Chapter 17

Detector Tubes, Direct-Reading Passive Badges, and Dosimeter Tubes

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Detector Tubes

Development of Detector Tubes

Three types of direct-reading, colorimetric indicators have been in use for the determination of contaminant concentrations in air: liquid reagents; chemically treated papers; and glass detector tubes containing solid indicating chemicals. An early comprehensive bibliography in this area was prepared by Campbell and Miller.(1)

Liquid Reagents

Convenient laboratory procedures using liquid reagents have been simplified and packaged for field use. Reagents are supplied in sealed ampules or tubes, frequently in concentrated or even solid forms that are diluted or dissolved for use. Unstable mixtures may be freshly prepared when needed by breaking an ampule containing one ingredient inside a plastic tube or bottle containing the other. Commercial apparatus of this type is available for tetraethyl lead, tetramethyl lead, and TDI/MDI. Certain liquid reagents, such as those used for nitrogen dioxide sampling, produce a direct color upon exposure without requiring additional chemicals or manipulations. These permit simplified sampling equipment. Thus, relatively high concentrations of nitrogen dioxide may be determined directly by drawing an air sample into a 50- or 100-mL glass syringe containing a measured quantity of absorbing liquid reagent, capping, and shaking. Liquids containing indicators have been used for determining acid or alkaline gases by measuring the volume of air required to produce a color change. These liquid methods are somewhat inconvenient and bulky to transport and require a degree of skill to use. However, they are capable of good accuracy because measurement of color in liquids is inherently more reproducible and accurate than measurement of color on solids.

Chemically-Treated Papers

Chemically treated papers have been used to detect and determine gases because of their convenience and compactness. An early example of this detection method is the Gutzeit method in which arsine blackens a paper strip impregnated previously with mercuric bromide. Such papers may be freshly prepared and used wet, or stored and used in the dry state. Special chemical chalks or crayons have been used(2) to sensitize ordinary paper for phosgene, hydrogen cyanide, and other war gases. Semi-quantitative determinations may be made by hanging the paper in contaminated air. Inexpensive detector tabs are available commercially which darken upon exposure to carbon monoxide.(3) The accuracy of such procedures is limited by the fact that the volume of the air sample is rather indefinite and the degree of color change in the paper is influenced by air currents and temperature. More quantitative results may be obtained by using a sampling device capable of passing a measured volume of air over or through a definite area of paper at a controlled rate, as is done in commercial devices known as *tape samplers* which detect hydrogen sulfide, toluene diisocyanate, hydrogen fluoride and other compounds. Particulate matter contaminants such as chromic acid and lead may be determined similarly, usually by addition of liquid reagents to the sample on a filter paper. Visual evaluation of the stains on the paper may be made by comparison with color charts or by photoelectric instruments. Recording photoelectric instruments that use sensitized paper tapes operate in this manner; however, they are not described in this chapter. For more information, see the extensive discussions in the 7th Edition (1989) of this book, Chapter N entitled "*Sequential and Tape Samplers*" pages 291–303, and the 8th Edition, in Chapter 19, pages 445, 478–480.

Accuracy of these methods requires uniform sensitivity of the paper, stability of all chemicals used, and careful calibration. In the case of particulate matter analysis, it may be necessary to calibrate with the specific dust being sampled if the degree of a chemical's solubility is important.

Surface Wipe Sampling and Analysis

Recently, industrial hygienists have shown more interest in the detection of hazardous materials on surfaces, dust, soil, and metal. Consequently, several vendors developed test kits for the qualitative and semi-quantitative detection of toxic metals such as Pb, Ni, Cd, Hg, and others, as well as for various types of organic and inorganic compounds. Chemically-treated papers are often used. The colorimetric chemical reactions for such detection are the classic chemical reactions used for qualitative analysis in chemistry, and many reactions are similar to those listed on Table 17-1. Vendors for such products can be found at the end of this chapter, under the vendors' section on wipe tests.

Glass Detector Tubes

Glass detector tubes containing solid chemicals are another type of convenient and compact direct-reading device. The earliest detector tubes were made in 1920 to detect carbon monoxide in coal mines. A listing of early references was presented in a previous edition of this text.(4) There has been a great expansion in the development and use of detector tubes,(5–17) and more than 400 different types are now available commercially. Several manuals provide comprehensive descriptions and listings.(18–22) Because of the great popularity and wide use of glass detector tubes, the bulk of this discussion will deal with them, although much of the information will be applicable to the liquid and paper indicators as well.

Applications of Detector Tubes

There are many uses for detector tubes. They are convenient for qualitative(23) and semi-quantitative evaluation of toxic hazards in industrial atmospheres and for rapid evaluation of spills of hazardous materials.(24) They are also used for ambient air pollution studies, although in most situations, few available tubes have the required sensitivity. Detector tubes may be used for detection of explosive hazards as well as for process control of gas composition. Confirmation of carbon monoxide poisoning may be made by determining carbon monoxide in exhaled breath or in gas released from a sample of blood (after following an appropriate procedure to release the bound carbon monoxide). Determination of benzene in the exhaled air has also been reported.(25) Detector tubes have been used to evaluate and monitor permeation of chemicals through chemical-protective clothing.(26)

Detector tubes may be used for law enforcement purposes, such as determining ethyl alcohol in the

TABLE 17-1. Common Colorimetric Reactions in Gas Detector Tubes

1. Reduction of chromate or dichromate to chromous ion:

Draeger: Acetaldehyde 100/a; acetone 500/a-L; alcohol 100/a; aniline 0.5a; cyclohexane 100/a; diethyl ether 100/a; ethanol 500/a-L, 1000/a-D; ethyl acetate 200/a, 500/a-D; ethyl glycol acetate 50/a; ethylene oxide 25/a; n-hexane 100/a; hydrocarbons 100/a-L; methanol 50/a; n-pentane 100/a; o-toluidine 1/a.

Gastec: Acetone 151; aniline 181; amyl acetate 147; butane 104; butyl acetate 142, 142L; n-butanol 115; cyclo hexanol 118; ethanol 112, 112L; ethyl acetate 141, 141L; ethyl ether 161, 161L; ethylene oxide 163; gasoline 101, 101L; hexane 102H, 102L; hydrocarbons 103; isoamyl acetate 148; isoamyl alcohol 117; isobutyl acetate 144; isobutanol 116; isopropanol 113, 113L; isopropyl acetate 146; LP gas 100A; methanol 111, 111L, 111LL; methyl cyclohexanol 119; methyl ethyl ketone 152; methyl isobutyl ketone 153; methyl methacrylate 149; petroleum naphtha 106; propane 100B; propyl acetate 145; sulfur dioxide 5H; tetrahydrofuran 159; vinyl chloride 131.

Kitagawa: Acetone 102SA, 102SD; acrylonitrile 128SA, 128B; allyl alcohol 184S; butadiene 168SA, 168SC; butane 221SA; butanol 207U; butyl acetate 138SA, 138U; butyl acrylate 211U; butyl cellosolve 190U; cyclohexane 115S; cyclohexanol 206U; cyclohexanone 197U; diacetone alcohol 195U; dichloroethane 235S, 230S; dimethyl ether 123; dioxane 154; ether 107SA, 107U; ethyl acetate 111SA, 111U; ethyl alcohol 104A; ethylene oxide 122; furan 161; gasoline 110S; general hydrocarbons 187S; n-hexane 113; isobutyl acetate 153; isoprene 241U; isopropanol 150; isopropyl acetate 149, 111U; methyl acetate 148; methyl acrylate 211U; methyl alcohol 119; methyl ethyl ketone 139B; methyl isobutyl ketone 155; naphthalene 226U; organic gases 186; propyl acetate 151; propylene oxide 163; sulfur dioxide 103; tetrahydrofuran 162; vinyl chloride 132.

MSA: Ethanol 804136; ethylene 804428; hexane 497664.

2. Reduction of iodine pentoxide plus fuming sulfuric acid to iodine:

Draeger: Benzene 2/a, 5/b, 20/a-L; carbon disulfide 5/a, 10/a-L; carbon monoxide 2/a, 5/c, 8/a, 10/a-L, 10/b, 50/a-L, 0.001%/a, 0.3%/b; ethyl benzene 30/a; hydrocarbon 0.1%/a; methylene chloride 100/a*, 50/a-I*, natural gas*; petroleum hydrocarbons 100/a; polytest; toluene 5/a, 200/a-L.

Gastec: Acetylene 171; benzene 121, 121L, 121S, 121SL; carbon monoxide 1HH, 1H, 1M, 1LK; chlorobenzene 126; o-dichlorobenzene 127; hydrocarbons 105; stoddard solvent 128; toluene 122, 122L; trichloroethylene 132HH; xylene 123.

Kitagawa: Benzene 118SB, SC; carbon monoxide 106, chlorobenzene 178S; chloropicrin 172; dichlorobenzene 214S; ethylbenzene 179S; toluene 124SA, SB; xylene 134S.

MSA: Carbon disulfide 492514; carbon monoxide 803943, 487334, 804423, 487335, 488906(HP); dichloromethane 804416, gasoline 492870, perchloroethylene 804429, 487337; qualitest 497665; toluene 803947; trichloroethane 487343.

3. Reduction of chemical with ammonium molybdate plus palladium sulfate to molybdenum blue:

Draeger: Ethylene 0.1/a, 50/a; methyl acrylate 5/a; methyl methacrylate 50/a.

Gastec: Butadiene 174, 174L; ethylene 172, 172L.

Kitagawa: Acetylene 101S; Butadiene 168SB; carbon monoxide 106A, 106B, 106C*; ethylene 108B, 108SA; hydrogen sulfide and sulfur dioxide 120C.

MSA: Carbon monoxide 47134, ethyl mercaptan 804589

4. Reaction with potassium palladosulfite:

Draeger: Carbon monoxide 50/a-D.

Gastec: Carbon monoxide 1L, 1La, 1LL; hydrogen 30; hydrogen cyanide 12H

Kitagawa: Carbon monoxide 100, 106.

5. Color change of pH indicators (e.g. bromphenol blue, phenol red, thymol blue, methyl orange):

Draeger: Acetic acid 5/a, 5/a-L, 10/a-D; acetone 1000/a-D*; acid test; acrylonitrile 1/a*, 5/a*; amine; ammonia 2/a, 5/a, 10/a-L, 20/a-D; 0.5%/a; carbon dioxide 1000/a-L, 500/a-D, 1%/a-D; chlorobenzene 5/a*; cyanide 2/a*; cyclohexylamine 2/a; dimethylformamide 10/b*; formic acid 1/a; halogenated hydrocarbons 100/a**; hydrazine 0.25/a; hydrochloric acid 2/a, 10/a-D, 10/a-L, 50/a; hydrocyanic acid 2/a*, 20/a-D*; hydrogen fluoride 2/a-L; nitric acid 1/a; perchloroethylene 50/a-L; phosphine 0.01/a*; phosphoric acid esters 0.05/a*; sulfur dioxide 0.1/a*, 2/a-L; triethylamine 5/a; vinyl chloride 0.5/a*.

Gastec: Acetaldehyde 92, 92M; acetic acid 81, 81L; acrolein 93; acrylonitrile 191, 191L; amines 180, 180L; ammonia 3H, 3M, 3L, 3La; arsine 19LA; tert-butyl mercaptan 75, 75L; carbon dioxide 2HH, 2H, 2L, 2LL; carbon disulfide 13, 13M; carbonyl sulfide 21; chlorine 8HH; diborane 22; 1,2-dichloroethylene 139; dimethylacetamide 184; dimethylformamide 183; ethyl mercaptan 72L, formaldehyde 91M, 91L; hydrazine 185; hydrogen chloride 14M, 14L; hydrogen cyanide 12M, 12; hydrogen fluoride 17; mercaptans 70L; methacrylonitrile 192; nitric acid 15L; 2-pentenenitrile 193; perchloroethylene 133HA, 133M, 133L, 133LL; phosphine 7, 7La; pyridine 182; sulfur dioxide 5M, 5L, 5La, 5Lb; trichloroethylene 132HA, 132HM, 132L, 132LL; vinyl chloride 131La, 131L; vinylidine chloride 130L.

Kitagawa: Acetaldehyde 133A, 133SB; acetic acid 216S; acetone 102SC; acrolein 136; acrylonitrile 128SC, 128SD; ammonia 105, 105B; arsine 121U; mercaptans 130U; carbon dioxide 126SA, 126SB, 126SC, 126SD, 126SH,

TABLE 17-1 (cont.). Common Colorimetric Reactions in Gas Detector Tubes

126UH; carbon disulfide 141SA, 141SB; carbonyl sulfide 239S; chloroprene; diborane 242S; dichloroether 223S; diethylamine 222S; formaldehyde 171SA; hydrazine 219S; hydrogen chloride 173SA; hydrogen cyanide 112B; nitric acid 233S; silane 240S.

MSA: Acetic acid 804138; ammonia 804405, 800300, 804406, carbon dioxide 497606, 487333, 804419, 488907(HP); formaldehyde 497649; hydrogen chloride 803948; hydrogen cyanide 803945, hydrogen fluoride 804142; sulfur dioxide 497661; triethylamine 804134.

6. Reaction with o-tolidine:

Draeger: Chlorine 0.2/a, 0.3b, 1/a-L, 50/a; chloroform 2/a*; epichlorohydrin 5/b*; fluorine 0.1/a*; nitrogen dioxide 10/a-D; perchloroethylene 10/b, 200/a-D; trichloroethane 50/d*; trichloroethylene 2/a*, 10/a, 10/a-L*, 200/a-D; vinyl chloride 1/a*, 10/a-L*.

Gastec: Chlorine 8H, 8Ha; chloroform 137; methyl bromide 136H, 136L, 136La; methylene chloride 138; nitrogen dioxide 9L; nitrogen oxides 11HA, 11S, 11L; nitric oxide 10; 1,1,1-trichloroethane 135, 135L.

Kitagawa: Bromine 114; chlorine 109SA, 109SB; chlorine dioxide 116; nitrogen dioxide 117.

7. Reaction with tetraphenylbenzidine:

MSA: Part 82399 for bromine, chlorine, chlorine dioxide. Part 83099 for nitrogen dioxide. Part 85833** for chlorobromomethane; 1,1-dichloroethane; dichloroethylene (cis-1,2 and trans-1,2); ethyl bromide; ethyl chloride; perchloroethylene (tetrachloroethylene); trichloroethylene; 1,2,3-trichloropropane; vinyl chloride (chloroethylene). Part 85834* for chlorobenzene (mono); 1,2-dibromoethane (ethylene dibromide); dichlorobenzene (ortho); 1,2-dichloroethane (ethylene dichloride); dichloroethyl ether; 1,1-dichloroethylene (vinylidine chloride); methyl bromide; methylene chloride (dichloromethane); propylene dichloride (1,2-dichloropropane); 1,1,2,2-tetrabromoethane; 1,1,2,2-tetrachloroethane; 1,1,3,3-tetrachloropropane; trichloroethane (beta 1,1,2); vinyl chloride (chloroethylene). Part 87042 for bromine; chlorine. Part 88536* for carbon tetrachloride; chlorobromomethane; 1-chloro-1,1-difluoroethane (Genetron 14213); chlorodifluoromethane (Freon 22); chloroform (trichloromethane); chloropentafluoroethane (Freon 115); chlorotrifluoromethane (Freon 13); 1,2-dibromoethane (ethylene dibromide); dichlorodifluoromethane (Freon 12); 1,1-dichloroethylene (vinylidine chloride); dichloroethylene (cis-1,2); dichlorotetrafluoroethane (Freon 114); fluorotrichloromethane (Freon 11); Freon 113; Freon 502; methyl bromide; methyl chloroform (1,1,1-trichloroethane); methylene chloride (dichloromethane); perchloroethylene (tetrachloroethylene); trichloroethane (beta 1,1,2); trichloroethylene; 1,1,2-trichloro-1,2,2-trifluoroethane (Freon 113); trifluoromonobromomethane (Freon 13131). Part 91624** for acetonitrile; acrylonitrile; 1-chloro-l-nitropropane; cyanogen; 1,1-dichloro-l-nitroethane; dimethylacetamide; dimethylformamide; fumigants (Acritet, Insect-O-Fume, Fume-I-Gate, termi-Gas, Termi-Nate); methacrylonitrile; nitroethane; nitromethane, 1-nitropropane; 2-nitropropane; n-propyl nitrate; pyridine; vinyl chloride. Part 460225 for chlorine. Part 460424* for nitric oxide.

8. Reaction of 2,4-dinitrophenylhydrazine forming a hydrazone:

MSA: Acetone 804141; methyl ethyl ketone 813334

9. Oxidation by a iodate/sulfuric acid reagent:

MSA: Aromatic hydrocarbons 804132; benzene 807024, 804411.

10. Oxidation of an aromatic amine:

MSA: Chlorine 803944; chlorine dioxide 804133, nitrogen dioxide 487341, 804435; nitrous fumes 487336, 804425, 803946, 804426; trichloroethane 487342; vinyl chloride 803950.

11. Reaction with a lead or silver compound forming the sulfide or metal.

MSA: Hydrogen sulfide 487399, 487340, phosphine 497101, 485680, 489119

12. Reaction of chemical with copper iodide.

MSA: Mercury 497663.

13. Oxidation of indigotine to isatine.

MSA: Ozone 804140

14. Reaction of chemical with sulfuric acid:

MSA: Phenol 813778, styrene 804135.

15. Reaction with an aromatic aminoaldehyde and an aromatic amine.

MSA: Phosgene 803949.

16. Reaction of chemical with iodine, forming an iodide.

MSA: Sulfur dioxide 487338, 497662, SF_6 decomposition products 804433.

17. Precipitation of selenium from selenium/sulfuric acid.

MSA: Water vapor 488908.

* = Multiple reactions or multiple layer tube for improved specificity or preliminary reaction
** = Pyrolyzer required
HP = high pressure tube

breath, or to detect gasoline in soil in cases of suspected arson or leakage from underground tanks. Subsoil diffusion of volatile liquid contaminants can be inexpensively tracked.(27) One method of tracking subsoil diffusion involves hammering a Draeger-Stitz probe (a drill rod and probe tip) up to 6 meters deep into the soil at each sampling location. The rod is then withdrawn slightly to open the tip, and a detector tube in a capillary probe is lowered inside to the bottom to sample the vapor. It is connected through a capillary tube to a pump above ground. Alternatively, a charcoal tube or monitoring instrument probe may be inserted to sample the vapor. Minute quantities of ions in aqueous solutions also may be determined, such as sulfide in wastewater from pulp manufacturing, chromic acid in electrolytic plating wastewater, and nickel ion in wastewater of refineries.

Volatile contaminants in sewage or wastewater, such as ammonia, hydrogen cyanide, hydrogen sulfide, benzene, or chlorinated hydrocarbons, may be rapidly estimated with detector tubes. For this detection method, a 100-mL of sewage or wastewater sample is placed in a bubbler. One liter of air is then drawn through a train comprised of a charcoal tube, the bubbler, and a detector tube, which responds to the stripped contaminants.(28) Detector tubes were developed for the determination of aerosols such as oil, chromium (VI) oxide, cyanide, and sulfuric acid.(29) A special use of detector tubes for analyzing uranium hexafluoride hydrolysis products (uranyl fluoride and hydrofluoric acid) by utilizing hydrogen fluoride tubes has been reported.(30) Use of the detector tubes in the construction industry has been reported.(31)

Detector tubes have been widely advertised as being capable of use by unskilled personnel. Although it is true that the operating procedures are simple, rapid, and convenient, many limitations and potential errors are inherent in this method. The results may be dangerously misleading unless the sampling procedure is supervised and the findings are interpreted, preferably by an adequately trained occupational hygienist or by a professional with a science background. In the last few years, portable electronic instruments have been introduced by several manufacturers that can automatically do the air sampling and also the measurement, i.e., directly read the color changes, convert to ppb or ppm concentration and display it on an LCD screen, thus increasing accuracy and precision. Also, there are electronic units that can convert color changes on the passive badge samples and display their concentrations. Similarly, there are electronic colorimeter units that can convert color changes in passive bubblers and display them as concentration.(32)

Operating Procedures–Detector Tubes

Preparation for Sampling

The use of detector tubes is extremely simple. After its two sealed ends are broken open, place the glass tube in the manufacturer's holder which is fitted with a calibrated squeeze bellows or piston pump. Ascertain that the air flow direction is first through the tube to the pump. [Caution: use the same manufacturer's pump and tubes; do not mix different manufacturers' pumps and tubes; see further discussion section below under "Interchangeability of Detector Tube Brands."] Most detector tubes manufacturers have an arrow printed on the tube, indicating the direction that air should be entering the tube. The recommended air volume is then drawn through the tube by the operator. Adequate time must be allowed for each stroke. Even if a squeeze bellows is fully expanded, it may still be under a partial vacuum and may not have drawn its full volume of air. The manufacturer's sampling instructions must be followed closely.

Reading the Result

The observer then reads the concentration in the air by examining the exposed tube. Some of the earlier types of tubes were provided with charts of color tints to be matched with the solid chemical in the indicating portion of the tube. This visual judgment depended, of course, on the color vision of the observer and the lighting conditions. In an attempt to reduce the errors due to variations among observers, more recent types of tubes are based on a variable length of stain being produced on the indicator gel. There are a few tubes in which a variable volume of sample is collected until a standard length of stain is obtained; however, in most cases a fixed volume of sample is passed through the tube and the stain length is measured against a calibration scale. The scale may be printed either directly on the tube or on a provided chart.

The range in the interpretation of results by different observers is large because in many cases the end of a stain front is diffuse rather than sharp. Experience in sampling known concentrations is of great value in training an operator to know whether to measure the length at the beginning or end of the stain front or at some other portion of an irregularly shaped stain. In some cases, the stains change with time; thus, reading the stain length should not be unduly delayed.

Testing the Pump

Care must be taken to see that leak-proof pump valves and connections are maintained. A leakage test to ensure adequate performance may be made by inserting an unopened detector tube into the holder and squeezing the bulb; at the end of two minutes, any appreciable bulb expansion is evidence of a leak. If the apparatus is fitted with a calibrated piston pump, the handle is pulled back and locked. Two minutes later, it is released cautiously and the piston is allowed to pull back in; it should remain out no more than 5% of its original distance. Leakage indicates the need to replace check valves, tube connections, or the squeeze bellows or to grease the piston.

Flow Test

At periodic intervals, the flow rate of the apparatus should be checked and maintained within specifications for the tube calibrations (generally ± 10%). This may be done simply by timing the period of squeeze bellows expansion. A more accurate method is to place a used detector tube in the holder and draw an air sample through a calibrated rotameter. Alternatively, the air may be drawn from a burette in an inverted vertical position, which is sealed with a soap film, and the motion of the film past the graduations can be timed with a stop watch.(33) The latter method also provides a check on the total volume of the sample which is drawn. In some devices, the major resistance to the air flow is in the chemical packing of the tube; thus, each batch might require checking. An incorrect flow rate may indicate a partially clogged strainer or orifice that should be cleaned or replaced.

With most types of squeeze bellows and hand pumps, the sample air flow rate is variable, being high initially and low toward the end when the bulb or pump is almost filled. This variability has been claimed to be an advantage because the initially high rate gives a long stain and the final low rate sharpens the stain front. If the concentration is rapidly fluctuating during the sampling period, the variable flow rate will cause the reading to be an inaccurate mean value. The stain lengths may depend more on flow rate than on concentration. Colen(34, 35) found that flow patterns for six commonly used pumps were different. When five popular brands of carbon monoxide tubes were used with pumps other than their own, grossly erroneous results (with 268% variability) were observed, even with identical sample volumes. It should be noted that accuracy requires a close reproduction of the flow rate pattern for the calibrations to be correct.

Interchangeability of Detector Tube Brands

Interchanging brands can cause large errors that may not be apparent to the user. This practice could result in erroneous concentration levels of the toxic gas being measured. The detector tube and its pump form a system that is calibrated at the factory. A new calibration is conducted with each individual production lot of tubes.(36) The pump must provide the correct volume of air and provide a flow rate curve comparable to that used at the factory calibration in order for the calibration marks placed on that lot of tubes to remain valid.

Because all five major brands of detector tubes use a 100 cc pump, many people reason that the systems must be interchangeable. The fallacy of this reasoning lies in the fact that the rate of airflow also affects stain length. The target gas and the reagent in the analyzer layer of the tube must have adequate contact time to react with one another. If something is done to speed up the flow rate, the contact time is decreased and a smaller percentage of the reagent will react. The target gas will travel farther into the tube before it is consumed. The result is a stain that is paler in color but longer than the stain produced during factory calibration at that particular gas concentration. The typical user reads the length of the stain and not the color intensity; thus, the tube will be reading high, producing a loss in system accuracy.

Conversely, if the flow rate is slowed, the contact time is increased and a higher percentage of the reagent layer will react than was reacted at the factory calibration. This produces a shorter stain that is darker in color than the intended stain for that concentration. Now the tube is reading low, a potentially dangerous situation in applications like confined space entry testing, where a hazardous condition could be misconstrued as being safe.

Detector tube brands control flow rate in a variety of ways. Some systems use an orifice in the pump to slow the flow rate and produce the desired target gas/reagent-layer contact time. Other systems use densely packed detector tubes to provide the resistance. Interchanging systems that use these opposite flow restrictions can produce very wide accuracy swings. A nonrestricted tube with a non-restricted pump produces a flow rate that is much too fast and can produce high readings. A restricted pump mated with a restricted tube can slow the flow rate significantly below the tube's intended flow rate and produce low readings.

Even similarly restricted designs can produce faulty flow rates if interchanged. For example, piston pumps produce a much higher initial vacuum than bellows pumps. Even if two systems use tube restriction to control flow rate, the restrictions can be drastically different to accommodate the different pump vacuum levels intended for each brand of tube. Various agencies and organizations, both domestic and international, have been advocating the non-interchangeability of brands: the American Industrial Hygiene Association (AIHA),(22) National Institute for Occupational Safety and Health (NIOSH),(34) Occupational Safety and Health Administration (OSHA),(37) International Union of Pure and Applied Chemistry (IUPAC),(38) American National Standards Institute/Industrial Safety Equipment Association (ANSI/ISEA),(39) and Safety Equipment Institute (SEI).(40) The SEI certification on detector tubes is a system-certification that includes the pump and tube as a unit. Interchanging of components of different brands voids the certification. Therefore, do not mix bellows pump/tube systems with piston pump tube systems. However, there have been recent discussions and tests done for the interchangeability of the same piston-pump designs. A study conducted by a university laboratory for RAE Systems using their LP-1200 hand pump against Gastec/Sensidyne (GV/100) and Kitagawa (8014-400A) hand pumps indicated that these three manufacturers' gas detection tubes gave the same readings within 20% of the standard gas values (results can be viewed at *www.raesystems.com/tn129.htm*). The maximum deviation between any two pumps on a given tube was 10%. The conclusion was independent of the types of gases measured (10 different gases, total of 25 different gas concentrations in triplicate).

Special Air Sampling Techniques

Hard-to-Reach Areas. A number of special techniques may be used in appropriate cases. When sampling in inaccessible places, the indicator tube may be placed directly at the sampling point and the pump operated at some distance away. A rubber or Tygon tube extension of the same inside diameter as the indicator tube may be inserted between the pump and indicator tube. Such tubes are available commercially as accessories. Lengths as great as 60 ft have been successfully used without appreciable error, provided that more time is allowed between strokes of the pump to compensate for the reservoir effect and to obtain the full volume of sample. This method has the disadvantage that the detector tube cannot be observed during the sampling.

Hot-Temperature Areas. A second arrangement may be used when sampling hot gases such as from a furnace stack or engine exhaust. Cooling the sample is essential in these cases; otherwise, the calibration would be inaccurate and the volume of the gas sample uncertain. A probe of glass or metal, available commercially as an accessory, may be attached to the inlet end of the detector tube with a short piece of flexible tubing.(41) If this tube is cold initially, as little as 10 cm of tubing outside of the furnace is sufficient to cool the gas sample from 250°C to about 30°C. Such a probe has to be employed with caution. In some cases, serious adsorption errors occur either on the tube or in condensed moisture. The dead volume of the probe should be negligible in comparison to the volume of sample taken. Solvent vapors should not be sampled by this method. When sampling air colder than 0°C, clasping the tube in the hand warms it sufficiently to eliminate any error.(41) Critical studies(42, 43) of applications for analysis of diesel exhaust showed serious errors for some tubes.

Other special techniques also may be employed. Combustion and decomposition gases from a fire may be rapidly evaluated with a set of five different tubes in a special holder that allows simultaneous sampling using one pump. These systems require special calibration. Some symmetrical tubes can be reversed in the holder and used for a second test. In certain special cases, tubes may be reused if a negative test was previously obtained; however, this should be done with caution and only after reading the manufacturer's recommendations for reuse of detector tubes. Two tubes also may be connected in series in special cases; e.g., first passing crude gas through a Kitagawa hydrogen sulfide tube and then through a phosgene tube to obtain two simultaneous determinations and remove interferences. These techniques may be used only after testing verifies that they do not impair the validity of the results.

High-Pressure Areas. Tubes also have been used for sampling in pressures as high as several atmospheres. This situation would exist, for example, in underwater stations. If both the tube and pump are in the chamber, the calibrations and sample volumes both may be altered. It has been reported(41, 44) that only the latter occurs for the following Draeger tubes: ammonia 5/a, arsine 0.05/a; carbon dioxide 0.1%/a; carbon monoxide 5/c,10/b; and hydrogen sulfide 1/c, 5/b. For these tubes, the corrected concentration is equal to the scale reading (ppm or vol %) divided by the ambient pressure (in atmospheres) at the pump. When tube tips are broken in a pressure chamber, the tube filling should be checked for possible displacement.

Specificity and Sensitivity of Detector Tubes

Multiple Uses

The specificity of the detector tubes is a major consideration for determining applicability and interpreting results. Most tubes are not specific. Chromate reduction is a common reaction used in tubes for detection of organic compounds. In the presence of mixtures, the uncritical acceptance of such readings can be grossly misleading. Comprehensive listings of reactions, as well as a discussion of other major aspects, are available.(18–21, 45) Seventeen common reactions and the associated tube types are listed in Table 17-1. The name of the compound listed on the tube often refers to its calibration scale rather than to a unique chemical reaction of its contents. [*Caution*: The detector tube may be useful for several compounds, but it is calibrated only for one, e.g., the aromatic hydrocarbons tube is calibrated for benzene.]

The lack of specificity of some tubes may be used to advantage for detection of substances other than those indicated by the manufacturer. In this respect, tubes using colorimetric reactions 1, 2, 6, and 7 (Table 17-1) are widely applicable. Thus, the Draeger Polytest screening tube (reaction 2) and ethyl acetate tube (reaction 1) may be used for qualitative indications of reducing and organic materials, respectively.(46) The Draeger trichloroethylene tube (reaction 6) is also applicable to chloroform, o-dichlorobenzene, dichloroethylene, ethylene chloride, methylene chloride, and perchloroethylene. The methyl bromide tube may be used for chlorobromomethane and methyl chloroform. The chlorine tube may be used for bromine and chlorine dioxide. The toluene tube may be used for xylene. Such use requires specific knowledge of the identity of the reagent and of the proper corrections to the calibration scales.

For some brands of indicator tubes, the units of the calibration scales are in milligrams per cubic meter. Although it has been said that this method of expression eliminates the necessity of making temperature and pressure corrections, such a claim is debatable because the scale calibrations themselves may be highly dependent on these variables. Units of parts per million or percent by volume are most common for industrial hygiene purposes and are used on most of the newer tubes. Conversions may be made from milligrams per cubic meter to parts per million by using the formula below (explained in Chapter 8, Calibration of Gas and Vapor Samples).

$$\text{ppm} = [(\text{mg/m}^3) \cdot 24.45] / \text{MW}$$

where MW = molecular weight

Low Levels of Detection

Although detector tubes are generally designed for detection of relatively high gas concentrations found in industrial workplaces, some have been applied to much lower outdoor air pollutant concentrations. Kitagawa(47) determined 0.01–2 ppm of nitrogen dioxide using two glass tubes in series, with the temperature controlled at 40°C. The first tube contained diatomaceous earth impregnated with a specific concentration of sulfuric acid to regulate the humidity of the air sample. The second tube, 120 mm long × 2.4 mm inside diameter, contained white silica gel impregnated with *o*-tolidine (now available as Matheson-Kitagawa commercial tube no. 8014-117SB, has a range of 0.5–30 ppm, SEI-certified.) Air was drawn through the tubes for 30 min at 180 mL/min by an electric pump with a stainless steel orifice plate at its inlet. Grosskopf(48, 49) determined 0.007–0.5 ppm nitrogen dioxide by drawing air through a Draeger 0.5/a nitrous gas tube with a diaphragm pump for 10–40 min at the rate of 0.5 L/min. Readings were not affected by flow rates if the flow rates exceeded 0.5 L/min. No comments were given on the specificity, except that humidity from 30 L of air at 70% relative humidity did not impair the sensitivity. This tube responds to nitric oxide and to oxidants, both of which commonly may be present. Leichnitz(50) reported a tube (Draeger sulfur dioxide 0.1/a) capable of measuring 0.1–3 ppm of sulfur dioxide. This tube requires 100 strokes of a hand bellows pump (each taking 7–14 seconds) or use of the Draeger Quantimeter electric pump in which a motor-driven crank controlled by a microprocessor operates a bellows. This pump is described in the "Instrument Descriptions" section at the end of this chapter.

Less success was attained when carbon monoxide detector tubes were used for sampling periods of 4 hrs or longer with continuous pumps. It was found that at low concentrations, after an initial period, the stain lengths ceased to increase.(8) However, at higher concentrations, a new calibration could be made(51) (for 3- to 5-hr samples at 8 mL/min through a Kitagawa 100 tube in the range of 30–100 ppm of carbon monoxide). The latter investigator hypothesized that the oxygen in air bleached the black palladium stain and caused the front of stain produced by low concentrations to remain stationary after the first 20–30 min. Effects of water vapor and other contaminants must also be considered in this application. A new calibration is essential under the flow conditions to be used. Studies confirmed that secondary reactions, which bleached the indication and prevented long-term sampling, could be avoided with appropriate reagent systems.(52)

Long-Duration Sampling Tubes

Detector tubes have been developed(53, 54) for long duration sampling (4–8 hrs). These appear to be very similar to the tubes designed for short duration sampling and are effective within the same concentration ranges. They are calibrated for use with a continuous sampling pump, but they operate at lower flow rates. The application of these tubes is to provide time-weighted average concentrations rather than short-term (few minutes) values. To provide valid averages, the calibrations must be linear both with concentration and time and should display uniformly spaced markings for uniform increments of contaminants. The scales on these tubes usually are in terms of microliters of test gas (ppm × liters), rather than ppm, and the latter is calculated by dividing the scale reading by the liters of air sampled. Over 30 types of long-duration tubes are now available commercially. It should be noted that they must be used within the ranges of flow rate and total sampling time established during their calibration by the manufacturer, using the specified continuous sampling pump. A comparison of grab samples and long-term samples for ammonia in swine confinement buildings showed a consistent discrepancy; the long-term values were double the grab sample averages.(55) In other studies, low flow MDA Accuhaler pumps were used, with some loss of accuracy.(56) They generally are not suitable for analysis of concentrations in ranges lower than those of ordinary tubes designed for short duration sampling(57) because of the previously mentioned problems of water vapor, oxygen, and other contaminants.

Increasing Accuracy of Detector Tubes

Greater accuracy can be obtained when several detector tubes are used for replicate sampling. A simplified statistical approach based on an assumed normal distribution of values was recommended for taking 3–10 samples.(58) However, subsequent work indicated that most of the variations were due to the environmental fluctuations rather than to the relatively small analytical errors, and that a lognormal distribution was more appropriate. A step-by-step procedure was presented(59) which categorized the results into noncompliance (less than 5% chance of erroneously citing when actually compliance exists), no decision, and compliance (less than 5% chance of failing to cite when actually noncompliance exists).

Problems in the Manufacture of Detector Tubes

Color-Indicating Gel

The accuracy, limitations, and applications of detector tubes are highly dependent on the skill with which they were manufactured.(60) Generally, the supporting material is silica gel, alumina, ground glass, pumice, or resin. This material is impregnated with an indicator chemical that should be stable, specific, sensitive, and produce a color which strongly contrasts with the unexposed color and is non-fading for at least an hour. If the reaction with the test gas is relatively slow, a color is produced throughout the length of the tube because the gas is incompletely adsorbed and the concentration at the exiting end is an appreciable fraction of that at the entrance. Such a color must be matched against a chart of standard tints. A rapidly reacting indicating chemical is much more desirable and yields a length-of-stain type of tube in which the test gas is completely adsorbed in the stained portion.

There is a very wide and unpredictable variation in the properties of different batches of indicating gel. The major portion of the chemical reaction probably occurs on the surface. Therefore, the number of active centers, which are highly sensitive to trace impurities, affect the reaction rate. These problems are well known in the preparation of various catalysts. Close controls must be kept on the purity and quality of the materials, the method of preparation, the cleanliness of the air in the factory or glove box in which the tubes are assembled, the inside diameter of the glass tubes, and even on the size analysis of the impregnated gel, which, in some cases, is important in controlling the flow rate. The manufacturer must also accurately calibrate each batch of indicating gel.

Some tube types are constructed with multiple layers of different impregnated gels with inert separators. Generally, the first layer is a precleansing chemical to remove interfering gases and improve the specificity of the indication. Thus, in the case of some carbon monoxide tubes, chemicals are provided to remove interfering hydrocarbons and nitrogen oxides. In carbon disulfide tubes, hydrogen sulfide is first removed. In hydrogen cyanide tubes, hydrogen chloride or sulfur dioxide are removed first. In other cases, the entrance layer provides a preliminary reaction essential to the indicating reaction. Thus, in some trichloroethylene tubes, the first oxidation layer liberates a halogen which is indicated in the subsequent layer. In some tubes for NO_x gases, a mixture of chromium trioxide and concentrated sulfuric acid is used to oxidize nitric oxide to nitrogen dioxide, which is the form to which the sensitive indicating layer responds. Although such multiple layer tubes are advantageous when properly constructed, they frequently have a shorter shelf life because of diffusion of chemicals between layers and consequent deterioration.

Shelf-Life Factors

A shelf-life of at least two years is highly desirable for practical purposes. A great deal of disappointment with various tube performances is no doubt due to inadequate shelf-life. Because some tubes have only been on the market for a short time, the manufacturer may have inadequate experience with the shelf-life of the product. Small variations in impurities, such as the moisture content, may have a large effect on the shelf-lives of different batches. The storage temperature, of course, greatly

TABLE 17-2. Shelf Life of Draeger Carbon Monoxide Detector Tubes

Temperature		
°C	°F	Shelf Life
25	77	>2 years
50	122	>1/2 year
80	176	weeks
100	212	1 week
125	257	3 days

[Note: above data may vary or may not be valid with other types of detector tubes or other brands. These data plot as an approximately straight line when the logarithm of the shelf-life time is plotted against a linear scale of the reciprocal of absolute temperature. Such a plot is usual for the reaction rate of a simple chemical reaction. In other cases, relationships may be more complex.]

affects the shelf-life, and it is highly desirable to store these tubes in a refrigerator or in a cool dark place. The accuracy of tubes stored on the back window shelf of a car may be rapidly destroyed by hot sunlight. In some cases, shelf-life has been estimated by accelerated tests at higher temperatures. Such a variation of shelf-life (length of time within which the calibration accuracy is maintained at ± 25%) is illustrated by the data listed in Table 17-2 received in a personal communication from Dr. Karl Grosskopf of the Draeger Company before 1965 and reconfirmed with Dr. Kurt Leichnitz of the Draeger Company in 1999, however, these data were not published.

Shipping

The shipping properties of tubes must also be controlled carefully. Loosely packed indicating gels may shift, causing an error in the zero point of scales printed directly on the detector tube, as well as an error in total stain length. When the size analysis indicates an appreciable range of fine particles, the fines may segregate during shipment to one side of the bore, causing different flow resistances and rates on each side of the tube. This may cause oval stain fronts that are not perpendicular to the tube bore. If the indicating gel is friable, the size analysis may change during shipping.

Obviously, satisfactory results can be obtained only if the manufacturers take great pains in the design, production, and calibration of tubes.

Theory of Calibration Scales

Up to now, calibration scales have been entirely empirical. The variables that can affect the length of stain are concentration of test gas, volume of air sample, sampling flow rate, temperature, and pressure, and a number of factors related to tube construction. There is a striking similarity in the fact that most of the length of stain calibration scales are logarithmic with respect to concentration in spite of the widely differing chemicals employed in different tube types. Although very few data are available for these relationships, a basic mathematical analysis was made by Saltzman.(61) The theoretical formulas discussed below will, of course, have to be modified as more data become available. The relationships were also studied by Grosskopf(49) and Leichnitz.(62)

In the usual case, although the test gas is adsorbed completely, equilibrium is not reached between the gas and the adsorbing indicator gel because the sampling period is relatively short and the flow rate is relatively high. The length of stain is determined by the kinetic rate at which the gas either reacts with the indicating chemical or is adsorbed on the silica gel. The theoretical analysis shows that the stain length is proportional to the logarithm of the product of gas concentration and sample volume:

$$L/H = \ln (CV) + \ln (K/H) \qquad \textbf{(1)}$$

where: L = the stain length, cm
C = the gas concentration, ppm
V = the air sample volume, cm3
K = a constant for a given type of detector tube and analyte gas, cm^{-2}
H = a mass transfer proportionality factor having the dimension of centimeters, and known as the height of a mass transfer unit

The factor H varies with the sampling flow rate raised to an exponent of between 0.5 and 1.0, depending on the nature of the process that limits the kinetic rate of adsorption. This process may be diffusion of the test gas through a stagnant gas film surrounding the gel particles, the rate of surface chemical reaction, or diffusion in the solid gel particles. If the detector tube follows this mathematical model, a plot of stain length, L, on a linear scale, versus the logarithm of product CV (for a fixed constant flow rate) will be a straight line of slope H. It is important to control the flow rate because it may affect stain lengths more than gas concentrations due to its influence on the factor H.

If larger volume samples are taken at low concentrations and the value of L/H exceeds 4, the gel approaches equilibrium saturation at the inlet end, and calibration relationships are modified. The solution to the equations for this case has been presented graphically by Saltzman(61) in a generalized chart. However, there is little advantage to be gained in greatly increasing the sample size, because the stain front is greatly broadened and various errors are increased.

For some types of tubes such as hydrogen sulfide and ammonia and for long duration tubes, the reaction rate is fast enough that equilibrium can be attained between the indicating gel and the test gas. Under these conditions, there is a stoichiometric relationship between the volume of discolored indicating gel and the quantity of test gas adsorbed. In the simplest case, the stain length is proportional to the product of concentration and volume sampled:

$$L = K\,C\,V \tag{2}$$

If adsorption is important, the exponent of concentration may differ from unity:

$$L = K\,C^{(1-n)}\,V \tag{3}$$

The value of n is the same as that in the Freundlich isotherm equation for equilibrium adsorption, which states that the mass of gas adsorbed per unit mass of gel is proportional to the gas concentration raised to the power n. If the value of n is unity, which is not unusual, Equation 3 indicates that stain length is proportional to sample volume but is independent of concentration. The physical meaning of this is that all concentrations of gas are adsorbed completely by a fixed depth of gel. Such a tube is obviously of no practical value.

Equilibrium conditions may be assumed for a given type of indicator tube if stain lengths are directly proportioned to the volume of air sampled (at a fixed concentration) and are not affected by air sampling flow rate. A log-log plot then may be made of stain length versus concentration for a fixed volume. A straight line with a slope of unity indicates that Equation 2 applies; if another value of slope is obtained, Equation 3 applies.

In some of the narrower indicator tubes, manufacturing variation in tube diameters produces an appreciable percentage variation in tube cross-sectional areas. This results in an error in the calibration as high as 50% because the volume of sample per unit cross-sectional areas is different from that under standard test conditions. An additional complicating factor is the variation produced in flow rate per unit cross-sectional area. If an exactly equal quantity of indicating gel is put into each tube, variations in cross-sectional areas will be indicated by corresponding variations in the filled tube lengths. Correction charts are provided by one manufacturer on which the tube is positioned according to the filled length and a scale is given for reading stain lengths. Although the corrections are rather complex, practically linear corrections are very close approximations that can reduce the errors to 10%. In most tubes, the tube diameters are controlled closely enough that no correction is necessary.

Temperature is another important variable for tube calibrations. The effect is different for different tubes. Because the color tint type of tube depends on the degree of reaction, it is most sensitive to temperature. For example, some old types of carbon monoxide tubes require correction by a factor of 2 for each deviation of 10°C from the standard calibration conditions.

Errors in judging stain lengths produce equal percentage errors in concentration derived from the calibration scale. Errors in measuring sample volume and in flow rate may also result in errors in the final value, although the exact relationships might vary according to the tubes.

Many other complications can be expected in calibration relationships. Thus, for nitrogen dioxide, the proportion of side reactions is changed at different flow rates. Changing sample volumes freely from calibration conditions is not recommended unless the tube is known to be thoroughly free from the effects of interfering gases and humidity in the air.

A crucial factor in the accuracy of the calibration is the apparatus used for preparing known low concentrations of the test gas (this subject is discussed more fully in "Calibration of Gas Vapor Samples" in Chapter 8). Some manufacturers have used static methods for calibration. However, experience has shown that losses of 50% or more by adsorption are not uncommon. Low concentrations of reactive gases and vapors are best prepared in a dynamic system. This has the further advantages of capabilities to generate extended volumes and to rapidly change concentrations as required. With either type of apparatus, it is highly desirable to check the concentrations using chemical methods of known accuracy. Some successful systems have been described.(63–69)

A simple and compact dynamic apparatus for accurately diluting tank gas (which may be either pure or a mixture) was developed by Saltzman(64, 65) and Avera.(66) The asbestos plug flowmeter measures and controls gas flows in the range of a few hundredths to a few milliliters per minute (note: because asbestos is no longer available, a similar inert packing material may be substituted). Air-vapor mixtures of volatile organic liquids may be prepared in a flow dilution apparatus using a motor-driven hypodermic syringe. High quality gears, bearings, and screws are needed in the motor drive to provide the uniform slow motion. Some commercial devices have been found unsatisfactory in this regard. Many types of permeation tubes now available have also been proven useful.

It is highly desirable for the user, as well as the manufacturer, to have facilities available for checking calibrations. Only in this manner may the user be confident that the tubes and corresponding technique are adequate for the intended purposes. Tubes may also be applied to gases other than those for which they have been calibrated by the manufacturer, in certain special cases, if the user can prepare a new calibration scale.

Performance Evaluation and Certification of Detector Tubes

Background

Evaluations by users of many types of tubes have been reported.(15, 72–95) Temperature and humidity were found to be significant factors in some cases.(96, 97) Accuracy was found to be highly variable. In some cases, the tubes were completely satisfactory; in others, completely unsatisfactory. Manufacturers, in their efforts to improve the range and sensitivity of their products, are rapidly changing the contents of their tubes, and these reports are frequently obsolete before they appear in print. Improved quality control, and perhaps greater self-policing of the industry, would greatly increase the value of the tubes, especially for the small consumer who is not in a position to check calibrations.

ACGIH Recommendations for Certification

After reviewing this need, a joint committee of the American Conference of Governmental Industrial Hygienists (ACGIH)—and AIHA in 1971 made the following recommendations:(98)

1. Manufacturers should supply a calibration chart (ppm) for each batch of tubes.
2. Length-of-stain tubes are preferable to those exhibiting change in hue or intensity of color.
3. Tests of calibrations should be made at 0.5, 1.0, 2.0, and 5.0 times the ACGIH Threshold Limit Value (TLV®).
4. The manufacturer should specify the methods of tests. Values should be checked by two independent methods.
5. Calibration at each test point should be accurate within ±25% (95% confidence limit).
6. Allowable ranges and corrections should be listed for temperature, pressure, and relative humidity.
7. Each batch of tubes should be labeled with a number and an expiration date. Instructions for proper storage should be given.
8. Tolerable concentrations of interferents should be listed.
9. Pumping volumes should be accurate within ±5%, and flow rates should be indicated.
10. Special calibrations should be provided for extended sampling for low concentrations, and flow rates should be specified.

Former NIOSH Certification Program

A performance evaluation program was initiated in the early 1970s by NIOSH. Known concentrations of test substances were generated in flow systems from sources such as cylinder mixtures, vapor pressure equilibration at known temperatures, or permeation tubes. Although few tubes achieved an accuracy of ±25%, many types showed accuracies in the range of ±25% to ±35%.(79–85)

A formal certification program (99, 100) was the next step. In addition to passing performance evaluation tests at the Morgantown, West Virginia, NIOSH laboratory, manufacturers were required to provide information on the contents of the tubes and to conduct a specified quality control program. Because of the dependence of the calibrations on the pumps used with the tubes, certifications were periodically updated and issued(101) for specified combinations of tubes and pumps. By 1981, tubes of four manufacturers for 23 contaminants had been certified. Unfortunately, the program was terminated in 1983 for lack of funding.(102)

The requirements for certification generally followed the recommendations of the joint ACGIH/AIHA committee. However, the accuracy requirement was modified to ±35% at 0.5 times the ACGIH TLV and ±25% at 1.0, 2.0, and 5.0 times the TLV, to be maintained until the expiration date, if the tubes were stored according to the manufacturer's instructions. At the TLV concentration, either the stain length had to be 15 mm or greater, or the relative standard deviation of the readings of the same tube by three or more independent tube readers had to be less than 10%. If the stain front was not exactly perpendicular to the tube axis (because of channeling of the air flow), the difference between the longest and shortest stain length measurements to the front had to be less than 20% of the mean length. Color intensity tubes had to have sufficient charts and sampling volume combinations to provide scale values including at least the following multiples of the TLV: 0.5, 0.75, 1.0, 2.0, 2.5, 3.0, 4.0, and 5.0; the relative standard deviation for readings of a tube by independent readers had to be <10%. Tests were to be conducted generally at 18.3°–29.5°C (65°–85°F) and at relative humidity of 50%, unless the humidity had to be reduced to avoid disturbing the test system. The manufacturer had to file a quality control plan and keep records of inspections of raw materials, finished tubes, and calibration and test equipment. Acceptable statistical quality levels for defects in finished tubes were as follows: critical 0% where tests were nondestructive; otherwise, 1.0%, major 2.5%, minor 4.0%, and accuracy 6.5%. Typical statistical calculations have been described.(103) Certification seals were affixed to approved devices. NIOSH reserved the right to withdraw certification for cause.

National and International Certification Programs

Because important legal and economic consequences depend on the accuracy of measurements of contaminant concentrations, enforcement agencies will most likely prefer certified equipment. Standards for detector tubes have been issued by more than 25 organizations,(104) including OSHA,(105) IUPAC,(106) Japanese Standards Association,(107) British Standards Institution,(108) ANSI,(109) the International Standards Organization (ISO),(110, 111) European Committee for Standardization (ECS/CEN),(112) France, the Soviet Union, the Council of Europe, and a variety of private organizations in the United States and Europe. Requirements are mostly similar to those cited above. A comparison study of the detector tube method versus European Standards has been reported. (113)

Certification by the Safety Equipment Institute

In 1986, the Safety Equipment Institute (SEI) announced a voluntary program for third-party certification of detector tubes.(114) Manufacturers submit tubes for testing as the schedule for each type is announced. Two AIHA-accredited laboratories were selected to evaluate the tubes according to the NIOSH protocol.(99) Another contractor makes onsite, quality assurance audits of manufacturing facilities every 6 months for three audits, and then annually. If the tubes meet all requirements, the manufacturer may apply the SEI certification mark. This program should provide a stimulus for greater acceptance and use and for further improvements in detector tube technology. Tubes will be retested every 3 years. Table 17-3 gives the current listing of certified tubes.(115) Types of tubes for more substances are currently in the testing process. For the latest information on SEI-certified detector tubes contact SEI at their Internet homepage at *http://www.SEInet.org*.

Passive Dosimeters (Stain Length)

Background

An important new advance has been the development of direct-reading, passive dosimeters. Passive dosimetry uses diffusion of the test gas and eliminates the need for a sampling pump and its calibration. These attractive devices are compact, convenient, and relatively inexpensive. (Description of lab-analyzed passive dosimeters is found in Chapter 16). In early work, detector tubes for toluene, ethanol, and isopropanol were cut open at the entrance of the chemical packing.(116) Later, glass adapters with a membrane (e.g., Millipore®, or silicone rubber) were used (117–119) to provide a draft shield, in some cases a pretreatment chemical layer, and a diffusion resistance. Simpler commercial devices merely provided a score mark which permitted breaking the tube at a controlled point.(120) Some allowed a controlled air space (e.g., 15 mm) upstream from the indicating gel to serve as the initial resistance to diffusion.(121) In some devices, rather than an indicating gel, a strip of chemically impregnated paper is inserted in the glass tube.

Theory

The theoretical calibration relationships for these devices rest upon Fick's First Law of Diffusion, which can be expressed as:

$$W = 10^{-6}\, C\, t\, D\, (A/X) \tag{4}$$

where: W = cm^3 of analyte gas collected
t = time, seconds
D = diffusion coefficient, cm^2/s
A = effective orifice cross-section area, cm^2
X = orifice length, cm

This equation assumes that the gas is completely adsorbed in the indicating gel and that there is no significant back diffusion pressure. A second common assumption is that the stain length is proportional to the amount adsorbed (analogous to Equation 2):

$$L = K\, W \tag{5}$$

The test gas diffuses through a membrane or air space, then through the stained length of indicating gel, and is finally adsorbed at the stain front, which is assumed to be relatively narrow. It is convenient to express X in terms of L:

$$X = r + L \tag{6}$$

TABLE 17-3. Certifications of Detector Tubes by the Safety Equipment Institute (SEI)[A] as of May 2000

Substance	Matheson/ Kitagawa	Mine Safety Appliances Co.	Draeger Safety, Inc.	Sensidyne/ Gastec	TLV/TWA (ppm)
Acetic acid	8014-216S	—	—	81	10
Acetone	8014-102SD	—	—	151L	750
Ammonia	8014-105SC	—	—	3La	25
Benzene	8014-118SC	—	—	121	10
Carbon dioxide	8014-126SA	—	—	2L	5000
Carbon disulfide	8014-141SB	—	—	13	10
Carbon monoxide	8014-106S	—	—	1La	50
Chlorine	8014-109SB	—	—	8La	1.0
Hydrogen chloride	8014-173SB	—	—	14L	5 [C]
Hydrogen cyanide	8014-112SB	—	2/a, CH25701	12L	10 [C]
Hydrogen sulfide	8014-120SD	487339	—	4LL	10
Methyl bromide	8014-157SB	—	—	136La	5
Nitric Oxide	8014-175U	—	—	10	5
Nitrogen dioxide	8014-117SB	—	0.5/c, CH30001	9L	3
Ozone	8014-182U	—	—	18L	0. 1 [C]
Phosphine	8014-121U	—	—	7La	0.3
Sulfur dioxide	8014-103SE	—	—	5Lb	2
Toluene	8014-124SA	—	—	122	100
Trichloroethylene	8014-134S	—	—	132M	50
Vinyl chloride	8014-132SC	—	—	131La	5
Xylene (pure)	8014-143S	—	—	—	100
(commercial grade)	—	—	—	123	—
Pump model(B)	8014-400A	—	—	—	—
Kwik draw	—	488543	—	—	—
Kwik draw deluxe	—	487500	—	—	—
Bellows pump, model 31	—	—	67 26065	—	—
Gastek 800 pump	—	—	—	GV-100	—
Gastek GV-100	—	—	—	GV-100S	—

[A] For up-to-date information, contact SEI on the web at *http://www.SEInet.org* or at (703) 442-5732

[B] Tubes are certified only when used with specified pump model of same manufacturer.

[C] = TLV Ceiling value

where: r = effective length, cm, corresponding to the diffusive resistance of the membrane or air space

Combining Equations 4–6 and rearranging yields:

$$r\,L + L^2 = (10^{-6}\,K\,D\,A)\;C\,t = K'\,C\,t \qquad (7)$$

where: K' = a constant equal to the bracketed expression, cm^2/s

This equation has been shown to fit MSA tubes with a 15-mm air space.(121–123) When L was expressed in mm and t in hrs, r was taken as 15 mm, and K' was 0.59 mm^2/hr for carbon monoxide, 11.0 for ammonia, 14.2 for nitrogen dioxide, 22.6 for hydrogen sulfide, 67.3 for sulfur dioxide, and 74.0 for carbon dioxide. For Draeger tubes, which do not use an air space, the equation applied with a zero value for r.(120) For membrane-type devices, the equation was modified by adding another constant: (117–119)

$$C\,t = a + b\,L + c\,L^2 \qquad (8)$$

where: a, b, c = empirical constants

These constants may differ for each individual membrane. The inapplicability of a general calibration is a disadvantage of this type of passive monitor.

A more complete mathematical analysis(124) showed that for rapidly changing concentrations the errors would be small. This was experimentally confirmed(125) for both passive dosimeters and for long-term tubes. Most of the published work on passive dosimeters has been studied by the staffs of manufacturers.(120–123, 125) Much larger errors were reported(126, 127) by users. Some of the stain boundaries were very diffuse and difficult to read, and some calibrations were inaccurate. Because these tubes are in an early state of development, the values should be checked as much as possible.

Colorimetric Badges

Background and Use

Another type of passive dosimeter is the direct-reading colorimetric badge. These dosimeters rely on the principle of diffusion. (Description of the theory of diffusive sampling can be found earlier in this chapter under the heading of "Passive Dosimeters", and also in Chapter 16). Colorimetric badges are extremely easy to use. Once the badge is exposed to a specific chemical gas or vapor, its reagent-coated film reacts and forms a color tint (stain) that is related to the product of time and concentration. The color is compared against known color standards. The ppm result is simply calculated by dividing the ppm • hours by the hours of sampling (exposure) time. Automated electronic colorimetric badge readers are available, see instrument descriptions in sections 17-1, 17-3, 17-11, and 17-33. Badges are utilized for short-term (STEL) monitoring or for 8-hour shift (TWA). Badges for low-level detection down to parts-per-billion are available for toluene diisocyanate (TDI), hydrazine, hydrides, and phosgene. Tables 17-5 through 17-9, 17-19, and 17-27 contain the instrument descriptions. Short- term sampling with low-level detection of ozone and formaldehyde are described in sections 17-16 through 17-18. Additional applications of colorimetric badges and instrument descriptions are found in sections 17-11, 17-16 through 17-19, 17-23 through 17-24, 17-27, and 17-33. All passive devices require a minimum air velocity at their entrances (0.008 m/s or 15 ft/min) to avoid "starvation" effects (depletion of the air concentration near the entrance).(70, 71)

Use Problems

When using a colorimetric badge for long-term sampling, such as for several days, it may result in an error of accumulation indicating higher than actual results. The solution to this problem is to change badges as often as possible. Some badges may "regenerate" after sampling if they are removed from the contaminated environment to a "clean" environment; they may fade over time and return to their original color. Re-use of an exposed badge should be discouraged because the level of sensitivity could not be guaranteed.

Conclusions

Use of direct-reading detector tubes and badges for analysis of toxic gas and vapor concentrations in air is a very rapid, convenient, and inexpensive technique that can be performed by semiskilled operators. These tubes and badges are in various stages of development, and highly variable results have been obtained. Accuracy depends on a high degree of skill in the manufacture of the tubes. At present, results may be regarded as only range-finding and approximate in nature. The best accuracy that can be expected from indicator tube systems of the best types is on the order of ±25%. Recent advances with electronic concentration readers have improved precision and accuracy. Because many of the tubes are far from specific, an accurate knowledge of the possible interfering gases present is very important. The quantitative effect of these interferences depends on the volume sampled in an irregular way. To avoid dangerously misleading results, the operation and interpretation should be under the supervision of a skilled occupational hygienist.

The manufacturers' descriptions for individual instruments are given in the pages which follow this discussion. It was not possible to check the accuracy of every detail of the description and claims made, and the responsibility for this material rests entirely with the individual manufacturers.

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Instrument Descriptions

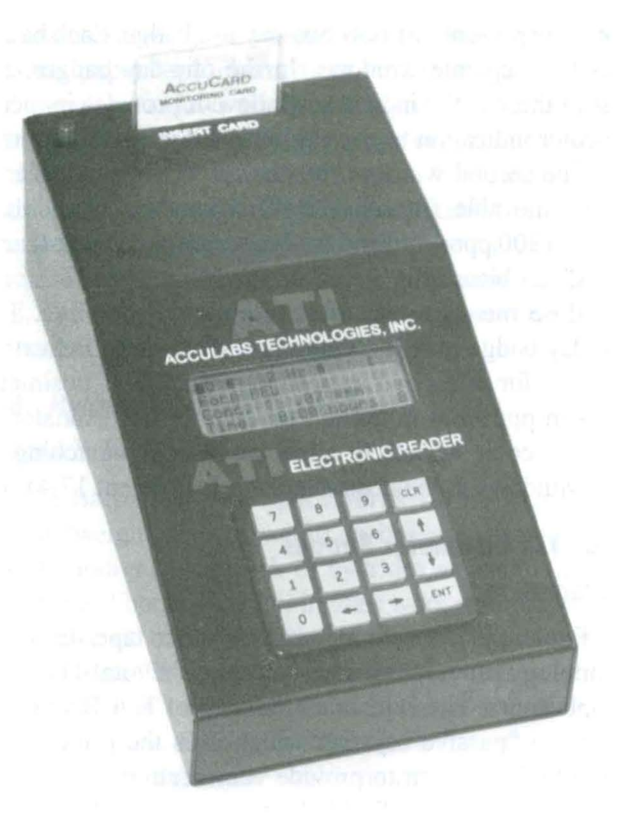
Introduction

Detector tubes, direct-reading passive badges, and dosimeter tubes can be classified by certain general characteristics. For example, many detector tubes aspirate short-term air samples using a few strokes of a hand piston pump or rubber bulb. The long-term types use a continuous pump at a very low flow rate for periods as long as 8 hours to give time-weighted average (TWA) concentrations. No pump is required by passive dosimeter and badges that rely on diffusion of the analyte from air into the sensing absorbent. After each manufacturer's description of the instruments, a list of analytes with range of measurement and part number is included. The last table of this chapter lists the commercial sources and contact information of the instrument manufacturers described, as well their distributors.

17-1. ATI Air Monitoring System

Acculabs Technologies, Inc.

The ATI air monitoring system offers the user an accurate and cost effective method of determining personal and area exposure levels to hazardous chemicals. The lightweight monitoring cards are simply attached to the personnel or placed in the area to be monitored, and after the exposure period, a time-averaged hazard concentration can be read directly by means of a portable electronic reader. The ATI electronic reader automatically corrects for variables such as temperature and humidity, and converts a chemically-induced color change in the card to parts per million exposure. Results are available immediately and on-site without the pumps, tubes and the laboratory expense associated with conventional methods. All ATI monitoring cards are validated in accordance with the "NIOSH Protocol for the Evaluation of Passive Monitors." Sensitivity and range



INSTRUMENT 17-1. ATI Air Monitoring System.

are based on the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs) and Short-Term Exposure Limits (STELs). The precision and accuracy of the ATI system exceeds both OSHA and NIOSH requirements (see Instrument 17-1).

17-2. Personal Protection Indicators

American Gas & Chemical Company, Ltd.

Personal Protection Indicators (PPI) change color on exposure to low concentrations of various toxic gases or vapors, allowing the user to evaluate ceiling or time weighted average (TWA) exposure. PPI are lightweight and easy to use. They do not require activation, chemical analysis or calibration. PPI change color as a result of a chemical reaction with the gas or vapor. As the time of exposure and/or the concentration of gas seen by the PPI increases, the color change becomes increasingly more pronounced. By using a color chart the user can estimate exposure.

INSTRUMENT 17-2. LEAK-TEC Personal Protection Indicators.

Personal Protection Indicators (PPI) are available in three forms:

1. Disposable plastic badges with pocket clips
2. Reusable badge plaques, with inexpensive indicator refills
3. Area Contamination Monitors—adhesive-backed papers that can easily be attached to a wall to monitor the area or wrapped around a critical joint on a pipe to monitor fugitive leaks

PPIs are available for a number of gases including: ammonia, carbon monoxide, chlorine, hydrazine, hydrogen sulfide, nitrogen dioxide and ozone (see Table 17-I-2). PPIs are field-proven over 10 years and are used in a great variety of applications from home heaters and stoves, to aerospace fuels, to oil drilling and petrochemical production (see Instrument 17-2).

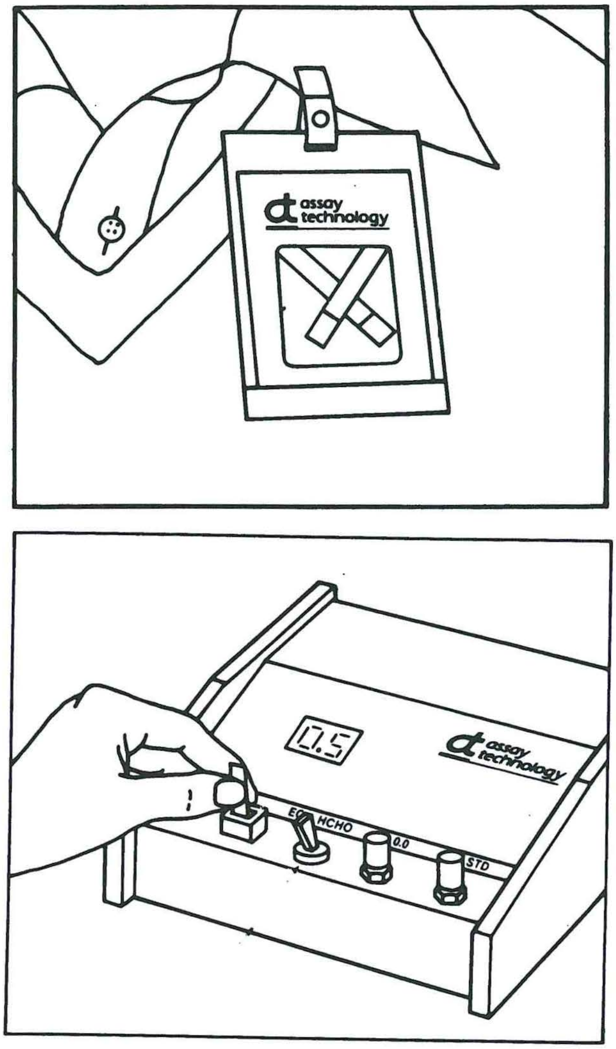
17-3. ChemChip™ Personal Monitoring System

Assay Technology

The ChemChip™ System includes a kit of Personal Monitoring Badges (Diffusive Samplers) and an Electronic Reader (Photometer) providing on-site measurement of time-weighted-average (TWA) and short-term exposure limit (STEL) exposures measured by the Badges in compliance with OSHA requirements (see Table 17-I-3).

Each Personal Monitor includes a chemically selective reagent system immobilized on a proprietary Monitor Strip encased within polymer membranes and incorporated in a lightweight (1/2 oz) Badge clipped to pocket or lapel. After the Badge is worn for a full shift (8-hr TWA) or short term (15-min STEL) exposure interval, the Monitor Strip is removed, developed, and inserted into a calibrated reflectance photometer (Electronic Reader) to obtain the result.

ChemChip Personal Monitors are available for monitoring ethylene oxide in 8-hr TWA and STEL formats. The ChemChip Electronic Reader is re-calibrated on-site to replicate a calibration determined at the factory for each manufacturing lot of Monitoring Badges. Lot-by-lot quality control and on-site calibration allow the



INSTRUMENT 17-3. ChemChip™ Personal Monitoring System.

optimization of accuracy in the range of 50% to 200% of the OSHA Permissible Exposure Limit (PEL) for each type of Monitor. ChemChip Monitors for Ethylene Oxide have been shown to comply with OSHA requirements for accuracy (±25% at PEL) in published third party investigations and in quality control tests performed on each manufactured lot (see Instrument 17-3).

17-4. Sure-Spot Dosimeter Badges

Bacharach, Inc.

Sections 17-5 through 17-9 describe the various types of Sure-Spot dosimeter badges (see Table 17-I-4).

17-5. Phosgene Dosimeter Badges

Bacharach, Inc.

The Bacharach Sure-Spot Phosgene Dosimeter Badges are available in three versions: the standard one-day badge; the one-day badge for use when chloroformates are present; the new two-day use badge. Each badge uses two separate windows. In the one-day badges, the first of these is the indicator window. It provides immediate color indication to the wearer when phosgene is present. The second window, the control window, is covered by a removable filter-barrier. This window extends the range to 300 ppm-min and the barrier protects against acid gases, sun bleaching, etc. This window is used for accurate dose measurement after peeling off the filter. The two-day badge uses the control window as an indicating window for a second exposure period. The dosimeter reads in ppm-min with the Phosgene Dose Estimator. It has two color wheels to allow rapid color matching of both windows in the dosimeter (see Instrument 17-4).

17-6. TDI Dosimeter Badges

Bacharach, Inc.

Exclusive isomer-independent paper tape detection technology provides an assessment of the total TDI dose in ppb-hours. The Bacharach Sure-Spot TDI Badge is a complete "passive" system which uses the principle of controlled diffusion to provide very accurate results. Its low-end threshold of sensitivity is also sufficient for approximating 15 minute short-term evaluations. In operation, a Sure-Spot TDI Badge card is activated and mounted in the reusable plastic holder. The unit is then clipped to the collar for sampling in the breathing zone. If TDI is present, a distinct stain develops in either the Control or Indicator windows or both, dependent on the concentration (see Instrument 17-4). At any time, the developed stain can be compared against known color standards and the dose in ppb-hours calculated. A similar badge is available for PPDI.

17-7. Hydrazine Dosimeter Badges

Bacharach, Inc.

The Bacharach Sure-Spot Hydrazine Dosimeter Badge meets the requirements for personal monitoring of exposure to both Hydrazine and Monomethyl

INSTRUMENT 17-4. Sure-Spot Dosimeter Badges.

Hydrazine (MMH). A unique design incorporates two separate paper tape chemistries in one badge housing. Two circular windows allow each tape to be exposed and observed. An automatic color change occurs in each tape in the presence of either substance. The reaction for Hydrazine is somewhat different from that for MMH and two Dose Estimators are required; one for each substance. The two tapes also have complimentary sensitivities, enabling their use in a wide variety of concentrations (see Instrument 17-4).

17-8. Hydrides Dosimeter Badges

Bacharach, Inc.

The Bacharach Sure-Spot Hydrides Dosimeter Badge is a lightweight, direct-reading dosimeter designed to be worn by individuals at risk of hydrides exposure (arsine, phosphine, diborane, silane) in their work environment. A highly specific color formation occurs in the presence of hydride gases. The color density produced is directly proportional to the concentration of hydrides and the total time of exposure. Dosage is expressed in ppm-hours. The highly accurate dosimeter works via diffusion with sensitivity well below the threshold limit values (TLV) of hydrides. The badge provides vivid visual warning of potentially harmful exposures. Any resulting stain is compared against color standards and the dose in ppm-hours determined directly. Personnel at risk will readily notice stain development on their own badge or on other's badges throughout the shift (see Instrument 17-4).

17-9. Bacharach Sure-Spot MDI/TDI/NDI (Isocyanates) Test Kit

Bacharach, Inc.

The Bacharach portable Sure-Spot Test Kit is a simple and fast means of testing for atmospheric concentrations of acutely toxic gases down to 1 ppb range. Operating from its internal rechargeable battery, it is ideal for quickly measuring vapor and aerosol levels of isocyanates during virtually any application involving MDI, TDI, HDI, or NDI. Based on well-proven colorimetric paper tape detection technology, the Sure-Spot Test Kit provides highly-accurate, dependable detection of toxic gas concentrations. In operation, a test card with the reactive paper tape is placed in a holder while a precalibrated pump pulls a measured air sample through it. The intensity of the resulting color stain is directly proportional to the concentration of gas present. The developed stain is visually matched against a concentration calculator, providing a readout of concentration in ppb. Each test card can serve as a record of test data, showing time, date, and location of the sample. The lightweight Sure-Spot Test Kit can be located in areas where work involving acutely gases is conducted, or it can be carried by a worker using the supplied belt pouch. The Kit is designed to allow you to take spot samples in the breathing zone, as well as for remote, confined space sampling prior to entry of personnel. Everything needed for an entire series of spot tests is packaged in a rugged, fitted carrying case (see Instrument 17-9).

INSTRUMENT 17-9. Bacharach Sure-Spot MDI/TDI/NDI (Isocyanates) Test Kits.

17-10. Carbon Monoxide Indicator

Bacharach, Inc.

The Bacharach Carbon Monoxide Indicator is a portable instrument for the detection of concentrations of carbon monoxide. Used by safety engineers and industrial hygienists, it finds applications in process industries, refineries, mines, tunnels, sewers, natural gas fields, and confined areas. Hazardous gas content, in ppm, is determined by measuring the length of the stain or bleach. Air is sampled with a hand-held sampling pump that has non-interchangeable scales and calibrated tubes. Measurements are read directly from the length of stain, and no color comparison charts or calibration curves are necessary. Kits for sampling carbon monoxide from hot flue-gases are available in 0–2,000 ppm and 0–5,000 ppm ranges (see Table 17-I-5).

17-11. CMS Chip Measurement System

Draeger Safety, Inc.

The Draeger CMS integrates established measurement principles with the power of new intelligent technology for determining gas and vapor concentrations. It integrates established measurement principles with the power of new intelligent technology. Draeger CMS

INSTRUMENT 17-11a. Draeger CMS Chip Measurement System.

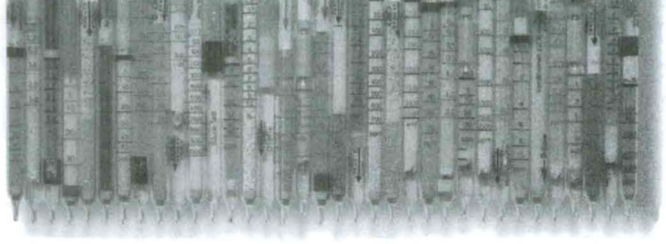
analyzer utilizes chips to serve as chemical sensors that provide the system with the versatility to measure various gases and vapors. Alternating between different gases or vapors is as easy as inserting a new chip (see Instruments 17-11a and 17-11b). The basis of the CMS is the combination of electronics, optics, chemical reagent systems and a special pump system. Each chip contains 10 measurement capillaries (measurement channels), filled with a substance-specific reagent system. Low quantities of reagent ensure a quick and reproducible reaction with the contaminant gas or vapor. Each chip is calibrated during manufacturing and can be used for up to two years. The interaction between the various chips and the analyzer will be directed by the instructions in the bar code. This bar code is found on the chip and will be read by the analyzer optics and interpreted by the analyzer software. All fundamental information such as gas type, measurement range, and other necessary parameters for the measurement evaluation are included in the bar code. Temperature and humidity influences are accounted for during calibration. The entire operation of the measurement process is menu driven. The flow sensor is integrated with the pump system and functions according to a mass flow measurement principle. The smallest reaction can be detected by the optics and registered by the microprocessor. The established reaction effect is converted to a measurement value according to instructions from the software program. This measurement value is then displayed in the form of a concentration on the digital readout. In order to measure inaccessible areas, the analyzer can be equipped with a remote system which consists of an additional pump and extension hose. Maintenance of the analyzer is not necessary. The analyzer is intrinsically safe and certified according to UL (USA), CSA (Canada), and CENELEC (Europe). Additionally, the system is protected against dust and water spray according to the IP 54 standard, and it is resistant to electromagnetic radiation. The CMS analyzer now includes a data recorder and 28 chips for analyzing 17 different chemicals (see Table 17-I-6).

17-12. Short-Term Tubes and Accuro®, Quantimeter 1000 and Accuro 2000.

Draeger Safety, Inc.

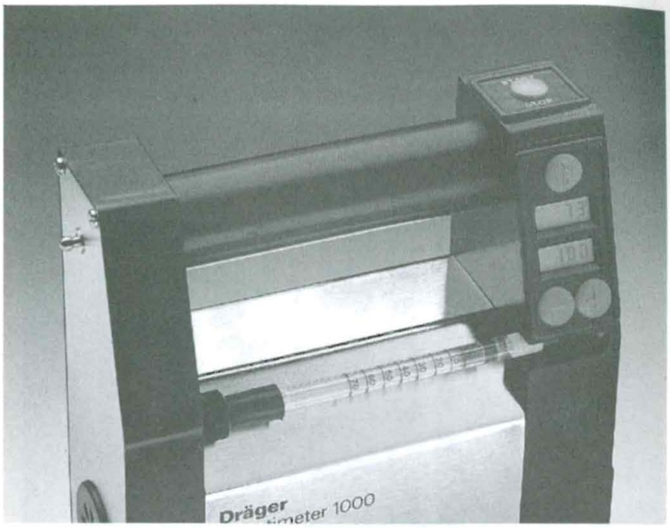
The Draeger Safety Accuro bellows pump and short-term detector tubes form a portable sampling unit for measuring concentrations of various gases and vapors (Instrument 17-12a). Draeger Short-Term colorimetric detector tubes are currently available for determining and measuring more than 350 different gases, vapors, and aerosols. The Accuro pump (see Instrument 17-12b) delivers 100 mL of sampled air with each pump stroke. After a prescribed number of pump strokes, the stain

INSTRUMENT 17-11b. Draeger Chemical Measuring Sensor Chips.



INSTRUMENT 17-12a. Draeger Short-Term Detector Tubes.


INSTRUMENT 17-12b. Draeger Accuro Bellows Pump.



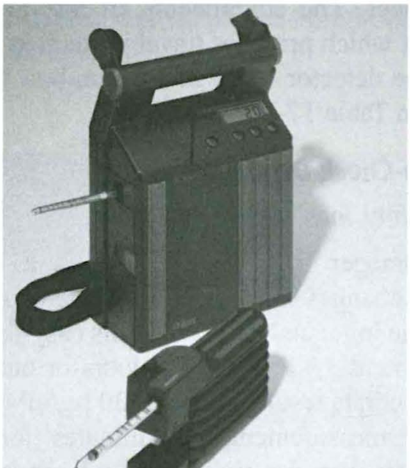
INSTRUMENT 17-12d. Draeger Quantimeter 1000 Pump.

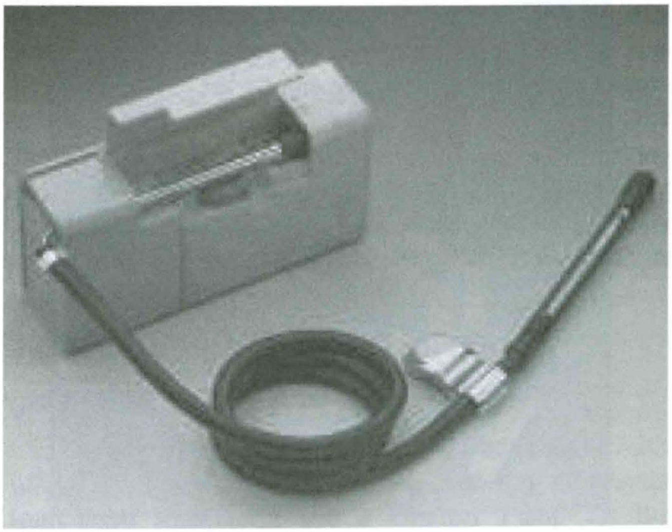
length or the discoloration of the tube gives a direct measure of the gas or vapor concentration. Calibration scales are printed directly on most types of tubes. The Accuro is a modular system. For large volume measurements, the Accuro slides into the electronically programmable Accuro 2000 (see Instrument 17-12c). The Quantimeter 1000 is a programmable, battery-operated bellows pump with the same flow characteristics as the hand-operated pump and it is intrinsically safe (see Instrument 17-12d). The complete Draeger Accuro deluxe pump kit with spare parts, tube opener, and screwdriver is contained in a vinyl carrying case and weighs approximately 1.5 kg (3.3 lbs). The detector tubes are essentially specific for particular gases or vapors. This specificity is achieved not only by the use of specific and stable reagents, but also by the use of precleansing layers placed in front of the actual reactive layer to selectively adsorb interfering components that may be contained in the gas or vapor sample. *Aerosols*: Draeger also provides aerosol tubes for arsenic trioxide, cyanides, chromic acid, nickel, oil mist, and sulfuric acid. The reading deviations for many of the detector tubes are not more than ±25% from the true value. Table 17-I-7 indicates the use of Draeger short-term detector tubes with the Accuro® bellows pump.

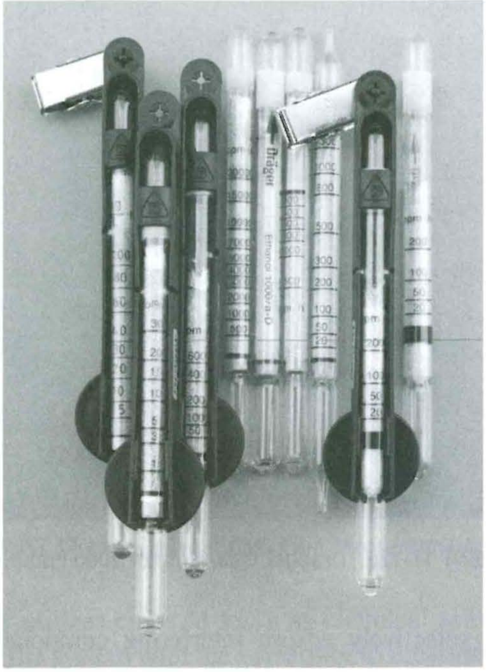
17-13. Long-Duration Detector Tubes and Polymeter

Draeger Safety, Inc.

The Draeger long-term detector tubes and the Draeger Polymeter® measure the mean value of the contaminant concentration over periods of up to 8 hrs (see Instrument 17-13). The long-term detector tubes are calibrated in units of microliters and are designed for use

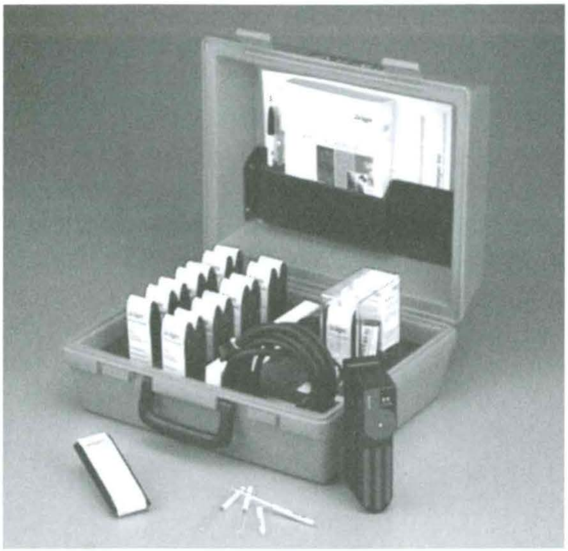

INSTRUMENT 17-12c. Draeger Accuro 2000 Pump.


INSTRUMENT 17-13. Long-Duration Detector Tubes and Polymeter.



INSTRUMENT 17-14. Diffusion Tube (long-term).

over a flow rate range of 10 to 20 mL/min. The TWA concentration in ppm is calculated by dividing the detector tube indication by the sample volume in liters. The Polymeter is a battery-powered peristaltic pump that provides a continuous flow at approximately 15 mL/min. A counter on the pump records the number of revolutions so the volume drawn can be calculated. The unit is supplied in a leather carrying bag with a shoulder strap. An extension hose is available as an accessory. Table 17-I-8 indicates the measuring range and usage of Draeger long-term tubes.



INSTRUMENT 17-15. Haz Mat Kit.

17-14. Diffusion Tubes (long-term)

Draeger Safety, Inc.

The direct-reading diffusion detector tubes from Draeger Safety, Inc. work on the principle of gaseous diffusion to give long-term, TWA measurements without a pump. The contaminant gas diffuses into the tube by means of the concentration gradient between the ambient atmosphere and the interior of the tube. The diffusion tubes have been calibrated in ppm × hrs, and/or volume % × hrs with the calibrated scale printed directly on the tube (see Instrument 17-14). This system consists of a tube holder and a diffusion tube that may be attached to a pocket or lapel. The range of measurement for various Draeger diffusion tubes is presented in Table 17-I-9.

17-15. Haz Mat Kit

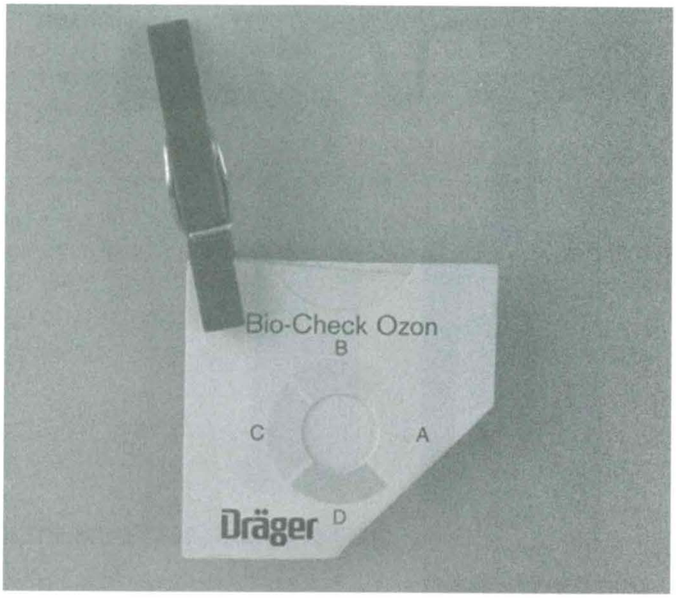
Draeger Safety, Inc.

The Draeger Safety Haz Mat Kit is designed to aid in the initial assessment of potentially hazardous situations. The detector tubes included in the kit have been selected to utilize a systematic sampling matrix. Using the polytest tube as a starting point, the sampling matrix provides a systematic test sequence to obtain information about the chemical group to which an unknown substance may belong. The haz mat kit can also be used for providing quantitative measurement of specific gases and vapors. Evaluation of test results can be performed onsite. Housed in a durable, lightweight case (see Instrument 17-15), the haz mat kit includes the Draeger bellows pump with an automatic stroke counter, a 3-meter extension hose for testing inaccessible areas, and an air current kit for determining wind direction and velocity. Other contents include spare parts and tools for pump maintenance and 17 types of detector tubes. The components fit into a closed-cell foam insert which provides travel protection and organization. The detector tubes in the standard haz mat kit are listed in Table 17-I-10.

17-16. Bio-Check Ozone Badge

Draeger Safety, Inc.

The Draeger Bio-Check Ozone is a lightweight badge that changes color to indicate the ozone concentration at the immediate location. This easy-to-use badge (see Instrument 17-16) works indoors or outdoors, and provides accurate results as low as 30 $\mu g/m^3$ (20 minutes for indoor measurements, 10 minutes for outdoor). Ozone levels are determined by comparing a color change against the color standard provided with the kit. For personal exposure monitoring, the Bio-Check Ozone



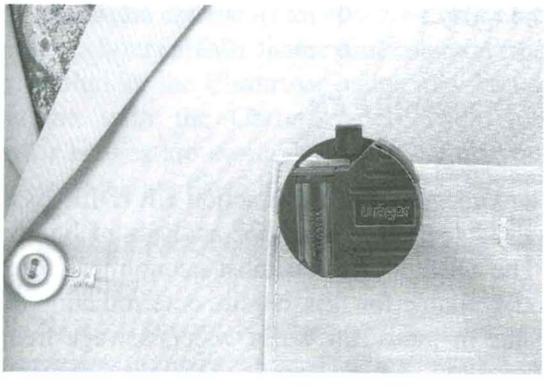
INSTRUMENT 17-16. Bio-Check Ozone Badge.

can be easily clipped onto clothing or for area monitoring, it can be placed on a flat surface. The measurement range is 30–240 μg/m³.

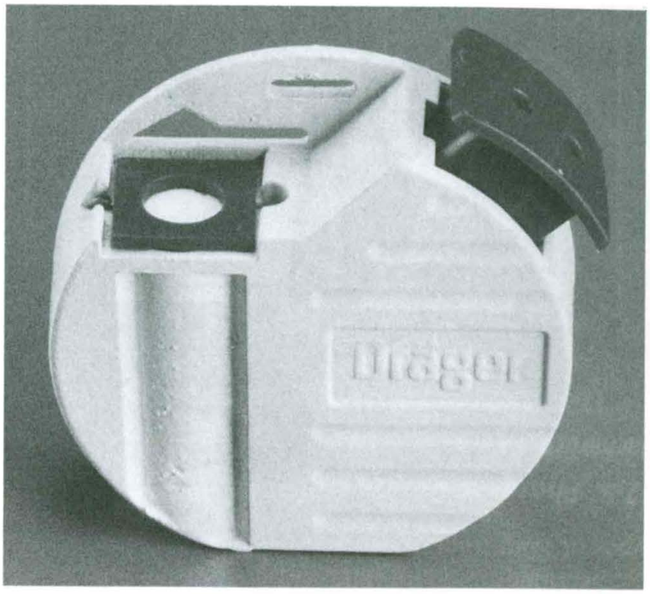
17-17. Bio-Check F Badge

Draeger Safety, Inc.

The Draeger Bio-Check F is a colorimetric badge specifically designed to measure *formaldehyde* in the air. The badge is so sensitive that within a 2-hour sampling period, concentrations from 0.02 to 0.7 ppm can be measured. The measurement results of the Draeger Bio-Check F are determined by comparing the discoloration of the badge with an enclosed set of color standards. The badge comes complete with a uniquely shaped holder that clips easily onto the user's clothing—or the device may be placed upright on a flat surface (see Instrument 17-17).



INSTRUMENT 17-17. Bio-Check F Badge.



INSTRUMENT 17-18. Bio-Check F 0.05/a Formaldehyde Badge.

17-18. Bio-Check F 0.05/a Badge

Draeger Safety, Inc.

The new Bio-Check F 0.05/a direct-reading badge is designed for measuring *indoor formaldehyde* levels at a workplace or home. Ideal for personal monitoring, this new badge provides an accurate reading in as few as 10 minutes, or as many as 120 minutes. Similar to the original Bio-Check F, the device measures formaldehyde concentrations in the range of 0.05–1.2 ppm and is simple to use (see Instrument 17-18).

17-19. Phosphine Badge

Draeger Safety, Inc.

The Draeger Phosphine Badge is a direct reading device utilizing color standards to determine the time-weighted average concentration down to 0.01 ppm. This badge is ideal for monitoring situations where background levels of phosphine are likely to exist (e.g. in the fumigation and semiconductor industries). The phosphine badges can be used for personal monitoring or area monitoring for up to 8 hours measuring phosphine in the range of 0.01–0.3 ppm. The range in absolute units is 0.1–2.4 ppm × hr (see Instrument 17-19).

17-20. Simultaneous Test Sets

Draeger Safety, Inc.

The Simultaneous Test system (see Instrument 17-20) offers three different sets which are used with an adapter (purchased separately) and a Draeger Pump for the semi-quantitative determination of inorganic gases and

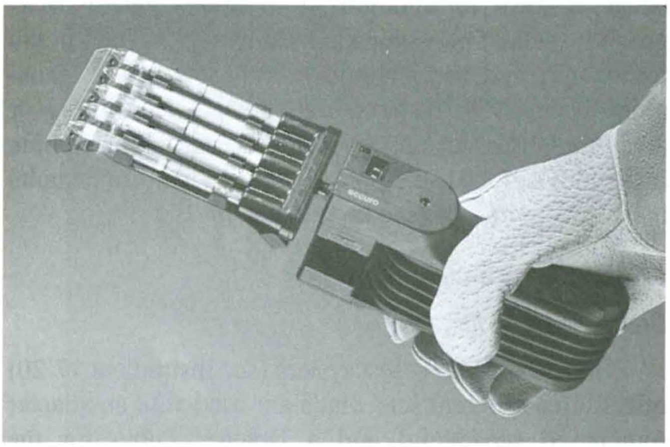
INSTRUMENT 17-19. Phosphine Badge.

organic vapors. Each test set is able to test for five different gases simultaneously in less than one minute. The sets provide on-site information to firefighters, Haz Mat teams, and environmental agencies. Please note: Draeger Tubes in the Simultaneous Test Sets are specifically calibrated to be used as a set. It is not recommended to mix tubes from any of the sets or use standard tubes with the Simultaneous Test Set Adapter. Table 17-I-11 provides a list of the hazardous chemicals that can be analyzed.

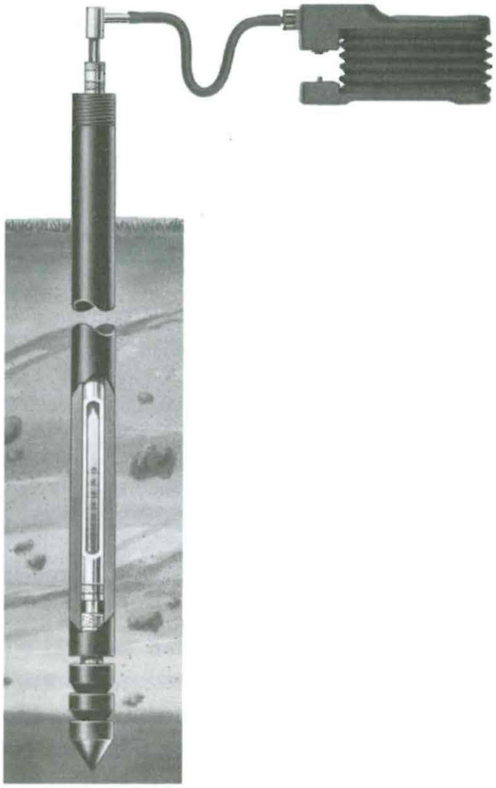
17-21. Soil Gas Probe

Draeger Safety, Inc.

Hazardous contaminants in soil may be the result of leaking underground storage tanks, previous use as an industrial waste site, or as the result of a landfill operation. A special method has been developed by Draeger for measuring volatile subsurface contaminants utilizing the Soil Gas Probe and Draeger Tubes. The Draeger Soil Gas Probe is driven into the soil to a desired depth. Next a Draeger Tube is inserted into the sampling chamber and is then placed into the probe. Using a short-term tube or sampling tube with a Draeger pump provides an extremely simple, rapid, and economical method to conduct soil gas measurements (see Table 17-I-12). The Soil Gas Probe is suitable for centralizing the concentration and tracing contaminant plumes. The complete Soil Gas Probe Set for 1 meter depth includes a drilling rod (25 × 1,000 mm), receiving chamber for Draeger Tubes, 1.5M extension hose with socket, grooved rod (25 × 1,000 mm), wrench set, brush set, and transport box (see Instrument 17-21).



INSTRUMENT 17-20. Simultaneous Test Sets.



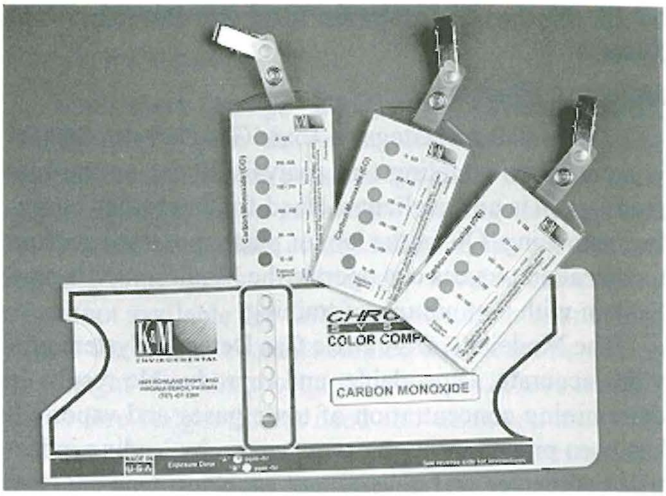
INSTRUMENT 17-21. Soil Gas Probe.

17-22. Draeger DLE Kit

Draeger Safety, Inc.

The Draeger Liquid Extraction Kit (DLE) is a contaminant detection method for analysis of liquid samples. The DLE Kit is the most economical screening method available for fast, on-site determination of contaminants in industrial waste water, sewage treatment and hazardous material spills. The measurement consists of two basic steps: 1) Extraction of the contami-

INSTRUMENT 17-22. Draeger DLE Kit.



INSTRUMENT 17-23. ChromAir® Colormetric Badge System.

nant—during the extraction process, the contaminant in the liquid sample is transferred from the liquid phase into the gas phase. 2) Measurement of the contaminant—the extracted contaminant is measured from the headspace of the bottle by the Draeger Tube (see Table 17-I-13). The system for this special method consists of a Draeger Tube used with the Draeger Accuro Pump and a specially calibrated washing bottle. The method provides on-the-spot results at a fraction of the cost of other methods (see Instrument 17-22).

17-23. ChromAir® Colorimetric Badge System

K&M Environmental

The ChromAir System is a simple, reliable, economical monitoring system. It consists of a monitor and a color comparator. The ChromAir badge is a colorimetric direct-read monitor. It relies on the principle of diffusion. The ChromAir monitor provides the user with six exposure levels. Most ChromAir badges indicate from 1/10 to 2 times the time-weighted-average for an eight-hour work period. The scale printed on the badges and color comparators is based on exposure dose [parts per million times hour (ppm-hr)] (see Instrument 17-23). For higher resolution, the ChromAir badge may be used in conjunction with the ChromAir color comparator. ChromAir badges are available for different hazardous chemicals which are listed in Table 17-I-15.

17-24. SafeAir® Passive Monitoring Badges

K&M Environmental

The SafeAir system is a low-cost detection system which provides immediate visual indication of a chemical hazard. The SafeAir badge uses a coated technology rather than impregnated filter paper, thus providing homogenous and stable color formation. A color change in the form of an "exclamation mark" warns the presence of the targeted hazard (see Instrument 17-24). The badge requires minimal training and no calibration, extra equipment, or laboratory analysis is required. For higher resolution and wider range, the SafeAir badge may be used in conjunction with the SafeAir color comparator. SafeAir badges are available for ammonia, aniline, arsine*, carbon dioxide*, carbon monoxide, chlorine, chlorine/chlorine dioxide, dimethyl amine, 1,1-dimethyl hydrazine*, formaldehyde, hydrazine*, hydrogen chloride*, hydrogen fluoride*, hydrogen sulfide, mercury, methyl chloroformate*, nitrogen dioxide, ozone, phosgene*, phosphine*, sulfur dioxide, and 2,4-toluene diisocyanate* (see Table 17-I-16). (* indicates SafeAir color comparators and validation reports are available).

INSTRUMENT 17-24. SafeAir® Passive Monitoring Badges.

17-25. Matheson-Kitagawa Toxic Gas Detector System

Matheson-Kitagawa

The Matheson-Kitagawa Toxic Gas Detector System is a complete sampling and analysis kit for on-the-spot readings. It is an excellent method for day-to-day checking, screening, QC in the lab, or plant spot testing. Non-technical employees can operate the Matheson-Kitagawa System with a minimum of training.

The Model 8014KA Toxic Gas Detector System provides accurate, dependable, and reproducible results in determining concentration of toxic gases and vapors. It has been proven through extensive use by leading industrial companies and government agencies. One constant and reproducible sample volume reduces sampling and analysis errors—as opposed to other pump designs, there are no orifice changes or multiple strokes to keep track of. Calibrated detector tubes are available for many different gases and vapors, are shown in Table 17-I-17. The same basic sampling technique applies to all Matheson-Kitagawa Precision Detector Tubes (see Instrument 17-25). Only three easy steps are required to operate the detector: 1) break off the tips of a fresh detector tube, 2) insert the tube with arrow pointing toward the pump into the pump's sample inlet, 3) pull out the pump handle to automatically lock, drawing a 100-mL sample. A proprietary Sample Vue™, indicator shows when sampling is completed. Only one stroke is needed for most analyses; no need for multiple volumes or stroke counters.

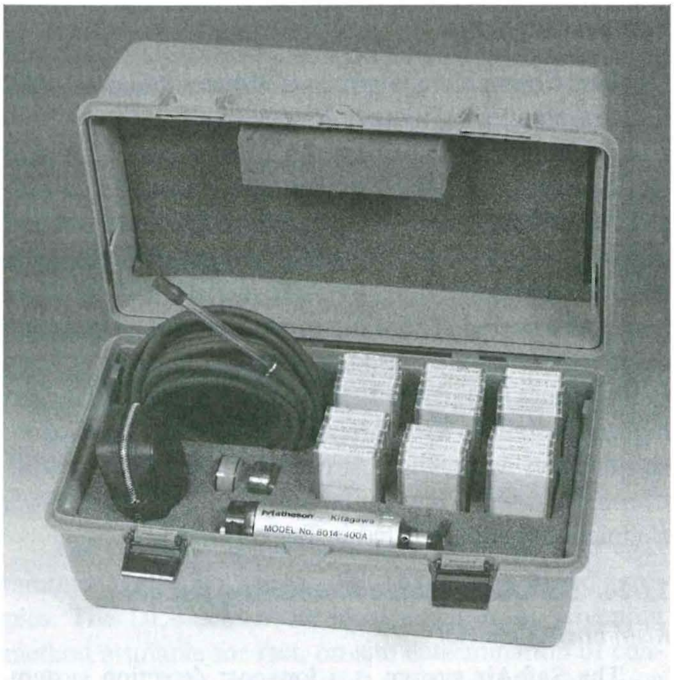
Matheson-Kitagawa precision detector tubes are formulated with high purity chemical reagents which absorb and react with the gas or vapor being measured. The reaction causes a colorimetric stain which varies in length to the concentration of the gas or vapor being measured. The length of stain is normally read directly off a scale printed on each tube. When used within their expiration date, the readings at 20°C (68°F) are designed to be within 5% to 10% of the true concentration. Temperature corrections for operating at other temperatures are normally unnecessary but are provided with those tubes requiring it.

17-26. Qualitative Analysis Tubes and Haz Mat Kit

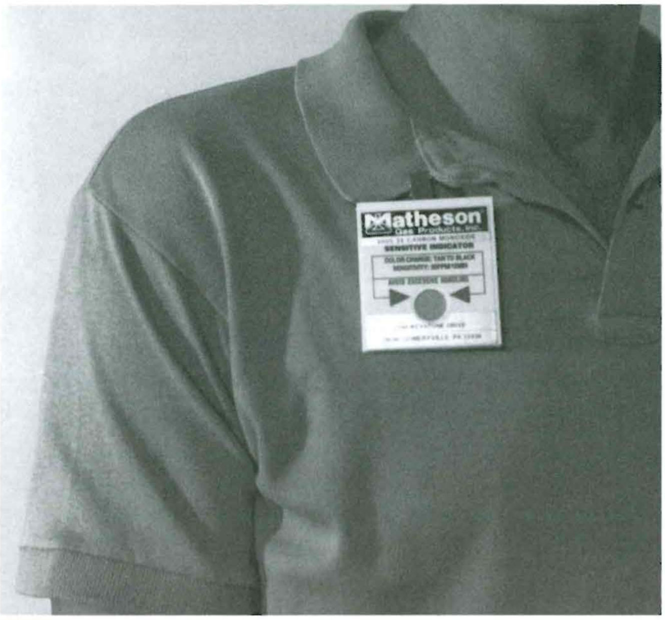
Matheson-Kitagawa

Matheson's Qualitative Detector Tubes (Models 8070, 8075) provide fast on-the-spot identification of unknown gases and vapors. There is no need for cumbersome grab samples, time delayed laboratory analyses, expensive analytical instrumentation or complex decision-tree matrix approaches. And since calibration, electricity and battery charging are not necessary, the tubes are always ready for immediate use. Two types of tubes are available. Model 8014-186B identifies a broad range of organic compounds, such as gasoline, alcohols,

INSTRUMENT 17-25. Matheson-Kitagawa Toxic Gas Detector System.



INSTRUMENT 17-26. Matheson-Kitagawa Qualitative Analysis Tubes and Haz Mat Kit.



INSTRUMENT 17-27. Matheson Badge Dosimeter.

hydrocarbons, etc. Model 8014-131 identifies inorganic compounds, such as carbon monoxide, sulfur dioxide, chlorine, etc. Typically, both models are used in concert, to assure detection of both organic and inorganic compounds (see Instrument 17-26).

Principle of Operation: In operation, Matheson's Qualitative Tubes are used in the same way as conventional detector tubes. That is, the high precision Matheson-Kitagawa pump, Model 8014-400A, is used to draw the sample air through the tubes. However, unlike conventional tubes which are "length of stain" providing quantitative measurements, these tubes are comprised of several sections. Each section contains a unique, high purity blend of reagents that will adsorb and react with a particular gas or vapor, or family of gases and vapors. The resulting reaction causes a color to change. The unknown gas or vapor is determined by which section(s) changed color, and to what color they changed to. Model 8014-131 is used to detect inorganic compounds and consists of 5 sections, labeled "A" to "E." Only one tube is needed to provide a complete analysis for inorganics. Model 8014-186B is used to detect organic compounds and consists of 4 sections, labeled "A" to "D." Because of the extensive number of detectable organic compounds, two tubes are required for a complete analysis. One tube is used for "A" side sampling (section A closest to pump), and is followed by a second, fresh tube for "D" side sampling (section D closest to pump). The combined results are used to identify unknown substances. Table 17-I-18 lists the compounds that can be detected and their limit of detection.

17-27. Monitors & Badge Dosimeters

Matheson-Kitagawa

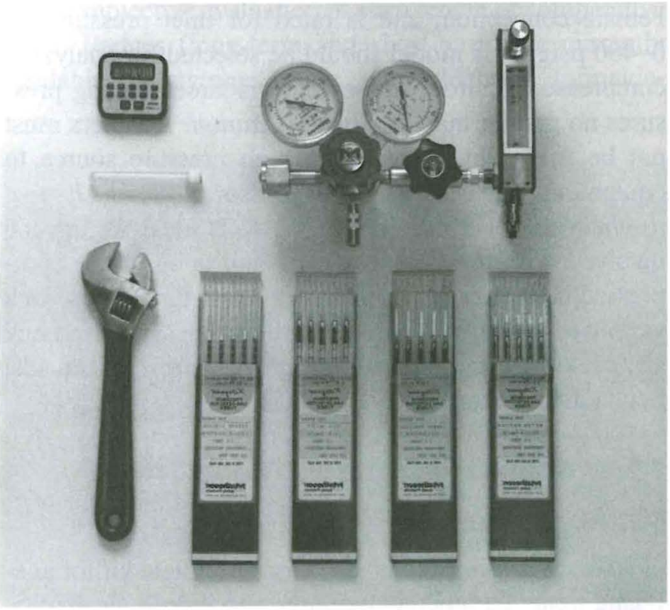
Matheson's Badge Dosimeters (Models 8005, 80069, 8007) provide an economical, easy-to-use method for monitoring personal exposure to seven toxic gases. Each badge is an instant reading detector and provides an immediate color change in the presence of specific toxic gases. Additionally a color comparison chart (not available for carbon monoxide or ozone) also allows the user to evaluate limited exposures as well as up to eight-hour time-weighted averages. These maintenance-free badges do not need activation and are ready for immediate use (see Table 17-I-19). No expensive analysis equipment or air samplers are required. Each badge clips easily to collar, shirt pocket or hat (see Instrument 17-27), or it can be used for area monitoring by affixing it to a wall or other support.

Each plaque weighs only 1/4 ounce and comes with a record form for recording employee name, date, time on, time off, elapsed exposure time and reading. Badges may be stored up to six months in unopened packs without deterioration. Usable life is one month after removing the badge from the package.

17-28. Matheson's Compressed Breathing Air Analysis Kit

Matheson-Kitagawa

The Matheson Model 8014BAK is an on-line analysis kit for ensuring the quality of compressed breathing



INSTRUMENT 17-28. Matheson Compressed Breathing Air Analysis Kit.

air. It quickly and easily measures the levels of carbon monoxide, carbon dioxide, oil mist, water vapor, and oxygen (see Table 17-I-20). Unlike other methods, there is no need to take a grab sample and analyze it off-line; the 8014BAK is designed to connect directly to the compressed breathing air source (see Instrument 17-28).

Principle of Operation: The Model 8014BAK system is essentially comprised of a pressure regulator, flowmeter, and a variety of detector tubes. In operation, measurements are made by passing the breathing air through each detector tube at a specified flow rate, pressure, and time interval. Each detector tube is formulated with a high purity reagent which adsorbs and reacts with the component being measured. This causes a colorimetric stain whose length is directly proportional to the amount of component in the breathing air. Its concentration can be read directly from the scale printed on each tube.

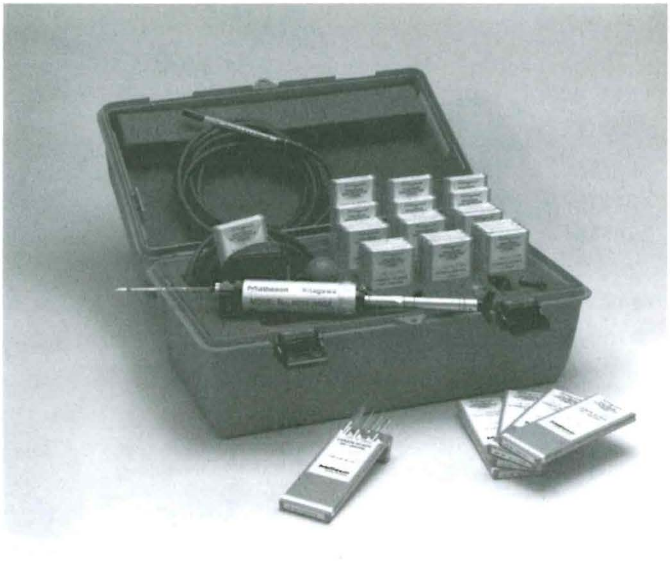
It is available with a choice of three connections-CGA 346, CGA 347, and 1/4" NPT Female. It is very important that the correct connection type be selected to match the application.

The Model 8014BAK-01 is fitted with a CGA 346 connection, and is rated for inlet pressures of 0-3000 psig. This model should be selected for analyzing compressed air in U.S. D.O.T.-approved cylinders with a Stamped Service Pressure in the range of 0–3000 psig. The Model 8014BAK-03 is fitted with a CGA 347 connection, and is rated for inlet pressures of 3001–5500 psig. This model should be selected for analyzing compressed air in U.S. D.O.T. approved cylinders with a Stamped Service Pressure in the range of 3001–5500 psig. The Model 8014 BAK-02 is fitted with a 1/4" NPT Female connection, and is rated for inlet pressures of 0–400 psig. This model should be selected for analyzing compressed air from non-cylinder sources having pressures no greater than 400 psig. [*Caution:* Adapters must not be used which connect a high pressure source to equipment rated at a lower pressure.] *Some Typical Applications:* The Model 8014BAK is ideal for anyone involved with the filling, generating, or usage of compressed breathing air. It has been proven through use in a variety of industries and applications such as: Emergency air packs/respirators, Fire departments/rescue squads, Scuba/diving, Hazardous waste cleanup.

17-29. Matheson's Indoor Air Quality Test Kit

Matheson-Kitagawa

The Matheson Model 8078 is a complete kit for analyzing many parameters pertaining to indoor air quality. All of the items included are also available as stand-alone products. The heart of the Model 8078 kit is the Matheson-Kitagawa precision air sampling pump. It is used in conjunction with a variety of detector tubes. Included in the kit are tubes for measuring the concentration of formaldehyde, carbon monoxide, carbon dioxide and organic hydrocarbons. And although not included in the kit as standard, tubes are available for ammonia, ozone and a host of other gases and vapors. Qualitative tubes are also included for analysis of unknown materials. An air flow indicator kit (smoke tubes) is provided for determining ventilation patterns and efficiencies. And a 10-meter extension sampling hose is provided for remote sampling in hard-to-reach places. All of these products are packaged with relevant maintenance items in a convenient, extremely durable carrying case (see Instrument 17-29).



INSTRUMENT 17-29. Matheson Indoor Air Quality Test Kit.

17-30. MSA Kwik-Draw Deluxe and Toximeter II Detector Tube Pumps

Mine Safety Appliances Company

The MSA Kwik-Draw Deluxe and Toximeter II pumps are designed for use with MSA's full selection of nearly 200 different detector tubes. They are partially listed in Table 17-I-21. Nearly all of MSA's detector tubes are printed with calibration scales that illustrate the concentration of the target contaminant. The Kwik-Draw Deluxe is a manual, bellows-type pump that delivers a 100 mL volume. The Kwik-Draw Deluxe features a patented end-of-stroke indicator and stroke counter. The Toximeter II is an automatic detector tube pump that requires no manual squeezing. It can be programmed for up to 250 pump strokes (see Instrument 17-30).

INSTRUMENT 17-30. MSA Kwik-Draw Deluxe and Toximeter II Detector Tube Pumps.

17-31. MSA Haz Mat Kit

Mine Safety Appliances Company

MSA offers a specialized Haz Mat Response Kit for use at Haz Mat spills. This kit features detector tubes for 12 different chemical classes which allows quick identification of hazards at spills (see Table 17-I-22). The MSA Haz Mat Response Kit offers a special manifold for testing four detector tubes at one time (see Instrument 17-31).

17-32. MSA Indoor Air Quality Kit

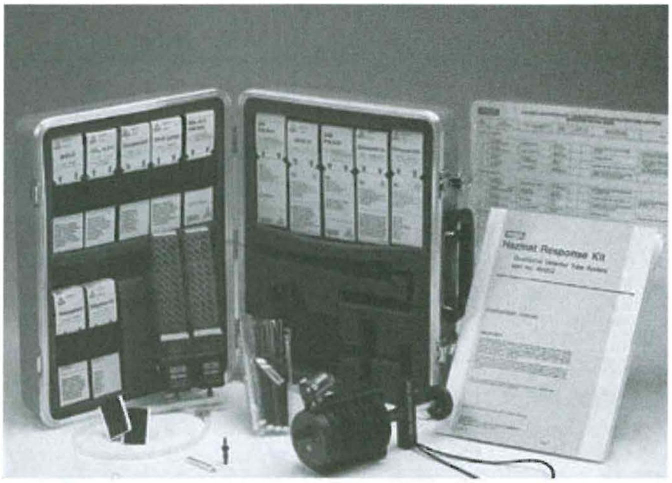
Mine Safety Appliances Company

The MSA Indoor Air Quality Kit checks for "sick building" syndrome, and can be used to identify worker complaints of headaches, dizziness, allergies, and nausea in the workplace. The kit includes tubes for carbon monoxide, carbon dioxide, formaldehyde, ozone and water vapor (see Table 17-I-23)—all of which are common components in office settings. The box of detector tubes includes a thermometer on the side to monitor temperature (see Instrument 17-32).

17-33. The PiezOptic Personal Dosimeter System

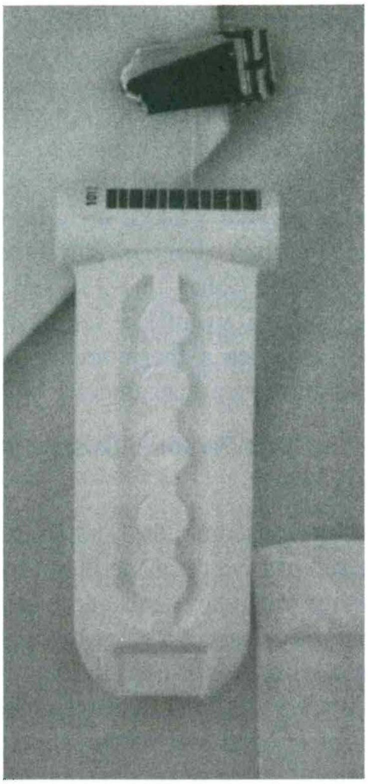
PiezOptic, Ltd.

Designed to overcome the shortcomings of most detector tube and passive diffusion direct-reading devices (poor sensitivity, accuracy and reproducibility), the PiezOptic system consists of a range of single-use passive badges and a generic reader used to quantify the results. The small (4.0 × 1.5 × 0.5 in), light-weight (<25g) badges are supplied foil-packed and ready-to-use. They can be clipped onto the clothing near the mouth to conveniently monitor the breathing zone. After the exposure period, which can be either short-term (15-30 min) or long-term (4-12h), the badge is placed into the reader and an accurate, quantitative value for exposure is obtained in a few seconds. The patented piezofilm sensing technology is extremely sensitive and precise allowing the detection of, for example, gluteraldehyde to ppb levels with a precision of around 5%. Bulky pumps and time-consuming pre-calibrations are not required and the result does not depend on the subjective evaluation of stain length or comparative color. Badges (long-term and short-term) are currently available for styrene, ozone, gluteraldehyde, formalde-



INSTRUMENT 17-31. MSA Haz Mat Kit.

INSTRUMENT 17-32. MSA Indoor Air Quality Kit.



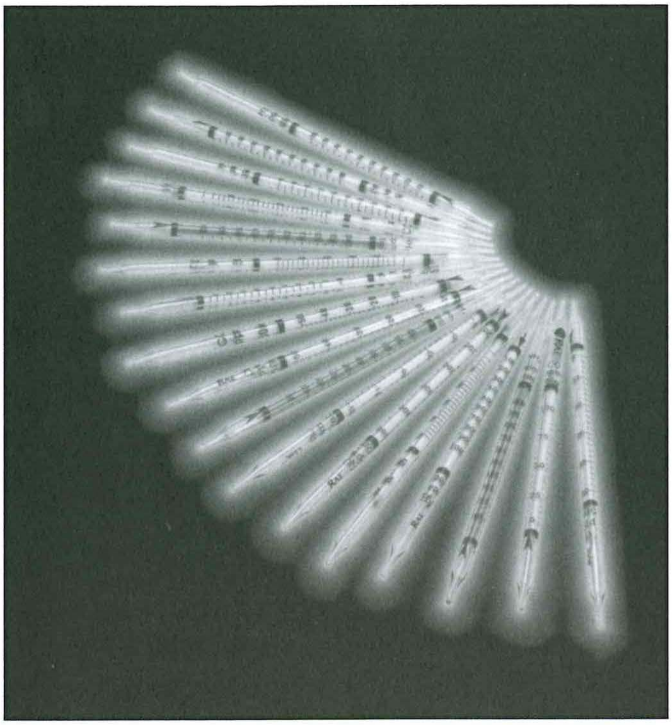
INSTRUMENT 17-33a. PiezOptic Personal Dosimeter Badge.

hyde, hydrazine, NO_2 and CO. Many others are becoming available (see Instruments 17-33a and 17-33b).

17-34. LP-1200, SampleRAE, RAE Tubes

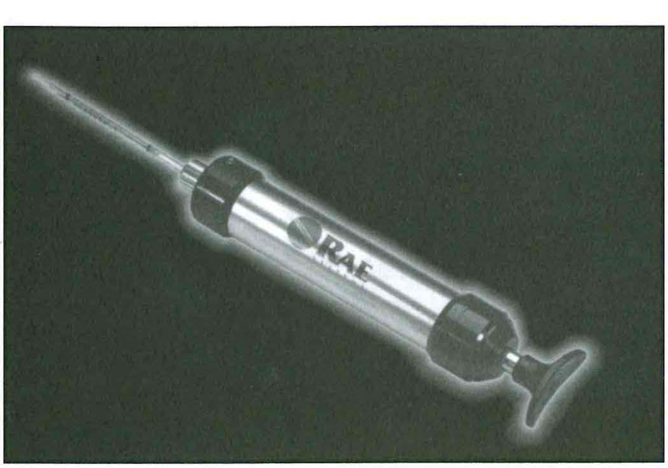
RAE Systems, Inc.

RAE Systems is a manufacturer who started producing their own colorimetric detector tubes and pumps since 1997. As of 2000, they manufactured 46 different types of tubes for a total of 19 organic and inorganic gases and vapors (see Table 17-I-24). Their tubes were designed with a two-year shelf life (see Instrument 17-34a). Most of the tubes work with a one-pump stroke. RAE Systems offers a hand-held piston pump (see Instrument 17-34b) and an automatic sampling pump. The hand pump (model LP-1200) samples either 50 or 100 cc volumes. The automatic pump (model SampleRAE) (see Instrument 17-34c) can be used with detector tubes to sample fixed volume samples; or it can be used to sample high-volume samples (multiple pump strokes) from 50-950 cc in 50 cc increments. The 12 ounce intrinsically-safe unit is battery-powered (16-hours with 4 AA alkaline batteries), has a microprocessor, an LCD direct readout for the volume or flowrate, and comes with a calibration tube. SampleRAE can also be used with sorbent tubes and can collect a



INSTRUMENT 17-34a. RAE Systems Detector Tubes.

INSTRUMENT 17-33b. PiezOptic Personal Dosimeter Reader.



INSTRUMENT 17-34b. RAE Systems LP-1200 Pump.

INSTRUMENT 17-34c. RAE Systems SampleRAE Automatic Pump.

fixed-volume of sample in a gas bag. RAE Systems funded an independent university lab study which resulted to a conclusion that the RAE tubes are interchangeable with Sensidyne and Kitigawa tubes; also, that their LP-1200 hand pump is interchangeable with the Gastek/Sensidyne GV/100 and Kitagawa 8014-400A hand pumps.

17-35. Sensidyne/Kitagawa Haz Mat Kits

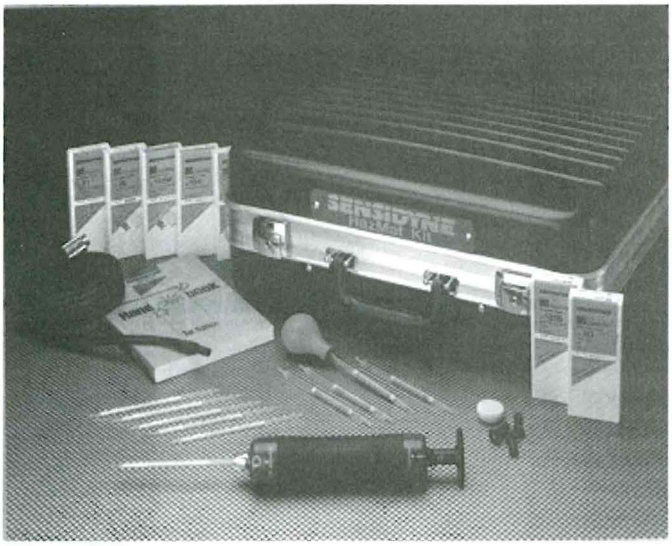
Sensidyne, Inc.

The Sensidyne/Kitagawa Haz Mat Kit is a portable hazardous material detection kit requiring no electrical power or user calibration. The kit uses the Model AP-IS hand-held piston pump and extension cable and incorporates 15 different types of detector tubes for commonly encountered substances, as shown in Table 17-I-25. The kit includes two laminated sampling logic charts which allow the user to identify unknown compounds using the 15 tubes and incorporates all of these elements plus an air flow indicator, smoke tube kit, and 15 boxes of detector tubes in a hard-sided carrying case. This system is expandable and is ultimately capable of measuring over 200 gases (see Instrument 17-35).

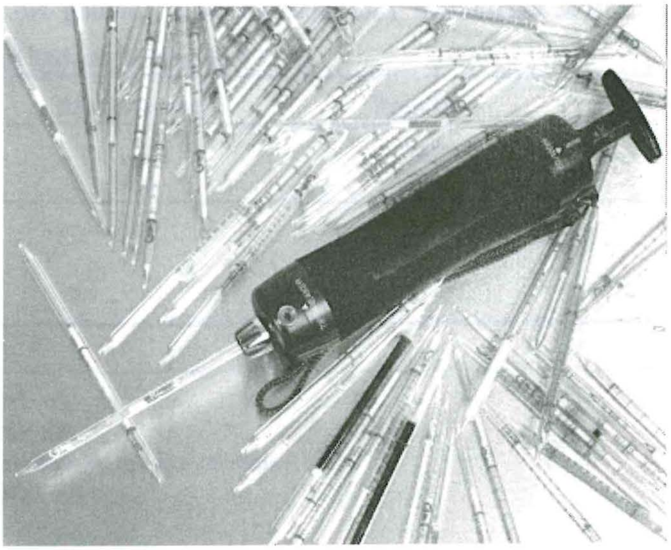
17-36. Sensidyne/Kitagawa Precision Gas Detector System

Sensidyne, Inc.

Over 200 gases and vapors can be measured with the High-precision Gas Sampling System using the detector tubes which are partially listed in Table 17-I-26. The two major components are: 1) direct-reading detector tubes



INSTRUMENT 17-35. Sensidyne/Kitagawa Haz Mat Kit.



INSTRUMENT 17-36. Sensidyne/Kitagawa Precision Gas Detector System.

and 2) the high-precision, piston-type volumetric pump (see Instrument 17-36). Each detector tube contains a reagent that is specifically sensitive to a particular vapor or gas. These reagents are contained on fine-grain silica gel, activated alumina, or other adsorbing media (depending upon application requirements), inside a constant-inner-diameter, hermetically sealed glass tube. To sample, the operator snaps off both breakaway ends of a tube, inserts the tube into the hand-held pump, and pulls the pump handle out. A measured volume of ambient air is drawn inside the tube. The reagent changes color instantly and reacts quantitatively to provide a length-of-stain indication. The farther the color stain travels along the tube, the higher the concentration of gas. The calibration mark on the tube, at the point where the color stain stops, gives the concentration. Calibration scales for the detector tubes are printed on the basis of individual production lots. Calibration scales are in ppm, mg/L, or %, depending on the substance to be measured and the desired measuring range. Every tube and tube box carries the quality control number, chemical symbol, and the expiration date. The expandable measuring range permits measurement of concentrations above or below the printed scale simply by increasing or decreasing pump strokes.

17-37. Sensidyne/Kitagawa Qualitative Multistage Tubes

Sensidyne, Inc.

Provides qualitative detection of 12 inorganic gases simultaneously with simple single pump stroke operation and results in 20 seconds. Ideal for haz mat, confined space entry, and fire site re-entry testing. The Inorganic Qualitative Tube detector tube (Catalog No. 131) incorporates a unique multi-layer design to qualitatively test for 12 common toxic gases simultaneously. These gases are ammonia, hydrogen chloride, hydrogen sulfide, chlorine, sulfur dioxide, nitrogen dioxide, carbon monoxide, amines, acetic acid, phosphine, acetylene, and methyl mercaptan. An operator simply breaks off the ends of the sealed glass tube and places it into the Model AP-IS piston pump, observing the directional arrow. After taking one pump stroke, the operator waits 20 seconds and then compares the tube to a color chart (see Instrument 17-37). A second tube (Catalog # 186B) for organic qualitative analysis of 41 compounds works in 30 seconds and utilizes the reverse side of the same color chart. The system is expandable with direct-reading quantitative detector tubes for over 200 substances.

INSTRUMENT 17-37. Sensidyne/Kitagawa Qualitative Multistage Tubes.

TABLE 17-I-1. Index of Direct-Reading Instrument Types and Manufacturers

	Manufacturer	Detector Tubes		Passive Dosimeter Tubes	Passive Badges
		Short-Term	Long-Term		
1.	Acculab Technologies, Inc.				✓
2.	American Gas & Chemical Co., Ltd.				✓
3.	Assay Technology, Inc.				✓
4.	Bacharach, Inc.	✓			✓
5.	Draeger Safety, Inc.	✓	✓	✓	✓
6.	K & M Environmental				✓
7.	Matheson-Kitagawa	✓			✓
8.	Mine Safety Appliances Co.	✓	✓		
9.	PiezOptic, Ltd.				✓
10.	RAE Systems	✓			
11.	Sensidyne, Inc.	✓	✓		

TABLE 17-I-2. LEAK-TEC Personal Protection Indicators (Instrument 17-2)

Gas	Part #	Sensitivity	Color Change*
Ammonia	A-15	25 ppm/5 min	Yellow to blue
Carbon monoxide	CO-50	50 ppm	Tan to black
Chlorine	C-2	1 ppm/15 min	White to yellow
Hydrazine	H-5	0.1 ppm/15 min	White to yellow
Hydrogen sulfide	HS-5	10 ppm/10 min	White to brown
Nitrogen dioxide	N-1	5 ppm/15 min	White to yellow
Ozone	O-1	0.1 ppm/15 min	White to brown

* A color chart is available for all badges except carbon monoxide and ozone

TABLE 17-I-3. Assay Technology *ChemChip*™ Personal Monitoring Badges (Instrument 17-3)

Analyte	for Sampling	Range (ppm)	Item No.
Ethylene Oxide	8-hr TWA	0.1–6.0	502
Ethylene Oxide	15-min STEL	1–60	506

TABLE 17-I-4. Bacharach/GMD System (Instrument 17-4)

Part Number	Description
2755-0610	TDI Starter Kit
2756-0610	Hydrides Starter Kit
2750-1010	Phosgene Dosimeter Badge (std. model) – 1 day
1753-0610	Hydrazine Starter Kit
2780-0700	MDI Test Kit
2780-0500	TDI Test Kit
2780-0800	HDI Test Kit
2780-0900	NDI Test Kit

TABLE 17-I-5. Bacharach Carbon Monoxide Indicator Ranges

Complete Kit	Gas Type	Range
19-0240	CO	0–0.2%
19-0241	CO	0–0.5%
19-0244	CO	0–2,000 ppm
19-0245	CO	0–5,000 ppm

TABLE 17-I-6. Draeger CMS Chips (Instrument 17-11)

Chip	Measuring Range	Catalog No.
Ammonia	2–50 ppm	6406130
Ammonia	10–150 ppm	6406020
Benzene*	0.2–10 ppm	6406030
Benzene*	0.5–10 ppm	6406160
Benzene	10–250 ppm	6406280
Carbon Dioxide	200–3,000 ppm	6406190
Carbon Dioxide	1,000–25,000 ppm	6406070
Carbon Dioxide	1–20% vol	6406210
Carbon Monoxide	5–150 ppm	6406080
Chlorine	0.2–10 ppm	6406010
Hydrochloric Acid	1–25 ppm	6406090
Hydrochloric Acid	20–500 ppm	6406140
Hydrogen Cyanide	2–50 ppm	6406100
Hydrogen Sulfide	2–50 ppm	6406050
Hydrogen Sulfide	20–500 ppm	6406150
Hydrogen Sulfide	100–2,500 ppm	6406220
Mercaptan	0.25–6 ppm	6406360
Nitrogen Dioxide	0.5–25 ppm	6406120
Nitrous Fumes	0.5–15 ppm	6406060
Nitrous Fumes	10–200 ppm	6406240
Perchloroethylene	5–150 ppm	6406040
Petroleum Hydrocarb.	20–500 ppm	6406200
Petroleum Hydrocarb.	100–3,000 ppm	6406270
Phosgene	0.05–2 ppm	6406340
Phosphine	1–25 ppm	6406410
Phosphine	20–500 ppm	6406420
Phosphine	200–5,000 ppm	6406500
Propane	100–2,000 ppm	6406310
Sulfur Dioxide	0.4–10 ppm	6406110
Sulfur Dioxide	5–150 ppm	6406180
Toluene	10–300 ppm	6406250
Training Chip	—	6406290
Vinyl Chloride	0.3–10 ppm	6406170
Vinyl Chloride	10–250 ppm	6406230
Xylene	10–300 ppm	6406260

TABLE 17-I-7. Short-Term Draeger Tubes (Instrument 17-12)

Note*: The list below is only a partial list of products. The full list can be found at *www.draeger-usa.com.

Gases and Vapors	Draeger Tube	Measuring Range	Part No.
Acetaldehyde	Acetaldehyde 100/a	100–1,000 ppm	6726665
Acetic Acid	Acetic Acid 5/a	5–80 ppm	6722101
Acetic Anhydride	Formic Acid 1/a	Qualitative	6722701
Acetone	Acetone 100/b	100–12,000 ppm	CH22901
Acetylene	Petroleum Hydrocarbons100/a	100–2,500 ppm	6730201
Acid Compounds in air	Acid Test	Qualitative	8101121
Acrolein	Dimethyl Sulfide 1/a	0.1–10 ppm	6728451
Acrylonitrile	Acrylonitrile 0.5/a	0.5–20 ppm	6728591
Air Current	Smoke Tube	—	CH25301
Aliphatic Hydrocarbons (Boiling Range 50–200°C)	Hydrocarbon 2	2–23 mg/L	CH25401
2-Aminoethanol	Ammonia 0.25/a	0.5–6 ppm	8101711
2-Aminopropane	Cyclohexylamine 2/a	2–30 ppm	6728931
Ammonia 0.25/a	Ammonia	0.25–3 ppm	8101711
	Ammonia 2/a	2–30 ppm	6733231
	Ammonia 5/a	5–700 ppm	CH20501
	Ammonia 5/b	2.5–100 ppm	81019,41
	Ammonia 0.5%/a	0.05–10 Vol. %	CH31901
n-Amyl acetate	Ethyl Acetate 200/a	200–3,000 ppm	CH20201
Aniline	Aniline 0.5/a	0.5–10 ppm	6733171
	Aniline 5/a	1–20 ppm	CH20401
Antimony Hydride (Stibine)	Arsine 0.05/a	0.05–3 ppm	CH 25001
Arsenic Trioxide	Arsenic Trioxide 0.2/a	0.2 mg/m3	6728951
Arsine	Arsine 0.05/a	0.05–60 ppm	CH25001
Aziridine	Ammonia 0.25/a	0.25–3 ppm	8101711
Basic Cmpds. in air Amine Test	Qualitative	—	8101061

TABLE 17-I-8. Long-Term Draeger Tubes (Instrument 17-13)

Draeger Tube	Measuring Range	Maximum Sampling Time (hrs)	Part No.
Acetic Acid 5/a-L	1.25–40 ppm	4	6733041
Acetone 500/a-L	62.5–10,000 ppm	8	6728731
Ammonia 10/a-L	2.5–100 ppm	4	6728231
Benzene 20/a-L	10–200 ppm	2	6728221
Carbon Dioxide 1000/a-L	250–6,000 ppm	4	6728611
Carbon Disulfide 10/a-L	1.25–100 ppm	8	6728621
Carbon Monoxide 10/a-L	2.5–100 ppm	4	6728741
Carbon Monoxide 50/a-L	6.25–500 ppm	8	6728121
Chlorine 1/a-L	0.13–20 ppm	8	6728421
Ethanol 500/a-L	62.5–8,000 ppm	8	6728691
Hydrocarbons 100/a-L	25–3,000 ppm	4	6728571
Hydrochloric Acid 10/a-L	1.25–50 ppm	8	6728581
Hydrocyanic Acid 10/a-L	1.25–120 ppm	8	6728441
Hydrogen Sulfide 5/a-L	0.63–60 ppm	8	6728141
Methylene Chloride 50/a-L	12.5–800 ppm	4	6728881
Nitrogen Dioxide 10/a-L	1.25–100 ppm	8	6728281
Nitrous Fumes 5/a-L (NO + NO2)	1.25–50 ppm	4	6728911
Nitrous Fumes 50/a-L (NO + NO2)	12.5–350 ppm	4	6728191
Perchloroethylene 50/a-L	12.5–300 ppm	4	6728671
Sulfur Dioxide 2/a-L	0.5–20 ppm	4	6728921
Sulfur Dioxide 5/a-L	1.25–50 ppm	4	6728151
Toluene 200/a-L	25–4,000 ppm	8	6728271
Trichloroethylene 10/a-L	2.5–200 ppm	4	6728291
Vinyl Chloride 10/a-L	1–50 ppm	10	6728131

TABLE 17-I-9. Draeger Long-Term Diffusion Tubes (Instrument 17-14)

Draeger Tubes	Range in Absolute Units	Range of Measurement for Max. Period of Use (8 hrs)	Part No.
Acetic Acid 10/a-D	10–200 ppm × h	1.3–25 ppm	8101071
Ammonia 20/a-D	20–1,500 ppm × h	2.5–188 ppm	8101301
Butadiene 10/a-D	10–300 ppm × h	1.3–40 ppm	8101161
Carbon Dioxide 500/a-D	500–20,000 ppm × h	65–2,500 ppm	8101381
Carbon Dioxide 1%/a-D	1–30 Vol.% × h	0.13–3.8 Vol.%	8101051
Carbon Monoxide 50/a-D	50–600 ppm × h	6.3–75 ppm	6733191
Ethanol 1000/a-D	1,000–25,000 ppm × h	125–3,100 ppm	8101151
Ethyl Acetate 500/a-D	500–10,000 ppm × h	63–1,250 ppm	8101241
Hydrochloric Acid 10/a-D	10–200 ppm × h	1.3–25 ppm	6733111
Hydrocyanic Acid 20/a-D	20–200 ppm × h	2.5–25 ppm	6733221
Hydrogen Sulfide 10/a-D	10–300 ppm × h	1.3–38 ppm	6733091
Nitrogen Dioxide 10/a-D	10–200 ppm × h	1.3–25 ppm	8101111
Perchloroethylene 200/a-D	200–1,500 ppm × h	25–188 ppm	8101401
Sulfur Dioxide 5/a-D	5–150 ppm × h	0.6–19 ppm	8101091
Toluene 100/a-D	100–3,000 ppm × h	13–380 ppm	8101421
Trichloroethylene 200/a-D	200–1,000 ppm × h	25–125 ppm	8101441
Water Vapor 5/a-D	5–100 mg/liter × h	0.6–12.5 mg/liter	8101391
Diffusion Tube Holder	Package of 3		6733014

TABLE 17-I-10. Draeger Haz Mat Kit (Instrument 17-15)

Detector Tubes	Part Number
Polytest	CH28401
Ethyl acetate 200/a	CH20201
Methyl bromide 5/b	CH27301
Hydrazine 0.25/a	CH31801
Benzene 0.05	CH24801
Hydrocarbons 0.1%b	CH26101
Acetone 100/b	CH22901
Carbon monoxide 10/b	CH20601
Alcohol 100/a	CH29701
Carbon dioxide 0.1%/a	CH23501
Hydrocyanic acid 2/a	CH25701
Hydrogen sulfide 5/b	CH29801
Nitrous fumes 0.5/a	CH29401
Trichloroethylene 10/a	CH24401
Chlorine 0.2/a	CH24301
Oxygen 5%/B	6728081
Formic acid 1/a	6722701

TABLE 17-I-11. Draeger Simultaneous Test Sets (Instrument 17-20)

Description	Catalog No.
Simultaneous Test Set I, Inorganic fumes	8101735
Acid Gases, e.g., Hydrochloric Acid	
Basic Gases, e.g., Ammonia	
Carbon Monoxide	
Hydrocyanic Acid	
Nitrous Gases, e.g., Nitrogen Dioxide	
Simultaneous Test Set II, Inorganic fumes	8101736
Carbon Dioxide	
Chlorine	
Hydrogen Sulfide	
Phosgene	
Sulfur Dioxide	
Simultaneous Test Set III, Organic Vapors	8101770
Alcohols, e.g., Methanol	
Aliphatic Hydrocarbons, e.g., n-Hexane	
Aromatics, e.g., Toluene	
Chlorinated Hydrocarbons, e.g., Perchloroethylene	
Ketone, e.g., Acetone	
Accuro Pump, required	6400000
Adapter	6400090

TABLE 17-I-12. Draeger Soil Analysis with Soil Gas Probe (Instrument 17-21)

Substance	Draeger Tube	Measuring Range	Part No.
Inorganic / Organic Substances			
Acetic Acid	Acetic Acid 5/a	5–80 ppm	6722101
Acid Compounds	Acid Test	Qualitative	8101121
Ammonia	Ammonia 5/a	5–700 ppm	CH20501
Benzene	Benzene 2/a	2–60 ppm	8101231
BTX-Aromatics	Toluene 5/b	5–300 ppm	8101661
Carbon Dioxide	Carbon Dioxide 100/a	100–3,000 ppm	8101811
Carbon Dioxide	Carbon Dioxide 0.5%/a	0.5–10 Vol.%	CH31401
Carbon Dioxide	Carbon Dioxide 5%/A	5–60 Vol.%	CH20301
Carbon Tetrachloride	Carbon Tetrachloride 1/a	1–15 ppm	8101021
Chloroform	Chloroform 2/a	2–10 ppm	6728861
Dichloromethane	Methylene Chloride 100/a	100–2,000 ppm	6724601
Hydrocarbon Screening Test	Polytest	Qualitative	CH28401
Hydrocyanic Acid (Cyanide)	Hydrocyanic Acid 2/a	2–30 ppm	CH25701
Hydrogen Sulfide	Hydrogen Sulfide 1/d	1–200 ppm	8101831
Mercaptan	Mercaptan 0.5/a	0.5–5 ppm	6728981
Natural Gas (Methane)	Natural Gas Test	Qualitative	CH20001
n-Octane	Petroleum Hydrocarb.10/a	10–300 ppm	8101691
n-Octane	Petroleum Hydrocarb.100/a	100–2,500 ppm	6730201
Organic Arsenic Compounds and Arsine	Organic Arsenic Compounds and Arsine	Qualitative	CH26303
Organic Basic Nitrogen Compounds	Organic Basic Nitrogen Compounds	Qualitative	CH25903
Perchloroethylene	Perchloroethylene 0.1/a	0.1–4 ppm	8101551
Perchloroethylene	Perchloroethylene 2/a	2–300 ppm	8101501
Perchloroethylene	Perchloroethylene 10/b	10–500 ppm	CH30701
Phosgene	Phosgene 0.02/a	0.02–1 ppm	8101521
Phosgene	Phosgene 0.25/b	0.25–75 ppm	CH28301
1,1,1-Trichloroethane	Trichloroethane 50/d	50–600 ppm	CH21101
Thioether	Thioether	Qualitative	CH25803
Toluene	Toluene 50/a	50–400 ppm	8101701
Trichloroethylene	Trichloroethylene 2/a	2–200 ppm	6728541
Trichloroethylene	Trichloroethylene 10/a	50–500 ppm	CH24401
Vinyl Chloride	Vinyl Chloride 1/a	1–50 ppm	6728031
Water Vapor	Water Vapor 1/a	1–20 mg/L	8101081
o-Xylene	Xylene 10/a	10–400 ppm	6733161
Alternative to Direct Reading Tubes Listed Above			
Activated Charcoal Tube (Type B/G)			8101821
Activated Charcoal Tube (NIOSH size)			6728631

TABLE 17-I-13. Draeger Analysis with DLE Kit (Instrument 17-22)

Substance	Draeger Tube	Measuring Range	Part No.
Aliphatic Hydrocarbons			
Diesel fuels	Petroleum Hydrocarbons 10/a	0.5–5 mg/L	8101691
Diesel fuels (soil analysis)	Petroleum Hydrocarbons 10/a	Qualitative	8101691
Fuels	Petroleum Hydrocarbons 10/a	0.5–30 mg/L	8101691
Fuels (soil analysis)	Petroleum Hydrocarbons 10/a	Qualitative	8101691
Jet Fuels	Petroleum Hydrocarbons 10/a	0.5–5 mg/L	8101691
Jet Fuels (soil analysis)	Petroleum Hydrocarbons 10/a	Qualitative	8101691
n-Octane	Petroleum Hydrocarbons 10/a	0.1–2 mg/L	8101691
n-Octane	Petroleum Hydrocarbons 100/a	2–25 mg/L	6730201
Aromatic Hydrocarbons			
BTX-Aromatics	Toluene 5/b	0.2–5 mg/L	8101161
BTX-Aromatics (oil muds/emulsions)	Toluene 5/b	Qualitative	8101161
BTX-Aromatics (soil analysis)	Toluene 5/b	2–50 mg/Kg	8101161
Benzene	Benzene 2/a	0.5–5 mg/L	8101231
Toluene	Toluene 50/a	1–10 mg/L	8101701
Xylene (o, m, p)	Xylene 10/a	0.3–10 mg/L	6733161
Chlorinated Hydrocarbons (Volatile)			
Carbon Tetrachloride	Carbon Tetrachloride 5/c +		CH27401
	Activation tube	0.2–4 mg/L	8101141
Chloroform	Chloroform 2/a	0.05–0.75 mg/L	6728861
Dichloromethane	Methylene Chloride 100/a	5–100 mg/L	6724601
Multiphase system	Chloroform 2/a	Qualitative	6728861
Multiphase system	Methyl Bromide 0.5/a	Qualitative	8101671
Multiphase system	Perchloroethylene 0.1/a	Qualitative	8101551
Multiphase system	Perchloroethylene 2/a	Qualitative	8101501
Multiphase system	Trichloroethane 50/d	Qualitative	CH21101
Oil muds/emulsions	Chloroform 2/a	Qualitative	6728861
Oil muds/emulsions	Methyl Bromide 0.5/a	Qualitative	8101671
Oil muds/emulsions	Perchloroethylene 0.1/a	Qualitative	8101551
Oil muds/emulsions	Perchloroethylene 2/a	Qualitative	8101501
Oil muds/emulsions	Trichloroethane 50/d	Qualitative	CH21101
Perchloroethylene	Perchloroethylene 0.1/a	10–80 µg/L	8101551
Perchloroethylene	Perchloroethylene 2/a	0.1–4 mg/L	8101501
Soil analysis	Chloroform 2/a	Qualitative	6728861
Soil analysis	Perchloroethylene 0.1/a	Qualitative	8101551
Soil analysis	Perchloroethylene 2/a	Qualitative	8101501
1,1,1 -Trichloroethane	Trichloroethane 50/d	0.5–5 mg/L	CH21101
Trichloroethylene	Perchloroethylene 0.1/a	10–100 µg/L	8101551
Trichloroethylene	Perchloroethylene 2/a	0.1–1 mg/L	8101501
Trichloroethylene	Trichloroethylene 2/a	0.2–3 mg/L	6728541
Inorganic Substances			
Ammonia	Ammonia 0.25/a	1.5–10 mg/L	8101711
Ammonia	Ammonia 0.25/a	10–100 mg/L	8101711
Hydrocyanic Acid	Hydrocyanic Acid 2/a	0.5–10 mg/L	CH25701
Hydrogen Sulfide	Hydrogen Sulfide 0.2/a	50–500 µg/L	8101461
Hydrogen Sulfide	Hydrogen Sulfide 5/b	0.5–10 mg/L	CH29801
Organic acids			
Acetic Acid	Acetic Acid 5/a	0.5–20 g/L	6722101
Formic Acid	Acetic Acid 5/a	1–20 g/L	6722101
Organic Acids	Acetic Acid 5/a	0.5–15 g/L	6722101
Propionic Acid	Acetic Acid 5/a	0.3–10 g/L	6722101

TABLE 17-I-14. Draeger DLE Kit (Instrument 17-22)

Description	Catalog No.
Deluxe Kit includes instructions, tablet and items listed below	4052944
Model 31 Pump	6726065
Spare Parts Kit for Model 31 Pump	6727211
Screwdriver for Model 31 Pump	4039003
Wrench for Model 31 Pump	CH06754
Automatic Stroke Counter	6726124
Carbon Pre-tubes, 10	CH24101
Calibrated Gas Wash Bottle	6400016
Measuring Jug, 250 mL	6400029
Deluxe Tube Opener	6400010
Thermometer (–10 to 60°C)	6400028
Pocket Calculator	9099399
Deluxe Carrying Case, rigid	8711942

TABLE 17-I-15. ChromAir® Badges (Instrument 17-23)

Analyte	Threshold level (ppm-hr)	Minimum detectable conc. in 8 hours (ppm)	Part #
Acetone	20–24000	2.50	380020
Ammonia	4–300	0.50	380003
Carbon Disulfide[1]	0.5–30	0.06	380011
Carbon Monoxide	10–525	1.25	380008
Chlorine	0.4–13	0.05	380004
Chlorine Dioxide	0.1–1.4	0.013	380024
Ethanol	62–7360	7.75	380015*
Ethylene	5–800	0.63	380028
Formaldehyde	0.3–12	0.04	380007
Glutaraldehyde	STEL: (15min)	0.04–0.95	380017
Hydrazine	0.01–0.8	0.002	380012
Hydrogen Sulfide	1–240	0.13	380009
Mercury	0.125–1.6 $mg/m^3 \cdot hr$	0.015 mg/m^3	380018
Methanol	27–3200	3.38	380015
Methyl Ethyl Ketone	18–21600	2.25	380020*
Methyl Isobutyl Ketone	16–19200	2.0	380020*
Nitrogen Dioxide	0.5–13.0	0.06	380006
Ozone[2]	0.08–1.6	0.01	380010
Sulfur Dioxide	0.1–16	0.013	380005

[1] 3 ppm H_2S causes color development in cell 1; 10 ppm H_2S causes color development in cell 2.

[2] Ozone monitor is ten times more sensitive to ozone than to nitrogen dioxide.

* Coefficient must be applied to scale printed on badge.

TABLE 17-I-16. SafeAir® Badges (Instrument 17-24)

Analyte	Threshold level (ppm-hr)	MDC+ in 8 hours (ppm)	MRST* (hrs)	SRST** (mins)	Part #
Ammonia	4.0 ppm·hr	0.50 ppm	48	15	380020
Aniline	0.2 ppm·hr	0.025 ppm	48	5	382021
Arsine	18.0 ppb·hr	2.25 ppb	12	15	382030
Carbon Dioxide	8,000 ppm·hr	1,000 ppm	10	15	380003
Carbon Monoxide	7 ppm·hr	1 ppm	10	15	380011
Chlorine	0.18 ppm·Ahr	0.023 ppm	48	15	382009
Chlorine/Chlorine Dioxide	Cl_2: 0.18 ppm·hr ClO_2: 0.2 ppm·hr	Cl_2: 0.025 ppm ClO_2: 0.025 ppm	10	15	380004
Dimethyl Amine	5 ppm·hr	0.625 ppm	48	5	382019
1,1-Dimethyl Hydrazine	Front: 30 ppb·hr Back: 10 ppb·hr	Front: 3.75 ppb Back: 1.25 ppb	48	5	380015
Formaldehyde	0.4 ppm·hr	0.05 ppm	16	15	382011
Hydrazine	8.0 ppb·hr	1.0 ppb	48	5	382002
Hydrogen Chloride	2.0 ppm	STEL	15 min	15	382024
Hydrogen Fluoride	2.8 ppm	STEL	15 min	15	382029
Hydrogen Sulfide	2 ppm·hr	0.25 ppm	48	15	380017
Mercury/Dual Level	Front: 0.25 mg/m^3·hr Back: 0.08 mg/m^3·hr	Front: 0.031 mg/m^3·hr Back: 0.01 mg/m^3·hr	48	15	382005
Methyl Chloroformate	0.025 ppm·hr	0.0083 ppm (3 hrs)	3	10	382000
Nitrogen Dioxide	1 ppm·hr	0.125 ppm	10	15	380018
Ozone	0.05 ppm·hr	0.006 ppm	48	15	380015
Phosgene	0.9 ppm·min	0.015 ppm	3 days	1	382000
Phosphine	5.0 ppb·hr	0.625 ppb	12	15	382031
Sulfur Dioxide	0.2 ppm·hr	0.025 ppm	48	15	380020
2,4-Toluene diisocyanate (TDI)	5.0 ppb·hr	0.6 ppb	24	15	382001

* Maximum Recommended Sampling Time
** Shortest Recommended Sampling Time
+ Minimum Detectable Concentration

TABLE 17-I-17. Matheson-Kitagawa Precision Detector Tubes (Instrument 17-25)

Substance to be measured	Measuring Range (ppm)	Model No.
Acetaldehyde	5–140	8014-133sb
Acetic acid	1–50	8014-216s
Acetone	100–5000	8014-102sd
Acetylene	50–1000	8014-101s
Acrolein	0.005–1.8%	8014-136
Acrylonitrile	0.25–20	8014-128sd
Allyl alcohol	20–500	8014-184s
Ammonia	1–20 0.2–1	8014-105sd
Aniline	2–30 1–15	8014-181s
Arsine	0.05–2.0	8014-121u
Benzene in presence of gasoline and/or other aromatic Hydrocarbons	5–200	8014-118sb
Benzene	1–100	8014-118sc
Bromine	1–20	8014-114
Butadiene	2.5–100	8014-168sc
N-butane	0.05–0.6%	8014-221sa
1-butanol	5–100	8014-190u
Butyl acetate	15–400	8014-138u
Butyl acrylate	5–60	8014-211u
Butyl cellosolve	10–1000	8014-190u
Carbon dioxide	100–4000	8014-126sf
Carbon disulfide	2–50, 1–25	8014-141sb
Carbon monoxide	1–50	8014-106sc

TABLE 17-I-18. Matheson Qualitative Analysis Tubes and HazMat Kit (Instrument 17-26)

Compound	Detection Limit (ppm)	Compound	Detection Limit (ppm)
Inorganic Tube Model 8014-131		**Organic Tube Model 8014-186B (cont.)**	
Acetic Acid	15	Ethylamine	100
Acetylene	10	Ethyl Benzene	400
Amines	5	Ethyl Cellosolve	100
Ammonia	5	Ethylene	10
Carbon Monoxide	10	Ethylene Oxide	100
Chlorine	5	Formaldehyde	10
Hydrogen Chloride	20	Gasoline	0.1 mg/L
Hydrogen Sulfide	10	Heptane	10
Methyl Mercaptan	10	Hexane	10
Nitrogen Dioxide	5	Isopropyl Alcohol	500
Phosphine	2	Kerosene	0.1 mg/L
Sulfur Dioxide	10	Methyl Alcohol	100
		Methyl Ethyl Ketone	100
Organic Tube Model 8014-186B		Methyl Isobutyl Ketone	100
Acetaldehyde	100	Methyl Mercaptan	20
Acetone	500	Pentane	10
Acetylene	100	Phenol	10
Aniline	50	Propane	100
Benzene	100	Styrene	100
Butadiene	1000	Tetrachloroethylene	1100
Butane	10	Tetrahydrofuran	100
1-Butanol	100	Toluene	200
Butyl Acetate	100	Trichloroethane	1000
Carbon Disulfide	100	Trichloroethylene	1000
Cresol	20	Vinyl Chloride	10
Ethyl Acetate	500	Xylene	1000

TABLE 17-I-19. Matheson Badge Dosimeters (Models 8005, 8006, 8007) (Instrument 17-27)

Detected Gas	M#	Sensitivity	Color Change
Ammonia	17	25 ppm/5 min	Yellow to Blue
Carbon Monoxide	28	50 ppm/10 min	Tan to Black
Chlorine	71	1 ppm/15 min	White to Yellow
Hydrazine	32	0.1 ppm/15 min	White to Yellow
Hydrogen Sulfide	34	10 ppm/10 min	White to Brown
Nitrogen Dioxide	46	5 ppm/15 min	White to Yellow
Ozone	48	0.1 ppm/15 min	White to Brown

TABLE 17-I-20. Matheson Compressed Breathing Air Analysis Kit (Instrument 17-28)

Components	Measured Range	Sampling Time
Carbon Monoxide	5–100 ppm	2 min
Carbon Dioxide	100–3000 ppm	2 min
Oil Mist	0.3–5 mg/m^3	25 min
Water Vapor	20–160 mg/m^3	1 min
Oxygen	2–24%	1 min

TABLE 17-I-21. MSA Detector Tubes (Instrument 17-30)

Substance	Range	P/N
Acetic Acid	1–80	804138
Acetone	100–10,000	804141
Alcohols	100–6,000	804136
Amines	5–30	804134
Ammonia	20–1,000	800300
Benzene	1–25	807024
Bromine	0.2–30	803944
Bromoethane	30–720	487834
Butane	200–3800	804418
Carbon, Dioxide	100–2,000	488907
Carbon Monoxide	5–1,000	803943
Carbon Disulfide	2–300	492514
Chlorine	0.5 & 2.5	804412
Chlorine Dioxide	0.05–15	804133
Dichloroethane	30–720	804416
Formaldehyde	0.15–10	497649
Gasoline	30–6,000	492870
Hexane	100 & 1,000	804410
Hydrocarbons Halogen	20–170	487343
Hydrogen Chloride	1–30	803948
Hydrogen Cyanide	2–50	803945
Hydrogen Fluoride	50–630	804132
Hydrogen Sulfide	10–4,000	807340
Mercaptans	0.5–100	804597
Mercury	0.01–0.08	497663
Methylene Chloride	50–1,000	804416
Nitric Oxide	2–140	804425
Nitrogen Dioxide	0.05–50	487341
Oil Mist	1–3 mg/m^3	488909
Ozone	0.05–5	804140
Perchloroethylene	5–2,000	804429
Phosgene	0.1–20	803949
Phosphine	0.1–100	485680
Styrene	10–300	804135
Sulphur Dioxide	0.5–25	487338
Toluene	5–1,000	803947
Trichloroethylene	5–250	487342
Vinyl Chloride	1–70	803950
Water Vapor	5–160 mg/m^3	804438
Xylene	1.5–2,600	803947

TABLE 17-I-22. MSA Haz-Mat Response Kit (Instrument 17-31)

— P/N 807472 includes:

Kwik-Draw pump	P/N 487500
Ethanol tube, Box of 10	P/N 804136
Aromatic hydrocarbons tube, Box of 10	P/N 804132
Hexane tube, Box of 10	P/N 497664
Hydrogen cyanide tube, Box of 10	P/N 803945
Trichloroethane tube, Box of 10	P/N 487343
Nitrogen dioxide tube, Box of 10	PIN 487341
Carbon monoxide tube, Box of 10	P/N 803943
Triethylamine tube, Box of 10	P/N 804134
Carbon dioxide tube, Box of 10	P/N 487333
Hydrogen chloride tube, Box of 10	P/N 803948
Ethyl mercaptan tube, Box of 10	P/N 804589
Ethylene tube, Box of 10	P/N 804428

TABLE 17-I-23. MSA Indoor Air Quality Kit (Instrument 17-32)

—P/N 710981 includes:

P/N 487500 Kwik-Draw Deluxe pump
P/N 70918 Box of detector tubes, two each for:
- Carbon monoxide
- Carbon dioxide
- Formaldehyde
- Ozone
- Water vapor

TABLE 17-I-24. RAE Colorimetric Tubes

Analyte	Range (ppm)	Product No.
Acetone	0.1–2%	10-111-40-151
Ammonia	1–30	10-100-05-3L
Ammonia	25–500	10-100-15-3M
Ammonia	1–15%	10-100-40-3H
Ammonia	5–100	10-100-10-3La
Benzene	5–100	10-101-20-121
Benzene	0.5–40	10-101-05-121SL
Carbon Monoxide	5–100	10-102-20-1LL
Carbon Monoxide	20–500	10-102-30-1La
Carbon Monoxide	0.2–4%	10-102-45-1H
Carbon Dioxide	1–20%	10-104-50-2H
Carbon Dioxide	0.25–3%	10-104-45-2L
Carbon Dioxide	0.05–1%	10-104-40
Carbon Dioxide	300–5000	10-104-30-2LL
Chlorine	0.5–8	10-106-10-8La
Chlorine	5–100	10-106-20
Hydrocarbons	50–1000	10-110-30
Hydrogen Fluoride	0.5–20	10-105-10-17
Hydrogen Sulfide	0.2–3	10-103-05-120UP
Hydrogen Sulfide	2.5–60	10-103-10-4LL
Hydrogen Sulfide	100–2000	10-103-30-4H
Hydrogen Sulfide	50–800	10-103-20-4HM
Hydrogen Sulfide	25–250	10-103-18-4M
Hydrogen Sulfide	2–50	10-103-10-4LL
Hydrogen Sulfide	0.1–2%	10-103-40-4HH
Hydrogen Sulfide	10–120	10-103-15-4L
Hydrogen Sulfide	2–40%	10-103-50-4HT
Hydrogen Chloride	20–500	10-108-20-14M
Hydrogen Chloride	1–20	10-108-10-14L
MEK	0.02–0.6%	10-113-20-152
Mercaptans	5–120	10-129-20-70
Nitrogen Dioxide	0.5–30	10-117-10
Nitrogen Oxides*	1–50	10-109-20
Phosphine	5–50	10-116-10-7
Phosphine	25–50	10-116-20-7J
Phosphine	50–1000	10-116-25
Sulfur Dioxide	2–30	10-107-15-5La
Sulfur Dioxide	200–4000	10-107-30
Sulfur Dioxide	100–1800	10-107-25-5M
Sulfur Dioxide	5–100	10-107-20-5L
Sulfur Dioxide	0.2–5%	10-107-40-5H
Toluene	10–300	10-114-20-122
Water Vapor	0.03–0.16 mg/L	10-120-10-6LP
Water Vapor	0.1–0.64 mg/L	10-120-20-6LP
Xylene	10–200	10-112-20-123

* Box contains 5 colorimetric tubes and 5 pre-tubes with 1 connector for a total of 5 measurements

TABLE 17-I-25. Sensidyne/Kitagawa Deluxe HazMat Kit III and Tubes (Instrument 17-35)

Part Number 7013627 comes complete with the following equipment:

Item	Part Number
Model AP-IS pump kit	7013585
Hard Shell Case	7015574-1
5-m extension hose	7013596
Gas detection manual	7013584
Logic chart III	7013628
Color Chart for qualitative tubes	7013655
Air flow indicator kit	500
Detector tubes (one box each):	
Acetone	102SC
Carbon dioxide	126SA
Hydrogen sulfide	120SB
Trichloroethylene	134SB
Benzene	118SB
Methyl mercaptan	130U
Arsine	121U
Hydrogen fluoride	156S
Methyl bromide	157SB
Ethyl acetate	111U
Hydrogen	137U
Carbon tetrachloride	147S
Carbon disulfide	141SB
Organic qualitative test	186B
Inorganic qualitative test	131

TABLE 17-I-26. Sensidyne Detector Tubes (partial list of 300+ tubes, Instrument 17-36)

***Note*: The list below is only a partial list of products. The full list can be found at *www.sensidyne.com*.**

Gas or Vapor	Range	Tube #
Acetaldehyde	0.004-1.0 %v 5-140 ppm	133A 133SB
Acetic Acid	1-50 ppm	216S
Acetic Anhydride	1-15 ppm	216S
Acetone	0.1-5.0 %v 0.01-4.0% 40-5,000 ppm	102SA 102SC 102SD
Acetylene	50-1,000 ppm	101S
Acetylene & Ethylene (separate measure)	A: 20-300 ppm, E: 200-2,000 ppm	280S
Acetylene *Dichloride (see* 1,2 Dichloroethylene)		
Acrolein	0.005-1.8 %v	136
Acrylic Acid	1-50 ppm	216S
Acrylonitrile (Vinyl Cyanide)	0.1-3.5 %v 1-120 ppm 0.25- 20 ppm	128SA 128SC 128SD
Air (Breathing Air) Tubes (see Separate Listing)		
Allyl Alcohol (propenyl Alcohol)	20-500 ppm	184S
Allyl Chloride (3-Chloroprene) Amines (see specific Amines)	1-40 ppm	132S
Aminobenzene (see Aniline)		
2-Aminoethanol (see Monoethanol Amine)		
2-Aminopropane (see Isopropyl Amine)		
Ammonia	0.5-10 %v 50-900 ppm 5-260 ppm 0.2-20 ppm 0.5-30 %v 0.1-1.0 %v	105SA 105SB 105SC 105SD 105SH 105SM
Amyl Acetate (see Pentyl Acetate)		
Aniline (Aminobenzene)	1-30 ppm	181S
Arsine	5-160 ppm 0.05-2.0 ppm	140SA 121U
Benzene	1-100 ppm	118SC
Benzene (in presence of gasoline and/or other aromatic HCs)	5-200 ppm	115SB
Benzyl Chloride	1-16 ppm	132SC
Breathing Air Tubes (see Separate Listing)		
Bromine	1-20 ppm	114
Bromochloromethane (Chlorobromomethane)	5-400 ppm	157SB
Bromoform (Tribromomethane)	0.5-20 ppm	157SB
Bromomethane (see Methyl Bromide)		

TABLE 17-I-27. Commercial Sources of Colorimetric Indicators

Manufacturers

Acculabs Technologies, Inc.
1018-E Morrisville Pkwy.
Morrisville, NC 27560
(888) 853-5030
FAX (919) 468-0185
E-mail: acculabs@mindspring.com

AGC
American Gas and Chemical Co.
220 Pegasus Ave.
Northvale, NJ 07647
(800) 288-3647 or (201) 767-7300
FAX (201) 767-1741
www.amgas.com

Assay Technology
1252 Quarry Lane
Pleasanton, CA 94566
(800) 833-1258 or (925) 461-8880
FAX (925) 461-7149
www.assaytec.com

BAC
Bacharach, Inc.
625 Alpha Drive
Pittsburgh, PA 15238
(412) 963-2000 or (800) 736-4666
FAX (412) 963-2091
help@bacharach-inc.com
www.bacharach-inc.com

NDR
Draeger Safety, Inc.
101 Technology Drive
Pittsburgh, PA 15275
(412) 787-8383 or
(800) 922-5518
FAX (800) 922-5519
www.draeger-usa.com

K&M Environmental
2421 Bowland Pkwy., Suite 102
Virginia Beach, VA 23454
(757) 431-2260 or
(800) 808-2234
FAX (757) 431-2255
www.kandmenvironmental.com

MGP
Matheson-Kitagawa
Matheson Tri Gas
166 Keystone Drive
Montgomeryville, PA 18936
(215) 641-2700 or (800) 416-2505
FAX (215) 641-2714
www.matheson-trigas.com

MSA
Mine Safety Appliances Co.
121 Gamma Drive
Pittsburgh, PA 15238
(800) 672-4678
FAX (412) 967-3451
www.MSAnet.com

PiezOptic, Ltd.
Viking House
Ellingham Way
Ashford
Kent TN23 6NF
United Kingdom
44(0)1233-641990
FAX +44(0)1233-645020
www.itl.co.uk/www/piezoptic

RAE
RAE Systems, Inc.
1339 Moffett Park Drive
Sunnyvale, CA 94089
(408) 585-3523 or (888) 723-8823
FAX (408) 752-0724
www.raesystems.com/home1.html

SEN
Sensidyne, Inc.
16333 Bay Vista Drive
Clearwater, FL 33760
(727) 530-3602 or (800) 451-9444
FAX (727) 839-0550
www.sensidyne.com

Distributors

AFC
AFC International, Inc.
(distrib. Draeger Safety and
K&M Environmental)
P.O. Box 408
Cedar Lake, IN 46303
(219) 374-4623 or (800) 952-3293
FAX (219) 374-4625
www.afcintl.com

Brandt Instruments
(distrib. PiezOptic, Ltd.)
750 East 1-10 Service Road
Suite D
Slidell, LA 70461
(504) 863-5597
FAX (504) 863-7112

Eirtech Instruments
(distrib. PiezOptic, Ltd.)
1057 East Henrietta Road
Rochester, NY 14623 U.S.A.
(716) 424-2030
FAX (716) 424-2166

Environmental Specialty
Products
(distrib. PiezOptic, Ltd.)
P.O. Box 365
Buford, GA 30515 U.S.A.
(770) 995-6678
FAX (770) 995-6079

O'Brien and Gere Companies
5555 East Genesse Street
Fayettville, NY 13066
(888) 976-2477
FAX (315) 637-2015

Safety First Environmental
(distrib. K&M Environmental)
429 Hinsonton Rd.
Meigs, GA 31765-3617
(912) 294-1926
(912) 294-0837
www.safetyfirst.com

SMG
SMG
(distrib. PiezOptic, Ltd.)
1631 Dorchester
Suite 117
Plano, TX 75075
(972) 985-0883
FAX (972) 985-3252

TABLE 17-I-27. (cont.). Commercial Sources of Colorimetric Indicators

Distributors, continued

ENM
ENMET Corp.
P.O. Box 979
Ann Arbor, MI 48106
(734) 761-1270
FAX (734) 761-3220
info@enmet.com
www.enmet.com

Safety & Hygiene Management Inc.
(distrib. of PiezOptic, Ltd.)
430 Hazelwood Avenue
Waynesville, NC 28786 U.S.A.
(828) 456-7798
FAX (828) 456-7583

Vendors for Wipe-Tests

BGI
BGI Incorporated
58 Cuinan Street
Waltham, MA 02451
(781) 891-9380
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