Dangerous Properties of Industrial Materials

Fourth Edition

N. IRVING SAX

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PREFACE

The intent of this new edition, like its predecessors, is to provide a single source for quick, up-to-date, concise, hazard-analysis information about nearly 13,000 common industrial and laboratory materials. The information is set forth in Section 12, General Chemicals. This section, which comprises the body of the book, is designed to expedite the retrieval of hazard information by categorizing the data into:

1 General information about substances listed, such as synonyms, description, formula, and the physical constants.

2 Hazard analyses, which include a toxic hazard rating or toxicology paragraph; a fire hazard rating; an explosion hazard rating, and a disaster hazard rating, to give some idea of the hazards produced when quantities of a material become involved in disasters such as fire, explosion or flood.

3 Countermeasures, or what may be done to mitigate the effects of using a given material, for instance, shipping regulations, storage and handling, first aid measures for exposed individuals, fire-fighting measures, ventilation controls, and personnel protection.

The concise material in Section 12, now very extensively revised, is all keyed to the textual material in Sections 1-11, which include a number of discussions of ways and means of bringing about the protective measures suggested in Section 12. There is detailed information about the meaning of the terminology used in Section 12.

In recognition of the great level of public interest now focused upon exploitation of the environment to the detriment of public health there are new sections on industrial hygiene, industrial noise, industrial meterology, industrial solid-waste handling, industrial carcinogenesis and, finally, on the labeling of hazardous materials.

In order to fit all this material into one book of reasonable size, it has been necessary to forego repetitive explanations and stereotyped instructions, warnings or reasons for a given recommendation. As a result, a vast number of cross references were required; these have been used with care and should not be overlooked by the user of the book, as they are essential in obtaining a complete picture of a given material.

Much additional information has been included because in this new edition much more industrial hygiene data are now available and those who use potentially hazardous materials, those who make them and ship them, and whose environment is polluted by them, all want and need to know much more than has generally been the case heretofore.

No effort has been spared to make this edition useful, informative, and relevant.

Boca Raton, Florida N. IRVING SAX

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The Author wishes to thank his wife, Paula, without whose tireless assistance this revision would not have been possible; also he wishes to express his gratitude to Lucille McKevitt for all the hard work and understanding she gave to this project.

N.I.S.

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SECTION 1

THE HISTORICAL PERSPECTIVE

ROBERT HERRICK

A. THE HISTORICAL PERSPECTIVE

The entire realm of science and legislation concerning the protection of the worker from the hazards of his occupation is, in 1974, in a rapid state of change. More progress has been made in the past 60 years than in all prior time; and through an improved understanding of the social, political, and technical factors leading to the present stage, we are provided with insight into the future of occupational safety and health.

Historically, the goal of occupational medicine is the promotion of optimal health, productivity, and social adjustments for the worker. Attaining this goal requires identification of the factors which deprive him of these conditions, the definition of possible solutions, and the implementation of such corrective action as is necessary.

As the sciences of medical diagnosis and engineering control advance, new steps forward will become possible. The present rate of growth and complexity of our industrial society creates new hazards at a rapid rate, so it can safely be said that the next decades will bring even more significant advances in raising the control of worker health closer to a science than an art.

The earliest of man's occupational injuries were probably the cuts, bruises, and eye injuries he suffered as he chipped out his first primitive rock tools. This same hunter might also have contracted anthrax from skinning his game, but that was a secondary hazard. Actually, at this stage in human development, just staying alive was such a significant occupational problem that probably no one paid any attention to chronic or secondary problems which might develop in time. Also life was so simple that there was no concern over specialized occupational hazards; indeed, there were few such in any case.

As agrarian societies developed, specialized occupations became identified and no longer was each individual responsible for meeting all the needs of himself and his family. As the processes for winning metals from their ores and working with these metals developed, separate workers identified as craftsmen were freed from their primary work of food production to do just that. Metallurgists were, in fact, the first class of craftsmen which came to be clearly identified as industrial workers.

Early history of mankind clearly points out the reality of social stratification by occupation, with individuals identified in one distinct group or another. As civilization developed, the practice of slavery also developed and provided a cheap source of power needed to keep civilization in motion. The supply of slaves seemed inexhaustible and, as slavery spread, the value and respect for the individual which we today hold so high nearly died out. This social stratification coupled with the moral philosophy of the day led to strangely conflicting (by today's standards) social values. Occupational medicine did not yet exist, although there were many occupations known to lead to specific diseases. Since mining and heavy labor were done by slaves, and it was their ills that resulted from the occupation in question, these ills were not considered medical problems. Ancient physicians were concerned only with the diseases of the ruling, i.e., powerful or able-to-pay classes, almost totally ignoring the craftsman and the laborer.

Ancient Egyptian, Greek, and Roman societies placed very high values on physical and moral perfection but their contempt for craftsmanship, i.e., handwork or manual labor, was so great that in many cities it was illegal for even an ordinary citizen to ply a trade. This prejudice against manual labor and the trades severely limited the interest in and the study of occupational diseases. Yet the fruits, the products produced by these laboring classes were highly valued, to the point that commerce demanded that they be even further developed. Thus the medical writing of Hippocrates, for instance, which exemplified this attitude, dealt almost exclusively with the health of citizens rather than workers.

One of the earliest known writings to include specific references to occupational medicine was *Historia Naturalis,* an encyclopedia of the natural sciences written by Pliny the Elder in the first century, A.D. He recommended that a protective mask consisting of a crude bladder be placed over the worker's face to prevent inhalation of the dust from cinnabar (mercury ore) grinding and lead fumes from lead smelting or working.

The Middle Ages, although a time of change in social systems, accomplished little to advance occupational medicine. Feudalism was the characteristic social order in Europe and the great landlord and his serfs lived nearly independent existences.

As the Renaissance approached, peasants and workers were attracted to the walled and crowded Medieval towns. New classes of merchants, free artisans, and laborers developed as did the guild system. The rigidly organized guilds regulated nearly every aspect of their members lives, but on the other hand, the same guilds also provided assistance (a sort of health insurance) to members who became ill and in time developed lasting prestige through the high standards of workmanship which guild members maintained.

The Middle Ages were, from a public health standpoint, characterized by epidemic diseases, truly terrible by today's living standards, and a total lack of knowledge of public hygiene. Even in the midst of these enormous problems, specific occupational diseases can be noted, isolated, and identified. For instance, the beautiful illuminated Medieval manuscript books contained illustrations drawn with metallic paints and some say that Medieval scribes developed lead and mercury poisoning as a result of moistening their metal pigment paint brushes on their tongues, in a manner similar to the workers who painted radium dials on watches in the early twentieth century. Also "Grinder's Disease" was identified as a hazard to those workers who, in sharpening knives and swords, worked close to sandstone wheels.

The specialized use of metals in industry led to significant problems. Paracelsus wrote of many of the hazards of metallurgy and mining in *Von der Bergsucht und anderen Bergkrankheiten* (ca. 1530). His description of mercury poisoning and his warnings of the hazards of toxic metals brought about an initial awareness of these problems. In France, for example, the hazardous nature of the vapors from mercury distillation were well enough acknowledged that workers were allowed only one month of employment at this trade in a year.

Georgius Agricola's *De Re Metallica*, published in 1556, was a classic volume on metallurgy. The 12 sections of the book describe nearly every facet of mining, smelting, and refining. The last section of the book describes the diseases and accidents prevalent among miners and the means for their prevention. Agricola was concerned with ventilation in mining, considering lack of fresh air as one of its greatest hazards. He proposed several ventilating devices as possible solutions to this hazard.

Bernardino Ramazzini is to occupational medicine what Galileo and Newton are to physical science. He developed an entirely new concept of occupational health and hygiene. *De Morbis Artificum Diatribe*, published in 1700, is a classic in the field. He examined the conditions of work and the diseases due to most of the occupations of his time. In addition to describing the diseases, Ramazzini proposed preventive measures which, although ignored for several centuries, were basically sound.

Among the early occupations wherein specific industrial diseases were identified were gilding, marble cutting, grinding, pyrite roasting, dyeing, mercury smelting, silvering of mirrors, and glass blowing.

The eighteenth century and the Industrial Revolution created a completely new set of occupational hazards. The social status of the worker was still very low, with children and women mainly being exposed to long hours in hazardous trades. In particular, English coal miners lived a precarious life and as a result of trying to improve this situation several English physicians made specific contributions which led to improved working conditions. Sir George Baker, for instance, traced lead poisoning of "Devonshire colic" to the practice of lining cider presses and vats with lead. This logically led to the abandonment of lead in the cider industry.

Percivall Pott identified the first occupational cancer in 1775. This was scrotal cancer caused by the soot to which chimney sweeps were exposed (see Section 8 and *Soot* in Section 12). Charles Thackrah devoted his life to the study and prevention of occupational hazards, and his treatise on occupational hazards and occupational medicine in the early 1800's was the first book of its kind published in England. It played an important part in stimulating factory and health legislation.

Thomas Beddoes founded the Pneumatic Institution in the late 1700's for the study of inhalation therapy in treating respiratory disease. Beddoes identified several occupations which made workers more susceptible to tuberculosis, including stone and metal grinding. Sir Humphry Davy studied at the Pneumatic Institution and is remembered for his study of mine explosions and his development of the miner's safety lamp.

In the United States an act was passed in Boston in 1726 preventing the use of lead in the distilling of rum and other liquors. Thomas Cadwalader published the first medical monograph in the United States, dealing with lead colic and lead palsy. Benjamin Franklin published the book in 1745.

The nineteenth century was a turning point for occupational medicine. The advent of the industrial society and the absence of social legislation make this the low point in society's concern for the worker and his health. The excesses of dangerous occupations and hazardous employment brought about a new social consciousness in Western society. The trade union movement gave organization and leadership to large groups of workers who had heretofore been without a voice. Concurrently, certain industrialists realized that worker well-being was in their economic self-interest. Combined with the genuine humanitarianism and utopian socialism, goals espoused by increasingly larger portions of the population, a reform movement was generated which has lasted well into the twentieth century.

During the years 1910 to 1912, modern occupational medicine was born. Physicians wrote about occupational diseases, the public was becoming aware of occupational hazards, and long needed legislation was finally being enacted. The work of Dr. Alice Hamilton at this point was outstanding, as she applied the science of pathology to occupational health. Her work in the area of lead poisoning is particularly significant.

From this point in time, occupational medicine, industrial hygiene, and industrial nursing became identified as specific occupations within a social system that now placed a high value on the individual and therefore his health and well-being. Advances in science and technology began to be applied to the protection of the worker and the emphasis shifted from diagnosis and treatment after the fact of occupational disease to the much more desirable prevention and control of hazardous situations so that the exposures leading to ill health would be recognized in advance and avoided.

B. LEGISLATION

With the exception of the banning in Boston of lead as a processing material for foodstuffs, the English factory and health laws were the first major worker health-related legislation. The early twentieth century is then, for all practical purposes, the beginning of modern industrial health legislation.

In 1898 the U.S. Supreme Court made the first broad statement that the health of the laborer as a producer is considered to be as much a public benefit as the health of the consumer. The protection of the laborer thus became a public purpose. However, it was some years before this basic court decision was to become a daily reality. The State of Massachusetts was one of the first to adopt progressive legislation. In 1905 Massachusetts employed health inspectors to investigate occupational dangers. By 1909, 21 states had enacted laws which attempted to regulate industrial working conditions in one way or another. Some of these dealt with ventilation, others with dust control, and still others with workshop sanitation. Unfortunately, enforcement lagged significantly behind the intent of the regulations. In many cases inspectors were political appointees untrained in the technical aspects of occupational health and unappreciative of the elements of the problems with which they dealt.

The accomplishments of Dr. Alice Hamilton as a member of a special Illinois commission centered on her correlation of 35,000 cases of lead poisoning which had occurred in American industry from 1908 to 1914. As a result, several states adopted "lead laws" in 1913 and 1914. The regulatory and enforcement powers for this legislation in New Jersey, Ohio, and Pennsylvania were vested in the Department of Labor at the state level. This was the origin of the splitting of public health functions between health and labor agencies which has continued through the years to the present time.

Workmen's compensation laws were enacted by about half of the states in 1913. Occupational diseases were included as compensable under these acts in the 1930's; but the greatest impact of this inclusion was that industry gained an economic awareness of the importance of the disciplines of industrial hygiene.

The Social Security Act of 1935 gave an economic boost to many health programs, including industrial hygiene. The period of 1936 to 1939 was the most important in the development of industrial hygiene as a distinct profession.

In the early 1940's, the U.S. Public Health Service provided professional industrial hygienists to serve in wartime munitions plants. Then in 1945 most of these personnel were transferred to state agencies on a loan basis to pursue their professions.

The Walsh-Healy Act, covering Federal requirements for industries engaged in government contract work, was the first piece of broad legislation which included numerical occupational health standards. The threshold limit values (TLV's) of the American Council of Governmental Industrial Hygienists (ACGIH) were included in the health requirements under this Act.

The most significant individual piece of legislation is the Occupational Safety and Health Act of 1970. When considered with the Federal Coal Mine Health and Safety Act of 1969, nearly every occupation and industry in the United States comes under Federal regulation. The Coal Mine Health and Safety Act is very specific in setting environmental levels for coal mine dust with health and safety being regarded as separate considerations.

The Occupational Safety and Health Act has been hailed as a particularly important piece of legislation because of its thoroughness in approaching the entire scope of occupational safety and health. The administration of the Act is the joint responsibility of the Department of Labor and the Department of Health, Education, and Welfare. The agencies involved are the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH), respectively.

The Department of Labor now has primary responsibility for determining priorities, setting standards, enforcement, operating a national record keeping and reporting system, providing employer/employee education, approving state plans, and awarding state grants. The Department of Health, Education, and Welfare has a supportive role in nearly all of these activities. HEW has specific responsibilities under the Act including health and safety research, industry-wide studies, hazard evaluations, toxicity determinations, publication of an annually compiled list of toxic substances, and development of an adequate supply of manpower to carry out the purposes of the Act.

It is the desire of Congress, as clearly stated in the Act, that state programs be developed to take. over the enforcement functions initially vested in the Department of Labor. Before the state can completely take over the responsibility from the Federal Government there are several specific requirements to be met, particularly that the state agency must demonstrate that it has enacted the necessary legislation and possesses the manpower and facilities to perform its function at least as well as the Federal agency in these areas. In any case, the Federal agencies will remain available in the event of special problems or when the states need this help.

The Occupational Safety and Health Act is specific in defining "consensus standards" as the principal mechanism for the adoption of specific regulations. Consensus standards are those which had been adopted by various technical societies and were generally accepted as good practice guidelines by professionals, industry, and regulatory agencies. Most of the consensus standards initially adopted as law concerned safety, but there were included, as well, several industrial hygiene standards. Among these were the Threshold Limit Values (TLV's) of the ACGIH and the ventilation standards of the American National Standards Institute (ANSI).

Most of the health-related standards will be promulgated in future years. The process will be one of standard setting by specific chemical, e.g., carbon monoxide, or physical hazard, e.g., heat stress. NIOSH will prepare a "criteria document" and present its recommendations by a panel of experts and consultation with affected parties; OSHA will promulgate and enforce the standard.

The development of a "criteria document" is a lengthy, in-depth procedure. All available toxicological data are collected and interpreted. Simple identification of a hazard is only the first step. The "criteria document" includes recommended procedures for measurement of the stress agent of interest, not only in terms of sampling and analysis but in terms of biological monitoring when appropriate. The source(s) of the agent are examined and the options for engineering control are discussed in detail. Personal protective measures are also examined in detail. Good practice recommendations are included. The net result is that the "criteria document" becomes a complete manual on the degree of hazard, procedures for monitoring, and control measures to be taken to reduce hazard to acceptable limits for the chemical studied. Even after OSHA standards are set and enforced, the "criteria document" remains as a primary reference for the working industrial hygienist.

These useful and carefully considered procedures will result in the promulgation of specific industrial hygiene standards on a national level. More of the enforcement of these standards will be on a state level as the states increase their budget and staff capabilities. While it is conceivable that the numerical standards adopted by a state could be more stringent than those of OSHA for certain compounds, it is not likely to happen, mainly because the Federal procedure described above is very scientific and detailed, with many checkpoints and plenty of opportunity for interested parties to make their influence felt before the standard is promulgated.

On-site inspections which could be made by Federal, state or local compliance officers will likely be handled at the lowest practical jurisdictional level. It is to the advantage of all concerned to have inspections performed by a local compliance officer who is familiar with the individual plant or process and who will be aware of and will be able to act upon any significant changes over a period of years. His observations can verify the benefits of process changes or added engineering controls. Likewise, he can be aware of the use or non-use of personal protective equipment by employees.

Certain hazards, such as carbon monoxide and noise, can be monitored by continuous instrumentation. The law allows for requiring such data from the employer when the need is justified and reliable instrumentation is available. Since this means considerable outlays of money on the part of a plant operator, it would normally not be required in any but critical situations. As research identifies these critical situations and new instrumentation is developed to provide monitoring data, it can be expected that more use will be made of this procedure for verifying the safety of working conditions.

The Occupational Safety and Health Act and its administration during the first few years of its existence have come under heavy attack because of certain alleged inconsistencies. However, as with any new piece of legislation, particularly with such far-reaching effects, these inconsistencies are being shaken out. The basic principles of the Act relating to occupational health are sound, and it is expected that this legislation will be the pattern to be followed for many years.

C. GENERAL PRINCIPLES OF INDUSTRIAL HYGIENE

Goals

The overall goal of the industrial hygienist is to protect workers from the health hazards of their working environment. The working industrial hygienist recognizes that there will nearly always be toxic and potentially hazardous materials to be processed or handled, and that some degree of physical stress such as noise or heat or radiation will be encountered as well.

Within this broad scope, or overall goal, is contained the need for a wide range of professional skills and disciplines. The industrial hygienist must be sensitive as well to the nontechnical cost-effectiveness of proposed measures to control the situations with which he works. It is his function to evaluate the degree of a hazard and the applicable regulatory requirements and balance the requirements against the costs of reducing exposures by means of a number of options. These can include engineering controls, process isolation in space or time, substitution of process materials, personnel protection, personnel rotation, and, in extreme cases, discontinuance of a process. However, before we can productively discuss implementation of the industrial hygienist's goals we must clarify the terms *toxicity* and *hazard*.

Toxicity and Hazard

The toxicity of a material is a property of that material, and can only be described by its effects upon a living organism. As a general principle, toxic materials are toxic to all living things, while the individual susceptibility of each species to the toxic material varies, as do the susceptibilities of the individual members within a species. Within a species, susceptibility varies with age, sex, state of health, rate of dosage, diet, etc. Therefore, toxicity data, to be useful, must include all of the above and must be stated in terms of the specific test animal or organism used, the routes of administration of the toxic matter, and the time of exposure. Also a sufficient number of test animals or organisms must have been tested to rule out some of the variables listed above and to make the data statistically significant; for further discussion see Sections 8 and 9. For purposes of this section, suffice it to state that all materials are more or less toxic. Those of any concern to this section are the ones which are or could be damaging to humans in amounts that ordinarily occur or might occur in the living environment or in the industrial or medical or scientific environments. Here is where hazard enters the picture. For instance, it is conceivable for a material to have a high "toxicity" rating but a low "hazard" rating. This is because the hazard rating or simply hazard associated with a material is simply a measure of the *likelihood* of damage to humans working with or studying the material in question. Thus while highly toxic materials such as arsenic and mercury or beryllium compounds are generally considered very hazardous as well, it is usually possible for the industrial hygienist to apply his professional know-how to, say, an industrial process so as to reduce its hazard to the people who work with it. The toxicity of the materials remain constant; he cannot change that.

Therefore, when highly toxic materials are included in an industrial process the competent industrial hygienist realizes that the chance for damage is great and he must do what he can to reduce the hazard or likelihood of the occurrence of damage from such materials.

Of course, other hazards, such as flammability and explosibility, though completely separate from toxicity, are still part of the industrial hygienist's job and must be controlled for the well-being of the workers and even the physical equipment.

A knowledge of toxicity and the ability to evaluate hazards are basic to the industrial hygienist's work performance. When evaluating an existing situation the goal is to evaluate the probability that a hazardous situation does or might exist. In new situations, such as a proposed raw material change in a process or the design of new process facilities, the goal is ample controls to be applied as necessary to reduce the probability of hazardous exposures to an acceptably low level.

Specialty Skills

The field of industrial hygiene encompasses a wide spectrum of specialty areas. Of particular importance is the fact that the industrial hygienist must be aware of the physiological effects of a mutitude of potentially hazardous compounds. Other aspects are the identification and quantification of exposure levels, application of realistic methods of evaluating the working environment, and selecting options for control or lessening of exposures. The basic disciplines are chemistry, toxicology, physics, and engineering. Few other professions cover such a broad spectrum of professional disciplines.

The industrial hygiene *chemist* has a broad knowledge of both organic and inorganic chemistry, especially those aspects dealing with the analysis of trace quantities of materials. Prior to about 1950 nearly all analytical work was done by wet-chemical methods. The advent of automated analytical techniques has provided new tools to the industrial hygiene chemist. Atomic absorption spectrometry, for example, is useful when analyzing for the heavy metals such as lead. The old reliable dithizone technique for lead analysis is quite sensitive but it is time-consuming and tricky in that it requires tight quality control over the reagents and laboratory practices involved. The automated determination of lead in biological specimens still requires extreme laboratory cleanliness to prevent contamination of samples, but the analysis time has been reduced from hours per sample to minutes by the new techniques. There is also voltammetry, polarography, infrared and ultraviolet spectroscopy, emission spectroscopy, mass spectrometry, gas and liquid chromatography, nuclear activation, and many combinations of all these.

The chemist is concerned also with the actual collection as well as the analysis of samples. The field industrial hygienist who collects samples at work stations must work closely with the industrial hygiene chemist to assure that the sample which is taken is of adequate size to allow accurate determination of the contaminant in question, that the sampling equipment and reagents are appropriate for the task at hand, and that the presence of significant interferences identified by the chemist is properly noted at the time of collection of the sample.

In the past it was the chemist who commonly interpreted toxicological data, but more and more there is a role for the industrial hygiene toxicologist as a specialist in industrial hygiene. In any case, some knowledge of toxicology is essential for all industrial hygienists and this knowledge should be based, in part, upon actual toxicological research work. The specialist in toxicology or the industrial hygiene toxicologist must understand not only the application of toxicological information to problems at hand but the procedures used to determine the toxicology of various compounds; whether the toxicity be acute or chronic; whether the significant route of exposure is via skin absorption, inhalation, or ingestion; and the possible synergistic effects of exposure to a number of compounds. He may himself perform these evaluations or supervise their performance in biological testing laboratories.

The industrial hygiene physicist generally works in the areas of radiation, heat stress, and noise (see also Sections 3 and 5). These are classed as physical rather than chemical hazards and their evaluation and control require the application of sound physical principles. Developing approaches to the control of heat and noise problems are particularly challenging parts of their work.

The principal function of the industrial hygiene engineer is to evaluate potentially hazardous situations and develop viable solutions for the control of exposures. Many innovative solutions to industrial problems have been developed by industrial hygiene engineers. Ventilation engineering, for example, is an important aspect of industrial hygiene engineering (see Section 2).

The melding of all these factors, with an overview that reaches from the occupational physician to the plant manager, is the scope of the industrial hygienist. Usually, no single individual is an expert in all aspects, but many are capable of meeting their acknowledged goal of protecting employees. An ability to adapt training and experience to new situations and to seek out expert assistance when required is important for a really functional team in this small but viable profession.

Toxicology for Industrial Hygienists

A basic knowledge of toxicology is one of the first skills needed by the industrial hygienist. Since this is covered in some detail in Section 9, and in a special sense in Section 8, the following paragraphs of this section will simply outline the areas of particular interest to the industrial hygienist.

Toxicity data are presented in many forms. The most common is the LD_{50} or the lethal dose of a material for 50% of a population of specified laboratory animals. This can be a single dose in mg/kg of weight of experimental animal to determine acute toxicity or a long-term repeated dosage to determine chronic effects. The National Institute for Occupational Safety and Health (NIOSH) has started to publish an annual *Toxic Substance List*, with LD (lethal dose) data on many thousands of compounds. It should become a valuable basic reference.

Each route of entry into the body—skin, via absorption; lungs, via inhalation; and intestines, via ingestion—has a special membrane wall which protects the body from absorption of some classes of chemicals. The skin, for example, is nearly impervious to hydroxy, carboxy, and ionized molecules while hydrocarbons, fats, and esters as well as some organometallics pass through with relative ease.

Some compounds have great mobility within the body. Benzidene base (see Section 12) placed on the skin can be detected in the urine within 20–30 minutes. Benzidene hydrochloride or sulfate, being of different molecular structure, do not penetrate the skin.

Certain critical organs of the body have definite protective screens. A brain-blood barrier exists which prevents many ions from reaching the brain tissue even though it gets into the blood. Inorganic lead encephalitis is hardly ever found in adults as a result of this barrier, but it is often found in young children because in them this barrier is not fully completed and the young are often exposed to lead.

The liver and kidneys perform the vital function of cleansing from the body most of what toxic substances get into it, but these "shock" organs can be damaged in the process. The effect of mercury, for instance, can be most severe on the kidneys, which, incidentally, do the work of separating it from body fluids. The liver, it appears, usually takes the brunt of the load of blood purification, and carbon tetrachloride exposures may thus lead to cirrhosis as the liver may thereby be overtaxed. See Section 9.

Acute exposures, strangely enough, put additional stress on the liver and kidneys in a different manner. The first effect of acute poison ing is usually a severe stress similar to shock. Circulation and respiration are threatened. The brain's blood supply is, however, preferentially maintained by blood shunting, and the liver and kidneys are among the first organs to have their blood supply cut off. While this also protects these organs from chemical damage, long periods of time in this condition can cause them to atrophy or otherwise be damaged.

In acute poisoning cases, therefore, treating the victim for shock is liable to save his life even without knowing the type of poison involved.

The route of entry into the body sometimes changes the whole toxicity mechanism and broad toxicological generalizations from a smattering of information may be quite dangerous. Trichlorethylene, for instance, acts as a systemic poison by ingestion while acute inhalation exposure mainly causes anesthesia. Two modes of entry, two completely different effects. This explains the advice against causing vomiting for the victim of an ingestion of solvents because vomiting can put some of the solvent into the lungs and the victim may then be subjected to both effects at the same time.

The industrial hygienist needs knowledge of this type because in doing his job, he is often near the site of an emergency. Even more, he may be the one whose name comes first to the mind of the person calling for aid and also because of his demonstrated knowledge and interest in the health of the employees.

Certain other specific toxic agents should be noted because of their wide exposure and/or high hazard. Hemoglobin has a preferential affinity for carbon monoxide which is about 200 times that of its affinity for O_2. A CO concentration in the air of 1000 ppm (0.1%), therefore, competes for hemoglobin on an equal basis with O_2 at its normal level of 20.4%. Carbon monoxide thus is very hazardous because it can be found in so many areas; because it is colorless, odorless, and tasteless; and because it is insidious, i.e., in acute exposures, collapse comes almost without warning and the victim is left in the high-exposure area in an unconscious state. Even at concentrations which do no more than cause an occasional headache, continuous or chronic exposures over a period of years can so starve the brain for O_2 that scar tissue develops and permanent brain damage ensues.

Hydrogen sulfide (H_2S), the rotten-egg gas, is particularly dangerous. Its toxic action is via an enzyme inhibition which causes respiratory paralysis. One breath of a very high concentration can be fatal, making it one of the most highly toxic materials found commonly in industry. It is particularly hazardous because its odor is strong and disagreeable at safe levels, but the more dangerous, high concentrations cause olfactory fatigue and there is soon no odor sensation at all. The rule of thumb in H_2S exposure areas is: "If you smelled it before but can't smell it now, get out while you still can."

There are three routes by which a toxic agent can enter the body: ingestion, inhalation, and skin absorption. The industrial hygienist must think of each of these possible mechanisms.

Ingestion, or swallowing of industrial products, reagents, and solvents, is sometimes encountered in industry where workers eat or even smoke without washing; or where foods or candy, gum, or cigarettes are stored near where these materials are used. Some cases of lead and mercury poisoning have been traced to this route of entry into the body.

Considerable ingestion toxicological data obtained from work on experimental animals is usually available for compounds encountered in industry. This is the quickest and easiest test used by toxicologists when evaluating new compounds. Also, FDA requirements demand this data for nearly every material which might end up in consumer hands. Thus, it is likely that some data will be available (though in many cases far from *readily* available) for the use of the industrial hygienist for most situations which he might encounter.

Skin absorption is a more insidious or hazardous route of entry into the body than ingestion because it is not easily noticed and there is so much handling of products and chemicals in industrial activities which give rise to it. Dermatitis from skin contact with materials is the most common industrial disease (see Section 9). Oil and solvent dermatitis cases are more common than acid or caustic burns simply because workers have a healthy respect for the acute damage caused by strong chemicals but chronic exposure to oils and solvents defat the skin, making it prone to cracking and subsequent infection, and this does not command the same respect. This example also points up the basic difference between toxicity and hazard as discussed above.

Inhalation is an even more general hazard than ingestion or skin absorption because no visible physical contact between the worker and the compound in question is required. Airborne particulates, gases, vapors, and mists travel freely with air currents in the work area, so potential inhalation hazards must be evaluated carefully even though the worker is unaware of any exposure.

The difference between acute and chronic toxicity must also be clearly understood. Acute toxicity refers to the effects of a single exposure or close-together-in-time series of exposures to the agent in question. Chronic toxicity refers to the effects of many exposures repeated over a long period of time.

Another important factor is physiological response to the exposure in question. Exposures to ionizing radiation must be considered in terms of a lifetime cumulative dose since there is no proof of complete recovery from each individual exposure. Chemical compounds which display this same characteristic are termed radiomimetic, i.e., their effect mimics that of radiation (see also Sections 5 and 9). Another broad grouping of compounds includes those with only a temporary effect and with complete recovery after exposure, such as the anesthetic class of hydrocarbons.

The effects of physical agents such as heat and noise are defined somewhat differently than the chemical toxicity discussed above, but the same principles apply.

The mechanism of the Occupational Safety and Health Legislation in the United States involves a detailed process for setting standards. Basic to this process is the issuance of criteria documents by NIOSH. These documents contain a compilation and interpretation of appropriate toxicological or human-effect data as justification for the recommended standards. They are a "must" in the library of every industrial hygienist concerned with the agents under consideration.

Survey Techniques

All of the industrial hygienist's training and skills are converted from theory to practice during surveys conducted at the job site. Whether the survey is a quick walk-through inspection or a detailed study of a particular work operation, many of the same principles apply.

A starting point for a survey should be the medical history of the employees in the area. Is there evidence of excessive illness or absenteeism? Are working conditions recognized as so severe that short hours are the rule? Has a pattern developed in workman's compensation claims? These questions are properly addressed to the medical or personnel department, if available.

The next step is to gain an understanding of the process; the actual raw materials, intermediates, and products which knowledge coupled with a knowledge of toxicity allows the industrial hygienist to frequently identify critical areas before even seeing the work site.

Upon entering the work area the first impression is very important. General housekeeping and cleanliness have a definite effect on the probability of hazardous conditions. Messy areas increase the chances for dermatitis due to the vapors of solvent spills and increase other safety problems as well.

The physical layout of the work area is another important aspect which can easily be noted. Certain operations should not be located close to each other. An example is welding, which must not take place where there are or may be halogenated solvent vapors, as from a degreaser because the intense heat from arc or flame welding can pyrolyze chlorinated hydrocarbons to form, among other things, the highly toxic phosgene gas.

Many processes inherently generate potentially hazardous quantities of dangerous materials and the workers must be protected. The first step in many survey recommendation reports is an investigation of the feasibility of substituting less hazardous process materials. Asbestos dust has been identified as a severe inhalation hazard. Several less toxic materials such as perlite might be substituted, depending of course on the properties needed to fulfill the function of the original material. Substitution of less toxic solvents to reduce hazard is likewise common. The principle involved is that the reduction of the hazard at its source is much more satisfactory than any attempt at control by after-the-fact procedures such as ventilation or personal protection. See Section 2.

Once it is established that a potential hazard is unavoidable the industrial hygienist utilizes his sampling and analytical skills to determine the personal exposure levels and then he must determine if such are acceptable. The TLV's are his primary reference in this regard (see below and Section 9), since they define the concentration levels of chemical compounds and physical agents below which the average healthy worker will suffer no demonstrably damaging effects. These levels are, whenever possible, determined at the breathing zone of the employee for an inhalation hazard, rather than simply at the work station.

For measuring noise exposures, use a simple and relatively inexpensive sound-level meter calibrated for A scale slow-response (the A scale is an electronically defined broad frequency band range which approximates the response of the human ear). See Section 3.

The TLV's define the maximum average daily noise dosage to which employees may be exposed in terms of dbA, decibels measured on the A scale. A slightly different instrument is required for measurement of impact noise, for which there is also a TLV.

Personal noise protective devices, i.e., earplugs and earmuffs, are frequently found in areas where noise levels approach or exceed the TLV criteria. Also, employee work duties can be rotated between noisy and relatively quiet work stations so that the allowable daily noise dosage is not exceeded.

For chemical hazards some type of air sampling and analysis is required. The quickest or spot-check method uses detector tubes. These are transparent tubes containing chemicals which change color or extend a stain in proportion to the amount of a specified compound drawn through the tube by means of a handheld air pump. The tubes may be specific for one compound (NO_2, CO) or for a category of compounds (olefins). Their accuracy is a subject of continual improvement by manufacturers, with $\pm 25\%$ as the NIOSH goal. Detector tubes must be recognized as a screening technique rather than a sophisticated sampling/analysis technique. If this is understood when they are used they will provide much useful information and can be a powerful field tool.

The details of sophisticated sampling and analysis techniques are beyond the scope of this volume. Since they are in a continual state of improvement, the reader is encouraged to scan current literature and follow OSHA and NIOSH recommendations as a best course of action when a specific need arises. The Analytical Guides published by the American Industrial Hygiene Association are good primary reference for analytical information.

The ventilation of process equipment is an important aspect of exposure control. Hood and other dust control equipment design are complex in some cases, simple in others. An initial survey of a ventilated process should always include an inspection of the fan while it is in operation. It is surprising to find that many systems are operating well below their design capacity because the fan is rotating in reverse.

The industrial hygienist must, above all other considerations, be guided by common sense. He must realize that first impressions have to be tempered by repeat visits to clarify and justify preliminary conclusions; that sampling must be conducted over extended time periods in borderline cases; that working conditions can become radically different under different weather conditions; that acute exposure hazards can develop from so-called "freak" conditions but which might be predicted when the situation is thoroughly studied; that several occupational diseases such as silicosis may show no symptoms for several years after exposure, so reliance for employee health must be placed on thorough survey procedures.

In terms of employee protection from hazards, the substitution of nonhazardous for hazardous materials is certainly the most foolproof. The next choice is engineering control to remove the potential hazard from the work station. The least satisfactory, unfortunately often the first one considered, is the stop-gap device of personal protective devices.

The basic fault of personal protection, whether it be protective clothing, ear protectors, or respirators, is that its successful use is dependent on the cooperation of the employee. Every manner of personal protective device is for some reason considered to be at least an encumbrance or perhaps even an "insult to manhood" by a certain segment of the workforce. In addition, there is a continuing problem with proper fit of the devices even with cooperative employees. Personal protection must never be considered anything but a temporary expedient which is to be used only until more positive methods of control are applied (see Section 2).

Detection of several hazardous exposures are amenable to the use of biological monitoring or bioassay to provide evidence of excessive exposures. In lead workers, for example, blood lead levels can identify those workers who have excessive lead input into their bodies. While not generally a legally acceptable proof of compliance with regulations, biological monitoring can be extremely valuable in protecting the health of the occasional worker whose exposure is excessive in spite of all efforts to protect him. After all, if there is no untoward exposure of a worker to lead or mercury it is difficult to explain abnormally high tissue concentrations as observed via bioassay. This technique is therefore an excellent screening device.

These survey technique comments, while not comprehensive, define the philosophy of the working industrial hygienist. He is a pragmatist with a substantial background in theory and an understanding of the physical stresses of the workplace. The industrial hygienist serves as a valuable part of the industrial economy by identifying potential hazards and effecting solutions *before* worker health is impaired.

D. THRESHOLD LIMIT VALUES

For many years the ACGIH has published an annual list of TLV's. The 1973 edition is reprinted below in its entirety because TLV's are a prime reference for industrial hygienists and not only are the numerical values important to occupational safety and health, but at least of equal importance are the explanations and limitations of these values as detailed in the text which accompanys the list.

The introduction to the TLV's states that they "represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect."

Since the TLV's are presented in terms of numerical standards, they suffer from common misinterpretations. The most common error is to interpret these values as being a precise definition of a hazard/nonhazard situation. This is not the case. The TLV's have been established on the basis of the best information available and are subject to annual revision. They are not intended to define values below which all individuals will be protected and above which damage will occur to all; it is predictable that some hypersensitives may suffer adverse effects even at exposure levels well below those defined by the TLV. The TLV's must be considered simply as good-practice guidelines and as such have been accepted as official U.S. government standards for industrial air.

Another common misinterpretation concerning the TLV's is the lack of understanding that they are mostly long-term average concentration values. When instantaneous grab-sampling techniques are used to determine the concentration of a specific substance in workroom air, it is to be expected that in many cases, even though a TLV is actually being met, there will be instantaneous concentration excursions above the TLV number. This is specifically covered in Appendix B of the TLV's, which discusses permissible excursions for time-weighted average (TWA) limits. It is clearly pointed out in Appendix B that the limiting excursions quoted are to be considered "rules of thumb." When the numerical value of the TLV is between 0 and 1 the rule of thumb excursion factor is that instantaneous values should not be more than 3 times the limit. When the numerical value of the TLV is between 100 and 1000 the rule of thumb for the excursion factor is that instantaneous concentrations should not exceed the TLV by more than a factor of 1.25. Intermediate factors are quoted for TLV's between 1 and 10 and 100.

Certain of the TLV's are listed as "C" or ceiling values rather than long-term averages. For these compounds, e.g., certain acid mists, the short-term (acute) effects of excursion concentrations are so undesirable that they outweigh the long-term (chronic) effects and careful protection of workers depends upon maintaining concentrations below the ceiling value at all times, i.e., no excursions over the TLV are permitted.

The selection of numerical values in working areas to compare with TLV's is based on the most reliable available sampling and analysis of workroom air. In almost all cases this means the use of sophisticated sampling and analytical techniques. The widespread use of detector tubes for the estimation of the concentration of several contaminants in workroom air has proven both a curse and a blessing. The blessing comes from the fact that the tubes are direct reading, relatively inexpensive, and convenient to use even by unskilled people. The "curse" comes from the use of them by personnel who frequently do not understand the principle of short-term excursions and the fact that the detector tubes are, at best, accurate to ±25%. It is not necessary that the user of detector tubes be a qualified industrial hygienist. It is, however, important that the individual who interprets such readings have a solid understanding of both the principles of TLV and the inherent shortcomings of the method of measurement he uses.

The TLV for mineral dusts is dependent upon the free silica content of the material in question. There are two techniques for evaluating these exposures: "total" airborne dust and "respirable" airborne dust. Both can be valid measurements yet the numerical limits applicable to each are different because the sampling techniques are not the same. The "total" dust technique has been used for many more years than the "respirable dust" technique, and so more data based on it are available.

Determination of "total" dust is based on the use of impinger-collected samples and requires somewhat detailed and lengthy laboratory analysis using microscopic techniques to interpret the data. The impinger itself was developed about 1930 for the purpose of evaluating the dust content of industrial air. The device draws dusty air at high velocity through a nozzle which is submerged in a liquid. Dust particles larger than about 0.8 microns mean diameter, impact on a collecting surface and are thus removed from the airstream. The liquid continually washes the impaction plate and retains the particles so they are not swept back into the airstream. For analytical purposes an aliquot of the liquid is transferred to a dust-counting cell, whose depth is carefully controlled. After a period of time, long enough for the particles to settle to the bottom of the cell, the particles are optically counted using a light-field microscope at 100× magnification. The results of the microscopic count are calculated to millions of particles per unit volume of air sampled.

The "respirable" dust sampling technique is a gravimetric procedure based on the increase in weight of a filter through which a known volume of air containing size-classified dust has passed. The size classification is accomplished via a small "cyclone" which, at a specified air flow rate is known to pass dust particles in approximately the same size range as the human respiratory system. The size selector passes 90% of 2-micron particles and 0% of 10-micron particles. The stated size is the aerodynamic diameter; that is, the diameter of a spherical particle with a $d = 1.00$. Since industrial particles can vary widely in their d (generally in the range of 2.0 to 3.5) an appropriate correction must be made in the rate of air flow through the size classification device in order to duplicate the size characteristics as required by the TLV's.

Regardless of the sampling technique used, the TLV depends upon the per cent of quartz in the respirable fraction. When using the respirable-mass sampler the determination is straightforward in that the quartz content can be determined from the sample filters themselves. The analytical methods for free silica are quite accurate, with a minimum detectable mass of 0.01 mg of silica. When using the