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11
Hazard Assessment: Art, Science, and Ideology[1]

Robert W. Kates

Human beings appear to become increasingly adept at creating, discovering, or rediscovering threats to themselves and to their environment. A new professional interest, hazard assessment, has developed in assessing these threats. Hazard assessors are becoming more numerous and their products in the form of risk assessments, risk/benefit analyses, environmental impact statements, and technology assessments are widely diffused.

The task is not one for specialists alone; people have always assessed environmental threat: storm, drought, fire, or disease. But for the new and newly discovered hazards, there is strong perception of risk but little experience with consequences. With such uncertainty it is not surprising that hazard-assessment practice is still more art than science and that distinctive, contrasting ideologies flourish.

Hazard Assessment Methods

Hazard assessment is the prime component of the intelligence function of hazard management (chapter 3). For descriptive convenience, Figure 1 separates the overall process into three overlapping elements, but it is important to recognize that in practice the distinctions are blurred. **Hazard identification** is the recognition of a hazard, the answer to the question: what constitutes a threat? Its methods are the methods of research and of screening, monitoring, and diagnosis. **Risk estimation** is the measurement of the threat potential of the hazard, an answer to the questions: how great are the consequences, how often do they occur? Its methods are methods of knowing: revelation, intuition, and extrapolation from experience. **Social evaluation** is the meaning of the measurement of threat potential, an answer to the question: how important is the estimated risk? Its methods are methods of comparison: aversion, balance, and cost/benefit analysis.

Hazard Identification

For much of human history, the identification of environmental hazards arose from the direct human experience of harmful events and consequences or from the application of ritual or magic. Technological hazards too often manifest themselves experientially as

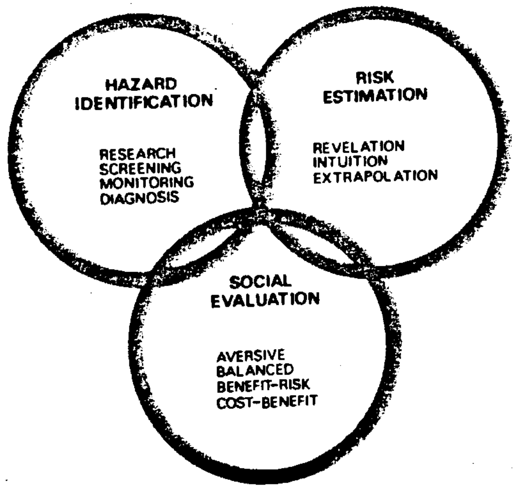

Figure 1. Elements of hazard assessment. Risk assessment is composed of three overlapping elements. Hazard identification is the recognition of risk; estimation is the measurement of the threat potential of the risk, and social evaluation, the appraisal of the meaning and importance of the risk.

surprises, chance discoveries, outbreaks--often disastrous. Thus Minamata disease is a graphic reminder of the hazards of mercury (chapter 9) and toxic shock syndrome dramatizes the hazards of tampons--thereby alerting society to new and rediscovered threats. But beyond such painful experiences, the identification of new and newly discovered hazards will continue to rely for the most part on science.

Basic research or "pure science" is not directed toward hazard assessment; it deals with knowledge for its own sake. Nevertheless, fundamental scientific inquiry discovers threats, albeit somewhat randomly, and provides the basis for directing and interpreting more purposeful search. "Critical" science[2] engages in a directed, intensive search for environmental or technological hazard as part of its effort to redress the perceived imbalance between technology and the human environment. But the institutionalized task of hazard identification falls to "practical" or "applied" science, employing screening, monitoring, and diagnosis.

In **screening**, a standardized procedure is applied to classify products, processes, phenomena, or persons for their hazard potential (see, for example, Committee 17 1975), whereas **monitoring** (in health studies, surveillance) observes, records, and analyzes the same for the recurrence of hazardous events or their consequences (SCOPE 1971;Munn 1973). In **diagnosis**, the identification of hazards takes place through analysis of indicators or symptoms of consequences (World Health Organization 1972, 1976; Engle and Davis 1963). Each of these methods has distinctive

historical origins and preferred usage in certain disciplines and professions, and only recently, in the context of such activities as Earthwatch (Jensen, Brown, and Mirabito 1975) is there emerging some searching comparison of these methodologies.

Implicit in these methods of hazard identification is a sequence in the suspectability of hazard potential. Screening procedures are akin to "fishing expeditions." Monitoring implies knowledge of threat potential, where the purpose of monitoring is to measure variation in some critical indicator, the cumulation of a hazardous condition, or the failure of a protective device. Diagnosis implies the ready existence of hazard-indicative "symptoms," some abnormal set of events or consequences--the location, etiology, or treatment of which are in doubt. Any complex socioenvironmental problem may call upon all the methods of hazard identification.

A current example is the recent and growing discovery of threats to the atmospheric ozone column that serves to protect us from ultraviolet radiation and resultant skin cancer. The basic chemistry of ozone formation and its observed concentration in the stratosphere dates back to Chapman's work in 1930. Stratospheric ozone, a molecule of oxygen that contains three atoms rather than the usual two, is formed when ultraviolet solar radiation dissociates O_2 into two atoms, freeing each to recombine with other O_2 molecules to form O_3. But only in the context of the United States debate over development of supersonic transport (SST) did the hazard potential emerge. James McDonald (1971), an atmospheric scientist with an interest in public policy issues, connected the distribution of skin cancer with latitudinal variations in ozone concentration. His favored mechanism for ozone destruction was water vapor injection from the SST. In this he erred, overestimating the effect. Crutzen (1970) and Johnston (1971), drawing on their basic research, proposed NO_x as the major catalyst of ozone destruction. An applied governmental research program, the Climate Impact Assessment Program, validated most of these early hypotheses at a cost of US $20 million (National Research Council 1975).

Once the potential for ozone destruction was recognized, basic knowledge of chemical reactions suggested other catalytic agents. Continuing laboratory experiments revised rate constants for many key reactions. Among the currently recognized agents of ozone destruction are atomic warfare, the space shuttle, nitrogen fertilizer, and chlorofluorocarbons in aerosol cans, solvents, and refrigeration. New efforts monitor ozone, its destructive catalysts, and incidence of skin cancer. Modeling efforts have led to a set of repeated, systematic risk assessments (National Research Council 1975, 1976a, 1976b, 1979a, 1979b, 1982;Great Britain 1976, 1979).

The case of ozone illustrates that all attempts at hazard identification pose problems of reliability (serious hazards do not get identified); of cost (of collecting large amounts of expensive data little used or of little use); and of bias (the data are misleading in some consistent way). The most serious problem, however, is the proliferation of unknown hazards. It seems unlikely that random research thrusts, underfinanced critical science, or massive screening, monitoring, and diagnostic methods can keep pace with the creation of environmental threat. In this context it is sobering to note that just a few years ago, atmospheric scientists had proposed monitoring a commercial chlorofluorocarbon, not because of its effect on ozone but because it was deemed an inert, nonreactive tracer!

Risk Estimation

Revelation, through divine or supernatural inspiration, of the likelihood of threatening events and their consequences is as old as the sacred prophetic religious experiences or as common as the astrology column of the newspaper (Jahoda 1971). Its value clearly depends on the degree of belief and number of believers. Intuition shares some qualities with revelation, but it is internally generated and is employed in both science and everyday experience (Westcott 1968).

Scientific risk estimation for the most part rests on extrapolation: forward into the future from experience; backwards from possible future unknown but imagined events to their known precursors; or sideways by analog and transfer of parallel experience from different but similar places, situations, or things. A great deal of ingenuity has gone into refining methods of extrapolation: extending the underlying data base, clarifying the meaning of probability (Savage 1954), developing more precise and powerful mathematical methods (Green and Bourne 1972), creating tree-like logical sequences of events and consequences (Nuclear Regulatory Commission 1975), modeling systems, quantifying subjective estimates (Keeney and Raiffa 1976;Selvidge 1973), and stretching imagination by scenarios (Erickson 1975).

The ingenuity and limitations of such extrapolative methods are well exemplified in the Reactor Safety Study (Nuclear Regulatory Commission 1975), discussed in detail in chapter 10. A landmark in the art of risk estimation, the study has undergone wide emulation, review, and criticism (American Physical Society 1975; Risk Assessment Review Group 1978). It may command a degree of belief in the hypothetical (Häfele 1974), because, the financial toll of Three Mile Island notwithstanding, more than 300 years of commercial reactor experience have witnessed no catastrophic accidents. Thus the study (and its users) must rely on varied substitutes for experience: logical analysis, understanding of physical laws, frequencies of component failures, and radiation dose-response curves derived from studies of animals and war victims. Using these in combination, it is possible to estimate the risk spectrum for catastrophic events as shown in Figure 2. The very complexity of the process of risk estimation weakens its credibility. And even for those who are not skeptical of its methods, the Reactor Safety Study offers very differing interpretations (see also chapter 10).

All such extrapolative methods, then, are hampered by common and sometimes subtle distortions of assumptions and method[3] and by the limits of human cognitive processes (Tversky and Kahneman 1974; Slovic, Fischhoff, and Lichtenstein 1976,165). But most difficult is the "prison of experience"--humans are at risk from threats greater than or different from individual and collective experience (Kates 1976,133). And extrapolative methods, no matter how ingenious, can only enlarge but not escape such containment. Indeed, the causal structure, as developed in chapter 2, underscores the uncertainty inherent in all risk estimates.

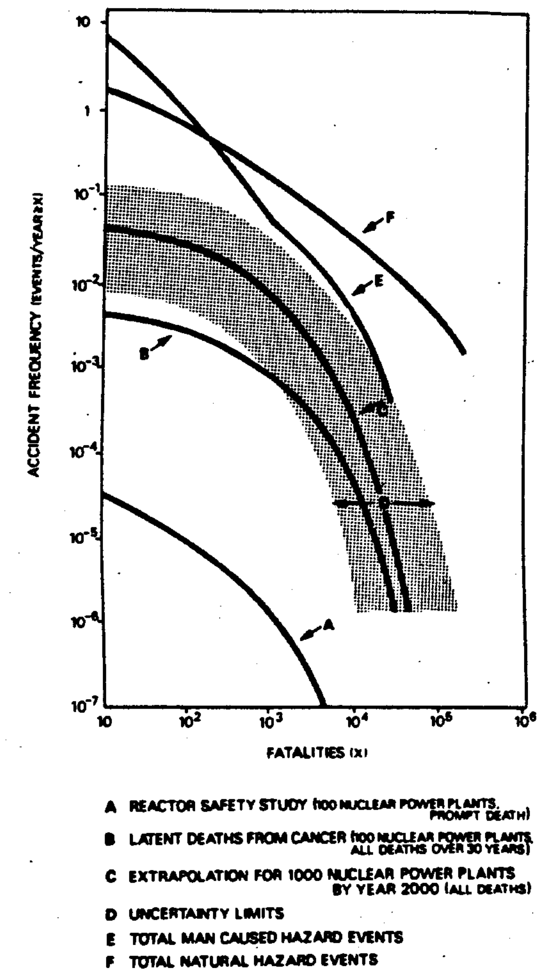

Figure 2. Risk of death from U.S. commercial nuclear power reactors. The Risk Spectrum is a graph that relates the frequency and magnitude of a catastrophic nuclear accident. Spectrum A is the one displayed in the Executive Summary of the Reactor Safety Study, and it applies to prompt fatalities only. In this widely reproduced graph, the risk of a nuclear power plant is many orders of magnitude below comparable risks of manmade and natural events. Using the data provided in the Reactor Safety Study, it is possible to reduce this apparent margin of safety by: 1) adding in the latent deaths that will occur from radiation-induced cancer over a 30-year period (Spectrum B); 2) extrapolating to 1000 nuclear reactors by the year 2000, a target of U.S. energy policy (Spectrum C); and 3) adding to that extrapolation the uncertainty limits of the Reactor Safety Study (Spectrum D). Extending the spectrum in this manner is a matter of judgment or bias, not of factual disagreement.

Social Evaluation

In the aversion of hazard or of risk itself, little or no consideration is given to comparison with other risks and benefits. Aversive methods lie embedded in culture as taboos, in society as absolute standards or regulations, and in individuals as avoidance preferences. Aversion as taboo may be considered "primitive," whereas as a regulatory standard (e.g., zero tolerance for carcinogens in food) it may be considered modern and indeed scientific (Douglas 1978). In contrast to the absolutes and imperatives of aversion, balanced risk methods--described in chapter 3 and discussed in chapter 12--seek to compare and equalize consequences. Comparisons of specific hazards with natural background levels (National Research Council 1980,66-67) and with other hazards prevalent in society (Cohen and Lee 1979;Wilson 1979) serve to encourage or inform some action or to reveal some inconsistency. Some studies compare risks in terms of the cost-effectiveness of control (Sinclair, Marstrand, and Newick 1972;U.S. Department of Transportation 1976;Siddall 1981). Other studies compare risks and benefits (Crouch and Wilson 1982) as in risk/benefit analyses or in some overall cost/benefit analysis. Again, much ingenious effort has gone to improving the data base for comparisons (Rowe 1977), to seeking revealed societal preferences for acceptable levels of risk (Starr 1972,17;Otway and Cohen 1975), to illuminating inconsistencies between different accepted risks and between different communities, cultures, and nations (Roschin and Timofeevskaya 1975;Winell 1975;Whyte and Burton 1980;Derr et al. 1981;Douglas and Wildavsky 1982), to comparing benefits and costs that have multiple attributes (Gardiner and Edwards 1975;Gros 1975), and to improving the making of judgments (Hammond and Brehmer 1969;Pill 1971;Howard, Matheson, and North 1971). These comparisons are limited by the data base but more importantly by differences in distributions of costs, risks, and benefits (see chapter 7).

Immediate benefits need to be compared to uncertain, amorphous, or long-term costs, or widely diffused benefits need to be compared to risks that fall heavily on a specific population or place. And hazards with low probabilities of occurrence but catastrophic consequences need to be compared to hazards of higher probability but less serious consequences.

Thus for the ozone hazard cited above, the social utility of the Concorde and of future SSTs, the convenience of aerosol sprays, and perhaps even the production of food (using nitrogen fertilizer) will have to be weighed against uncertain estimates of increase in skin cancer. And the risks of coal-produced electricity--the exacerbation of respiratory disease and increases in premature deaths for the exposed public, black-lung disease and accidents among miners--need to be compared to nuclear hazards of rare occurrence and latent effect. Consensually accepted methods for making such comparisons are not available.

Risk Assessment Ideology

The perception of hazard is strong, the facts of risk are ambiguous, the methods of analysis are limited and still evolving. It is not surprising, then, that hope, fear, and faith enter the

risk-assessment process as overriding views or assumptions that in archetypal expression border on ideology. Each view assumes a fundamental imbalance between prevailing risk assessments and their hazard potential. Each begins with the implicit assumption that the true hazard potential is greater than, less than, or different from, the prevailing risk assessment.

Tip of the Iceberg

For some risk assessors, the hazard is almost always greater than the risks assessed. Since for them the consequences of technology are too recent to be apparent, they assess only the tip of the iceberg:

> The roll of casualties of our time is incomplete. Among those numbered in hundreds every year we have counted invalid survivors of spina bifida, patients accidentally injured during cardiac catheterization, and those disabled by reactions to such drugs as chloramphenicol. Rising casualties numbering thousands annually result from the health environment surrounding certain infants born in our cities, from the vulnerability of young people to head injuries, drug addiction, and crime, and from chronic lung disease associated with air pollution. Increasing numbers, in the tens of thousands every year, suffer or die from arteriosclerotic heart disease or are disabled by the frailties of age. Other casualties may be on the way: additional victims of environmental pollution, more infants surviving with genetic defects, more casualties of affluence, made useless by automation or retirement from boring work, more artificially supported survivors, and more casualties of new drugs. Though these numbers may in a sense be outweighed by a rising standard of living, better education, less work, and less discomfort, they are surely enough to cause concern. (Ford 1970,262)

For these tip-of-the-iceberg assessors, by the time the roll of casualties is complete, it is already too late; such are the latent effects of carcinogens or mutagens.

The basic methods of tip-of-the-iceberg assessors complement their concern. They search for new hazards, try to estimate consequences, particularly from maximum events, and attempt to predict long-term effects. At the same time they avoid estimating the probability of events' leading to harmful consequences, arguing that in the absence of adequate experience these will tend to be underestimates. They favor the use of the scenario that stretches the imagination, renders the incredible more credible, and suggests the greater hazard lurking beneath seas of complacency.

Count the Bodies

For some risk assessors, the hazard is almost always less than the risks assessed. Because of scientific and technical advance, administrative oversight, and the long-term increase in societal ability to cope with threat, people are demonstrably better protected. If the environment appears less secure to many, it is because of changes in social expectations, certain processes of communication, and recurrent waves of public fad or mood.

Social values and expectations of security change, becoming more demanding over time, as evidenced in movements for consumer, environmental, and occupational safety. The dramatic increase in communication makes for exaggerated assessments. Improved reporting of events previously unreported creates an illusion of their increase and of global threat for what may be highly localized problems. And these trends may overlap with secular or cyclical changes in attitudes. Recurrent waves of pessimism are thought to alternate with periods of optimism, especially among intellectuals and elites. The populace, and especially youth, is currently seen as suspicious of authority, hostile to science, and attracted by irrationality. The public is viewed as ill-informed, depersonalized, and frustrated by the bigness, complexity, and remoteness of phenomena that have an impact on its life.

These assessors see themselves as struggling for fact, caution, and rationality to "count the bodies," not the speculations. Thus they tend to limit themselves to short-run consequences, arguing that these are reasonably knowable. In estimation, they favor quantifying the likelihood (usually small) of events and making comparisons with the likelihood (usually higher) of everyday hazards that are seemingly acceptable to society. Their favored method is quantification by reduction, extrapolating from unknown to known events. This fault-tree and event-tree methodology emphasizes the contingent nature of catastrophic hazard and its ensuing low probability.

Worry Beads

Finally, for some risk assessors the major hazards are different from those for which risks have been assessed. They accept the insights of those who assert that the visible risks assessed are but the tip of the iceberg as well as those of the skeptical statistician, technologist, or social commentator who knows that hindsight will show that many perceived risks have been exaggerated. Their concern is that the societal ability to assess risk is limited, expandable but not infinite, and in danger of being squandered on the unimportant while failing to identify the truly perilous.

Proponents of the "worry-bead" hypothesis argue that individuals and societies have a small, relatively fixed stock of worry beads to dispense on the myriad threats of the world. People are not irrational, but they are constrained in their rationality either by human limitations of cognition and judgment; by cultural, ideological, or personal aversions toward certain risks and the discounting of others; by ignorance, misunderstanding, or limited experience; or by the sheer number and complexity of threats confronting them. Societal capacity to worry intelligently exceeds that of individuals, thus it is possible to divide the labor and the anxiety. But even this expanded capacity, in this view, is less than the threats perceived, and to both individuals and societies, where and when to rub one's worry beads is baffling and difficult to rationalize even if desired.

Thus worry-bead assessors strive first to improve overall strategies of hazard identification. In examining evaluation methods, they study empirically the societal response to threat to determine "what is," not simply "what ought to be." Their favored methods are those designed for improving and making easier decision and choice and for allocating the appropriate institutional mechanisms and group processes to the "right" type of hazard.

Ideology in Nuclear Risk Assessment

All of these ideologies of risk assessment surface in the rancorous debate over nuclear power described in chapter 10. "Tip-of-the-iceberg" assessors readily accepted studies of maximum consequences (AEC 1975) even as they discounted studies of their probability (Nuclear Regulatory Commission 1975). Just the reverse seemed to characterize the "count-the-bodies" school, epitomized in the Reactor Safety Study, where the executive summary overdramatized the low probability of major accidents and minimized their consequences. Similarly, the laying to rest by the count-the-bodies school of one risk issue in the nuclear debate, such as environmental leakage under normal operations or functioning of the emergency core cooling system, only serves to encourage the tip-ofthe-iceberg assessors to identify new and troubling issues--such as containment durability, human error, weapons proliferation, radioactive waste, and evacuation plans.

Our own view is that of the "worry beads" assessors. This leads us to consider the catastrophic potential of the entire fuel cycle (as in Table 1, chapter 10), to recognize the validity of both the "double standard" claim of the count-the-bodies assessors and the "understudied and poorly understood" claims of the tip-of-the-iceberg assessors for some areas of the nuclear fuel cycle, and to try to understand the basis for the social distrust of nuclear power (chapter 10). Our fears that the acrimonious debate thwarts needed progress in dealing with perhaps the greater hazard of long-term energy needs lead us and others (Bupp and Derian 1978) to propose a compromise solution that combines limits on nuclear expansion with attention to the most pressing safety and waste issues, while keeping the nuclear power option open (Kasperson et al. 1979).

Living with Ideology

In individual risk assessors, these archetypes of hazard assessment ideology are clearly overdrawn and individuals display a mix of attitudes. Yet the typology can be readily applied, as has been done in the case of nuclear power above. As representative approaches, the archetypes are not easily displaced. Such is the nature of the environmental hazard problem.

The review by Lawless of 45 major public alarms over technology found that in over a fourth of the cases, the threat was not as great as originally described by opponents of the technology, but in over half of the cases, the threat was probably greater than that admitted by the proponents of the technology and the problem was allowed to grow. Early warning signs were present and mostly ignored in 40 percent of the cases, and existing technology assessments (which usually include a risk assessment) were judged by the study team as surely helpful in only about 40 percent of the cases (Lawless 1977).

In the classification of 93 hazards, from which we developed the taxonomy described in chapter 4, the scientific literature serves to define, within a single order of magnitude, the major characteristics of each hazard. These order-of-magnitude differences sufficed to differentiate across the set among hazard risks that differed by up to a million or more. Hence it was possible to bridge differences between conflicting assessments, the ranges of which were much smaller than those between hazards. At the same time, the analysis based on the causal structure of hazards (chapter 2) affirms the transscientific nature of much of hazard assessment. Real limits hamper our ever knowing the certain "true risk"--because we lack the theoretical understanding as to cause (e.g., cancer), because we are unable to conduct experiments (e.g., ethics of human experimentation), or because we cannot achieve consensus on how to weight the attendant value issues (e.g., equity vs. efficiency).

Thus, as the theory and methodology of hazard assessment continue to evolve and improve as they have over the past decade (chapter 1), there is hope for greater scientific consensus on what is known about the hazards assessed, what needs to be known and how to learn it, and what the limits of knowing are. But it is highly improbable that even improved procedures of hazard identification, risk estimation, and social evaluation can cope with the proliferation of threats. The burden of hazard needs reduction, not because many serious risks cannot be assessed and coped with, but because all of them cannot be.

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NOTES

1. This chapter is an updated and revised version of "Assessing the Assessors: The Art and Ideology of Risk Assessment," *Ambio* 6 no. 5 (1977):247-252. Reproduced by permission.

2. J. Ravetz (1971) describes the emergence of "critical" science, which seems preferable to the somewhat self-righteous "public-interest" variety.

3. It is not unusual to find in complex risk assessments that very diverse data, expressed originally in different measurement

scales, extrapolated by all three methods, with assumptions of process both deterministic and random and relationships both contingent and dependent, are then combined together in a single number or value.

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12 Weighing the Risks[1]

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The bottom line in hazard management is usually some variant of the question, "How safe is safe enough?" It takes such forms as: "Do we need additional containment shells around our nuclear power plants?" "Is the carcinogenicity of saccharin sufficiently low to allow its use?" "Should schools with asbestos ceilings be closed?" Lack of adequate answers to such questions has bedeviled hazard management.

Of late, many hazard management decisions are simply not being made--in part because of vague legislative mandates and cumbersome legal proceedings, in part because there are no clear criteria on the basis of which to decide. As a result, the nuclear industry has ground to a halt while utilities wait to see if the building of new plants will ever be feasible (Business Week 1978) the Consumer Product Safety Commission has invested millions of dollars in producing a few puny standards (chapter 16). Observers wonder whether the new Toxic Substances Control Act can be implemented (Culliton 1978), and the Food and Drug Administration is unable to resolve the competing claims that it is taking undue risks and that it is stifling innovation.

The decisions that are made are often inconsistent. Our legal statutes are less tolerant of carcinogens in the food we eat than of those in the water we drink or in the air we breathe. In the United Kingdom, 2,500 times as much money per life saved is spent on safety measures in the pharmaceutical industry as in agriculture (Sinclair, Marstrand, and Newick 1972). U.S. society is apparently willing to spend about $140,000 in highway construction to save one life and $5 million to save a person from death due to radiation exposure (Howard, Matheson, and Owen 1978).

Frustration over this state of affairs has led to a search for clear, implementable rules that will tell us whether or not a given technology is sufficiently safe. Various authors (e.g., Lowrance 1976 and Rowe 1977) discuss criteria for determining acceptable risk. Four approaches are most frequently used in attempting to make this assessment. They are cost/benefit analysis, revealed preferences, expressed preferences, and natural standards. Respectively, they would deem a technology to be safe if its benefits outweigh its cost; if its risks are no greater than those of currently tolerated technologies of equivalent benefit; if people say that its risks are acceptable; if its risks are no greater than