Perception and Acceptability of Risk from Energy Systems

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Decision Research
A Branch of Perceptronics
Eugene, Oregon

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Over the next few decades, the success of energy production policies will depend vitally on public attitudes. Gradually it has become recognized that energy decisions cannot be determined by technical criteria alone. Social, psychological, and political issues are crucial and involve such questions as: "What kinds of risks should be accepted in exchange for what kinds of benefits? With how much uncertainty of specific kinds does the public care to live? How does one weigh the substantial routine impact of some technologies (for example, burning coal) with the small chance of a big disaster associated with others . . ? " (Holdren, 1976, p. 22).

Despite the importance of these questions, we lack knowledge about the social and psychological factors (goals, values, criteria, etc.) that determine public responses to technological risks in general or risks from energy systems in particular. This is less because the problems in this area are difficult (which they are) than because very little time, effort, and research funding have been applied to them. One reason for this neglect is the fact that scientists and policy makers have been slow to recognize the importance of public attitudes and perceptions. Writing in the American Scientist, Alvin Weinberg (1976) observed:

> As I compare the issues we perceived during the infancy of nuclear energy with those that have emerged during its maturity, the public perception and acceptance of nuclear energy appears to be the question that we missed rather badly . . . . This issue has emerged as the most critical question concerning the future

of nuclear energy (p. 19).

Fortunately, a flurry of research activity in recent years has provided the beginnings of insight into the socio-psychological dynamics of societal risk taking. What follows is a brief review of that work. It starts with a discussion of the difficulties that human beings experience when attempting to estimate risks. With this as background, the remainder of the chapter discusses the perception and acceptance of risks from energy systems, with particular emphasis being placed on response to nuclear power.

Coping Intellectually with Risk

Evaluation of the risks from various energy systems requires, of experts and lay people alike, an appreciation of the probabilistic nature of the world and an ability to think intelligently about unlikely but consequential events. As Weinberg (1976) noted in the context of nuclear power, ". . . . we certainly accept on faith that our human intellect is capable of dealing with this new source of energy" (p. 21). Recently, however, the faith of many who study human judgment and decision processes has been shaken.

Consider, for example, probabilistic reasoning. Because of its importance to decision making, the question of how people assess the probabilities of uncertain events has been a focus of research interest. This research indicates that intelligent people systematically violate the principles of rational decision making when judging probabilities, making predictions, or otherwise attempting to cope with uncertainty. Frequently, these violations can be traced to the use of judgmental heuristics, mental strategies by which people reduce difficult judgments to simpler ones (Tversky & Kahneman, 1974). These heuristics are useful guides in some circumstances, but in others they lead to large and persistent biases with serious implications for decision making.

Availability Bias

This is not the place to pursue a full discussion of heuristics and biases in probabilistic thinking. Extensive reviews are available in a number of articles (Slovic, Kunreuther & White, 1974; Slovic, Fischhoff & Lichtenstein, 1977; Tversky & Kahneman, 1974). However, one heuristic bears mention here because of its special relevance to energy decisions. This is the "availability heuristic" whereby an event is judged likely or frequent if it is easy to imagine or recall instances of it. Generally, instances of frequent events are easier to recall than instances of less frequent events and likely occurrences are easier to imagine than unlikely ones. Thus availability is often an appropriate cue for judging frequency and probability. However, availability is also affected by numerous factors unrelated to likelihood. As a result, reliance on it may lead people to exaggerate the probabilities of events that are particularly recent, vivid, or emotionally salient.

The notion of availability is potentially one of the most important ideas for helping us understand the distortions that occur in our perceptions of risks. For example, in discussing flood plain residents, Kates (1962) writes:

> A major limitation to human ability to use improved flood hazard information is a basic reliance on experience. Men on flood plains appear to be very much prisoners of their experience . . . . Recently experienced floods appear to set an upward bound to the size of loss with which managers believe they ought to be concerned. (p. 140).

Kates attributes much of the difficulty in improving flood control to the "inability of individuals to conceptualize floods that have never occurred" (Kates, 1962, p. 92). He observes that in making forecasts of future flood potential, individuals "are strongly conditioned by their immediate past and limit their extrapolation to simplified constructs, seeing the future as a mirror of that past" (Kates, 1962, p. 88). In this regard, it is interesting that the purchase of earthquake insurance increases sharply after a quake, and then decreases steadily as the memories become less vivid (Steinbrugge et al., 1969).

Availability bias is illustrated by several recent studies in which college students and members of the League of Women Voters were asked to judge the frequency of various causes of death, such as smallpox, tornadoes, and heart disease (Lichtenstein et al., 1978). In one study, they were first told the annual death toll for motor vehicle accidents in the United States (50,000) and then asked to estimate the frequencies of forty other causes of death. In another study, participants were given two causes of death and were asked to judge which of the two was more frequent.

Both studies showed people's judgments to be moderately accurate in a global sense; that is, people usually knew which were the most and least frequent lethal events. However, within this global picture, people made serious misjudgments, many of which seemed to reflect availability bias. For example, accidents were judged to cause as many deaths as diseases, whereas diseases actually take about fifteen times as many lives. Homicides were incorrectly judged to be more frequent than diabetes and stomach cancer. Homicides were also judged to be about as frequent as stroke, although the latter actually claim about eleven times as many lives. Frequencies of death from botulism, tornadoes, and pregnancy (including childbirth and abortion) were also greatly overestimated.

Table 1 lists the lethal events whose frequencies were most poorly judged in our studies. In keeping with availability considerations, overestimated items were dramatic and sensational whereas underestimated items tended to be unspectacular events which claim one victim at a time and are common in nonfatal form. A follow-up study showed that newspaper coverage of the various causes of death was biased in much the same way as were people's judgments (Combs & Slovic, in press).

Insert Table 1 about here

Overconfidence

A particularly pernicious aspect of heuristics is that people are typically very confident about judgments based on them. For example, in a follow-up to the study on causes of death, participants were asked to indicate the odds that they were correct in their judgments about which of two lethal events was more frequent (Fischhoff, Slovic & Lichtenstein, 1977). Odds of 100 : 1 or greater were given often (25% of the time). However, about one out of every eight answers associated with such extreme confidence was wrong (fewer than 1 in 100 would have been wrong if the odds had been appropriate). About 30 percent of the judges gave odds greater than 50 : 1 to the incorrect assertion that homicides were more frequent than suicides. The psychological basis for this unwarranted certainty seems to be people's insensitivity to the tenuousness of the assumptions upon which their judgments are based (in this case, the validity of the availability heuristic). Such overconfidence is dangerous. It indicates that we often do not realize how little we know and how much additional information we need about the various problems we face.

Overconfidence manifests itself in other ways as well. A typical task in estimating failure rates or other uncertain quantities is to set upper and lower bounds so that there is a 98 percent chance that the true value lies between them. Experiments with diverse groups of people making many different kinds of judgments have shown that, rather than 2 percent of true values falling outside the 98 percent confidence bounds, 20 percent to 50 percent do so (Lichtenstein, Fischhoff & Phillips, 1977). People think that they can estimate such values with much greater precision than is actually the case.

Unfortunately, experts seem as prone to overconfidence as lay people. Hynes and Vanmarcke (1976) asked seven "internationally known" geotechnical engineers to predict the height of an embankment that would cause a clay foundation to fail and to specify confidence bounds around this estimate that were wide enough to have a 50 percent chance of enclosing the true failure height. None of the bounds specified by these experts actually did enclose the true height. The multi-million dollar Reactor Safety Study (The "Rasmussen Report," U.S. NRC, 1975), in assessing the probability of a core melt in a nuclear reactor, used a procedure for setting confidence bounds that has been found in experiments to produce a high degree of overconfidence. Related problems led a recent review committee to conclude that the Reactor Safety Study greatly overestimated the precision with which it had assessed the probability of a core melt (U.S. NRC, 1978).

Another case in point is the 1976 collapse of the Teton Dam. The Committee on Government Operations has attributed this disaster to the unwarranted confidence of engineers who were absolutely certain they had solved the many serious problems that arose during construction (U.S. Government, 1976). In routine practice, failure probabilities are not even calculated for new dams even though about 1 in 300 fails when the reservoir is first filled. Further anecdotal evidence of overconfidence may be found in many other technical risk assessments (Fischhoff, 1977). Some common ways in which experts may overlook or misjudge pathways to disaster include:

--Failure to consider the ways in which human errors can affect technological systems. Example: In violation of NRC rules, operators of the reactor at Three Mile Island had closed all three auxiliary feed-water pumps, thus rendering the emergency cooling system inoperative.

--Overconfidence in current scientific knowledge. Example: The failure to recognize the harmful effects of X rays until societal use had become widespread and largely uncontrolled.

--Insensitivity to how a technological system functions as a whole. Example: The rupture of a liquid natural gas storage tank in Cleveland in 1944 resulted in 128 deaths, largely because no one had realized the need for a dike to contain spillage. The DC-10 failed in several early flights because none of its designers realized that decompression of the cargo compartment would destroy vital parts of the plane's control system running through it.

--Slowness in detecting chronic, cumulative environmental effects. Example: Although accidents to coal miners have long been recognized as one cost of operating fossil-fueled plants, the effects of acid rains on ecosystems were slow to be discovered.

--Failure to anticipate human response to safety measures. Example: The partial protection offered by dams and levees gives people a false sense of security and promotes development of the flood plain. When a rare flood does exceed the capacity of the dam, the damage may be considerably greater than if the flood plain had been unprotected.

Desire for Certainty

Every technology is a gamble of sorts and, like other gambles, its attractiveness depends on the probability and size of its possible gains and losses. Both scientific experiments and casual observation show that people have difficulty thinking about and resolving the risk/benefit conflicts even in simple gambles. One way to reduce the anxiety generated by confronting uncertainty is to deny that uncertainty. The denial inherent in this anxiety-reducing search for certainty is thus an additional source of overconfidence. This type of denial is illustrated by people who, when faced with natural hazards, view their world as either perfectly safe or as predictable enough to preclude worry. Thus, some flood victims interviewed by Kates (1962) flatly denied that floods could ever recur in their areas. Some thought (incorrectly) that new dams and reservoirs in the area would contain all potential floods, while others attributed previous floods to freak combinations of circumstances, unlikely to recur. Denial, of course, has its limits. Many people feel that they cannot ignore the risks of nuclear power. For these people, the search for certainty is best satisfied by outlawing the risk.

Scientists and policy makers who point out the gambles involved in societal decisions are often resented for the anxiety they provoke. Borch (1968) noted how annoyed corporate managers get with consultants who give them the probabilities of possible events instead of telling them exactly what will happen. Just before a blue-ribbon panel of scientists reported that they were 95 percent certain that cyclamates do not cause cancer, Food and Drug Administration Commissioner Alexander Schmidt said, "I'm looking for a clean bill of health, not a wishy-washy, iffy answer on cyclamates" (Eugene Register-Guard, January 14, 1976). Senator Edmund Muskie has called for "one-armed" scientists who do not respond "on the one hand, the evidence is so, but on the other hand . . . " when asked about the health effects of pollutants (David, 1975). In 1976, when people all over the country were demanding to know whether the swine flu vaccine was safe, the nature of their demands indicated that they were really trying to determine whether or not it was perfectly safe.

Perseverence of Beliefs

The difficulties of facing life as a gamble contribute to the polarization of opinions about hazards. For example, some people view nuclear power as extraordinarily safe, while others view it as a catastrophe in the making. It would be comforting to believe that these divergent beliefs would converge towards one "appropriate" view as new evidence was presented. Unfortunately, this is not likely to be the case. A great deal of research suggests that people's beliefs change slowly, and are extraordinarily persistent in the face of contradictory evidence (Ross, 1977). Once formed, initial impressions tend to structure and distort the way in which subsequent evidence is interpreted. New evidence appears reliable and informative if it is consistent with one's initial beliefs; contradictory evidence is dismissed as unreliable, erroneous, or unrepresentative. Ross (1977) concluded his review of this phenomenon as follows:

> Erroneous impressions, theories, or data processing strategies, therefore, may not be changed through mere exposure to samples of new evidence. It is not contended, of course, that new evidence can never produce change--only that new evidence will produce less change than would be demanded by any logical or rational information-processing model (p. 210).

The Fallibility of Judgment

Our examination of risk perception leads to the following conclusions:

--Cognitive limitations, coupled with the anxieties generated by facing life as a gamble, cause uncertainty to be denied, risks to be distorted, and statements of fact to be believed with unwarranted confidence.

--Risk judgments are influenced (and sometimes biased) by the imaginability and memorability of hazards. People may, therefore, not have valid judgments even for familiar risks.

--Disagreements about risk should not be expected to evaporate in the presence of "evidence." Definitive evidence, particularly about rare hazards, is difficult to obtain. Weaker information is likely to be interpreted in a way that reinforces existing beliefs.

Since it can be shown that even well-informed lay people have difficulty judging risks accurately, it is tempting to conclude that the public should be removed from the decision-making process. The political ramifications of such a transfer of power to a technical elite are obvious. Indeed, it seems doubtful that such a massive disenfranchisement is feasible in any democratic society.

Furthermore, this transfer of decision making would seem to be misguided. For one thing, we have no assurance that experts' judgments are immune to biases once they are forced to go beyond documented evidence and rely upon judgment. Although judgmental biases have most often been demonstrated with lay people, there is evidence that the cognitive functioning of experts is basically like that of everyone else.

In addition, in many if not most cases, effective management of societal risks requires the cooperation of a large body of lay people.

These people must agree to do without some things and accept substitutes for others; they must vote sensibly on ballot measures and for legislators who will serve them as surrogate hazard managers; they must obey safety rules and use the legal system responsibly. Even if the experts were much better judges of risk than lay people, giving experts an exclusive franchise on decision making would involve substituting short-term efficiency for the long-term effort needed to create an informed citizenry.

Forecasting Public Response Towards Nuclear Energy

People respond to the hazards they perceive. The basic research cited above, supplemented by studies of perceptions of specific energy systems, could enable public response to those systems to be forecasted. To date, most studies of perceptions and attitudes towards energy systems have focused on nuclear power. In this section, we shall discuss some conclusions based on this research.

The General Problem

Even before the accident at Three Mile Island, the nuclear industry was foundering on the shoals of adverse public opinion. A sizeable and tenacious opposition movement had been responsible for costly delays in the licensing and construction of new power plants in the United States and for political turmoil in several European nations.

The errant reactor at Three Mile Island has stimulated a predictable immediate rise in anti-nuclear fervor. Any attempt to plan the role of nuclear power in the nation's energy future must consider the determinants of this opposition and anticipate its future course. One clue lies in recent research showing that the images of potential nuclear disasters that have been formed in the minds of the anti-nuclear public are remarkably different from the assessments put forth by most technical experts. We shall describe these images and speculate on their origins, permanence, and implications.

Political Realities

Although questions of safety are preeminent in the nuclear debate, it is important to recognize that opposition to nuclear power is an organized political movement fueled by many other concerns besides safety (Bronfman & Mattingly, 1976; Otway, Maurer & Thomas, 1978; Wilkes, Lovington, Horne, Pulaski & Poole, 1978). While some nuclear opponents are motivated primarily by fear of routine or catastrophic radiation releases, others join the movement because they are disenchanted with growth, centralization, corporate dominance, technology, or government. These latter individuals may argue about safety because they view the hazardousness of nuclear power as its "Achilles Heel." While the discussion that follows is not directly concerned with this larger political context, it does highlight the special qualities of nuclear power that cause (or allow) political opposition to be focused around considerations of risk.

Basic Perceptions

Opponents of nuclear power tend to believe both that its benefits are quite low and its risks are unacceptably great (Fischhoff et al., 1978). On the benefit side, people do not see nuclear power as a vital link in the meeting of basic energy needs (Porkorny, 1977). Many believe it to be merely a supplement to other sources of energy which themselves are adequate (or could be made adequate by conservation).

On the risk side, nuclear power appears to evoke greater feelings of dread than almost any other technological acitvity (Fischhoff et al., 1978). Some have attributed this reaction to fear of radiation's invisible and irreversible contamination, threatening cancer and genetic damage. However, use of diagnostic X rays, another radiation technology which incurs similar risks, is not similarly dreaded. If anything, people underestimate its risks. The difference may lie in another characteristic of nuclear power, its association with nuclear weaponry. As a result of its violent origins, nuclear power is viewed by people as a technology whose risks are uncontrollable, lethal, and potentially catastrophic, characteristics which are not present in people's perceptions of X rays.

Research in which people are asked to describe their mental images of nuclear accident and its consequences reveals the uncontrollable, lethal, and catastrophic qualities of perceived nuclear risks. There is a widely held expectation that a serious reactor accident is likely within one's lifetime and could result in hundreds of thousands, even millions, of deaths (Slovic, Fischhoff & Lichtenstein, 1979). In addition, such an accident is expected to cause severe, irreparable environmental damage over a vast geographic area. These expectations contrast dramatically with the nuclear industry's official view that multiple safety systems will limit the damage in the extremely unlikely event of a major accident.

One inevitable consequence of this "perception gap" is uncertainty and distrust on the part of a public which suspects that the risks are incomparably greater than the experts' assessments (Kasper, 1979). The experts, in turn, question the rationality of the public and decry the "emotionalism" stymying technological progress. Bitter and sometimes violent confrontations result.

Recognition of the perception gap has led many experts to claim that the public must be "educated" about the "real" risks from nuclear power. One public opinion analyst (Pokorny, 1977) put the matter as follows:

The biggest problem hindering a sophisticated judgment on this question is basic lack of knowledge and facts. Within this current attitudinal milieu, scare stories, confusion, and irrationality often triumph. Only through careful education of facts and knowledge can the people know what the real choices are . . . (p. 12).

Our own view is that attempts designed to reduce the perception gap face major obstacles. This pessimistic conclusion is based on two key aspects of the problem, one technical and one psychological.

The Technical Reality

The technical reality is that there are few "cut and dried facts" regarding the probabilities of serious reactor mishaps. The technology is so new and the probabilities in question are so small that risk estimates cannot be based on empirical observation. Instead, such assessments must be derived from complex mathematical models, such as the fault trees and event trees used in the Reactor Safety Study (U.S. NRC, 1975) to assess the probability and consequences of a loss-of-coolant accident. Despite an appearance of objectivity, risk assessments are inherently subjective. Someone, relying on judgment, must structure the analysis to determine the ways that failure might occur, their relative importance, and their logical interconnections.

The difficulties of performing risk assessments have led many critics to question their validity (Bryan, 1974; Fischhoff, 1977; Primack, 1975). One major concern is that important initiating events or pathways to failure may be omitted, causing risks to be underestimated. If omissions are as common and difficult to detect as suggested earlier (p. 7), the underestimation may be substantial. Another problem in assessing the reliability of reactor designs is the difficulty of taking proper account of "common-mode failures." To insure greater safety, many technological systems are highly redundant. Should one crucial part fail, there are others designed to do the same job or to limit the resulting damage. Since the probability of each part failing is very small, the probability of all failing, thereby creating a major disaster, should be miniscule. This reasoning is valid only if the various components are independent (so whatever causes one part to fail will not automatically cause the others to fail). "Common-mode failure" occurs when the independence assumption does not hold. For example, because electrical cables controlling the redundant safety systems at a reactor in Browns Ferry, Alabama, were not spatially separated, all five emergency core cooling systems were rendered inoperative by a single fire. Developing models that take proper account of such contingencies is a very difficult enterprise. The potential for omissions is complicated by the tendency for problems that are out of sight to be effectively out of mind, their omission unrecognized (Fischhoff, Slovic & Lichtenstein, 1978).

One critic's skepticism regarding the defensibility of assessments of rare catastrophies summarizes the technical problem concisely:

> . . . the expert community is divided about the conceivable realism of probability estimates in the range of one in ten thousand to one in one billion per reactor year. I am among those who believe it to be impossible _in principle_ to support numbers as small as these with convincing theoretical arguments. . . . The reason I hold this view is straightforward: nuclear power systems are so complex that the probability the safety analysis contains serious errors . . . is so big as to render meaningless the tiny computed probability of accident (Holdren, 1976, p. 21).

The Psychological Reality

Public fears of nuclear power should not be viewed as irrational. In part, these fears are fed by the realization that the facts are in dispute and that experts have been wrong in the past, as when they irradiated enlarged tonsils or permitted people to witness A-bomb tests at close range. Furthermore, experts' errors seem often to be in the direction of underestimating risks. What one can criticize, perhaps, is the extent to which people's fundamental ways of thinking (such as reliance on the availability heuristic) lead them to a distorted view of such information as is presented. Certainly the risks from nuclear power would seem to be a prime candidate for availability bias because of the extensive media coverage they receive and their association with the vivid, imaginable dangers of nuclear war. In contrast, the chronic, unspectacular effects of pollution associated with other energy sources may attract too little attention.

One disturbing implication of the availability heuristic is that any discussion of low-probability hazards, regardless of its content, may increase their memorability and imaginability and hence increase their perceived risks. This possibility poses a major barrier to open discussions regarding nuclear safety. Consider an engineer arguing the safety of disposing of nuclear wastes in a salt bed by pointing out the improbability of the various ways radioactivity could be accidentally released. Rather than reassuring the audience, the presentation might lead them to think, "I didn't realize there were that many things that could go wrong."

The availability heuristic magnifies fears of nuclear power by blurring the distinction between what is remotely possible and what is probable. As one nuclear proponent lamented, "When laymen discuss what <u>might</u> happen, they sometimes don't even bother to include the 'might'"

(B. Cohen, 1974, p. 36). Another analyst has elaborated a similar theme in the misinterpretation of "worst case" scenarios:

> It often has made little difference how bizarre or improbable the assumption in such an analysis was, since one had only to show that some undesirable effect could occur at a probability level greater than zero. Opponents of a proposed operation could destroy it simply by exercising their imaginations to dream up a set of conditions which, although they might admittedly be extremely improbable, could lead to some undesirable results. With such attitudes prevalent, planning a given nuclear operation becomes. . . perilous. . . (J. Cohen, 1972, p. 55).

Whereas the above discussion helps clarify the source of the perception gap between pro-nuclear experts and their lay opponents, it does not point unambiguously to one side or the other as having the most accurate appraisal of the overall risks from nuclear power. Although memorability and imaginability are capable of enhancing public fears, inability to imagine all the possible ways that a system could fail might produce a false sense of security among technical experts. As a result, the identification of judgmental difficulties does not, in itself, afford an external criterion for closing the perception gap. Insofar as the actual risks may never be known with great precision and much new information is given to alternative interpretations, the gap may be with us for a long time. Thus, Three Mile Island "proved" the possibility of a catastrophic meltdown to some, while to others, it demonstrated the reliability of the multiple containment systems.

A Nuclear Future?

Are the strong fears and determined opposition to nuclear power likely to persist? Will nuclear power ever gain widespread public acceptance? Although answers to these questions are by no means clear, public response to X rays provides some clues. The almost universal acceptance of X rays shows that a radiation technology can be tolerated once its use becomes familiar, its benefits clear, and its practitioners trusted.

Nerve gas provides an enlightening case study. Few human creations could be more dread or more potentially catastrophic than this deadly substance. When, in December of 1969, the army decided to transfer nerve gas from Okinawa to the Umatilla Army Depot in Hermiston, Oregon, citizens of Oregon were outraged--except those in Hermiston. Whereas public opinion around the state was more than 90% opposed, residents of Hermiston were 95% in favor of the transfer (Eugene Register-Guard, December 18, 1969 and January 11, 1970). Several factors seem to have been crucial to Hermiston's acceptance of nerve gas. For one, munitions and toxic chemicals had been stored safely there since 1941 (so the record was good and the presence of the hazard was familiar). Second, there were recognized economic benefits to the community from continued storage at the depot of hazardous substances, in addition to the satisfaction of doing something patriotic for the country. Finally, the responsible agency, the U.S. Army, was respected and trusted.

These examples illustrate the slow path through which nuclear power might gain acceptance. It requires an incontrovertible long-term safety record, a responsible agency that is respected and trusted, and a clear appreciation of benefit. In the aftermath of Three Mile Island, this path appears not only slow but unnavigable. A quicker path to acceptance, and one that may provide the only hope for the industry, could be forged by a severe energy shortage. Society has shown itself willing to accept increased risks in exchange for increased benefits. Brownouts, blackouts, or rationing of electricity would likely enhance the perceived need for nuclear power and increase public tolerance of its risks. One example of such a reaction is the oil crisis of 1973-4, which broke the resistance to offshore drilling, the Alaska pipeline, and shale oil development, all of which had previously been delayed because of environmental concerns. Such crisis-induced acceptance of nuclear power may, however, produce anxiety, stress and conflict in a population forced to tolerate what it perceives as great risk because of its addiction to the benefits of electricity.

Acceptance of Non-Nuclear Energy Systems

The arguments presented above suggest that problems of public acceptance should be much less severe for non-nuclear sources of energy. Fossil fuels and hydroelectric systems are familiar, common and appear to be perceived as less risky than they actually are (although data are needed to test this speculation). Fossil, hydroelectric, and solar energy systems have their origins in antiquity and work via mechanisms (combustion, water force, and sunshine) that are familiar, natural, and well understood. Accidents and fatalities with these systems tend to involve relatively few individuals who are spatially and socially isolated from the rest of society. Furthermore, their effect is consummated in a fixed period of time, without the threat of lingering consequences.

Observation of the recent failure of the Teton Dam in Idaho suggests that even such catastrophic hazards as the collapse of a hydroelectric dam will quickly be forgotten by those not directly involved, in contrast to the consequences of a reactor accident.

Conclusions

Management of nuclear power and alternative energy systems must be based upon an understanding of how people think about risks. Our aim here was not to document public opposition and fear of nuclear power, which are already well known. Instead, we have attempted to point out that this reaction stems both from recognition of the unresolved technical issues in the risk assessment process and from the fundamental thought processes that determine perceptions of risk. Nuclear hazards are particularly memorable and imaginable, yet hardly amenable to empirical verification. Their special qualities blur the distinction between the possible and the probable and produce an immense gap between the views of most technical experts and a significant portion of the public. This gap must be acknowledged and the difficulty of reducing it by educational programs or empirical demonstrations of safety must be recognized by planners and policy makers.

Facing this problem means addressing some hard questions. Does technology force us to make decisions that cannot be made well (or successfully) in a democratic society? What kind of political institutions are needed to preserve democratic freedoms and insure public participation when decisions involve extreme technical complexity, catastrophic risk, and great uncertainty?

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Table 1

Bias in Judged Frequency of Death

Most Overestimated	Most Underestimated
All accidents	Smallpox vaccination
Motor vehicle accidents	Diabetes
Pregnancy, childbirth & abortion	Stomach cancer
Tornadoes	Lightning
Flood	Stroke
Botulism	Tuberculosis
All cancer	Asthma
Fire and flames	Emphysema
Venomous bite or sting	
Homicide	

Adapted from Lichtenstein et al., 1978.