difluoroethane	...	Qual.	Isoamyl alcohol	100	Qual.
Chlorodifluoromethane	1000	200-2800	Isobutyl acetate	150	10-1000
Chloroform	10 ^E	2-500	Isobutyl alcohol	50	5-2900
1-Chloro-1-nitropropane	2	...	Isocetane	...	10-1500
Chloropicrin	0.1	0.1-15	Isopropyl acetate	250	20-12 000
β -Chloroprene	10	0.5-90	Isopropyl alcohol	400	20-50 000
Chromic acid, as Cr	0.05 mg/m ³	0.1-0.5 mg/m ³	Isopropylamine	5	2-30
Cumene	50	5-400	Mercury (inorganic)	0.025 mg/m ^{3G}	0.05-13.2 mg/m ³
Cyanogen	10	...	Methyl acetate	200	100-30 000
Cyanides, as CN	5 mg/m ³	2-15 mg/m ³	Methyl acrylate	10	5-200
Cyanogen chloride	0.3 ^A	0.25-5	Methylacrylonitrile	1	0.2-32
Cyclohexane	300	100-6000	Methyl alcohol	200	20-60 000
Cyclohexanol	50	5-500	Methylamine	5	1-60
Cyclohexylamine	10	2-38	Methyl bromide	5	0.5-600
Decaborane	0.05	...	Methyl chloride	50	...
Demeton	0.01	Qual.	Methyl chloroformate	...	...
Demetonmethyl	0.5 mg/m ³	Qual.	Methyl chloroform	350	5-1500
Diborane	0.1	0.02-5	Methyl cyclohexanol (all isomers)	50	5-100
1,2-Dibromoethane	^E	5-700	Methylene chloride	50 ^E	25-3000
o-Dichlorobenzene	25	2.5-300	Methyl ethyl ketone (MEK)	200	20-50 000
p-Dichlorobenzene	10 ^F	2.5-300	Methyl hydrazine	0.2 ^{A,E}	0.2-10
Dichlorodifluoromethane (R-12)	1000	...	Methyl iodide	2 ^E	5-40
1,1-Dichloroethane	100	8-300	Methyl isobutyl carbinol	25	...
1,2-Dichloroethane	10	5-720	Methyl isobutyl ketone (MIBK)	50	5-15 600
1,2-Dichloroethylene	200	5-500	Methyl mercaptan	0.5	0.25-1650
Dichloroethyl ether	5	...	Methyl methacrylate	100	5-700
1,1-Dichloro-1-nitroethane	2	...	Methyl styrene	50	10-500
Dichlorotetra fluoroethane (R-114)	1000	200-2800	Morpholine	20	Qual.
Dichlorovos	0.1	0.05	Nickel carbonyl	0.05	0.1-800
Diethylamine	5 ^A	1-60	Nitric acid	2	0.1-700
Diethyl benzene	...	...	Nitric oxide	25	0.5-5000
Diisobutyl ketone	25	...	Nitroethane	100	...
Diisopropylamine	5	Qual.	Nitrogen dioxide	3	0.5-1000
Dimethyl acetamide	10	1.5-400	Nitroglycerine	0.05	Qual.
Dimethylamine	5	1-60	Nitroglycol	...	0.25

TABLE A1.1 *Continued*

Substance	1994–1995 TLV ACGIH, ppm(v)	Measurement Range, ppm(v)	Substance	1994–1995 TLV ACGIH, ppm(v)	Measurement Range, ppm(v)
Nitromethane	20	...	Sulfuric acid	1 mg/m ³	1–5 mg/m ³
1-Nitropropane	25	...	1,1,2,2-Tetrabromoethane	...	25–200
2-Nitropropane	10 ^F	...	1,1,2,2-Tetrachloroethane	1	50–1000
Octane	300	10–5000	Tetrachloropropene	...	...
Oil (mist and vapour)	5 mg/m ³	1–10 mg/m ³	Tetrahydrofuran	200	20–50 000
Oxygen	...	1.5–24 vol. %	Tetrahydrothiophene	...	1–16
Ozone	0.1 ^A	0.025–1000	Toluene	50	1–1800
Pentane	600	50–3900	2,4-Toluene diisocyanate	0.005	0.02–0.2
Perchloroethylene	25 ^F	0.1–10 000	2,6-Toluene diisocyanate	...	0.02–0.2
Phenol	5	0.4–63	1,1,2-Trichloroethane	10	10–170
Phosgene	0.1	0.02–75	Trichloroethylene	50 ^H	0.125–10 000
Phosphine	0.3	0.01–3000	Trichlorofluoromethane (R 11)	1000 ^A	100–1400
Propane	^{B,C}	100–20 000	1,2,3-Trichloropropane	10	10–1200
Propyl acetate (both isomers)	200	20–14 000	1,1,2-Trichloro-1,2,2-tri- fluoroethane (R 113)	1000	200–2800
Propylene	^{B,C}	20–31 400	Triethylamine	1	1–60
Propylene dichloride	75	5–440	Trifluorobromomethane	1000	Qual.
Propylene imine	2 ^E	0.25–3	Trimethylamine	5	1–30
Propylene oxide	20	500–50 000	Vinyl chloride	5 ^P	0.025–10 000
Propyl mercaptan	...	0.5–10	Vinylidene chloride	5	0.4–600
n-Propyl nitrate	25	...	Vinyl pyridine	...	...
Pyridine	5	0.2–35	Water vapour	...	0.05–40 mg/L
Stibine	0.1	0.05–3	Xylene (all isomers)	100	5–2500
Styrene, monomer	50	2–1000			
Sulfur dioxide	2	0.1–80 000			

- ^A Denotes ceiling limit.
^B Simple asphyxiant.
^C Explosive.
^D Confirmed human carcinogen.
^E Suspected human carcinogen.
^F Animal carcinogen.
^G Not classifiable as a human carcinogen.
^H Not suspected as a human carcinogen.

REFERENCES

- (1) *Air Sampling Instruments by the American Conference of Governmental Hygienists*, 4th ed., 1972.
- (2) American Industrial Hygiene Association: *Direct Reading Colorimetric Indicator Tubes*, 1st ed., 1976.
- (3) Collings, A. J., "Performance Standard for Detector Tube Units Used to Monitor Gases and Vapors in Working Areas," *Pure and Applied Chemistry*, Vol 54, pp. 1763–1767, 1982.
- (4) Saltzman, B. E., *Direct Reading Colorimetric Indicators, Air Sampling Instruments for Evaluation of Atmospheric Contaminants*, fourth ed., American Conference of Governmental Industrial Hygienists, 1972.
- (5) Ketcham, N. H., "Practical Experience with Routine Use of Field Indicators," *American Industrial Hygiene Association Journal*, Vol 23, p. 127, 1962.
- (6) Linch, A. L. and H. Pfaff, "Carbon Monoxide—Evaluation of Exposure Potential by Personnel Monitor Surveys," *American Industrial Hygiene Association Journal*, Vol 32, p. 745, 1971.
- (7) Kitagawa, T: "The Rapid Measurement of Toxic Gases and Vapors," Transactions of the 13th International Congress on Occupational Health, New York, NY, 1960.
- (8) Ringold, A., Goldsmith, J. R., Helwig, H. L., Finn, R., and F. Scheute, "Estimating Recent Carbon Monoxide Exposures, A Rapid Method," *Archives of Environmental Health* Vol 5, p. 38, 1963.
- (9) Liechnitz, K., "Detector Tube Measuring Techniques," *Ecomed*, 1983.
- (10) Beatty, R. L., "Methods for Detecting and Determining Carbon Monoxide," *Bureau of Mines Bulletin 557*, 1955.
- (11) Ingram, W. T., "Personal Air Pollution Monitoring Devices," *American Industrial Hygiene Association Journal*, Vol 25, p. 298, 1964.
- (12) Linch, A. L., *Evaluation of Ambient Air Quality by Personnel Monitoring*, CRC Press Inc., 1974.
- (13) Shepherd, M., "Rapid Determination of Small Amounts of Carbon Monoxide," *Analytical Chemistry* Vol 19, pp. 77–81, 1947.
- (14) Shepherd, M., Schuhmann, S., and M. V. Kilday, "Determination of Carbon Monoxide in Air Pollution Studies," *Analytical Chemistry* Vol 27, pp. 380–383, 1955.
- (15) Shepherd, G. M., "Colorimetric Gas Detection," U.S. Patent No. 2 487 077, 1949.
- (16) McConnaughey, P. W., "Article for the Determination of Carbon Monoxide," U.S. Patent No. 3 507 623, April 21, 1970.
- (17) Littlefield, J. B., Yant, W. P., and L. B. Berger, "A Detector for Quantitative Estimation of Low Concentrations of Hydrogen Sulfide," Department of the Interior, U.S. Bureau of Mines Report, Vol 3276, 1935.
- (18) Underhill, Dwight W., "New Developments in Dosimetry," Department of Industrial Environmental Health Science, University of Pittsburgh, Pittsburgh, PA, 1982.
- (19) Jentzch, D., and D. A. Frazer, "A Laboratory Evaluation of Long Term Detector Tubes," *American Industrial Hygiene Association Journal*, Vol 42, pp. 810–823, 1981.
- (20) Liechnitz, K., "Detector Tubes and Prolonged Air Sampling," *National Safety News*, April 1977.
- (21) Liechnitz, K., "Detector Tubes for Long-Term Measurements," *Annals of Occupational Hygiene*, Vol 19, pp. 159–161, 1976.
- (22) Portable Pump, Model C-210 Instruction Manual, Mine Safety Appliances Company; Revision 2 1983.
- (23) Coldwell, B. B., and H. W. Smith, "Alcohol Levels in Body Fluids After Ingestion of Distilled Spirits," *Canadian Journal of Biochemistry*, Vol 37, p. 43, 1959.
- (24) Turner, R. F. et al., "Evaluating Chemical Tests for Intoxication."

- (25) Hill, R. H., and D. A. Fraser, "Passive Dosimetry Using Detector Tubes," *American Industrial Hygiene Association Journal*, Vol 41, pp. 721–729, 1980.
- (26) Ayer, H. E., and Saltzman, B. E., "Notes of Interferences by Oxides of Nitrogen with Estimations of Carbon Monoxide in Air by the NBS Indicating Tubes," *American Industrial Hygiene Association Journal*, Vol 20, pp. 337–338, 1959.
- (27) McCammon, Charles S. Jr., et al., "The Effect of Extreme Humidity and Temperature on Gas Detector Tube Performance," *American Industrial Hygiene Association Journal*, Vol 43, pp. 18–25, 1982.
- (28) Gas and Vapor Detection Products, National Draeger, Inc., Pittsburgh, PA 1984.
- (29) Gas Detector Tubes, Sensidyne/Gastec, Sensidyne, Inc., Layo, FL.
- (30) Gas Detector Tubes (T-102-5), Matheson Kitagowa, Matheson Safety Products, East Rutherford, NJ, 1982.
- (31) Detector Tubes, Reagents and Accessories for Samplair[®] Pump (Data Sheet 08-01-02), MSA, Pittsburgh, PA, 1984.
- (32) Samplair Pump, Model A (Data Sheet 08-02-02), MSA, Pittsburgh, PA, 1981.
- (33) Colen, Frederick H., "A Study of the Interchangeability of Gas Detector Tubes and Pumps," Report No. TR-71, National Institute for Occupational Safety and Health, Morgantown, WV, June 15, 1972.
- (34) ISO/TC 146/SC 2N55, "Determination of the Mass Concentration of Carbon Monoxide by Direct Indicating Detector Tubes," April 1981.
- (35) "Certification of Gas Detector Tube Units," Federal Register, Vol 38, No. 88, p. 11458 May 8, 1973, or Code of Federal Regulations, Title 42, Part 84.
- (36) Roper, P., "The NIOSH Detector Tube Certification Program," *American Industrial Hygiene Association Journal*, Vol 35, p. 438, 1974.
- (37) *Threshold Limit Values for Chemical Substances in the Work Environment*, adopted by the A.C.G.I.H. with Intended Changes for 1989–1990, *American Conference of Governmental Industrial Hygienists*, Cincinnati, OH.
- (38) Leidel, N. A., and K. A. Busch, "Statistical Methods for the Determination of Noncompliance with Occupational Health Standards," *National Institute for Occupational Safety and Health Technical Report*, 1975.
- (39) Leesch, J. G., "Accuracy of Different Sampling Pumps and Detector Tube Combinations to Determine Phosphine Concentrations," *Journal of Economic Entomology*, Vol 75, pp. 899–905, 1982.
- (40) McKee, Elmer S., and Paul W. McConnaughey, "Evaluation of Eight Frequently Used Detector Tubes," presentation at the *American Industrial Hygiene Conference*, Detroit, MI, 1984.
- (41) Stead, F. M., and G. J. Taylor, "Calibration of Field Equipment from Air Vapor Mixtures in a Five Gallon Bottle," *Journal of Industrial Hygiene Toxicology*, Vol 29, p. 408, 1974.
- (42) Setterlind, A. N., "Preparation of Known Concentrations of Gases and Vapors in Air," *American Industrial Hygiene Association Quarterly*, Vol 14, p. 113, 1953.
- (43) Nelson, G. O., *Controlled Test Atmospheres, Principles and Techniques*, Ann Arbor Science Publishers, 1971.
- (44) Brief, R. S., "Problems and Pitfalls in the Application and Use of Portable Direct-Reading Air Sampling Instruments, Proceedings of the National Safety Congress," *Industrial Subject Sessions*, p. 24, 1972.

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