INDUSTRIAL POLLUTION

EDITED BY

N. IRVING SAX

Consultant, Environmental Pollution
and Industrial Safety and Health

VNR

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PREFACE

Environmental contamination is an inevitable consequence of the activities of man and a *natural* phenomenon as well.

Whether in an industrial society or in an agricultural society, placing waste material, partially used consumer goods and other by-products into the environment by man has characterized his activities.

Also, the physical processes of the world around us cause continual change by removing, replacing, and redistributing an enormous volume and variety of materials. Volcanos erupt and discharge gases; rains erode and transport silts and dissolved compounds; winds move dirt particles, salt particles, and a wide variety of other particulates. Plants remove nutrients from the soil, recycle them through the food web, and return them again to the soil in a different concentration. The physical world is, in fact, dynamic, constantly rearranging, and therefore constantly contaminating and decontaminating itself.

Contamination is also a *social* phenomenon. The communal activities of man as a social being have created a new order of byproducts which have increased in volume at a faster rate than population, and have been concentrated by our megalopolitan tendencies. This has resulted in increasing contamination of the environment surrounding the habitats of man to the point where the natural purifying activity can no longer keep up with it and what was once contamination, now becomes pollution.

Contamination is also a *historical* phenomenon. Throughout the development of the industrial age and, prior to that, even during the beginning of the agricultural age, there have always been by-products returned to the environment. Manure, plant parts, unharvestable by-products, industrial by-products were all eventually returned to the earth, sometimes via water or sometimes via the air. Historically, once man was able to maintain his food supply and bring great economic wealth and personal comfort to himself, he really began seriously to contaminate his surroundings.

Contamination must be considered an *amoral* phenomenon. It is neither right nor wrong—it is simply a consequence of living. However, excessive contamination is that which interferes with the health and happiness of a population; this is pollution and this is wrong.

Management of contamination, so that it does not become pollution, is essential at this time if we are to continue to grow as a nation, and as an industrialized world. However, a rational management program, designed to avoid adverse effects from contamination, starts with the recognition, description, and understanding of the effects of the contaminants themselves.

To understand effects, we must recognize that they are a function of the *kind* and quantity of contaminant that is being released into the environment. There are some contaminants that are specifically toxic to biological systems or perhaps destructive of physical systems. There are some materials that are irritants, some that are systemic poisons, some that produce abnormal growth, and some that interfere with reproduction. The *kind* of toxicant material is a significant factor in understanding its effects.

Another consideration is the *dose* of a contaminant. The concentration and the period of time that the contaminant is exposed to a receptor system (such as a population) is the dose, and it plays a significant role in the ultimate effects of this contaminant. A dose is in turn mediated by a number of parameters. In air pollution, meteorology is important. In water pollution, stream flow is important. In both cases, the rate of emission of the contaminant into the air or water plays a significant role in the ultimate dose that is presented to a receptor system.

Finally, the *sensitivity* of the receptor system is important. There are some plant materials that are extremely sensitive to even very low doses of certain toxicants, whereas there are other plant systems apparently indifferent to the same dose of the same material. There are some physical systems that are not bothered by a certain material and which see it as a contaminant, and others that are extremely sensitive to it and see it as a pollutant. There are many factors which influence the sensitivity of receptor systems, such as the environmental matrix in which they exist, the innate genetics in the case of biological systems, or the innate properties of the physical system; all these play a significant role in the sensitivity of the receptor system and, consequently, in the ultimate effects.

Judgments regarding the significance of effects will vary, depending upon whether the effect is found in the matrix of a biological system, a physical system, an esthetic system, an economic system, or a legal system. In each case, the matrix dictates the importance of the effect. In every case, also, the ultimate effect on the health and happiness of man, broadly conceived, colors the significance of the judgment.

In this book we have tried to inform rather than judge; our purpose is to present facts, underline problems, and suggest solutions. We regard contamination as inevitable, and its management depends upon an understanding of its effects. Understanding the effects of contaminants requires a knowledge of the kind of contaminant and its dose, as well as the sensitivity of the receptor system. This book, then, can be construed as a management tool because it contributes to the understanding of effects by identifying the contaminants and some of their properties, including receptor sensitivity, so that judgments of probable significance can be made with confidence. Good professional practice in the management of industrial contaminants requires that a judgment be made concerning the significance of the effects that contaminants will have on the various systems to which they are likely to be presented. It is the hope of all of us that this reference will serve as a reliable starting point in understanding the significance of contamination and the prevention of pollution.

I acknowledge with gratitude the invaluable assistance of my wife in every phase of the preparation of this manuscript, even to contributing creatively to Chapter 22.

My thanks to Lucille McKevitt for her clerical and typing help and finally to the residents of Boca Bayou who make this a great place to write.

N. IRVING SAX

Arrangement of Entries:

Entries are listed in strict alphabetical order; disregarding prefixes such as ortho, meta, para, alpha, beta, gamma, sec, tert, sym, unsym, cis, trans, endo, exo, d (for dextro), l (for levo) and structural numerals. However, prefixes which are integral to the name of a chemical such as di-, tri-, tetra-, cyclo-, bis-, neo-, pseudo-, are alphabetized. Iso is usually not alphabetized. Occasionally, as in Isoprene, where usage has made it part of the name it is alphabetized but in iso-Propyl Alcohol it is not.

List of Abbreviations

ALD = Approximate lethal dose
CNS = Central nervous system
iv = Intravenous
ip = Intraperitoneal
CEQ = Council on Environmental Quality
torr = 1mM of Hg at 0° C
PO_x = Oxides of phosphorus
SO_x = Oxide of sulfur
NO_x = Oxides of nitrogen
CO_x = Oxides of carbon
GI = gastrointestinal
G.I. = General information
MLD = median lethal dose
Sol = Soluble
LC_{50} = Lethal concentration to 50% of a specific population
LD_{50} = Lethal dose to 50% of a specific population
HC = Hydrocarbon(s)
IC = Internal combustion
Ecotox = A synthetic term used to express the toxic and/or otherwise hazardous effects upon an environment of a material or physical entity.
Hz = Hertz = 1 cycle/second
FWPCA = Federal Water Pollution Control Agency
EPA = Environmental Protection Agency
ICC = Interstate Commerce Commission
CG = Coast Guard
IATA = International Air Transport Association
g = Gram
Kg = Kilogram
m or M = Meter
mm or mM = Millimeter
cm or cM = Centimeter
μ or μM = Micron = micrometer
AEC = Atomic Energy Commission
bp = Boiling point °C
°C = Degrees centigrade
cc = cM^3 = cM^3 = cubic centimeter
°F = Degrees Fahrenheit
FDA = Food and Drug Administration
fp = Freezing point
gal = Gallon
lb = Pound
ml = Milliliter
mp = Melting point
ppm = Parts per million
sec = Secondary or second(s)
USDA = U.S. Department of Agriculture
/ = per
> = Greater than
< = Less than
PHS = Public Health Service
HEW = Health Education and Welfare

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1 TOXICOLOGY OF ENVIRONMENTAL POLLUTANTS

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Toxicology may be defined as the science of poisons: their effects, antidotes, and detection. Formerly, the toxicologist was viewed primarily as concerned with the detection of crimes and the apprehension of criminals. However, with the present increase in the use of chemicals for many purposes and with increasing concern over the presence of chemical pollutants in our air, water, food, and other parts of the environment, the responsibility of today's toxicologist is much broader than his narrow forensic area. The modern toxicologist is concerned with the quality of the environment and the safety of the food, water, air, household products, and other elements of basic human consumption. This concern focuses not only on the occasional immediate hazard, but on possible lifetime effects of exposure to our chemical environment (see Chapters 2, 5, 7, and 9). The concern is not only for man himself but for domestic animals, fish and wildlife and for the aesthetic qualities of our environment, such as streams and forests.

The use of chemicals as (defensive and offensive) weapons is not the invention of modern man. Both plants and animals employ foreign chemicals to poison or otherwise influence other individuals or species; for example, some snakes employ a toxic venom and the skunk an unpleasant smelling chemical to ward off their enemies. Early man was no exception. People used chemicals before the dawn of recorded history, as witness the savage and his curare-poisoned arrow or spear.

Modern man has borrowed this basic idea and has greatly extended and developed the use of foreign chemicals to enhance his health; to improve his production of food, feed, and fiber; to provide energy for various purposes, including particularly locomotion; and to protect himself from unwanted intrusion by insect, rodent, plant, human, and other types of enemies.

In the practice of his profession, the modern toxicologist makes use of a number of other disciplines, including pharmacology, biochemistry, analytical chemistry, pathology, medicine, and engineering. Actually, toxicology is more closely related to pharmacology than to any other single basic science. Pharmacology is concerned primarily with the useful, advantageous effects of drugs and other chemicals on living systems, and especially with their diagnostic or curative effects on disease. The principles governing the mechanisms of chemical-biological interaction and the methodologies are similar for the two sciences.

The science of toxicology may be subdivided into the following major areas.

1. Environmental toxicology. Environmental or ecologic toxicology is concerned with the harmful effects of chemicals that are present in air, water, soil, food, or other environmental vectors of exposure to man, domestic animals, fish, wildlife, and other biota. Since much of this type of exposure to chemicals is incidental and unrecognized, control is obviously much more difficult than with situations in which exposure to chemicals is more definite and circumscribed, such as in an industrial setting. The environmental

toxicologist is concerned with the entire range of potential effects of chemicals on the quality of our environment, including the aesthetic aspects. He is concerned with the possible extinction of certain species of wildlife as a result of chemical pollution of their food or habitat. For example, much of the impetus to restrict usage of DDT has come because of its effect on egg-shell thinning and consequent lowered reproduction of raptatorial birds. The benefits from chemicals have been purchased from nature at a price, and the cost to society is still being evaluated. It is clear that in some cases man has been short-sighted and sometimes over zealous in his use of chemicals. It is also clear, however, that because of the current public concern, chemicals of the future will be more carefully researched, developed, and tested before they are used. The environmental toxicologist has been in the forefront in alerting the general public to the environmental hazard posed by chemicals and he will be strongly involved in the formulation of solutions to the problems. It is primarily with environmental toxicology, in all of its various ramifications, that this book will deal.

2. Forensic toxicology. Toxicologists with specialized knowledge of law work together with pathologists and medical examiners to establish the cause of death or illness for medico-legal purposes in incidents in which a crime is suspected to have occurred. These scientists analyze the fluids and tissues of the body for the presence of poisonous substances and try to determine if they are present in sufficient amounts to account for death or the symptoms experienced by the victim. In the latter case, the examination may be of the utmost urgency so that specific therapeutic measures can be instituted. In cases involving criminal prosecution, the toxicologist may be called upon to testify to his findings in a court of law. The most sophisticated instruments are employed by the forensic toxicologist. For example, with a new technique called neutron activation analysis, a single hair taken from the exhumed body of Napoleon revealed, almost 150 years after his death, evidence which suggested that As poisoning contributed to the symptoms of the Emperor's terminal illness.

3. Clinical toxicology. The usual and expected effects of a therapeutic drug are improvement in the patient's condition and progress in treatment of the illness or disease condition. However, occasionally the patient's response is atypical and deterioration in the course of the current disease takes place or a new type of illness begins. In correlation with the physician's continually increasing use of a wide variety of synthetic therapeutic drugs, most of which were not even known a generation ago, these toxic or side reactions are occurring more frequently. The physician who specializes in treatment of these toxic reactions to therapeutic drugs as well as management of illness caused by poisons is the clinical toxicologist.

New methods for treating poisonings are continually becoming available as a result of current research. For example, the artificial kidney has been found to be life-saving in its ability to remove certain poisons from the body. Specific antidotes, for instance, have greatly improved the chances for patient survival in acute poisonings by the organophosphorus pesticides, the narcotic morphine derivatives, methyl alcohol, and cyanide. Other drugs greatly increase the body's ability to rid itself of toxic amounts of Pb, Hg, and As. Poison control centers are located in most major population centers and can rapidly provide physicians with up-to-date information on the toxicity of chemicals and currently recommended methods of treatment.

4. Occupational toxicology and industrial hygiene. In the last half of the nineteenth and the first half of the twentieth centuries, it gradually became known that workers in certain industries were incurring serious illness and fatal diseases because of exposure to dangerous chemicals under primitive working conditions. When public attention was drawn to this circumstance, toxicology became linked with social reform to improve working conditions and to make the work environment safe. It should be recognized that most of the early problem was lack of recognition that the occupational health problems existed. Where new techniques and equipment showed that industrial hygiene improvements were needed, these have been brought about partly through legislative mandate and partly through spontaneous cooperation on the part of the industries involved. Occupational toxicologists have pointed out the hazards of exposure to Ra in the watch industry, the nervous disorders produced by CS_2 in the viscose rayon industry, the severe poisonings suffered by munitions workers exposed to dinitrophenol, the debilitating diseases produced by exposure to Pb and Hg, the facial disfigurement common to those who made white P matches, the blood disorders produced by C_6H_6 exposure, Be lung disease, and many others. With the constant flow of new compounds from the chemical industry, it is important that constant health surveillance of these more heavily exposed workers be maintained, not only as a safeguard for their own welfare but also as an early warning system to safeguard the health of the general population before the compounds become generally available.

5. Safety evaluation. The requirements for exhaustive testing of compounds for efficacy and safe use in a variety of biological species are rigidly enforced by a number of federal regulatory agencies, including the FDA and the EPA. Insofar as pesticides are concerned, such agencies set permissible trace levels or tolerances of harvest residues of the parent compound or metabolites on edible commodities, basing their decision on a sizeable quantity of required toxicity data. These tolerance levels provide a wide safety margin. It is significant with regard to recent environmental concern that data is now also required on the potential hazard of these compounds to fish and wildlife. Food commodities are continually analyzed by federal and state laboratories and if contamination is excessive, the commodity is seized and fines may be levied if negligence is indicated. Potable water supplies must meet prescribed standards with

respect to their purity and content of chemicals. Our atmosphere is under surveillance for dangerous concentrations of air pollutants whose long-term effects are carefully evaluated in experimental laboratories. Dangerous ingredients of household products have been banned or replaced by safer substances. Carbon tetrachloride, which has produced severe liver or kidney disease, can no longer be found in spot removers. The safety of small amounts of F^- in drinking water and its benefit in the prevention of dental caries has been established. The use of the polychlorinated biphenyls (PCB) (see Chapter 22) has been restricted to usage in closed systems to minimize further contamination of the environment. Usage of a number of persistent pesticides has been severely restricted. Despite these efforts to detect potential problem compounds and disallow their usage, failure sometimes results in tragic consequences. A new drug called thalidomide caused thousands of birth defects in Europe before it was realized that it was unsafe for use during certain periods of human pregnancy. The test system in use at that time was inadequate to detect this particular adverse reaction. Fortunately, these hazards which are missed by the test systems are rare. Safety evaluation toxicologists are constantly working to improve these test procedures to decrease even further the chances that potentially hazardous chemicals would be released for use by the general population and thus into the environment.

TYPES OF TOXICITY

Toxicity is the ability of a chemical molecule or compound to produce injury once it reaches a susceptible site in or on the body. Hazard is the probability that injury may be caused by the circumstances of the exposure.

One subdivision of toxicity may be made on the basis of duration of exposure.

Acute exposure. This term is used to mean "of short duration." As applied to materials which are inhaled or absorbed through the skin, it refers to a single exposure of a duration measured in seconds, minutes, or hours. As applied to materials which are ingested, it refers generally to a single quantity or dose.

Subacute exposure. This refers to exposures of intermediate duration, i.e., between acute and chronic. Generally speaking, subacute exposures include durations up to about 90 days.

Chronic exposure. This term will be used in contrast to "acute" and means "of long duration." As applied to materials which are inhaled or absorbed through the skin, it refers to prolonged or repeated exposures of a duration measured in days, months, or years. As applied to materials which are ingested, it refers to repeated doses over a period of days, months, or years. The term "chronic" will not refer to severity of symptoms but will carry the implication of exposures or doses which would be relatively harmless unless extended or repeated over long periods of time (days, months, or years).

It is important to differentiate between acute and chronic *exposure* and acute and chronic *effects.* Although the expression "chronic toxicity" is sometimes used to indicate the result of repeated exposure to a chemical or to ionizing radiation, it would be much clearer if "chronic toxicity" were equated with chronic illness resulting from these agents without any committment regarding the duration of exposure. The fact is that some compounds have a strong tendency to produce chronic illness even though the exposure may be acute (i.e., only a single dose). Such compounds include the heavy metals and most carcinogens. Of course their tendency to produce chronic sickness is accentuated if they are absorbed in repeated doses. At the opposite extreme are compounds such as CN^- with which it is virtually impossible to produce chronic illness—even though a single excessive dose may produce acute poisoning and rapid death. Most compounds lie somewhere between the two extremes. Ordinary alcoholic intoxication is acute, but years of excessive drinking and the accompanying malnutrition can produce chronic organic disease that remains even though no more alcohol is consumed.

The words acute and chronic applied to illness have nothing to do with severity but only with the duration and character of illness. The common cold, intoxication from social drinking, plague, and parathion poisoning are all acute illnesses. The first two are mild, the last two potentially fatal; all are brief with little tissue reaction. Pulmonary tuberculosis and Pb poisoning are almost always chronic diseases. They are characterized by a prolonged course and by pathological changes in tissue that reflect continuing injury and perhaps ineffectual repair.

Toxic effects may also be subdivided on the basis of site of action:

Local effect. This term means that the action takes place at the point or area of contact. The site may be skin, mucous membranes of the eyes, nose, mouth, throat, or anywhere along the respiratory or gastrointestinal system. Absorption does not necessarily occur.

Systemic effects. This term refers to a site of action other than the point of contact and presupposes that absorption has taken place. It is possible, however, for toxic agents to be absorbed through a channel (skin, lungs, or intestinal canal) and produce later manifestations on one of those channels which are not a result of the original direct contact. Thus it is possible for some agents to produce harmful effects on a single organ or tissue as a result of both "local" and "systemic" actions.

Dosage

The single most important factor in determining whether or not illness will occur as the result of exposure to a specific chemical compound is dosage. The dosage concept leads to the conclusion that no chemical compound is completely safe and that none is entirely harmful. The same idea was expressed by Paracelsus (1493-1541), who wrote "All things are poisons, for there is nothing without poisonous qualities. It is only the dose which makes a thing a poison."

Compounds vary tremendously in their toxicity. Usually harmless and even essential substances, such as water and salt, may cause illness or death if consumed in sufficient amount. Even compounds recognized as poisons may differ in toxicity by a factor of at least ten billion. The most toxic compound is botulinum toxin, which is more poisonous by several orders of magnitude than any other compound known. It is interesting to note that this is not a synthetic compound but is a material of biological origin.

In comparing the toxicity of different compounds, it is convenient to have a standardized notation for describing the toxic level. The most commonly used notation is the median lethal dose or LD_{50}. The LD_{50} is a statistical estimate of the dosage necessary to kill 50% of an infinite population of the test animals. The LD_{50} is usually expressed in terms of the weight of poison/unit of body weight, most often as mg of chemical/kg of animal (mg/kg). This permits a meaningful comparison of the susceptibility of animals of different species regardless of their size.

The LD_{50} is a special case of a more general measure of effect, the median effective dosage (ED_{50}). The ED_{50} is the dosage necessary to produce any specified effect in 50% of the test animals. The effect can be anything that can be observed. It may be a specified degree of inhibition of an enzyme. It may be the production of a tumor. These measures of effect (i.e., ED_{50} or LD_{50} for a particular compound have meaning only if experimental conditions are defined, including the species, age, and sex of experimental animal, the number of doses, and the route of administration.

Compounds may be classified into several levels of toxicity based on the dosage necessary to produce poisoning. Since the dosage to cause illness in man is seldom accurately known, this classification is usually based on a more easily obtainable measure of toxicity. The value which is generally used is the acute oral LD_{50} for the laboratory rat. This value is given for most of the compounds which are listed in Chapter 22 of this book. It is important to note here that the acute oral LD_{50} value measures only the acute systemic effect of a compound. Serious delayed effects, such as tumors, or local effects, such as those on the eye or mucous membranes, have to be expressed in other ways. As a guide to visualizing more clearly the meaning of these values, the following rule may be followed: The lower the LD_{50} value, the higher the toxicity.

1. Compounds which are essentially nontoxic (acute oral LD_{50} to the laboratory rat greater than 5000 mg/kg). These are materials which are unlikely to produce harm under any normal conditions of occupational use or exposure. Ingestions of quantities of the order of one pint or more would probably be required to produce significant illness in an adult.

2. Compounds of slight toxicity (LD_{50} between 1000 and 5000 mg/kg). These compounds would be expected to cause illness following ingestion or absorption of quantities of the order of an ounce to a pint.

3. Compounds of moderate toxicity (LD_{50} between 100 and 1000 mg/kg). These compounds would be expected to cause illness following ingestion or absorption of quantities of the order of a teaspoonful to an ounce.

4. Compounds of high toxicity (LD_{50} less than 100 mg/kg). These compounds would be expected to cause illness following ingestion or absorption of quantities of the order of a few drops or even a taste for the more highly toxic materials (i.e., very low LD_{50} values).

In addition to the identity of the compound involved and dosage, there are a number of less important factors which play a role in determining whether or not illness may result from any particular exposure episode. Some of these factors are discussed in some detail in Chapter 2 as they apply to pesticides. Among the other factors which should be considered are:

1. Route of exposure. It is important to learn whether the toxicant was ingested, inhaled, spilled on the skin, or, as most often happens, some combination of these occurred.
2. Type of formulation or state of dispersion of the toxicant.
3. Temperature.
4. Humidity.
5. Physiologic condition of the subject.
6. Interaction of the toxicant with other chemicals and drugs. Interaction of chemicals may occur either in the external environment (such as when exposure to a mixture of two industrial chemicals occurs) or inside the patient (such as when previous dosage of a therapeutic drug may alter response to another foreign chemical). It is now recognized that the latter type of reaction occurs with some frequency as a result of stimulation of the drug-metabolizing enzyme system of the liver (microsomal enzymes) by various chemicals and drugs. This type of reaction is discussed in some detail in Chapter 2.

Threshold Limit Values. Another procedure for expressing toxic levels for different compounds is the use of Threshold Limit Values (TLV), formerly known as Maximum Allowable Concentrations (MAC).

It should be noted that the LD_{50} represents an experimentally derived value while the TLV is arbitrarily set on the basis of experimental and other available data. The acute oral LD_{50} value is most useful if one is dealing with an ingestion case while the TLV is more pertinent for industrial and occupational exposure restrictions.

In the United States, TLV's set by the American Conference of Governmental Industrial Hygienists (ACGIH) have received wide acceptance. The ACGIH has now set TLV's for about 500 chemical compounds. These values refer to airborne concentrations and represent conditions under which it is believed that nearly all workers may be repeatedly exposed for an 8-hour day, 5 days a week. Since there are wide variations in individual susceptibility, a small percentage of workers may experience some discomfort and a smaller fraction may be affected more seriously by substances at concentrations at or near the TLV. Sensitivity testing should be carried out on new industrial workers being placed in jobs involving significant exposure to potentially toxic chemicals so that hypersusceptible persons may be screened out.

With some few exceptions, the TLV's are time-weighted average concentrations. Thus, temporary overexposures may be permitted provided that they are compensated for by equivalent underexposures during the work day.

In spite of the fact that no serious injury is expected to occur as a result of exposure to TLV concentrations, the best industrial hygiene practice is to maintain concentrations of all atmospheric contaminants in workroom air at levels as low as practical.

The TLV's as set by the ACGIH are listed in Chapter 22 for those compounds for which values have been assigned.

Closely related to TLV's are the so-called acceptable concentration standards promulgated by the American Standards Association (ASA). According to the ASA, these standards are designed to prevent "(1) undesirable changes in body structure or biochemistry; (2) undesirable functional reactions that may have no discernible effects on health; (3) irritation or other adverse sensory effects."

For gases and vapors the TLV is usually expressed in parts per million (ppm), that is, parts of the gas or vapor per million parts of air.

For fumes and mists, and for some dusts, the TLV is usually given as milligrams per cubic meter (mg/m^3) or per 10 m^3 of air.

For some dusts, particularly those containing SiO_2, the TLV is usually expressed as millions of particles per cubic foot of air (mppcf).

Classes of Toxic Substances

Toxic or harmful substances encountered in industry or, in some instances, released into the environment (such as pesticides) may be classified in various ways. A simple and useful classification is given below, together with definitions adopted by the ASA.

Dusts. Solid particles generated by handling, crushing, grinding, rapid impact, detonation and decrepitation of organic or inorganic materials such as rocks, ore, metal, coal, wood, grain, etc. Dusts do not tend to flocculate except under electrostatic forces; they do not diffuse in air, but settle under the influence of gravity.

Fumes. Solid particles generated by condensation from the gaseous state, generally after volatilization from molten metals, etc., and often accompanied by a chemical reaction such as oxidation. Fumes flocculate and sometimes coalesce.

Mists. Suspended liquid droplets generated by condensation from the gaseous to the liquid state or by breaking up a liquid into a dispersed state, such as by splashing, foaming and atomizing.

Vapors. The gaseous form of substances which are normally in the solid or liquid state and which can be changed to these states either by increasing the pressure or by decreasing the temperature alone. Vapors diffuse.

Gases. Normally formless fluids which occupy the space of enclosure and which can be changed to the liquid or solid state only by the combined effect of increased pressure and decreased temperature. Gases diffuse.

This classification does not include the obvious categories of solids and liquids which may be harmful, nor does it encompass physical agents. The latter, strictly speaking, cannot be considered "substances." Living agents, such as bacteria, molds and other parasites comprise another group of "substances" that would appear in a comprehensive classification of industrial health hazards.

Routes of Absorption

In the physiologic sense, a material is said to have been absorbed only when it has gained entry into the blood stream and consequently may be carried to all parts of the body. Something which is swallowed and which is later excreted more or less unchanged in the feces has not necessarily been absorbed, even though it may have remained within the gastrointestinal tract for hours or even days.

Although there are a number of ways by which an individual may be exposed to a poisonous chemical, the three most important and usual encounter routes are: oral, dermal, and respiratory. In accidental poisoning, as is usually the case with children, ingestion or oral exposure is most common. In industrial situations, exposure may be either respiratory or dermal or a combination.

Absorption Through the Skin. In general, chemicals are absorbed more slowly and less completely through the skin than from the gastrointestinal tract or the lungs and thus toxic effects are less likely to occur when a toxicant is spilled on the skin than when it is ingested or inhaled. Fortunately, many compounds are just not absorbed to a significant degree by the skin; for example, botulinum toxin, the substance which produces botulism, is extremely toxic to man when taken orally, but is relatively harmless when applied to the skin. The principal reason for this difference is that the botulinus toxin molecule is very large in relation to most chemicals, and it is not readily absorbed by the skin. On the other hand, when it enters the digestive tract, the toxin is immediately absorbed and transported to susceptible sites of action. Thus, the chemical and physical properties of a toxicant determine which routes of exposure will produce toxic effects. There is a greater range of toxic effects between compounds with regard to skin absorption than for the other common exposure routes.

There are some few compounds which are more toxic when spilled on the skin than when swallowed. Usually these are compounds which are rapidly detoxified by the liver. The detoxication site is important since materials absorbed by the gastrointestinal tract are carried directly to the liver and only subsequently are distributed to the rest of the body. Materials absorbed from the skin or the lungs are distributed by the blood to the rest of the body at the same instant that a portion passes to the liver.

One of the problems with compounds which present a skin absorption hazard is that it is frequently difficult to convince a layman, such as a farmer, that a chemical can cause poisoning merely by spilling it on his skin.

It is recognized that skin absorption may be a significant factor in occupational Hg poisoning as well as in a number of other industrial diseases. In the case of metals other than Hg, however, entry through the skin is relatively unimportant except for some organometallic compounds such as Pb tetraethyl.

Skin absorption attains its greatest importance in connection with the organic solvents. It is generally recognized that significant quantities of these compounds may enter the body through the skin either as a result of direct accidental contamination or indirectly when the material has been spilled on the clothing. An additional source of exposure is found in the fairly common practice of using industrial solvents for removing grease and dirt from the hands and arms, in other words, for washing purposes. This procedure, incidentally, is a fruitful source of dermatitis.

There are a number of other important environmental and industrial chemicals which are also absorbed to a significant degree through the skin. Some of the organic P pesticides, including parathion, are notable in this regard.

Gastrointestinal Absorption. In accidental poisoning of children, oral ingestion is the most common route of exposure. In the past it has been common practice to attribute certain cases of occupational poisoning to uncleanly habits on the part of the victim, particularly failure to wash the hands before eating. There is not doubt that some toxic materials used industrially can be absorbed through the intestinal tract, but it is now generally believed that with certain notable exceptions this portal of entry is of minor importance. One outstanding exception is the case of the Ra dial painters who followed the practice of "pointing" their brushes between their lips, thus ingesting lethal quantities of radioactive material. Accidental swallowing of harmful amounts of poisonous compounds in single large doses has also been known to occur. In general it can be said that intestinal abosrption of industrial poisons is of minor importance and that the "dirty hands" theory of poisoning has been pretty well discredited.

Absorption Through the Lungs. The inhalation of contaminated air is by far the most important means by which occupational poisons gain entry into the body. It seems safe to estimate that at least 90% of all industrial poisoning (exclusive of dermatitis) can be attributed to absorption through the lungs. Harmful substances may be suspended in the air in the form of dust, fume, mist, or vapor, and may be mixed with the respired air in the case of true gases. Since an individual under conditions of moderate exertion will breathe about 10 m^3 of air in the course of an ordinary 8-hour working day it is readily understood that any poisonous material present in the respired air offers a serious threat to health.

Fortunately, all foreign matter which is inhaled is not necessarily absorbed into the blood. A certain amount, particularly that which is in a very finely divided state, will be immediately exhaled. Another portion of respired particulate matter is trapped by the mucus which lines the air passages and is subsequently brought up in the sputum. (In this connection it might be mentioned that some of the sputum may be consciously or unconsciously swallowed, thus affording an opportunity for intestinal absorption.) Other particles are taken up by "scavenger cells," following which they may enter the blood stream or be deposited in various tissues or organs. True gases will pass directly from the lungs into the blood in the same manner as the O_2 in inspired air. Because of the fact that a great majority of the known industrial poisons may at some time be present as atmospheric contaminants and thus constitute a potential threat to health, programs directed toward the prevention of occupational poisoning generally place major emphasis on ventilation to reduce the hazard.

Storage and Excretion

Some toxic substances can be retained or stored in the body for indefinite periods of time, being excreted slowly over periods of months or years. Lead, for example, is stored primarily in the bones and Hg principally in the kidneys. Smaller amounts may be stored in other organs or tissues. Particulate matter when inhaled can be phagocytosed and remain in regional lymph nodes where it may have little effect as in the case of coal dust, or may produce pathological changes as in the case of SiO_2 and Be.

The excretion of toxic agents takes place through the same channels as does absorption, namely lungs, intestines, and skin, but the kidneys (urine) are the main excretory organs for many substances. Sweat, saliva, and other body fluids may participate to a small extent in the excretory process. Gases and volatile vapors are commonly excreted in the lungs and breath. This can sometimes be used as a measure of earlier absorption.

Many organic compounds are not excreted unchanged, but pass through what is known as biotransformation. The processes by which this occurs are also "detoxication mechanisms." The resulting new compounds, or metabolites, can be found in the urine and are used as evidence of absorption of the parent substance.

Individual Susceptibility

The term "individual susceptibility" has long been used to express the well-known fact that under conditions of like exposure to potentially harmful substances there is usually a marked variability in the manner in which individuals will respond. Some may show no evidence of intoxication whatsoever; others may show signs of mild poisoning, while still others may become severely or even fatally poisoned. Comparatively little is known about the factors which are responsible for this variability. It is believed that differences in the anatomical structure of the nose may be concerned with different degrees of efficiency in filtering out harmful dusts in the inspired air. Previous infections of the lungs, particularly tuberculosis, are known to enhance susceptibility to silicosis. Most industrial toxicologists believe that obesity is an important predisposing factor among persons who are subject to occupational exposure to organic solvents and related compounds. Age and sex are also believed to play a part and previous illnesses may be significant.

Other possible factors relating to individual susceptibility are even less understood than those just mentioned. It has been suggested that different rates of working speed, resulting in variations in respiratory rate, in depth of respiration, and in pulse-rate may play a part. The action of the cilia, those tiny hairs present in the cells which line the air passages, may have some importance. The permeability of the lungs may influence absorption and the efficiency of of the kidneys may govern the rate at which toxic materials are excreted, but the underlying nature of these possible variations is not known. Since the liver plays a major role in the detoxication and excretion of harmful substances, subnormal functioning of that organ may lead to increased susceptibility.

There is considerable literature purporting to show that nutritional factors may have something to do with susceptibility to occupational poisoning. Most of the published material is rather unscientific and unconvincing, but a few reports strongly suggest that there actually exists a relationship between the nature of the diet and susceptibility to poisoning. There is as yet no substantial evidence that the addition of vitamin concentrates, milk or special foods have any protective value, but when diets are deficient in some of the essential nutritional elements it appears that poisoning is more likely to occur. There is considerable evidence that indulgence in ethyl alcohol will significantly increase the possibility of occupational poisoning occurring, particularly from organic solvents.

Acute and Chronic Effects

Industrial toxicology is generally concerned with the effects of low-grade sublethal exposures which are continued over a period of months or years. It is, of course, true that toxicological problems are not infrequently presented as a result of accidents which create sudden massive exposures to overwhelming concentrations of toxic compounds. The acute poisoning which results may cause unconsciousness, shock or collapse, severe inflammation of the lungs, or even sudden death. An understanding of the nature of the action of the offending agent may be of great value in the treatment of acute poisoning, but in some instances the only application of toxicological knowledge will be in establishing the cause of death.

The detection of minute amounts of toxic agents in the atmosphere and in body fluids (blood and urine) and the recognition of the effects of exposure to small quantities of poisons are among the principal jobs of the industrial toxicologist. The manifestations of chronic poisoning are often so subtle that the keenest judgment is required in order to detect and interpret them. The most refined techniques of analytical chemistry and of clinical pathology are called into play, involving studies of the working environment and of exposed individuals.

In order to demonstrate that chronic industrial poisoning has taken place or is a possibility it must be shown that an offending agent is present in significant concentrations, that it has been absorbed, and that it has produced in the exposed subject distrubances compatible with poisoning by the suspected substance. Significant concentrations are ordinarily expressed in terms of threshold limits (TL). Absorption of a substance may be proved by demonstrating its presence in the blood or urine in concentrations above those found in nonexposed persons, or by finding certain metabolic products in the excreta. To prove that disturbances have occurred in an exposed subject may require the application of all the diagnostic procedures used in medicine, including a medical history, physical examination, blood counts, urinalysis, x-ray studies, and other measures.

A few of the more widely used industrial chemicals, notably Pb and benzene, will produce changes in the blood in the very early stages of poisoning. Other chemicals, particularly chlorinated HC, give no such early evidence of their action. Heavy metals such as Hg and Pb produce their chronic harmful effects through what is known as "cumulative action." This means that over a period of time the material which is absorbed is only partially excreted and that increasing amounts accumulate in the body. Eventually the quantity becomes great enough to cause physiologic disturbances. Volatile compounds do not accumulate in the body but probably produce their chronic toxic effects by causing a series of small insults to one or more of the vital organs.

Site of Action of Poisons

Brief mention has already been made of the fact that different poisons act on different parts of the body. Many substances can produce a local or direct action upon the skin. The fumes and mists arising from strong acids, some of the war gases, and many other chemicals have a direct irritating effect on the eyes, nose, throat, and lower air passages. If they reach the lungs they may set up a severe inflammatory reaction called chemical pneumonitis. These local effects are of greatest importance in connection with acute poisoning. More important to the industrial toxicologist are the so-called systemic effects.

Systemic or indirect effects occur when a toxic substance has been absorbed into the blood stream and distributed throughout the body. Some materials such as As, when absorbed in toxic amounts, may cause disturbances in several parts of the body: blood, nervous system, liver, kidneys, and skin. Benzene, on the other hand, appears to affect only one organ, namely, the blood-forming bone marrow. CO causes asphyxia by preventing the hemoglobin of the blood from carrying out its normal function of transporting O_2 from the lungs to the tissues of the body. Although O_2 starvation occurs equally in all parts of the body, brain tissue is most sensitive; consequently the earliest manifestations are those due to damage to the brain. An understanding of what organ or organs can be damaged, and the nature and manifestations of the damage caused by various compounds, is among the more important functions of the industrial toxicologist.

At the cellular level, toxic agents may act on the cell surface or within the cell, depending on "receptors" or binding sites. A familiar example is the affinity of As and Hg for sulfhydryl (S-H) groups in biological material.

Absorption and Poisoning

As mentioned above, with the exception of external irritants, toxic substances generally must be absorbed into the body and distributed through the body by means of the blood stream in order for poisoning to occur. In other words, poisoning ordinarily does not occur without absorption. On the other hand, absorption does not necessarily or always result in poisoning. The human body is provided with an elaborate system of protective mechanisms and is able to tolerate to an amazing degree the presence of many toxic materials. Some foreign materials are excreted unchanged through the urine and feces. Toxic gases, following absorption, may be given off through the lungs. Some chemical compounds go through processes of metabolism and are excreted in an altered form. Some of these processes are known as detoxication (or detoxification) mechanisms. In some instances the biotransformation products in a detoxication process may be more toxic than the original substance; this is true, for example, for the conversion of parathion to paraoxon.

PREVENTION: FIRST AID

Emergency Treatment of Acute Poisoning

Acute poisoning may be the result of entry into the body of large or concentrated doses of a poison through:

(a) breathing (inhalation)
(b) swallowing (ingestion)
(c) skin absorption
(d) injection (hypodermic or intravenous entry).

It is obvious that the route of entry will influence the type of emergency treatment.

In every case of acute poisoning, summon medical assistance immediately. The names and telephone numbers of one or more on-call physicians and the nearest hospital and ambulance service should be posted near appropriate telephones. If the police department, fire department, or utility company maintains an emergency service, its telephone numbers should also be posted.

Every industrial establishment, no matter how small, should have at least one person on duty at all times who is trained and designated to take charge in the event of an emergency due to poisoning. This individual should be conversant with the emergency handling of the particular situations that may arise.

Improper first aid may be more harmful than none at all. Although prompt action is always important, there are relatively few situations in which a delay of seconds or minutes will have a significant bearing on the outcome.

When possible, a sample of the suspected poison, or the container from which it came, should be preserved for the guidance of the treating physician, the police, or the medical examiner (coroner).

General Procedures

Inhalation

(1) Remove victim from contamined area. Rescuers should be properly protected or provided with life lines.

(2) Keep victim warm (not hot) and quiet. Lying flat is usually the best position.

(3) If breathing has stopped, give artificial respiration.

(4) Administer oxygen, if it is available.

(5) Keep breathing passages open. Examine mouth for false teeth and chewing gum and remove them if present.

Ingestion

(1) Attempt to empty the stomach by causing victim to vomit. This should be done even if a period of several hours has passed since the poison was swallowed. Exceptions: Corrosive chemicals such as strong acids or caustic alkalies; victim having convulsions; victim unconscious.

(2) Dilute the poison by administering fluids in any of the following forms:

(a) Plain tap water: 3–4 glasses.
(b) Soapy water: 2–3 glasses.
(c) Table salt in warm water: one tablespoon to an ordinary 8-ounce tumbler.
(d) Milk: 3–4 glasses.

If these fluids are vomited, which is desirable, the doses may be repeated several times.

Table 1.1 Some Poisons for Which Specific Antidotes are Available

Poison	Antidote
Arsenic	BAL
Mercury	BAL
Lead	EDTA and BAL
Warfarin and other anticoagulants	Vitamin K
Cyanide	Thiosulfate
Organic phosphorus Compounds (Pesticides and war gases)	Atropine and 2-PAM (Pralidoxime)

(3) Give the victim a "universal antidote." A mixture of powdered burnt toast (charcoal), strong tea, and milk of magnesia will absorb and neutralize many poisons. (One piece of toast and 4 tablespoons of milk of magnesia in a cup of strong tea.)

Skin contact

(1) Dilute the contaminating substance with large amounts of water. This is best done in a shower, but may also be done with a hose, buckets, or other means. The water should be lukewarm if possible.

(2) Remove contaminated clothing. Those assisting the victim should protect their own skin with gloves, if available.

(3) Chemical burns of the eye should be treated with large amounts of water or with a weak solution of bicarbonate of soda (a level teaspoonful of bicarbonate to 1 quart of warm, clean water).

Injected poisons

(1) Absorption may be delayed by the application of a tourniquet about the point of injection if this is in the arm or leg. The tourniquet should not be so tight that it impairs the flow of arterial blood.

(2) Excretion can be hastened by administering large doses of water or other fluid.

(3) Attempt to determine the nature of the poison so that the proper antidote can be given.