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Chapter 29

Facts vs. Fears:

Understanding Perceived Risk

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People respond to the hazards they perceive. If their perceptions are faulty, efforts at personal, public and environmental protection are likely to be misdirected. For some hazards, such as motor vehicle accidents, extensive statistical data are readily available. For other familiar activities, such as the consumption of alcohol and tobacco, assessment of risk requires complex epidemiological and experimental studies. However, even when statistical data are plentiful, the "hard" facts can only go so far towards developing policy. At some point, human judgment is needed to interpret the findings and determine their relevance.

Still other hazards, such as those associated with recombinant DNA research or nuclear power, are so new that risk assessment must be based on complex theoretical analyses such as fault trees (see Figure 1), rather than on direct experience. Despite an appearance of objectivity, these analyses, too, include a large domponent of judgment. Someone, relying on educated intuition, must determine the structure of the problem, the consequences to be considered, and the importance of the various branches of the fault tree. Once the analyses have been performed, they must be

Insert Figure 1 about here

communicated to those who actually manage hazards, including industrialists, environmentalists, regulators, legislators, and voters. If these people do not understand or believe the data they are shown, then distrust, conflict and ineffective hazard management are likely.

This paper explores some psychological elements of the risk-assessment process. Its basic premises are that both the public and the experts are necessary participants in that process, that assessment is inherently subjective, and that understanding judgmental limitations is crucial to effective decision making.

JUDGMENTAL BIASES IN RISK PERCEPTION

When lay people are asked to evaluate risks, they seldom have statistical evidence on hand. In most cases, they must make inferences based on what they remember hearing or observing about the risk in question. Psychological research, much of which has been described earlier in this book, has identified a number of very general inferential rules that people seem to use in such situations. These judgmental rules, known as heuristics, are employed to reduce difficult mental tasks to simpler ones. Although they are valid in some circumstances, in others they lead to large and persistent biases with serious implications.

Availability

One heuristic that has special relevance for risk perception is called availability (Tversky & Kahneman, 1973; Chapter). People using this heuristic judge an event as likely or frequent if instances of it are easy to imagine or recall. Because frequently occurring events are generally easier to imagine and recall than are rare events, availability is often an appropriate cue. However, availability is also affected by numerous factors unrelated to frequency of occurrence. For example, a recent disaster or a vivid film such as "Jaws" or "The China Syndrome" could seriously distort risk judgments.

Availability bias helps explain people's misperceptions and faulty decisions with regard to certain natural hazards. For example, in discussing flood plain residents, Kates (1962) wrote:

> 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 attributed 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 observed that individuals forecasting flood potential "are strongly conditioned by their immediate past and limit their extrapolation to simplified constructs, seeing the future as a mirror of that past" (p. 88). Similarly, the purchase of earthquake insurance increases sharply after a quake, and then decreases steadily as memories fade (Steinbrugge et al., 1969).

One particularly important implication of the availability heuristic is that discussion of a low-probability hazard may increase its memorability and imaginability and hence its perceived riskiness, regardless of what the evidence indicates. For example, leaders in the field of recombinant DNA research quickly regretted ever bringing to public attention the remote risks of contamination by newly created organisms. Rosenberg (1978) summarized the reaction that followed the revelation of such hypothetical risks:

> Initially, the response was one of praise for the . . . social responsibility shown by the scientists involved . . . . Gradually and predictably, however, the debate became heated. Speculation abounded and the scarier the scenario, the wider the publicity it received. Many of the discussions of the issue completely lost sight of the fact that the dangers were hypothetical in the first place and assumed that recombinant DNA laboratories were full of raging beasts. Ultimately, the very scientists whose self-restraint had set the whole process in motion were vilified (p. 29).

Judged frequency of lethal events. Availability bias is illustrated by several studies in which college students and members of the League of Women Voters judged the frequency of 41 causes of death (Lichtenstein, Slovic, Fischhoff, Layman & Combs, 1978). In one study, these people were first told the annual death toll for one cause (motor vehicle accidents) in the United States (50,000) and then asked to estimate the frequency of the other 40. In another study, participants were asked to judge which of two causes of death was more frequent (i.e., "How many times more frequent is it?" In both studies, judgments were moderately accurate in a global sense: people usually knew which were the most and least frequently lethal events. Within this global picture, however, people made serious misjudgments, many of which seemed to reflect the influence of availability.

Figure 2 compares the judged number of deaths per year with the number reported in public health statistics. If the frequency judgments were accurate, they would equal the statistical rates, with all data points failing on the identity line. Although more likely hazards generally evoked higher estimates, the points seem scattered about a curved line that lies sometimes above and sometimes below the line of accurate judgment. In general, rare causes of death were overestimated and common causes of death were underestimated.

Insert Figure 2 about here

In addition to this general bias, sizable specific biases are evident. For example, accidents were judged to cause as many deaths as diseases, whereas diseases actually take about 15 times as many lives. Homicides were incorrectly judged more frequent than diabetes and stomach cancer deaths. Homicides were also judged to be about as frequent as death by stroke, although the latter actually claims about 11 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 various studies. In keeping with availability considerations, overestimated causes of death were dramatic and sensational, whereas underestimated causes tended to be unspectacular events, which claim one victim at a time and are common in nonfatal form.

Insert Table 1 about here

Biased newspaper coverage and biased judgments. The availability heuristic highlights the vital role of experience as a determinant of perceived risk. If one's experiences are biased, one's perceptions are likely to be inaccurate. Unfortunately, much of the information to which people are exposed provides a distorted picture of the world of hazards. Consider author Richard Bach's observation about the fear shown by a couple taking their first airplane ride:

> In all that wind and engineblast and earth tilting and going small below us, I watched my Wisconsin lad and his girl,

> to see them change. Despite their laughter, they had been afraid of the airplane. Their only knowledge of flight came from newspaper headlines, a knowledge of collisions and crashes and fatalities. They had never read a single report of a little airplane taking off, flying through the air and landing again safely. They could only believe that this must be possible, in spite of all the newspapers, and on that belief they staked their three dollars and their lives (Bach, 1973, p. 37).

As a follow-up to the studies reported above, Combs and Slovic (1979) examined the reporting of causes of death in two newspapers on opposite coasts of the United States. Various indices of newspaper coverage were recorded for alternate months over a period of one year. The results indicated that both newspapers had similar biases in their coverage of life-threatening events. For example, examination of Table 2 indicates that many of the statistically frequent causes of death (e.g., diabetes, emphysema, various forms of cancer) were rarely reported by either paper during the period under study. In addition, violent, often catastrophic, events such as tornadoes, fires, drownings, homicides, motor vehicle accidents, and all accidents were reported much more frequently than less dramatic causes of death having similar (or even greater) statistical frequencies. For example, diseases take about 16 times as many lives as accidents, but there were more than three times as many articles about accidents, noting almost seven times as many deaths. Among the more frequent events, homicides were the most heavily reported category in proportion to actual frequency. Although diseases claim almost 100 times as many lives as do homicides, there were about three times as many articles about homicides as about disease deaths.

Insert Table 2 about here

Furthermore, homicide articles tended to be more than twice as long as articles reporting disease and accident deaths.

Moreover, the biases in newspaper coverage and people's judgments were quite similar. The correlation between judged frequency of death and the number of deaths reported in the newspapers was about .70. This high correlation was not due to a common association of both judged and reported deaths with statistical frequency. When the latter was held constant, the partial correlations between people's judgments and the number of deaths reported were .89 and .85 for the two newspapers. Although it is tempting to conclude from these correlations that media coverage biases perceptions of risk, it might also be the case that people's opinions about what is important influence the media. The journalism literature is replete with instances in which influence has occurred in each direction (Brucker, 1973).

It won't happen to me. People's judgments of causes of death may be about as good as could be expected, given that they are neither specialists in the hazards considered nor exposed to a representative sample of information. Accurate perception of misleading samples of information might also be seen to underlie another apparent judgmental bias, people's predilection to view themselves as personally immune to hazards. The great majority of individuals believe themselves to be better than average drivers (Näätänen & Summala, 1975; Svenson, 1979), more likely than average to live past 80 (Weinstein, 1979), less likely than average to be harmed by products they use (Rethans, 1979), and so on. Although such perceptions are obviously unrealistic, the risks look very small from the perspective of each individual's experience. Consider automobile driving: despite driving too fast, tailgating, etc., poor drivers make trip after trip without mishap. This personal experience demonstrates to them their exceptional skill and safety. Moreover, their indirect experience via the news media shows them that when accidents happen, they happen to others. Given such misleading experiences, people may feel quite justified in refusing to take protective actions such as wearing seat belts (Slovic, Fischhoff & Lichtenstein, 1978).

Out of sight, out of mind. In some situations, failure to appreciate the limits of "available" data may lull people into complacency. In a study by Fischhoff, Slovic and Lichtenstein (1978), three groups of college student subjects were asked to evaluate the completeness of a fault tree showing the risks associated with starting a car (see Figure 3). One group saw the full tree. Each of the other two groups received a different pruned tree. In one version, the starting, ignition and mischief branches were missing; the other lacked branches detailing battery, fuel and other engine problems.

Insert Figure 3 about here

Instructions for the task read as follows (numbers in brackets were given to people who saw the pruned trees):

> Every day, across the United States, millions of drivers perform the act of getting into an automobile, inserting a key in the ignition switch, and attempting to start the engine. Sometimes the engine fails to start, and the trip is delayed. We'd like you to think about the various problems that might be serious enough to cause a car to fail to start so that the driver's trip is delayed for at least 1 minute.
>
> The chart on the next page is intended to help you think about this problem. It shows six [three] major deficiencies that cause a car's engine to fail to start. These major categories probably don't cover all possibilities, so we've included a seventh [fourth] category, All Other Problems.

Please examine this diagram carefully and answer the following question:

For every 100 times that a trip is delayed due to "starting failure," estimate, on the average, how many of those delays are caused by each of the seven [four] factors. Make your estimates on the blank lines next to the factors named below. Your estimates should sum to 100.

If people who saw the pruned trees were properly sensitive to what had been omitted, the proportion of problems that they attributed to "other" would have equaled the sum of the proportions of problems attributed to the pruned branches and to "other" by those who saw the full tree. The results in Table 3 indicate that what was out of sight was effectively out of mind. For example, pruned tree Group 1, "other" should have increased by a factor of six (from .078 to .468) to reflect the proportion of failures due to starting and ignition problems and mischief, which had been omitted from the diagram. Instead, "other" was only doubled, whereas the importance of the three systems that were mentioned was substantially increased. A second study not only replicated these findings, but showed that persons who observed pruned trees judged starting failure (due to all causes) to be less likely than did those who observed the unpruned tree.

Insert Table 3 about here

Overconfidence

Knowing with certainty. A particularly pernicious aspect of heuristics is that people typically have great confidence in judgments based upon them. In another follow-up to the study on causes of death, people were asked to indicate the odds that they were correct in choosing the more frequent of two lethal events (Fischhoff, Slovic & Lichtenstein, 1977). Table 4 shows the percentages of correct answers for each of the most frequently used odds categories. In Experiment 1, subjects were reasonably well calibrated when they gave odds of 1:1, 1.5:1, 2:1, and 3:1. That is, their percentage of correct answers was close to the appropriate percentage correct, given those odds. However, as odds increased from 3:1 to 100:1, there was little or no increase in accuracy. Only 73% of the answers assigned odds of 100:1 were correct (instead of 99.1%). Accuracy "jumped" to 81% at 1000:1 and to 87% at 10,000:1. For answers assigned odds of 1,000,000:1 or greater, accuracy was 90%; the appropriate degree of confidence would have been odds of 9:1. The 12% of responses that are not listed in Table 3 because they fell between the most common odds categories showed a similar pattern of overconfidence. In summary, subjects were frequently wrong at even the highest odds levels. Moreover, they gave many extreme odds responses. More than half of their judgments were greater than 50:1. Almost one-fourth were greater than 100:1.

Insert Table 4 about here

A second experiment attempted to improve performance by giving subjects more instruction. The experimental session began with a 20-minute lecture in which the concepts of probability and odds were carefully explained. The subtleties of expressing one's feelings of uncertainty as numerical odds judgments were discussed, with special emphasis on how to use small odds (between 1:1 and 2:1) when one is quite uncertain about the correct answer. A chart was provided showing the relationship between various odds and the corresponding probabilities. Finally, subjects were taught the concept of calibration (Chapter) and were urged to make odds judgments in a way that would lead them to be well calibrated. Although performance improved somewhat, subjects again exhibited unwarranted certainty (see Table 4). They assigned odds greater than or equal to 50:1 to approximately one-third of the items. Only 83% of the answers associated with these odds were correct.

In a third experiment, people proved to be just as overconfident when answering questions of general knowledge (e.g., Which magazine had the largest circulation in 1970? (a) Playboy or (b) Time) as when they answered questions about the frequency of lethal events (see Table 4). Additional studies tested people's faith in their odds assessments by asking if they would stake money on them by playing the bet described in Table 5. This bet is advantageous for perfectly calibrated and underconfident participants and disadvantageous to overconfident ones. Most participants in our studies were eager to play the game. Because their confidence was unjustified, they suffered sizeable monetary losses (which we returned to them after the experiment was over).

Insert Table 5 about here

Although the psychological basis for unwarranted certainty is complex, a key element seems to be people's lack of awareness that their knowledge is based on assumptions that are often quite tenuous. For example, 30% of the respondents in Experiment 1 gave odds greater than 50:1 to the incorrect assertion that homicides are more frequent than suicides. These individuals may have been misled by the greater ease of recalling instances of homicide, failing to appreciate that memorability is an imperfect basis for inference.

Hyperprecision. Overconfidence manifests itself in other ways as well. A typical task in estimating uncertain quantities such as failure rates is to set upper and lower bounds so that there is a 98% 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% of true values falling outside the 98% confidence bounds, 20-50% do so (Alpert & Raiffa, Chapter ; Lichtenstein, Fischhoff & Phillips, Chapter). Thus people think that they can estimate such values with much greater precision than is actually the case. Tversky and Kahneman (Chapter 1) have attributed such hyperprecision to reliance on the anchoring and adjustment heuristic.

Overconfident experts. Unfortunately, experts, once they are forced to go beyond their data and rely on judgment, may be as prone to overconfidence as lay people. Fischhoff, Slovic and Lichtenstein (1978) repeated their fault-tree study (Figure 3) with professional automobile mechanics (averaging about 15 years of experience) and found these experts to be almost as insensitive as lay persons to deletions from the tree (see Table 6). 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% chance of enclosing the true failure height. None of the bounds specified by these individuals actually did enclose the true failure height. Figure 4 shows these results, along with another example of expert overconfidence.

The multi-million dollar Reactor Safety Study (U.S. Nuclear Regulatory Commission, 1975), in assessing the probability of a core melt in a nuclear reactor, used the very procedure for setting confidence bounds that was shown in Chapters and to produce a high degree of overconfidence. In fact, the "Lewis Committee" concluded its review of the Reactor Safety Study by noting that despite the great advances made in that study "we are certain that the error bands are understated. We cannot say by how much. Reasons for this include an inadequate data base, a poor statistical treatment, [and] an inconsistent propagation of uncertainties throughout the calculation" (U.S. Nuclear Regulatory Commission, 1978, p. vi).

Insert Table 6 and Figure 4 about here

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 are shown in Table 7. The 1976 collapse of the Teton Dam provides a tragic case in point.

Insert Table 7 about here

The Committee on Government Operations 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). Failure probabilities are typically not even calculated for new dams even though about 1 in 300 fails when the reservoir is first filled.

Informing People About Risks

Thinking clearly about risk is difficult. Unfortunately, it is also necessary. Radiation hazards, medical side effects, occupational diseases, food contaminants, toxic chemicals and mechanical malfunctions increasingly fill our newspapers and our thoughts. Since the management of these hazards is vital to the well-being of individuals and society, people are presently asserting their right to play an active role in the decision-making process. As a result, the promoters and regulators of hazardous enterprises face growing pressure to inform people about the risks they face (see Figure 5). For example:

--The Food and Drug Administration is mandating patient information inserts for an increased number of prescription drugs.

--The Department of Housing and Urban Development now requires the sellers of homes built before 1950 to inform buyers about the presence of lead-based paints.

--The proposed federal products liability law places increased weight on adequately informing consumers and workers about risks they are likely to encounter.

--The White House has directed the Secretary of Health, Education and Welfare to develop a public information program on the health effects of radiation exposure.

Insert Figure 5 about here

Despite these good intentions, creating effective informational programs may be quite difficult. Doing an adequate job means finding cogent ways of presenting complex, technical material that is often clouded by uncertainty. Not only is the allotted time sometimes very limited, but messages must confront the listeners' preconceptions (and perhaps misconceptions) about the hazard in question and its consequences. For example, in some situations, misleading personal experiences may promote a false sense of security, whereas in other circumstances, mere discussion of possible adverse consequences may enhance their apparent threat. Moreover, as Ross and Anderson (Chapter) have demonstrated, people's beliefs often change slowly and show extraordinary persistence in the face of contrary evidence. What follows is a brief overview of some additional challenges that information programs must confront.

Presentation Format is Important

Subtle changes in the way that risks are expressed can have a major impact on perceptions and behavior. For example, the designers of a fault tree like that in Figure 3 must make numerous discretionary decisions regarding how to organize and present the various sources of trouble. One such decision which apparently makes little difference is how much detail to offer; Fischhoff, Slovic and Lichtenstein (1978) found similar perceptions with varying levels of detail. Merely mentioning a branch allowed people to estimate accurately how troublesome that branch would look when fully detailed. However, fusing branches (e.g., combining starting system and ignition system into one broader category) or splitting branches (e.g., separating ignition system into ignition system--items 1 and 3 in Figure 3 and distribution system--items 2 and 4) did make a difference. A given set of problems was judged to account for about 30% more failures when it was presented as two branches than when it was presented as one.

A second demonstration of the importance of presentation format comes from a study of attitudes towards the use of automobile seat belts (Slovic, Fischhoff & Lichtenstein, 1978). Drawing upon previous research demonstrating the critical importance of probability of harm in triggering protective action (Slovic, Fischhoff, Lichtenstein, Corrigan & Combs, 1978), Slovic et al. argued that people's reluctance to wear seat belts voluntarily might be due to the extremely small probability of incurring a fatal accident on a single automobile trip. Since a fatal accident occurs only about once in every 3.5 million person trips and a disabling injury only once in every 100,000 person trips, refusing to buckle one's seat belt may seem quite reasonable. It looks less reasonable, however, if one adopts a multiple-trip perspective and considers the substantial probability of an accident on some trip. Over 50 years of driving (about 40,000 trips), the probability of being killed rises to .01 and the probability of experiencing at least one disabling injury is .33. In a pilot study, Slovic et al. showed that people asked to consider this lifetime perspective responded more favorably towards seat-belts (and air bags) than did people asked to consider a trip-by-trip perspective. Whether the favorable attitudes towards seat belts induced by a lengthened time perspective would be maintained and translated into behavior, remains to be seen.

One of the most general of presentation artifacts is anchoring, the tendency of judgments to be anchored on initially-presented values (Poulton, 1968; see also Chapter 1). In another condition of the experiment presented in Figure 2, Lichtenstein et al. (1978) asked a second group of people to estimate the frequency of death in the United States from each of the 40 different causes. However, instead of being told that about 50,000 people die annually in motor vehicle accidents, these individuals were told about the 1,000 annual deaths from electrocution. Although both reports were accurate, provision of a smaller number reduced respondents' estimates of most frequencies. Such anchoring on the original number led the estimates of the two groups to differ by as much as a factor of 5 in some cases.

Fischhoff and MacGregor (1980) asked people to judge the lethality of various potential causes of death using one of four formally equivalent formats (e.g., for each afflicted person who dies, how many survive? For each 100,000 people afflicted, how many will die?). Table 8 expresses their judgments in a common format and reveals even more dramatic effects of question phrasing on expressed risk perceptions. For example, when people estimated the lethality rate for influenza directly (Column 1), their mean response was 393 deaths per 100,000 cases. When told that 80,000,000 people catch influenza in a normal year and asked to estimate the number who die (Column 2), respondents' mean response was 4,800, representing a death rate of only 6 per 100,000 cases. This slight change in the question changed the estimated rate by a factor of more than 60. Similar discrepancies occurred with other questions and other hazards.

Insert Table 8 about here

Another study (Fischhoff, 1980) asked respondents to estimate the risks of an unnamed drug (actually, an oral contraceptive) as these were described in two package inserts distributed by the manufacturer, one designed for doctors and one for patients. Readers of the patients' form thought that the risk of death from blood clots (the major risk described) was 5.1 times as large for users as for non-users; readers of the doctors' form thought that it was "only" 2.5 times as large. On the other hand, readers of the patients' form estimated a much lower overall death rate (1 in 40,000 vs. 1 in 2,000 with the doctors' form). Thus, in the doctors' form, the risk seemed greater by one measure and less by another, almost identical measure. The reason for this discrepancy seems to be that the patient's version gave a number of representative death and morbidity rates, revealing that the absolute value of a risk that seemed relatively high was an order of magnitude smaller than that imagined by readers of the doctors' form. Had only one risk question been asked, one would have had a rather different picture of readers' knowledge and the effect of the textual differences between the inserts.

Numerous other format effects have been documented in the literature on risk-taking behavior. For example, people have been found to evaluate gambles much differently when they consider them in pairs than when they judge them singly (Grether & Plott, 1979; Lichtenstien & Slovic, 1971; 1973).

Fischhoff, Slovic and Lichtenstein (1980), Hershey and Schoemaker (1980), and Schoemaker and Kunreuther (1979) have noted that decisions about whether to buy insurance are frequently reversed when the problem is portrayed as a choice between facing a gamble or accepting a loss of a smaller amount of money. The same risk options, described in terms of lives saved, may be evaluated much differently when framed in terms of lives lost (Tversky & Kahneman, in press). Additional format and context effects can be found in Fischhoff, Slovic and Lichtenstein (1980), Kahneman and Tversky (1979), and Tversky and Kahneman (in press).

The fact that subtle differences in how risks are presented can have marked effects on how they are perceived suggests that those responsible for information programs have considerable ability to manipulate perceptions. Moreover, since these effects are not widely known, people may inadvertently be manipulating their own perceptions by casual decisions they make about how to organize their knowledge.

Cross-Hazard Comparisons May Be Misleading

One of the most common approaches for deepening people's perspectives is to present quantified risk estimates for a variety of hazards. Presumably, the sophistication gleaned from examining such data will be useful for personal and societal decision making. Wilson (1979) observed that we should "try to measure our risks quantitatively . . . . Then we could compare risks and decide which to accept or reject" (p. 43). Lord Rothschild (1979) added, "There is no point in getting into a panic about the risks of life until you have compared the risks which worry you with those that don't, but perhaps should."

Typically, such exhortations are followed by elaborate tables and even "catalogs of risks" in which diverse indices of death or disability are displayed for a broad spectrum of life's hazards. Thus, Sowby (1965) provided extensive data on risks per hour of exposure, showing, for example, that an hour riding a motorcycle is as risky as an hour of being 75 years old. Wilson (1979) developed Table 9, which displays a set of activities, each of which is estimated to increase one's chances of death (during the next year) by 1 in one million. Wilson claimed that " . . . these comparisons help me evaluate risks and I imagine that they may help others to do so, as well. But the most important use of these comparisons must be to help the decisions we make, as a nation, to improve our health and reduce our accident rate" (p. 45). Similarly, Cohen and Lee (1979) ranked many hazards in terms of their expected reduction in life expectancy on the assumption that "to some approximation, the ordering (in this table) should be society's order of priorities. However, we see several very major problems that have received very little attention . . . whereas some of the items near the bottom of the list, especially those involving radiation, receive a great deal of attention" (Cohen & Lee, 1979, p. 720).

Insert Table 9 about here

Properly speaking, comparing hazards is not a decision-making procedure. It does not require any particular conclusion to be drawn, say, from the contrast between the risks of motorcycling and advanced age (Fischhoff, Slovic, Lichtenstein, Derby & Keeney, 1980). Moreover, even as aids to intuition, cross-hazards comparisons have a number of inherent limitations. For example, although some people feel enlightened upon learning that a single takeoff or landing in a commercial airliner reduces one's life expectancy by an average of 15 minutes, others find themselves completely bewildered by such information. On landing, one will either die prematurely (almost certainly by more than 15 minutes) or one will not. For many people, averages do not adequately capture the essence of such risks. Indeed, McNeil, Weichselbaum and Pauker (1978) found that patients facing the prospect of surgery for lung cancer were as concerned with the possibility of imminent death during the operation as with its contribution to their life expectancy.

A further limitation is that summary statistics may mask important characteristics of risk. Where there is uncertainty or disagreement about the facts, presentation of point estimates may inspire undue confidence. Since people are particularly concerned about the potential for catastrophic accidents (Slovic, Fischhoff & Lichtenstein, 1980), some indication of the probability and magnitude of extreme losses is needed. Other characteristics that affect people's attitude toward hazards, but are neglected in statistical summaries, are voluntariness, controllability, familiarity, immediacy of consequences, threat to future generations, the ease of reducing the risk and the degree to which benefits are distributed equitably to those who bear the risk (Slovic, Fischhoff & Lichtenstein, 1980. Although some faults, such as the omission of uncertainty bands, are easy to correct, determining how to weight catastrophic potential, equity and other important characteristics, will require a serious research effort.

Conclusions

Informing people, whether by warning labels, package inserts, or extensive media programs, is but part of the larger problem of helping people cope with the risks and uncertainties of modern life. We believe that some of the responsibility lies with our schools. Public school curricula should include material designed to teach people that the world in which they live is probabilistic, not deterministic, and to help them learn judgment and decision strategies for dealing with that world (Marôm & Dekel, 1980). These strategies are as necessary for navigating in a world of uncertain information as geometry and trigonometry are to navigating among physical objects.

NUCLEAR POWER: A CASE STUDY OF RISK PERCEPTION

Nowhere are issues of perceived risk more salient or the stakes higher than in the controversy over nuclear power. This section examines the controversy in light of the findings discussed above.

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 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 many technical experts. We shall describe these images and speculate on their origins, permanence, and implications.

Basic Perceptions

Questionnaire studies of people opposed to nuclear power show that they judge its benefits as quite low and its risks as unacceptably great (Fischhoff, Slovic, Lichtenstein, Read & Combs, 1978). On the benefit side, these individuals do not see nuclear power as a vital link in meeting basic energy needs (Pokorny, 1977); rather many view it as a supplement to other sources of energy which are themselves adequate (or could be made adequate by conservation). On the risk side, nuclear power evokes greater feelings of dread than almost any other technological activity (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, a radiation technology which incurs similar risks, is not similarly dreaded. To the contrary, its risks are often underestimated (Slovic et al., 1979a). The association of nuclear power with nuclear weaponry may account for these different perceptions. As a result of its violent origins, nuclear power is regarded as a technology whose risks are uncontrollable, lethal, and potentially catastrophic, characteristics that are not associated with the use of diagnostic X rays.

When people opposed to nuclear power describe their mental images of a nuclear accident and its consequences, they reveal the expectation that a serious reactor accident is likely within their lifetime and could result in hundreds of thousands, even millions, of deaths (Slovic, Fischhoff & Lichtenstein, 1979a, b). Such an accident is also expected to cause irreparable environmental damage over a vast geographic area. These expectations contrast dramatically with the nuclear industry's 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 suspecting that the risks are much greater than the experts' assessments (Kasper, 1979; Starr & Whipple, 1980). 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 this perception gap has led some technical 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 conclusion is based on two key aspects of the problem, one technical and one psychological.

Technical Obstacles

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 accurate risk estimates cannot be based on empirical observation. Instead, such assessments must be derived from complex mathematical models and subjective judgments.

The difficulty of performing risk assessments has 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 (see Table 7). Another problem in assessing the reliability of reactor designs is the difficulty of taking proper account of "common-mode failures," in which ostensibly independent systems designed to back up one another fail due to the same unanticipated common cause . Nuclear critic, John Holdren'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).

Psychological Obstacles

Public fears of nuclear power should not be viewed as irrational. In part, they are fed by the realization that the facts are in dispute and that experts have been wrong inthe past, as when they irradiated enlarged tonsils or permitted people to witness A-bomb tests at close range. What one may question is the extent to which people's fundamental ways of thinking (such as reliance on the availability heuristic) lead them to distorted views. 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.

As mentioned earlier, the availability heuristic implies that any discussion of nuclear accidents may increase their imaginability and hence their perceived risk. 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 (see Figure 1). 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." In this way, reliance on memorability and imaginability may blur 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 "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).

Conclusion

Although the above discussion designated some possible sources of the perception gap between pro-nuclear and anti-nuclear individuals, it does not point unambiguously to one side or the other as having the most accurate appraisal of the overall risks from nuclear power. The effects of memorability and imaginability are capable both of enhancing public fears and obscuring experts' awareness of ways that a system could fail. Insofar as the actual risks may never be known with great precision and new information tends to be interpreted in a manner consistent with one's prior beliefs, the perception gap may be with us for a long time. Thus, for some people, Three Mile Island "proved" the possibility of a catastrophic meltdown, whereas for others, it confirmed their faith in the reliability of the multiple safety and containment systems.

WHO SHALL DECIDE?

The research described in this chapter demonstrates that judgment of risk is fallible. It also shows that the degree of fallibility is often surprisingly great and that faulty estimates may be held with great confidence. Since even well-informed lay people have difficulty judging risks accurately, it is tempting to conclude that the public should be removed from society's risk assessment and decision-making processes. Such action would seem to be misguided on several counts. First, close examination shows that people do perceive some things quite well, although their perspective may often be quite different from that of technical experts. In situations where misunderstanding is rampant, people's errors can often be traced to biased experiences, which education may be able to counter. In some cases, people's strong fears and resistance to experts' reassurances can be traced to their sensitivity to the potential for catastrophic accidents, to their awareness of expert disagreement about the probability and magnitude of such accidents, and to their knowledge of serious mistakes made by experts in the past. Even in difficult cases, such as the conflict over nuclear power, an atmosphere of trust and a recognition that both experts and lay persons have something to contribute, may permit some exchange of information and deepening of perspectives.

Moreover, in many if not most cases, effective hazard management 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 for hazard management would mean substituting short-term efficiency for the long-term effort needed to create an informed citizenry.

For non-experts, the findings discussed above pose an important series of challenges: to be better informed, to rely less on unexamined or unsupported judgments, to be aware of the factors that might bias risk judgments, and to be more open to new evidence; in short, to realize the potential of being educable.

For experts and policy makers, these findings pose what may be a more difficult challenge: to recognize and admit one's own cognitive limitations, to attempt to educate without propagandizing, to acknowledge the legitimacy of public concerns, and somehow to develop ways in which these concerns can find expression in societal decisions without, in the process, creating more heat than light.

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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, and abortion	Stomach cancer
Tornadoes	Lightning
Flood	Stroke
Botulism	Tuberculosis
All cancer	Asthma
Fire and flames	Emphysema
Venomous bite or sting	
Homicide	

Source: Slovic, Fischhoff & Lichtenstein (1979 a).

Table 2

Statistical Frequency and Newspaper Coverage
in the Eugene, Oregon Register Guard (R-G) and the
New Bedford, Massachusetts Standard Times (S-T)
for 41 Causes of Death

Cause of Death	Rate per 2.05×10^8 U.S. Res.	Subjects' Estimates	Reported Deaths		Occurrences		Articles	
			R-G	S-T	R-G	S-T	R-G	S-T
1. Smallpox	0	57	0	0	0	0	0	0
2. Poisoning by vitamins	1	102	0	0	0	0	0	0
3. Botulism	2	183	0	0	0	0	0	0
4. Measles	5	168	0	0	0	0	0	0
5. Fireworks	6	160	0	0	0	0	0	0
6. Smallpox Vaccination	8	23	0	0	0	0	0	0
7. Whooping cough	15	93	0	0	0	0	0	0
8. Polio	17	97	0	0	0	0	0	0
9. Venomous bit or sting	48	350	0	0	0	0	0	0
10. Tornado	90	564	36	25	10	6	14	7
11. Lightning	107	91	1	0	1	0	1	0
12. Non-venomous animal	129	174	4	2	4	2	4	2
13. Flood	205	736	4	10	2	2	2	2
14. Excess cold	334	314	0	0	0	0	0	0
15. Syphilis	410	492	0	0	0	0	0	0
16. Pregnancy, birth & abort.	451	1,344	0	0	0	0	0	0
17. Infectious hepatitis	677	545	0	0	0	0	0	0
18. Appendicitis	902	605	0	0	0	0	0	0
19. Electrocution	1,025	766	5	0	5	0	6	0
20. MV/train collision	1,517	689	0	1	0	1	0	1
21. Asthma	1,886	506	1	0	1	0	1	0
22. Firearm accident	2,255	1,345	8	1	8	1	9	1
23. Poison by solid/liquid	2,563	1,013	3	3	1	1	1	1
24. Tuberculosis	3,690	658	0	0	0	0	0	0
25. Fire and flames	7,380	3,336	94	46	33	9	38	10
26. Drowning	7,380	1,684	47	60	44	24	45	37
27. Leukemia	14,555	2,496	1	0	1	0	1	0
28. Accidental falls	17,425	2,675	15	7	15	6	16	9
29. Homicide	18,860	5,582	278	208	167	122	329	199
30. Emphysema	21,730	2,848	1	0	1	0	1	0
31. Suicide	24,600	4,679	29	19	28	18	36	20
32. Breast cancer	31,160	2,964	0	0	0	0	0	0
33. Diabetes	38,950	1,476	0	1	0	1	0	1
34. Motor vehicle accident	55,350	41,161	298	83	245	69	180	73
35. Lung cancer	75,850	9,764	3	2	3	2	4	2
36. Stomach cancer	95,120	3,283	0	1	0	1	0	1
37. All accidents	112,750	88,879	715	596	421	152	374	177
38. Stroke	209,100	7,109	12	4	12	4	13	4
39. All cancer	328,000	45,609	25	12	25	12	26	15
40. Heart disease	738,000	23,599	49	30	45	25	46	25
41. All disease	1,740,450	88,838	111	87	100	76	104	78
Total # of reports (causes 10, 11, 13, 29, 31, 37 & 41)			1,174	945	729	376	860	483
Correlations (R-G vs. S-T)			r = .97		r = .94		r = .98	

Source: Combs & Slovic (1979).

Table 3

Attribution of Starting Failures for Pruned and Unpruned Trees

		Mean proportion of starting failures attributed to:						
Group	n	Battery	Starting System	Fuel System	Ignition System	Engine	Mis-Chief	Other
Unpruned tree	93	.264	.195	.193	.144	.076	.051	.078
Pruned tree 1	29	.432	----	.309	----	.116	----	.140[a]
Pruned tree 2	26	----	.357	----	.343	----	.073	.227[b]

Note: A dash indicates that the branch was deleted.

[a] Should be .468

[b] Should be .611

Source: Fischhoff, Slovic and Lichtenstein (1978).

Table 4

Percentage of Correct Answers for Major Odds Categories

		Lethal events						General-knowledge questions		
		Experiment 1[b]			Experiment 2[b]			Experiment 3[b]		
Odds	Appropriate % correct[a]	*N*	% *N*	% correct	*N*	% *N*	% correct	*N*	% *N*	% correct
1:1	50	644	9	53	339	8	54	861	19	53
1.5:1	60	68	1	57	108	2.5	59	210	5	56
2:1	67	575	8	64	434	10	65	455	1	63
3:1	75	189	2	71	252	6	65	157	3.5	76
5:1	83	250	4	70	322	8	71	194	4	76
10:1	91	1,167	17	66	390	9	76	376	8	74
20:1	95	126	2	72	163	4	81	66	1.5	85
50:1	98	258	4	68	227	5	74	69	1.5	83
100:1	99	1,180	17	73	319	8	87	376	8	80
1,000:1	99.9	862	13	81	219	5	84	334	7	88
10,000:1	100	459	7	87	138	3	92	263	6	89
100,000:1	100	163	2	85	23	.5	96	134	3	92
1,000,000:1	100	157	2	90	47	1	96	360	8	94
Total		6,098	88		2,981	70		3,855	75	
Overall % correct				71.0			72.5			73.1

Note: % N refers to the percentage of odds judgments that fell in each of the major categories. There were 66 subjects in Experiment 1, 40 in Experiment 2, and 42 in Experiment 3.

[a] For well-calibrated subjects

[b] Experiments 1, 2 and 3 were labeled Experiments 2, 3 and 4 in the original report.

Source: Fischhoff, Slovic and Lichtenstein (1977).

Table 5

Instructions for "Trivia Question Hustling"

The experiment is over. You have just earned $2.50, which you will be able to collect soon. But before you take the money and leave, I'd like you to consider whether you would be willing to play a certain game in order to possibly increase your earnings. The rules of the game are as follows:

1. Look at your answer sheet. Find the questions where you estimated the odds of your being correct as 50:1 or greater than 50:1. How many such questions were there? _______ (write number).

2. I'll give you the correct answers to these "50:1 or greater" questions. We'll count how many times your answers to these questions were wrong. Since a wrong answer in the face of such high certainty would be surprising, we'll call these wrong answers "your surprises."

3. I have a bag of poker chips in front of me. There are 100 white chips and 2 red chips in the bag. If I reach in and randomly select a chip, the odds that I will select a white chip are 100:2 or 50:1, just like the odds that your "50:1" answers are correct.

4. For every "50:1 or greater" answer you gave, I'll draw a chip out of the bag. (If you wish, you can draw the chips for me.) I'll put the chip back in the bag before I draw again, so the odds won't change. The probability of my drawing a red chip is 1/51. Since drawing a red chip is unlikely, every red chip I draw can be considered "my surprise."

5. Every time you are surprised by a wrong answer to a "50:1 or greater" question, you pay me $1 (raised to $2.50 in some conditions). Every time I am surprised by drawing a red chip, I'll pay you $1.

6. If you are well calibrated, this game is advantageous to you. This is because I expect to lose $1 about once out of every 51 times I draw a chip, on the average. But since your odds are sometimes higher than 50:1, you expect to lose less often than that.

7. Would you play this game?

Source: Fischhoff, Slovic & Lichtenstein (1977).

Table 6

Experts' Insensitivity to Omissions from the Car-Won't-Start Fault Tree

Group	n	Mean proportion of starting failures attributed to						
		Battery	Starting System	Fuel System	Ignition System	Engine	Mischief	Other
Unpruned tree ordinary subjects	93	.264	.195	.193	.144	.076	.051	.078
Unpruned tree experts	13	.410	.108	.096	.248	.051	.025	.060
Pruned tree 1 experts	16	.483	----	.229	----	.073	----	.215[a]

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[a] Should be .441

Source: Fischhoff, Slovic and Lichtenstein (1978).

Table 7

Pathways to Overconfidence in Experts' Risk Assessments

- Failure to consider the ways in which human errors can affect technological systems. Example: Due to inadequate training and control room design, operators at Three Mile Island repeatedly misdiagnosed the problems of the reactor and took inappropriate actions (Sheridan, 1980; U.S. Government, 1979).

- Overconfidence in current scientific knowledge. Example: Use of DDT came into widespread and uncontrolled use before scientists had even considered the possibility of the side effects that today make it look like a mixed and irreversible blessing (Dunlap, 1978).

- Failure to appreciate how technological systems function as a whole. Example: The DC-10 failed in several early flights because its designers had not realized that decompression of the cargo compartment would destroy vital control systems (Hohenemser, 1975).

- Slowness in detecting chronic, cumulative 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 afforded by dams and levees gives people a false sense of security and promotes development of the flood plain. Thus, although floods are rarer, damage per flood is so much greater that the average yearly dollar loss is larger than before the dams were built (Burton, Kates & White, 1978).

- Failure to anticipate "common-mode failures" which simultaneously afflict systems that are designed to be independent. Example: Because electrical cables controlling the multiple safety systems of the reactor at Browns Ferry, Alabama, were not spatially separated, all five emergency core cooling systems were damaged by a single fire (U.S. Government, 1975; Jennergren & Keeney, in press).

Table 8

Lethality Judgments with Different Response Modes

Geometric Means

	Death Rate per 100,000 Afflicted				
Malady	Estimate Lethality Rate	Estimate Number Died	Estimate Survival Rate	Estimate Number Survived	Actual Lethality Rate
Influenza	393	6	26	511	1
Mumps	44	114	19	4	12
Asthma	155	12	14	599	33
Venereal Disease	91	63	8	111	50
High Blood Pressure	535	89	17	538	76
Bronchitis	162	19	43	2,111	85
Pregnancy	67	24	13	787	250
Diabetes	487	101	52	5,666	800
Tuberculosis	852	1,783	188	8,520	1,535
Automobile Accidents	6,195	3,272	31	6,813	2,500
Strokes	11,011	4,648	181	24,758	11,765
Heart Attacks	13,011	3,666	131	27,477	16,250
Cancer	10,889	10,475	160	21,749	37,500

Note: The four experimental groups were given the following instructions:
(a) Estimate lethality rate: for each 100,000 people afflicted, how many die?
(b) Estimate number died: X people were afflicted, how many died?
(c) Estimate survival rate: for each person who died, how many were afflicted but survived?
(d) Estimate number survived: Y people died, how many were afflicted but did not die?
Responses to questions (b), (c), and (d) were converted to deaths per 100,000 to facilitate comparisons. Source: Fischhoff & MacGregor, 1980.

Table 9

Risks Which Increase Chance of Death in Any Year by 0.000001*

Smoking 1.4 cigarettes	Cancer, heart disease
Drinking 1/2 liter of wine	Cirrhosis of the liver
Spending 1 hour in a coal mine	Black lung disease
Spending 3 hours in a coal mine	Accident
Living 2 days in New York or Boston	Air pollution
Travelling 6 minutes by canoe	Accident
Travelling 10 miles by bicycle	Accident
Travelling 300 miles by car	Accident
Flying 1000 miles by jet	Accident
Flying 6000 miles by jet	Cancer caused by cosmic radiation
Living 2 months in Denver on vacation from N.Y.	Cancer caused by cosmic radiation
Living 2 months in average stone or brick building	Cancer caused by natural radioactivity
One chest x-ray taken in a good hospital	Cancer caused by radiation
Living 2 months with a cigarette smoker	Cancer, heart disease
Eating 40 tablespoons of peanut butter	Liver cancer caused by aflatoxin B
Drinking Miami drinking water for 1 year	Cancer caused by chloroform
Drinking 30 12 oz. cans of diet soda	Cancer caused by saccharin
Living 5 years at site boundary of a typical nuclear power plant in the open	Cancer caused by radiation
Drinking 1000 24 oz. soft drinks from recently banned plastic bottles	Cancer from acrylonitrile monomer
Living 20 years near PVC plant	Cancer caused by vinyl chloride (1976 standard)
Living 150 years within 20 miles of a nuclear power plant	Cancer caused by radiation
Eating 100 charcoal broiled steaks	Cancer from benzopyrene
Risk of accident by living within 5 miles of a nuclear reactor for 50 years	Cancer caused by radiation

*(1 part in 1 million)

from Wilson, 1979.

Figure Captions

1. A fault tree indicating the various ways in which radioactive material might accidentally be released from nuclear wastes buried within a salt deposit. To read this tree, start with the bottom row of possible initiating events, each of which can lead to the transportation of radioactivity by groundwater. This transport can in turn release radioactivity to the biosphere. As indicated by the second level of boxes, release of radioactivity can also be produced directly (without the help of groundwater) through the impact of a large meteorite, a nuclear weapon, or a volcanic eruption. Source: McGrath (1974).

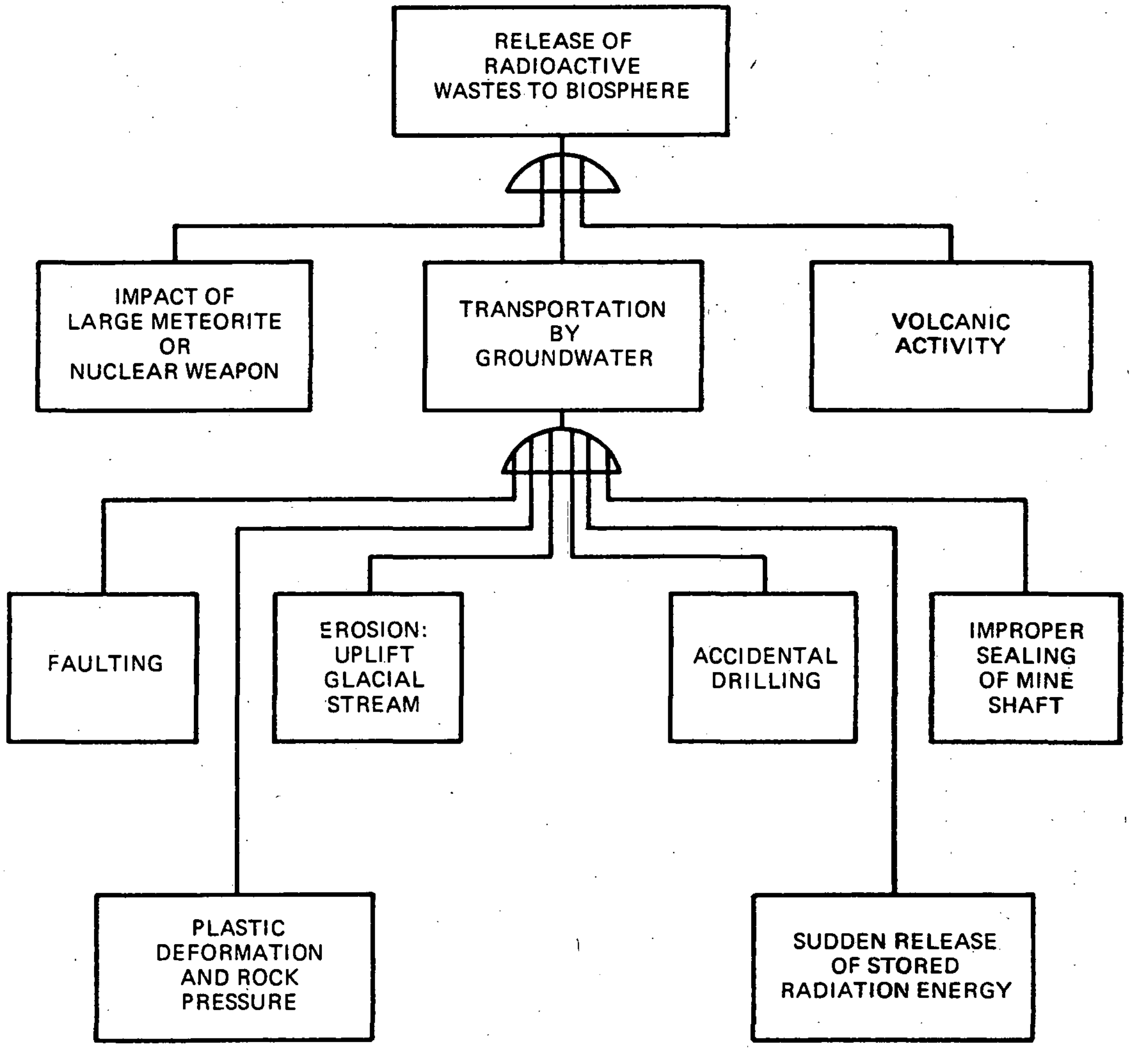
2. Relationship between judged frequency and the actual number of deaths per year for 41 causes of death. If judged and actual frequencies were equal, the data would fall on the straight line. The points, and the curved line fitted to them, represent the averaged responses of a large number of lay people. As an index of the variability across individuals, vertical bars are drawn to depict the 25th and 75th percentiles of the judgments for botulism, diabetes and all accidents. The range of responses for the other 37 causes of death was similar. Source: Slovic, Fischhoff & Lichtenstein (1979a).

3. Fault tree indicating the ways in which a car might fail to start. It was used by the authors to study whether people are sensitive to the completeness of this type of presentation. Omission of large sections of the diagram was found to have little influence on the judged degree of completeness. In effect, what was out of sight was out of mind. Professional automobile mechanics did not do appreciably better on the test than did lay people. Source: Fischhoff, Slovic & Lichtenstein (1978).

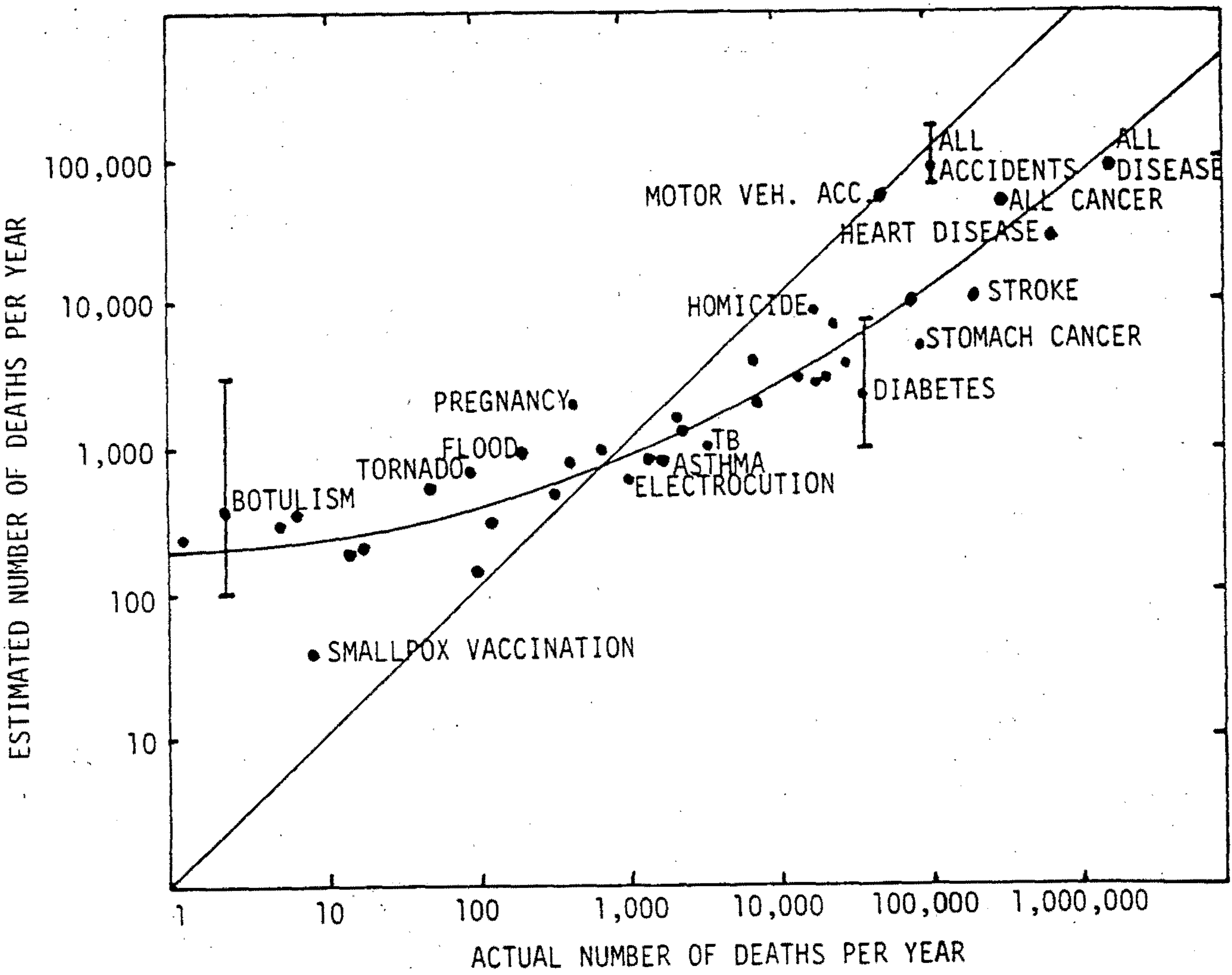
4. Two examples of overconfidence in expert judgment. Overconfidence is represented by the faulure of error bars to contain the true value: (a) estimates of the rest mass of the electron (Taylor, 1974); (b) estimates of the height at which an embankment would fail (Hynes & Vanmarcke, 1976). Our thanks to Max Henrion for Figure a.

5. Drawing by S. Harris; ©1979. The New Yorker Magazine, Inc.

FIGURE 1
FAULT TREE OF SALT MINE USED FOR STORAGE OF RADIOACTIVE WASTES



Note.—Source: McGrath (1974).



Source: Slovic, Fischhoff & Lichtenstein (1979a)

Figure 2

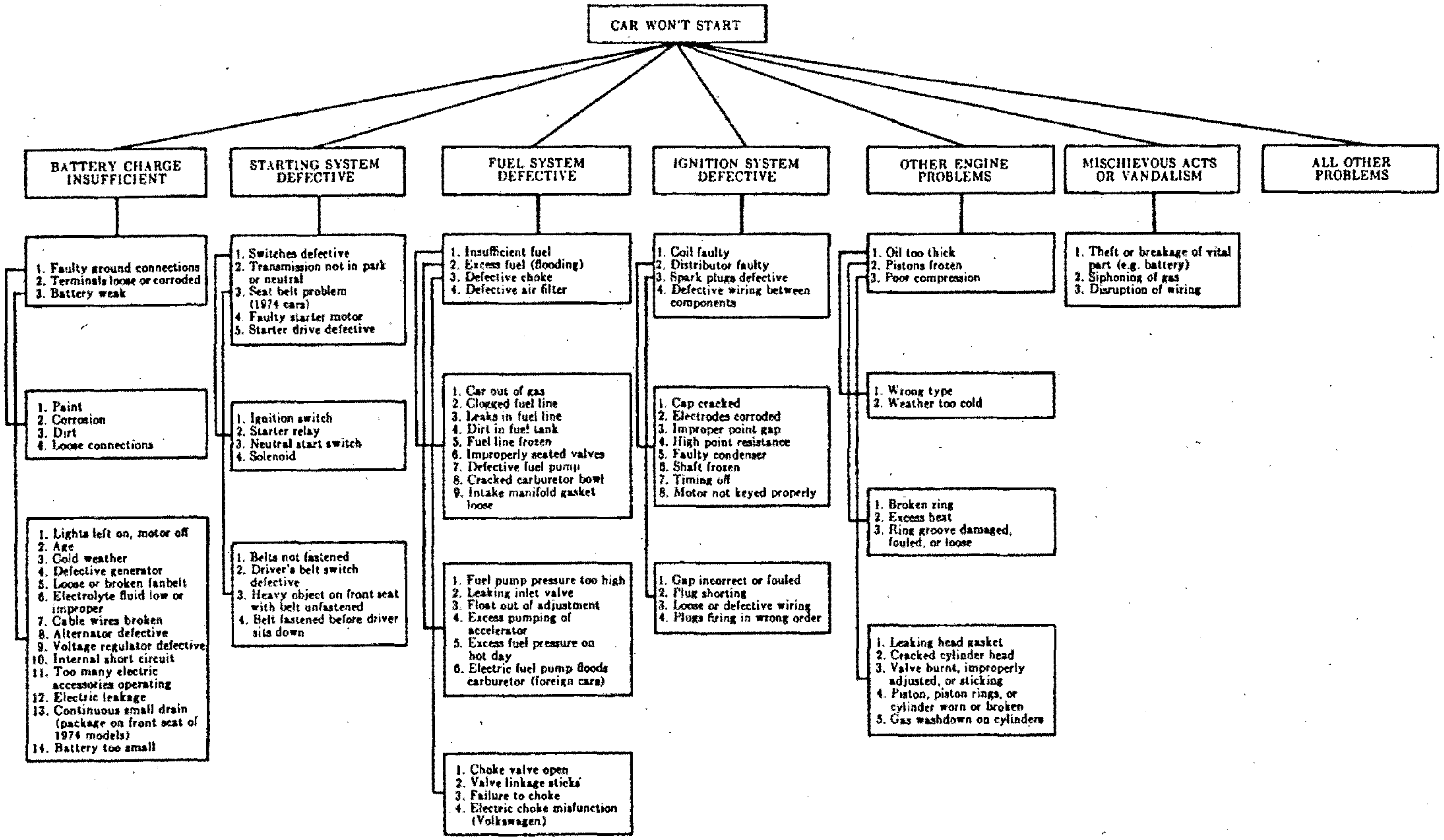


Figure 3

Source: Fischhoff, Slovic & Lichtenstein (1978)

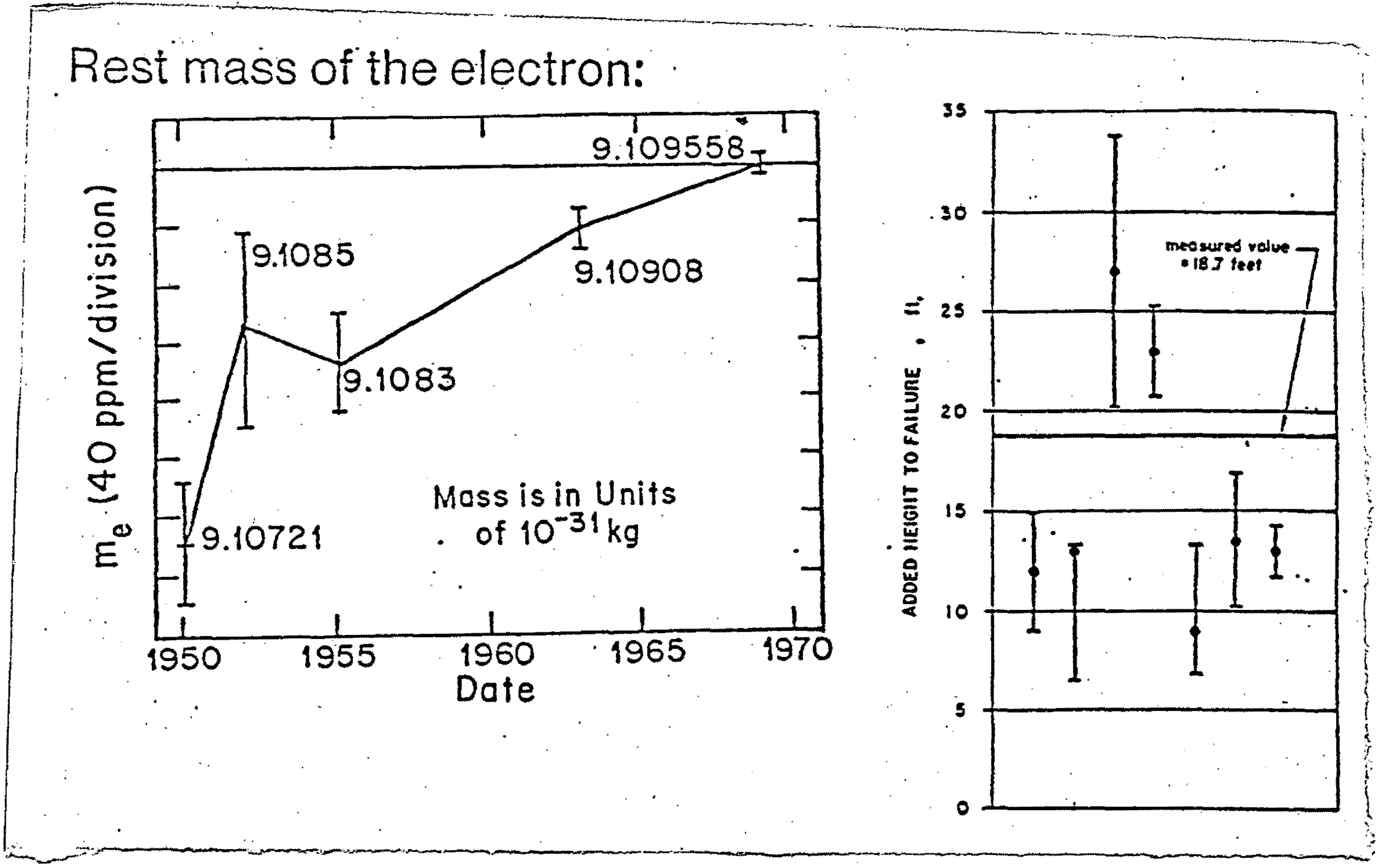


Figure 4. Two examples of overconfidence in expert judgment. Overconfidence is represented by the failure of error bars to contain the true value: (a) estimates of the rest mass of the electron (Taylor, 1974); (b) estimates of the height at which an embankment would fail (Hynes & Vanmarcke, 1976). Our thanks to Max Henrion for Figure a.

Figure 5

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