3 Basic Toxicology

Exposure to hazardous chemicals is one of the dangers of processing clandestine lab scenes. As described in the last chapter, the hazardous effects among chemicals vary widely. The short-term effects of a chemical exposure can differ from the long-term effects. In some instances, a single exposure can be lethal. In other situations, the effects are seen in the exposed person's offspring. That is why chemical exposure is the "silent" hazard.

Toxicology is the study of the adverse health effects of exposure to a chemical substance. As in many situations, knowledge is power. To have the power to protect oneself from the effects of chemical exposure, a person needs to know where the exposures can occur, how toxins enter the body, and how the various chemical classes will affect the body physiologically. Knowing how a chemical affects the body provides the knowledge required to protect against its toxic effects.

The goal in this chapter is to provide basic knowledge concerning toxic effects of hazardous chemicals encountered at clandestine lab scenes. Addressed in this chapter will be the entry routes by which chemicals enter the body, conditions that affect the absorption of chemicals, chemical toxicity ratings, types of toxins, and their systemic effects. This chapter is not a scientific treatise concerning the toxicology of hazardous material. It presents basic explanations of how toxic materials can enter the body and what happens when they do.

3.1 Entry Routes

Hazardous chemicals must have contact with the body to have a toxic effect. The point of contact determines the entry route and can affect the body's response to a particular toxin. For example, the body's response to a dermal exposure to sodium cyanide differs from ingestion of the same compound.

Cyanide is a chemical asphyxiant that inhibits the blood's ability to carry oxygen. If the cyanide does not enter the circulatory system, i.e., through skin contact (dermal exposure), it cannot affect the blood's oxygen-carrying ability. However, if the sodium cyanide is ingested or inhaled, it can be adsorbed into the circulatory system, resulting in its toxic effects.

The three entry routes by which toxic materials enter the body are through inhalation, dermal adsorption, oral ingestion, and direct contact. As chemicals can have multiple hazardous effects (i.e., nitric acid is a corrosive, oxidizer, and poison), they can also have multiple toxic effects. The entry route of a toxin plays a role in what toxic effect the substance has on the body.

3.1.1 Inhalation

Inhalation is the most common and efficient entry route by which toxins enter the body. It is the most common entry route, because people have to constantly breathe to survive. (People can survive for extended periods without eating or touching things.) Thus, the respiratory system (Figure 3.1) is constantly exposed to the outside environment, which may contain toxic substances. It is the most efficient entry route, because the respiratory system provides a direct conduit from the environment to the body's circulatory system. Once the toxin is in the circulatory system, it is a simple ride on the blood express to the toxin's target organ of choice.

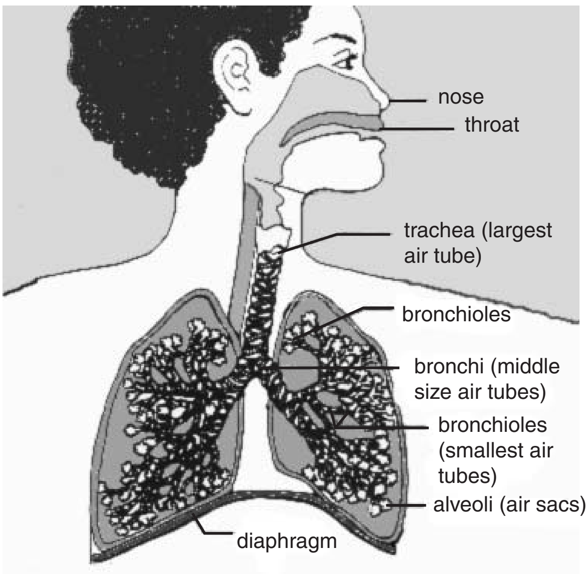

Figure 3.1 Respiratory system.

The respiratory tract is comprised of the upper airway, the lower airway, and the alveoli. Each portion has a specific function. Portions filter out toxic material that would inhibit the oxygen–carbon dioxide exchange in other portions. Other portions exchange toxic materials between the blood and the air that is breathed.

The upper airway is comprised of the nose and larynx. Its purpose is to increase the relative humidity of the incoming air. It is lined with hairs called ciliated epithelia that keep large particles from the incoming air from getting into the lower airway and alveoli. The upper airway's moist environment provides an atmosphere in which water-soluble materials can dissolve and potentially enter the circulatory system.

The lower airway is comprised of the trachea, bronchi, and bronchioles. They are lined with mucus-coated ciliated epithelia. The purpose of the lower airway is to prevent particles that passed through the upper airway from getting into the alveoli. The ciliated epithelia move the trapped particle up the lower airway to the oral cavity for elimination. Smoking and the use of cough suppressants can, in effect, paralyze the ciliated epithelia, affecting their ability to filter and remove particles from the incoming air. Water-soluble toxins can be adsorbed in the mucus, also affecting the function of the ciliated epithelia.

The alveoli are the tiny sacks attached to the bronchioles. They contain the blood vessels that exchange oxygen and carbon dioxide. Another function of the alveoli is to exchange volatile toxins with the incoming air and eliminate them in the expired air.

The alveoli provide the largest surface area of the body that is constantly exposed to the environment. They provide a direct connection between the environment and the body's circulatory system. Toxins can enter the circulatory system directly at this point. The act of breathing constantly refreshes the supply of toxic substances that can be introduced to the circulatory system for distribution throughout the body.

Chemicals do not absorb into the body at the same rate. A person's physiology and the chemical properties of the toxin work in tandem to affect how readily the toxins are absorbed through the respiratory system. Respiratory rate, particle size, and chemical solubility are the principle issues that affect how readily a toxin is absorbed by the body.

The exposure rate to a toxin is directly proportional to the amount of air breathed. The faster the breathing rate is, the greater the amount of air that enters the lungs. This leads to an increase in the amount of toxic exposure. The slower the breathing rate is, the lower the amount of air that enters the lungs. This leads to a decrease in the amount of toxins that can enter the respiratory system for absorption.

To limit toxic inhalation exposure, it is recommended that the respiratory rate be kept to a minimum by being in good physical condition and maintaining composure during processing activities. Being in good physical shape influences the efficiency of the lungs' oxygen exchange ability, which assists in reducing the respiratory rate. Being in an excited state increases the respiratory rate. Maintaining composure keeps the respiratory rate low, minimizing the exposure.

The substance's particle size affects if or where the toxic effect will result. Solid particles ranging in size from 5 to 30 μm are filtered out in the upper airway. Particles in the 1 to 5 μm range are filtered out in the lower airway. They collect on the mucus-covered epithelium and are transported to the oral cavity for elimination. These particles can also embed themselves into a portion of the respiratory system, causing infection or disease. Asbestos is an example of an insoluble particle that embeds itself into the respiratory system, producing adverse effects.

When working in toxic environments, it is imperative that responders do nothing to affect the ciliated epithelia's ability to remove particles from the incoming air. Smoking and the use of cough suppressants could inhibit the cleansing movement of the cilia, allowing particles to embed themselves into some portion of the respiratory system or to be introduced into the circulatory system.

A substance's water solubility will determine its toxic effects through inhalation. Water-soluble substances will dissolve in the mucus of the upper and lower airways. This may produce a localized toxic effect or allow the compound to be absorbed in the circulatory system. Water-insoluble substances can travel past the upper and lower airways into the alveoli, where they can enter the circulatory system.

3.1.2 Dermal Absorption

Dermal absorption is the second route of entry by which toxins enter the body. Many people have the misconception that the skin is impervious to everything. If contact with the substance does not produce some sensation of pain or discomfort, there must be no toxic or hazardous effect. This is not the case when considering the skin as an entry route for toxic materials.

The skin is comprised of the dermis and epidermis (Figure 3.2). By weight, it is the largest organ of the body. The skin has two main functions. First, it protects the internal organs of the body from adverse environmental conditions. Second, it regulates the body's temperature. Both of these functions affect how toxic substances are absorbed into the body.

The epidermis is the top layer of skin cells that provides the first line of defense from environmental toxins. It can intrinsically repel the toxic effects

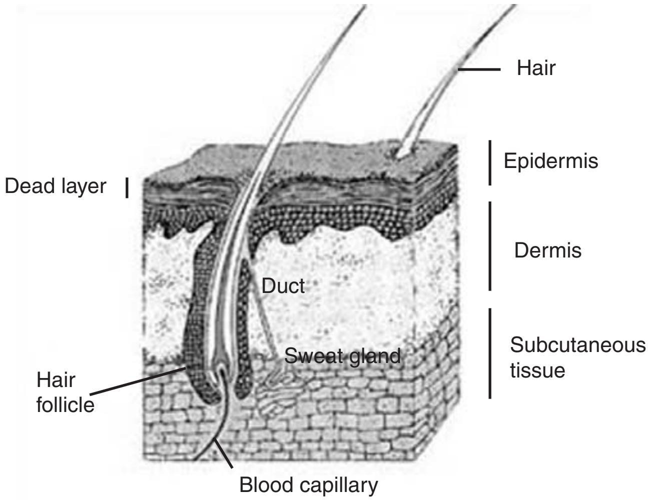

Figure 3.2 Skin cross-section.

of a number of substances. The condition of the epidermis plays a critical role in its ability to repel toxins. Dry skin or skin damage as a result of cuts or abrasions can result in toxins bypassing the protective traits of the epidermis. Corrosives can damage the skin and provide an opening for other toxins to enter.

The dermis comprises the lower layers of the skin. It contains the sweat glands and ducts, oil glands, fatty cells, connective tissues, and blood vessels. It provides a nonselective diffusive environment by which toxins travel into the circulatory system.

The rate toxins are absorbed through the skin is affected by a number of factors. The relative effect of one may affect the relative effect of one or more of the others when combined. The factors that affect the rate of dermal absorption include skin damage, hydration state, temperature, concentration, and carriers. Each factor affects whether a substance is repelled or absorbed by the skin.

Skin damage is the simplest to understand. The skin can be equated to the plastic coating that protects a package's contents from water damage. A cut or an abrasion in the skin can be equated to a break in the package's plastic coating. Breaking the plastic coating provides an entrance for water to enter the package. Breaking the protective coating provided by the epidermis provides toxins a direct route into the circulatory system.

The hydration state of the epidermis can affect its ability to absorb or repel toxic substances. The epidermis has an optimum hydration state. If it is too dry, it may more readily adsorb liquid toxins or let them pass through to the dermis. If the epidermis is overhydrated, it may provide an environment that will allow the toxins to diffuse through it into the blood vessels in the dermis.

The ambient temperature affects dermal defenses in a couple of ways. It can affect the hydration state of the skin. Skin perspires in elevated temperatures. Perspiration increases the hydration state of the epidermis, leading to the effects described above. The sweat ducts also provide a conduit for toxins to travel past the epidermis into the dermis and potentially into the circulatory system.

A second effect concerns the blood vessels in the dermis. In hot environments, the blood vessels expand to increase the blood flow in the dermis in an effort to reduce the body's internal temperature. In cold environments, the blood vessels in the dermis contract to restrict the blood flow in the dermis in an effort to keep the body warm. In elevated temperatures, the surface area of the blood vessels increases, increasing the ability for a diffusion transfer through the dermis into the circulatory system.

The concentration of a substance plays a role in how it affects the skin. The epidermis is resilient. It can compensate for the toxic effects of low concentrations of a given substance. Exposures to these low concentrations produce little or no toxic effect. However, higher concentrations of the same substance can produce devastating effects.

Chemical carriers can provide a ride for a toxin through the skin's natural defenses. A solid toxin that the epidermis would normally repel may pass through it, if it is dissolved into a solvent carrier that permeates the epidermis. The solvent shuttles the dissolved toxic substance past the epidermis into the dermis and then into the circulatory system.

3.1.3 Ingestion

Ingestion is the final mode by which toxins enter the body. This is the least effective way for toxins to enter the system. The physical state of the substances introduced through this mode, and the nature of the digestive tract, keep the amount of toxin and toxic effects to a minimum (Figure 3.3).

Solids and liquid substances enter the body through this mode, which makes intentional ingestions difficult. The mouth is a relatively guarded entry point. People have the common sense to not intentionally eat or drink something that has hazardous potential, as opposed to dermal contact, with which unintentional direct contact with the substance is common.

Inadvertent ingestions of toxic substances can happen. People in toxic environments inadvertently handle items that are placed in the mouth. Smoking and eating in an area where toxic substances are present affords the opportunity for toxins to be placed in the mouth if a contaminated hand handles the cigarette or food. For example, people taking notes at a clandes-

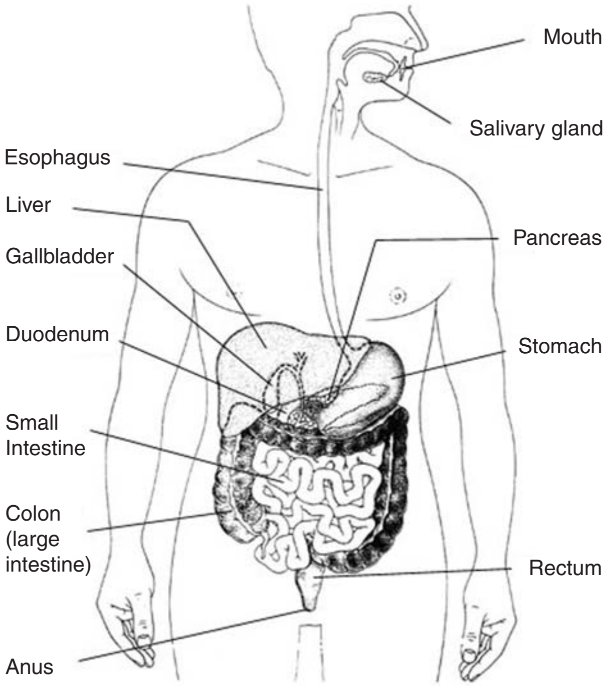

Figure 3.3 Gastrointestinal tract.

tine lab scene will place the pen with which they have been writing in their mouths. Just before, they handled toxic chemicals that have now been ingested into the gastrointestinal tract. The only saving grace in this incident is that the concentration of the substance may be low enough that it will not produce a toxic effect.

A third consideration is the environment within the digestive system. The highly acidic and alkaline environments in the various portions of the gastrointestinal tract have a tendency to neutralize the toxic effects of many substances before they can be introduced into the bloodstream. Even if a toxin is introduced, interaction with the digestive juices may alter the toxic properties of the substance before it has a chance to enter the circulatory system.

3.2 Modes of Action

Every substance has a different effect on the body. The mode of action refers to the physiological system, which is affected by the exposure. The three general modes of action consist of the physical, chemical, and enzymatic.

The physical mode of action refers to how the substance interacts with all tissues of the body. The substance's hazardous characteristics can be used to characterize its physical mode of action. For example, a substance with corrosive properties will produce the same effect, no matter the tissue with which it comes into contact, i.e., corrosive substances are nonselective in the type of tissue with which it reacts.

The chemical mode of action refers to how a substance interacts with specific tissues of the body. It can be characterized by generic toxic properties of the substance. For example, chemical asphyxiants interfere with the blood's ability to carry oxygen. The reactions are tissue specific and deal with the chemistry between the substance and tissue involved.

The enzymatic mode is also referred to as the physiological mode. It refers to how the substance interacts with specific enzymes in the body. The substance can enhance or inhibit the processes of the enzyme it affects.

3.3 Influences on Toxicity

A number of variables will affect the body's response to a given toxin. The length and the degree of exposure play a determining role. The chemical's physical properties, its concentration, and the duration of exposure have their own influences on the body's reaction. Even environmental factors, such as the temperature, play a role in how a substance will react with the body. The variables that affect the toxicity of a substance are the length of the exposure, the degree of exposure, toxicity factors of the substance, factors concerning the exposure, environmental factors, and factors concerning the person exposed.

3.3.1 Length of Exposure

As discussed in Chapter 2, the length of exposure to a hazardous substance will determine the effects the substance has on the system. Also, the short-term effects differ from the long-term effects.

Exposures to toxic hazards have acute and chronic effects. Acute effects are experienced with exposure to hazards of high concentrations of short duration. The effects are felt immediately. The exposed will recover if the exposure does not exceed the lethal limits. Chronic effects are generally experienced with exposure to hazards of low concentrations over a long period of time. The effects are cumulative, creating a toxic effect. These effects are usually different than the acute effects of the same hazard.

The duration of an exposure may be too short to produce an acute effect. The body may have enough natural defenses to ward off any adverse effects. However, because of the depletion of these natural defenses, subsequent short-term exposures may have a compounded acute effect if the body has not had an opportunity to regenerate its defense mechanisms.

In some instances, the body stores the substance in the fat cells, liver, or other target organ. The concentration increases until it reaches a toxic level. Numerous insignificant short-term exposures may not produce any acute effects. However, the cumulative effect may produce a chronic toxic effect.

3.3.2 Degree of Exposure

The degree of exposure differs from the length of exposure. Exposure length is strictly a measure of the time a person is exposed to the substance. The degree of exposure relates to the substance's chemical properties, the concentration, and the specific duration of the exposure. These properties are interrelated and affect how the substance will react with the body. Degree and length of exposure are interrelated in that by changing one of the properties of the degree of exposure, the length of time required to produce a toxic effect will be altered. The group of exposure properties interacts in different ways. The effect produced results from the relationships between the different factors surrounding the exposure. The factors concerning the compound, the circumstances surrounding the exposure, the exposed person, and the environment of the exposure will combine and establish the total hazardous potential of the exposure.

3.3.2.1 Compound Factors

The substance has properties that establish its inherent toxicity. Its chemical properties, concentration, duration of the exposure, and interaction with other chemicals will interact in different ways to produce different effects. The ratio of these is different in each exposure. Thus, the effects of the same substance will vary depending on this ratio.

Each chemical has an inherent set of physical and chemical properties. Some have a hazardous potential. Some physical properties prevent the substance from interacting with the body. For example, under normal circumstances, solids and liquids cannot be inhaled. However, change the solid into an airborne dust or a liquid into an aerosol, and these physical states can be inhaled.

The substance's chemical properties will determine what effects it will have on the body when an exposure occurs. For example, under normal circumstances and without outside influences, a corrosive chemical will not burn or explode. However, contact with an incompatible property may create an explosive situation.

The concentration of the substance during the exposure will affect the body's response. The body has the ability to compensate for exposure to low concentrations of a wide variety of chemicals. Its internal defenses can neutralize or compensate for the toxic effects of a given substance. However, high concentrations of the same substance during the same exposure time may overload the body's ability to defend or compensate for the toxic effects.

The duration of the exposure will affect how the body reacts. The effects of instantaneous contacts differ from those of prolonged contacts. Instantaneous contacts may not allow enough time for the substance to interact with the body, or the body may have sufficient defenses to compensate for that exposure duration.

A dramatic example of this is exposure to liquid nitrogen. Liquid nitrogen has a boiling point of –196°C (–321°F). The human body can tolerate a direct instantaneous exposure to liquid nitrogen. Beyond that, the temperature of the liquid nitrogen overcomes the body's ability to compensate, and severe damage results.

Interaction with other substances can potentially affect the substance's toxicity. Contact with other chemicals may alter the substance's physical state, which may affect the entry routes available to the substance. For example, the reaction between cyanide salts and acids converts cyanide salt from a solid (with low inhalation potential) to hydrogen cyanide gas (with high inhalation potential). Dissolving a substance into a liquid may alter its ability to be adsorbed through the skin.

3.3.2.2 Exposure Factors

The circumstances surrounding the exposure will affect hazard potential. The entry route and the duration and number of exposures will determine what the body will experience. The combination and ratio of these factors will affect the body's toxic response.

The entry route is the primary factor in the exposure scenario. If the substance can neither get into nor have contact with the body, it cannot produce a toxic effect. As discussed earlier, different entry routes provide access to different physiological systems. A toxin's effect may differ depending on the entry route. For example, under normal conditions, cyanide salts have a negligible potential for dermal absorption. However, they are readily adsorbed through ingestion. A person can handle these highly poisonous substances with minimal effects from dermal absorption. However, when the person's contaminated hands come into contact with food that is then ingested, that insignificant exposure just became lethal.

The number of exposures influences the toxic effects of a substance. Certain substances are known as sensitizing agents. An initial encounter with the substance may not produce an effect. However, all subsequent exposures produce a toxic reaction. Other substances can have a cumulative effect. The body may store a substance until the concentration builds to the point where it reaches a toxic level.

3.3.2.3 *Personal Factors*

Personal factors can be directly attributed to the exposed individual. The exposed person's age, sex, health, and genetics are directly related to how the person's body will react to an exposure to certain toxic substances.

A person's metabolism changes over time. The metabolism of an infant is different than that of a teenager entering puberty. A young adult's body's ability to bounce back from injury and disease is greater than that of someone who reached retirement age. This difference in metabolism between the ages dramatically affects the body's ability to fight the effects of toxic substances.

A person's sex may determine if a person will be affected by an exposure to a particular toxic substance. In some instances, the metabolism of males differs from that of females. In other instances, a toxin may target a specific organ. If the toxin specifically targets the reproductive system of a particular sex, it will not have a detrimental effect on the opposite sex. This can be of special concern to women of reproductive age. There is also a group of toxins that, when exposed to, can cause birth defects (teratogens) or fetal death (embryonic toxins).

The health condition of the person exposed to toxic substances will affect the body's response to the exposure. The body's ability to counter the effects of exposure to toxic substances is diminished if the immune system is fighting disease or infection. Poor health extends beyond illness. Fatigue can be included in this category. If the body is run down due to lack of sleep or other fatigue factors, its ability to ward off toxic effects is reduced, because the body's metabolism is not functioning at its optimum level for the person's age and normal physical health.

A person's genetic makeup will play a role in how certain toxic substances will affect the body. Some people are genetically predisposed to have a toxic reaction to a substance that another person is not affected by. Just as some people are allergic to dogs, pollen, or a variety of other allergens, some people will demonstrate a toxic reaction when exposed to a particular chemical, while others will exhibit no toxic symptoms to the same exposure.

Factors related to the environment affect if or how a toxin enters the body. The carrier, ambient conditions, and chemical interactions determine whether a particular exposure will produce toxic effects.

The carrier a toxin is associated with can provide the toxin an entry route that would not normally be available to it. Cyanide salts are an example of a solid poisonous substance that cannot easily enter the body under normal circumstances. However, accidental contact with ingested food provides the carrier the needed entry route. The same cyanide salt that cannot normally be absorbed dermally can enter the system through the skin if it is dissolved in the appropriate carrier solvent under the appropriate ambient conditions.

The ambient conditions during the exposure also have their effects. Cold slows the body's metabolism to an extent. Cold affects dermal exposures by closing pores and restricting blood flow along the surface of the skin. Inversely, heat increases the potential for toxic exposures. Heat opens pores and increases the hydration state of skin, which increases the potential for solvent-soluble toxins to permeate the epidermis and enter the dermal layer, which contains blood vessels. Also, blood flow in the surface of the skin is increased in an effort to cool the body. Dilated capillaries provide a greater surface area and, therefore, greater potential for toxins to enter the bloodstream.

3.3.2.4 Distribution and Elimination

Many toxins do not stay at the initial contact site. They enter the body through one of the exposure routes and travel through the body to a specific target organ. Movement of the toxins through the body is facilitated by the circulatory system, which consists of blood and lymphatic systems. These systems also provide a method with which to remove toxins from the body.

In Figure 3.4, the flow of toxins is graphically depicted. Toxins enter the circulatory system via inhalation, dermal absorption, or ingestion. Liquid- and water-soluble solids are filtered out in the liver and kidneys and then are excreted from the body in urine. Solid toxins are excreted in feces. Volatile toxins are exchanged with incoming air and expelled in expired air. Other toxins are transported into cellular fluid, where they are stored in the organs, soft tissue, or fat cells.

3.4 Toxicity Measurements

There are a number of ways to establish toxicity of a substance. Some of the measurements relate to the lethal dose. Others have to do with the amount a person can be exposed to before they feel any effects. Other measurements relate to the instantaneous exposure or the amount of exposure a person can experience over a period of time. All of these measurements identify the dose threshold of a substance that a person can experience before suffering adverse effects.

Most toxicity measurements are derived from epidemiological and animal test data. The test values are usually derived from exposures given to rats that are then extrapolated to human ratios. Values are reported as ratios of weight of substance per weight of subject. For example, a toxic value of 5 mg/kg rat means that 5 mg of substance will produce the toxic effect in a 1 kg rat. This can be extrapolated to mean that 500 mg of substance would be needed to produce the same effect in a 100 kg human.

Many substances have an established LD_{50} value. The LD_{50} is the concentration of a substance that produces a lethal response in 50% of the test

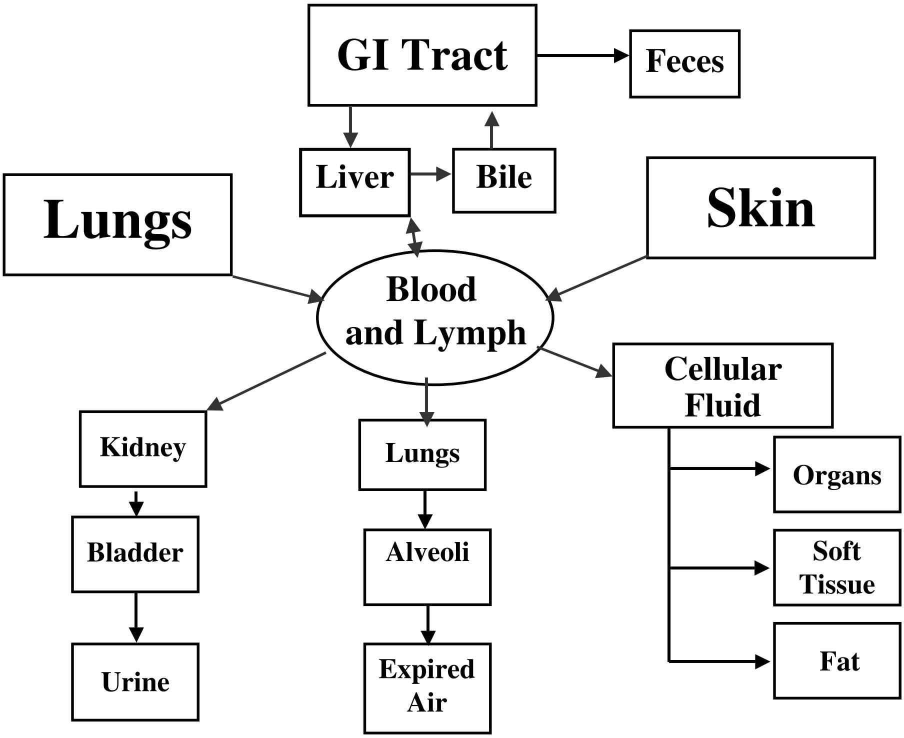

Figure 3.4 Toxin distribution chart.

population. In other words, it is the concentration of the substance that will kill 50 of 100 of the test subjects.

In the body, substances will react differently. Some have an immediate effect. Others can come into contact with the body at low concentrations without the body demonstrating symptoms of exposure.

Low-dose-response substances produce an almost immediate effect on the body (Figure 3.5). The percent of the population affected by exposure to a given substance increases with the concentration of the substance. The rate of increase of the affected population will vary between substances. At some point, the concentration will reach the LD_{50} for the substance. Eventually, a concentration will be reached at which everyone in the population will experience the toxic effects of the substance.

Substances with a high-dose response will not produce a toxic response until a certain concentration is reached (Figure 3.6). Up to that point, the body's natural defenses can counteract the toxic effects of the substance. Once the concentration of the substance reaches a threshold value, the population will begin to exhibit toxic effects. At that point, the percentage of the population experiencing toxic effects increases with dosage concentration.

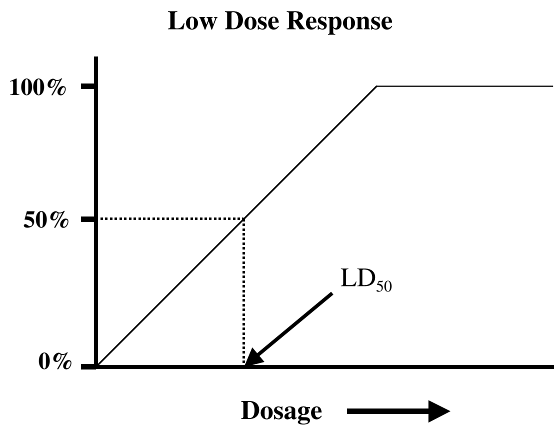

Figure 3.5 Low-dose curve.

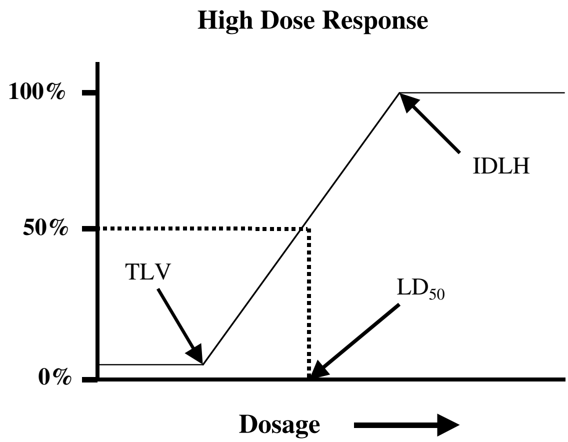

Figure 3.6 High-dose curve.

The relative toxicity of a substance is a function of the substance. Each compound has a relative toxicity. Terms commonly used to describe the toxicity of a substance are listed in Table 3.1. Each term has an associated concentration range. Extremely toxic compounds can cause death upon minute exposure, while you can literally bathe in relatively harmless substances before a toxic effect is experienced.

3.4.1 Exposure Guidelines

A number of agencies have established guidelines used to determine the toxic levels of various substances. The National Institute for Occupational Safety and Health (NIOSH), the Occupational Safety and Health Administration

Table 3.1 Relative Toxicity

Rating	LD_{50} (Oral Rat)	Example
Extremely toxic	<1 mg/kg	Hydrogen cyanide (HCN)
Highly toxic	1–50 mg/kg	Mercuric chloride ($HgCl_2$)
Moderately toxic	50–500 mg/kg	Sodium hydroxide (NaOH)
Slightly toxic	0.5–5 gm/kg	Cyclohexanone
Practically nontoxic	5–15 gm/kg	Methanol
Relatively harmless	>15 gm/kg	Water

Source: Drug Enforcement Administration, Clandestine Laboratory Training Guide, Vol. 1, p. 22.

(OSHA), and the American Conference of Governmental Industrial Hygienists (ACGIH) have their own rating systems. Each measures a specific effect and is used to establish safety parameters with which to create a safe work environment.

The threshold limit value (TLV) is an exposure guideline established by the ACGIH. It corresponds to the concentration required to produce toxic symptoms. Low TLV values indicate a substance with a low-dose response. High TLV values indicate a substance with a high-dose response. The exposure concentration values are reported as either a time–weight average (TWA) or as a ceiling (c). The TWA value is the average concentration a person can be exposed to over a period of time (either 8 or 40 hours). The c value is the maximum concentration for an instantaneous exposure.

The relative exposure limit (REL) is the exposure limit established by the NIOSH. These values are similar to the TLV values and are directed toward industrial applications.

The most relevant exposure level to clandestine lab seizures is the IDLH. The IDLH is the concentration that NIOSH determined to be immediately dangerous to life and health. It is the concentration at which death or serious injury will be caused upon a single unprotected exposure.

The OSHA established permissible exposure limits (PEL) for numerous substances. These values are similar to the NIOSH REL values and can be found in Chapter 29 of the Code of Federal Regulations (CFR), Section 1910.1000, Table Z-1.

The significance of the PEL values is that they hold legal weight. An employee cannot be exposed to concentrations exceeding PEL of a substance without appropriate personal protective equipment (PPE). Law enforcement and emergency responders are not exempt from these regulations. Even under exigent circumstances, law enforcement and emergency responders are required to adhere to the PPE requirements established by 29 CFR 1910.120 when concentrations exceed the PEL.

3.5 Toxin Properties

Now that we know how toxins enter and affect the body, we can discuss toxins. A toxic material is a substance that in relatively small quantities is capable of producing localized or systemic damage. Toxic materials come in a variety of physical states and can affect the body in a number of different ways.

3.5.1 Physical States

Toxins come in all physical states. They can be in the basic physical states of solid, liquid, or gas. They could be in some combination of these forms, such as fumes, smoke, aerosols, mists, vapors, or dust. Knowing the various physical states of a toxic substance that can be encountered provides a means for determining what types of PPE will be required.

All substances have a normal physical state of solid, liquid, or gas. The normal physical state is related to the standard temperature and pressure (uncontained at room temperature). Changing the temperature or the pressure conditions can affect the physical state of the substance.

Water is the simplest substance that can be used to demonstrate effects on temperature. Water is a liquid in an open container at room temperature (25°C). When the water's temperature is reduced to 0°C by placing it into a freezer or exposing it to liquid nitrogen, the water turns into a solid. When temperature is elevated to 100°C by adding heat from an external source, the water turns into a gas.

Changing the pressure conditions under which the substance is stored will affect the substance's physical state. Increasing the pressure in a closed container will condense a gas into a liquid, and the container will experience an increase in temperature. (That is why a bicycle tire's temperature increases as air is added.) Reducing the pressure over a liquid will convert the liquid into a gas and reduce the temperature of the container. (That is why an aerosol can gets cold when the contents are released.)

The conditions encountered in clandestine labs are dynamic. Ambient temperatures can be at extremes of hot and cold. Boiling reaction mixtures can vaporize substances that are normally liquids at room temperature. The excessive heat generated in an automobile in 110°F weather may pressurize chemical containers. Rapidly cooling a boiling liquid that was enclosed in a container may create a vacuum, which may make opening the container difficult. These environmental factors will affect the physical state of the substance.

The dynamics of the environment the substance encounters causes hybrid physical states. They are transitory or a combination of the basic physical states. These hybrid physical states include vapors, fumes, smoke, aerosols, mists, or dust.

A vapor is the gas phase of a substance that is a solid or a liquid at standard temperature and pressure (room temperature). Vapors are produced when the temperature of the substance is elevated through natural (high ambient temperatures) or artificial means (heat added to a reaction mixture). The substance returns to its natural state when its temperature is reduced.

Fumes are vapors from substances that are solids at room temperature. They are the result of heating the substance, which produces airborne particles less than 0.1 μm in diameter. They can aggregate into fine clumps and eventually settle out of the air. Lead and iodine are examples of substances that can produce fumes.

Smoke is the result of incomplete combustion. The particle size is greater than 0.5 μm. These particles do not generally settle out of the air.

An aerosol is a stable suspension of solid or liquid particles of various sizes in the air that will eventually settle out of the air. Aerosols are usually the result of a mechanical distribution of the substance that atomizes the substance and disperses it into the air. The size and weight of the particles do not allow them to remain airborne.

Mists are liquid aerosols formed by liquid vapor condensing on airborne solid particles, which may or may not be visible.

3.5.2 Toxic Properties

Exposure to toxic materials produces localized or systemic damage to the body. That is, the toxic effect is experienced at the point of contact or when the toxin enters the body, travels to the target organ, and disrupts its function in some manner. Localized effects are experienced immediately. Systemic effects may be seen immediately, may not manifest for years, or may occur in the exposed person's offspring.

In Chapter 2, the hazardous properties of the chemicals found in clandestine labs were discussed. Discussed in this section will be how the hazardous properties correlate to toxic effects on the body. The toxic effects can be divided into corrosives, asphyxiants, irritants (respiratory, systemic, external), and special toxins.

Corrosives are localized toxins that can cause visible damage or irreversible alteration to human tissue at the point of contact. They include acids and caustics. The effects are generally considered to be localized. However, the damage can lead to systemic effects. For example, exposure to hydrochloric acid fumes can produce localized damage to the alveoli. This localized damage produces a systemic effect on the body's respiratory system.

Asphyxiants affect the supply of oxygen to the body. Even small reductions in the oxygen supply to the body can potentially produce a variety of effects on the body. Asphyxiants are divided into simple and chemical.

Table 3.2 Oxygen Deficiency Effects

Percent Oxygen	Effects
21	No abnormal effects
12–16	Increased breath volume
	Accelerated heartbeat; impaired attention, thinking, and coordination
10–14	Faulty judgment and coordination; rapid onset of fatigue; intermittent respiration; permanent heart damage may occur
6–10	Nausea and vomiting; inability to perform vigorous movement or loss of all movement; unconsciousness and death
<6	Spastic breathing; convulsive movements; death in minutes

Source: Drug Enforcement Administration, Clandestine Laboratory Training Manuals, Vol. 1, p. 25.

Simple asphyxiants displace the oxygen in the atmosphere. There is no direct interaction with the body. They simply reduce the amount of an essential element available to the body. In Table 3.2, the effects that can be felt as the result of lack of oxygen in the air are presented. These chemicals may be inert when they come in direct contact with the body. Freon, which is used legitimately as a refrigerant and clandestinely as an extraction solvent, is an example of a simple asphyxiant.

Chemical asphyxiants are substances that affect the blood's ability to carry oxygen. This involves a chemical reaction with hemoglobin. The results will be similar to the oxygen concentration in the air being reduced. Carbon monoxide (CO) and hydrogen cyanide (HCN) are examples of chemical asphyxiants.

Irritants are compounds that disrupt the function of the system at the point of contact. They commonly affect the respiratory system. Water-soluble irritants such as acids can be absorbed into the mucus of the upper respiratory system, disrupting the ciliated epithelia's ability to function properly. These effects are usually experienced immediately. Non-water-soluble irritants travel into the lower respiratory system. The irritating effects disrupt the lung's ability to perform its oxygen exchange function. Asbestos is the most notorious non-water-soluble irritant. However, phosphine and phosgene gas, which are by-products of methamphetamine manufacturing operations, are examples relating to clandestine lab operations.

Allergens are substances that cause an immunological response upon exposure. The effect may be localized or systemic, and the point of contact determines the effects. For example, a dermal exposure to a substance may or may not produce a reaction. However, ingesting the substance may cause nausea, vomiting, or some other allergic reaction.

Systemic toxins affect the function of a physiological system. They travel from the point of contact to the target organ before the toxic effect is experienced. The central nervous system is affected by asphyxiants, hydrocarbons (such as hexane), and metals (like lead). Aromatic solvents, such as benzene and toluene, can affect the circulatory system. The function of the liver can be affected by aromatic compounds, chlorinated solvents (such as chloroform and carbon tetrachloride), and hydrocarbons. Halogenated compounds, such as Freon and metals, affect kidney function. The spleen is affected by halogenated aromatic compounds. Aromatics, pesticides, and organic metal compounds affect the reproductive systems. Listed in Appendix F are the target organs of the chemicals commonly associated with clandestine labs.

External toxins target the body's external organs. Various solvents, oils, metals, and corrosives target the skin and affect its ability defend itself from toxic exposures. The eyes are the external target organs for corrosives, solvents, oils, and lacrimators.

Special toxins are the "silent" toxins. Their effects are not seen immediately and may produce effects unrelated to the effects of the initial exposure. Carcinogens are substances that cause uncontrolled cell growth (cancer). Mutagens are substances that cause changes in the genetic code. Teratogens cause nonlethal congenital birth defects. The effects of mutagens and teratogens will be seen in the offspring of the exposed person. Embryonic toxins will cause fetal death. Reproductive toxins are sex specific and target the reproductive organs. Also listed in Appendix F are the toxic effects produced by exposure to the chemicals encountered in clandestine labs.

3.6 Summary

The chemicals encountered in clandestine labs can produce a variety of effects on the human body. Some are inert. Others generate an immediate lethal response. A great majority are somewhere in the middle.

The toxic effects of the chemicals involved in clandestine labs have the potential to affect the personnel processing the clandestine lab scene, including those beyond the personnel who have direct contact with the clandestine lab scene. There are many unwilling people who can potentially experience the toxic effects of the chemicals in a lab. The operators; the people living in the lab area, including spouses, their significant others, and children; and the people who subsequently move into the apartment, house, or motel room that was not properly decontaminated after the lab was removed, may potentially come in contact with the toxic materials. The responders may inadvertently bring toxic substances home or to the office, exposing families and coworkers to the hazards. The people in the criminal justice system, who come in contact with the evidence throughout the adjudication process, including people in the property room, court clerks, and attorneys, may also be exposed.

As stated at the beginning of this chapter, knowledge is power. Knowledge provides the power to prevent toxic exposure. However, with knowledge of all of the potentially harmful things that can happen as a result of encountering any or all of the toxic substances, the clandestine lab investigator must ask the question: "Why am I investigating clandestine labs?"