CHAPTER 16

DIRECT READING INSTRUMENTS FOR DETERMINING CONCENTRATIONS OF AEROSOLS, GASES AND VAPORS

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INTRODUCTION

This chapter deals with direct reading instruments which may be portable devices or fixed-site monitors; it does not include those instruments which have been designed primarily for use in the laboratory.

Direct reading instruments are used for on-site evaluations for a number of reasons, including:

1. To find the sources of emission of hazardous substances on the spot;
2. To ascertain if select OSHA air standards are being exceeded;
3. To check the performance of control equipment;
4. As continuous monitors at fixed locations,
   a. To trigger an alarm system in the event of a breakdown in a process control which could result in the accidental release of copious amounts of harmful substances to the workroom atmosphere;
   b. To obtain permanent recorded documentation of the concentrations of a contaminant in the atmospheric environment for future use in epidemiological and other types of occupational studies, in legal actions, to inform employees as to their exposure, and for information required for improved design of control measures.

Such on-site evaluations of the atmospheric concentrations of hazardous substances make possible the immediate assessment of undesirable exposures and enable the industrial hygienist to make an immediate correction (including a shutdown) of an operation, in accordance with his judgment of the seriousness of a situation, without permitting further risk of injury to the workers. It cannot be over-emphasized that great caution must be employed in the use of direct reading instruments and in the interpretation of their results. Many of these instruments are nonspecific and the industrial hygienist may find it necessary before recommending any action to make certain of his on-site findings by supplemental sampling and laboratory analyses to characterize fully the chemical nature of the contaminants in a workroom area and to develop the supporting quantitative data with more specific methods of greater accuracy. Such precautions become the more mandatory if the industrial hygienist has not had extensive experience with the particular process area in question or when the possibilities of a change in the process or in the substitution of chemical substances may have occurred. The last possibility must always be foremost in the minds of industrial hygienists.

Calibration

The calibration of any direct reading instrument is an absolute necessity if the data are to have any meaning. Considering this to be axiomatic, we must also recognize that the frequency of calibration is dependent upon the type of instrument as well as individual instruments within any one class. It is well known that certain classes of instruments, because of their design and complexity, require more frequent calibration than others. It is also recognized that peculiar "quirks" in an individual instrument produce greater variations in its response and general performance, thus requiring a greater amount of attention and more frequent calibration than other instruments of the same design. Direct personal experience with a given instrument serves as the best guide in this matter.

Another unknown factor which can be evaluated only by experience is the variability of sampling locations. For example, when locating a particular fixed-station monitor at a specific site, consideration must be given to such problems as the presence of interfering chemical substances, the corrosive nature of contaminants, vibration, voltage fluctuations and other disturbing influences which may affect the response of the instrument.

Finally, the required accuracy of the measurements must be determined initially. Obviously, if an accuracy of ± 3 percent is needed, more frequent calibration must be made than if ± 25 percent accuracy is adequate in the solution of a particular problem.

Properties of Aerosols

An aerosol is an airborne solid or liquid substance. Aerosol particles normally present in ambient air have been dispersed as a result of nature's or man's activities. The latter source is of greatest concern to environmental control specialists. Aerosols are generated by fire, erosion, sublimation, condensation and the abrading action of friction on minerals, metallurgical materials, organic and other inorganic substances in construction, manufacturing, mining, agriculture, transportation and other gainful pursuits.

Aerosols are classified conveniently as dusts, fumes, smokes, mists and fogs according to their physical nature, their particle size, and their method of generation. Dusts range from 1 to 150 μm in diameter; they are produced mechanically by grinding and other abrasive actions occurring in natural and commercial operations.

Fumes are particulate substances whose diameters range from 0.2 to 1 μm; they are produced by such processes as combustion, distillation, calcination, condensation, sublimation, and chemical reactions. They form true colloidal systems in air. Examples are such substances as heated metals or metallic oxides, ammonium chloride, hot asphalt and volatilized polynuclear hydrocarbons from coking operations.

Smokes are colloidal systems whose particle sizes range from 0.3 to 0.5 μm in diameter. They are produced by the incomplete combustion of carbonaceous materials such as coal, oil, tobacco, and wood.

Mists and fogs cover a wide range of particle sizes and are considered to be primarily liquid; they may consist of liquids, such as water vapor, condensed on the surfaces of submicroscopic particles of dust or gaseous ions.

Mineral, vegetable and animal fibers constitute a unique situation insofar as exposures are concerned. Inhalation of asbestos fibers up to 200 μm in length has been reported.[1,2] Microscopic procedures are used to assist in the identification of, and to determine, the atmospheric concentration of fibrous materials.

Properties of Gases and Vapors

Gases and vapors are "elastic fluids," so-called because they take the shape and volume of their containers. A fluid is generally termed a gas if its temperature is very far removed from that required for liquefaction; it is called a vapor if its temperature is close to that of liquefaction. In the field of occupational health, a substance is considered a gas if this is its normal physical state at room temperature and atmospheric pressure. It is considered a vapor if, under the existing environmental conditions, conversion of its liquid or solid form to the gaseous state results from its vapor pressure affecting its volatilization or sublimation into the atmosphere of the container, which may be the process equipment or the workroom. Our chief interest in distinguishing between gases and vapors lies in our need to assess the potential occupational hazards associated with the use of specific chemical agents, an assessment which requires a knowledge of the physical and chemical properties of these substances (see Chapter 15).

Characteristics of Direct Reading Instruments

Direct reading instruments for atmospheric contaminants are classified as those devices which provide an immediate indication of the concentration of aerosols, gases, or vapors by a dial reading, a strip chart recording, a tape printout or a color change on an impregnated paper or in an indicator tube. These devices, when properly calibrated and when used with full cognizance of their performance characteristics and limitations, can be extremely helpful to industrial hygienists who are engaged in on-site evaluations of potentially hazardous conditions. There are many types of instruments which depend on certain physical or chemical principles for their operation. They are discussed later in this chapter.

The advantages of direct reading instruments include:

1. Immediate estimations of the concentration of a contaminant, permitting on-site evaluations;
2. Provision of permanent 24-hour records of contaminant concentrations using continuous monitors;
3. Attachment of alarm system to instrument to warn workers of build-up of hazardous situations;
4. Reduction of number of manual tests;
5. Reduction of number of laboratory analyses;
6. Provision of more convincing evidence for presentation at hearings and litigation proceedings;
7. Reduced cost of obtaining individual results.

The disadvantages of different types of direct reading instruments may include some of the following:

1. High initial cost of instrumentation;
2. Need of frequent calibration;
3. Lack of adequate calibration facilities;
4. Lack of portability;
5. Lack of specificity.

DIRECT READING PHYSICAL INSTRUMENTS

The physical properties of aerosols, gases, and vapors are used in the design of direct reading physical instruments for quantitative estimations of these types of contaminants in the atmosphere. The principles upon which these instruments are based are presented in the following discussion.

Operating Principles

Aerosol Photometry (Light Scattering). The principle of aerosol photometry is the generation of an electrical pulse by a photocell which detects the light scattered by a particle. A pulse height analyzer estimates the effective particle diameter. The number of electronic pulses is related to the number of particles counted per unit flowrate of the sampled gaseous medium. Calibrations may be made using a reference standard such as polystyrene spheres whose diameters and refractive index are known although the aerosol under study is the reference of choice because of the unique effects of shape factor, angle of scatter, and refractive index, as well as particle size. Whereas certain commercial instruments are designed to give a size analysis based upon the above principles, there are others which use a forward light scattering principle to provide an integrated measurement of total particle concentration in a large illuminated volume. The latter are used in monitoring particulate concentrations in experimental rooms and exposure chambers.

Aerosol photometry can usually provide only an approximate analysis of particulate classified according to particle size in plant surveys because of the impracticality of calibrating the instrument with each type of particulate suspension which is to be measured. The great variations in shape, size, degrees of agglomeration and refractive indices of the mixture of chemical components in a given dust or fume suspension make such a calibration exceedingly difficult. Whereas aerosol photometry can, therefore, provide an indication of the particulate concentration in the different particle size ranges of interest, it is still necessary to perform size distribution analyses by microsieving and microscopic procedures for greatest accuracy.

Chemiluminescence. Chemiluminescence is a phenomenon which occurs with certain chemical reactions. The process provides a distinctly colored glow which accompanies such reactions as the oxidation of certain decaying wood, of luciferin in fireflies and of yellow phosphorus. Recently, analytical advantage of this phenomenon is taken in the reaction of ozone with such other gases as ethylene and nitric oxide for the measurement of ozone or nitrogen oxides in ambient atmospheres.

The chemiluminescent principle has been incorporated into continuous ambient air monitors which are selective for ozone or for NO — NO_x. Measurements of ozone at concentrations extending from 0.001 to 1 ppm in ambient atmospheres are based upon the photometric (photomultiplier tube) detection of the chemiluminescence produced by the flameless gas phase reaction of the ozone in the air sample stream with ethylene gas whose flow from a bottled supply is regulated through a calibrated capillary tubing to the reactor chamber.

Similarly, NO measurements from 0.01 to 5,000 ppm are based upon the chemiluminescent reaction of NO and ozone to produce NO_2 and $O_2 + h\gamma$. The ozone is produced from bottled oxygen by an in-line ozone generator. Monitoring of NO_x is accomplished by means of an NO_2 to NO catalytic converter which operates in a bypass line on a timed sequence basis. Thus, NO_2 measurements can be obtained by difference.

The selectivity of these instruments is enhanced by the use of narrow-band optical filters to provide negligible interference effects from other atmospheric contaminants. Although designed for ambient air studies, these instruments may be used advantageously as fixed-station monitors of in-plant atmospheres.

Colorimetry (see Photometry)

Combustion. A combustible gas or vapor mixture is passed over a filament heated above the ignition temperature of the substance of analytical interest. If the filament is part of a bridge circuit, the resulting heat of combustion changes the resistance of the filament, and the measurement of the imbalance is related to the concentration of the gas or vapor in the sample mixture. The method is basically nonspecific, but it may be made more selective by choosing appropriate filament temperatures for individual gases or vapors or by using an oxidation catalyst for a desired reaction such as Hopcalite for carbon monoxide.

Combustible gas indicators must be calibrated in the laboratory for their response to the anticipated individual test gases and vapors, such as benzene, toluene, hexane (for hydrocarbons in general), carbon monoxide, acetone, and styrene. These instruments are definitely portable and they are valuable survey meters in the industrial hygienist's collection of field instruments. Readings are in terms of 0-1000 ppm or 0-1.0 Lower Explosive Limit (LEL). However, it is essential to recognize that industrial atmospheres rarely contain one gaseous contaminant and that these indicators will respond to all the combustible gases present. Hence, supplementary sampling and analytical techniques should be used for a complete definition of hazardous environmental conditions.

Conductivity, Electrical. A gas-air mixture is drawn through an aqueous solution. Those gases which form electrolytes produce a change in the electroconductivity as a summation of the effects of all ions thus produced. Hence, the method is nonspecific. If the concentrations of all other ionizable gases are either constant or insignificant, then the resulting changes in conductivity may be related to the gaseous substance of interest. Temperature control is extremely critical in conductance measurements; if thermostated units are not used, then electrical compensation must enter into the measurements to allow for the 2% per degree C conductivity temperature coefficient average for many gases.

The electrical conductivity method has found its greatest application in the continuous monitoring of sulfur dioxide in ambient atmospheres. However, a lightweight portable analyzer which uses a peroxide absorber to convert SO_2 to H_2SO_4 is now available; this battery operated instrument can provide within one minute an integrated reading of the SO_2 concentration over the 0-1 ppm range. A larger portable model which may be operated off a 12-volt automobile battery is also available for the higher concentration ranges of SO_2 encountered in field sampling.

Conductivity, Thermal. The specific heat of conductance of a gas or vapor is a measure of its concentration in a carrier gas such as air, argon, helium, hydrogen, or nitrogen. However, thermal conductivity measurements are nonspecific and the method finds its greatest usefulness in estimating the concentration of the separately eluted components from a gas chromatographic column. The method operates by virtue of the loss of heat from a hot filament to a single component of a flowing gas stream, the loss being registered as a decrease in electrical resistance measured by a Wheatstone bridge circuit. The applications of this method are limited mostly to binary gas mixtures and are based upon the electrical unbalance produced in the bridge circuit by the difference in the filament resistances of the sample and reference gases passed through the separate cavities in the thermal conductivity cell.

Coulometry. Coulometry is the precise measurement of the quantity of electricity passing through a solution during an electrochemical reaction. The substance of analytical interest is oxidized or reduced at one electrode in a primary coulometric analysis or it may react stoichiometrically (in a secondary coulometric analysis) with one of the electrolytic products. The method is capable of a high degree of precision. It is used in the automatic monitoring of part per billion to part per million concentrations of reactive inorganic gases present in ambient atmospheres; air samples are drawn through the electrolytic cell in which the reactant is generated in controlled quantities to meet the concentration requirements.

The method is basically nonspecific; it is made more selective for specific atmospheric oxidants by adjusting the concentration, pH and composition of the electrolyte used in the reaction. In certain instances a chemical filter or a selective membrane is used to remove serious interferents from the sampled gas stream. Both portable and fixed monitor types of instruments, based upon this principle, are used to monitor ozone, nitrogen dioxide and sulfur dioxide concentrations.

Flame Ionization. The hydrogen flame ionization detector (FID) is a stainless steel burner in which hydrogen is mixed with the sample gas stream in the base of the unit; combustion air or oxygen is fed axially and diffused around the jet through which the hydrogen — gas mixture flows to the cathode tip where ignition occurs. A loop of platinum serves as the collector electrode which is set about 6 mm above the tip of the burner. The current carried across the electrode gap is proportional to the number of ions generated during the burning of the sample; the detector responds to all organic compounds, except formic acid, but its response is greatest with hydrocarbons and diminishes with increasing substitution of other elements: notably oxygen, sulfur and chlorine. Its low noise level of 10^{-12} amperes provides a high sensitivity of detection and it is capable of the wide linear dynamic range of 10^7. Its usefulness is enhanced by its insensitivity to water, the permanent gases and most inorganic compounds thus simplifying the analysis of aqueous solutions and atmospheric samples. It is used to great advantage in both laboratory and field models of gas chromatographs as well as in hydrocarbon analyzers which are set up as fixed station monitors of ambient atmospheres in the laboratory or field.

Hydrocarbon analyzers, operating with an FID detector, are carbon counters; their response to a given quantity of a typical C_6 hydrocarbon is six times to that of methane, at a fixed flowrate of the sample stream. Thus, the instrumental characteristics such as sensitivity, are usually given as methane equivalent. In addition to hydrocarbons, these analyzers respond to alcohols, aldehydes, amines and other compounds which will produce an ionized carbon atom in the hydrogen flame. The electronic stability of at least one model is within 1 percent over 24 hours of operation; this instrument is equipped with electronic span calibration to improve the accuracy of the data.

Gas Chromatography. Gas chromatography is a physical process for separating the components of complex mixtures and is now being used profitably as a portable technique for in-plant studies. A gas chromatograph consists of (1) a carrier gas supply complete with a pressure regulator and flow meter, (2) an injection system for the introduction of a gas or vaporizable sample into a port at the front end of the separation column, (3) a stainless steel, copper or glass separation column containing a stationary phase consisting of an inert material, such as diatomaceous earth, used alone as in gas-solid chromatography (GSC) or as a support for a thin layer of a liquid substrate, such as silicone oils, in gas-liquid chromatography (GLC), (4) a heater and oven assembly to control the temperature of the column(s), injection port and detector unit, (5) a detector and (6) a recorder for the chromatograms produced during the separations. The separations are based upon the varied affinities of the sample components for the packing materials of a particular column, the rate of carrier gas flow and the operating temperature of the column. Improved separations are made possible by the use of temperature programming. The sample components, as a consequence of their varied affinities for a given column, are eluted sequentially and thus evoke separate responses by the detection system whose signal is amplified to produce a peak on the strip chart recorder. The height and area of the peak are proportional to the concentration of the eluted sample component. Calibrations are made using known mixtures of the pure substance in a gas-air mixture prepared in a 5- to 100-liter Saran bag or other suitable container. The time of retention on the column and supporting analytical techniques (infrared spectrophotometry, for example) are used in the identification of the individual peaks of a chromatogram. The method is capable of providing extremely clean-cut separations and is one of the most useful techniques in the field of organic analysis. It is sensitive to fractional part per million concentrations of organic substances. The most commonly used detectors include flame ionization, thermal conductivity and electron capture (see Chapter 21 on Gas Chromatography).

Rugged, battery operated, portable gas chromatographs have been refined to the point where they may now be considered practical for many field study applications. These instruments may now be obtained with a choice of thermistor-type thermal conductivity, flame ionization and electron capture detectors and, in some instances, the latter two types are interchangeable. Complete with gas sampling valve, rechargeable batteries, appropriate columns and self-contained supplies of gases, these chromatographs have much to offer to the industrial hygienist engaged in on-site analyses of trace quantities of organic compounds and the permanent gases. The gas lecture bottles provide 8 to 20 hours of operation dependent on the flowrates and must be recharged using high pressure gas regulators. The retention times of the compounds of analytical interest must be determined in the laboratory for a given type of column, as is true for the laboratory type chromatographs.

Photometry (Colorimetry). Photometry is the measurement of the relative radiant power of a beam of radiant energy, in the visible, ultraviolet or infrared region of the electromagnetic spectrum, which has been attenuated as a result of passing through a solution, a gas-air mixture containing a substance such as mercury vapor, ozone or benzene vapor, a suspension of solid or liquid particulates in air or other gaseous medium, or a photographic image of a spectral line or an x-ray diffraction pattern on a photographic film or plate. Photometers used for the indicated types of applications contain (1) a lamp or other generating source of energy, (2) an optical filter arrangement to limit the bandwidth of the incident beam of radiation, (3) an optical system to collimate the filtered beam, which is then passed through (4) the sample system contained in a cuvette or gas cell to (5) a photocell, bolometer, thermocouple or pressure sensor type of detector where the signal is amplified and fed to a (6) readout meter or to a strip chart recorder.

The more sophisticated technique is termed spectrophotometry which makes use of prisms made of glass (visible region), quartz (ultraviolet), and sodium chloride or potassium bromide (infrared) or of diffraction gratings, instead of optical filters, to provide essentially monochromatic radiation as a "purer" source of energy. Spectrophotometers are used mostly in laboratories for highly specific and precise analytical determinations.

Most field type colorimetric analyzers have been designed to function as fixed-station monitors for the active gases such as oxides of nitrogen, sulfur dioxide, "total oxidant," ammonia, aldehydes, chlorine, hydrogen fluoride, and hydrogen sulfide. These instruments require frequent calibration with zero and span gases at the sampling site to assure the provisions of reliable data. However, built-in automated calibration systems, which standardize regularly zero and span controls against pure air and a calibrated optical filter, are now available from one source of colorimetric analyzers for the nitrogen oxides, sulfur dioxide and aldehydes. A further advantage is the 0-10 ppm working range of these instruments with the optional capability of extending the upper limit to 10,000 ppm.

Another recent advance is the provision of a portable, colorimetric analyzer for NO_2-NO_x by another manufacturer. This instrument, which uses dual photometric cells, is designed for rugged field use, may be operated from a 12-volt automobile battery and operates over the 0-2.0 ppm range, with higher ranges available. It may also be used as a field monitor, if desired.

Polarography. Polarographic analysis is based on the electrolysis of a sample solution using an easily polarized microelectrode (the indicator electrode) and a large nonpolarizable reference electrode. In laboratory instruments the indicator electrode is a noble metal, usually a dropping mercury electrode for reduction reactions and a platinum electrode for oxidation reactions. The reference electrode may be a pool of mercury on the bottom of the electrolysis vessel or a saturated calomel electrode.

The method provides both qualitative and quantitative information. As the increasing voltage to the polarographic cell is applied at a steady rate, the decomposition potentials of electroreducible (or electrooxidizable) ions are reached in turn. At the decomposition potential of a given ion, the current increases rapidly and then levels off to a limiting current thus producing an S-shaped curve or "wave." The value of the half-wave potential is characteristic of the discharged ion in a given electrolyte. The height of the wave, i.e., the rise in the current, is proportional to the concentration of the discharged ion species in the sample.

The method has been used largely for the analysis of metallic ions and organic species. Manufacturers of modern field instruments, however, are taking advantage of advanced, compact, long-lived polarographic sensors to provide continuous monitors for oxygen in such diversified environments as furnace atmospheres, flue gases, auto exhausts, space vehicles, manholes and physiology test chambers.

These portable instruments may be easily calibrated for gaseous oxygen by exposing the sensor to ambient air and adjusting the calibration pot to provide a meter reading of 20.9 on the 0-25 percent scale. These instruments provide a rapid response to changes in the concentration of oxygen and should prove valuable to the industrial hygienist who may encounter oxygen deficient atmospheres during his surveys.

Radioactivity. Radioactive substances emit three principal types of radiation, vis. alpha (α), beta (β), and gamma (γ). Radioactive particles and gases may be monitored manually or automatically in gas streams, in ambient atmospheres, in process water or in solid process materials or products by means of ionization chambers, scintillation detectors or Geiger-Mueller counters. Choice of detectors for alpha, beta-gamma or alpha-beta-gamma monitors is determined by the isotopes of interest. Electronic recorders are available for graphic presentation of monitoring data.

Portable lightweight air monitors for gamma, beta-gamma, and alpha-beta-gamma radiation are available with interchangeable probes to survey work areas for the different types of radiation encountered. One such instrument thus provides the capability of measuring alpha and weak beta radiation using one probe and gamma radiation up to 10 or 60 mr per hour with the others. Other portable survey meters include the "Cutie Pie" with ranges of 50, 500, and 5000 mr per hour and a fast neutron survey meter designed with tissue equivalent response in making health hazard surveys in the range of 0.2 to 14 MEV around reactors and neutron generators.

A summary of the operating characteristics of the current (1972) commercially available direct reading physical instruments is presented in Table 16-1. The information provided in this table is based upon that given in the manufacturers' literature; in certain instances, e.g., repeatability, a range of values may represent either the specifications given by more than one source of supply or different applications of an operating principle to the estimation of multiple chemical entities. In other cases, the information has not been provided

TABLE 16-1

Direct Reading Physical Instruments

Principle of Operation	Applications & Remarks	Code*	Range	Repeatability (Precision)	Sensitivity	Response Time
Aerosol Photometry	Measures, records and controls particulates continuously in areas requiring sensitive detection of aerosol levels; detection of 0.05 to 40 μm diameter particles. Computer interface equipment is available.	A & B	10^{-3} to 10^2 μg per liter	Not given	10^{-3} μg per liter (for 0.3 μm DOP)	Not given
Chemiluminescence	Measurement of NO in ambient air selectivity and NO_2 after conversion to NO by hot catalyst. Specific measurement of 0_3. No atmospheric interferences.	B	0 to 10,000 ppm	± 0.5 to ± 3%	Varies: 0.1 ppb to 0.1 ppm	ca 0.7 sec NO Mode and 1 sec NO_x mode; Longer period when switching ranges
Colorimetry	Measurement and separate recording of NO_2-NO_x, SO_2, total oxidants, H_2S, HF, NH_3, $C1_2$ and aldehydes in ambient air.	A & B	ppb & ppm	± 1 to ± 5%	0.01 ppm (NO_2, SO_2)	30 sec. to 90% of full scale
Combustion	Detects and analyzes combustible gases in terms of percent LEL on graduated scale. Available with alarm set at ⅓ LEL.	A	ppm to 100%	——	ppm	<30 sec.
Conductivity, Electrical	Records SO_2 concentrations in ambient air. Some operate off a 12-volt car battery. Operate unattended for periods up to 30 days.	A & B	0 to 2 ppm	<±1% to ±10%	0.01 ppm	1 to 15 sec. (lag)
Coulometry	Continuous monitoring of NO, $N0_2$, 0_3 and SO_2 in ambient air. Provided with strip chart recorders. Some require attention only once a month.	A & B	Selective: 0 to 1.0 ppm overall, or to 100 ppm (optional)	±4% of full scale	varies: 4 to 100 ppb dependent on instrument range setting.	<10 min. to 90% of full scale.
Flame Ionization (with gas chromatograph)	Continuous determination & recording of methane, total hydrocarbons and carbon monoxide in air. Catalytic conversion of CO to CH_4. Operates up to 3 days unattended.	B	Selective: 0 to 1 ppm; 0 to 100 ppm	±1% of full scale	Not given	5 min. (cycle time)
Same as above	Separate model for continuous monitoring of SO_2, H_2S and total sulfur in air. Unattended operation up to 3 days.	B	0-20 ppm	±4% of full scale	0.005 ppm (H_2S); 0.01 ppm (SO_2)	5 min. (cycle time)
Flame Ionization (Hydrocarbon Analyzer)	Continuous monitoring of total hydrocarbons in ambient air; potentiometric or optional current outputs compatible with any recorder. Electronic stability from 32° to 110°F.	B	0 to 1 ppm as CH_4; X1, X10, X100, X1000 with continuous span adjustment	±1% of full scale	1 ppm to 2% full scale as CH_4; 4 ppm to 10% as mixed fuel.	<0.5 sec. to 90% of full scale

TABLE 16-1 (Continued)

Principle of Operation	Applications & Remarks	Code*	Range	Repeatability (Precision)	Sensitivity	Response Time
Gas Chromatograph, Portable	On site determination of fixed gases, solvent vapors, nitro and halogenated compounds and light hydrocarbons. Instruments available with choice of flame ionization, electron capture or thermal conductivity detectors and appropriate columns for desired analyses. Rechargeable batteries.	A	Depends on detector	Not given	<1 ppb (SF_6) with electron capture detector; <1 ppm (HC's)	——
Infrared Analyzer (Photometry)	Continuous determination of a given component in a gaseous or liquid stream by measuring amount of infrared energy absorbed by component of interest using pressure sensor technique. Wide variety of applications include CO, CO_2, Freons, hydrocarbons, nitrous oxide, NH_3, SO_2 and water vapor.	B	From ppm to 100% depending on application	±1% of full scale	0.5% of full scale	0.5 sec. to 90% of full scale
Photometry, Ultraviolet (tuned to 253.7 mμ)	Direct readout of mercury vapor; calibration filter is built into the meter. Other gases or vapors which interfere include acetone, aniline, benzene, ozone and others which absorb radiation at 253.7 mμ.	A	O.005 to 0.1 and 0.03 to 1 mg/m³	±10% of meter reading or ± minimum scale division, whichever is larger	0.005 mg/m³	Not given
Photometry, Visible (Narrow-centered 394 mμ band pass)	Continuous monitoring of SO_2, SO_3, H_2S, mercaptans and total sulfur compounds in ambient air. Operates more than 3 days unattended.	B	1 to 3,000 ppm (with air flow dilution)	±2%	0.01 to 10 ppm	<30 sec. to 90% of full scale.
Particle Counting (Near Forward Scattering)	Reads and prints directly particle concentrations at 1 of 3 preset time intervals of 100, 1000 or 10,000 seconds, corresponding to 0.01, 0.1 and 1 cubic foot of sampled air.	B	Preset (by selector switch) Particle Size Ranges: 0.3, 0.5, 1.0, 2.0, 3.0, 5.0, and 10.0 μm. Counts up to 10^7 particles per cu. ft. (35×10^3/liter)	±0.05% (probability of coincidence)	——	Not given
Polarography	Monitor gaseous oxygen in flue gases, auto exhausts, hazardous environments and in food storage atmospheres and dissolved oxygen in wastewater samples. Battery operated, portable, sample temperature 32° to 110°F, up to 95% relative humidity. Potentiometric recorder output. Maximum distance between sensor and amplifier is 1000 feet.	A	0-5 and 0-25%	±1% of reading at constant sample temperature	Not given	20 sec. to 90% of full scale

TABLE 16-1 (Continued)

Principle of Operation	Applications & Remarks	Code*	Range	Repeatability (Precision)	Sensitivity	Response Time
Radioactivity	Continuous monitoring of ambient gamma and x-radiation by measurement of ion chamber currents, averaging or integrating over a constant recycling time interval, sample temperature limits 32°F to 120°F; 0 to 95% relative humidity (weatherproof detector); up to 1,000 feet remote sensing capability. Recorder and computer outputs. Complete with alert, scram and failure alarm systems. All solid-state circuitry.	B	0.1 to 10^7 mR/hr.	±10% (Decade Accuracy)	——	<1 sec.
Radioactivity	Continuous monitoring of beta or gamma emitting radioactive materials within gaseous or liquid effluents; either a thin wall Geiger-Mueller tube or a gamma scintillation crystal detector is selected depending on the isotope of interest; gaseous effluent flow — 4 cfm; effluent sample temperature limits 32° F to 120°F using scintillation detector and —65°F to 165°F using G-M detector. Complete with high radiation, alert and failure alarms.	B	10 to 10^6 cpm	±2% full scale (rate meter accuracy)	<10^{-7} μCi of I-131 per cc of air and 10^{-7} μCi of Cs-137 per cc of water using a scintillation detector	0.2 sec. at 10^6 cpm (rate-meter)
Radioactivity	Continuous monitoring of radioactive airborne particulates collected on a filter tape transport system; rate of air flow — 10 SCFM; scintillation and G-M detectors, optional but a beta sensitive plastic scintillator is provided to reduce shielding requirements and offer greater sensitivity. Air sample temperature limits 32°F to 120°F; weight 550 pounds. Complete with high and low flow alarm and a filter failure alarm.	B	10 to 10^6 cpm	±2% of full-scale (rate-meter accuracy)	10^{-12}μ Ci of Cs-137 per cc of air using a scintillation detector	0.2 sec. at 10^6 cpm (rate-meter)

* Code: A-Portable Instruments; B-Fixed Monitor or "Transportable" Instruments.
Taken from Draeger Detector Tube Handbook, Draegerwerk. Lübeck, West Germany, 1970, pp. 33-71.

in a manufacturer's list of specifications for an instrument and this has been so noted in Table 16-1. The material presented under "Applications and Remarks" provides information on the individual substances which may be analyzed directly by the stipulated technique along with specified interferences and other important considerations. This tabulation is not an official certified list; it is intended as a useful guide in selecting direct reading physical instruments on the basis of desired operating parameters.

DIRECT READING COLORIMETRIC DEVICES

Operating Principles

Direct-reading colorimetric devices utilize the chemical properties of an atmospheric contaminant for the reaction of that substance with a color-producing reagent. Reagents used in detector kits may be in either a liquid or a solid phase or provided in the form of chemically treated papers. The liquid and solid reagents are generally supported in sampling devices through which a measured amount of contaminated air is drawn. On the other hand, chemically treated papers are usually exposed to the atmosphere and the reaction time noted for a color change to occur.

Liquid Reagents. Liquid reagents may be supplied in sealed ampoules or in tubes for field use. Such preparations are provided in a concentrated or a solid form for easy dilution or dissolution at the sampling site. Representative of this type of reagent are the ortho-tolidine and the Griess-Ilsovay kits for chlorine and nitrogen dioxide, respectively. Although the glassware needed for these applications may be somewhat inconvenient to transport to the field, methods based on the use of liquid reagents are more accurate than those which use solid reactants. This is due to the inherently greater reproducibility and accuracy of color measurements made in a liquid system.

Chemically Treated Papers. Papers impregnated with chemical reagents have found wide applications for many years for the detection of toxic substances in air. Examples include the use of mercuric bromide papers for the detection of arsine, lead acetate for hydrogen sulfide, and a freshly impregnated mixture of o-tolidine and cupric acetate for hydrogen cyanide. When a specific paper is exposed to an atmosphere containing the contaminant in question, the observed time of reaction provides an indication of the concentration of that substance. Thus, in the case of hydrogen cyanide a 5-second response time by the o-tolidine-cupric acetate paper is indicative of a concentration of 10 ppm of HCN in the tested atmosphere.

Similarly, sensitive detector crayons have been devised for the preparation of a reagent smear on a test paper whose response to a specific toxic substance in a suspect atmosphere may then be timed to obtain an estimation of the atmospheric concentration of a contaminant. Crayons for phosgene, hydrogen cyanide, cyanogen chloride, and Lewisite (ethyl dichloroarsine) have been formulated for this purpose.[3]

Colorimetric Indicator Tubes. Colorimetric indicating tubes containing solid reagent chemicals provide compact direct-reading devices, which are convenient to use for the detection and semiquantitative estimation of gases and vapors in atmospheric environments. There are tubes for nearly two hundred atmospheric contaminants on the market, and seven U.S. companies manufacture and/or distribute these devices currently in this country.[4] Whereas it is true that the operating procedures for these tubes are simple, rapid and convenient, there are distinct limitations and potential errors inherent in this method of assessing atmospheric concentrations of toxic gases and vapors. Therefore, dangerously misleading results may be obtained with these devices unless they are used under the supervision of an adequately trained industrial hygienist who (1) enforces rigidly (a) the periodic (as required) calibration of individual batches of each specific type of tube for its response to known concentrations of the contaminant and (b) the refrigerated storage of all tubes to minimize their rate of deterioration; (2) informs his staff of the physical and chemical nature and extent of interferences to which a given type of tube is subject and limits the tube's usage accordingly; and (3) stipulates how and when other independent sampling and analytical procedures will be employed to derive needed quantitative data.

Colorimetric indicating tubes are filled with a solid granular material, such as silica gel or aluminum oxide, which has been impregnated with an appropriate chemical reagent. The ends of the glass tubes are sealed during manufacture. When a tube is to be used, its end tips are broken off, the tube is placed in the manufacturer's holder, and the recommended volume of air is drawn through the tube by means of the air moving device provided by the manufacturer. This device may be one of several types such as a positive displacement pump, a simple squeeze bulb, or a small electrically operated pump with an attached flow meter. Each air moving device must be calibrated after each usage or after sampling 100 tubes as an arbitrary rule or more often if there are reasons to suspect changes due to effects of a corrosive action from contaminants in tested atmospheres. An acceptable pump should be correct to within ± 5% by volume; with use, its flow characteristics may change. It should also be checked for leakage and plugging of the inlet after every 10 samples.

In most cases, a fixed volume of air is drawn through the detector tube although, with some systems, varied amounts of air may be sampled. The operator compares either an absolute length-of-stain produced in the column of the indicator gel or a ratio of the length-of-stain to the total gel length against a calibration chart to obtain an indication of the atmospheric concentration of the contaminant that reacted with the reagent. In another type of tube, a progressive change in color intensity is compared with a chart of color tints in making the estimation. In a third type of detector, the volume of sampled air which is required to produce an immediate color change is noted; it is intended that this air volume should be inversely proportional to the concentration of the atmospheric contaminant. The remainder of this chapter is devoted to the direct-reading, colorimetric indicating detector tube systems because of the widespread use of these devices.

Detector Tube Characteristics

Reagents and Interferences. Complete information on the formulations of the chemical reagents used in the manufacture of the commercial devices is not available owing to the understandably competitive nature of this enterprise. However, there is sufficient knowledge of the chemical nature of certain solid reactants commonly used for this purpose to provide the limited information on chemical reactants, products, color changes, and stated interferences given in Table

TABLE 16-2

Select List of Detecting Reactions in Colorimetric Indicating Tubes*

Test Gas or Vapor	Reagents in			Product(s)	Color Change	Stated Interferences
	Pre-cleanse Layer	Ampoule or Conversion Layer	Indicating Layer			
Acetone	None	None	2, 4-Dinitrophenylhydrazine	A hydrazone	Pale Yellow to Yellow	Other ketones and aldehydes, alcohols, esters
Acrylonitrile	None	(1) Chromate (VI) Compound	(2) Mercuric chloride (3) Methyl red	(1) Hydrogen cyanide (2) Hydrogen chloride (3) Red form of indicator	Yellow to red	HCl, HCN, organic CN compounds, aromatic solvents
Alcohol	Drying agent	None	Chromate (VI) compound	Chromic (III) compound	Yellow to green	Other oxygenated compounds
Ammonia	None	None	(1) Acid (2) Bromophenol blue	(1) Ammonium salt (2) Blue form of indicator	Orange to dark blue	Amines, Hydrazines
Aniline	None	(1) Furfural	(2) Acid	(1) Schiff base (2) Dianiline derivative	White to red	Ammonia
Arsine	Copper compound (to retain reduced S compounds, H_2Se, NH_3 and HCl)	None	Gold compound	Colloidal gold	White to weak violet grey	Phosphine, stibine
Benzene	Acid and aldehyde (to retain other aromatics)	None	(1) Formaldehyde (2) Sulfuric acid	(1) Diphenylmethane (2) p-Quinoid compound	White to brown	None affect the indication
Carbon Dioxide	None	None	(1) Hydrazine (2) Crystal violet	(1) Carbonic Acid Monohydrazide (2) Blue form of indicator	White to blue	None affect the indication
Carbon Disulfide	Copper compound (to retain H_2S)	None	(1) Copper compound (2) Amine	Copper Dialkyldithiocarbamate	Pale blue to yellowish green	None affect the indication (except H_2S)
Carbon Monoxide	Chromate (VI) compound (to retain H_2S,C_6H_6, petroleum compounds)	None	(1) Iodine pentoxide (2) Selenium dioxide (3) Fuming sulfuric acid	Iodine (and carbon dioxide)	White to brownish green	Acetylene and easily cleaved halogenated hydrocarbons

TABLE 16-2 (Continued)

Select List of Detecting Reactions in Colorimetric Indicating Tubes*

Test Gas or Vapor	Reagents in Pre-cleanse Layer	Reagents in Ampoule or Conversion Layer	Reagents in Indicating Layer	Product(s)	Color Change	Stated Interferences
Carbon Tetrachloride	None	(1) Fuming Sulfuric acid	(2) Dimethyl-amino-benzaldehyde (3) Dimethyl-aniline	(1) Phosgene (2) "Blue reaction product"	Yellow to blue	Fluorochloromethane compounds
Chlorine	Drying agent	None	o-Tolidine	"Yellow reaction product"	White to yellow	Bromine, chlorine dioxide; discoloration by nitrogen dioxide
Chloroprene	None	None	Permanganate	"Yellowish Brown Reaction Product"	Violet to yellowish brown	Other organic compounds with carbon-carbon double bonds
Cyanogen Chloride	None	(1) Pyridine (2) Water	(3) Barbituric acid	(1) & (2) Glutacon-aldehyde cyanamide (3) "Pink Reaction Product"	White to pink	Cyanogen bromide
Ethyl acetate	Drying agent	None	Chromosulfuric acid	Chromic (III) compound	Orange to brown green	Easily oxidized organic compounds including other acetates
Formaldehyde	None	(1) Xylene vapor	(2) Sulfuric acid	(1) Dixylyl methane (2) "Pink quinoid compound"	White to pink	Other aldehydes and styrene
Hydrazine	None	None	(1) Acid (2) Bromophenol blue	(1) Hydrazinium salt (2) Blue form of indicator	Yellow to blue	1,1-Dimethyl hydrazine, ammonia, amines
Hydrochloric Acid	Drying agent	None	Bromophenol blue	Yellow form of indicator	Blue to yellow	Chlorine; R.H.>80%
Hydrocyanic Acid	Lead compound (to retain H_2S,HC1, SO_2,NO_2 and NH_3)	None	(1) Mercuric Chloride (2) Methyl red	(1) Hydrogen chloride (2) Red form of indicator	Yellow to red	None affect the indication (except those not retained in precleanse layer)
Hydrogen fluoride	None	None	Zirconium-alizarin lake	Alizarin	Pale violet to pale yellow	High humidity
Hydrogen sulfide	None	None	Lead compound	Lead Sulfide	White to light brown	None affect the indication
Mercaptan	None	(2) Sulfur solution	(1) Copper compound	(1) Copper mercaptide (2) Yellowish brown copper compound	White to yellowish brown	Other mercaptans, hydrogen sulfide, ammonia, amines

TABLE 16-2 (Continued)

Select List of Detecting Reactions in Colorimetric Indicating Tubes*

	Reagents in					
Test Gas or Vapor	Pre-cleanse Layer	Ampoule or Conversion Layer	Indicating Layer	Product(s)	Color Change	Stated Interferences
Methyl bromide	None	(1) Sulfur trioxide (2) Permanganate	(3) o-dianisidine	(1) & (2) Bromine (3) "Brown Reaction Product"	White to brown	Halogens, halides, halogenated hydrocarbons
Monostyrene	Drying agent	None	Sulfuric acid	"Yellow Reaction Product"	White to yellow	Butadiene and other polymertending organic compounds
Nickel tetracarbonyl	None	(2) Dioxime	(1) Iodine	(1) Nickel iodide (2) Nickel dioxime complex	Pale brown to pink	Iron pentacarbonyl, hydrogen sulfide, sulfur dioxide
Nitrogen dioxide (NO_2)	Drying agent	None	N,N'-diphenylbenzidine	"Bluish grey Reaction Product"	White to bluish grey	Ozone, chlorine
Nitrous fumes ($NO + NO_2$)	None	(1) Chromium (VI) compound	(2) N,N'-diphenylbenzidine	(1) Nitrogen dioxide (2) "Bluish grey reaction product"	White to bluish grey	Ozone, chlorine
Ozone	None	None	Indigo	Isatine	Pale blue to white	Chlorine, nitrogen dioxide
Perchloroethylene	None	(1) Permanganate	(2) N,N'-diphenylbenzidine	(1) Chlorine (2) "Greyish blue Reaction Product"	White to greyish blue	Halogens, hydrogen halides, easily cleaved halogenated hydrocarbons, petroleum vapor
Phenol	None	(1) 2,6-dibromoquinone chlorimide	(2) Activated silica gel	(1) & (2) Indophenol dye	White to blue	Other aromatic hydroxy compounds, quinones; ammonia and amines discolor indicating layer
Phosgene	Drying agent	None	(1) Dimethylaminobenzaldehyde (2) Diethylaniline	Bluish green complex	Yellow to bluish green	Carbonyl bromide
Phosphine	Copper compound (to retain reduced sulfur compounds, NH_3,H_2S & H_2Se)	None	Gold compound	Colloidal gold	White to weak greyish violet	Arsine, stibine
Sulfur dioxide	Copper compound (to retain H_2S)	None	Iodine/ Starch	Sulfuric acid	Blue to white	Nitrogen dioxide

TABLE 16-2 (Continued)

Select List of Detecting Reactions in Colorimetric Indicating Tubes*

Test Gas or Vapor	Reagents in Pre-cleanse Layer	Reagents in Ampoule or Conversion Layer	Reagents in Indicating Layer	Product(s)	Color Change	Stated Interferences
Toluene	Drying agent	None	(1) Iodine pentoxide (2) Dilute sulfuric acid	(1) & (2) Iodine	White to brown	Xylenes, benzene
Trichloroethane	None	(1) Sulfuric acid (2) Oxidizing agent	(3) o-dianisidine	(1) & (2) Chlorine (3) "Brownish red Reaction Product"	Pale grey to brownish red	Some other halogenated hydrocarbons; petroleum hydrocarbons & aromatic compounds >1000 ppm
Trichloroethylene	None	(1) Permanganate	(2) o-tolidine	(1) Chlorine (2) "Orange Reaction Product"	White to orange	Halogens, halides, easily cleaved halogenated hydrocarbons, petroleum distillate vapors
Vinyl chloride	None	None	Permanganate	Light brown manganese compound	Violet to light brown	Organic compounds with carbon-carbon double bond

* Taken from Draeger Detector Tube Handbook, Draegerwerk. Lübeck, West Germany, 1970, pp. 33-71.

16-2. From this table it is apparent that the lack of specificity encountered with certain detector tubes is due to the use of common reagents for numerous compounds. Thus, the use of a hexavalent chromium compound for the oxidation of a wide variety of organic substances with the production of a green chromic reaction product is a completely nonspecific procedure for these substances. This type of detector tube must be used with the realization that all readily oxidizable substances may affect the indication and efforts should therefore be taken to ascertain the chemical nature of the various associated contaminants in each exposure situation. Further, aromatic hydrocarbons, hydrides, halides, and chlorinated hydrocarbons provide other examples of class compounds for which single formulations in detector tube reactants may have been used. Such formulations limit the usefulness of these tubes in mixed exposure areas as the estimations are then based on the results of the reaction of a mixture of contaminants. Furthermore, errors of estimation may be positive or negative depending upon whether a stain is intensified (or lengthened) by the presence of a similarly reacting contaminant or bleached by a differing chemical contaminant present in the sampled air stream. This general situation has evoked a great deal of criticism of detector tube systems by the industrial hygiene profession which recognizes the need for improved devices of this type.

Efforts to overcome this cross sensitivity have been attempted by: a. Use of a pre-layer to remove certain known interferences from the air stream before they reach the indicating layer; and b. Use of a conversion layer to transform the desired gaseous substance to a different chemical compound which can then react with the indicating layer.

Examples of the incorporation of a pre-layer in the formulation of a tube include the Dräger Arsine 0.05/a and the Benzene 0.05 tubes. The former uses a copper compound to retain in the pre-layer such interferences as hydrogen sulfide, hydrogen selenide, mercaptans, ammonia, and hydrogen chloride, but allows arsine to pass through to the indicating layer containing a gold compound with which the arsine reacts to yield a weak violet-gray color. The benzene 0.05 tube has an acid-aldehyde reagent to remove toluene, xylene and naphthalene; benzene passes on into the indicating layer where it produces a brown color from its reaction with formaldehyde and sulfuric acid.

Another difficulty arising from detector tube reagents is the catalyzed reaction of gaseous contaminants with one another due to the active contact surface provided by the column of chemicals in the detector tube. This phenomenon has been observed with sulfur dioxide and nitrogen dioxide when these gases are brought into closer molecular contact in detector tubes than that prevailing in ambient atmospheres where their reaction rate with each other is generally low.

Quality Control. The rigid control of the purity of reagents, grain size of the gel, method of packing the tubes, moisture content of the gel, uniformity of tube diameter, and proper storage precautions is required for the optimal performance of any detector tube. The lack of such controls will lead to an inferior product whose use may produce disastrous results in the evaluation of health related problems. Thus, an incompletely responsive tube could cause a hazardous situation to remain uncorrected. Conversely, an overly reactive response may cause undue concern, wasted effort and needless expense for unwarranted corrections.

Failure of certain manufacturers to maintain a rigid control over manufacturing practices has been observed in the past. Although it has been established[5] that an elevated moisture content above 20% will cause a rapid deterioration of the silica gel used in the potassium pallado-sulfite formulation for a carbon monoxide tube, one observer found during a visit to a detector tube manufacturing facility that there was a lapse of many hours following the packing but preceding the hermetical sealing of the tubes.[6] Indeed, such a practice permits the entry of not only moisture but also other contaminating vaporous substances which might produce a deleterious effect on the reagent's future response to the analysis substance.

Another critical parameter is the tube diameter. Manufacturing variations in the internal diameter of the narrower tubes can produce appreciably different cross sectional areas. Saltzman has pointed out that this situation leads to calibration errors as high as 50 percent due to a varying volume of air sample per unit cross sectional area as compared with those provided under standard test conditions.[7] At least one manufacturer minimizes the effect of this source of error by loading equal amounts of the indicating gel into each tube; the variations in cross sectional areas are then compensated by corresponding variations in the filled lengths of the tubes.[8] The manufacturer provides calibration scales which permit the positioning of each tube in accordance with its filled length when measuring the length of stain and thus reduce the overall error of measurement of the gas concentration.

Variations in the grain size of the gel, in the purity of the reagents and the cleanliness of the air in the tube manufacturing facility can affect the properties of different batches of the indicating gel markedly. If not controlled carefully, these parameters can cause marked and unpredictable changes in the number of active centers on the solid surface of the gel and thus affect the reaction velocity of the indicating system.

The method of storage has a profound effect on the shelf life of an indicator tube. Deterioration of the tubes increases greatly at elevated temperatures and storage under refrigeration by both the manufacturer and the user is mandatory to realize a useful shelf life which may approximate two years for some of the tubes. Multiple layer tubes may have a shorter shelf life due to diffusion of chemicals between layers. For these reasons a realistic expiration date for tubes stored under refrigeration should be stamped on each box of tubes by the manufacturer.

Calibration. Saltzman has presented an excellent treatment of the theory of indicator tube calibration where he has developed a basic mathematical analysis of the relationships between the variables which affect the length of stain, i.e., the concentration of test gas, volume of air sample, sampling flowrate, grain size of gel, tube diameter and other variables. This source should be consulted for a full appreciation of the complex interrelationships between the factors affecting the kinetics of indicator tube reactions. It is sufficient to point out in this chapter that the length of stain is proportional to the logarithm of the product of gas concentration and air sample volume as shown in the following equation:[7]

$$L/H = \ln(CV) + \ln(K/H)$$

where: L = the length of stain in centimeters,

C = the gas concentration in parts per million,

V = the air sample volume in cubic centimeters,

K = a constant for a given type of indicator tube and test gas,

H = a mass transfer proportionality factor having the dimensions of centimeters, and known as the height of a mass transfer unit.

If this mathematical model is correct for a given indicator tube, a linear plot of L versus the logarithm of the CV product, for a fixed constant flowrate, will yield a straight line with slope = H. The significance of this equation is the implication that it is important to control the flowrate, which may produce a greater effect on the length of stain than does the concentration of the test gas. Therefore, in the optimal design of an indicator tube it is desirable that the reaction rate be sufficiently rapid to permit the establishment of equilibrium between the indicating gel and the test gas and thus produce a stoichiometric relationship between the volume of stained indicating gel and the quantity of the absorbed test gas. Such equilibrium conditions may be assumed to exist when stain lengths are directly proportional to the volume of sampled air and are not affected by the sampling flowrate.[7] With this situation a log-log plot of stain length versus concentration for a fixed sample volume may be prepared in the calibration of a given batch of tubes.

From the preceding discussion of the complexity of the heterogeneous phase kinetics of indicator tube reactions, the quality control problems associated with their manufacture and storage, and the difficulties posed by interfering substances, it is obvious that frequent, periodic calibration of these devices should be made by the user. Dynamic dilution systems for the reliable preparation of low concentrations of a test gas or vapor are recommended for this purpose (see

Chapter 12). Such calibrations should be performed before each use if there has been an appreciable period since the last calibration was performed.

Evaluation of Performance

As of January 1, 1972, the results of the evaluation of gas detector tubes for five substances had been published by the National Institute for Occupational Safety and Health.[9,10,11,12,13]

The results are as follows:

	No. of Manufactured Tubes Meeting Approval Criterion Within	
Substance	± 25% at 95% C.L.*	± 50% at 95% C.L.
Benzene	None	3
Carbon Monoxide	None	8
Carbon Tetrachloride	None	None
Perchloroethylene	3	—
Sulfur Dioxide	4	—

*95% Confidence Level

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CHAPTER 17

MEDICAL ASPECTS OF THE OCCUPATIONAL ENVIRONMENT

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THE PHYSICIAN, NURSE AND INDUSTRIAL HYGIENIST

(The Occupational Health Protection Team)

The Role of The Physician

Elucidation of Human Parameters of Response. The health of man in the working environment is the central theme of occupational health. While measurement of atmospheric concentrations of an environmental pollutant, per se, in the work place is of interest, it has little relevance to occupational health except in terms of what it means to man's health and well-being. Hence, measurements of environmental contamination must be evaluated in terms of their effects, or lack of them, upon humans. In order to elucidate the effects upon man of potentially deleterious physical or chemical agents found in the work place, the physician, as a specialist in human biology, must provide and interpret such "readouts" of human response. Only then can the main component of this "agent-host" interaction be defined. Only within such a frame of reference may the ultimate significance for man be ascertained of such quantifications of occupationally encountered biological, physical or chemical agents.

Promotion of Human Health. The physician's role in occupational health cannot be that of a mere passive interpreter of human response. He has a positive responsibility for utilizing his special expertise in conjunction with his societal status to actively promote health in industry. One aspect of this responsibility relates to occupationally-related disease and injury; the other to prevention, where feasible, of non-occupational health deterioration; e.g., diabetes or glaucoma detection. Regarding the former, the physician must be prepared to extend his capacities so as to detect early, even subclinical responses; in addition he must be unhesitating in his readiness to insist upon management's taking notice and acting upon his recommendations for amelioration and control of the working environment. In the industrial environment, the *ex cathedra* stance carries only limited impact as compared to the private practice physician-patient relationship. It is because of this reality that the physician requires all the available facts to buttress his opinion. Here the industrial hygienist with his quantitative evaluation of the situation provides the irreplaceable other portion of the equation, "man + agent = effect."

As to the physician's responsibility for prevention of the deleterious effects of non-occupational disease, here his duty parallels usual medical functions elsewhere. However, by virtue of the physician's place in the industrial setting, he has several advantages over the practitioner in the private sector. This largely stems from his knowledge of human interactions in the work place; he is in a unique position to evaluate the social as well as the physical demands made upon the worker in industry. Thus, hypertensive cardiovascular disease is a process which is not purely biological; its course is affected by the transactions between the patient and his socio-economic environment. A not insignificant segment of this environment is constituted by that setting in which the worker spends approximately one-fourth his life span, i.e., the work place. Operationally, this gives the physician the opportunity to manipulate within limits the human environment within the work place so as to favorably influence the course of the employees' health and well-being.

The Role of the Nurse

The nurse is the "front line" worker in occupational medicine. It is the nurse whom the worker meets 90% of the time when he encounters the medical department. She must be ready to keep a highly "tuned" ear. Information bearing upon the work environment or the individual's health will be imparted to her long before it is transmitted to others. Therefore, as the eyes and ears of the medical department she must guard against "tuning out" worker plaints and statements. Given human tendencies for just such response after years of listening, both the physician and nurse must be constantly alert to prevent the development of a hardened, unsympathetic auditor. While suspending value judgments as regards the merit, — or lack of same, — of employee complaints is difficult, nevertheless all such information inputs contain some value, positive or otherwise. Workers perceive through the nurse the attitude toward them of the medical organization. If they conclude that their statements are consistently ignored, disputed or denied, soon this invaluable intelligence concerning the total work environment within the plant will disappear. From these facts stem the reality that the actions and treatment afforded by the industrial nurse will primarily determine the effectiveness of the medical department.

However, the nurse is not merely a passive reporter. While not implying that she is practicing psychiatry, nevertheless as a skillful listener she fulfills many of the requirements for promotion of mental hygiene. As a sympathetic auditor, she provides the opportunity for verbal ventilation, a significant part of the therapist-patient transaction.

Beyond even this role, the nurse is being given greater responsibilities in worker evaluation. Many more components of the pre-placement and periodic medical evaluation process are being relegated by the physician to the nurse. While restrictions imposed by various of the Medical Practice Acts must be observed, nevertheless with the aid of new automated devices many of these examinations are being performed by the nurse. Execution of the amanuensis by use of appropriately designed printed forms can conserve significant portions of physician time. Indeed, it appears that given sympathetic listening, such historical portions of the medical examination can be more effectively performed by the nurse rather than the physician.

The Role of The Industrial Hygienist

As alluded to previously, the physician in private practice can frequently assume an authoritative relationship with the patient. However, in the world of business and industry decisions are usually made and action taken upon the basis of quantitative objective parameters. While by the use of clinical laboratory modalities the physician can provide many mensurable descriptions of human response, such data may or may not be a reflection of work environment-induced biological change. For example, while anemia may result from chronic benzene absorption, it may also stem from non-occupational medical causes. Thus, in any determination of the reality of possible benzene exposure, it is necessary to know whether sufficient benzene was present in the work environment to cause the observed anemia. Only the industrial hygienist can provide this necessary environmental quantification. Without this information it should be readily apparent that the physician can only guess at causal relationships between the worker's condition and the work place. Such "guesses" are not considered, and should not be, sufficient basis for action by industrial management.

The Need for Coordination of the Work of the Medical Team with the Industrial Hygienist

Evaluation of the Host-Agent Interaction. It should be apparent from the foregoing that measurement of environmental parameters, while intellectually interesting, has little relevance in industry except in terms of its human health implications. It is equally clear that human biological response is usually non-specific in nature. It is only when these two components, environmental and biological, are interdigitated does reality emerge. Accordingly, both medical personnel and industrial hygienists have their contribution to make in elucidating this reality. Since the host-environment interaction is a dynamic ever-changing relationship, an on-going relationship must be developed and maintained between these two disciplines, medicine and industrial hygiene. From the results of such quantitatively validated investigations appropriate engineering and medical control programs are developed.

Evaluation of the Efficacy of Occupational Hazard Control Programs. In response to validated needs for industrial hazard control, engineering measures (e.g., ventilation, enclosure, etc.) are instituted. Despite the highest quality of engineering design and performance, because such measures are controlled, operated and maintained by men, human imperfections impose themselves upon the efficacy of such controls.

While physical and chemical measurements of the effectiveness of such approaches to hazard control are useful, once more their relevance to the ends desired are man-oriented. Therefore, the adequacy of control performance must be measured in terms of human protection or its lack. Once more, the inputs of the biological scientist (the physician) and the physical scientist (the industrial hygienist) are required to round out the entire picture. Only by coordinating their interrelating investigational data can these two contributors to industrial health control be effective. Since these interactions may be long-term as well as immediate, adequately coordinated record systems must be developed. Such systems must not only provide records of events, they must be so designed as to provide adequate and early signals of ongoing failures or inadequacies of control systems. Once more, coordination of medical and work environment data must be carefully built into such recording methods.

Detection of New or Potential Problems. Among the greatest challenges to occupational health is the delineation of new occupational hazards. Early warning systems for new health conditions arising out of the working environment have only infrequently been achieved before harm has been done. As quantitative environmental and biological indicators develop greater sensitivities, the potential for detection of a problem before human harm occurs becomes more feasible. With thousands of new chemical agents entering the industrial scene there is an increasing opportunity for development of new knowledge as well as for preventing human damage. Only by coordinating the activities of the medical and industrial hygiene components of the occupational health team will this potentiality be realized.

The Special Qualifications of the Physician Specialist in Industry

Preventive Medicine in Industry

1. Primary prevention

(a) Definition: This has been defined as the prevention of the occurrence of disease or disability arising from pathological processes. While its accomplishment in relationship to the usual chronic or degenerative disease process has been less than spectacular, the potentials for realization of the concept of primary prevention are uniquely feasible in the industrial setting.

(b) Applicability to environmentally induced disease: While the mechanisms responsible for the common degenerative disease processes (e.g., cancer, heart disease, diabetes) remain obscure, the etiologies of environmentally induced diseases are relatively accessible. Thus, if the etiological agents causing occupational diseases can be prevented from contacting the human host, a potentially pathologic process can be totally prevented. Within the limits of an adequate perspective, one cannot imply that certain biological variables, e.g., age, sex, nutritional status, do not affect the course of an agent-host interaction. These variables, and other poorly defined, genetically controlled factors, will also affect the human response. But while the importance of these determinants of human response to environmentally encountered agents cannot be disregarded, the intrinsic potency of occupational chemical or physical agents can be prevented from being expressed. The knowledge that such agents are capable of inciting human damage upon absorption leads logically to design of measure directed toward prevention of this event. This in turn requires that the physician have the capability of *quantitatively* determining which level of contaminant presents no health hazard (viz., the "no-effect" portion of the dose-response relationship) so that control design criteria can be developed.

Another potential method of primary prevention depends upon detection of special susceptibilities of individual workers to certain occupational hazards. Obvious examples, such as crane operators with inadequacies in their visual fields, come to mind. More subtle potential opportunities for prevention arise out of detection of inborne defects in certain metabolic processes, e.g., a "serum antitrypsin," activity defect which interferes with normal cleansing of the lungs, should preclude such workers' contact with pulmonary irritants.

(c) Limitations in primary prevention: One considerable limitation placed upon the efficacy of primary prevention stems from the fact that at present there are few existant physical or clinical laboratory indicators of special susceptibility to environmental agents. Thus, which worker, upon exposure to benzene, will develop a leukemic response cannot be adequately predicted; similarly, predictors of special susceptibility to low back injury are not existent.

2. Secondary Prevention

(a) Definition: By secondary prevention we refer to the precluding of progression of disease or disability resulting from some pathologic process.

(b) Work and disease acceleration: While the causation of the usual degenerative disease process rarely directly results from occupational exposure, there is sufficient reason to believe that certain work demands may unfavorably influence the course of common degenerative disorders. Thus, the requirement of the brittle diabetic for strict and regular dietary control makes rotating shift work difficult for such an individual. The anxiety, physical and mental strain associated with jobs requiring rapid, weighty decisions or excessive travel may aggrevate coronary artery disease. Workers with chronic bronchitis hardly make fit candidates for jobs wherein there exists risks of exposure to pulmonary irritant gases and vapors. Since medical evaluation can detect such individuals, even though medical measures have not prevented the occurrence of such disease processes, exclusion from such risk can prevent acceleration or aggravation of those pathological processes.

(c) Limitations upon secondary prevention: As previously discussed, it is our inability to predict response or understand the inherent nature of many diseases which limits our ability to prevent disease. Similarly, in many cases which factors associated with work or a pathologic process may accelerate or aggravate such conditions also remain obscure. Furthermore, peculiar to the problem of prevention at the secondary level is the fact that such activity is usually most productive when directed to an early stage of development. Accordingly, effectiveness here depends upon preexistence indicators of minimal or subliminal disease; unfortunately our abilities in this regard are at present somewhat limited.

Understanding the Patho-physiology of Human Response to Environmental Change

1. Physiological principles

(a) Mechanism of human response: While previously discussed (see Chapter 6) extensively, some mention of the interplay of homeostatic mechanisms should be reviewed. Because the human organism lives within a dynamic ever-changing environment and receives a constant stream of external stimuli, the ability to adapt to such continuous change is a necessity of existence. In effect, this means that the body must be able to change the rate at which various activities were previously occurring.

While physiologically at the whole organ level of organization this is readily perceived, e.g., as a tachycardia in response to running, at the cellular level similar changes in rates of metabolic activities must occur. Similarly as with the previous example, until an optimal new rate which meets the new demand is achieved, activity may overshoot and then compensate by slackening in attempting ultimately to ascertain what the optimum might be. Thus oscillation about an optimum rate, i.e., the eventual new steady state, has been characterized as a "hunting phenomenon." This control system also has an information gathering component which reports all activity changes to control centers; the latter, in response to such information directs the activity to hasten or slacken. In turn, it is receptive to new information which assesses the result of the control center's previous directions. In effect, what we have described is a self-regulating dynamic system.

It should be emphasized that this system can meet new conditions within limits. Essentially, the rate at which it may function has finite limits, i.e., "rate limits," at all levels of biological organization. It is such "rate limits" at the cellular level which determine the response of the body to agents encountered at this level. Among the most prominent at this level of organization are the physical and chemical agents; these rate limits are at the heart of such encounters which constitute the science of toxicology.

2. Toxicologic principles

While these are described in more detail in Chapter 7, review of the dose-response relationship is especially pertinent to the role of medicine in industry. The physician clearly recognizes that the effectiveness of therapeutic agents are a function of the quantity of a medication given as well as the time period over which such agent is administered. However, for unknown reasons the same considerations are not usually applied to non-therapeutic elements, e.g., lead. In short, "poisons" are considered to be "poisonous" regardless of dose and time consideration. Regardless of such a viewpoint, the fact remains that the same dynamic principles of dose and time apply to *all* elements or compounds entering the bodily economy. That is, when the organism encounters a material in its internal milieu, as long as too much is not presented over too short a time period, i.e., the body's rate limit for handling such a compound is not exceeded, such a foreign material will have little if any effect. *For most practical purposes, this appears true regardless of the material.* That this must be the case is reflected in the fact that sophisticated analysis will find all 92 original elements in the body. It should, therefore, be apparent that the dose-response relationship (Chapter 7) is basic to an understanding of the effect of "foreign" elements or compounds in the body.

(a) Measurement of response or body loadings

The numerous methods utilized by the body to bind, transport or readily excrete a foreign element have been reviewed in Chapter 7. Thus detoxification mechanisms which depend upon the formation of polar conjugates, e.g., glucuronates, sulfates, also present an opportunity to measure the body's effectiveness in dealing with a chemical. Measurements of such or similar metabolites in various body excreta provide a readily utilized technique to both detect such responses as well as measuring any effectiveness of metabolic handling.

Similarly, certain non-polar solvents, because of their low solubility in blood (essentially an aqueous medium), readily diffuse from the lungs upon cessation of exposure. This too can be measured to gain insights into the amounts which have previously been taken up in the body. Following the breath concentration of such solvents as they leave the lungs over a time course permits even more exact estimates of such body loadings.

Other possible indirect measurements of body loadings may be elucidated by measurements of altered bodily functions induced by such foreign materials. For example, exposure to SO_2 will produce bronchial constriction; the increased airway resistance which ensues can be readily measured and the amount of effect determined.

While this last measurement can be derived from human experimental exposures, at least at relatively low concentrations, other metabolic insights frequently require analysis and extrapolation from animal data.

(b) Extrapolation from animal data

(1) Values

By loading animals with varying concentrations of toxic materials, both the threshold for effect as well as related excretory and metabolic handling rates can be ascertained. Data require the study of multiple species, since some of these animal species may not handle certain agents in a similar fashion as man; nevertheless, where sufficient data are collected such information *may* be applicable to setting levels which are not deleterious as well as determining the rates at which man might safely handle such material (see Chapter 8). By construction of appropriate curves describing lung excretion over time periods, it is possible to estimate from similar curves in exposed workers the quantity of a chemical they have absorbed; thus the means of estimating risk as well as identifying the absorbed agent, can aid the occupational health team in determining its course of action for both treatment and prevention. That is, this latter end can be achieved since indications of overexposure suggest the failure of established control measures.

(2) Limitations

Unfortunately, the use of animal testing to predict human response has limitations arising from the fact that man is a higher and different mammal from species used for such test purposes. This problem in extrapolation from animals to man is exemplified by the fact that because of metabolic pathway differences, aromatic amines, e.g., beta naphthyl amine, which clearly produce urinary bladder tumors in man, have not such effect in rats, mice or other rodents. Likewise sensitization processes, e.g., to toluene diisocyanates, which occur in man, cannot be reproduced in animals. Accordingly, in view of such extrapolation problems negative results found after animal exposure to toxic chemicals is no guarantee of safety to man. Though this risk may be minimized by testing several different species, the results of such investigations must be applied to man with caution.

Understanding Manufacturing Processes

1 Periodic plant inspection

(a) As with production and management personnel, the physician in industry should be totally aware of everything that occurs in the plant from its roof to sub-basement. In order to place any human aberration in its occupational context he should be familiar with every step of every process in the plant. In order to attain such understanding, it is useful if plant tours be made with technical and production personnel who can explain any ramifications of any process, work station relationships, job requirements, material used or product produced within the plant. This may require an understanding of chemistry, physics or mechanics which such personnel can impart. The physician must be familiar with every job, its title (official or otherwise) and demands in order to visualize it when such are referred to by workers who come to the medical department. Since every industrial plant is a dynamic, organic entity, what occurs within the plant is subject to constant change. Accordingly, such tours should be frequent and regularly repeated.

(b) Plant tours can be of even more value to the physician if carried out with an industrial hygienist. Many of the health ramifications of materials and processes which are unknown to production or other plant technical personnel can be readily recognized and their significance estimated by industrial hygienists. For example, while the safety hazards of Stoddard solvent are self evident, the industrial hygienist should recognize and be prepared to answer the question of how much benzene may be present. Furthermore, by careful use of environmental measurement devices in the plant, he comes to be recognized as having a responsibility for protecting health. Such tours with the industrial hygienist, and especially working tours, serves to demonstrate to employees that there is a serious team effort directed toward making the work place safe and healthy (see below).

The Position of the Physician in the Management-Labor Relationship

1. The honest broker

The physician, as a staff member of the management group, does not have executive responsibility (except in the medical department) within the plant hierarchy. As any other staff person, he is essentially an advisor, with management having the executive rights and responsibilities for action. Thus management need not heed the advice of any staff member, although if untoward results ensue it is the executive who is held responsible. While it is obvious to much of management that technical advice, e.g., engineering, marketing, etc., should be heeded, this occasionally may not be so apparent to management as regards medical questions. Since the executive is subject to multiple pressures and demands, frequently they may be inclined to "trade-off" long-term requirements to solve "short-term" needs. Thus, it can be seen that while production requirements make immediate demands on management, that on occasions when health or safety requirements might impede production, they might be induced to "short-cut" such inhibitions upon production.

While top management most frequently can see the long-term objective, the daily demands imposed upon middle or lower management more frequently leads them to such "short-term" observations. While this is yet another reason why the medical departments should report at the highest levels, this does not relieve them of the responsibility for vigorously presenting the rationale behind their judgments.

Most assuredly, the position and responsibility of the medical organization is to consistently promote all activities designed to protect employee health and welfare. This reinforces the fact that as a staff individual, given the responsibility for health and welfare, he should take a position based upon only these questions. While such health controls as are required to meet these demands may indeed intrude upon "short-term" production requirements, these latter requirements are clearly *not his responsibility,* and should not intrude upon professional judgments. Thus the medical department should be the "honest broker," always acting upon the basis of health need requirements. While this may make for some short-term problems for management, if such health and safety positions are soundly based they are more profitable for all concerned in the long-run. If such a consistent position is taken by the medical department, the trust of all — management and labor — will follow. If the medical department thus sincerely follows up all health and safety problems brought to their attention by employees, such a position of integrity is further re-inforced. Both the physician and the industrial hygienist have their responsibilities for equitable, fair and consistent evaluations based upon facts, uncolored by either the desires of management or labor.

2. The medical department and the confidence of labor and management — privileged communications. All information dealing with health and welfare matters should be treated carefully and within the context of a written management policy. Personal medical questions especially should be dealt with as priviledged information. Thus the "need to know" should govern how information is handled, e.g., while personal medical details are not necessary for the ends of management, such information should only be made available in terms of management needs and comprehension. Therefore, *detailed* information describing the medical status of any individual is neither needed nor useful to management. The functional ability of a worker in terms of his ability to do a specific job is pertinent and necessary. Similarly the relationship of health hazards to production rather than the intimate medical details of the situation, are required by management.

MEDICAL APPROACHES TO CONTROL OF THE OCCUPATIONAL ENVIRONMENT

Medical Examination Procedure — A Re-Orientation of Medical Practices

The historical examination. While medical practitioners generally have been trained to reflexly think in terms of the diseased patient, in the industrial setting it becomes necessary for him to appreciate that he is dealing in the main with essentially healthy individuals. While the historical examination of any person should consider him in terms of deviation from normal, it is also important to evaluate the worker in terms of his functional, total health status. Accordingly, it becomes appropriate to carry out the medical history by use of self completion questionnaire. Thus, not only is greatest economy of physician time and cost achieved, it is possible for him to readily obtain an entire health inventory. This is in contrast to the usual situation wherein an individual consults a physician because of some health complaint, and the historical examination becomes oriented to elaboration of some specific pathologic process, affecting a specific organ system.

The physical examination. The same principle as elaborated above applies here also. Thus, investigations directed toward the whole person rather than toward a single organ system directs the physical examination. It should, therefore, be obvious that in dealing with the relatively HEALTHY person the physical examination should take another form. For example, in a cost-yield basis the relative cost of percussion and auscultation of the chests of large numbers of individuals is high in terms of the information obtained. Thus, for large numbers of persons it becomes less costly, for example, to obtain a chest X ray and a timed vital capacity determination rather than to laboriously perform a chest examination. This is especially true since essentially the same information is obtained. Thus any deviations obtained by such a "screening examination" can be followed up by the usual more elaborate examination procedures. Certainly, in view of the relatively few deviations expected in an essentially healthy population, such procedure has its obvious cost-effectiveness savings and yields.

Much of the physical as well as historical examination can be performed by paramedical personnel. With the rapid development of medical-electronic investigative techniques, increasingly more of the examination can be achieved by these means.

Use of the clinical laboratory for examination of ostensibly normal individuals. Our increasing capability to inexpensively and rapidly carry out clinical laboratory tests makes use of such determinations ever more fruitful. As automated laboratory procedures develop, the per unit cost decreases. In this fashion, a complete health profile can be more adequately and rapidly achieved. Problems arising out of the work environment may cause changes which can be detected by tests, such as multiphasic examination (i.e., medical, laboratory). This profile provides a useful baseline which aids in the detection of any possible subsequent health deviations. Should any physical or chemical agent produce health change, a health profile previously obtained has obvious comparison values for use in the control of health hazards.

Where small numbers of workers are involved, consideration should be given to the purchase of multiphasic laboratory services. The cost per worker for such services in this case will be far less expensive than the cost of setting up a laboratory. Accordingly, medical services for small plants should seriously investigate contract proposals and performance of such commercial laboratories.

The Pre-Placement and Pre-Employment Examination

Philosophy and Purposes. The basic purpose of the pre-placement examination is to determine the capability of the job applicant to perform a specific job for which he is to be hired. Thus such an evaluation is directed toward *capabilities, not disabilities.* While not all employees necessarily require testing of color perception, such evaluations become highly pertinent for workers for jobs requiring this adequacy; e.g., in color printing, color-coded electrical wiring, etc. While this theory applies in part, in reality many corporations recognize the point that they accept the *whole worker* with all his immediate health problems and possibly his long-term medical problems. This becomes especially pertinent as more and more of health and medical benefit costs are assumed through employer purchased health insurance. Accordingly, pre-placement examinations increasingly have become pre-employment examinations, so that total health evaluation becomes increasingly the rule.

Nevertheless, there is still required an evaluation of physical and psychological capabilities to perform a specific range of jobs. It therefore becomes necessary for the medical department to determine that a prospective employee does not have a pre-existing health problem that can be aggravated by his expected range of work duties. What has been previously stated regarding the use of electronic medical modalities and paramedical personnel applies equally here. However, it still remains the responsibility of the occupational health team to be fully cognizant of the job requirements and work environment so as to design an appropriate examination regimen. This once more underlines the necessity for the occupational health group to be comprehensively knowledgeable concerning any and all jobs, their peculiarities or needs within the plant.

Values and limitations. While fitting the right man in the right job is the aim of these examinations, the limitations inherent in this procedure must be recognized. These largely stem from the limitations inherent in medical prognostication of special susceptibility or inherent biological risk. The inability to clearly determine which individual possesses an inherent weakness of the lower back immediately comes to mind. Certainly the present inability to clearly evaluate the state of psychological fitness of an individual to fit into a specific social and physical environment presents even more serious problems. Recognizing these inherent weaknesses makes even more apparent the need for periodic re-evaluation of workers.

Job restrictions and transmission of information to management. Once more, the executive is primarily interested in being informed of the job applicant's ability to do a job. Accordingly, all *medical* information derived from such examinations *should remain privileged information,* inaccessible to all but medical personnel. Management should be fully informed of job abilities; *why* limitations are necessary in terms of specific *medical* diagnoses is neither necessary to his needs nor pertinent. Management should be kept informed *through established channels* (usually through the personnel departments) largely in terms of fitness to do a certain job. If medical conditions require job limitations or restrictions, such restrictions upon activities should be clearly and simply stated; the medical details as to "why" should not be divulged.

The purpose of these job restrictions is to prevent deleterious effects upon the employee's health. Since each person undergoes dynamic changes with time, the medical department has a responsibility for following and re-evaluating the appropriateness of such restrictions as time passes. As regards the need for follow-up of individuals placed under job restrictions, plant tours will also serve to determine whether the persons with restrictions are performing in appropriate jobs. As for re-evaluation, this too requires periodic re-examination to determine the current appropriateness of work restrictions previously applied.

The Periodic Health Examination

Philosophy and purposes. As related to the working environment, present limitations in our knowledge of human response to environmental changes requires that the periodic re-evaluation of exposed workers be performed. Thus, early detection of health changes becomes the primary orientation of this examination. In addition, because of the inexorable course of aging, those responsible for health protection need detect such changes so that work conditions do not accelerate or aggravate the aging process.

Method of execution. General health maintenance: Too often the pathology oriented physician seeks only to elucidate the presence of disease. However, equally important is a careful evaluation of the individual's hygiene of living. Due consideration should be directed toward elaboration of life habits, e.g., smoking, diet, social interactions and mental health, sleep patterns, etc. Out of such a matrix of life habits and styles emerges a picture of the whole man, and the effects of his life style upon health and well being. While inquiry into medical status is appropriate and accepted, the physician in industry must carefully direct such evaluation of a personal nature along the same lines of action of the medical practitioner whose appropriate concern is the whole man. Only insofar as he is recognized as being *primarily* concerned with the employee's well being, this approach is proper. Otherwise, this all-encompassing approach may represent an encroachment by the employer upon a realm of employee's personal life which is wholly inappropriate. Obviously, the methods employed in these examinations should be consistent with the cost-yield considerations noted above.

Examination of workers exposed to occupational risk. Such examinations should be oriented toward medical and health evaluation procedures which delineate human responses to special environments. For example, workers handling defatting solvents should be carefully examined to determine that dermatoses do not ensue. Other examples of special occupational risks, e.g., potentially hepatotoxic solvent, pulmonary irritants, etc., will determine which clinical and laboratory examinations are required. Again, the health protection team must be completely familiar with the risk potentials of *all* jobs in the plant so as to intelligently design such examinations.

Since engineering controls may fail or personal protective devices may be inadequately utilized, such examinations of workers at special risk should be *regularly and periodically* carried out. Record and scheduling systems should be so designed that these examinations are not missed and so that the information gathered can be rapidly and rationally reviewed. This requires both careful organizational efforts and design of medical records.

Sources of information regarding occupational risks. The clinical literature in occupational medicine and industrial hygiene is a rich mine of information. Herein will usually be found, to varying degrees of adequacy, much information regarding human response to environmental agents. In addition, the literature concerning experimental investigation of these special risks also becomes essential (see suggested readings).

However, the occupational health team should be aware of the shortcomings inherent in that body of information. Newly encountered occupational chemicals may be associated with little available data concerning *clinical* effects. However, the experimental literature can contribute to an understanding of risk potentials. For example, while there is little clinical data concerning N-dimethylnitrosoamines, the experimental literature extensively documents that agent's potential for carcinogenesis in animals. Accordingly, that agent should be treated as a potential carcinogen in the work place, despite an absence of such recorded effects on man.

The problems of extrapolation of data derived from animal experiments to man are self evident (see Chapter 7). Therefore, the experimental literature while potentially useful for health control requires that it be used with appropriate care. This makes even more important the need for careful periodic clinical evaluation being performed with due consideration of such animal data.

Other Examinations

Separation Examinations. If a worker has been exposed to some occupational hazard and is to be separated from employment, it is the employer's responsibility to ascertain his health status before such an event. While the legal responsibility of the employer ends only in part with discharge, any subsequent change may represent an aggravation or progression of a disease state incurred while at work. If a later status represents disease progression caused by work, the employer should be made aware of his legal and moral responsibility. If his future condition is unrelated to a work incurred condition, then equity demands that this ascertainment also be made.

It should be apparent that the role of the medical department is to accumulate and evaluate all health information so that the best medical opinion can be clearly and equitably applied to the matter in question.

THE ROLE OF THERAPY IN OCCUPATIONAL MEDICINE

For Occupational Disease

The Occupational Medical Practitioner as a Specialist. In the treatment of occupational disease of a non-surgical nature, the occupational medical practitioner should be prepared to provide definitive therapy. Certainly, in the area of clinical toxicology, such physicians more frequently encounter these problems, e.g., as in chemical plants, than do their fellow practitioners. Thus all ramifications (diagnosis, treatment and management) should be clearly within his competence. Should such medical problems arise, the occupational health specialist should be prepared to assume responsibility for all such cases, making use of appropriate medical or surgical consultants as the patient's complications may require.

The Use of Consultants

(1) Principles governing choice

Since the occupational medical specialist should know more about occupational diseases and the conditions of the work place, it follows that he should assume responsibility for medical management and direction of such occupationally caused problems. However, as noted above, should complications involving special organ systems arise, e.g., cardiovascular, respiratory, etc., it is appropriate that such specialists be consulted. Nevertheless, except for unusual reasons the responsibility should remain in the occupational medical specialist's hands. A close working relationship with such specialists should be developed in each case, as such physicians are invariably non-cognizant of in-plant conditions or the effects of toxic or physical agents. While it becomes the occupational medical specialist's responsibility to cooperatively aid the outside specialist in becoming aware of those problems, the latter should not nevertheless abandon his primary responsibility.

In one case of surgical problems, it is axiomatic that the best specialist help is the least expensive in the long-term prospect as well as being the most effective. While full responsibility for surgical treatment and management should be in such specialist's hands, the occupational medical specialist still has an important role to play. Again, since he is the most knowledgeable regarding work requirements or opportunities for less demanding tasks, he is in the best position to guide the rehabilitation of the injured worker during the recovery phase. Close cooperation with physicians, utilizing both extra- and intra-mural (i.e., plant) facilities can lead to the most effective programs of rehabilitative therapy.

(2) Limitations

It should be pointed out that in many, if not most, jurisdictions the worker has the final and definitive choice of who should treat his occupational disease or injury. Thus, the occupational medical specialist must observe this legal right. However, if the work force has confidence in the medical capabilities and the probity of the plant physician, most often the worker will accept his ministrations. However, should he decide otherwise, the plant physician has an ethical responsibility for cooperating with and aiding the management of the outside physician.

Therapy of Non-Occupational Disease

Stated Positions. It has been the position of organized medicine that plant medical departments should not become involved in the treatment of non-work conditions. The only qualification of this position is related to treatment of minor conditions, e.g., headache, indigestion, of a non-recurring nature for which the patient would not ordinarily seek medical help. Except for making it medically possible for the worker to safely finish his work-shift, he was to refer other medical problems to the private practitioner.

Trends in Occupational Medicine Regarding Management of Non-Occupational Conditions. Because of increased medical care utilization, rising health expectations and modes of medical practice, the availability of primary medical care has become somewhat diminished. Accordingly, strict application of the foregoing principles have been tempered by present realities. Especially in areas where medical care resources are limited, the plant physician is seen as providing a scarce capability. As health care delivery systems become integrated, it would appear that the occupational health specialist will play a more active role within such systems.

In addition, since the employer assumes increasingly more financial responsibility for general medical care, he demands that medical care utilization become optimized. All of these forces cannot but help affect the present and future patterns of occupational health practice. While the form such activity will take is unclear, given the present dynamism of this system, changes in such patterns of care are and will be occurring.

OPPORTUNITIES FOR RESEARCH IN THE PRACTICE OF OCCUPATIONAL HEALTH

Research in the Natural History of Disease. Use of Medical Records. At present, medical records in industry are largely oriented toward providing a data base for the several immediate responsibilities of the medical department. They are primarily directed toward providing the medical information necessary to adequate management of medical conditions. Except where they also provide health base lines needed for estimation of alteration due to environmental factors encountered in the work place or because of periodic health evaluation program needs, they are frequently ill-suited for long-range assessments.

In the past such records consisted of hand entries into medical forms. As such, ready assessments of large populations could not be achieved. Until the development of electronic tape and disc data storage systems, existent record systems inhibited worker-population studies. However, it is becoming increasingly possible to store and readily retrieve discrete data "bits" involving large numbers of workers. As such capabilities become increasingly more available, it should be possible to more readily use the masses of industrial health data presently unavailable. Given these capabilities, invaluable opportunities for the development of new medical knowledge will present themselves. Because working populations represent a useful cross-section of the active, non-hospitalized, the opportunity for delineation of the long-term, natural history of disease arises. In addition, study of the long-term effects of environmental stresses upon health should be accessible.

As an example of the former type information, industrial populations have been useful in developing new insights upon the effects of diabetes, hypertension and cardiovascular disease on long-term health status and productivity. Because such non-hospitalized populations can be studied, the misapprehensions derived from biased populations investigated in hospitals are avoided.

Elucidation of the Effects of Environmental Pollution upon Health

The Work Population as an Exposed Population. Because occupational exposures usually are more intensive than that incurred by the general population, working groups represent ideal study groups for the evaluation of such environmental effects. Relatively higher doses of common environmental pollutants (e.g., CO, SO_2) encountered in industry should, theoretically, accelerate the rate of development of deleterious health effects, if any, as compared to the rate of development possible because of lower doses in the community. Coupled with the advantage of the possibility of long-term observations is the fact that large numbers of exposed groups are concentrated in one area. Given adequate record systems the opportunities for epidemiological investigation are unparalleled.

The Use and Limitations of the Epidemiologic Method. The epidemiologic method depends upon the systematic collection of information which makes possible the comparison of one population's behavior with that of another similar group. Thus one assumes that the variables determining, e.g., health status, are completely similar in all regards except for a specific variable acting on only one of these two groups.

Obviously, as many of these variables are operating upon *both* groups they must be defined, since *assumptions* of such comparability in all regards (except for the one under scrutiny in the group at risk) are unacceptable. Thus, data collection involves large numbers of variables, e.g., age, sex, activity and residence. These must be adjusted for in both groups. The use of industrial populations in this connection given adequate data collection, should be obvious. Especially pertinent is the opportunity for construction of a control group derived from a working population in order to estimate health or mortality experience. Such comparison groups are essentially the only group with which a working population at a special environmental risk can be compared.

Nevertheless, the use of industrial populations for delineation of occupational health risks presents some attendant problems. One of these relates to assessment of exposure to a risk, since frequent in-plant job turnover may make tracing individual work or exposure experience difficult, especially in certain occupations, e.g., chemical operations. In addition, workers who are no longer on the rolls are a source of loss to a population of some consequence. This follows since they may have left employment because of incurring the health consequence under study. While conclusions indicating a *positive* association between work and some condition might only lead, at worst, to underestimation of risk, the significance of absence of an association becomes severely compromised because of such losses. This points up the obvious need for careful, painstaking follow-up of those separated from the groups under study. However, *carefully* performed multi-corporation or industry-wide studies, e.g., of mortality, have succeeded in providing valuable medical knowledge.[1] Studies of morbidity have been less satisfactory, yet present a considerable potential source of valuable medical information.

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