Images of Disaster:

Perception and Acceptance of Risks from Nuclear Power

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> I do not know if our occupation [of the Trojan Nuclear Plant] will be effective in educating the people to the dangers of nuclear radiation. I hope so. I was terribly uncomfortable in jail for five days in a six-person cell with 40 other women, three towels for all of us, 16 mattresses, 16 blankets, and no air.
>
> I could go on and on . . . but to what use? Perhaps only that you might take notice that we give up our loving homes and gardens and children to be arrested, jailed, fined, brutalized, and degraded. WHY? WHY? Because we truly believe that the planet and the human race is in grave danger because of nuclear power plants. Will you hear us?
>
> Published letter to the Governor of
> Oregon from a nuclear power protester--1978

Our concern in this paper is with public response to the risks of nuclear energy. The topic is a vital one. Writing recently in the American Scientist, Alvin Weinberg (1976, p. 19) 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.

At present, the nuclear industry is foundering on the shoals of adverse public opinion. A sizable and tenacious opposition movement has 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. Any attempt to plan the future role of nuclear power must consider the determinants and possible course of this opposition.

Although opposition to nuclear power has many causes, concerns about safety undoubtedly play a major role (see, e.g., Bronfman & Mattingly, 1976; Hohenemser, Kasperson & Kates, 1977; Melber, Nealey, Hammerslea & Rankin, 1977; Otway, Maurer & Thomas, 1978). Over the past several years, we and others have been systematically investigating public perceptions of risk from nuclear power and other hazardous activities. From this research, we have pieced together a quantitative description of the attitudes, perceptions and expectations of some members of the anti-nuclear public. The images of potential nuclear disasters that have been formed in these people's minds are remarkably different from the assessments put forth by most technical experts. In this paper, we shall describe these images and speculate on their origins, permanence, and implications.

Many of the studies described below have *not* examined a representative sample of the public at large, or even of the anti-nuclear public. Instead, much of the new data comes from two populations, both known to be strongly anti-nuclear by their voting behavior in the 1976 nuclear power referendum in Oregon. One population consists mainly of students from the University of Oregon. The second consists of members of the Eugene, Oregon, League of Women Voters. Members of the League (hereafter designated as the LOWV) were not selected because of their generally anti-nuclear views, but because they constitute a thoughtful, articulate, and influential group of private citizens. In general, we have found many points of similarity between the views expressed by these particular individuals and those expressed by more representative samples of people in the United States and abroad.

Perceived Risks and Benefits

How is nuclear power viewed, relative to other activities? One answer to this question is provided by a study by Fischhoff, Slovic, Lichtenstein, Read and Combs (1978) in which 40 LOWV members judged the risk of dying (across all U.S. society as a whole) as a consequence of nuclear power and 29 other activities and technologies. Each activity appeared on a 3" x 5" card. Respondents first studied the items individually, thinking of all the possible ways someone might die from each. Then they ordered the items from least to most risky and assigned numerical risk values by giving a rating of 10 to the least risky item and making the other ratings accordingly. For example, they were told "a rating of 12 indicates that that item is 1.2 times as risky as the least risky item (i.e., 20% more risky). A rating of 200 means that the item is 20 times as risky as the least risky item, to which you assigned a 10 . . . . " They were urged to cross-check and adjust their numbers until they believed they were right.

After rating the risks from the various activities, the respondents indicated whether each risk was (a) presently acceptable, (b) low enough so that it could even be greater before serious action (such as legislation) would need to be taken to control it, or (c) too high so that such action needed to be taken now. If categories (b) or (c) were selected, the respondent was asked to indicate how many times riskier or safer that activity's risk level needed to be to reach an "acceptable level."

An additional group of 36 LOWV members rated the present benefits to society from each activity and technology by means of the same scaling technique that was used to determine perceived risk. They also rated the acceptability of current risk levels.

The results from this study, shown in Table 1, give some clues as to why 95% of these individuals voted to curtail development of nuclear power in the state-wide referendum held several months after these data were collected. For one, the benefits of nuclear power appeared unappreciated, being lower than those of home appliances, bicycles, and general aviation. Perhaps this is because nuclear power was seen merely as a supplement to other sources of energy, which themselves were viewed as adequate. Nuclear power's low perceived benefit in these studies is consistent with more general conclusions from a representative survey of the adult U.S. population by Pokorny (1977). This survey showed that people do not see nuclear power as a vital link in the supply of basic energy needs. A second major result was that risks from nuclear power were judged to be extremely high. Only motor vehicles, which take about 50,000 lives each year, were viewed as comparably risky. Third, participants in this study wanted nuclear power to be far safer than they perceived it to be at the present time (29 times safer to be exact). When this study was repeated with a sample of 69 students, the results (not shown here) were quite similar to those from the LOWV sample.

Insert Table 1 about here

Risk Characteristics

The same LOWV members who judged risks and benefits in the study by Fischhoff et al. (1978) also rated nuclear power and the 29 other hazardous activities on nine characteristics which have been hypothesized to influence perceptions of actual or acceptable risk (e.g., Lowrance, 1976). These rating scales are described in Figure 1.

Insert Figure 1 about here

The "risk profiles" derived from these ratings showed that nuclear power had the dubious distinction of scoring at or near the extreme high-risk end for most of the characteristics. Its risks were seen as involuntary, unknown to those exposed or to science, uncontrollable, unfamiliar, potentially catastrophic, severe (likely to be fatal rather than injurious), and dreaded. Its spectacular and unique risk profile is contrasted in Figures 2 and 3 with non-nuclear electric power and another radiation technology, X rays, both of whose overall risks were judged to be much lower. Both non-nuclear electric power and X rays were judged much more voluntary, less catastrophic, less dreaded, and more familiar than nuclear power. Nuclear power was rated far higher on the characteristic "dread" than any of the 29 other hazards studied. This may stem from the association of nuclear power with nuclear weapons and from fear of radiation's invisible, permanent bodily contamination that causes genetic damage and cancer (Lifton, 1976; Pahner, 1975). A replication of this study with the student sample produced results virtually identical to those of the LOWV members.

Insert Figures 2 and 3 about here

Why Is Nuclear Power Thought So Dangerous?

Although questions of safety seem to be preeminant 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 fears of routine or catastrophic radiation releases, others join the movement because they are disenchanted with growth, centralization, corporate dominance, technology, or government and its institutions. The latter individuals may argue questions of safety because they view the hazardousness of nuclear power as its "Achilles Heel." While the studies presented here are not directly concerned with this larger political context, they do highlight the special qualities of nuclear power that cause political opposition to be focused around considerations of risk.

Seriousness of a Death from Nuclear Power

One hypothesis we studied is that people think nuclear risks are great because they believe a death from nuclear power is somehow much worse than a death from other activities. For example, deaths from involuntary or dread risks might be given extra weight, causing people to view a death from nuclear power as particularly serious.

We tested this hypothesis by asking new groups of students and LOWV members to evaluate the seriousness of death from the 30 activities and technologies (plus four additional hazards) according to the following instructions:

> Decision makers often have a very difficult time determining whether or not the risk of death from some new product or technology is acceptable to society. One question that comes up repeatedly when people try to assess the acceptability of risk is whether or not all deaths are equally bad regardless of their cause. Some people say that a life is a life, no matter how it is lost. Other people disagree with this notion. They argue that deaths from some causes should receive a lesser weight in our societal decisions.

Listed on the following pages are some specific causes of death. We'd like to know how you think society should weight these causes of death.

Assume there is some standard unit of loss for a single death. This unit might be represented by an amount of money, such as one million dollars lost. Call this unit a standard loss. How should this standard loss be altered for each of the circumstances we list?

Example: Death due to Cause A

Loss is less than standard Divide standard by ___?___	Standard loss is appropriate	Loss is greater than standard Multiply standard by ___?___

In considering the value of a death due to Cause A, you have 3 options:

(1) If you believe that the standard loss is appropriate, simply put an X below the middle option. If you believe that all kinds of deaths are equally bad, you should always use this middle option.

(2) If you believe that deaths due to Cause A are particularly bad for society so that the standard loss needs to be increased by 10%, 50%, a factor of 2, 10, etc., put the necessary multiplier in the right hand column. (For an increase of 10% enter 1.1; for an increase of 50% enter 1.5; for two- or ten-fold increases, enter 2 or 10, respectively, etc.).

(3) If you believe that deaths due to Cause A are not as bad as most deaths for society and should be weighted less than the standard loss, put the factor by which the standard should be reduced in the left hand column (1.1, 1.5, 2, 10, etc.). The standard will then be divided by this factor.

The results of this study, shown in Table 2, surprised us. Although a death from nuclear power was seen as the most serious kind of death by the students and third most serious for the LOWV members, the differences in seriousness, across the 30 hazards, were not that large. In essence, our respondents appeared to be saying that all modes of death are about equally bad. Results obtained when the standard loss was changed to $10,000 also supported this conclusion.

Insert Table 2 about here

If extreme aversion to nuclear power cannot be attributed to the subjective seriousness of deaths due to that technology, perhaps they might stem from horrific, but non-fatal, consequences, such as genetic defects and malformed babies. While we did not test specific non-fatal consequences of nuclear power, we did ask our judges to rate the social costs of several very serious non-fatal afflictions. These included severe mental retardation, congenital blindness, and a Thalidomide baby (seal-like flippers instead of arms and legs). The instructions were similar to those used for rating the social cost of death. The results indicated that individual cases of these afflictions were not viewed as significantly more serious than deaths due to nuclear power or any of the other activities. In sum, it seems unlikely that the aversiveness of nuclear power reflects extreme weighting of radiation-induced death or disability.

Expected Number of Deaths

Using a method very different from that just described, Otway, Maurer and Thomas (1978) also found that aversion to nuclear power was not due to overweighting of the seriousness of its consequences. Specifically, they found that various forms of nuclear-induced mortality, morbidity, and environmental and social damages were judged about equally bad by pro-nuclear and anti-nuclear individuals. Where nuclear proponents and opponents did differ, however, was in their expectations about how likely these aversive consequences were to occur or how many of them there might be. This suggests that one major source of aversion to nuclear power may be the expectation that this technology will cause an exceedingly large number of fatalities.

Evidence supporting this hypothesis comes from a study in which we asked 39 students and 38 LOWV members to estimate the frequency of death to be expected from the 30 activities and technologies shown in Table 1. Specifically, we asked: "How many people are likely to die in the U.S. next year (if next year is an average year) as a consequence of these activities and technologies." All sources of deaths from an activity were to be considered. For example, the instructions specified that fatalities from non-nuclear electricity should consider mining of coal and other energy production activities as well as electrocution; motor vehicle fatalities were to include collisions with bicyclists and pedestrians, etc. As a guideline, the instructions indicated that the total number of deaths in the U.S. averages about 2,000,000 per year.

In addition to estimating fatalities for an average year, the students and LOWV members were asked to provide a multiplying factor indicating how many times more deaths than the average would occur if next year was "particularly disastrous" for the activity being considered. This second estimate allowed concerns about catastrophic potential to be expressed. Mean fatality estimates and multiplying factors are presented in Table 3. Examination of these data shows that the expected number of fatalities in an average year was <u>smaller</u> for nuclear power than for any other activity or technology. However, nuclear power was in a class by itself with respect to the multiplying factor. More than 40% of the respondents had multiplying factors for nuclear power that were greater than 1,000. For each individual respondent, an estimate of the expected number of fatalities in a disastrous year was calculated by applying that person's disaster multiplier to his or her fatality estimate for an average year. When this was done for nuclear power, almost 40% of the respondents had estimates greater than 10,000 fatalities and more than 25% had estimates exceeding 100,000 fatalities.

Insert Table 3 about here

Disaster scenarios. These extreme multiplying factors suggest that many people expect nuclear power to lead to disasters of immense proportions. In an attempt to better understand the nature of these concerns, we asked a new group of 28 students to write scenarios for nuclear power and commercial aviation describing their image of the maximum credible disaster that might be produced by each activity during their lifetime. The instructions read:

> In this task you will be asked to describe, for nuclear power and commercial aviation, your image of the maximum credible disaster. This should not be the biggest disaster that you can dream up, but rather the biggest disaster you seriously think might occur during your lifetime.
>
> Simply describe your image of the maximum credible mishap or disaster in a brief written paragraph. The paragraph should indicate the circumstances of the mishap, the number of injuries or fatalities that might occur, and the size of the geographic region affected.

Some examples of the nuclear-power scenarios these instructions elicited are the following:

Subject 11: "An unpredicted failure occurs in the cooling system of a reactor. The critical point is attained where an explosion destroys the plant and emits masses of radioactive material into the atmosphere. The populations of neighboring communities are decimated; 5,000 die."

Subject 19: "A core meltdown occurs in the reactor of a nuclear power plant located a few miles from a major city. The backup systems fail and a lot of deadly radiation escapes. The winds blow it toward the metropolitan area which has a population of 2 million. The nuclear fallout kills 200,000 people within a 35-mile radius of the plant."

The distributions of fatalities associated with the various scenarios are shown in Table 4. The most common scenarios for commercial aviation were based on crashes between two jumbo jets (usually Boeing 747's). The two extreme aviation disasters in Table 4 involved crashes into heavily populated areas. Overall, these estimates of our subjects are not much higher than those made by experts. The Reactor Safety Study (U.S. Nuclear Regulatory Commission, 1975) reports data suggesting that the probability of an aviation accident involving 1,000 deaths (our subjects' median estimate) occurring at least once during a 60-year lifetime is about .02 or .03. Thus, such a response is not unreasonable in light of our instructions to describe "the biggest disaster you seriously think might occur during your lifetime." Only three of our 29 subjects estimated aviation fatalities beyond the range considered as at least remotely possible by experts.

Insert Table 4 about here

In contrast, the fatality estimates associated with nuclear power would not be considered reasonable by most technical experts. These estimates tended to be several orders of magnitude greater than those provided in the Reactor Safety Study (U.S. Nuclear Regulatory Commission, 1975).

According to that study, the maximum possible accident, coincident with the most unfavorable combination of weather and population density, would cause about 3,300 prompt fatalities and 45,000 latent cancer fatalities with a probability of 5×10^{-9} per reactor year. Assuming 100 reactors operating over a period of 60 years, the probability of one or more such disasters is only .00003. Yet, a sizeable percentage of our scenario writers appear to expect a disaster of greater severity within their lifetimes.

Facing the Facts: Can the Public Be Unscared?

These results document what many other observers have suspected: there is an immense gap between the opinions of most technical experts and the views of the public regarding the risks from nuclear power. The contribution of the present study is the evidence that public fears are not derived from a feeling that nuclear power is a particularly aversive mode of death, but from the expectation that an enormous number of deaths are likely to result as a consequence of that technology. Many people, like the letter writer quoted in the introduction to this paper, apparently believe that nuclear power threatens the survival of "the planet and the human race."

Kasper (1978) has commented at length on the consequences of the discrepancy between expert and lay judgments of nuclear risk. One consequence is that experts, fearing overreaction by the public, feel forced to overstate the precision of their estimates. A more important consequence is the confusion and distrust on the part of a public which believes the risks to be vastly greater than the experts' assessments indicate. The experts, in turn, question the rationality of the public and decry the emotionalism stymying technological progress. Bitter and occasionally violent confrontations result.

Recognition of the "perception gap" has naturally resulted in the belief that the public must be educated about the "real" risks from nuclear power. One public opinion analyst 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 and can thereafter make the decision wisely (Pokorny, 1977, p. 12)

A Pessimistic View

Our own view is that educational attempts designed to reduce the "perception gap" are probably doomed to failure. This pessimistic conclusion is based on two key aspects of the problem, one technical and one psychological. The technical problem is that the disputed risks are so improbable that they are not amenable to precise empirical verification. The psychological problem is that people's perceptions are not irrational but are based on normal ways of thinking which, when applied to the special qualities of nuclear risks, are likely to thwart attempts to modify beliefs.

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 the risk estimates cannot be based on empirical observation.

Instead, risk assessments must be derived from complex mathematical models and structures such as the fault trees and event trees used in the Reactor Safety Study to estimate the probability of a loss-of-coolant accident (U.S. Nuclear Regulatory Commission, 1975). Despite an appearance of objectivity, such assessments are inherently subjective. Someone, relying on judgment, must determine the structure of the analysis, including the ways that failure might occur, their relative importance, and their logical interconnections.

The difficulties of applying fault-tree and event-tree analysis have led many critics to question the validity of these methods (e.g., 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. Another problem is the difficulty of taking proper account of "common-mode failures." To insure greater safety, many technological systems are built with a great deal of redundancy. Should one crucial part fail, there are others designed either to do the same job or to limit the resulting damage. Since the probability of each individual part failing is very small, the probability of all failing, thereby creating a major disaster, should be extremely small. This reasoning is valid only if the various components are independent--that is, if what causes one part to fail will not automatically cause the others to fail. "Common mode failure" occurs when the independence assumption does not hold. As an example, the discovery that a set of pipes in several nuclear plants were all made from the same batch of defective steel (<u>Eugene Register Guard</u>, Oct. 13, 1974) suggests that the simultaneous failure of several such pipes was not inconceivable. The same fire that caused the core to overheat in a reactor at Brown's Ferry, Alabama also damaged the electrical system needed to shut the plant down. Developing models to assess such contingencies is a very difficult enterprise.

Questions about completeness, treatment of common-mode failures, and related statistical problems have caused a recent review of the Reactor Safety Study (U.S. Nuclear Regulatory Commission, 1978) to conclude that the error bounds on the probabilities calculated in that study are greatly underestimated. This review has led the Nuclear Regulatory Commission to caution that the absolute values of risk reported in the Reactor Safety Study should not be used uncritically either in the regulatory process or for public policy purposes.

Holdren's skepticism regarding the defensibility of assessments of rare catastrophes 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 (that is, in the absence of operating experience in the range of 10,000 reactor-years or more), even ignoring the crucial possibility of malevolence. 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 note be viewed as irrational. In part, these fears are fed by the realization that (a) the experts have been wrong in the past, as when they irradiated enlarged tonsils or permitted people to witness A-bomb tests at close range, and (b) the experts are still disputing the "facts" about risks from nuclear power. Furthermore, when examined in detail, people's fears appear to reflect fundamental ways of thinking that usually lead to satisfactory judgments and decisions. However, when applied to low-probability, high-consequence risks such as those encountered with nuclear power, these modes of thinking lead to heightened fears and reluctance to change beliefs in the face of new evidence.

One mode of thought that provides insight into perceived nuclear risks is a judgmental rule or strategy known as the availability heuristic (Tversky & Kahneman, 1974; Slovic, Fischhoff, Lichtenstein & Hohenemser, 1979). This rule leads people to judge an event as likely or frequent if instances of it are easy to imagine or recall. Frequently occuring events are generally easier to imagine and recall than rare events; thus, reliance on availability is typically an appropriate mental strategy. However, memorability and imaginability are also affected by numerous factors not related to likelihood. As a result, this natural way of thinking leads people to exaggerate the probabilities of events that are particularly recent, vivid, or emotionally salient. Certainly, the risks from nuclear power would seem to be a prime candidate for enhancement by the availability heuristic, because of the extensive media coverage they receive and their association with the vivid, imaginable dangers of nuclear war. As Zebroski (1976) noted, "fear sells;" the media dwell on potential catastrophes, not on the successful day-to-day operations of power plants.

One subtle and disturbing implication of the availability heuristic is that any discussion of low-probability hazards, regardless of its content, may increase the memorability and imaginability of those hazards and, hence, increase their perceived risks. This possibility poses a major barrier to open, objective discussions of nuclear safety. Consider an engineer demonstrating the safety of disposing nuclear wastes in a salt bed by using the fault tree shown in Figure 4 to point out the improbability of the various ways radioactivity could be 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."

Insert Figure 4 about here

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 might 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 "worse 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 somewhat perilous since it requires predicting the extent to which the adversaries can employ their imagination (J. Cohen, 1972, p. 55).

An example of the politicized use of worst-case scenarios is a recent letter sent out by the Union of Concerned Scientists which contains the following statement:

> "These are the facts: One accident from one plant could kill as many as 45,000 people, cause $17 billion in property damage, and

contaminate an area the size of Pennsylvania."

Notice that no mention is made of the miniscule probabilities assigned to this worst-case scenario by those who developed it in the Reactor Safety Study.

Whereas the availability heuristic implies that educational attempts may often backfire, another likely outcome is that information designed to educate people will simply have no effect. This consequence is implied by psychological research demonstrating that people's beliefs change slowly, and are extraordinarily persistent in the face of contrary evidence (Ross, 1977). Once formed, initial impressions tend to structure the way that subsequent evidence is interpreted. New evidence appears reliable and informative if it is consistent with one's initial belief; contrary evidence is dismissed as unreliable, erroneous, or unrepresentative (Mazur, 1973). Thus, depending on whether one is predisposed in favor of nuclear power or against it, intense effort to reduce nuclear hazards may be interpreted to mean either that the technologists are responsive to the public's concerns or that the risks are great. Likewise, opponents of nuclear power may perceive minor mishaps as near catastrophes and dismiss the opinions of experts who rebut such claims as biased by vested interests. From a statistical standpoint, convincing people that the catastrophe they fear is extremely unlikely is difficult under the best conditions. Any mishap can be seen as proof of high risk, whereas demonstrating safety requires a massive amount of evidence (Green & Bourne, 1972). Nelkin's (1974) case history of a nuclear plant siting controversy provides a good example of the inability of technical arguments to change opinions. Each side in that debate capitalized on technical ambiguities in ways that reinforced its own position. Similarly, the Swedish government's massive campaign to educate people about nuclear power and other energy sources showed that 10 or more hours of instruction had little influence on the attitudes of the 80,000 participants. The most significant effect was an increase in confusion and uncertainty about nuclear power, caused by an inability to resolve the conflicting opinions of technical experts (Nelkin, 1977).

Pathways Towards Acceptance

With all this working against it, what pathways might lead to widespread acceptance of nuclear power? Public response to X rays and nerve gas provides some clues. Widespread acceptance of X rays shows that a radiation technology can be tolerated once its use becomes familiar, its benefits clear, and its practitioners trusted. Of course, X rays are not perceived as potentially catastrophic, nor do they create the dread presently associated with nuclear power (see Figure 3).

Nerve gas also 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, despite the warning that the fuses on the gas bombs deteriorate with age, but that the gas does not (Eugene Register Guard, Dec. 18, 1969 and Jan. 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 presence of the hazard was familiar). Second, there were clear 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. However, since people are generally willing to accept increased risks in exchange for increased benefits (Starr, 1969; Fischhoff et al., 1978), a quicker path to acceptance might be forged by a severe energy shortage. Brownouts, blackouts, or rationing of electricity would undoubtedly enhance the perceived benefits from nuclear power and increase society's tolerance of its risks. A recent example of this process 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 their environmental risks. Such crisis-induced acceptance of nuclear power may, however, produce anxiety and stress in a population forced to tolerate what it perceives as great risk because of its addiction to the benefits of electricity.

What About Acceptance of Alternative Energy Systems?

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. Fossil, hydroelectric and solar energy systems have their roots in man's ancient past and work via mechanisms (combustion, water force, and sunshine) that are familiar, natural, and understood by all.

Many of the accidents and fatalities resulting from these systems involve individuals isolated spatially and socially from the rest of society. 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--quite a contrast to the likely consequences of a reactor accident.

Conclusions

Development and regulation of nuclear power need to be based upon an understanding of the ways in which people think about risk and uncertainty. Our aim in this paper was not to document public opposition and fear of nuclear power, which are already well known, but to point out that this reaction stems in part from the recognition that there are important unresolved technical issues in the risk assessment process and in part from fundamental mental processes such as the use of imaginability and memorability as the basis for estimates of probability and frequency. Normal modes of thought, coupled with the special qualities of nuclear hazards that make them particularly memorable and imaginable yet hardly amenable to empirical verification, blur the distinction between the possible and the probable and produce an immense gap between the views of technical experts and a significant portion of the public. This gap must be acknowledged and the difficulty of reducing it by appeal to reason or empirical demonstrations of safety must be recognized by planners and policy makers. Facing this problem means addressing some hard questions. Does nuclear 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?[1]

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1. This article was written before the disastrous accident at the Three Mile Island reactor. While it is too early to foretell the major consequences of this event, it will undoubtedly aggravate the disagreements about the risks from nuclear power. Some experts will argue that even very improbable events do sometimes happen, and that their occurrence does not necessarily invalidate the previous assessment of their improbability. Others will point to the safety systems that did work as evidence of the effectiveness provided by overlapping systems. Still others will admit error but say that the system can be improved so that such accidents will never again happen. Other experts and most of the public will interpret the Three Mile Island accident as evidence that the previous risk estimates were much too low. We expect the perception gap to increase. The slow path towards acceptance of nuclear power seems even less navigable than before. The need to address the hard questions appears even more urgent.

Table 1

Perceived Risk and Need for Risk Adjustment for 30 Activities and Technologies[a]

Activity or Technology	Perceived Benefit	Perceived Risk	Need for Risk Adjustment[b]
1. Alcoholic beverages	41	161	4.4
2. Bicycles	82	65	1.5
3. Commercial aviation	130	52	1.3
4. Contraceptives	113	50	2.0
5. Electric power	274	52	1.0
6. Fire fighting	178	92	1.1
7. Food coloring	16	31	3.0
8. Food preservatives	44	36	2.7
9. General aviation	53	114	2.1
10. Handguns	14	220	17.3
11. H.S. & college football	35	37	1.7
12. Home appliances	133	25	1.1
13. Hunting	30	82	2.5
14. Large construction	142	91	1.7
15. Motorcycles	29	176	5.3
16. Motor vehicles	187	247	6.1
17. Mountain climbing	28	68	1.0
18. Nuclear power	52	250	29.0
19. Pesticides	87	105	9.5
20. Power mowers	30	29	1.5
21. Police work	178	111	1.8
22. Prescription antibiotics	209	30	1.3
23. Railroads	185	37	1.2
24. Skiing	38	45	1.0
25. Smoking	20	189	15.2
26. Spray cans	17	73	7.8
27. Surgery	164	104	1.9
28. Swimming	68	52	1.0
29. Vaccinations	194	17	.8
30. X rays	156	45	1.7

[a] Data adapted from Fischhoff et al. (1978)

[b] Values of 1.0 indicate that the activity is presently at an acceptable level of risk. Values greater than 1.0 mean the activity needs to be safer by the factor indicated in the column; values less than 1.0 mean the activity could be riskier and still be acceptable to society.

Table 2

Geometric Mean Judgments of Social Cost of Death

		Social Cost in 10^6 dollars (Students; N=77)	Social Cost in 10^6 dollars (LOWV; N=45)
1.	Alcoholic beverages	.91	.77
2.	Bicycles	1.25	1.27
3.	Cancer	1.37	1.22
4.	Commercial aviation	1.41	1.27
5.	Construction	1.15	1.25
6.	Contraceptives	1.80	1.39
7.	Dam failure	1.47	1.73
8.	Electric power (non-nuclear)	1.38	1.25
9.	Fire fighting	1.49	1.45
10.	Food coloring	1.60	1.75
11.	Food preservatives	1.72	1.83
12.	Handguns	1.48	2.52
13.	H.S. & college football	1.35	1.41
14.	Home appliances	1.25	1.19
15.	Homicide	1.97	3.08
16.	Hunting	1.05	.94
17.	Motorcycles	1.10	.97
18.	Motor vehicles	1.25	1.25
19.	Mountain climbing	1.04	.97
20.	Nuclear power	2.26	2.41
21.	Pesticides	1.73	2.05
22.	Police work	1.39	1.64
23.	Power mowers	1.22	1.28
24.	Prescription antibiotics	1.52	1.29
25.	Private aviation	1.07	1.06
26.	Railroads	1.29	1.16
27.	Skiing	1.17	1.12
28.	Smoking	.96	.70
29.	Spray cans	1.59	1.61
30.	Suicide	.95	.94
31.	Surgery	1.34	1.21
32.	Swimming	1.09	1.11
33.	Vaccinations	1.61	1.42
34.	X rays	1.59	1.52

Table 3

Fatality Estimates and Disaster Multipliers

for 30 Activities and Technologies

	Geometric Mean Fatality Estimates Average Year		Geometric Mean Multiplier Disastrous Year	
Activity or Technology	LOWV	Students	LOWV	Students
1. Alcoholic beverages	12,000	2,600	1.9	1.4
2. Bicycles	910	420	1.8	1.4
3. Commercial aviation	280	650	3.0	1.8
4. Contraceptives	180	120	2.1	1.4
5. Electric Power	660	500	1.9	2.4
6. Fire fighting	220	390	2.3	2.2
7. Food coloring	38	33	3.5	1.4
8. Food preservatives	61	63	3.9	1.7
9. General aviation	550	650	2.8	2.0
10. Handguns	3,000	1,900	2.6	2.0
11. H.S. & college football	39	40	1.9	1.4
12. Home appliances	200	240	1.6	1.3
13. Hunting	380	410	1.8	1.7
14. Large construction	400	370	2.1	1.4
15. Motorcycles	1,600	1,600	1.8	1.6
16. Motor vehicles	28,000	10,500	1.6	1.8
17. Mountain climbing	50	70	1.9	1.4
18. Nuclear power	20	27	107.1	87.6
19. Pesticides	140	84	9.3	2.4
20. Power mowers	40	33	1.6	1.3
21. Police work	460	390	2.1	1.9
22. Prescription antibiotics	160	290	2.3	1.6
23. Railroads	190	210	3.2	1.6
24. Skiing	55	72	1.9	1.6
25. Smoking	6,900	2,400	1.9	2.0
26. Spray cans	56	38	3.7	2.4
27. Surgery	2,500	900	1.5	1.6
28. Swimming	930	370	1.6	1.7
29. Vaccinations	65	52	2.1	1.6
30. X-rays	90	40	2.7	1.6

Table 4

Fatality Estimates Associated with "Maximum Credible Disasters"

from Commercial Aviation and Nuclear Power

Commercial Aviation		Nuclear Power [a]	
50		0	
100		3	
100		10	
100		48	
138		60	
200		60	
220		1,000	
300		2,000	
hundreds		3,000	
431		5,000	
450		10,000	
500		20,000	median
600		25,000	values
700		30,000	
900	median	50,000	
1,000	values	100,000+	
1,000		200,000	
1,500		200,000	
2,000		250,000	
2,000		1,000,000	
2,000		1,000,000	
2,000		2,000,000	
2,000		10,000,000	
3,000		20,000,000	
3,500			
5,000			
10,000			
200,000			
300,000			

Note: Each value represents the expectations of a different respondent.

[a] Four persons did not provide numerical estimates with their scenarios. Of these, three wrote scenarios postulating world-wide contamination and death.

Figure Captions

1. Risk characterisitcs rated by LOWV members and students.

2. Comparison between nuclear power and non-nuclear electric power on nine risk characteristics (from Fischhoff et al., 1978).

3. Comparison between nuclear power and X rays on nine risk characteristics (from Fischhoff et al., 1978)

4. Fault tree of salt mine used for storage of radioactive wastes (after closure of the mine). From McGrath (1974).

Voluntariness of risk

Do people face this risk voluntarily? If some of the risks are voluntarily undertaken and some are not, mark an appropriate spot towards the center of the scale.

risk assumed voluntarily 1 2 3 4 5 6 7 risk assumed involuntarily

Immediacy of effect

To what extent is the risk of death immediate--or is death likely to occur at some later time?

effect immediate 1 2 3 4 5 6 7 effect delayed

Knowledge about risk

To what extent are the risks known precisely by the persons who are exposed to those risks?

risk level known precisely 1 2 3 4 5 6 7 risk level not known

To what extent are the risks known to science?

risk level known precisely 1 2 3 4 5 6 7 risk level not known

Control over risk

If you are exposed to the risk, to what extent can you, by personal skill or diligence, avoid death?

personal risk can't be controlled 1 2 3 4 5 6 7 personal risk can be controlled

Newness

Is this risk new and novel or old and familiar?

new 1 2 3 4 5 6 7 old

Chronic-catastrophic

Is this a risk that kills people one at a time (chronic risk) or a risk that kills large numbers of people at once (catastrophic risk)?

chronic 1 2 3 4 5 6 7 catastrophic

Common-dread

Is this a risk that people have learned to live with and can think about reasonably calmly, or is it one that people have great dread for--on the level of a gut reaction?

common 1 2 3 4 5 6 7 dread

Severity of consequences

When the risk from the activity is realized in the form of a mishap or illness, how likely is it that the consequence will be fatal?

certain not to be fatal 1 2 3 4 5 6 7 certain to be fatal

Figure 1. Risk characteristics rated by LOWV members and students

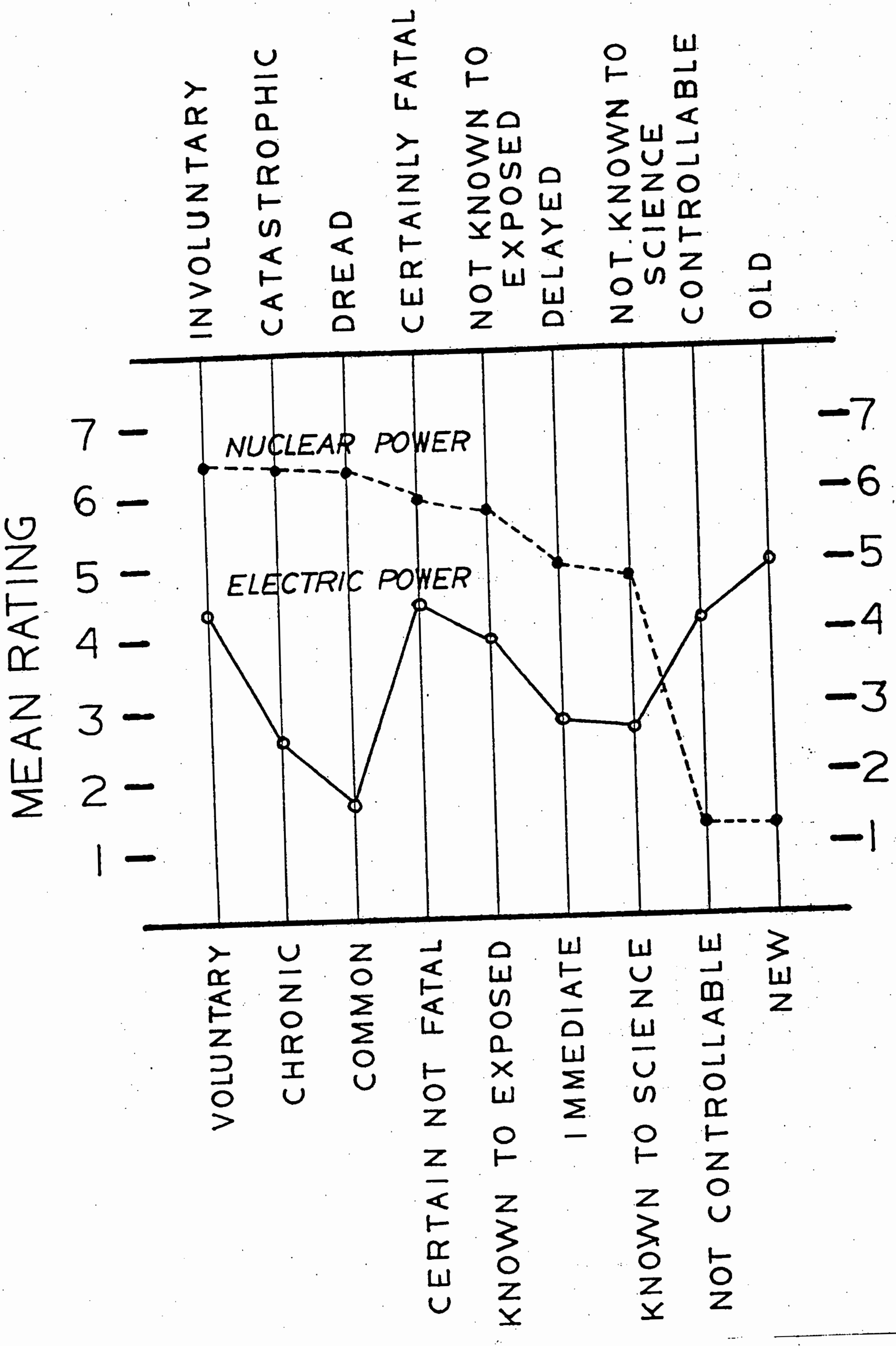

Figure 2. Comparison between nuclear power and non-nuclear electric power on nine risk characteristics (from Fischhoff et al., 1978).

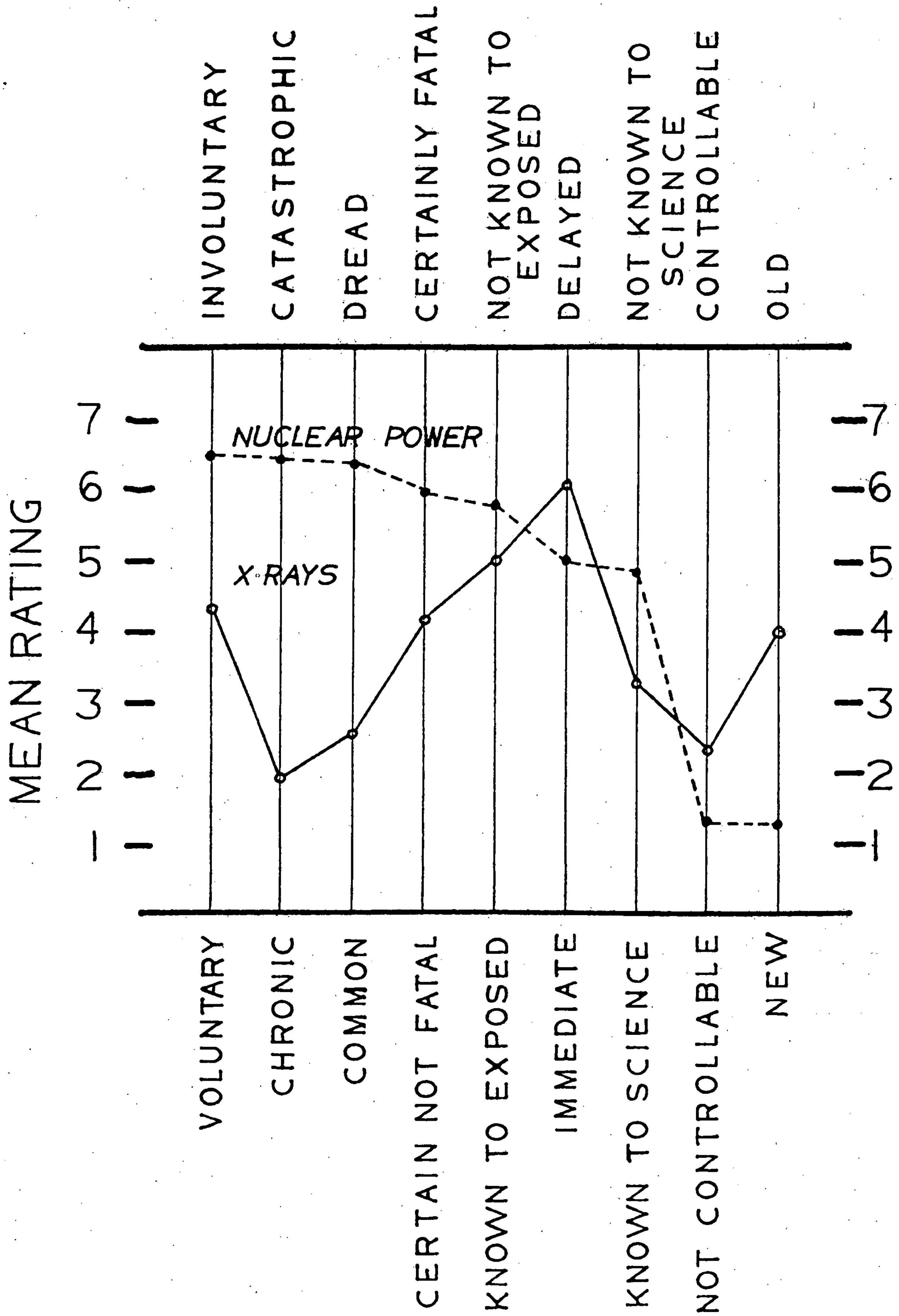

Figure 3. Comparison between nuclear power and X rays on nine risk characteristics (from Fischhoff et al., 1978)

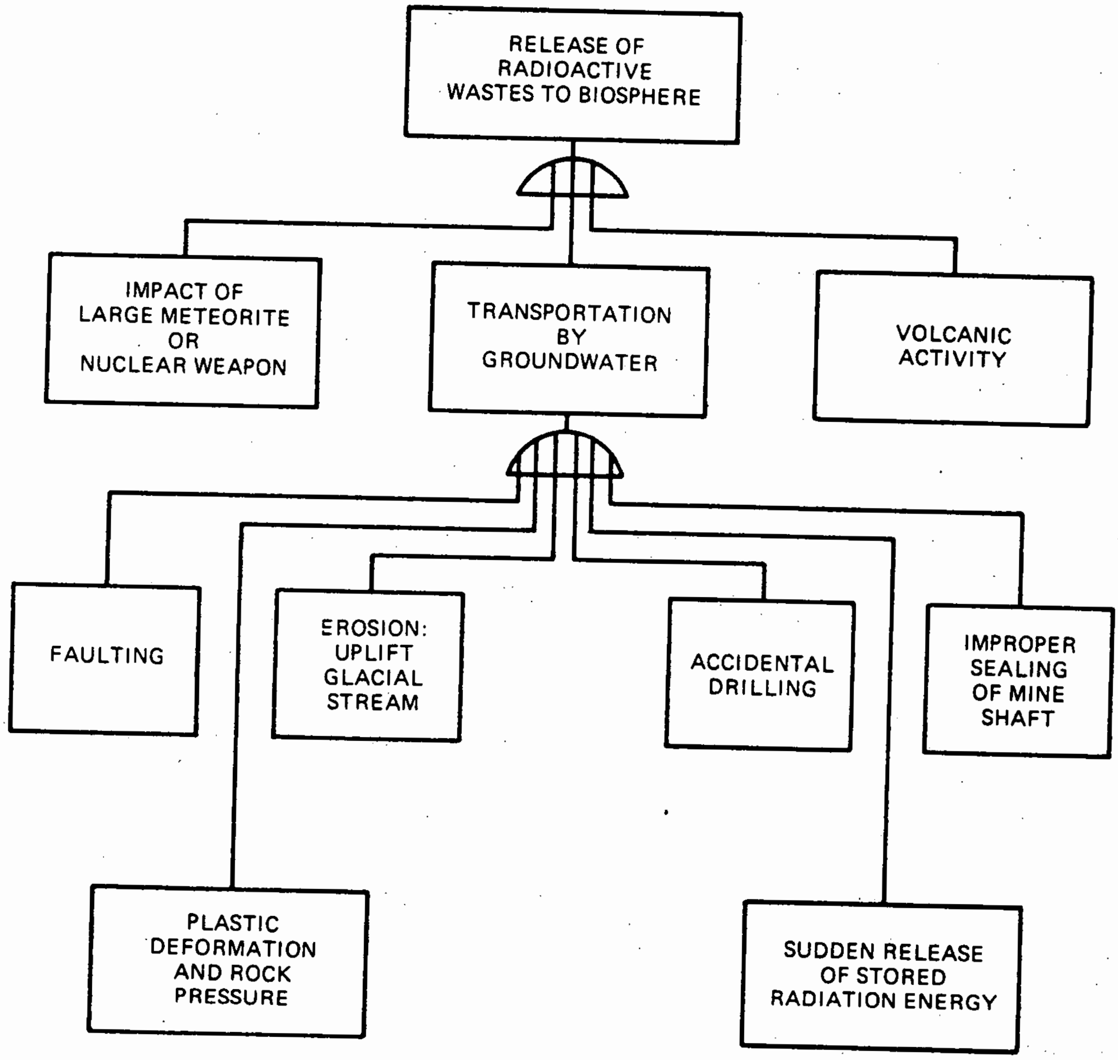

Figure 4. Fault tree of salt mine used for storage of radioactive wastes (after closure of the mine). From McGrath (1974).