Chapter 23

Environmental Management

INTRODUCTION

In the past four decades, there has been an increased awareness of a wide range of environmental issues covering all resources: air, land, and water. More and more people are becoming aware of these environmental concerns and it is important that professional people, many of whom do not possess an understanding of environmental problems, have the proper information available when involved with environmental decisions. All professionals should have a basic understanding of the technical and scientific terms related to these issues. In addition to serving the needs of the professional, this chapter examines how one can increase his or her awareness of and help solve the environmental problems facing both industry and society.

This chapter provides a broad discussion of environmental issues facing today's engineers and presents some of the more recent technology to deal with the issues at hand. Some of the topics covered in this chapter include air pollution, water pollution, solid waste, etc., and several illustrative examples dealing with these topics are presented.

This chapter is not intended to be all-encompassing. Rather, it is to be used as a starting point. Little is presented on environmental regulations because of the enormity of the subject matter; in a very real sense, it is a moving target that is beyond the scope of this text. Further, the material primarily keys on traditional environmental topics. Although much of the material is qualitative in nature, some quantitative material and calculations are presented in the illustrative examples that appear in the last section (Applications).

ENVIRONMENTAL MANAGEMENT HISTORY

BANG! The Big Bang. In 1948, physicist G. Gamow proposed the big bang theory to explain the origin of the universe. He believed that the universe was created in a gigantic explosion as all mass and energy were created in an instant of time. Estimates on the age of the universe at the present time range between 7 and 20 billion years, with 13.5

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billion years often mentioned as the age; 4.5 billion years is generally accepted as the planet Earth's age.

The bang occurred in a split second and within a minute the universe was approximately a trillion miles wide and expanding at an unbelievable rate. Several minutes later, all the matter known to humanity had been produced. The universe as it is known today was in place. Environmental problems, as they would later relate to living organisms and humans, were born.

Flash forward to the present. More than any other time in history, the 21st century will be a turning point for human civilization. Human beings may be facing ecological disasters that could affect their ability to survive. These crises could force them to re-examine the value system that has governed their lives for the past two million years (approximately) of existence.

The year 1970 was a cornerstone year for modern environmental policy. The National Environmental Policy Act (NEPA), enacted on January 1, 1970, was considered a "political anomaly" by some. NEPA was not based on specific legislation; instead, it referred in a general manner to environmental and quality-of-life concerns. The Council for Environmental Quality (CEQ), established by NEPA, was one of the councils mandated to implement legislation. April 22, 1970, brought Earth Day, where thousands of demonstrators gathered all around the nation. NEPA and Earth Day were the beginning of a long, seemingly never-ending debate over environmental issues.

The Nixon Administration became preoccupied with not only trying to pass more extensive environmental legislation but also with implementing the laws. Nixon's White House Commission on Executive Reorganization proposed in the Reorganizational Plan #3 of 1970 that a single, independent agency be established, separate from the CEQ. The plan was sent to Congress by President Nixon on July 9, 1970, and this new U.S. Environmental Protection Agency (EPA) began operation on December 2, 1970. The EPA was officially born.

The aforementioned EPA works with the states and local governments to develop and implement comprehensive environmental programs. Federal laws such as the Clean Air Act, the Safe Drinking Water Act, the Resource Conservation and Recovery Act, the Comprehensive Environmental Response, Compensation, and Liability Act, etc., all mandate involvement by state and local government in the details of implementation. These laws, in a very real sense, have dictated the environmental management policies and procedures that are presently in place and serve as the subject matter for this chapter.

A waste management timetable that provides information on environmental approaches since World War II is provided in Table 23.1.

ENVIRONMENTAL MANAGEMENT TOPICS

There are two dozen major topics that the author considers to be integral parts of environmental management (there are, of course, more). Reviewing each subject area in any detail is beyond the scope of this text; the reader is referred to a key reference in the literature[(1)] for an extensive review of the entire field of environmental

Table 23.1 Waste Management Timetable

Time frame	Control
Prior to 1945	No control
1945–1960	Little control
1960–1970	Some control
1970–1975	Greater control (EPA founded)
1975–1980	More sophisticated control
1980–1985	Beginning of waste reduction management
1985–1990	Waste reduction management
1990–1995	Pollution Prevention Act
1995–2000	Sophisticated pollution prevention approaches
2000–2010	Green chemistry and engineering; sustainability
2010–	?????

management. Additional and more specific references for each of the topics referred to above are provided below:

1. Air pollution control equipment, etc.[2–4]
2. Atmospheric dispersion modeling[5]
3. Indoor air quality[6]
4. Industrial wastewater management[6,7]
5. Wastewater treatment technologies[6,7]
6. Wastewater treatment processes[5–7]
7. Solid waste management[5–8]
8. Superfund[5,6,8]
9. Municipal solid waste management[5,6,8]
10. Hospital waste management[5,6,8]
11. Nuclear waste management[5,6]
12. Pollution prevention[9–15]
13. Multimedia analysis and lifecycle cost analysis[6,7]
14. Noise[5,6,16,17]
15. ISO 14000[5,6,18,19]
16. Environmental justice[5,6,20–22]
17. Electromagnetic fields[5,6]
18. Acid rain[5,6]
19. Greenhouse effect and global warming[5,6]
20. Public perception of risk[5,6,20–22]
21. Health risk assessment[5–7,23]

22. Hazard risk assessment(5–7,24)
23. Risk communication(5,6,20–22)
24. Environmental implication of nanotechnology(25,26)

APPLICATIONS

This last section is devoted to environmental management applications. Nine illustrative examples complement the presentation; much of this material has been drawn from Natural Science Foundation (NSF) literature[1–5] plus several other sources(6–9, 25–26).

ILLUSTRATIVE EXAMPLE 23.1

List at least three examples of actions that can be taken as a means of conserving energy from home cooling applications.(13)

***SOLUTION*:**

1. Install air conditioners that have been properly sized for the target area.
2. Installing ceiling fans can magnify the cooling effects of air conditioners with minimal added energy consumption.
3. Hang shades or blinds to block direct sunlight from entering the house.
4. Plant leafy trees in the east/west faces of the house for added shade.
5. Make sure that attics are both well ventilated during the summer months and sufficiently insulated during the winter.
6. During hot weather, use outdoor barbecue grills and microwaves rather than kitchen stoves to reduce the heat load in the kitchen. ■

ILLUSTRATIVE EXAMPLE 23.2

List at least three examples of actions that can be taken as a means of conserving energy from heating and cooling applications in the workplace.(14)

***SOLUTION*:**

1. The location of a new office or building should be considered with respect to environmental elements like sunlight, wind exposure, etc.
2. Carefully select materials of construction that will enhance energy conservation effects.
3. Regularly maintain the building's heating and cooling systems.
4. Use timers to adjust the thermostat for periods of high and low usage.
5. Institute summer hours when applicable.
6. Encourage employee participation in energy conservation practices. ■

ILLUSTRATIVE EXAMPLE 23.3

Describe several of the environmental impacts that can be attributed to energy consumption.

SOLUTION**:** Energy production facilities that generate energy through the combustion of fossil fuels emit pollutants like CO_2, SO_2, and NO_x, which can lead to urban smog, acid rain, deforestation, water pollution, and (possibly) global warming. Generators can also produce large amounts of solid waste in the form of ash, slag, coke, and nuclear waste that can affect land and groundwater quality. ■

ILLUSTRATIVE EXAMPLE 23.4

The offensive odor of butanol (C_4H_9OH) can be removed from stack gases by its complete combustion to carbon dioxide and water. It is of interest that the incomplete combustion of butanol actually results in a more serious odor pollution problem than the original one. Write the equations showing the two intermediate malodorous products formed if butanol undergoes incomplete combustion.

SOLUTION**:** The malodorous products are butyraldehyde (C_4H_8O) and butyric acid (C_3H_7COOH), which can be formed sequentially as follows:

$$C_4H_9OH + \tfrac{1}{2}O_2 \longrightarrow C_4H_8O + H_2O$$
$$C_4H_8O + \tfrac{1}{2}O_2 \longrightarrow C_3H_7COOH$$

or the acid can be formed directly as follows:

$$C_4H_9OH + O_2 \longrightarrow C_3H_7COOH + H_2O$$

For complete combustion:

$$C_4H_9OH + 6O_2 \longrightarrow 4CO_2 + 5H_2O$$

■

ILLUSTRATIVE EXAMPLE 23.5

Even with an aggressive energy conservation program, the growing population will continue to demand increasing amounts of electricity. Identify and describe the environmental impacts, both positive and negative, of the two means of power generation: coal-fired steam boilers and nuclear power.

SOLUTION**:** The following answer itemizes the positive and negative aspects of each of the two energy generation methods from the standpoint of their impact on the environment.

A contemporary coal-fired boiler and electric generation facility requires three primary raw materials: coal (the energy source), water (for steam, cooling, and probably emissions control), and limestone (for emissions control of SO_2). Therefore, the potential impacts of raw materials suppliers and waste management, as well as the potential impacts of coal combustion, must be considered. Some negative impacts usually include:

1. Air pollution caused by SO_2, NO_x, particulate matter, and CO_2 (*potential* global warming).
2. Water pollution from boiler operations (thermal pollution).
3. Surface or groundwater contamination from mining of coal and limestone.
4. Land pollution from mining wastes and disposal of scrubber sludge (i.e., calcium sulfate).

Some positive impacts can include:

1. Producing huge amounts of electricity at one location where highly efficient environmental controls are cost effective.
2. Producing a potentially useful waste/by-product in the form of calcium sulfate.
3. Producing potentially useful surplus heat (e.g., hot water, low-pressure steam, etc.).

The principal raw materials for a nuclear power facility are uranium and water (for cooling). The potential impacts of nuclear fission must be considered, as well as the potential impacts of uranium mining and processing. Some negative impacts may include:

1. Accidental release of radiation to the environment (as recently encountered in Japan following the tsunami of 2011).
2. Thermal pollution of the cooling water supply.
3. Voluminous uranium mining and processing wastes since only a very small percentage of uranium bearing ore is beneficially used.
4. Difficult and costly storage and disposal of spent nuclear fuel, with a potentially continuous, indefinite threat to the environment.

Some positive impacts may include:

1. Producing huge amounts of electricity at one facility, although highly toxic waste volumes are relatively small.
2. Virtually contaminant-free stack emissions if the plant is operating properly. No particulate emissions, heavy metals from fuel combustion, etc., are generated from nuclear power.
3. No waste materials generated in the treatment of gas streams, so that the impact of nuclear power plants to the land are minimal when operated properly. ■

ILLUSTRATIVE EXAMPLE 23.6

In 1900, it took about 20,000 Btu fuel input to produce 1 kW · h of electricity. Estimate the efficiency of conversion and compare it with a typical value for today's power industry.

***SOLUTION*:** The solution to this problem is based, in part, on unit conversions. From standard conversion tables, 1 kW · h is equivalent to 3412 Btu. Since only 1 kW · h was being produced in 1900 from 20,000 Btu, the energy requirement (ER) was

$$\begin{aligned} \text{ER} &= (20{,}000\,\text{Btu})/(3412\,\text{Btu/kW}\cdot\text{h}) \\ &= 5.86\,\text{kW}\cdot\text{h} \end{aligned}$$

Since only $1\,\mathrm{kW \cdot h}$ was being produced, the efficiency (E) of energy conversion is

$$E = \frac{\text{Actual energy produced}}{\text{Energy production potential}}$$
$$= \frac{1\,\mathrm{kW \cdot h}}{5.86\,\mathrm{kW \cdot h}}$$
$$= 0.171$$
$$= 17.1\%$$

Today's energy conversion efficiency has improved over this value from a century ago (thankfully!), but not as much as many would like. Typical values range from 30 to 35% efficiency, or approximately 100% better than before. However, as one can see, there is significant room for improvement. ■

ILLUSTRATIVE EXAMPLE 23.7

The James David University runs it own coal-fired power plant, consuming Utah bituminous coal with an energy content (in the combustion literature, energy content is defined as the lower heating value, LHV) of 25,000 kJ/kg. The coal contains, on average, 1.0 wt% sulfur and 1.2 wt% ash (based on the total mass of the coal). The power plant is 35% efficient (indicating that 35% of the energy in the coal is actually converted to electrical energy), and is operated at a 2.0-MW average daily load (ADL).

Assume that the coal is completely burned during combustion, and also that the power plant captures 99% of the ash and 70% of the sulfur dioxide produced during combustion. After a U.S. Environmental Protection Agency (EPA) Green Lights energy audit, James David found that it could install energy-efficient lighting and reduce its average daily electrical generating needs by 25%.

Using the information given above, calculate the average reduction in electrical load and the new average daily load for the power plant.

***SOLUTION*:** The new electrical load will be 75% of the old electrical load with a 25% reduction in electrical load resulting from the implementation of energy conservation measures.

For a 2.0-MW power plant, the new ADL will be

$$\text{new ADL} = (2.0\,\mathrm{MW})(0.75)$$
$$= 1.5\,\mathrm{MW}$$

The average reduction (AR) in electrical load becomes

$$\text{AR} = (\text{new ADL}) - (\text{old ADL})$$
$$= 2.0\,\mathrm{MW} - 1.5\,\mathrm{MW}$$
$$= 0.5\,\mathrm{MW}$$

■

ILLUSTRATIVE EXAMPLE 23.8

Describe the health risk assessment process.

***SOLUTION*:** Health risk assessments provide an orderly, explicit way to deal with scientific issues in evaluating whether a health problem exists and what the magnitude of the problem may 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 examining risk, how does one decide how safe is "safe" or how clean is "clean"? To begin with, one has to look at both sides of the risk equation; that is, both the toxicity of a pollutant and the extent of public exposure. Information is required for both the current and the potential exposure, considering all possible exposure pathways. In addition to human health risks, one needs to look at potential ecological or other environmental effects. It should be remembered that there are always uncertainties in conducting a comprehensive health risk assessment and these assumptions must be included in the analysis.

In recent years, several guidelines and handbooks have been produced to help explain approaches for doing 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: hazard identification, dose-response assessment or hazard assessment, exposure assessment, and risk characterization (see Figure 23.1). For some perceived health problems the risk assessment might stop with the first step, identification, if no adverse effect is identified, or if an agency elects to take regulatory action without further analysis.[5] Regarding health problem identification, a 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. The identification process involves an evaluation of various forms of information in order to identify the different health 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 to cause adverse effects. This step frequently requires that assumptions be made to relate experimental data from animals and humans.

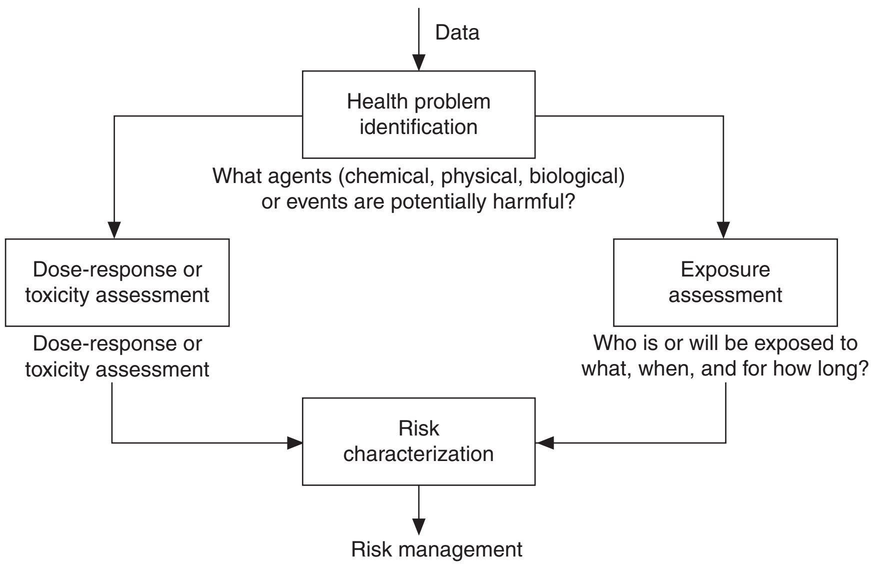

Figure 23.1 The health risk evaluation process.[5–7]

Exposure assessment is the determination of the magnitude, frequency, duration, and routes of exposure of human populations and ecosystems. Finally, in risk characterization, toxicology, and exposure data/information are combined to obtain qualitative or quantitative expressions of risk.

Risk assessment also 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 the aforementioned uncertainties associated with each of the major steps. All of the essential problems of toxicology are encompassed under this broad concept of risk assessment. Risk assessment takes into account all of the available dose-response data. It should treat uncertainty not by the application of arbitrary safety factors, but by stating them in quantitatively and qualitatively 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.[(4)] In effect, risk characterization is the process of estimating the incidence of a health effect under the various conditions of human or animal exposure described in the exposure assessment. As noted above, it is performed by combining the exposure and dose-response assessments, and the summary effects of the uncertainties in the preceding steps should also be described in this step.

Risk assessment and risk management are two different processes, but they are intertwined. Risk assessment and risk management give a framework not only for setting regulatory priorities but also for making decisions that cut across different environmental areas. Risk management refers to a decision-making process that involves such considerations as risk assessment, technology feasibility, economic information about costs and benefits, statutory requirements, public concerns, and other factors. Therefore, risk assessment supports risk management in that the choices on whether and how much to control future exposure to a suspected problem may be determined.

Regarding both risk assessment and risk management, this illustrative example primarily addresses this subject from a health perspective; the next chapter will primarily address this subject from a safety and accident perspective.

The reader should note that two general types of potential risks exist. These are classified as:

1. *Acute*. Exposures that occur for relatively short periods of time, generally from minutes to one or two days. Concentrations of (toxic) air contaminants are 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 adverse health effects. This subject area falls, in a general sense, in the domain of hazard risk assessment (HZRA), a topic treated in the next chapter.
2. *Chronic*. Continuous exposure occurring over long periods of time, generally several months to years. Concentrations of inhaled (toxic) contaminants are usually relatively low. This subject area falls in the general domain of health risk assessment (HRA) and it is this subject that is addressed in this example. Thus, in contrast to the acute (short-term) exposures that predominate in hazard risk assessment, chronic (long-term) exposures are the major concern in health risk assessments.

Finally, there are two major types of risk: maximum individual risk and population risk. Maximum individual risk is defined exactly as it implies (i.e., the maximum risk to an individual person). This person is considered to have a 70-yr lifetime of exposure to a process or a chemical. Population risk is basically the risk to a population. It is expressed as a certain number of deaths per thousand or per million people. These risks are often based on very conservative assumptions that may yield too high a risk. ■

ILLUSTRATIVE EXAMPLE 23.9

Provide a more detailed presentation on dose-response and/or toxicity.

***SOLUTION*:** Dose-response assessment is the process of characterizing the relation between the dose of an agent administered or received and the incidence of an adverse health effect in exposed populations, and estimating the incidence of the effect as a function of exposure to the agent. This process considers such important factors as intensity of exposure, age pattern of exposure, and other possible variables that might affect responses such as sex, lifestyle, and other modifying factors. A dose-response assessment usually requires extrapolation from high to low doses and extrapolation from animals to humans, or one laboratory animal species to a wildlife species. A dose-response assessment should describe and justify the methods of extrapolation used to predict incidence, and it should characterize the statistical and biological uncertainties in these methods. When possible, the uncertainties should be described numerically rather than qualitatively.

Toxicologists tend to focus their attention primarily on extrapolations from cancer bioassays. However, there is also a need to evaluate the risks of lower doses to see how they affect the various organs and systems in the body. Many scientific papers focus on the use of a safety factor or uncertainty factor approach, since all adverse effects other than cancer and mutation-based developmental effects are believed to have a threshold—a dose below which no adverse effect should occur. Several researchers have discussed various approaches to setting acceptable daily intakes or exposure limits for developmental and reproductive toxicants. It is thought that an acceptable limit of exposure could be determined using cancer models, but today they are considered inappropriate because of thresholds.[5–7]

Dangers are not necessarily defined by the presence of a particular chemical, but rather by the amount of that substance one is exposed to, also known as the dose. A dose is usually expressed in milligrams of chemical received per kilogram of body weight per day. For toxic substances other than carcinogens, a threshold dose must be exceeded before a health effect will occur, and for many substances, there is a dosage below which there is no harm; i.e., a health effect will occur or at least will be detected at the threshold. For carcinogens, it is assumed that there is no threshold, and, therefore, any substance that produces cancer is assumed to produce cancer at any concentration. It is vital to establish the link to cancer and to determine if that risk is acceptable. Analyses of cancer risks are much more complex than those for non-cancer risks.

For a variety of reasons, it is difficult to precisely evaluate toxic responses caused by acute exposures to hazardous materials. First, humans experience a wide range of acute adverse health effects including irritation, narcosis, asphyxiation, sensitization, blindness, organ system damage, and death. In addition, the severity of many of these effects varies with intensity and duration of exposure. Second, there is a high degree of variation in response among individuals in a typical population. Third, for the overwhelming majority of substances encountered in industry, there is insufficient data on toxic responses of humans to permit an accurate or precise assessment of the substance's health potential. Fourth, many releases involve multiple components. There are presently no rules on how these types of releases should be evaluated. Fifth, there are no toxicology testing protocols that exist for studying episodic releases on animals. In general, this has been a neglected area of toxicology research. There are many useful measures available to employ as benchmarks for predicting the likelihood that a release event will result in serious injury or death.

Not all contaminants or chemicals are equal in their capacity to cause adverse effects. Thus, clean-up standards or action levels are based in part on the compounds' toxicological properties. Toxicity data employed are derived largely from animal experiments in which the animals (primarily mice and rats) are exposed to increasingly higher concentrations or doses. As described above, responses or effects can vary widely from no observable effect to temporary and reversible effects, to permanent injury to organs, to chronic functional impairment, to, ultimately, death. ■

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