CHAPTER 11

THE STUDY OF RISK

Finally we come to one of the most difficult tasks that confronts toxicologists, physicians, and each individual: assessing risk. There is probably no human activity that does not carry with it some risk. However, it is only in recent years that risk has become something we frequently think about. What is the risk of having a heart attack? What is the risk of getting AIDS? What is the risk of an earthquake or a tornado? What is the risk of a nuclear disaster? What is the risk that greenhouse gases will cause the ice caps to melt? Our concerns run the gamut from personal to global. What do we mean by the word *risk,* and how do we evaluate it? And, when it comes to chemicals, not only what is the risk, but also what benefit does that chemical confer, and how do we as individuals and as members of society decide whether the benefit derived is greater than the risk taken? In this chapter, we define *risk* and look at some ways in which to understand the risk-benefit ratio.

Risk refers to the chance that some unpleasantness, injury, loss, or other harm will befall us or someone or something we are concerned about. A consideration of risk, either intentionally or unknowingly, probably has always been part of human thought processes. Even small children rapidly learn the risks of arousing parental ire. Hardly a day goes by that we do not consider the risk presented by some activity, even if it is as simple as not carrying an umbrella when the skies are threatening. Risk has many facets. We hear of risk, risk assessment, perceived risk, acceptable risk, unacceptable risk, risk-benefit, risk communication, risk management, and so forth. To understand these concepts better, we begin by looking at public health statistics, which provided the earliest systematic basis for evaluating risks that affected groups of people.

PUBLIC HEALTH STATISTICS

A major goal of public health agencies is the prevention of disease. In order to accomplish this, the nature of diseases and their incidence in the

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population must be known. The bookkeeping of public health serves this mundane but essential role by compiling vital statistics, the record of births, deaths, and morbidity. One use of vital statistics is to provide estimates of risk of occurrences of diseases.

The traditional method of expressing risk of disease has been based on historical information organized in the form of cause-specific death rates. These rates are calculated from the actual experience of a population group by counting the total number of people who died during a specified time period from a particular disease and dividing the deaths by the population at risk for that disease. The result, a number between zero and one, is the fraction of the population that died from the disease. To make this fraction a whole number, public health statisticians usually multiply the fraction by 100,000. The result is the number of deaths per 100,000 people in a specific population, say the United States or Europe. For example, the rate of death from breast cancer among Caucasian females living in the United States during 1990 to 1994 was approximately 0.00026, or 26 per 100,000.

Public health statistics can be used to compare the relative impact of various diseases, to examine the trend of diseases over a period of time, or to demonstrate the effectiveness of treatment of that disease. For example, in 1950, the death rate from Hodgkin's disease (lymphoma) among white males was approximately 2.3 per 100,000. Statistics for 1994 showed that the death rate decreased to 0.68 per 100,000, demonstrating the results of more effective cancer chemotherapy (see National Cancer Institute, Cancer Mortality Maps and Graphs, http://cancercontrolplanet.cancer.gov/atlas).

Such statistics also can be used to predict future risk presented by various causes of death. In making predictions, an assumption is made that next year will be about the same as past years or next year will follow the trend established by past years. Depending on the nature of the disease, such forecasts can be quite accurate. A good example of this is actuarial forecasting made by insurance companies. Such forecasts are based on statistical calculations of life expectancy and the causes and rates of death according to population age groups. Causes may be age, accidents, or other risks covered by the insurance company. Risks are calculated for the purpose of determining what premiums the company should charge for insurance. In making their estimates, actuaries consider factors that modify risk, such as age, smoking practices, obesity, and past history of disease. The financial strength of the insurance industry over a period of many years is evidence that risks for populations can be estimated with fair accuracy by using historical information on adverse outcomes and by continually adjusting these estimates as new information is available. Of course, the risk of any one individual dying during a particular time frame cannot be calculated with any certainty.

INHERENT RISK

The risk inherent in any situation or activity is one that cannot be modified by whether it is considered acceptable or unacceptable, how great or small it is perceived to be, or even whether it is recognized as a risk. Risk can be changed only by altering the conditions that produce the risk. For example, the risk of developing cardiovascular disease from eating a diet high in sugar cannot be changed by accepting or rejecting the risk, by considering it to be important or of no consequence, or by not knowing that it exists. The risk can be modified only by changing the diet or other factors responsible for it.

The actual chance that some harm or loss will occur, and how great or small the inherent risk is, cannot be known exactly, but in some cases, it can be approximated. For example, no one knows the true risk of any one 40-year old individual developing lung cancer from smoking for 20 years, but the chances can be estimated by examining the large body of data on the association between smoking and lung cancer. Risk estimates based on actuarial data can be quite accurate because they are based on records of adverse outcomes in large population groups. Further, the accuracy of the assumptions made for the estimates can be tested by how well they predict future occurrences.

However, many of the risks we face, particularly those associated with low-level exposure to environmental agents, cannot be estimated using traditional public health statistics. One reason is that morbidity and mortality statistics are based on medical diagnoses of causes of illness or death. The attending physician or autopsy pathologist can identify the immediate cause of death, such as bronchial cancer, leukemia, pancreatic cancer, or cardiovascular disease. At the present time, however, in many cases, medical science is unable to reveal what caused the cancer or other disease. This is especially true in the case of chemicals for which there are no known associations between exposure and some form of cancer.

Even with the very strong association between smoking and lung cancer, it can never be stated with certainty that a cancer in the lung of an individual smoker was caused by smoking. The reason is that although respiratory cancers, such as squamous cell cancer of the lung, are associated with smoking, they also occur in nonsmokers. If a squamous cell cancer occurs in a smoker, the chances are good that it was caused by smoking. However, it cannot be known for sure that the cancer would not have occurred if the person had not smoked. We all know this from the startling information that a friend who never smoked died of lung cancer while the fellow who smoked like a chimney is still going strong at age 85. If

there were a true one-to-one correspondence between smoking and lung cancer *and there were no other causes of lung cancer*, then this could not have happened.

In the case of cigarette smoking, very large population studies have shown a clear association between smoking and increased rates of respiratory cancer. Studies with rodents have shown that smoke will produce higher rates of respiratory cancer. Some of the carcinogens in cigarette smoke have been identified and shown to cause cancer in test animals. Yet, as stated, despite all of this evidence, it is impossible to prove that a particular respiratory cancer in an individual was caused by smoking. It is possible only to say that, based on population statistics and animal experimentation, the risk of respiratory cancer in that person was very much higher than it would have been had he or she not been a smoker.

With the exception of some very rare cancers that appear to be caused only by specific carcinogens, it is impossible to determine the actual cause of any cancer in an individual. Similarly, birth defects can be recorded, associations determined, and risks of occurrence estimated, but the specific cause in individual cases usually cannot be determined.

There are no statistics for many of the risks we face, such as the risk of cancer from environmental exposures to chemicals, but there are no known cases of cancer (or birth defects) caused by exposure to trace quantities of any environmental chemical, natural or synthetic. As a general rule, medical diagnosis alone is unable to show a relationship between exposure to very small quantities of any chemical and cancer or birth defects. Thus, estimates of the risk of cancer or birth defects from exposure to trace amounts of a chemical cannot be based on a known incidence, nor can the accuracy or validity of the estimates be tested. In short, we can estimate the risk of occurrence of a particular kind of cancer, but we cannot accurately estimate the fraction, if any exists, of a particular cancer risk attributable to exposure to trace amounts of chemicals. The same is not true for certain medications (which are not found in the environment) for which animal studies clearly show that the drug produces a specific and rare defect and where the mother took the drug during the period of organogenesis (e.g., phocomelia produced by thalidomide).

It is important to note that a few diseases are caused by environmental agents that are directly diagnosable. Lead poisoning is a good example, even though the early symptoms of low-level exposure are vague and not particularly different from those of many minor illnesses. These symptoms include decreased physical fitness, tiredness, sleep disturbance, aching bones and muscles, abdominal pains, and constipation. Despite the vague symptoms, laboratory tests for levels of lead and certain biochemicals in blood can

identify the cause of the illness and provide an estimate of the degree of poisoning.

Another example of an environmental agent that can be traced by the disease it produces is the organic chemical vinyl chloride. Studies of workers exposed to very low levels of vinyl chloride have shown that this chemical causes an extremely rare liver tumor known as angiosarcoma, which is almost never found in people with no exposure to vinyl chloride. Additionally, another relatively rare tumor, mesothelioma, usually can be attributed to asbestos.

RISK ASSESSMENT

When chronic toxicity testing became a common requirement less than a century ago, the emphasis was on what was a safe amount of exposure for the population rather than on the risks associated with trace quantities of chemicals in foods. Tests were designed to determine no-effect levels in animals, and permissible levels for human exposure were set by applying margins of safety to those levels determined by animal experimentation. Despite subsequent cries of outrage that so many carcinogens had been permitted to contaminate our food supply, the process worked well. We will use cancer as a model to explain the risk assessment process, but remember that this process works for other illnesses and for side effects from environmental chemicals and drugs.

During the past decade, a large number of chemicals has been retested using more sophisticated and more sensitive techniques. Except for a few chemicals that had a long history of use, such as some food color additives, retesting has not produced information requiring significant changes in regulatory procedures to protect public health. Despite the greatly increased use of synthetic chemicals in food production and processing during the past century, the general health of the nation has improved and life expectancy has gradually increased, increases that can be attributed to better nutrition, cleaner air, and better diagnosis and treatment of disease.

Increased public awareness that some chemicals can cause cancer created the demand for government regulation of chemical carcinogens and thus the need to estimate carcinogenic risk and to set safe levels of exposure to such chemicals. There are two very serious obstacles to such a task. One, mentioned previously, is the lack of data. Except for cancers resulting from occupational exposures and a few rare forms of cancer known to be caused only by specific carcinogens, there are no documented cases of human cancer from exposure to trace quantities of chemical carcinogens. Despite the

conviction that trace amounts of chemicals, such as pesticide residues, are causing cancer, those cases cannot be identified because, even if they occur, they are so rare that they are hidden in the background incidence of cancer. If they cannot be identified, they cannot be counted.

The second obstacle to estimating carcinogenic risk and setting safe levels of exposure is the theory that there is *no* safe level of exposure and thus that regulatory agencies reject the use of classic no-effect levels and thresholds in establishing permissible levels of exposure. The decision that the initiation of a cancer process is a chance event requires a new approach for evaluating safety, a procedure called risk assessment.

Risk assessment is the procedure that is used to estimate the chance that an untoward event will occur. In cancer risk assessment, the untoward event is the occurrence of one or more cases of cancer resulting from exposure to a given quantity of carcinogen. Originally, the one-hit (chemical bullet) model was used to estimate such risk, as described in Chapter 7.

All available scientific data on the subject indicate that chemical carcinogens do not act on this simple chance basis. A number of other controlling or modifying factors must be included in carcinogenic risk analysis. This fact greatly complicates the risk assessment process. The simple one-hit model was expanded into a multistage model based on the premise that, in addition to one hit by a molecule of carcinogen, one or more other conditions must be present, simultaneously or sequentially, to initiate a cancer. The one-hit model might be likened to the proposition that an automobile will start when the ignition is turned on. A multistage model would add the requirement that the battery be charged and the tank contain fuel.

Numerous multistage statistical models have been developed to assess cancer risk from exposure to known or suspected carcinogens, because no one model seems to apply in all situations. To date, a few have been accepted as appropriate, but improvements and refinements continue. The multistage models currently used in cancer risk assessment assume that a chemical that causes cancer in an animal study can cause cancer in humans, that human exposure to the carcinogen is daily for a lifetime of 70 years, and that one molecule of carcinogen is capable of causing cancer. Based on these assumptions, assessments are then made to determine what level of carcinogenic risk is associated with various levels of human exposure to a specific chemical.

Those charged with protecting the public against dangerous exposures to carcinogens obviously must have some means for making estimates of what exposures are dangerous and what exposures would be virtually safe. However, in the process of estimating risk, mathematical models and formulas should be an adjunct to, not a substitute for, scientific judgment. In addition, regulatory agencies must be free from special-interest pressures if the

standards they promulgate are to be based on concern for the public good, not political expediency.

A review of a large mouse study (see Chapter 7) by the Society of Toxicology (SOT) includes a concise, clear statement that addresses the issue of cancer risk assessment:

> The SOT Task Force recognizes the need for establishing acceptable exposure levels and the significant need for societal (regulatory) understanding of the effects of chronic low level exposure to potential carcinogenic materials. The Task Force further acknowledges that the determination of the acceptability of risk is a societal (regulatory) decision. However, the Task Force strongly asserts that the evaluation of toxicological responses (carcinogenic or otherwise) and the estimation of risk to a given exposure is a scientific endeavor and must be conducted free and separate from regulatory considerations. The scientific estimate of risk must use appropriate methods (models) to obtain "best" estimates for risk with levels of confidence clearly stated. The use of the most conservative methods (models) for estimating risk can be both scientifically inappropriate and misleading to those charged with the responsibility of setting levels of acceptable risk. When "best estimates" models are used which incorporate time to tumor data into risk assessment as opposed to only adjusting for time, the ED01 Study demonstrates that linear quantal models, i.e., non-threshold models, do not fit the data and non-linear models which often suggest practical thresholds provide a better expression of observed responses.
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> —Reexamination of the ED01 Study, *Fundamental and Applied Toxicology* 1, no. 1 (1981): 29.

The literature is replete with papers describing the various models used for carcinogenic risk assessment. The journal *Risk Analysis*, the official journal for the SOT, debuted in March 1981 in response to the increasing need for communication among scientists and regulators. This journal is an excellent source for anyone interested in more information on the subject of risk. It presents papers dealing with all aspects of risk, not just risk assessment procedures.

A good deal of knowledge of statistical methodology is necessary to understand the models used in risk assessment. People without such knowledge, but who want more information on risk assessment, will find the review written by Hopper and Oehme of the risk assessment process, its history, its definitions, and its methods a valuable introduction to the subject ("Chemical risk assessment," *Veterinary and Human Toxicology* 31, no. 6 (1989): 543–554).

Here is a real-life example of a cancer risk assessment performed by the California Office of Environmental Health Hazard Assessment. Acrylamide

is a by-product that results when carbohydrates such as potatoes are cooked at high temperatures. The State of California has listed acrylamide as a cause of cancer and birth defects or other reproductive harm as required under Proposition 65, a California ballot initiative enacted in 1986 which requires the state to publish a list of chemicals known to cause cancer or birth defects. Let us assume for this example that the animal data on acrylamide are an accurate predictor of human toxicity.

Although it is possible to lower the amount of acrylamide in cooked foods, it is not possible to eliminate it altogether because of food processing methods. Unless you become a raw foodist, you will always ingest some acrylamide each day. Based on an analysis of fast-food french fries, various brands of potato chips, and other foods processed at high temperature, the risk assessment calculations found that if 100,000 people ate french fries once every 26 days for their entire lifetime, one additional case of cancer would result. For potato chips, one additional case would result if 100,000 people ate a serving of chips every 14 days. And for coffee, where acrylamide is produced in the roasting process, one cup every 3 days would lead to an additional case of cancer.

As you can see from this calculation, the effect of eating fried foods in moderation would be extremely difficult to detect, given the background incidence of cancer. However, if one takes into account the fact that many Americans eat fast food every day and that french fries are a large component of such meals, the increase in cancer due to acrylamide would be considerably larger. *But* the effect on obesity and the resulting decrease in life expectancy from eating fries daily is so much greater than the possible carcinogenic effect that when choosing your lunch or dinner menu, you should be more concerned about your weight due to the ingestion of all that fat and potatoes.

Before you run out and pitch all cooked carbohydrate-containing foods, remember that humans have been exposed to acrylamide ever since a person first tossed a potato into the fire and that the rat study showed a 10 percent increase in cancer at a dose about 900 times greater than the normal human diet. So, based on what we have discussed in this book concerning thresholds for cancer-causing agents, the applicability of animal data (especially rodent data) to humans, and perhaps even hormesis, it is up to you, the consumer, to decide whether to take the possible cancer risk by eating temperature-processed foods.

PERCEIVED RISK

How people perceive risk has been the subject of many social and psychological studies because of its importance in making decisions to control risks.

Legislators and regulators can obtain assessments of risk from scientists and statisticians. However, since the public often perceives a risk differently from the way it is described in risk assessment, legislators also must know how the public views the risk and the reasons for its perception.

Decisions by local government agencies are based on the public's perception of risk more often than on assessments made by scientists. A major goal of politicians is to be reelected, a goal that will not be achieved by antagonizing the electorate. Since local officials are closer to their constituents than state and federal officials, they are more vulnerable to public displeasure. For example, no matter how small a risk of reduced air quality is posed by a waste-to-energy conversion plant, and despite great need for management of household waste, some people will oppose having such a facility in their community because they consider the risk associated with incineration unacceptable, particularly in their own neighborhoods. The decision by local officials about building such a facility would depend largely on the strength of the opposition rather than on scientific or statistical risk assessment.

Risk perception is a very personal matter, and a very complex one. Just as no two people have the exact same fingerprints, so there are no two people who have the exact same perceptions of all possible risks. Risks may be viewed similarly by people who share the same value system, but many risks are not so linked. For example, some people are terrified of flying, but others enjoy it immensely without fear. Yet some people from both groups share a perception that smoking cigarettes is a very dangerous activity while others from both groups enjoy smoking and consider that the surgeon general's warnings are considerably overexaggerated or not pertinent to them. The risks associated with flying and with smoking, like so many other risks, are not coupled; they are viewed independently.

A brief mention of some of the factors that influence the perception of risk may be of value to understanding one's own perceptions, particularly those relating to risks associated with chemicals. The closer the public's perception of a specific risk agrees with the risk determined by an objective scientific and statistical risk assessment process, the greater the chance that regulatory decisions will be based on knowledge rather than on emotion, and the greater the chance that good and lasting benefit will accrue to society from the controls imposed. When all facets of society, industry, government, and the public agree on the magnitude of a risk, political decisions made to control the risk will be more generally acceptable, and cooperation with regulations will be easier to achieve.

Education is an obvious factor in risk perception. As a general rule, people who are highly educated in one discipline see the risks associated

with the technologies developed from their disciplines much differently from people educated in other fields. Recent concerns about genetic engineering provide an example of how the difference in perception of risk depends on the education people possess. Microbiologists view the risk to public or environmental health from the manipulation of genetic composition of microorganisms differently from people educated in other disciplines. They know the processes, the significance of the alterations, the controls employed, and so forth.

People who have a college education perceive risks differently from people who do not. These differences cannot be attributed to less intelligence, since many people with above-average intelligence do not go beyond high school for a number of reasons, including financial resources, lack of interest in academic subjects, and family or peer pressures. The same can be said for blue-collar workers, who often see the risks associated with their occupations as being less than indicated by statistics on occupational illness and injury.

A primary source of information for a majority of people is the news: television, radio, print media, and the Internet. Television and radio commentators seldom have the luxury of delving into any news story with the breadth and depth required to provide viewers with enough facts to make informed decisions. Journalists who write for newspapers and magazines have more time to ascertain facts and more space to present a balanced story. Some may see themselves merely as reporters, but they are in fact educators. Those who write blogs may be biased and present information that supports their agenda.

Education is only one of many factors that influence perceptions of risk. Others can be of equal or greater importance, depending on the nature of the hazard and the risk involved. These factors include such diverse conditions as social status, economic status, age, sex, sexual orientation, national origin, place of residence, racial and cultural background, religious orientation, and the opinions of friends and relatives.

ACCEPTABLE RISK

The acceptability of a risk may be viewed on two levels, societal and personal. On the societal level, the process is generally something like this: The responsible governmental agency holds public hearings to obtain testimony from scientists and members of the public. After all information is gathered, the agency quantifies the risk using statistical methods described in the section on risk assessment. Next must come a policy decision as to how much

risk is acceptable. In the case of cancer risk assessments, regulatory agencies are faced with the weighty responsibility of deciding how many cancer cases due to a carcinogen would be acceptable. Government officials, acting for society, have decided that one excess cancer in a population of a million constitutes an acceptable risk.

Several problems are associated with assigning a specific number of cases of cancer that are considered acceptable. One problem is the false impression that the figure is a matter of scientific fact rather than a statistically derived estimate. It delivers the erroneous message that one in a million people—no more, no less—will actually develop cancer from exposure to the chemical in question. It misleads the public into believing that one extra case of cancer in a population of a million people actually could be measured and the cause could be identified. Finally, it frightens people who fear that they or one of their loved ones may become that one unfortunate soul in a million. They wonder why their government would consider that any extra cases of cancer are acceptable. Stevie O. Daniels, former executive editor of the magazine *Organic Gardening*, articulated these concerns in her March 1989 editorial:

> The EPA defines negligible risk for adults as a one-in-a-million chance of getting cancer from a particular residue in a lifetime. … That means roughly 231 people will develop cancer. … What kind of a world do we have if we accept the incidence of cancer in one in every million people?

On a personal level, the determination that a risk is acceptable (or unacceptable) is quite a different matter. Often people reject societal decisions concerning acceptability. The organic food movement is a case in point. People who purchase only produce grown without the use of synthetic pesticides reject the societal decision that the risk of cancer from exposure to trace quantities of pesticides is negligible (acceptable).

As another example, statistical analysis shows definitively that wearing a helmet while on a motorcycle leads to reduced head injury in accidents, yet some people are willing to take on the risk of riding without a helmet, despite laws requiring the wearing of helmets in some states. Society is not willing for its people to take on this risk, but individuals may be. The risk of side effects from mosquito spraying may be quite small (and the benefit of preventing West Nile disease quite large), but because individuals do not have a choice in this matter—their streets will be sprayed whether they want them to be or not—they may be less willing to take on this small risk than the larger but personal risk of not wearing a motorcycle helmet or not buckling a safety belt. Personal decisions concerning the acceptability of risk are

not based on statistical models but rather on how the risks are perceived. Whether the risks are familiar or foreign, voluntary or involuntary, result in a mild inconvenience or a disaster, and so forth, all play a role in their acceptance or rejection by individuals.

RISK BENEFIT AND COST BENEFIT

Risk benefit and cost benefit might be likened to two sides of a coin. The former balances the risk involved in some action or event against the benefit derived. The latter examines the cost of some action, such as reduction of a risk, in relation to the benefit achieved.

Almost every risk can be subjected to evaluation of benefits and costs from both personal and societal perspectives. Using the earlier example, the risk of not wearing a helmet when riding a motorcycle is suffering a massive head injury. For the individual, the benefit of not wearing a helmet might be the pleasure of feeling the wind blow through her hair. Some cyclists feel the benefit is worth the risk. For society, there is no benefit. Society has enacted laws requiring the wearing of helmets; such laws demonstrate its decision that, in the absence of benefit, the cost of caring for people permanently disabled with massive head injuries is unacceptable.

Chlorination of drinking water is another example in which there are individual and societal risk-benefit and cost-benefit considerations. Public drinking water supplies are chlorinated to kill pathogens that cause serious illness or death. The risk from chlorination is the production of trace amounts of chemicals, such as chloroform, suspected of causing cancer. The risk of not chlorinating public water supplies is the occurrence of mass outbreaks of waterborne diseases, such as cholera. For society, the former risk is negligible whereas the latter risk is unacceptable. The benefit of chlorination is considered to be greater than the cost. Most people probably give little thought to the matter. However, for a few individuals, the risk of exposure to trace quantities of carcinogens, no matter how slight, is unacceptable. For them, avoiding the perceived risk is worth the cost of bottled water. However, the risk from plastic eluting from these water bottles into the water should be accounted for in this personal equation, as well as the cost to society for disposal of the empty bottles. No risk-benefit equation is really as simple as we think.

The regulation of chemicals, particularly those that cause or are suspected of causing cancer, is the result of public demand for such controls. Few would dispute the need for government regulation of hazardous chemicals to protect public health from exposure to toxic and carcinogenic chemi-

cals in workplaces, homes, and the general environment. In addition to the need for regulation, legislators recognize that risks, benefits, and costs must all be taken into account when setting standards for chemical exposures, because regulation of chemicals costs money—taxpayers' money. Unfortunately, people usually do not consider the cost of regulation and are not as involved as they should be in demanding rigorous risk-cost-benefit evaluations from their government officials.

The regulation of chemical carcinogens is a case in point. The cancer risk models used by regulatory agencies assume that one molecule of a carcinogen is capable of initiating a cancer process, that exposure to the carcinogen is a lifetime exposure (daily exposure for 70 years), and that data obtained from animal carcinogenicity studies are directly translatable to humans. Cancer risk estimates derived from these models are very conservative because of the nature of the assumptions on which they are based. It is usual and appropriate for public officials to err on the side of safety in matters relating to public and environmental health, if they are going to err at all. Regulatory agencies acknowledge that the cancer risk estimates currently being used for regulatory purposes have a large error on the side of safety. Thus, if the assumptions are incorrect, the errors can result only in excess safety for the public, not less safety. But if regulations are based on risk assessments that are in error by several orders of magnitude, the benefits to society could well be negligible or nonexistent and the costs to taxpayers could be overburdening.

As an example, the U.S. Department of Agriculture had a program in place for over 15 years that tested the concentrations of pesticides in various food crops; the data, along with Environmental Protection Agency (EPA) data on pesticide use, were collated and used to set acceptable food limits for pesticides. This program cost about $8 million per year. In 2008, the administration decided that budget cuts needed to be made and eliminated this program. The groups that used these data can now obtain the data from a private company for a fee, but many critics feel that the government data were more reliable and, of course, less expensive. Apparently, the government's risk assessment revealed that the cost of the analysis was not worth the benefit of knowing the pesticide levels.

Society has the right to decide on the level of safety it wants. It also has a right to know the cost increments for each increase in degree of safety so it can decide if the benefits are worth the cost. However, risk, benefit, and cost evaluations are proper only when the risk takers, benefit receivers, and pocketbooks are the same or equivalent. For example, assume that a person decides to paint his house himself to save money. One risk he faces is injury from falling off the ladder. The benefit is that he saves money. The risk and

benefit are equitable—he takes the risk and he reaps the benefit. Now assume a factory decides to speed up an assembly line to increase profits. One risk is that a worker may suffer injury from the more rapidly running machinery. The benefit is increased profits for the company. In such a situation, the risk and benefit are not equitable—the worker takes the risk and the company receives the benefit.

The risk-benefit ratio for drugs is easier to calculate because drugs are taken for their benefit. Most of us don't really understand the risk involved and so we are unable to make a true risk-benefit calculation. For example, perhaps you have rheumatoid arthritis and are severely limited in your ability to perform the everyday tasks of life. The doctor recommends one of the newer tumor necrosis factor (TNF) antibodies on the market (e.g., Humira® or Embrel®). You read the label and see that a rare side effect of the drug is leukemia. Now you must make a risk-benefit assessment for yourself based on how rare is the leukemia, your age (so you can estimate for how long you will take the medication), your severity of impairment, the cost, and whether insurance will pay. In the end, most people with severe rheumatoid arthritis who can afford these expensive drugs end up taking them and benefit from a better quality of life. However, some people who are terribly afraid of getting cancer will refuse. Both choices are acceptable because each person has calculated his or her own level of risk and compared it to the expected benefit. What is not acceptable is to accept these drugs (or any drug) without examining the risk-benefit relationship.

But the choice is not always so easy. Take the case of anemia where the doctor recommends taking an iron supplement. Eating liver instead of taking the supplement might be an option. Liver is high in iron, is relatively inexpensive as a protein source, and no one ever overdosed on liver, Alternatively, iron supplement pills are inexpensive and are easy to take; but one can overdose on these pills, and iron overdosage is especially dangerous for children in two ways:

1. Children under the age of six can accumulate iron from too much daily supplement, which can lead to serious disease.
2. Iron pills, which look like little candies, may be stored where children can access them easily, leading to an acute overdose causing metabolic shutdown and leading to serious consequences.

It is estimated that over 20,000 children each year accidentally ingest iron, making iron overdose one of the leading causes of death by a toxic agent in young children.

RISK COMMUNICATION

Risk communication embraces the very delicate task of explaining all aspects of risks to the public. People are perfectly capable of understanding complex subjects that are of interest or importance to them if they are explained correctly. Unfortunately, government, industry, and academic scientists are not always capable of making such explanations understandable. Scientists and bureaucrats have much to learn about communicating with the public.

People also have a responsibility. They must appreciate that most scientists have little experience in communicating with the public and that some are intimidated by doing so. People should attempt to learn the meaning of some scientific words and terms to help them better evaluate conflicting opinions about risks. Some civic groups, such as the League of Women Voters, provide forums for interaction between scientists and the community because they recognize the need for public understanding of environmental issues. Industry, consumer groups, government, environmental groups, and civic groups must learn to communicate with each other to discuss openly and rationally the pros and cons of arguments relating to environmental matters.

Risk communication can carry with it its own special kind of risk for scientists who attempt to explain their science to the public objectively and in nontechnical terms. In doing so, they face the risk of being labeled apologists by one side or the other of an issue, and perhaps by both. This is particularly true in the fields of toxicology and carcinogenesis. Scientists who attempt to put the risks from exposure to trace quantities of synthetic chemicals into proper perspective are met with derision by environmental partisans. As a result, some scientists are hesitant to take part in public debates. Scientists face similar issues in the debate about evolution versus creationism or intelligent design, so many just stay quiet and out of the debate.

Journalists form one of the most important communication links between science and the public. Much of what the public knows about the risks and benefits of science and technology is obtained from television, newspaper, magazine, and Internet stories. Even scientists themselves gain some of their knowledge of other sciences from these same sources: the media. The importance of journalists in informing the public and, as a consequence, shaping public policy cannot be overstated. In *Health Risks and the Press* Victor Cohen, a senior writer for the *Washington Post*, has described the journalist's position:

> Whether we like it or not, we journalists have become gatekeepers. In some measure, our choices of what will be reported, and how the data will be reported, set the national agenda vis-a-vis health risks. In a sense, we have become part of the regulatory machinery. … The very way we

> report a situation can affect the outcome. If we ignore a bad situation or write a "no danger" piece, the public may suffer. If we write "danger" the public may quake.
>
> —M. Moore, ed., *Health Risks and the Press*
> Washington, DC: Media Institute, 1989.

Of course, this is also true of all other sources of news as well.

Journalists are often blamed for the public's misunderstanding, or lack of appreciation, of the safety or danger of some technology, when circumstances beyond their control may really be at fault. Journalists can communicate only that information given to them by their sources, who may not express themselves clearly, may exaggerate, or may voice conflicting opinions; experts of seemingly equal repute often disagree with each other. In addition, there are the ever-present time and space constraints that limit a journalist's ability to explain the nuances of a story. These constraints probably are also responsible for some instances in which scientists feel they have been misquoted or their words have been taken out of context. And finally, the public's penchant for stories that are brief, with dramatic or frightening headlines, guides editors, who are the final authority about what gets into print. We all know that the nine-second sound bite is what makes the news, regardless of how complex the story may be.

The majority of professional journalists are truly interested in serving their communities through the media. Those who attempt to explain both sides of issues so that readers can form their own opinions perform a valuable public service. Further, good journalists investigate the competence and biases of their sources so they can better evaluate the information they receive. Journalists who permit their personal biases to influence the content of their news stories can do a great deal of damage, particularly if they write well and interestingly. Unfortunately, some journalists who let their biases show in their reporting do not recognize their own failing. They may feel they are performing a public service, but if they misinform and mislead the public, deliberately or inadvertently, they are subverting an informed electorate. People who have access to reports of journalists who present all sides of an issue, particularly science issues, free of editorializing, are truly fortunate.

The popular press is also an important avenue for risk communication. A number of scientists, through lectures, essays, and books, have become as influential as journalists in forming public opinion. Some of these scientists describe the risks to society presented by science and technology in general and the petrochemical and drug industries in particular. Some have publicly aligned themselves with one or more environmental or social causes that they support with great fervor. Other scientists who are unaligned with any pro- or anti-chemical movement attempt to provide the public with a bal-

anced perspective of the risks associated with chemicals in the environment. Several in the latter group attempt to counter the biases that feed poison paranoia by examining the arguments, actions, and motives of the anti-science and anti-technology movements.

Unfortunately, there are some people whose minds are closed to any idea contrary to their beliefs, regardless of whether they are convinced that some technology is perfect and has no drawbacks or that some technology is bad and has no virtues. There can be no communication with people with closed minds. Fortunately, they represent a minority of the public. The majority do have open minds and are willing to listen to opposing views. In scientific matters, as in every other facet of human endeavor and interaction, there is no substitute for communication.

RISK MANAGEMENT

Risk management is the control of risk by eliminating or modifying the conditions that produce it. People practice risk management in every aspect of daily life, often without realizing it. The parent who stores medicines and household chemicals out of a child's reach is practicing risk management. The driver who fastens a seat belt is practicing risk management. The hobbyist who provides good ventilation in the area where solvents are used is practicing risk management. The gardener who puts on protective clothing before spraying pesticides is practicing risk management. The chemist who puts on safety glasses before entering the laboratory is practicing risk management.

Governments practice risk management by passing rules and regulations that specify procedures for controlling risks and penalties for disregard of the procedures. The risks managed by governments are those that affect the public in general or specific groups of people. Businesses, industries, and public agencies become the risk managers by complying with the rules and regulations. However, before government can manage a risk, it must be recognized and described, and its importance to society must be evaluated. This process requires time, money, and considerable effort in laboratory and field research. The public, not recognizing the difficulties involved in the process, often becomes impatient with regulatory agencies for not acting rapidly enough to protect it or becomes angry at the costs involved. The risk management agencies that have suffered the greatest amount of criticism are EPA and FDA, both of whose jobs are to reduce risk to the U.S. population.

EPA was created in 1970 with the broad and almost unmanageable mandate to protect both public health and environmental health. It was

created in response to public concerns that pesticides were destroying the habitat and the inhabitants of the planet. In its almost 40 years of existence, EPA has done fairly good job, despite the tremendous difficulties under which it has had to operate. It has restored the ecological balance in some locations that formerly had been sites of major water or air pollution and has prevented further deterioration in other areas.

The function of FDA was created in 1906 with the passage of the Pure Food Act, which contained regulations to prevent the sale of adulterated products. Consider that prior to this time, cocaine and arsenic, for example, were available over the counter in various foods and medicinal products. The passage of this seminal legislation and its various additional laws over the years has led to a considerably safer consumer environment in the United States compared with that found prior to this legislation and even today in many other countries. However, new problems arise every day that require FDA to be alert to issues such as the importation of adulterated food products (melamine in baby food and pet food from China) and medicinal products (new and serious side effects that require marketed prescription products to be removed from the market). *Regulatory Toxicology* (2001) edited by S. C. Gad details the whole regulatory history of FDA, EPA, the Consumer Product Safety Commission, and the Occupational Health and Safety Administration.

Risk management is most effective when combined with risk communication. Local industries that fail to communicate their activities to concerned citizens may face community antipathy or opposition, and perhaps even restrictive legislation by local governments. Companies that explain their problems and listen to the concerns of their neighbors with open two-way communication are those most likely to achieve successful risk management programs. Programs of risk communication and risk management that involve the community take considerable top management and staff time and can add to costs, but the benefits of community understanding and cooperation can more than offset the expenditure. Companies that are responsible citizens and the communities in which they reside both benefit from the relationship.

Now that you understand the science of toxicology and the methods used to gather toxicology data, you should be able to read those scary headlines with some degree of understanding and perform your own personal risk-benefit assessment. You can be an informed citizen, keep an open mind when you hear conflicting data and opinions, and remove some of the fear from your life. As we have seen throughout this book, chemicals are everywhere, and although they can be our friends, frequently their use can lead to health and environmental risks that we, as an informed public, need to assess in order to help our government and its agencies regulate rationally.

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