RISK ASSESSMENT AND RISK MANAGEMENT: A PROCESS

Charles H. Ris and Peter W. Preuss
United States Environmental Protection Agency
Washington, D.C.

ABSTRACT

Risk assessment and risk management are relatively new terms that can be used to describe decision making in the field of environmental and related public health protection. As one of several health regulatory agencies, the U.S. Environmental Protection Agency (EPA) has fully adopted the concepts involved as outlined by the National Academy of Sciences in 1983. The components and institutional process of risk assessment/management are described, and examples from EPA experience are discussed.

INTRODUCTION

Assessing the risk posed by either deliberate or accidental release of harmful substances into the environment is a key factor in developing a strategy for the control of environmental pollution and the protection of public health. Scientific and managerial review of environmental health-related decision making has identified a means for conceptualizing, discussing, and perhaps ultimately improving the interplay of science and social and political values in assessing and making decisions about risks to public health. Risk assessment and risk management are terms describing fundamental activities involved in environmental control and related public health protection. The subject is timely because concern for the environment, although a relatively new national priority, has an ever-popular advocacy.

The development of risk assessment and risk management themes has been most evident within the Federal government's environmental and public health

1. Address correspondence to: Charles H. Ris, Office of Health and Environmental Assessment, RD-689, U.S. EPA, Washington, DC 20460.

2. Key words: assessment, benefits, regulation, risk.

3. Abbreviations: CPSC, Consumer Product Safety Commission; EPA, U.S. Environmental Protection Agency; FDA, U.S. Food and Drug Administration; NAS, National Academy of Sciences; NAAQS, National Ambient Air Quality Standards; OSHA, Occupational Safety and Health Administration; VOC, volatile organic compound.

regulatory programs, most of which come under the jurisdiction of the U.S. Environmental Protection Agency (EPA), the Food and Drug Administration (FDA), the Occupational Safety and Health Administration (OSHA), and the U.S. Consumer Product Safety Commission (CPSC). The experiences of the EPA will be discussed extensively, since these can be described with firsthand knowledge by the authors. The discussion can have implications for industry and for state and local institutions, and some comments will be offered in this regard.

Within the arena of environmental concern, one of the newest scientific and public policy activities is focused on explicitly evaluating hazards to public health from exposure to toxic substances, and thereafter recommending regulatory actions that will reduce the hazard of the defined public health problem. The predecision activities of the Federal, state, and local governments, of private industry, and of others responsible for environmental cleanup or control have given rise to a culture of risk assessment in the broadest sense of the term. This culture can be more easily understood and evaluated if it is considered as a process with two distinguishable parts, risk assessment and risk management.

In a speech to the National Academy of Sciences, EPA Administrator William Ruckelshaus very simply described the distinction between risk assessment and risk management (EPA, 1984): "Scientists assess a risk to find out what the problems are. The process of deciding what to do about the problems is risk management."

A formal recognition of risk assessment and risk management and the intertwining of science, policy, and public administration developed during the 1970s, a period of visible public concern about the effects of modern society on the environment. In the 1960s, national environmental leadership emerged from initial Federal programs for water and air pollution control and pesticide use and from public health programs in drinking water and radiological health, leading to the aggregation of these programs into an Environmental Protection Agency in 1970. In 1976, the first clue appeared that risk assessment of health hazards and its complement, risk management, were coming into prominence. The Federal Insecticide, Fungicide, and Rodenticide Act contained legislative criteria stating that unreasonable health risks, economic and social factors, and costs and benefits of environmental control measures were to be jointly considered. A resulting need for guidelines to evaluate cancer data that would characterize hazards to human health signaled the beginning of the present day health risk assessment programs at the EPA. In 1976 the EPA Carcinogen Assessment Group was formed to advocate the science and science policy considerations for evaluating hazards resulting from exposure to suspect carcinogenic agents. The reports from this Group were quickly tagged as "risk assessments." The assessment reports actually contained statements of risk or probability of contracting cancer based on exposure and other information. Since 1976, the Carcinogen Assessment Group has been a worldwide advocate of cancer risk assessment. In the early 1980s, other health disciplines that sought to identify and characterize harmful effects from exposure to toxic substances adopted the terminology of risk and risk assessment to describe analyses and evaluations of toxicity and

resulting harmful effects for humans. While risk assessment terminology is certainly apropos to noncancer effects, in the strict sense only the risk of cancer and mutagenicity is assessed on the basis of numerical probability, since the risk of experiencing other effects is at present discussed in the context of a no-observable-adverse-effect exposure level divided by a series of uncertainty factors to estimate a dose below which appreciable risk is unlikely.

While risk assessment had its genesis in the mid-1970s and, in the broader use of the term, covered all aspects of science, policy, and decision making, the identification of a complementary risk management theme is very recent. In response to a directive from the United States Congress, the FDA asked the National Academy of Sciences (NAS) to conduct a study of the institutional practice of risk assessment. The NAS began its study in 1981 and in March 1983 published a report entitled "Risk Assessment in the Federal Government: Managing the Process" (NAS, 1983). This report mentioned "risk management" activities. EPA Administrator Ruckelshaus described risk management as "... a procedure involving a much broader array of disciplines (compared to risk assessment), which is aimed toward a decision about control. Risk management assumes we have assessed the health risks of a suspect chemical. We must then factor in its benefits, the costs of various methods available for its control and the statutory framework for a decision ..." (EPA, 1984). While this and the earlier plain-language descriptions of risk management and risk assessment are useful for overview purposes, a more definitive characterization is needed in order to better understand the process as practiced. The 1983 NAS report provides a comprehensive explanation of the concept, many features of which have been endorsed by the Federal regulatory agencies and the EPA in particular.

RISK ASSESSMENT

Public health-based regulatory activities, as indicated earlier, can be viewed as being based on two distinct elements. Risk assessment is the use of scientific data to define the health effects resulting from exposure of individuals or populations to hazardous materials and situations. Risk assessment provides information for risk management activities. Risk assessments contain some or all of the following four steps:

- *Hazard identification*: The determination of whether a particular chemical is or is not causally linked to particular health effects. Four general types of information may be used in attempting to identify a hazard, including epidemiologic data, animal bioassay data, data on *in vitro* effects, and comparisons of molecular structure and biochemical activities. The NAS (1983) has compiled a list of 25 components in carcinogenic hazard identification.
- *Dose-response assessment*: The determination of the relation between the magnitude of exposure and the probability of occurrence of the health effects. This analysis takes into account such variables as intensity of

exposure, activity patterns of those exposed, and other factors such as metabolism that may affect the relationship.

- *Exposure assessment*: The process of describing, measuring, or estimating the amount of a substance that a human comes in contact with, the duration of that exposure, and the size and nature of the population exposed.
- *Risk characterization*: The overall description of the nature and often the magnitude of possible or likely human risk, including attendant uncertainty.

In each step, several decision points (components) occur at which a human health hazard can only be inferred from the evidence. Both scientific judgments and policy choices may be involved in selecting from among possible alternatives that arise in the four-stage risk assessment process, and thus the term "risk assessment policy" or "science policy" can be used to differentiate those judgments and choices from the social and economic judgments inherent in risk management. Some of the controversy surrounding regulatory actions can be attributed to a blurring of the distinction between risk assessment policy and risk management policy.

Hazard Identification. A risk assessment might end with hazard identification if no harmful effect is found or if identification is all that is needed. Of the four steps, hazard identification may be the easiest to recognize in a regulatory action because it is the fundamental statement that exposure to a substance can or may cause an adverse health effect. These effects can range from temporary discomforts such as skin irritation, coughing, or dizziness, to more serious and possibly fatal conditions such as kidney disease, lung disease, birth defects, or cancer. Often a lack of experimentation on human subjects prevents answering directly the question of whether a substance causes an adverse human effect. With the application of risk assessment guidelines and related policies, positive results in animals may be taken as evidence that the substance may pose a risk for an exposed human. Other information such as genotoxicity, metabolism, or structural similarity to chemicals with known hazards may also be used with animal data to support or further explain the hazard potential of a substance to humans.

Well-conducted epidemiologic studies that show a positive association between an agent and a disease are the most convincing evidence regarding hazards to humans. However, such evidence is difficult to accumulate; often the risk is low compared to the statistical power of the study population to show a response, the number of persons exposed is small, the latent period between exposure and disease is long, and exposures are mixed and multiple. Only a few of the chemicals in the environment have been studied using rigorous epidemiologic methods. More often than not, it is necessary to rely on less direct evidence (e.g., data from experimentation on animals) that a human health hazard exists.

Dose-Response Assessment. A dose-response assessment demonstrates the relation between the dose of an agent and the incidence of an adverse effect in the exposed population and, if the exposed population is not human (as in an animal study), estimates the incidence of the effect as a function of human

exposure. In carcinogen risk assessments done by the EPA, this step develops the quantitative human risk factors, popularly known as slope values, unit risks, or potency values, while in the case of chronic effects other than cancer, reference doses are the desired answers from a dose-response analysis.

The dose-response assessment takes into account intensity of exposure, age of subject, pattern of exposure, and other variables such as weight or dietary habits which may influence a response. A dose-response assessment usually requires extrapolation from high to low dose and, in the case of animal studies, conversion to a human equivalent exposure. If a dose-response analysis for several substances can be shown to have data of similar quality, then the toxic strength or potency of substances as determined from a consistently applied dose-response assessment procedure may be compared. For instance, both arsenic and chromium VI cause lung cancer in humans exposed by the inhalation route, but it takes three times as much arsenic to produce an equivalent risk in humans.

Exposure Assessment. Exposure assessment is the process of measuring or estimating the intensity, frequency, and duration of human exposure to an agent present in the environment or of estimating hypothetical exposures that might arise from the release of new chemicals into the environment. Exposure assessment is often used to identify alternative control options and to predict the effect of control technologies on exposure.

Concern about exposure varies depending on the particular substance. For some substances, the focus may be lifetime exposure of large populations; for others, levels of exposure for people near a source of contamination (discharge or emission point) or peak levels of short-term exposure may be important concerns. There may also be concern for unusually sensitive subpopulations such as children, elderly people, or people suffering from a particular disease.

Risk Characterization. Risk characterization is the process of estimating the incidence of an adverse health effect under the various conditions of human exposure described in exposure assessment. Risk characterization is performed by combining the exposure and dose-response assessments. Ideally, the summary effect of the uncertainties detailed in the preceding assessment steps are described.

The relationships among the four steps of risk assessment and between risk assessment and risk management are depicted in Figure 1, as are the general types of input information needed for each step.

Of the four steps, risk characterization is perhaps the most influential, because it uses information from the other steps to communicate the overall picture to the risk manager or other audience. It is factual, it explicitly or implicitly uses risk assessment policy, and its utility is frequently a matter of how well it communicates the possibilities as suggested by scientific fact and the uncertainty. Often, the certainty of a risk occurring is not easily determined.

Each of the analytical steps and the concluding risk characterization step involve assumptions, judgments, the use of conventions, and uncertainties. These elements must be identified in the characterization so that the influence of fact, assumption, judgment, or policy on the assessment can be discerned. One

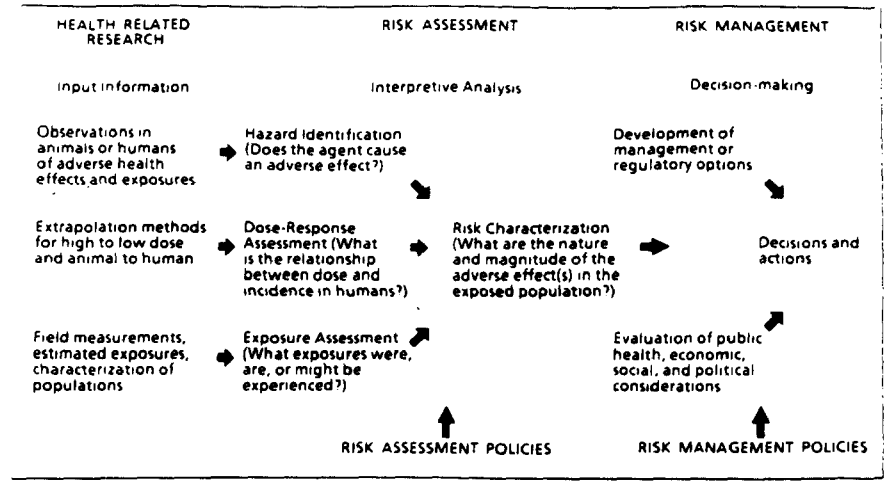

FIGURE 1. Elements of risk assessment and risk management. (Source: adapted from NAS, 1983).

approach to articulating such factors is to establish guidelines for assessment which define the principles and criteria that guide assessment and provide the framework for articulating a conclusion. As of September 1986, the EPA has risk assessment guidelines for several specific topics, including cancer, mutagenicity, developmental toxicity, chemical mixtures, and exposure assessment.

RISK MANAGEMENT

The NAS has defined risk management as the complex of judgment and analysis that uses the results of risk assessment to produce a decision about environmental action. Since publication of the 1983 NAS report, the EPA has found the terminology useful for explaining, studying, and organizing its environmental risk activities. Risk management terminology was originally intended to distinguish the political, economic, and social aspects of decision making from the scientific exercise of the risk assessment. The risk management/risk assessment concept, however, has broader utility because it can be applied to resources, priorities, organizations, policies, and other descriptive themes.

The nature of a particular risk management activity is dictated by the environment in which it occurs. The risk management activity of corporate industry may have criteria, objectives, and goals different from those that form the risk management activity of a Federal regulatory agency. The legislation that authorizes Federal programs dictates the goals for risk management and to varying degrees provides operational criteria and objectives. That which is not provided by Federal statute is generated by the Federal agency to provide the framework for decision making, i.e., risk management. Risk assessment per se is not a subject usually dealt with in detail in such legislation, although its use may

be mentioned or implied in the context of goals to reduce adverse or unreasonable hazards to the public health or to the environment.

THE PRACTICE OF RISK ASSESSMENT AND RISK MANAGEMENT (FEDERAL)

The public health aspect of an environmental protection program can be described by several types of activity. These activities provide a framework for discussing the practical ways in which the concepts of risk assessment and risk management are applied:

- Setting priorities;
- Determining target levels and standards;
- Deciding "How clean is clean?"; and
- Balancing risks and benefits.

A regulatory process can be initiated in many ways. The Federal health regulatory community (including the EPA, FDA, CPSC, and OSHA) has criteria for defining priorities among a large number of substances, but circumstances frequently require that decisions be focused on a selected few substances. Such a statement may not seem supportable considering the broad scope of the EPA's agenda; however, the EPA also has eight different legislated programs to administer, thus increasing the potential size of its agenda. The decision as to which substances to study for regulation is based at least in part on some notion of relative human health or other environmental hazard, whether explicit or implicit, internally generated or imposed by outside group pressure. There are critics of Federal regulation who say that the Federal government does not have the right priorities; it is often the case that risk assessment and risk management conducted to set priorities have been more informal and less visible than activities for establishing specific regulations.

Setting an agenda involves analyses leading to decisions concerning which substances should be selected, and perhaps in what order, for a more intensive risk assessment and risk management review. All programs, both in government and private industry, face this question, although the problem has different configurations. Given a finite list of chemicals that must be addressed, the risk assessment and risk management process can help define the "worst-first" priority. This is actively pursued, for example, in the EPA programs for pesticides and toxic air pollutants. Interestingly, however, a finite listing of chemicals is frequently supplemented by private-sector initiatives or public concern about specific substances (e.g., public awareness of increased incidences of leukemia and other cancers in particular neighborhoods, and public suspicion that pollution may be a causative factor). Also, some Federal programs—the FDA's drug certification program and the portion of the EPA's toxic substances program dealing with the marketing of new chemicals, for instance—are almost totally driven by private-sector initiatives. The common motivating factor is concern for health based on formal or informal risk assessment or judgment that defines the reason for concern.

For many issues that appear on an agenda, hazard identification alone supports a conclusion that there is little or no risk to human health, so that the issue can be removed from further consideration. If hazard identification shows that an issue has a potential for harm, then the issue can be subjected to dose-response assessment, exposure assessment, and risk characterization. At any of these stages, an evaluation might demonstrate that an inconsequential risk exists and that the issue can therefore be taken off the agenda.

Issues that are characterized as presenting appreciable risk or which otherwise trigger a risk management action criterion will become formal agenda items for risk management analysis and eventual decision making. At some point, regulatory options will be defined which may be recycled into risk assessment to demonstrate their before, after, and relative effectiveness of health risk reduction.

The approach described above is overly simplified, and it is used here to illustrate one of the practical uses of risk assessment and risk management. In reality, a number of programs do not conform to the sequence and may not require that all the steps be followed to reach a decision about regulation. Varied use of risk assessment and risk management (within the EPA, the process varies depending on which of the eight legislated authorities is the focus) places different requirements on risk assessors and their methods and on risk managers and their approaches. Interestingly, the EPA has benefitted from moving its risk managers from one area to another to broaden the experience of the individual and to increase the flexibility of the system, the risk manager perhaps being more bound by program specifics than is the risk assessor. As the importance of a candidate issue increases, so does the rigor of the related risk assessment and risk management activities.

Risk assessment and risk management are key to the process of setting priorities when health hazards or other ecological risks exist. The results of any of the four risk assessment steps may affect the order of priorities. Two examples of the EPA's use of risk assessment for setting priorities include:

(1) The preparation of health hazard profiles for candidate toxic air pollutants, termed Tier 1 Assessments and Health Issue Papers. These are short documents, and identification of a hazard matched with exposure data results in a decision to engage in more comprehensive risk assessment analysis.

(2) The use of risk assessment to show that a health hazard does not exist. This is as important a consequence of assessment as finding that a hazard is present. The EPA's evaluation of manganese as a candidate toxic air pollutant is a good example (EPA, 1985a).

Evaluation of Manganese: A Case Study. Manganese is a common element that exists in the earth's crust mainly in the form of oxides and carbonates. Manganese is emitted as a component of particulate matter during industrial operations that utilize ores and during combustion of fossil fuels. Manganese was considered a candidate because of a potential for significant public exposure and concern that manganese might be carcinogenic in humans.

The principal sources of manganese air emissions include steel production, iron and steel foundries, ferroalloy production, sewage sludge incineration,

synthetic manganese dioxide production, dry cell battery production, fossil fuel combustion, cement production, and cooling towers when manganese compounds are used as biocides. Fossil fuel combustion and steel and ferroalloy production are the largest sources of manganese air emissions. These three sources account for approximately 90 percent of the estimated 4,100 metric tons of manganese emitted from all the above sources.

Hazard identification indicated that the toxicity of numerous manganese compounds had been tested in animals by all common routes of exposure. Chronic occupational exposure to particulate matter containing concentrations of manganese of 5,000 micrograms per cubic meter or greater had resulted in a severe central nervous system disorder in humans known as manganism, a result of manganese being absorbed into the bloodstream over an extended period of time and accumulating in the brain. Manganese fumes as well as fumes of many other heavy metals have been known to cause an acute illness called metal fume fever in workers exposed in confined occupational settings to high concentrations of metallic fumes such as those associated with welding operations. Particulate matter that may or may not contain manganese has been associated with increased incidences of common respiratory ailments in both occupationally exposed people and the general population. The respiratory effects elicited by particulate matter containing manganese are not, however, attributable to the concentration of manganese in the particulate matter. Exposure to particulate matter of any composition can be associated with an increased incidence of adverse respiratory effects. The hazard identification also reports the existence of negative animal carcinogenicity studies using routes of exposure other than ingestion or inhalation. There were no epidemiologic studies available for assessment. The weight-of-evidence for carcinogenicity (see Table 1) was judged to be Group D, inconclusive.

In order to assess the potential for noncarcinogenic health effects that might occur from ambient exposures to manganese, an analysis was conducted to determine if ambient manganese concentrations would be likely to exceed levels that were associated with other health effects. The approach used in this analysis

TABLE 1
Weights-of-Evidence (Scale of Likelihood for Human Carcinogenicity)

Category	Estimate of cancer risk	Type of data supporting category
Group A	Known human carcinogen	Human
B1	Probable carcinogen	Human
B2	Probable carcinogen	Animal
C	Possible carcinogen	Animal
D	Carcinogenic potential unknown	ND
E	Not carcinogenic	Human or animal

ND = No data or inconclusive data.
(Source: EPA, 1986).

involved four steps. First, target protective levels were identified for both neurotoxic and respiratory effects. Second, manganese emissions from the major source categories were modeled to estimate both long-term and short-term concentrations of manganese. Next, total suspended particulate matter concentrations measured in the vicinity of selected manganese emitting facilities were obtained. Finally, the target protective levels were compared with the modeled manganese concentrations and the monitored particulate matter concentrations.

The target protective levels identified for respiratory effects are the primary National Ambient Air Quality Standards (NAAQS) for particulate matter that were established to protect the public health with an adequate margin of safety. These levels were selected on the basis that the respiratory effects elicited by particulate matter containing manganese are identical to those elicited by particulate matter not containing manganese. The target protective levels identified for neurotoxic effects were those recommended by the World Health Organization and the American Conference of Governmental Industrial Hygienists. These levels are considered reasonable and conservative given that the hazard identification showed that neurotoxic effects have been documented only in workers chronically exposed to manganese concentrations around 5,000 micrograms per cubic meter or higher. Protective levels were not identified for metal fume fever, because this acute occupational hazard is confined to the immediate workplace and does not occur at ambient concentrations.

The modeling exercise used worst-case meteorological conditions in a conservative screening model and the most current emissions data available for each major source of manganese emissions. The highest manganese concentrations predicted by the model were 250 micrograms per cubic meter for 15 minutes and 125 micrograms per cubic meter for 8 hours. All of the modeled concentrations were well below the protective levels for comparable averaging times.

This conclusion was further supported by the fact that monitored total suspended particulate concentrations within 3 miles of three of the five currently operating ferroalloy facilities in the United States showed that both the 24-hour and the annual NAAQS for particulate matter had been attained since at least 1981.

Neither the modeling nor the monitored results suggested that noncarcinogenic health effects should be expected from exposure to ambient concentrations of manganese emissions from industrial sources. In conclusion, the EPA determined that no regulation directed specifically at manganese was presently necessary to protect the public health under the Clean Air Act.

Establishment of Advisory Levels and Standards. The setting of advisory (target) levels and standards is certainly one of the most visible applications of risk assessment and risk management and often generates the most reaction from the public, industry, and environmental advocacy groups. Functionally, such levels serve as goals or levels that trigger a risk management process or other institutional response. Examples in the EPA's programs include water quality criteria and reportable quantities for spills of hazardous substances. For

water quality criteria, the EPA was obligated to recommend nationwide criteria for a large number of chemicals that would protect the public health; no provisions were included in the statute for considering social and economic factors in setting the criteria.

The risk assessment process is quite rigorous in setting standards and advisory levels, and risk management activities are typically quite lengthy unless a hazard to the public health is thought to be imminent. The EPA has chemical-specific standards for drinking water, air, and certain types of radiation, as well as many emission, discharge, and disposal standards such as those governing industrial wastewater pretreatment, municipal wastewater discharge, and operation of solid waste landfills.

A closer look at how advisory levels and standards are expressed is interesting because they derive from the risk characterization step of risk assessment. According to current practice, the EPA and other Federal health regulatory agencies divide adverse health effects into two groups. One group is termed threshold effects, the other nonthreshold effects. This separation signifies that the hazard and dose-response characteristics can be considered to be hazardous above some known or estimated concentration, whereas below that concentration the exposed individual can tolerate the substance without a harmful effect. At present, only substances considered to be carcinogens and mutagens are treated as nonthreshold, while all other adverse effects are regarded as having a threshold for toxicity. For substances that cause threshold effects, the objective of risk assessment is to identify that exposure below which there is no harmful effect and, conversely, above which a harmful effect could be anticipated. Because such identification is difficult to obtain, a system of uncertainty or safety factors is typically used to arrive at levels that are prudently protective of public health. Various Federal agencies use different terms to describe the final concentration level. The EPA, for example, has in the past used the term "acceptable daily intake," which is that amount of total exposure over a time period (e.g., per day with a margin of safety built in) which is thought to be prudently safe. Risk management use of these threshold levels, whatever their configuration, is not absolute because of the margin of safety usually present. On the other hand, public health is protected if the exposure is less than the acceptable daily intake or, not protected, perhaps, if the exposure is higher, depending on how large a margin of safety is thought to be reasonable.

On the other hand, a risk characterization for carcinogens (nonthreshold) is distinctly different because of the underlying knowledge (with many assumptions) that any exposure to a true human carcinogen can be described in terms of a mathematical probability of contracting cancer and possibly dying from the cancer. For nonthreshold effects, there is no defined exposure level above or below which the effect is certain. To accommodate this situation, the EPA treats exposure to possible or known carcinogens in terms of a "risk" of developing cancer. The risk is a mathematical statement of probability that correlates exposure over a period of time with the likelihood of contracting cancer.

The concept of risk is not new because many human activities carry some degree of risk. Some risks are so commonplace that they are accepted with

little thought, and some—the risk of dying from a motor vehicle accident or from a home accident or the probability of dying from any cause at a specific age—are known with a relatively high degree of accuracy because data have been collected on their historical occurrence. The risk characterization for carcinogens has yet a further dimension because of the way in which substances are evaluated for their carcinogenic potential. The EPA, in concert with government-wide guidelines for cancer risk assessment, attempts to address two questions:

(1) What is the likelihood, i.e., the "weight-of-evidence," that a substance is carcinogenic in humans (as opposed to being carcinogenic only in laboratory test animals)?

(2) If a substance is shown to be carcinogenic in humans, or assumed to be so, what is the measure of its impact, i.e., the "risk" it poses, to the public health?

The typical cancer risk assessment, then, includes two important items of information which are fed into the risk characterization and risk management process. Six weight-of-evidence categories (Table 1) are used by the EPA in response to question (1) alone, and one or more estimates of possible cancer risk to exposed populations are given in response to question (2).

The dual aspect of cancer risk characterization presents interesting issues for risk managers, who could be simultaneously considering regulatory action for a Group B substance, a probable human carcinogen, that has a fairly low risk (perhaps 1 in 1 million per unit dose) compared with a Group C substance that is only possibly carcinogenic in humans and that may have a risk of 1 in 1,000. In this example, the Group C substance is 1,000 times more potent but is less likely to be a human carcinogen. If 1 million people were exposed to substances in each of these groups, the population exposed to the Group B substance might have 1 cancer case, whereas the population exposed to the Group C substance might have 1,000 cancer cases.

The interplay of the two-part cancer risk characterization can be quite varied as one substance is compared with another for purposes of setting an agenda or other priority, establishing advisory levels, or setting standards. The very fact that cancer risk is expressed in two parts gives rise to a doubling of the issues and debate about the scientific accuracy of cancer risk characterization.

Between 1976 and 1987, linear nonthreshold dose-response models were used to provide plausible upper-bound estimates of cancer risk in hundreds of priority- and agenda-setting, advisory, and standard-setting activities of the EPA. The hazard identification and dose-response assessment were used to help decide how much should be spent in social and economic terms to reduce risks to some reasonably low level. These risk management decisions did not hinge on any predetermined "acceptable or reasonable level" of cancer risk; rather, each decision involved a variety of factors, the risk being one factor. Once a decision is made, the risk becomes an informational consequence of the decision. Thus, a range of risks can be seen when many EPA decisions are reviewed retrospectively. In general, estimated individual risks higher than 10^{-5} are usually actively analyzed, whereas risks in the 10^{-5} to 10^{-7} range are of greater concern when large populations may be exposed.

Evaluation of Risk Reduction by Control of Pollutants. Another practical use of risk assessment is to compare residual risk after the application or proposal of a technology to control a pollutant. The risk remaining after control of a pollutant can be compared with that posed by other pollutants which have not been controlled, thereby providing a basis for deciding, based on health impact factors, whether more control of the first pollutant is warranted or whether the public health will be better served by shifting the focus to other toxic substances.

The use of risk assessment is key to defining the risk so that a balancing of risk and benefits can be demonstrated. Such balancing objectives are found in some, but not all, of the legislation of concen to EPA, FDA, OSHA, and CPSC. Usually, the balancing that goes into balancing-type risk management decisions includes consideration of at least three major components. The first is the harmful effect of the substance proposed for control. When human health is affected, this factor may be expressed as a numerical risk estimate in the case of cancer hazard. But there are other effects that cannot be so expressed, such as the societal value of pristine wilderness areas or the value of an unused aquifer. A health-balancing decision will also consider the distribution of the harmful effect in terms of how many people it affects over how wide a geographic area, the reversibility or persistence of the effect, and perhaps the impact of the decision on the long-term health of an ecological system. (Consideration is even now being given to framing the boundaries of ecological risk assessment.)

The second factor is cost, which may include the cost of pollution controls, consideration of the effects of alternative practices, the trade-off benefits of using a different toxic chemical as a replacement in industry, or the impact of a regulatory approach on employment, firms, or communities.

The third factor is related to the uncertainty or confidence associated with a risk assessment. Cost-effect relationships may appear to be different if there is less confidence in tying a pollutant to a hazardous effect, as may easily be seen with the cancer weight-of-evidence categories.

Three major categories of costing relationships are typically employed, depending on the situation:

(1) Benefit/cost analysis weighs the cost of control against the monetary benefits of control;

(2) Risk/benefit analysis weighs the economic benefits of a polluting activity against the risks to health and the environment; and

(3) Cost-effectiveness analysis accepts the desirability of regulation and identifies the least-cost solution to achieve a given goal, such as a pollutant discharge standard.

Several examples follow which show the scope of standard setting and risk-benefit balancing. EPA's pesticide legislation (Federal Insecticide, Fungicide and Rodenticide Act) defines one basis for regulation as the presence of unreasonable risks to man or the environment, taking into accout the economic, social, and environmental costs and benefits. Chlorobenzilate, a miticide used on citrus fruits, was shown to induce a carcinogenic response in male and female mice, whereas studies in rats were negative (EPA, 1977, 1978). Although the risk

assessments for this compound were done prior to EPA's adoption of the six-tiered weight-of-evidence classification scheme for carcinogens, the appropriate retrospective classification would be either Group C or B2.

On the assumption that chlorobenzilate is carcinogenic to humans, cancer risk estimates for humans were developed from the available mouse carcinogenicity data. When used with exposure values for the general public (consumers of treated fruits) and applicators of the pesticides, individual cancer risks as well as the number of cancer deaths per year can be estimated. The values are understood to be upper-limit estimates, meaning that although the true risk is not ascertainable, it is not likely to be higher than the estimated value and may be lower, possibly even close to zero.

The risk estimates were as follows:

Population exposed	Individual risk Upper limit	Expected cancer deaths per year Upper limit
220 million consumers	2×10^{-6}	7
Pesticide applicators	4×10^{-4} to 1×10^{-3}	not available

The risk estimates indicate that the risk to a single individual from the general population of consumers exposed is relatively low (2 in 1 million), whereas a pesticide applicator with higher exposure has a higher risk (from 1 in 1,000 to 4 in 10,000). Thus, the risk of applicators is on the order of 100 or more times higher than the risk for consumers. The expected cancer deaths in the general population were perhaps as high as 7, a relatively low value considering that 1 in 5 people in the general public will die from all cancer causes. With the number of applicators not known exactly, the corresponding mortality was assumed to be very low as well. Since the pesticide act requires the balancing of risks and benefits, the presence of higher individual risk for applicators was judged in view of the fact that a substitute for chlorobenzilate was not available for use on citrus fruit. The EPA decided that the risks did not outweigh the benefit of the pesticide and therefore allowed the continued use of the pesticide under specified conditions that would further protect applicators.

Another example concerns the use of pesticide products containing diazinon, a pesticide used to control insects on grass and lawns, including golf courses, sod farms, and other broad, exposed areas such as recreational parks. The EPA (1987a) found through risk assessment (noncancer in this case) that the use of diazinon on such broad areas resulted in unreasonable adverse effects on nontarget birds (including robins, cardinals, and others) and announced an intent to cancel this use of the pesticide. The EPA's findings were based on an analysis showing that the risk to the birds far outweighed the beneficial use of diazinon on large areas and therefore that a continued approved use of the compound on the designated areas posed an unreasonable adverse threat to the environment. Diazinon's acute toxicity, estimated residual levels on grass and seed, estimated dose levels consumed by birds, diazinon application practices,

exposure, diazinon residue data, bird kills, problems with the reporting of bird kills, and the effect on endangered species were all considered in evaluating the hazard. In evaluating the benefits of using diazinon, the EPA considered the biology of insect pests, their control, the cost to users of prohibiting the use of diazinon, the efficacy of diazinon and its major alternatives, and the hazards posed by the major alternatives to diazinon.

A more complex example of standard setting and risk benefit balancing can be seen in decision making regarding gasoline vehicle refueling emission regulations. The environmental issue concerns the gasoline vapors that escape during the refueling of vehicles and their environmental impact. About 90 percent of all refueling emissions consist of vapors displaced from the vehicle fuel tank by the incoming gasoline (EPA, 1985b).

Less significant sources of refueling emissions are spillage and underground tank-emptying losses. Spillage occurs as a result of the "splash back" from the fill pipe or the escape of gasoline from the dispensing nozzle. Underground tank-emptying losses represent the escape of vapor from the vent of a service station's underground storage tank. The spillage and emptying loss sources each account for about 5 percent of the total emissions associated with the refueling process.

The composition of refueling vapors depends on their source (i.e., fuel tank displacement or spillage), the fuel type (i.e., leaded or unleaded), and the volatility of the fuel. Gasoline, in general, is a complex mixture containing varying amounts of hydrocarbons and much smaller amounts of various additives. The hydrocarbons in gasoline are classified as paraffins (alkanes), olefins (alkenes), naphthenes (cycloparaffins or cyclanes), and aromatics (benzene or benzene derivatives).

The composition of the liquid gasoline and that of its vapor are not necessarily the same. Available information shows that the "light-end" hydrocarbons generally evaporate more readily than the higher molecular weight hydrocarbons, so that refueling emission vapors are primarily light-end hydrocarbons. The portion of refueling emissions that results from spilling gasoline, on the other hand, reflects the composition of the liquid fuel. This is due to the total evaporation of liquid fuel that is spilled. However, estimates indicate that no more than 5 percent of total refueling emissions currently result from fuel spillage and evaporation.

While the majority of refueling emissions are the light-end hydrocarbons, the other components of liquid gasoline are also represented in the vapor emissions generated during the refueling process. Benzene is of particular concern. A recent EPA study suggests that a liquid fuel containing 1.6 weight percent benzene would generate refueling vapors containing 0.8 weight percent benzene. The principal environmental concerns associated with refueling emissions focus on their contribution to ozone formation in the atmosphere and on their direct health effects. Refueling emissions consist almost entirely of hydrocarbons. In the presence of sunlight, these volatile organic compounds (VOCs) combine with other pollutants in a series of chemical reactions to produce ozone (and other photochemical oxidants). Ozone and other oxidants are pulmonary

irritants that adversely affect pulmonary membranes, lung tissues, and lung function. Animal studies also indicate that ozone may lead to an increased susceptibility to bacterial infection. These detrimental health effects may aggravate existing illness or lead to a lung disease. In addition to human health concerns, ozone may adversely affect vegetation and cause damage to various types of materials (e.g., elastic compounds).

In accordance with the Clean Air Act, EPA promulgated and revised primary and secondary NAAQS for ozone in the 1970s. The primary standard is intended to protect the public health with an adequate margin of safety. The secondary standard is aimed at protecting the public welfare. The current NAAQS (i.e., both primary and secondary) for ozone require that the expected number of days in a calendar year with 1-hour measured concentrations of ozone above 0.12 ppm be less than or equal to 1. Despite the imposition of various hydrocarbon controls, many areas of the nation continue to violate the ozone NAAQS. Based on the latest 3-year period for which complete air quality monitoring data are available, the EPA has determined that more than 70 urban areas are currently exceeding the ambient standard. Twelve of these areas are located in California. The significance of the nationwide nonattainment problem is clearly indicated by considering the fact that well over 100 million people live in areas that are known to exceed the ozone standards.

The carcinogenic concerns associated with the refueling process have historically focused on benzene, a normal constituent of gasoline, and gasoline vapors as a whole. The EPA believes that the human and animal evidence provides an adequate basis for classifying benzene as a human carcinogen and for estimating the carcinogenic potency of this compound at the lower exposure levels that are typical of refueling operations, because the studies are of good quality and they show consistent results. The EPA listed benzene as a hazardous air pollutant, stating that "ambient exposures (to benzene) may constitute a cancer risk and should be reduced."

As with exposure to benzene, the carcinogenic risk associated with exposures to gasoline vapors as a whole has also been assessed by evaluating existing epidemiologic and animal studies. The available epidemiologic studies of workers in the petroleum industry are considered to be suggestive of increased cancer incidence but are inconclusive concerning the causal role of gasoline vapors per se at this time. As a result, the carcinogenic risk of exposure to gasoline vapors has been estimated largely on the basis of animal studies. These well-designed, chronic inhalation studies with unleaded gasoline vapors showed evidence of significantly increased kidney cancer in male rats and liver cancer in female mice. The EPA's refueling risk assessment is based on the potency estimates from the male rat tests. However, the risk estimates derived by assessing data from both animal species were in close agreement.

The carcinogenic activity observed in these animal tests is thought to be induced by active agents other than benzene contained in the fuel. This is a reasonable assumption, since the sites of carcinogenic activity are generally observed to be different for benzene than for gasoline vapors (i.e., circulatory system and bone marrow versus liver and kidney), and since the concentration

of benzene during the animal experiments was too small to induce the observed response. In estimating human risks from gasoline vapor, the risk of the benzene component itself is added to the human-equivalent gasoline vapor risk determined from the animal experiments, since the two effects are apparently independent of each other and additive at low concentrations. Such an approach for estimating the potential risks posed by a mixture of carcinogens is suggested in the EPA's carcinogen risk assessment guidelines.

The two areas of greatest uncertainty in the EPA's analysis of gasoline vapors are (1) the relevance of using a quantitative risk factor based on the male rat kidney response in human quantitative risk estimates and (2) the difference in chemical composition between the gasoline exposures in the laboratory studies and that typical of actual population exposure during refueling emissions.

A finding of uniqueness in the male rat would weaken, but not eliminate, the presumption of a carcinogenic response in humans. Overall, most scientists agree with the EPA that the role of acute kidney toxicity in the induction of kidney tumors in male rats and its relevance to human cancer are currently unresolved issues. However, it is important to note that a carcinogenic response to gasoline vapors was also demonstrated in the studies of female mice. Further, the Agency and its review panel agreed that the carcinogenic effect of gasoline vapors in animals is real and can not be ignored as a potential human hazard.

Regarding the second area of uncertainty, the EPA agrees that there may be a difference between the vapor composition to which animals were exposed in the chronic inhalation study and that to which humans may be exposed under ambient conditions. As previously discussed, refueling emissions consist of a greater proportion of light-end hydrocarbon molecules than does wholly vaporized gasoline. Due to the obvious differences in chemical composition, it is possible that the carcinogenic potential of gasoline vapors emitted during refueling is not well represented by the animal results derived from wholly vaporized gasoline. The EPA believes it would be unwise to base the quantitative risk assessment on an assumption that may significantly underestimate the potential health problem. Instead, the EPA finds it prudent to interpret the results of the risk assessment as plausible upper limits, with the actual risks being at or below the estimates. Nonetheless, to illustrate the effects of the assumption that the heavier molecular weight compounds are responsible for the carcinogenic properties of refueling emissions, the EPA included in its risk assessment an estimate of the incidences attributed to the $>C_6$ fraction of gasoline vapors.

The risk assessment analysis focused on four exposure scenarios: (1) occupational, (2) self-service, (3) community, and (4) excess evaporative emissions. Each of these exposure scenarios can be characterized in terms of the intensity, frequency, and duration of exposure; the number of people affected; and the geographic range of emissions.

The occupational exposure scenario, in terms of refueling emission control, is a rough estimate of the potential risk to service station attendants exposed to gasoline vapor.

Self-service exposure refers to the exposure persons are subjected to in

refueling their own vehicles. It is characterized by high concentrations of gasoline vapor for relatively brief durations. However, the frequency of exposure is much lower than that to which service station attendants are subjected. The rapid expansion of self-service gasoline outlets means that, today and for the foreseeable future, the majority of the population experiences such exposure.

Community exposure refers to the exposure experienced by persons residing in the immediate vicinity of service stations. It has a wider geographic range than do the occupational or self-service scenarios. The dispersion of gasoline vapor into the atmosphere in the vicinity of service stations means that the concentration of gasoline vapors is much lower than that in the preceding scenarios. However, the duration of such exposures is much longer, approaching constant exposure in the case of 24-hour stations.

For each scenario, the estimated annual cancer incidences are summarized and shown in Table 2. The column headed "Bz" refers to incidences resulting from exposure to benzene. The column headed "GV" refers to incidences resulting from exposure to gasoline vapor as a whole. Although the benzene exposure occurs as part of the exposure to gasoline vapor, the EPA is treating these risk and incidence estimates as additive.

The column in Table 2 headed ">C6" refers to the estimated incidences resulting from exposure to that fraction of gas vapor composed of heavy-end hydrocarbon compounds. These values are presented to illustrate the effects of using only these heavier compounds to evaluate the carcinogenic risk associated with exposure to gasoline vapors.

In addition to the annual incidences, which are based on "average" exposures, the EPA also estimated the lifetime risk for individuals highly exposed to gasoline vapors for each of the refueling-related exposure scenarios. The lifetime risks are 4×10^{-3}, 8×10^{-5}, and 1×10^{-4} for occupational, self-service, and community exposures, respectively.

The results of the analysis show that the highest lifetime risk of cancer is incurred by service station attendants. The lowest lifetime risk is for individuals using self-service pumps. These individuals may potentially be exposed to significant vapor concentrations from the fill neck, but the number of refueling events is far lower than for the occupational category. Nonetheless, as shown in Table 2, self-service exposure shows the greatest annual cancer incidence because of the large number of people that pump their own gasoline. The upper bound of annual incidences (i.e., Bz plus GV) for all refueling categories is estimated to be about 67. Of this, about 90 percent is attributable to gasoline vapors, with the remainder attributed to benzene.

In looking at the possible results of control, achievement of the NAAQS for ozone and concerns about the carcinogenicity of gasoline vapors were both taken into account. There are two basic alternatives for the control of refueling emissions. These are generally referred to as "Stage II" and "onboard." The two vapor recovery systems are vastly different, with Stage II equipment installed at the service station and onboard equipment installed in the vehicle. In choosing between the alternative control technologies, several important factors affecting

TABLE 2
Estimated Total Cancer Incidences Resulting from Uncontrolled Refueling Emissions (Annual Incidence, 1987-2020)

Scenario	Bz	$>C_6$	GV	Total (Bz + GV)
Occupational	2	4	17	19
Self-serve	5	8	33	38
Community	1	3	10	10
Total[a]	7	15	60	67

[a]Columns and rows may not add exactly to totals due to rounding.
(Source: EPA, 1985b).

the decision were evaluated: Emission reductions, cancer incidence reductions, timing of the benefits, cost, cost effectiveness, enforcement burden, user convenience, equity, and competitive effects.

Onboard controls, as a national refueling emissions strategy, would provide additional ambient air quality benefits and direct health benefits throughout the country. The benefits of reducing emissions of ozone precursors in nonattainment areas are relatively obvious. While the potential benefits of similar emission reductions in areas currently meeting the ozone NAAQS may not be as readily apparent, they are still important. In addition, benefits in terms of direct health effects (cancer risk reductions) occur in both attainment and nonattainment areas as a result of controlling refueling emissions.

The potential value and effect of controlling ozone precursor emissions in attainment areas include the atmospheric transport of VOC emissions from attainment to nonattainment areas, making it more difficult to comply with the ozone NAAQS in regions with existing air quality problems. There are also many areas which, while meeting the ozone NAAQS, are very close to the standard. Reductions of VOCs in these areas can be expected to have a value similar to reductions in nonattainment areas if they are necessary to maintain compliance. These facts suggest that there is a benefit from a refueling emissions-control program that achieves emission reductions in attainment areas as well as nonattainment areas.

Reducing human exposures to refueling vapors also directly reduces the potential cancer risk associated with these emissions. The EPA's estimates of these reductions are given in Table 3. Again, the numbers given here for Stage II reflect the assumption that Stage II would be implemented in nonattainment areas only.

On the basis of overall effectiveness of control, onboard produces larger cancer incidence reductions, because control is not confirmed to nonattainment areas only. These additional effects are certainly of value to society, just as are ozone reductions in nonattainment areas. They accrue without any added expense and can be viewed as partially offsetting the costs of ozone reduction in nonattainment areas. The Federal Register (EPA, 1987b) should be consulted for specific details of the value analysis.

TABLE 3
Incidence Reductions from Stage II and Onboard (Annual Incidence, 1988-2020)

Scenario	Bz	$>C_6$	GV
Stage II	1	2-4	10-15
Onboard	4	10	38

(Source: EPA, 1985b).

Based on existing technology and demonstrated refueling tests using onboard controls, the EPA has proposed an emission standard of 0.1 grams of vapor per gallon of fuel dispensed for light-duty vehicles, light-duty trucks, and gasoline-fueled, heavy-duty vehicles. The benefits of the standard are summarized as improving ambient ozone levels in all areas of the country including those that may be in violation of existing NAAQS standards for ozone, and helping to protect the general public from the risks of cancer due to exposure to benzene, a component of gasoline vapor, and to evaporated gasoline as a whole. The standard would reduce the emissions of gasoline refueling vapors by nearly 90 percent from uncontrolled levels.

RISK COMMUNICATION

The ability to explain risk assessment findings, explain risk management choices, and describe the basis for risk management decisions is probably the newest challenge in the 1980s. Each step in the risk assessment/risk management process requires an explanation of what exists initially, how it is analyzed, what assumptions are made, and what uncertainties are present, in addition to a conclusion undoubtedly based partly on facts and partly on judgment. External to the institutional use of risk assessment and risk management, the public perception of why decisions are made very often influences the public's acceptance of the decision, and, in the case of popular public health issues, a residual impression regarding continued or reduced health hazard. The subject is doubly complex because explaining health hazards to people is a difficult undertaking, as indicated by society's mixed responses to the hazards of cigarette smoking, the saccharine debate of the 1970s, and the recent concern over use of the pesticide alar on apples, which the public shunned even though the EPA's assessment was that there was much uncertainty about whether a hazard really existed.

In one sense, risk assessment/risk management is a form of communication if practiced ideally. Technical analysis of health data and of the costs and benefits of a proposed action does not guarantee a correct answer, since all such analyses are typically too sensitive to judgmental and subjective values and are far too dependent on uncertain data. Ideally, risk assessment and risk management communicate information we believe is reliable, the values we want to apply, and the way these two are linked to produce a conclusion. The information is

derived from the best sources available (normally a subject for continuing data), although even the scientific aspects of risk management decision making are influenced by judgmental considerations and may not be verifiable with available scientific tests. The judgmental considerations are derived from statutory charters (EPA has eight separate charters) and the judicial interpretations that have grown up around them, from the exercise of judgment and choice by top managers, who, for Federal regulatory agencies, are politically appointed. The clear explanation of values, of uncertainties, and of the tradeoffs involved in every risk assessment/risk management decision about public health protection is a sought-after objective. It is this objective that the EPA and others have taken to heart and that drives the current practices and policy initiatives that in the 1980s we call the culture of risk assessment and risk management.

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