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Factoring Risk into Environmental Decision Making

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1 INTRODUCTION

The public is deluged with information about environmental risks. Rarely a day passes when the print or TV media do not report about some environmental hazard. We have been advised to test our homes for radon, quit smoking, eat less meat, and increase our daily exercise. Even when we make life-style changes, we find our lungs are exposed to toxic emissions from automobiles and factories; our drinking water contains alien chemicals with names like trihalomethanes and trichloroethylene; and our food is adulterated with an ever-increasing list of intentional and unintentional additives from ethylene dibromide (EDB) to cyanide. Our communities are besieged by toxic dumps, our beaches are strewn with medical waste, and our lakes and forests are dying from acid rain. Everything we thought we could depend on—air, water, food, even sex—is suspect. Now we learn that global warming threatens the stability of the entire biosphere.

Is our world really becoming more hazardous? How much risk do we face? How should we respond? Why do we worry about some risks and not others? The burgeoning field of risk assessment and risk management attempts to provide some answers to these difficult questions. But is risk assessment a science, an art, or a social process? Who decides how to manage risk—and can we have confidence in their decisions?

These are some of the questions we address in this chapter. We begin with a brief historical introduction to the field of risk analysis, while providing basic definitions of terms and concepts. We then describe the two dominant methods of risk assessment—the engineering and the toxicological approaches. Finally, we discuss the contributions of social theory to our understanding of the selection and management of risks.

Risk assessment is often viewed as an objective, scientific endeavor that is, or

should be, isolated from the policy aspects of the decision-making process. Throughout this chapter we use examples to illustrate that science and policy are closely intertwined, and that neither can be isolated from the other. Science and scientists alone cannot determine which risks to worry about (risk selection), what levels of risk should be tolerated (risk acceptability), and how they should be managed (risk management).

In the final section of this chapter, we present a case study that explores the assessment and management of the risks associated with pesticide residues in food.

1.1 Historical Background

People have engaged in risk assessment and management since ancient times (Covello & Mumpower, 1985). By trial and error, they have learned to cope with the vicissitudes of the natural environment, to build structures that collapse only rarely, and to minimize the toll of disease. Each day we all conduct informal risk analyses, for example, when we put on our seat belts or choose where to cross the street (Wilson, 1979).

Not until the early part of this century did engineers, epidemiologists, actuaries, and industrial hygienists—among others—begin conducting analyses of the hazards associated with technology (Kates & Kasperson, 1983). At the same time, geographers, geologists, hydrologists, sociologists, and others were engaged in interdisciplinary research on natural hazards and disaster management (Burton, Kates, & White, 1978; White & Haas, 1975).

Legislation in the early 1970s, beginning with the formation of the Environmental Protection Agency (EPA) and the Occupation Safety and Health Administration (OSHA), elevated the role of risk assessment in the regulatory process and led to the professionalization of risk analysis and decision analysis in conjunction with a newly emerging industry of private consulting firms and academic centers (Kates & Kasperson, 1983; Cumming, 1981; Lind, 1987). This professionalization is illustrated by the formation in 1980 of the Society for Risk Analysis (SRA) with its own journal *(Risk Analysis)*. Since that time, the literature on risk has grown exponentially (Kates & Kasperson, 1983). The field now boasts three additional journals devoted solely to risk *(Risk Abstracts, Journal of Risk and Uncertainty,* and *Risk: Issues in Health and Safety)*. A range of other journals and newsletters regularly deal with related issues (e.g., *International Journal of Mass Emergencies and Disasters, Disasters,* and the *Natural Hazards Observer*).

2 CONCEPTS AND DEFINITIONS

Terms such as *hazard, risk, risk analysis, risk assessment,* and *risk management* are not consistently used in the growing body of literature (Fischhoff, Watson, & Hope, 1984). For simplicity, hazards may be thought of broadly as "threats to

humans and what they value" (Hohenemser, Kates, & Slovic, 1983, p. 378), and risks as "quantitative measures of hazard consequences, usually expressed as conditional probabilities of experiencing harm" (Hohenemser, Kasperson, & Kates, 1985, p. 21). For example, riding a bicycle is a hazard. If you ride a bicycle for two miles a day for the next week, there is a risk of 1 in N that you will break a leg (where N can be determined from actuarial data on bicycle accidents). Risk is therefore a measure of the likelihood and severity of harm, and the hazard is the source of the risk (Cohrssen & Covello, 1989).

When we study the social response to hazards, it is helpful to classify the many different types into a few recognizable categories. A common distinction can be made between natural hazards—such as floods, hurricanes, and earthquakes—and technological hazards—such as automobile accidents, oil spills, and nuclear power plant accidents. Natural hazards may be further classified

TABLE 5–1 Common Natural Hazards by Principal Causal Agent

Geophysical		Biological	
Climatic and Meteorological	Geological and Geomorphic	Floral	Faunal
Blizzards and Snow	Avalanche	Fungal Diseases	Bacterial and Viral Diseases
		For example:	*For example:*
Droughts	Earthquakes		
		Athlete's foot	
Floods	Erosion (including soil erosion and shore and beach erosion)	Dutch elm	Influenza
		Wheat stem rust	Malaria
Fog		Blister rust	Typhus
			Bubonic Plague
Frost		Infestations	Venereal Disease
	Landslides	*For example:*	Rabies
Hailstorms			Hoof and Mouth Disease
	Shifting Sand	Weeds	
Heat Waves		Phreatophytes	Tobacco Mosaic
	Tsunamis	Water hyacinth	
Hurricanes			Infestations
	Volcanic Eruptions	Hay Fever	*For example:*
Lightning Strokes and Fires		Poison Ivy	Rabbits
			Termites
Tornadoes			Locusts
			Grasshoppers
			Venomous Animal Bites

Source: From Burton and Kates. 1964. "The perception of natural hazards in resource management." *Natural Resources Journal* 3(3):415.

according to causal agent as in Table 5–1 (Burton & Kates, 1964), and by the nature or characteristics of the hazard event, as in Figure 5–1 (Burton, Kates, & White, 1978). Such classifications have important implications for research and managment. Blizzards are quite frequent events in the northern United States, providing a good data base and less uncertainty than for other natural hazards, such as earthquakes. Similarly, the management responses for earthquakes and blizzards are quite distinct because the two hazards differ markedly in terms of frequency, areal extent, speed of onset, and spatial dispersion.

The wide variety of technological hazards may be similarly classified according to a group of characteristics, such as type of consequences (human injury, illness, or death; property damage; ecological and environmental damage), pathways of exposure (air, land, water), and population exposed (workers versus the public; children and other vulnerable groups). Several taxonomies have been developed to simplify this complexity by identifying what appear to be the most pertinent variables for management and response (von Winterfeldt & Edwards,

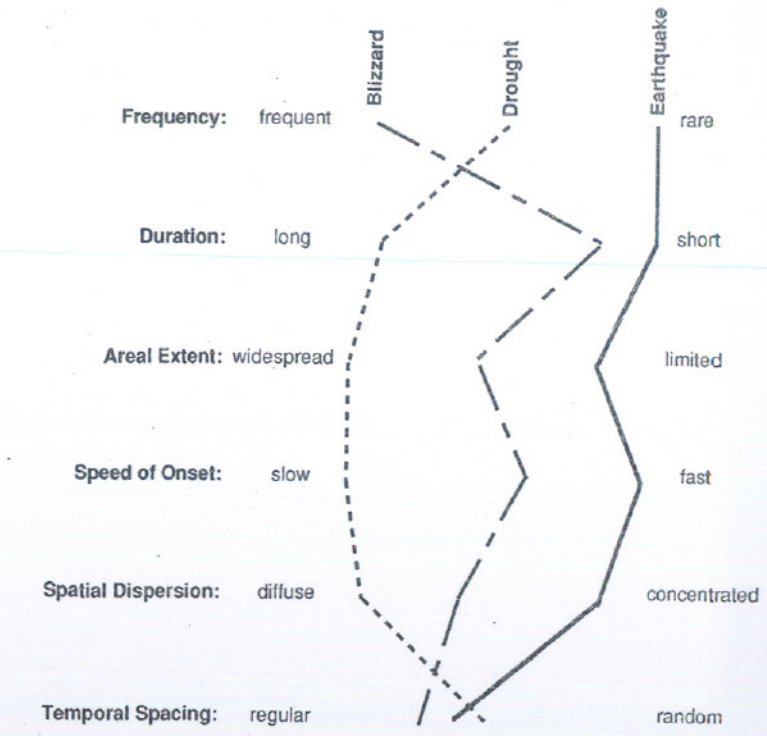

FIGURE 5–1. Hazard-event profiles. (From Burton, Kates, & White, 1978, p. 29.)

1984). For example, Starr (1969) drew attention to a fundamental distinction between voluntary and involuntary risks, and others have extended the list of dichotomous variables for consideration, as indicated in Figure 5–2 (Fischhoff et al., 1978). Risk profiles, like those in Figure 5–2, are helpful in understanding new technologies. If, for example, a new technology were to have a risk profile that was similar to the nuclear power profile, then one could expect a public response for this technology similar to that of nuclear power.

Another taxonomy (Table 5–2) combines several of the above categories to distinguish between natural and technological hazards (Litai, Lanning, & Rasmussen, 1983). The conceptual distinctions, however, are often "fuzzy" and incomplete. For example, dam failures may be caused by earthquakes, and industrial pollution may be exacerbated under certain meteorological conditions. Some observers also question whether occupational risks should be considered voluntary. These shortcomings aside, taxonomies are useful organizing frameworks that allow us to group hazards with common characteristics of importance in risk assessment and management.

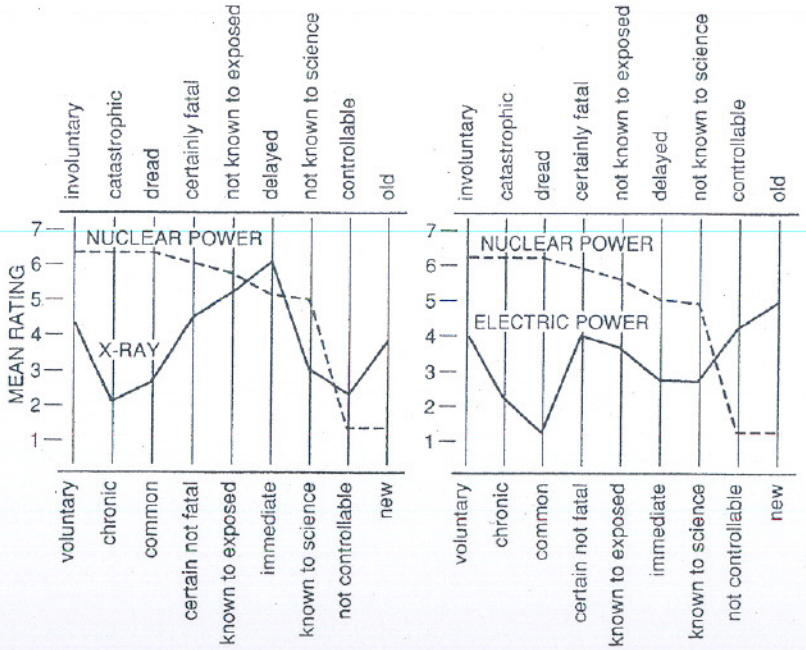

FIGURE 5–2. Hazard-event profiles. (From Fischhoff et al. 1978, "How Safe Is Safe Enough? A Psychometric Study of Attitudes Towards Technological Benefits," in *Policy Science*, Vol. 9, no. 2, p. 142.)

TABLE 5–2 (Incomplete) Classification of Some Common Risks

	Voluntary		Involuntary	
	Immediate	Delayed	Immediate	Delayed
Man-Made				
Catastrophic	Aviation Passenger liners Railways		Dam failures Chlorine release Sabotage Nuclear energy	Some industrial pollution
Ordinary	Occupational risks Sporting activities Surgery	Smoking Saccharin Occupation risks	Aircraft crashes	Food additives Pesticides, e.g., EDB Nuclear energy (cancer) Coal energy Industrial pollution
Natural				
Catastrophic			Earthquakes Hurricanes Epidemics	
Ordinary			Lightning Animal bites Acute diseases	Various diseases

Source: From Litai, D., D. Lanning, & N. C. Rasmussen, 1983. The public perception of risk. In *The Analysis of Actual vs. Perceived Risks*, eds. V. T. Covello, W. G. Flamm, J. V. Rodricks, and R. G. Tardiff. p. 216. New York: Plenum Press.

Before the technical assessment of a risk is undertaken, it must already have been placed on the public agenda. Ordinarily, however, when risk is the subject of technical study, the starting point is risk assessment. Here we follow disciplinary conventions rather than the chronological sequence of events, and begin with a discussion of risk assessment and conclude by discussing the social and cultural theories of risk selection.

3 RISK ASSESSMENT

Risk analysis involves both risk assessment and management of natural and technological hazards. Risk assessment refers to the technical assessment of the nature and magnitude of risks (Cohrssen & Covello, 1989); risk management is the process of evaluating and selecting appropriate responses to control hazards or mitigate their consequences (Kasperson, Kates, & Hohenemser, 1985; National Academy of Sciences, 1983).

The principal goal of risk assessment is to identify quantitative measures of hazard in terms of probability and magnitude. Methods of risk assessment vary according to disciplinary focus and the nature of the hazard in question, but they all rely on *extrapolation* (Kates & Kasperson, 1983). Actuaries may extrapolate from past to future experience; engineers and experts in natural hazards may extrapolate from computer and simulation models to field conditions; toxicologists extrapolate from animal data to predict effects in humans. All these methods use different assumptions, and the levels of uncertainty will depend on the quality of the data, the level of understanding of the causal linkages, and the use of expert judgment.

While there are different disciplinary approaches to risk assessment, there are two dominant methods derived from engineering and health sciences. As illustrated in Figure 5–3, engineers have been most involved in assessing the probabilities of acute, catastrophic failures of engineered systems, such as airplanes and nuclear power plants, using event- and fault-tree analysis. Engineers have focused on acute events involving rapid releases of energy or toxic materials (such as the involuntary, immediate catastrophic risks shown in Table 5–2). Epidemiology and toxicology have emphasized the relationship between the resulting exposure (dose) and the adverse consequences (effect). Epidemiologists and toxicologists usually focus on chronic exposures and delayed health effects of the delayed voluntary and involuntary risks also shown in Table 5–2.

3.1 The Engineering Approach to Risk Assessment

In Figure 5–3, a loss-of-coolant accident (LOCA) at a nuclear power plant is the initiating event that leads to an eventual release of radioactive materials into the environment. Engineers calculate the probability of such an event using fault- and event-tree analysis (Figures 5–4 and 5–5). In Figure 5–4, the event tree begins with a pipe break, or LOCA, as the initiating event and traces the possible pathways ("branches") that lead to a variety of outcomes ("twigs"). To read the figure, begin at the left. At each node in the tree there is a possibility that the safety system will either be available or will fail. For example, if the pipe breaks, electric power is available, the emergency core cooling system (ECCS) works as intended, fission product removal is accomplished, and containment integrity holds, then only a very small release will result (i.e., the small amount of radioactive water released from the small pipe break). Alternatively, reading across the bottom branch, if electric power is unavailable, the remaining safety systems will necessarily fail and a very large release of radioactivity will result. Engineers calculate the probabilities of each of the safety system's failing to estimate the overall probability that a particular series of events ("accident sequence") might lead to a release. The probabilities of each path are calculated on the basis of previous operating and accident experience with data on human

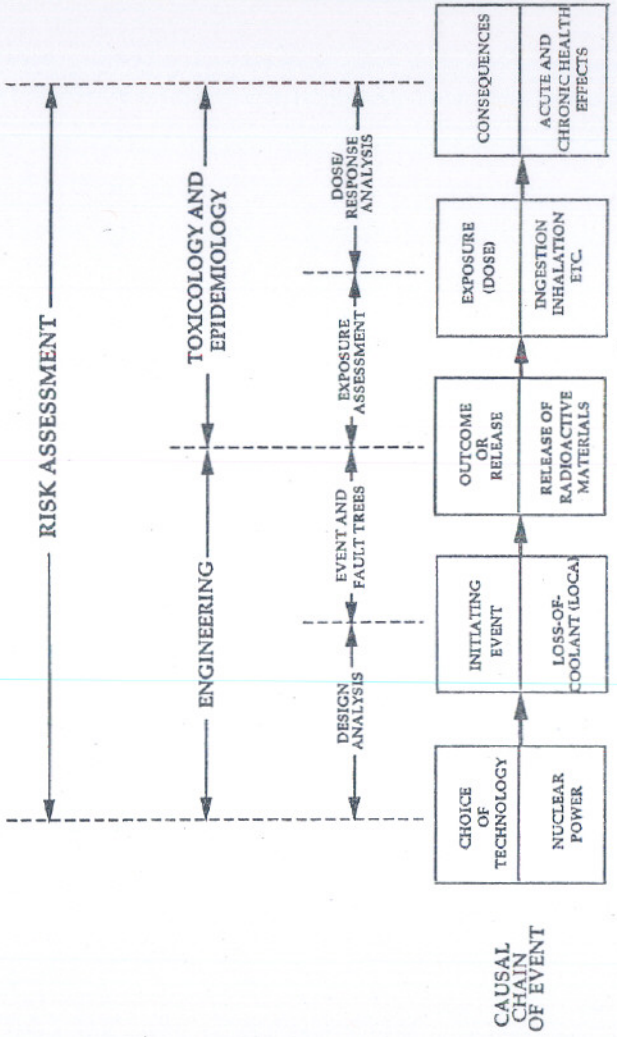

FIGURE 5–3. Methods of risk assessment. (Modified from Hohenemser, Kasperson, & Kates, 1985, p. 40.)

errors, and the failure rates of components such as valves, pipes, and dials. Since data are often missing or inadequate, expert judgment and simulations or models may have to be substituted.

Whereas in Figure 5–4 the event tree has one initiating event and several outcomes ("twigs"), the fault tree in Figure 5–5 has one outcome (the loss of electric power to safety systems) with several initiating events. Using fault trees, engineers begin with an outcome of concern and try to trace backward all the possible events that could lead to that outcome. The logic of a fault tree is therefore the reverse of an event tree. To read Figure 5–5 begin at the bottom. If the reactor loses both off-site ac power *and* on-site ac power, then all ac power is lost. If either all ac power or all dc power is lost, then there will be a total loss of all electric power to the safety systems.

Assuming there is an accident that leads to a release, radioactive materials will be dispersed according to the nature of the release (e.g., particulates versus gases), the local topography, and the prevailing weather conditions. Dose models developed by meteorologists, radiologists, and others are used to estimate how many people might be exposed to radiation and in what amounts. Based on the estimates of exposure, radiological toxicologists and epidemiologists are then able to estimate the likelihood, nature, and severity of the harm. Toxicologists

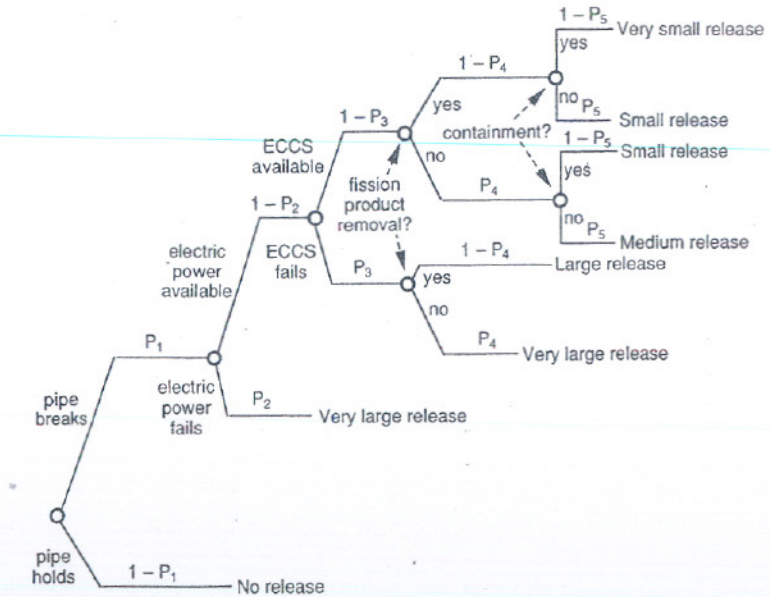

FIGURE 5–4. Simplified event tree for loss of coolant accident (LOCA) in a typical nuclear power plant. (Modified from Rasmussen, 1981, p. 130.)

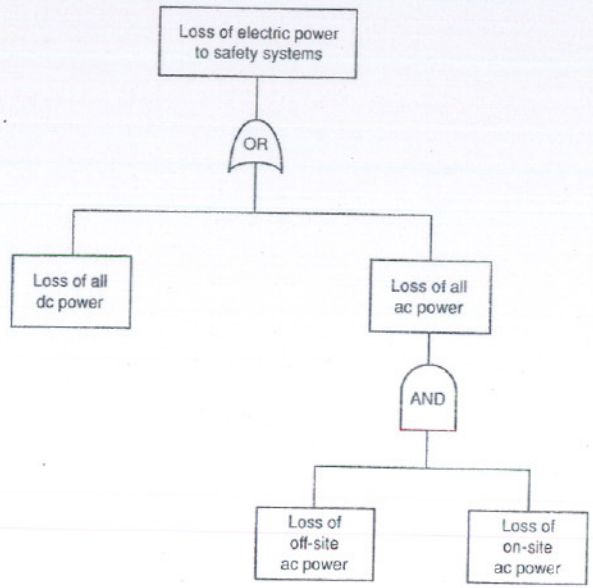

FIGURE 5–5. Simplified fault tree for loss of electric power in a nuclear power plant. (From Rasmussen, 1981, p. 128.)

extrapolate from experiments on animals to determine the relationship between the dose received and the likely adverse effects (dose–response relationships). Various epidemiological studies may be conducted, but one type looks at adversely affected populations (such as the Japanese exposed to radiation from the U.S. bombing of Hiroshima and Nagasaki) and attempts to correlate observed effects with estimates of exposure.

3.2 The Toxicological Approach to Risk Assessment

One of the outcomes of the professionalization of risk studies has been the development of standardized approaches to risk assessment. The demand for uniform standards came from both public and private interests.

To illustrate this, we will take a closer look at the toxicological model of risk assessment. Often two or more regulatory bodies have the responsibility for evaluating the risks of a single chemical, but different agencies use different approaches to toxicological evaluation. These differences became an obstacle to interagency cooperation and created confusion in the public's mind (National Academy of Sciences, 1983). Moreover, as chemical liability and toxic torts

became more prominent aspects of industrial life (Brown & Mikkelsen, 1990), demands were placed on government to promote standard methods of toxicological risk assessment. Consequently, the National Academy of Sciences (1983) pressed for the use of uniform methodologies.

The four-part framework developed by the Academy comprises: (1) hazard identification; (2) dose-response assessment; (3) exposure assessment; (4) risk characterization. Four corresponding questions emerge from this framework (National Academy of Sciences, 1983):

1. Does the agent cause the adverse effect, and if so, what are the pathologies?
2. What is the relationship between the dose received and the incidence of the adverse effect in humans?
3. What exposures are currently experienced or anticipated under different conditions?
4. What is the estimated incidence of the adverse effect in a given population?

3.2.1 Limitations of the Toxicological Approach

The above framework provides guidelines for risk assessment. But each stage in this process involves multiple levels of uncertainty and judgments that are not subject to scientific verification. Yet these are the assumptions that make the risk-assessment process possible.

One of the most refractory problems in toxicological risk assessment is the long-term, cumulative effects of low doses of a toxin. This problem is common to many areas of environmental decision making, including setting air- and water-quality standards, determining safe uses of food additives, regulating toxic chemicals in the workplace, and establishing safe residue levels for pesticides and herbicides in food. The risk-assessment framework is formal; it serves no practical use without data and inferential models. Risk assessors offer decision makers a menu of models that turn data on dose and exposure into risk assessments.

A widely adopted convention assumes that there is a continuity (linearity) between the effects of high and low doses of a toxin. In its extreme form, the assumption implies that even one molecule of a chemical may pose a cancer risk. Increasingly, the linearity assumption has come under attack by those who consider it too stringent a standard for setting public policy. Instead, they believe there are levels of exposure (thresholds) below which there are no significant adverse biological effects. However, the only means available to test the significance of threshold levels in humans involves complex, large-scale, costly, and often impractical epidemiological studies.

The third stage of the standard toxicological risk-assessment framework involves determining exposure. Such a determination can be extraordinarily difficult, however, and it is not unusual to find large error bars in any exposure assessment, particularly when large, diverse populations are at issue. In highly structured situations, such as controlled workplace environments, better exposure estimates can be made; these are nonetheless often still inadequate. The 1989 controversy over the use of daminozide (commonly known as alar), a chemical sprayed on apples to control ripening and improve appearance, illustrates the wide variance among experts on exposure estimates. The EPA indicated that about 5% of apples are treated with alar, whereas the Natural Resources Defense Council (NRDC) presented data that treatment is closer to 20%. EPA calculated a lifetime risk of 3-4 cancers per 100,000 people exposed to alar over the first 6 years of life, whereas the NRDC calculated a risk of 24 per 100,000 (Roberts, 1989).

Science informs risk assessment, yet the determination of risk is not a science. The standard desiderata of science are testability of theories, replicability of results, shared frameworks of analysis, and accumulated knowledge. For any particular risk determination, there are usually important gaps in knowledge; "transcientific ideas" (Weinberg, 1972) often masquerade as science, and hypothesis testing is conducted by analogy. One important difference between science and risk determination is in the standards of validation. In science, results are accepted when the author has met the standards of the discipline. Premature results must wait until there is sufficient evidence. By contrast, the requirements of public policy, and ultimately the market system, drive risk assessment. It is almost unheard of for the release of the results of a risk assessment to be postponed for lack of sufficient information. Technological choices demand publication of risk assessments regardless of the state of scientific knowledge in the field.

Risk determination involves layers of uncertainty. Certain presuppositions of the technical risk analyst are not justified exclusively on scientific grounds. McCray (1983, p. 83) states: "A single risk management decision is often based on an assessment that, itself, comprises many discrete decisions—choices among assumptions, interpretations, relative weighting of conflicting pieces of evidence. . . ." For this reason, risk is sometimes viewed as a social construction and not a property of the real world (Wynne, 1982). Others describe risk analysis as "value-laden." In spite of the theoretical possibility that some uncertainties can be narrowed, once the transition from risk assessment to risk evaluation is made, value considerations are central and irreducible.

4 RISK EVALUATION

According to conventional wisdom, most of the risks people face in daily life cannot be totally eliminated. We can ban a product such as DDT or asbestos and

therefore eliminate all the risks associated with it, but then we have to deal with the risks of substitutes. If there are no substitutes, we have to face the risks that the product was designed to eliminate (such as pest infestations and fires).

When it is not practical or politically feasible to reduce risks to zero, how do risk managers decide what level of risk is acceptable? Many factors beyond the hazard outcome itself are relevant to such a decision. Some considerations are the following: Does the activity or product produce widely sought benefits? Are the risks and benefits distributed among the same people? Do people perceive the risks as voluntary or involuntary? Do the risks disproportionately affect vulnerable populations such as children or the elderly? Do the risks affect well-defined groups (such as workers) or are they randomly distributed over the general population? Will setting a lower risk level conflict with individual rights? What are the costs associated with risk reduction? Are the risks new or old?

The technical measure of risk as the conditional probability of experiencing harm [i.e., probability x the magnitude (number affected) and severity (injury, illness, death) of the consequences] is only one of several competing factors relevant to risk evaluation. Let us suppose that the use of a product is expected to result in no more than one fatality per year for a population of N individuals. What value of N makes the risk acceptable or tolerable? In regulating carcinogens, some experts have chosen a one-in-a-million lifetime (70 years) risk as acceptable (Milvy, 1986). Thus, if the population of the United States is 280 million, then at the acceptable level one would expect 280 additional deaths from cancer over a 70-year period, or 4 additional deaths per year. But this one-in-a-million standard has been criticized as being too restrictive when applied to specific occupational exposures. It would result in an infinitesimally small increase in the 450,000 expected cancer deaths per year in the United States.

For several reasons, regulatory bodies sometimes impose more stringent health standards on new chemicals than on chemicals already in use. First, when new environmental laws are passed, chemicals already approved for use are often "grandfathered in," or exempted from the new regulations. In such cases, the regulatory authority must show that the substance is unsafe before it may be banned. There are many examples of substances ranging from aspirin to alar that would not have been approved for use under current standards. Ordinarily, the burden of proof is on the manufacturer to show that the chemical is safe.

Second, most regulatory agencies are obligated to consider benefits in their decision to restrict or ban a product's use. An established product has accrued more benefits by virtue of its position in the economic system. Withdrawing a product is generally more expensive to society overall than preventing one from being introduced.

Third, there are more advocacy groups in support of established products than there are in support of new products. In the case of alar, growers had organized their schedules around the use of a chemical that allowed the apples to remain on the trees longer. The manufacturers of alar, the growers, and their advocates lobbied hard to prevent the prohibition of the chemical.

Several approaches have been advanced for setting acceptable or tolerable levels of risk (e.g., Kasperson, 1983). We shall discuss three of these: *de minimis* risk, comparative-risk, and risk-benefit analysis.

4.1 *De minimis* risk

The term *de minimis* comes from the legal concept *de minimis non curat lex* which means the law does not concern itself with trifles. The idea behind *de minimis* risk is that, below some level of risk, it is not worth the allocation of social or personal resources to address the problem. For example, if the annual expected fatality for a product or an activity is 1 in 500 million, the risk would be considered exceedingly low. Most environmental laws use a term like "significant hazards" when referring to the appropriateness of regulation. Natural hazards sometimes are used as a baseline indicator of *de minimis* risk. If the risk of a particular product or technology (measured as probability x consequence) is less than the risk of some common natural hazards (e.g., floods, background radiation, lightning strikes, earthquakes), then it is sometimes viewed as below the threshold of concern.

Another approach to setting a threshold is based upon the methods of detection. The point at which the risks cannot be detected might be viewed as an acceptable level. This is a much weaker criterion than one based on natural hazards, because methods of detection, particularly in epidemiological studies, are very insensitive instruments and may fail to detect even significant risks. One of the benefits of a generalized *de minimis* risk is that it can be applied across regulatory regimes.

4.2 Comparative-Risk Analysis (CRA)

Comparative-risk analysis (CRA) involves weighing the risks of new products or technologies against other products or technologies that are already "accepted" or "tolerated" by society. Starr (1985, p. 97) maintains that CRA can "provide a basis for the rational distribution of society's resources to improve public health and safety." Wilson (1979) proposes using CRA for setting priorities in risk management and making more sense out of the risks society faces. Wilson (1979) also believes it is better to evaluate the risks quantitatively and then to reduce the largest risks first, rather than to try to eliminate all risks or to spend a lot of time and effort reducing insignificant risks. Comparing risks requires organizing disparate hazard events under a single metric, as illustrated in Table 5–3. This sometimes results in some bizarre comparisons among very dissimilar types of hazards.

TABLE 5–3 A Comparison of Risks

Quantity	Action	Cause of Death
2 (U.K.)	Cigarettes	Cancer, heart disease
3 (U.S.)		
2 months	Of living with a cigarette smoker	Cancer, heart disease
½ liter	Wine	Cirrhosis of the liver
40 T.	Peanut butter	Liver and other cancers caused by aflatoxin
1 year	Miami drinking water	Cancer caused by chloroform
30 cans	Diet soda	Cancer caused by saccharin
100	Charcoal-broiled steaks	Cancer caused by benzo(α)pyrene (risks of red meat, fattening, etc., additional)
2 months	Visit to Denver	Cancer caused by cosmic rays
6000 miles	Jet flying at 35,000 ft.	Cancer caused by cosmic rays
1	X-ray in a good hospital	Radiation cancer
20 years	Living within 5 miles of a polyvinyl chloride plant	Cancer caused by vinyl chloride
2 days	In New York or Boston	Air pollution
3 hours	In coal mine	Accident
1 hour	In coal mine	Black lung disease
150,000 times	Dyeing hair with lead acetate dye	Cancer caused by lead
1000 times	Drinking from banned plastic bottle	Cancer caused by acrylonitrite
6 minutes	In a canoe	Accident
1 year	At site boundary of nuclear power plant	Radioactive accident
3 weeks	Living below a dam	Accident (dam failure)

Note: Actions which can increase the average risk of death by 1 part in 1 million or reduce life expectancy by 9 minutes for cancer or 15 minutes for accident.
Source: From Richard Wilson, 1984. Commentary: risks and their acceptability, in *Science, Technology and Human Values*, Vol. 9, no. 2, p. 19.

The Nuclear Regulatory Commission's classic Reactor Safety Study compared the risks of nuclear accidents with the risks of daily life, of natural hazards, and of other technologies. Its purpose was to show how minuscule the probability of a fatality from a nuclear accident was compared to that of other more commonplace accidents (Nuclear Regulatory Commission, 1975).

Used in conjunction with other methods, CRA provides a basis for determining acceptable levels of risk. The decision logic is as follows: If product A is acceptable to the public and has a risk factor greater than that of product B, everything else being equal, then product B ought to be acceptable. Biochemist Bruce Ames of the University of California at Berkeley is a strong proponent of CRA to evaluate food additives and agricultural chemicals. Ames and Gold (1989) believe the risks of some highly publicized pesticide residues on food (such as EDB and alar) are trivial, based upon their studies comparing the risks

of these chemicals to the risks of natural carcinogens in foods, such as aflatoxin in peanut butter.

These types of comparisons often confuse rather than clarify the issues. For example, the comparison between peanut butter and EDB or alar did not make much of an impact on the public. Similarly, the NRC's assertion that the probability of being killed in a reactor accident was equivalent to the probability of someone being killed by a meteorite (National Research Council, 1975) did little to allay public fears about nuclear power. Making such analogies is like trying to compare apples and oranges—there is no common metric.

The risks of nuclear accidents are qualitatively different from the risks of driving, for example. Driving is a voluntary activity over which we believe we have a large measure of personal control—and most of us have *no* sense of control over the way the nuclear industry runs its reactors. Furthermore, comparisons such as those in Table 5–4 are viewed by some critics as disingenuous, plainly intended to influence public opinion and not merely to inform about risk. Although it may be that out of 15 million people we can expect 4200 automobile-related deaths annually, the fear of nuclear accidents is far greater, because it has little to do with the low annual average fatalities (only two) that result from day-to-day operations of nuclear facilities. Rather, people fear the low-probability/high-consequence accidents that may kill thousands of people. This fear is exacerbated by public distrust of the nuclear industry in general (Otway & Wynne, 1989), further blurring the benefits of making comparisons in the first place. Thus, these efforts to make comparisons serve primarily to highlight the differences between the way scientists and the vast majority of nonscientists view risk.

4.3 Risk-Benefit Analysis

A third approach to determining risk acceptability involves the comparison of risks and benefits. As individuals, we face many decisions where risks and

TABLE 5–4 Average Annual Risks from Various Accidents for 15 Million People Living Near a Reactor Site

Accident Type	Annual Fatalities	Injuries
Automobile	4,200	375,000
Falls	1,500	75,000
Fire	560	22,000
Electrocution	90	—
Lightning	8	—
Reactor (100 plants)	2	20

Source: From Nuclear Regulatory Commission. 1975. Reactor Safety Study Executive Summary. WASH-1400 (NUREG/74/104). Washington, D.C.: Nuclear Regulatory Commission: 9.

benefits are intertwined. An arthritic patient is advised that aspirin may reduce his discomfort, but that the drug may cause side effects like abdominal ulcers. The risks are acceptable or tolerable when the benefits outweigh the risks. For the individual decision maker, this result is tautological. Once advised about the risks and benefits, the individual's choice is an expression of personal risk-benefit balancing. Thus, the notion of setting acceptable risks in this manner is ideally suited to those circumstances where conditions of autonomous choice and best available information are satisfied.

The main problem with risk-benefit balancing is the incommensurability of risks and benefits. This problem is solvable when a single individual is both the decision maker and the recipient of both risks and benefits. Moreover, this method precludes the need to set a fixed acceptable level of risk, since the latter is a function of the benefits, which vary greatly across products and activities.

Problems arise when regulatory agencies are responsible for setting an acceptable risk level and the risks and benefits are not distributed homogeneously throughout the society. In the case of chemical exposures, some individuals—because of their life-style, location, health status, or genetic endowment—may be more vulnerable to harm. Furthermore, those who benefit most from the product usually are not the people who are most at risk. In such situations, the problem of incommensurability of risks and benefits looms large.

While there are no sure-fire methods for drawing comparisons between fatalities and economic savings, the use of risk/benefit or cost/benefit analysis to establish acceptable risks has many adherents (Leonard & Zeckhauser, 1986). One method, often employed, builds on the autonomous-choice model. In following this model, decision makers view society as an aggregate of individuals who separately balance the risks and benefits of products and technologies. The role of the decision maker is to interpret and implement public choice. "Acceptable risk" must be determined for every individual product since there can be no *a priori* comparisons across different benefit regimes. However, implementing such a scheme for the tens of thousands of chemicals, consumer products, and technologies would be prohibitive.

5 CONCLUSION: CULTURAL THEORY AND RISK SELECTION

Decision scientists consider risk assessment an integral tool in environmental decision making. It offers policymakers a rational basis for risk selection and risk comparison. But the public response to many of the risks of industrial society is often at considerable odds with what the experts believe. Recent studies in the social and cultural aspects of risk have brought a fresh perspective to our understanding of the role risk assessment plays in decision making. Instead of viewing risk assessment as a neutral and purely scientific aspect of the policy process, some view it as a social construction subject to the same influences of the political process that befall nontechnical problems. Some cultural theorists maintain that "risk" itself has no objective status and therefore is not fundamental to a decision process. Rather than viewing risk as an ojective phenomenon of the physical world, they consider risk a subjective attribute molded by social processes (Rayner & Cantor, 1987; Schwartz & Thompson, 1990; Thompson, 1980).

A more fundamental question than "What are the risks of a product or technology?" exists, namely: "How did the issue get on the public agenda?" Selecting or rejecting risks is made intelligible by more completely understanding the cultural and social fabric within which the risk is embedded. Different cultures emphasize different risks. Douglas and Wildavsky (1982, p. 8) maintain that: "Each form of social life has its own typical risk portfolio." In the case of the pesticide ethylene dibromide (EDB), the numbers in the risk estimates were largely irrelevant. More important were the powerful messages sent by TV pictures of exposed workers suffering obvious neural disorders, and the fact that people—especially children—would be exposed through the consumption of foods. Any adulteration of food is a social anathema, and adulteration with a potentially carcinogenic pesticide particularly so. The public discourse over EDB is therefore rooted in a more general concern about the use of pesticides, the adulteration of food, and cancer as the scourge of modern civilization.

In contrast to engineers, economists, and decision scientists, cultural theorists reject the idea of a common metric for rating and comparing different hazards. They view risk as a polymorphic concept (Rayner & Cantor, 1987) and advise risk managers not to treat risk as if it were a real property of the world. Rather, they believe that risk managers should focus on the technology and the institutions that control its utilization.

Cultural theorists also distinguish themselves by the way they treat rationality in risk assessment. Wynne (1982) argues that science created an elaborate mythology about risks to legitimate control over technology. Krimsky and Plough (1988) distinguish between technical and cultural rationality of risk, where each mode of analysis is internally consistent and representative of a different set of values and interests. Perrow (1984) cites three forms of rationality: absolute rationality held by economists and engineers, bounded or limited rationality held by risk assessors, and cultural rationality held by the majority of people. Different viewpoints about how risk is factored into decision making can sometimes be explained by reference to the divergent concepts of rationality within microcultures.

The most ardent cultural theorists believe that scientific rationality is reducible to political anthropology and sociology. Weinberg (1981, p. 5) argues that ". . . even when the risks can be quantified, the setting of standards is intrinsically a political act. That is the standards themselves must in the final

analysis be arbitrary." This leads to the conclusion that environmental decision making incorporating risk assessment is embedded in a social process that at times yields consensus among members of the scientific community and policymakers, but most often mirrors the ebbs and flows of any political debate.

Perhaps the most significant difference between cultural and technical perspectives on risk bears on the issue of where democratic process enters into decision making. Much of the research in risk studies is grounded on the distinction between a descriptive-scientific component and a normative-policy component in the decision matrix. The scientific component is sought in risk assessment (what are the risks and who is at risk), whereas the normative component is sought in risk management (what risks we should accept and what we should do about the risk levels that are unacceptable). This suggests distinctive roles for the scientific and democratic process. Cultural and sociological theorists reject this division of science and value. Instead, they place risk selection and the public's confidence in scientific and political institutions as primary factors of analysis. Environmental risk itself is derived from a configuration of special interests and selected paradigms of rationality.

To understand fully how and why certain issues are brought to public attention, we must investigate the roles and decision choices of all the actors. This may include nonprofit organizations such as the Environmental Defense Fund (EDF), not necessarily part of the formal process of risk assessment and hazard management.

An excellent example to illustrate the cultural approach to risk selection is the EDB controversy (see the case study in Section 6). First, in the United States, environmental advocacy groups played a key role in highlighting the risks of EDB as a cause for concern. EDB was "selected" and placed on the regulatory and political agenda years before there were conclusive data from animal studies to show that EDB was a potential human carcinogen. The EDF petitioned the EPA to investigate the risks and suspend its use. Organizations like EDF thereby acted in *loco parentis* of society.

Second, EDB has a risk profile similar to other chemicals that have excited major public controversy and concern in the past. Exposure to EDB is widespread: it represents a largely involuntary risk beyond the control of individual citizens. The pesticide is associated with a dread disease—cancer. No safe level of exposure is known to exist, and children may be particularly vulnerable to the toxic and carcinogenic effects.

Third, the media and popular culture respond most effectively to singular, dramatic events, so the disturbing film footage of workers suffering severe neural damage from prolonged exposure to high doses of EDB served as a lens through which to evaluate the long-term effects on consumers of exposure to relatively low doses in food.

Fourth, as a potential human carcinogen, EDB cast a cloud over foods in which people wish to have unqualified trust—foods that are symbolic of sustenence and purity, such as bread, baby cereals, and cake mixes. The selection of concerns is not homogeneous across all food groups. Also, it is a notable cultural irony that, under EPA and FDA regulations, EDB would not have been permitted as a food additive in any amount, but was permitted as a pesticide residue in small amounts.

Finally, while EPA and several states set stricter standards for EDB in 1983, it has not been banned from all uses. Very little public attention will be given to substitute pesticides and their associated risks until the social selection process highlights a new concern.

Risk assessment cannot be ignored as a component of environmental decision making. But the particular role it plays and the influence it exerts in public policy are still very much matters of debate. Two cultures are in stark contrast. The first chooses as its goal the rigorous quantification of risk and the standardization of risk measurements leading toward a unification of the field and a rationalization of public policy. We may call this approach "risk scientism." The other approach sees risk not as a reified property of the natural or technological world subject to objective measurement and quantification, but rather as the outcome of a process of social selection. We may call this approach "risk populism." Environmental decisions generally involve balancing "risk scientism" and "risk populism." The balance point depends on our collective notions of uncertainty and rationality, and on our trust in the institutions that generate and control risks.

6 APPENDIX: A CASE ANALYSIS OF PESTICIDE RESIDUES IN FOOD

To illustrate how risk-analysis and risk-management concepts are applied in a real situation, we present a case in which regulators were faced with assessing the risks of chemical pesticide residues in the food supply. Risk estimation is just one of several factors that are considered in the decision process.

6.1 Background

Certain hazards involving health risks to humans of low doses of chemicals exhibit certain patterns of complexity to decision makers. The following case, which concerns the pesticide ethylene dibromide (EDB), is characteristic of many of the cases where chemicals were brought under regulatory authority. Typically, after the chemical has been in use for many years, information about its potential adverse consequences to human health becomes known. The review process for chemicals that is already part of the industrial system generally requires different considerations of benefits than those chemicals that have not

yet been introduced. Additionally, scientific uncertainty preys on the risk-assessment process.

Beginning in the 1930s, ethylene dibromide was widely used in agriculture as a post-harvest fumigant for grains.* EDB protected stored wheat and corn against insects, molds, and fungi. It was first registered as a pesticide in 1948. By 1955, food tolerances had been established for the presence of EDB metabolites. A year later, Dow Chemical Company, one of the principal manufacturers of EDB, petitioned and received from the federal government an exemption from tolerance levels when the chemical was used as a grain fumigant. The justification for the exemption was based on evidence that the compound would not remain active for long. Moreover, it was believed that any residues would be driven off when the grains were cooked.

Advanced technologies for measuring minute quantities (parts per billion) of chemicals became available in the 1960s. Also, animal models were developed to test mutagenicity and carcinogenicity of chemical compounds. Within a decade, laboratory findings linked EDB to cancers in rats and mice.

Regulatory agencies began setting standards for EDB after preliminary risk assessments were completed. In 1977, the EPA concluded that EDB was a potent carcinogen in animals and likely to be carcinogenic in humans. Under what was then the current usage, EPA estimated a cancer risk of 3.3 cancers per 1000 people exposed. Since EDB was used on grains basic to the American diet, practically everyone in the country was exposed to some level of the chemical. Precise estimates of exposure could not be made because several questions remained unanswered: What percentage of EDB remains in processed food? What percentage of EDB is destroyed by cooking? What amount of EDB is found on food that is eaten without cooking? What amount of EDB is consumed on the average by adults and children?

The chemical industry responded to the EPA's risk estimates by funding its own risk assessment. It concluded that EPA greatly exaggerated the risks. A more sober estimate, according to an industry trade association, was 1 cancer per million children exposed and 1 cancer per 12 million adults exposed. Industry spokespersons argued that this would be a miniscule increase in the already significant cancer burden faced by society.

Faced with growing evidence of EDB's potency as an animal carcinogen, EPA began a review of the pesticide permit in 1980. Within three years the issue came to a head. Several states discovered EDB in groundwater. A few issued their own tolerance levels which were more stringent than those set by the federal government. Action by the states and petitions filed by national environmental groups attracted extensive media attention, which eventually led EPA to accelerate its review process.

*This case study is adapted from Chapter 2 in Sheldon Krimsky and Alonzo Plough (1989). *Environmental Hazards: Communicating Risks as a Social Process*. Dover, MA: Auburn House.

Throughout its regulatory involvement in EDB, the EPA has been guided by the Federal Insecticide, Fungicide and Rodenticide Act and its 1972 Amendments, which state that pesticides should not present "any unreasonable risk to man or the environment, taking into account the economic, social, and environmental costs and benefits."

By 1983 the EPA was facing a highly charged atmosphere in which health risks were pitted against the economic benefits of a fungicide the grain industry viewed as critical to protecting the grain supply. Public confidence in the EPA was at an all-time low. States were passing their own regulations. Unions were demanding that the government pass an emergency standard to protect workers from occupational exposure. Environmental groups were mobilized. The media dramatized the removal of product lines from supermarket shelves. All these factors contribute to the risk-management decision.

6.2 Agency Options

From our discussion of risk evaluation, we see that the agency decision makers reviewing the health, environmental, and economic impact of EDB were faced with several options.

6.2.1 Delaying Action

Because there were large gaps in the knowledge base, particularly in regard to the potential for cancer in people exposed to relatively small concentrations over a lifetime, one option was for the EPA to delay its decision. The agency could support additional studies on other mammalian species in order to narrow the uncertainty before changing the registration requirements for EDB. This would give EPA time to pursue the availability of substitute products before significantly reducing EBD use.

6.2.2 Setting Stricter Standards

The agency could set stricter standards that would require lower levels of EDB residues on food, thereby reducing the risks of human exposure. Because EDB is destroyed in the cooking process, stricter standards could be set for food products that do not require cooking. The decision on what tolerance levels to adopt would be determined first by what can be measured, second by what can be implemented, and finally by what risk is "acceptable." Determining acceptability would involve a series of comparisons between the risks of EDB and the risks of other pesticides already deemed "safe," between the risks and benefits of using EDB, and between the risks of EDB and the costs of reducing or eliminating them.

The agency could compare the risks of EDB with those of other pesticides it regulates, or with those of other products or activities of daily life. Comparative-risk analysis (CRA) might be used to establish uniform standards of

acceptable risk across many different types of products, activities, and environmental media. One of the main problems introduced by CRA is choosing a sample of comparison that will be credible to the general public.

Two prominent toxicologists made the following comparison between EDB and natural substances.

> Eliminating a carcinogen may not always be a good idea. For example, ethylene dibromide (EDB), the main fumigant in the United States before it was banned, was present in trivial amounts in our food: The average daily intake was about one-tenth of the possible carcinogenic hazard of the aflatoxin in the average peanut butter sandwich, a minimal possible hazard in itself.*

The agency could weigh the uncertain risks of cancer incidence from EDB exposure against the risks of removing the pesticide from the agricultural system. A scientist from the American Council on Science and Health (an industry-supported research group) advanced the following argument for the continued use of EDB:

> Just as individuals choose to take voluntary risks, society as a whole takes risks in order to provide the best possible standard of living for its populace . . . [O]ne must evaluate the tradeoff between the risk and the offsetting benefits associated with the product's use. Nowhere does this apply more aptly than to the agricultural and health protection uses of pesticides. Because of the use of EDB and other pesticides, we in America have escaped the negative health consequences of eating uncontrolled amounts of insect fragments and mold toxins in our food.†

Decision makers can look exclusively at the health benefits (i.e., the risks of using EDB versus the health benefits of using EDB, as above) or they can compare the risks with wider benefits (such as reduced spoilage of stored grain due to insects, molds, and fungi). In some cases, chemicals that are proven to cause cancer in animals have been permitted as food additives on the grounds that to remove them would introduce greater risks to the public. One such case is the use of nitrites and nitrates for the preservation of cold meats. If these additives were removed, it has been predicted, there would be a significant rise in food poisonings due to botulism.

Another comparison is that of potential health risks with other costs of reducing or eliminating EDB use. Examples include losses in production, jobs,

*From Ames, Bruce and Lois Gold. 1989. *Misconceptions Regarding Environmental Pollution and Cancer Causation*. Washington, D.C.: The Media Institute. p. 33.

†From Krimsky, Sheldon and Alonzo Plough, 1988. *Environmental Hazards*. Dover, MA: Auburn House. p. 16.

international competitiveness, and profits. In this case the decision maker is faced with comparisons of attributes that are not, on the surface, commensurable. Methodologies designed to create a common metric of comparison—such as dollars—exist, but they involve assumptions about which there is no broad consensus. For instance, how can we balance the additional cancers caused by EDB with the savings it yields to the grain industry by protecting grain from pest contamination?

6.2.3 Banning the Use of EDB

The agency's third option would be to withdraw the registration for EDB's use as a pesticide. In doing so, however, the agency would have to take into consideration the economic consequences of such an action on the grain industry. Decisions of this nature have become commonplace in government. The United States regulates thousands of pesticides and tens of thousands of industrial chemicals. The withdrawal of a pesticide from agricultural use is usually restricted to worst cases.

Where there is strong public interest against use of a particular pesticide, the agency may view it as a political liability and defer to public opinion. Arguing against this approach are those who posit scientific risk assessment as a policy instrument that ought to take precedence over the public's perception of risk. The public's views about the risks of technologies are often at odds with experts' views (Fischhoff, Slovic, & Lichtenstein, 1982), as noted above. Moreover, public attitudes toward environmental hazards may be easily influenced by the amount of media attention.

6.3 Agency Decision

In actuality, the EPA followed a combination of options: first, it delayed taking action until its hand was forced by public opinion and the initiatives of individual states. At that point, not acting would have lost the agency significant control over the issue.

The EPA was first petitioned to remove EDB by the Environmental Defense Fund in November 1975, but took no action until September 1983. In the interim the agency reviewed the available scientific data on the risks and benefits of the pesticide while coming under increasing pressure from environmental groups. In July 1983, Florida announced the ban of EDB as a soil fumigant in eight counties of the citrus belt; this forced EPA to announce the emergency suspension of EDB as a soil fumigant in September. Florida again forced the issue in December of that year when it passed a stop-sale order and began to remove grain-based products from grocery shelves. This was a major-risk communication event, providing dramatic film footage that fostered public indignation. Soon thereafter, the EPA banned the use of EDB in fumigating grains and set interim tolerance

BOX 5–1

Chronology of the EDB Case

1948 EDB is registered as a pesticide with USDA.

1949 EDB is registered for use as a soil fumigant.

1956 EDB is registered as a fumigant for stored grains, fruits, and vegetables.

1974 The National Cancer Institute issues an alert on EDB after tests show it caused cancer in animals.

1975 The Environmental Defense Fund petitions EPA to cancel EDB as a pesticide.

1976 EDB is cited by the National Institute for Occupational Safety and Health (NIOSH) as a potential occupational carcinogen.

1977 EPA cites EDB as a carcinogen and begins a review.

1980 EPA issues a position document stating that EDB is a risk to human health and proposes to ban its use on stored grain.

1981 California limits workers' exposures to EDB.

1982 EDB is detected in the groundwater in Georgia.

1983 EDB is detected in California groundwater. Hawaii wells are closed because of EDB contaminaton. Florida finds EDB in wells and sets tolerance levels at 1 ppb.

1984 EPA orders an emergency suspension of EDB's use as a soil fumigant and issues tolerance levels of EDB in the food supply; 900 ppb on raw grain intended for human consumption; 150 ppb on flour mixes and cereal; 30 ppb on ready-to-eat products. Massachusetts sets an EDB tolerance level of 1 ppb on all food products and wins a court challenge on the standard. New York State sets an EDB standard of 6 ppb on ready-to-eat food. Federal interim tolerance standards expire whereupon any detectable levels constitute food adulteration.

levels for residues in food; this was a first step to revoking the tolerance exemptions initially granted in the 1950s. By September 1984, these interim standards had expired, and any food with detectable levels of EDB was considered legally adulterated. Box 5–1 summarizes the chronology of events in the EDB case.

EXERCISES

1. Construct a fault tree for why a car fails to start. What are the major shortcomings of this method? What are some of the ways of overcoming them?

2. Construct a personal "risk diary" for all the risks that you worry about on a daily basis for the period of a week. Indicate the activity or risk, your length of exposure, and the potential adverse outcome. Plot the risk profiles in terms of voluntariness, delay, and so on (see Figure 5–2) for 10 of the biggest risks you face.

3. How would you construct a comparative risk assessment for EDB? What is the appropriate field of comparison? Support a position either for or against comparative risk assessment. What is your response to the argument that there are natural carcinogens in our food that pose equal or greater risk than EDB residues?

4. Select a risk that you think is important in your life. Under what conditions is that risk acceptable or unacceptable? Are you able to quantify the risk? What factors are important in how you view the risk?

ADDITIONAL READINGS

For further general reading on risk, see Glickman and Gough (1990), Hohenemser, Kasperson, and Kates (1985), and Lowrence, W.W. (1976). For more information on the topic of risk assessment, see Cohrssen and Covello (1989), National Academy of Sciences (1983), and Rasmussen (1981). To read more on risk communication studies, see Krimsky and Plough (1988) and NRC (1989).

For more information on the psychometric approach, see Fischoff, et al. (1981), Slovic, Fischhoff, and Lichtenstein (1979), and Slovic, Fischhoff, and Lichtenstein (1980). To read more on the topic of social and cultural theory, see Douglas (1986), Douglas and Wildavsky (1982), and Johnson and Covello (1987). For more information on the issue of public responses to risk, see Brown and Mikkelsen (1990), Nelkin and Brown (1984), Raynor and Cantor (1987), and Schwartz and Thompson, (1990).

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