15

Environmental Health and Hazard Risk Assessment

This chapter is concerned with process environmental health and hazard risk assessment. As with all the chapters in Part II, there are several sections: Overview, several technical topics, illustrative open-ended problems, and open-ended problems. The purpose of the first section is to introduce the reader to the subject of environmental health and hazard risk assessment. As one might suppose, a comprehensive treatment is not provided although numerous references are included. The second section contains three open-ended problems; the authors' solutions (there may be other solutions) are also provided. The third (and final) section contains 45 problems; *no* solutions are provided here.

15.1 Overview

This overview section is concerned with—as can be noted from its title—environmental health and hazard risk assessment. As one might suppose, it was not possible to address all topics directly or indirectly related to this topic. However, additional details may be obtained from either the references provided at the end of this Overview and/or at the end of the chapter.

Note: Those readers already familiar with the details associated with this subject may choose to bypass this Overview.

This chapter deals not only with the dangers posed by hazardous substances but also examines the general subject of health, safety, and accident prevention. In addition, the laws and legislation passed to protect workers, the public and the environment from the effects of these chemicals and accidents are also reviewed. The chapter also discusses regulations (with particular emphasis on emergency planning) and the general subject of health and hazard risk assessment. In effect, the chapter addressed topics that one would classify as health, safety, and accident prevention. The bulk of the material has been adapted from:

1. L. Theodore, J. Reynolds, and K. Morris, *Accident and Emergency Management*, A Theodore Tutorial, Theodore Tutorials, East Williston, NY, 1994, originally published by the USEPA/APTI, RTP, NC, 1996 [1].
2. M.K. Theodore and L. Theodore, *Introduction to Environmental Management*, CRC Press/Taylor & Francis Group, Boca Raton, FL, 2010 [2].
3. L. Theodore and R. Dupont, *Environmental Health and Hazard Risk Assessment: Principles and Calculations*, CRC Press/Taylor & Francis Group, Boca Raton, FL, 2012 [3]

Two general types of potential chemical health, safety and accident exposures and/or concerns exist. These are classified as:

1. *Acute*: Exposures occur for relatively short periods of time, generally seconds to minutes to 1-2 days. The concentration of (air) contaminants is usually high relative to their protection criteria. In addition to inhalation, airborne substances might directly contact the skin, or liquids and sludges may be splashed on the skin or into the eyes, leading to toxic effects.
2. *Chronic*: Continuous exposure occurs over longer periods of time, generally several months to years. The concentrations of inhaled contaminants are usually relatively low. Direct skin contact by immersion, by splash, or by contaminated air involve contact with substances exhibiting low dermal activity.

In general, acute exposures to chemicals in air are more typical in transportation accidents, explosions, and fires, or releases at chemical manufacturing or storage facilities. High concentrations of contaminants in air usually do not persist for long periods of time. Acute skin exposure may occur when workers come in close contact with substances in order to control a release – for example, while offloading a corrosive material, uprighting a drum, or while containing and treating a spilled material.

Chronic exposures on the other hand, are usually associated with longer-term removal and remedial operations. Contaminated soil and debris from emergency operations may be involved in the around-the-clock discharges to the atmosphere. Soil and groundwater may be polluted or temporary impoundment systems may contain diluted chemicals. Abandoned waste sites typically represent chronic exposure problems. As activities start at these sites, personnel engaged in certain operations, such as sampling; handling containers; bulking compatible liquids; or, activities involving the release of vapors, gases, or particulates may be exposed to health and/or hazard problems.

The remaining Sections in this chapter include:

1. Safety and Accidents
2. Regulations
3. Emergency Planning and Response
4. Introductions to Environmental Risk Assessment
5. Health Risk Assessment
6. Hazard Risk Assessment

15.2 Safety and Accidents

There is a high risk of accidents due to the nature of the processes and the materials used in the chemical industry. Although precautions are taken to ensure that all processes run smoothly, there is always (unfortunately) room for error and accidents will occur. This is especially true for highly technical and complicated operations, as well as processes under extreme conditions such as high temperatures and pressures. In general, accidents occur due to one or more of the following 8 causes:

1. Equipment breakdown
2. Human error
3. Terrorism
4. Fire exposure and explosions

5. Control system failure
6. Natural causes
7. Utilities and ancillary system outages
8. Faulty sitting and plant layout

These causes are usually at the root of most industrial accidents. Although there is no way to guarantee that these problems will not arise, steps can be taken to minimize the number, as well as the severity, of incidents. In an effort to reduce occupational accidents, measures should be taken in the following areas [4].

1. *Training*: All personnel should be properly trained in the use of equipment and made to understand the consequences of misuse. In addition, operators should be rehearsed in the procedures to follow should something go wrong.
2. *Design:* Equipment should only be used for the purposes for which it was designed. All equipment should be periodically checked for damage or errors in the design.
3. *Human Performance:* should be closely monitored to ensure that proper procedures are followed. Also, working conditions should be such that the performance of workers is improved, thereby simultaneously reducing the chance of accidents. Periodic medical examinations should be provided to assure that workers are in good health, and that the environment of the workplace is not causing undue mental and/or physical stress. Finally, under certain conditions, it may be advisable to test for the use of alcohol or drugs—conditions that severely handicap judgment, and therefore make workers accident-prone.

15.3 Regulations

Each company must develop a health and safety program for its workers. For example, OSHA has regulations governing employee health and safety at hazardous waste operations and during emergency responses to hazardous substance releases. These regulations (29 CFR 1910.120) contain general requirements for the following 10 topics:

1. Safety and health programs
2. Training and informational programs

3. Work practices along with personal protective equipment
4. Site characterization and analysis
5. Site control and evacuation
6. Engineering controls
7. Exposure monitoring and medical surveillance
8. Material handling and decontamination
9. Emergency procedures
10. Illumination

The EPA's Standard Operating Safety Guides supplement these regulations. However, OSHA's regulations must be used for specific legal requirement in industry. For example, other OSHA regulations pertain to employees working with hazardous materials or working at hazardous waste sites. These, as well as state and local regulations, must also be considered when developing worker health and safety programs [5].

Information on chemical hazards must be dispatched from the manufacturers to employers via *material safety data sheets* (MSDSs) and container labels. This data must then be communicated to employees by means of comprehensive hazard communication programs which usually include training programs as well as the aforementioned MSDSs and container labels. Companies with multi-employer workplaces must include the MSDS methods that the employer will use for the contractors at the facility. These employers must also describe how they will inform the subcontractor (if applicable) and employees about precautions which must be followed and the specific labeling system used in the work place. This topic will be revisited in Part III, Chapter 31—Environmental Management Term Project 31.4.

15.4 Emergency Planning and Response

The extent of the need for emergency planning is significant, and continues to expand as new regulations on safety are introduced. Planning for an industrial emergency must begin at the very start, when the plant itself is still being planned. The new plant will have to pass all safety measures and OSHA standards. This is emphasized by Armenante, author of *Contingency Planning for Industrial Emergencies,* [5] "The first line of defense against industrial accidents begins at the design stage. It should be obvious that it is much easier to prevent an accident rather than to try and rectify the situation once an accident has occurred."

Successful emergency planning begins with a thorough understanding of the event or potential disaster being planned for. The impacts on public health and the environment must also be estimated. Some of the types of emergencies that should be included in the plan are:

1. Natural disasters such as earthquakes, tornadoes, hurricanes, floods, and meteorites
2. Explosions and fires
3. Acts of terrorism
4. Hazardous chemical leaks
5. Power or utility failures
6. Radiation accidents
7. Transportation accidents

In order to estimate the impact on the public or the environment, the affected area or emergency zone must be studied in depth. A hazardous gas leak, fire, or explosion may cause a toxic cloud to spread over a great distance, as it did in Bhopal, India. An estimate of the minimum affected area, and thus the area to be evacuated, should be performed based on an atmospheric dispersion model [3]. There are various models that can be used. While the more difficult models produce the most realistic results, simpler models are faster to use and usually still provide adequate data and information for planning purposes.

The main objective for any plan should be to prepare a procedure to make maximum use of the combined resources of the community in order to accomplish the following 7 steps:

1. Safeguard people during emergencies
2. Safeguard people during an act of terrorism
3. Minimize damage to livestock, property, and the environment
4. Initially contain and ultimately bring the incident under control
5. Effect the rescue and treatment of casualties
6. Provide authoritative information to the news media who will communicate the facts to the public
7. Secure the safe rehabilitation of the affect area

15.5 Introduction to Environmental Risk Assessment

Risk-based decision making and risk-based corrective action (RBCA) are decision-making processes for assessing and responding to a chemical release. The processes take into account effects on human health and the environment, in as much as chemical releases vary greatly in terms of complexity, physical, and chemical characteristics, and in the risk that they may pose. RBCA was initially designed by the American Society for Testing and Materials (ASTM) to assess petroleum releases, but the process may be tailored for use with any chemical release. For example, in the 1980s, to satisfy the need to start corrective action programs quickly, many regulatory agencies decided to uniformly apply regulatory cleanup standards developed for other purposes at underground storage tank (UST) cleanup sites. It became increasingly apparent that applying such standards without consideration of the extent of actual or potential human and environmental exposure was an inefficient means of providing adequate protection against the risks associated with UST releases. The EPA now believes that risk-based corrective-action processes are tools that can facilitate efforts to clean up sites expeditiously, as necessary, while still assuring protection of human health and the environment [6].

The EPA and several state environmental agencies have developed similar decision-making tools. The EPA refers to the process as "risk-based decision making". While the ASTM RBCA standard deals exclusively with human health risk, the EPA advises that, in some cases, ecological goals must also be considered in establishing cleanup goals.

For the purpose of this chapter, a few definitions of common terms will suffice. *Risk* is the probability that persons or the environment will suffer adverse consequences as a result of an exposure to a substance. The amount of health risk is determined by a combination of the concentration of the substance, and the toxicity of the environment to which it is exposed, the rate of intake or dose of the substance, and the toxicity of the substance. *Risk assessment* is the procedure used to attempt to quantify or estimate this risk. Risk-based decision making also distinguishes between the "point of exposure" and the "point of compliance". The *point of exposure* is the point at which the environment or the individual comes into contact with the chemical release. An individual may be exposed by methods such as inhalation of vapors, as well as physical contact with the substance. The *point of compliance* is a point in between the point of release of the chemical (i.e., the source) and the point of exposure. The *point of compliance* is selected to provide a safety buffer for effected individuals and/or environments.

15.6 Health Risk Assessment

As noted in the previous Section, there are many definitions for the word *risk*. People face all kinds of risks every day, some voluntarily and other involuntarily. Therefore, risk plays a very important role in today's world. Studies on cancer caused a turning point in the world of risk because it opened the eyes of not only risk scientists and health professionals but also chemical engineers to the world of risk assessment.

Since 1970 the field of risk assessment has received widespread attention within both the engineering, scientific, and regulatory committees. It has also attracted the attention of the public. Properly conducted risk assessments have received fairly broad acceptance, in part because they put into perspective the terms toxic, hazard, and risk. Toxicity is an inherent property of all substances. It states that all chemical and physical agents can produce adverse health effects at some dose or under specific exposure conditions. In contrast, exposure to a chemical that has the capacity to produce a particular type of adverse effect represents a health problem. As noted, risk is the probability or likelihood that an adverse outcome will occur in a person or a group that is exposed to a particular concentration or dose of the hazardous agent. Therefore, risk is generally a function of exposure *and* dose. Consequently, health risk assessment is defined as the process or procedure used to estimate the likelihood that humans or ecological systems will be adversely affected by a chemical or physical agent under a specific set of conditions [7].

More importantly, the term risk assessment is not only used to describe the likelihood of an adverse response to a chemical or physical agent, but it has also been used to describe the likelihood of any unwanted event. This subject is treated in more detail in the next section. These include risks such as: explosions or injuries in the workplace; natural catastrophes; injury or death due to various voluntary activities such as skiing, ski diving, flying, bungee jumping, diseases; death due to natural causes; and many others [8].

Health risk assessment provides an orderly, explicitly, and consistent way to deal with scientific issues in evaluating whether a health problem exists and what the magnitude of the problem might be. This evaluation typically involves large uncertainties because the available scientific data are limited, and the mechanisms for adverse health impacts or environmental damage are only imperfectly understood. When one examines risk, how does one decide how safe is safe, or how clean is clean? To begin with, the chemical engineer has to examine both sides of the risk equation, i.e., both the toxicity (and dose) of a pollutant and the extent of exposure. Information is required at both the current and potential exposures, considering all possible exposure pathways. In addition to human health risks, one needs to look at potential ecological or other environmental effects. In conducting a comprehensive risk assessment, one should remember that there are always uncertainties and these assumptions must be included in the analysis [9].

In recent years, several guidelines and handbooks have been produced to help explain the approaches for performing health risk assessments. As discussed by a special National Academy of Sciences committee convened in 1983, most human or environmental health problems can be evaluated by dissecting the analysis into four parts: health problem identification; dose-response assessment (or health problem assessment); exposure assessment; and risk characterization (see also Figure 15.1). For some perceived health problems, the risk assessment might stop with the first step, health problem identification, if no adverse effect is identified or if an agency elects to take regulatory action without further analysis [8]. Regarding identification, a health problem is defined as a toxic agent or a set of conditions that has the potential to cause adverse effects to human health or the environment. Identification involves an evaluation of various forms of information in order to identify the different problems. Dose-response or toxicity assessment is required in an overall assessment; responses/effects can vary widely since all chemicals and contaminants vary in their capacity

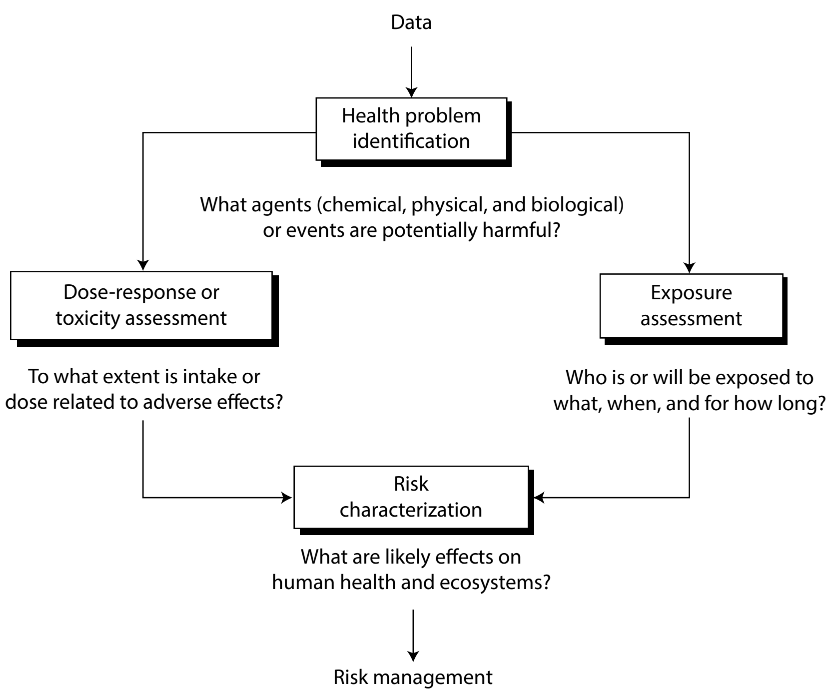

Figure 15.1 The health risk evaluation process.

to cause adverse effects. This step frequently requires that assumptions be made regarding experimental data for animals and humans. Exposure assessment is the determination of the magnitude, frequency, duration, and route of exposure on human populations and ecosystems. Finally, in risk characterization, toxicology and exposure data information are *combined* to obtain a qualitative or quantitative expression of risk.

The risk assessment involves the integration of the information and analysis associated with the above four steps to provide a complete characterization of the nature and magnitude of risk and the degree of confidence associated with this characterization. A critical component of the assessment is a full elucidation of *uncertainties* associated with each of the major steps are encompassed under this broad concept of risk assessment. It should treat uncertainty not by the application of arbitrary safety factors, but by stating them in quantitatively explicit terms, so that they are not hidden from decision makers. Risk assessment, defined in this broad way, forces an assessor to confront all the scientific uncertainties and to set forth in explicit terms the means used in specific cases to deal with these uncertainties [10].

15.7 Hazard Risk Assessment

Risk evaluation of accidents serves a dual purpose. It estimates the probability that an accident will occur and also assesses the severity of the consequences of an accident. Consequences may include damage to the surrounding environment, financial loss, or injury to life. This section is primarily concerned with the methods used to identify hazards and the causes and consequences of accidents. Issues dealing with health risks have been explored in the previous section. Risk assessment of accidents provides an effective way to help ensure either that a mishap does not occur or reduces the likelihood of an accident. The result of the risk assessment allows concerned parties to take precautions to prevent an accident before it happens.

The first thing a chemical engineer needs to understand is what exactly an accident is. An accident is defined as an unexpected event that has undesirable consequences [11]. The causes of accidents have to be identified in order to help prevent accidents from occurring. Any situation or characteristic of a system, plant, or process that has the potential to cause damage to life, property, or the environment is considered a hazard. A hazard can also be defined as any characteristic that has the potential to cause an accident. The severity of a hazard plays a large part in the potential amount of damage a hazard can cause if it occurs. The risk is the probability that human injury, damage to property, damage to the environment, or financial loss will occur.

An acceptable risk is a risk whose probability is unlikely to occur during the lifetime of the problem or plant or process. An acceptable risk can also be defined as an accident that has a high probability of occurring, with negligible consequences. Risks can be ranked qualitatively in categories of high, medium, and low. Risk can also be ranked quantitatively as annual number of fatalities per million affected individuals. This is normally denoted as a number times one millionth that is, 3×10^{-6}; this representation indicates that on the average, three individuals will die every year for every million individuals.

There are several steps in evaluating the risk of an accident (see also Figure 15.2). These are detailed below, if the system in question is a chemical plant.

1. A brief description of the equipment and chemicals used in the plant is needed.
2. Any hazard in the system has to be identified. Hazards that may occur in a chemical plant are one or a combination of the following:
    1. Corrosion
    2. Explosions
    3. Fire
    4. Rupture of a pressurized vessel
    5. Runaway reactions
    6. Slippage
    7. Unexpected leaks
    8. Temperature excursions
    9. Pressure excursions
3. The event or series of events that will initiate an accident has to be identified. An event could be a failure to follow correct safety procedures, improperly repaired equipment, or failure of a safety mechanism.
4. The probability that the accident will occur has to be determined. For example, if a nuclear power plant has a 10 year life, what is the probability that the temperature in a reactor will exceed the specified temperature range? The probability can be qualitatively ranked from low to high. A low probability means that it is unlikely for the event to occur in the life of the plant. A medium probability suggests that there is a possibility that the event will occur. A high probability

means that the event will probably occur during the life of the plant. Naturally, a quantitative estimate of the probability is preferred.

5. The severity of the consequences of the accident must be determined.
6. If the probability of the accident and the severity of its consequences are low, then the risk is usually deemed acceptable and the plant should be allowed to operate. If the probability of occurrence is too high or the damage to the surroundings is too great, then the risk is usually unacceptable and the system needs to be modified to minimize these effects.

The heart of the hazard risk assessment algorithm provided is enclosed in the dashed box in Figure 15.2. This algorithm allows for reevaluation of the process if the risk is deemed unacceptable (the process is repeated starting with either step one or two).

The reader should note that health assessment and hazard risk assessment plus accompanying calculations receives an extensive treatment by Theodore and Dupont [3]

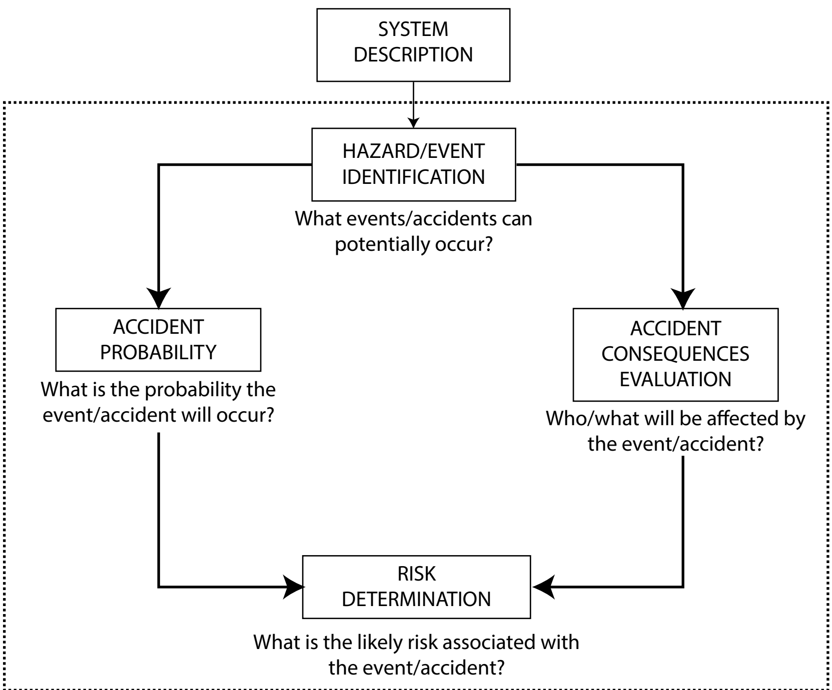

Figure 15.2 Hazard risk assessment flowchart.

A detailed and expanded treatment of environmental health and hazard risk assessment is available in the following two references.

1. L. Theodore and R. Dupont, *Environmental Health and Hazard Risk Assessment: Principles and Calculations*, CRC Press/Taylor & Francis Group, Boca Raton, FL, 2012 [3].
2. L. Theodore, *Chemical Engineering: The Essential Reference*, McGraw-Hill, New York City, NY, 2014 [12].

15.8 Illustrative Open-Ended Problems

This and the last section provide open-ended problems. However, solutions *are* provided for the three problems in this section in order for the reader to hopefully obtain a better understanding of these problems which differ from the traditional problems/illustrative examples. The first problem is relatively straightforward while the third (and last problem) is somewhat more difficult and/or complex. Note that solutions are not provided for the 45 open-ended problems in the next section.

Problem 1: The term *liability* is very often used with environmental regulations. Related terms are *strict liability*, *joint and several liability*, *retroactive liability,* and *cradle-to-grave liability*. In addition, of the terms used in connection with environmental regulations and enforcement, include their implications in environmental management. Briefly explain those terms.

Comment: Refer to the literature for assistance [13,14]

Solution: One person's definitions follow:

Liability: This means responsibility for an action. If an individual causes damage to property or other individuals, he/she are liable.

Strict Liability: This means responsibility without regard to negligence or care. A corporation could comply with all the applicable regulations in 1980 but when these regulations are changed in 1990, the corporation is liable for the new compliance.

Joint and Several Liability: In this case the responsibility is assigned (or shared) when several individuals (or corporations) do not perform properly, and it is not possible to divide the harm. If three plants contributed to a hazardous waste, each of them is liable to clean the site and mitigate the damages; this also includes the generators, the transporters, the storage facilities, and the operators. They are all collectively or individually responsible for damages.

Retroactive Liability: This is the case when a law is enacted, such as the Superfund Act; the liability goes back many years before the date enactment.

Cradle-to-Grave Liability: This implies that the generator of the waste is responsible (liable) for the waste until its ultimate destruction. Simply selling the waste to another facility does not absolve liability.

Negligence: Negligence is an act of failure to act which breaches a responsibility that one person (or company) has to another person (or company) and which unintentionally results in harm to a person (or company) or to a person's (or company's) property. Negligent behavior leads to liability. If, for example, through a failure to exercise its responsibility to take proper care, a company allows a release of a toxic gas that kills the cows on a neighboring farm, then the company would be liable for the damages caused. Violation of a regulation would be virtual proof of negligence.

Trespass: Trespass to reality is the type of trespass most often used in environmental law cases. It involves the unlawful physical invasion of another's property that interferes with the use of that property. Trespass is independent of negligence. For example, even if there was not negligence, it is a trespass if gasoline from a gas station underground storage tank leaks out and flows under a neighbor's home, filling it with toxic and flammable vapors.

Nuisance: A nuisance is the use by a person of their property in a way that causes injury or annoyance to their neighbor. Allowing bad smelling gases, dust, smoke or other annoying or harmful materials to drift over a neighbor's property would be examples of nuisance in environmental cases. These terms and liabilities imply that:

1. It is very attractive for waste generators to dispose of any waste on-site under carefully controlled conditions.
2. It places a burden on the waste generator with the threat of future costs due to the improper action of others.
3. Citizens are protected from the loss of property and/or health due to the action of others.
4. It is extremely important to select a reputable firm for waste treatment/management.

Problem 2: A dose-response relationship provides a mathematical formula or graph for estimating a person's risk of illness at each exposure level for air toxics. To estimate a dose-response relationship, measurements of health risks are needed for at least one dose level of the air toxic compared to an unexposed group. However, there is one important difference between the dose-response curve commonly used for estimating the risk of cancer and the ones used for estimating the risk of all other illnesses: the existence of a threshold dose, i.e., the highest dose at which there is no risk of illness. Because a single cancerous cell may be sufficient to cause a clinical case of cancer, EPA's and many other dose-response models for cancer assume that the threshold dose level for cancer is *zero*. In other words, people's risk of cancer is possible even at very low doses. However, it should be noted that the increased cancer risk at very low doses is likely to be very low.

1. Draw a straight line model showing the level of cancer risk increasing at a constant rate as the dose level increases. The model should illustrate increasing risk of cancer for the air toxic.
2. Also develop a straight line model to show EPA's methodology in which the EPA adjusts the observed threshold downward by dividing by uncertainty factors that range from 1 to 10,000 known as the human threshold.

Solution: It is accepted by scientists that the human body is capable of adjusting to varying amounts of cell damage without showing signs of illness. Therefore, EPA has developed models for non-cancer illnesses which include a threshold dose level that is greater than zero; this means that at low doses there may be no risk of non-cancer health effects. For non-cancer health effects, such as permanent liver or kidney damage, temporary skin rashes, or asthma attacks, information from human or animal studies is used to estimate the threshold dose levels.

1. Figure 15.3 shows the cancer dose-response curve plotted from data on a dose of 100 μg/d. this dose caused an extra change of cancer of about 1 in 100 in the study for which animals that received that dose. The straight line

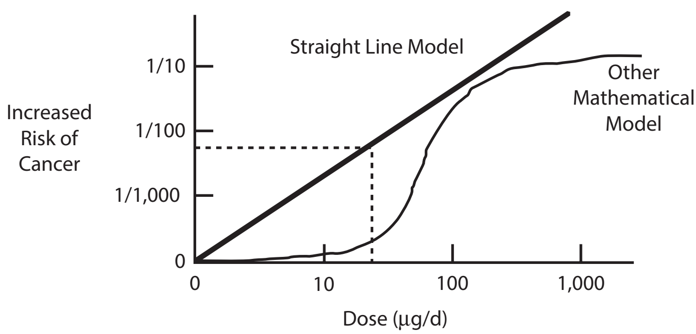

Figure 15.3 Cancer dose-response curve highlighting the straight line dose-response model.

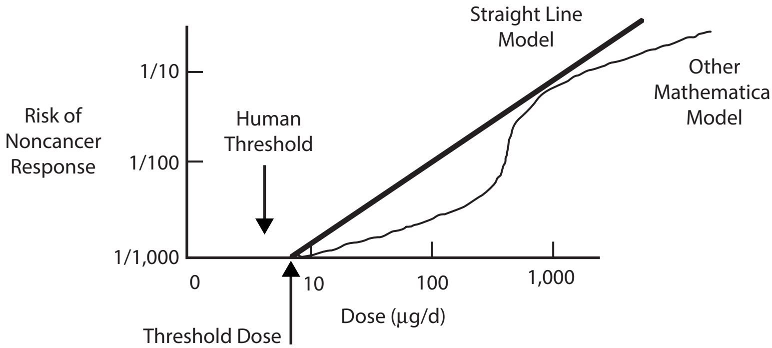

Figure 15.4 Non-cancer dose-response curve highlighting the straight line dose-response and the threshold dose.

model developed here indicates that the level of cancer risk increases at a constant rate as the dose level increases. This rate of increasing cancer risk is known as the slope factor.

2. Figure 15.4 illustrates the non-cancer dose-response curve which was drawn after converting uncertainties from animal to human data. Since individuals vary in their susceptibility to the harmful effects of toxic air pollutants, EPA adjusts the observed threshold dose downward by dividing by uncertainty factors that range from 1 to 10,000. This new adjusted value is known as the human threshold. Below the human threshold, EPA expects no appreciable risk of harmful health effects for most of the general population.

Problem 3: Storage tanks are the most common item of equipment to be involved in accidents. Although level control appears to be one of the simplest control schemes, many accidents result from overfilling storage tanks. Level indicators frequently depend on weight measurements rather than volume measurements. Level measurements can be made at the tank site by viewing a gauge glass or using a dipping device, but the operators obviously prefer to stay in the control room if it is dark or if the weather is bad. It is common practice to install a high-level alarm that actually measures volume if the level indicator measures weight. A high-level alarm may be assumed to be faulty even if it is correct, especially if the level indicator shows that the tank is not full and the operators do no understand the level measuring mechanism.

A tank that was designed to store gasoline (specific gravity 0.81) overflowed while being filled with pentane (specific gravity 0.69). The tank overflowed when the level indicator said that it was only 85 percent full. The level indicator was a differential pressure cell that measured weight not volume, but the operators did not realize that the level indicator did not measure the level directly. Prepare an event-tree diagram [3, 12] for this type of incident starting with "low-density feed". Assume that manual measurement is available, but the operators may or not check it. Assume that a high-level alarm based on volume is present, but that alarm may or may not work and the operators may or may not believe it, even if it works. Include other events that will determine whether the tank overflows.

Solution: One possible event-tree diagram for a "low density feed" tank overflow accident from a high density feed storage tank is as follows: (see Figure 15.5)

15.9 Open-Ended Problems

This last section of the chapter contains open-ended problems as they relate to environmental health and hazard risk assessment. No detailed and/or specific solution is provided; that task is left to the reader, noting that each problem has either a unique solution or a number of solutions or (in some cases) no solution at all. These are characteristics of open-ended problems described earlier.

There are comments associated with some, but not all, of the problems. The comments are included to assist the reader while attempting to solve

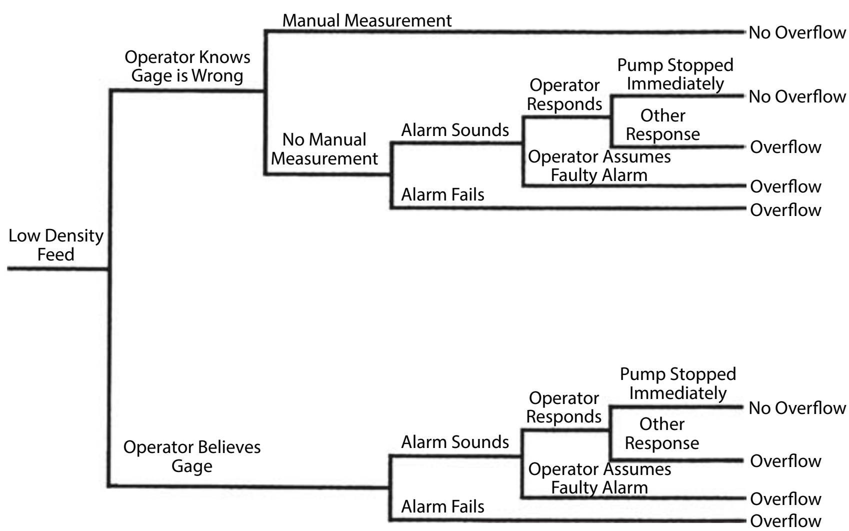

Figure 15.5 Event tree for "low density feed" tank overflow accident from high density feed storage tank.

the problems. However, it is recommended that the solution to each problem should initially be attempted *without* the assistance of the comments.

There are 45 open-ended problems in this section. As stated above, if difficulty is encountered in solving any particular problem, the reader should next refer to the comment, if any is provided with the problem. The reader should also note that the more difficult problems are generally located at or near the end of the section.

1. Describe the early history associated with health risk assessment.
2. Discuss the recent advances in the general field in health risk assessment.
3. Select a refereed, published article on health risk assessment from the literature and provide a review.
4. Provide some normal everyday domestic applications involving the general topic of health risk assessment.
5. Develop an original problem on health risk assessment that would be suitable as an illustrative example in a book.
6. Prepare a list of the various technical books that have been written on health risk assessment. Select the three best (try to include a book written by one of the authors) and justify your answer. Also select the three weakest books and, once again, justify your answer.
7. Select three chemical compounds from the list of "Extremely Hazardous Substances" as given in the Federal Register, April 22, 1987. For each of the three compounds find the:
   - Chemical formula
   - Molecular weight
   - Vapor pressure at 25°C
   - Boiling point
   - Freezing point
   - Flash point
   - Occupational threshold limit value
8. The National Air Toxics Information Clearinghouse (NATICH) data base contains information on selected EPA risk analysis results calculated using the Human Exposure Model (HEM). Explain the steps that regulatory bodies use for quantifying the number of people exposed to air pollutants emitted by stationary sources.

9. Suggest a method for estimating the uncertainty associated with health risk assessment calculations.
10. A possible health risk policy for a company could take the following form
    1. The average individual risk level for the public should be less than ______________________________.
    2. The maximum individual risk for employees should be less than ______________________________.
    3. The probability of one or more public deaths should be less than ______________________________.
    4. The probability of 100 or more public deaths should be less than ______________________________.
    5. The probability of one or more public illnesses should be less than ______________________________.
    6. The probability of 100 or more public illnesses should be less than ______________________________.

    The above form can be applied on either an annual or lifetime basis.

    Your company has requested that you improve on the present/proposed company policy. Submit your recommendations.
11. What is the technical definition of carcinogenic "unit risk"? How can this term be best described to a layman?
12. Describe and illustrate the process of setting a reference dose (RfD) using a schematic dose-response curve. Correctly label the axes and all other important information on your illustration. Develop another method of setting an RfD.
13. Discuss in general terms the means available for protecting humans from the *health* effects associated with radiation.
14. With reference to the previous problem can you suggest a better means of protecting the public from this health effect?
15. Can health-risk and hazard-risk communication aid the general population in ranking the importance of risk?
    Comment: Does the general population rank risk the same way that the "experts" do?
16. Communications about hazards and health risk present difficult problems in information presentation. What are some of these problems and how would you deal with them?
    Comment: Refer to the literature [1–3] for more details.

17. Describe the early history associated with hazard risk assessment.
18. Discuss the recent advances in the general field in hazard risk assessment.
19. The Occupational Safety and Health Act (OSHA) enforces basic duties which must be carried out by employers. Discuss these basic duties as they apply to an industry of your choice.
20. State the major roles of the National Institutes of Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA).
21. If one informs workers about the hazard risk associated with their jobs, what steps and/or guidelines should be followed to best get the message (information) across to the worker(s)?
22. Provide a list of the various safety hazard regulatory groups.
    Comment: Examples can include:
    - American Petroleum Institute (API)
    - American Society for Testing Materials (ASTM)
    - Associated Factory Mutual Insurance Companies, Boston.
    - Manufacturing Chemists' Association.
    - National Board of Fire Underwriters.
23. Discuss in general terms the means available for protecting humans from the *hazard* effects associated with radiation. Can you improve on this?
24. Select a refereed, published article on hazard risk assessment from the literature and provide a review.
25. Provide some normal everyday domestic applications involving the general topic of hazard risk assessment.
26. Develop an original problem on hazard risk assessment that would be suitable as an illustrative example in a book.
27. Prepare a list of the various technical books which have been written on hazard risk assessment. Select the three best (try to include a book written by one of the authors) and justify your answer. Also select the three weakest books and, once again, justify your answer.
28. Education and training of personnel are critical components of efforts to reduce hazards in a chemical processing plant or a chemical laboratory. Identify the major topics that should be included in an effective education and training program.

29. The effectiveness of accident and emergency management plans can be enhanced by informed and receptive citizens. What factor or factors have been identified as most important in addressing public opposition to siting industrial facilities involving toxic and/or hazardous chemicals? With this in mind, what efforts must be undertaken to counter this opposition?
30. Suggest a method for estimating the uncertainties associated with hazard risk assessment calculations.
31. Discuss the many pieces of equipment and protective clothing available for routine safety practices and emergencies in a well organized chemical laboratory.
32. Locate newspaper and/or news magazine articles in the library about a recent accident that involved evacuation of a population due to the risk to their health and/or safety. From these sources, write a brief essay describing what happened, where the incident took place, the number of people killed and/or injured, the immediate impact on the community, etc.
33. Very often, the actions of the first person on the scene of an accident can have a significant impact on the final outcome of the incident. However, it is crucial that this person does not subject himself or herself to personal injury. The actions of an untrained person and trained person may differ greatly.
    - What sequence of actions would you recommend for the *untrained* individual who observes a large spill from a tank truck accident?
    - How would you, the *trained* leader of an emergency response team, behave in a similar circumstance?
34. One of the authors has employed the Delphi Panel approach in consulting activities. Provide your definition of this approach as it applies to environmental risk assessment.

    Comment: Refer to the literature [1–3] for background information.
35. You are the manager of a 25,000 gallon tank facility storing oil and oil-based products. This facility is located on a hillside 200 ft above and 2,000 ft away from a navigable river. The river intake for a water treatment plant serving 30,000 people is located 3 miles downstream from your location. This is a relatively new facility with no history of past chemical spills. You are responsible for the preparation of

the Spill Prevention Control and Countermeasures (SPCC) plan for the emergency response to a tank failure or other spill in this facility.

Prepare an outline listing the items or topics that the plan must address under the Clean Water Act (CWA) Amendments, the Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). This is to be a "first step" outline addressing what is required and who (job title or job description) is involved. You may assume that the details of implementation are not required at this stage of the response-planning process.

36. An out-of-control forklift has ruptured a water line and a benzene storage tank in a small building. The tank contains 1000 kg of benzene. The water line discharged 800 m^3 of water before a cutoff valve could be activated. Both fluids accumulated in the basement of the building, which is not vented. The remaining airspace in the basement is 1000 m^3.
    - Determine if a separate phase of benzene exists on the top of the water.
    - Does a flammability hazard exist in this basement?
    - Suggest several methods of cleanup that do not exacerbate the flammability problem.

    Assume the following information applies at 25°C and 1 atm:
    Water vapor pressure = 23.8 mmHg
    Benzene aqueous solubility = 1800 mg/L
    Benzene LFL = 1.4%v/v (by volume)
    Benzene UFL = 8%v/v (by volume)
    Henry's Law constant for benzene = $10^{-2.25}$ atm·m^3/gmol

37. Consider two plants that process and store large quantities of hazardous materials. Plant A is located in a narrow valley approximately 200 ft from the nearest major stream. The climate can be described as humid. A thick clay extends from the land surface in the area to a depth of 100 ft. Unfractured shale at least 200 ft thick underlies the clay. Plant B is located on a hillside in an area where the climate is arid. At the surface there is a 20 ft thick layer of till (an unsorted glacial deposit of differing grain sizes). The till is underlain by a fractured basalt that is several hundred feet thick. Discuss how the features of these two sites would influence dispersion of hazardous materials at the two sites.

38. You are a member of the Local Emergency Planning Committee (LEPC) for your community. You have been assigned the task of planning for evacuation of the community in the event of a major accident at the nearby railroad yard. Propose a scheme or schemes for notifying all people in the community, as quickly and efficiently as possible, that they should immediately leave the area and assemble at the regional high school four miles away. Your community covers an area of 0.6 square miles with a total population of 5,000. Of this total, 2,200 live in 850 single-family housing units; 1,600 live in 900 two-story apartments; and 1,200 live in four high-rise apartment buildings. List the advantages and disadvantages of each notification scheme that addresses cost, manpower requirements, effectiveness, and other concerns you believe appropriate.

    Comment: Since this is an open-ended problem involving a great deal of individual judgment, considerable variation in answers can therefore be expected.
39. You have been hired by the World Health Organization (WHO) to *quantify* the risk(s) associated with global *warming* over the next 25 year period. Repeat the exercise for this century.
40. You have been hired by the World Health Organization (WHO) to *quantify* the risk(s) associated with global *cooling* over the next 25 year period. Repeat the exercise for this century.
41. The Pentagon has hired you as an outside consultant to develop a procedure that could be employed to estimate the probability and associated risk that a foreign power will launch a nuclear attack at another nation.
42. With reference to the previous problem, the Pentagon has asked that you *quantify* (your best estimate) the probability and risk that North Korea will successfully deliver a nuclear attack on the U.S mainland.
43. With reference to the previous problem, provide your best estimate of the probability and associated risk of Iran launching a nuclear attack on Israel.
44. It is 2:00 am, and you have just received a call from your boss stating that a boxcar used for transporting a hygroscopic (moisture adsorbing) dry solid chemical, manufactured in your department, has been involved in a train derailment just outside the quiet little town of

Smallville. The boxcar is in a section of the train that has not derailed, but fumes issuing from the car are at high enough concentrations to cause irritation to personnel in the immediate vicinity of the boxcar. Local EPA personnel are headed to the site to take control of the situation, and have already notified the press that your company will pay for any and all costs in cleaning up the derailment. You must develop a plan of action and issue direction to personnel at the site.

- What information should you obtain from the personnel at the site related to the derailment?
- What information is necessary from personnel who are not at the site related to the chemical?
- What are your instructions to personnel at the site after you obtain all of the following data:

  There is a brisk 20 km/h wind blowing normal to the railroad tracks and away from Smallville.

  There is a high probability the boxcar involved is actually returning from a customer carrying empty shipping containers. This means that a thing layer of chemical dust is deposited on the inner walls of each container.

  It is not unusual for the customers to return containers that are only partially closed.

  The earliest you or any other personnel familiar with this chemical can arrive at the site is eight hours.

Comment: Fumes resulting from the reaction of the chemical with moisture are characterized as:

- noticeable in concentrations of 0.1 ppmv,
- hazardous for eight hour exposures in excess of 200 ppmv,
- can cause loss of consciousness in concentrations above 400 ppmv, and
  - can be fatal if inhaled when concentrations exceed 700 ppmv.

The diffusivity of the hazardous gas is similar to hydrogen. The rate of reaction between water vapor and the chemical is slow under ambient conditions.

45. In 1963, two 20-year-old (or, possibly older) bottles labeled "diisopropyl ether ($C_3H_7OC_3H_7$) – student preparation" were discovered in a basement storeroom at a major New

England university. Diisopropyl ether is a clear liquid. Both bottles were approximately one-third full with a solid water-insoluble material, presumably the corresponding ether peroxide ($C_3H_7OOC_3H_7$). Each bottle had a total capacity of approximately 2.5 L. The bottles were decanted and the solids were thrown (while still inside the bottles) into a dump at the edge of the nearest town. When the bottles did not break, stones were cast at them until, at last, they suddenly exploded. The density of solid dialkyl ether peroxides is approximately 0.72 g/mL. The total heat released may be estimated from the heat of combustion, which can be obtained by applying Hess' Law using the bond energies supplied below in Table 15.1. Assume sufficient oxygen was available to allow complete combustion to CO_2 and H_2O. The energy equivalent of 1.0 lb of TNT = 2,000 Btu.

Estimate the lb of TNT equivalent released in this explosion and comment on the choice of a disposal method used in this case.

Table 15.1

Bond Energies (Btu/lbmol)

C-H	178,000	C-O	144,000
C-C	149,000	O_2	212,400
O-O	59,300	C=O	304,000
O-H	199,000		

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