

CHAPTER 4

Trends and Attitudes in Assessing Environmental Threat

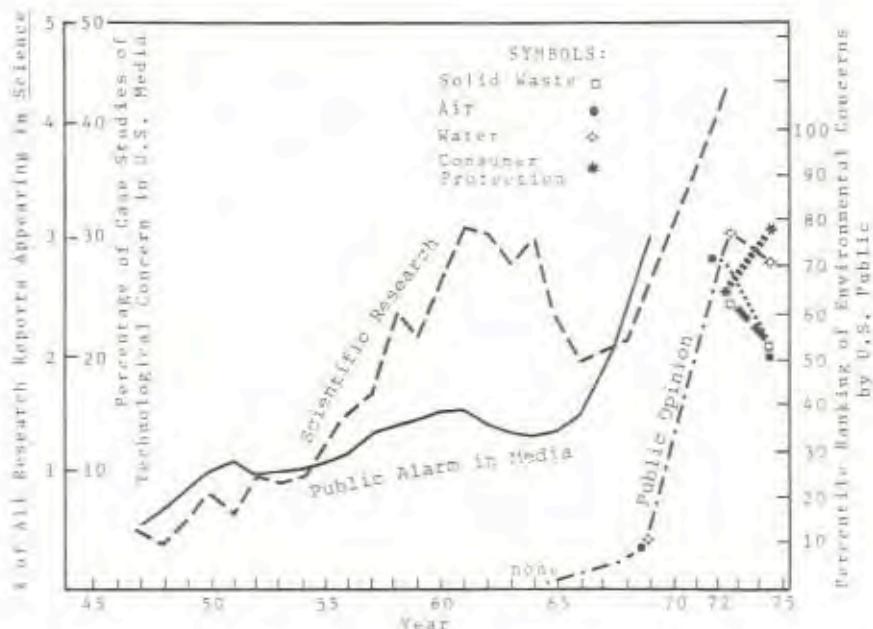
Over the last three decades, since the end of World War II, the environment has become demonstrably more hazardous according to scientific journals, daily newspapers, or typical citizens. But this sense of increasing threat is diminished if causes of death are examined or statistical abstracts consulted. Therein lies a seeming paradox, the resolution of which is the essence of risk assessment.

4.1 TRENDS IN SCIENTIFIC RESEARCH, MEDIA AND PUBLIC OPINION

The perception of many environmental hazards, and for almost all of the newly created or discovered ones, comes first in the laboratory, library or field station. Scientists, researchers or guardians of health or ecosystem are major actors in risk assessment. Seen through the scientific literature, there has been a major escalation in the scope and intensity of their research efforts related to environmental hazard.

Nature and *Science*, both distinguished journals catering to a broad spectrum of the scientific community, are somewhat unique in the world of scientific publication. Thus they were chosen for an analysis of trends in scientific research over a twenty-seven year period, 1945 to 1972 (Halverson and Pijawka, 1974). Using the 'Research Reports' of *Science* and the 'Letters' of *Nature* as comparable and voluntarily submitted sets of significant research findings, a content analysis was made. To the degree that these journals are representative, some 2.0 percent of reported research was related to environmental hazard, almost entirely of technological origin (excluding disease unless environmentally implicated). Over time, there has been an exponential increase in the proportion of research reports related to environmental hazard. Research dealing with man-made environmental hazard doubled in the first fifteen years studied and doubled again in the last decade until 1971, when 6.7 percent of the 'Letters' in *Nature* and 4.0 percent of the 'Research Reports' in *Science* were concerned with findings related to environmental threat. Reported effort in *Science* has continued high since then. (See Figure 4.1).

The role the media play in risk assessment is much different from that of the scientist, being much more one of disseminating rather than originating such assessments. Lundqvist (1974) finds that in his case studies of scientific information and public response to mercury pollution in Sweden, the press role was more than just reactive, and in a sense 'agenda-setting.' By the extensive space given to scientific pronouncements and the accurate but simplified and uncritical citation of such evidence, the press helped to form public assessment of mercury risk that led to a major and somewhat unnecessary boycott of fish.



Scientific Research is based on analysis of research reports appearing in the interdisciplinary journal *Science* (Halverson and Pijawka, 1974). Public Alarm over Technology is based on a 5-year running average of 45 case studies of alarm as evidenced by major newspapers and periodicals (Lawless, 1974). Public Opinion is based on rankings of between 20-30 worries and concerns from repeated nation-wide U.S. opinion polls. In 1964 no environmental concerns were deemed important enough to list.

Figure 4.1 Trends in scientific research, media, and public opinion

As with scientific research, press coverage of environmental hazard has increased exponentially. A study of newspaper content dealing with air pollution in three countries shows increases of four to six times in coverage in New York, Toronto and London over the last decade (but a slight decrease in London from the great smog episode of 1955). The actual number of articles fluctuates with air pollution crises and is modified by long-term trends in concern with environmental threat and the short-term competition for public attention (Burton, Kates and White, forthcoming).

Similarly, a study of media alarm over technology (Lawless, 1974) has carefully detailed 45 cases of such concern in the United States over the past 28 years. Sixty percent of the cases of public concern, as evidenced by major newspapers and periodicals, originated in the last five years of the study period (1968-1973). (See Figure 4.1)

Public opinion, as distinguished from opinions aired in public and represented by the citizen or 'man in the street' survey, lags behind scientific research and media concern but shows the same explosive increase in recognition of environmental threat.

Surveys taken in 1964 by the Institute for International Social Research (and continued since then) did not find any environmental concerns among the top worries of the American people. In 1968, air and water pollution was ranked 19 among 21 causes of concern (Free, Personal Communication). By 1972 water and air pollution was ranked (6) and (7), consumer protection (9) and solid waste disposal (10) out of 27 possible major national issues of concern. In 1974, these shifted somewhat with consumer protection (7), water pollution (8), air pollution (13), and solid wastes (14) out of 30 possible concerns. (Watts and Free, 1973, 1974).

In all these trends, there are fluctuations from peaks of crises or from competition with compelling worries of economy and violence that shift public interest. Nevertheless, high levels of concern by factors of three to six times greater than two decades ago should persist. But what of the statistical trends?

4.2 TRENDS IN STATISTICAL INDICATORS

Scientists in their research efforts, journalists in their reporting, citizens in their opinions, have shown an increasing perception of environmental hazard over the past several decades. Such perception would appear to be in anticipation of rather than in response to a marked deterioration of the security of life.

For most people everywhere, on balance, the everyday is more secure. The life expectancy of people rises, rapidly in poor nations through increased survival of the young, slowly in rich nations pressing on a ceiling of medical, life and environmental understanding. In the industrialized nations, people live longer today than fifty years ago, die less of infectious disease and more of stress, diet and malignancy. Cars kill more frequently than in the past, but other accidents less; the balance is favourable. Least of all are deaths from natural hazards, although they are more costly in terms of lost wealth. In this, the industrialized countries are fortunate. Overall, deaths have climbed from natural hazards (see Figure 4.2).

In places of rapid social change, the social environment may be less secure but not necessarily less satisfying. Well-to-do societies appear somewhat more perilous in recent times; crime rates, while dropping, are higher than accustomed, business failures and unemployment are up, while inflation is frightening. Global peace is obtained at the price of great peril, and the price of more localized warfare continues to be high (Griesman and Finsterbusch, 1974). The newly discovered hazards of the manmade environment, while they offer much recent concern, are too new to assess or measure their consequences: mankind has yet to experience their peril sufficient for the statistical yearbook.

4.3 RISK ASSESSMENT: ATTITUDES

There is, then, a seeming paradox between the perception of both scientists and lay people as to increased environmental threat and much, but not all, of the statistical data. The paradox is not easily resolvable. Indeed, its very existence serves to reinforce three overriding assumptions or attitudes that in their archetypal expression border on ideology.

Each of these attitudes assumes a fundamental imbalance between true hazard potential and the prevailing risk assessment; each in turn views prevailing assessment

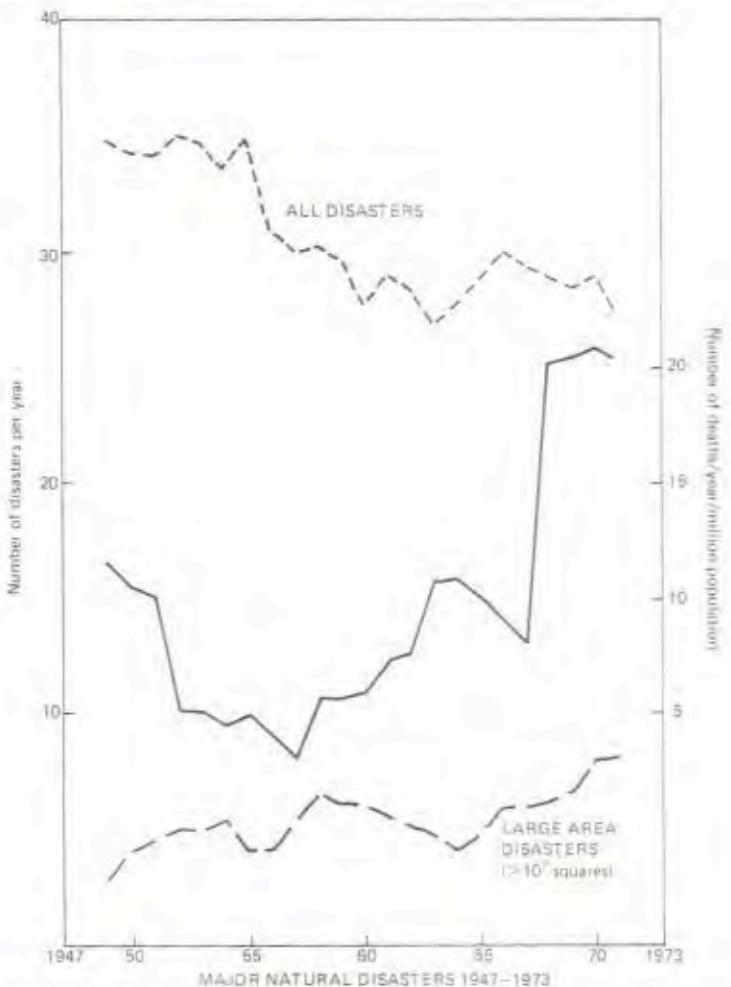


Figure 4.2 A five-year moving average of major internationally reported disasters (excluding drought). For this period, the average of all reported natural disasters appears to decline and then remain constant. However, both death rates and large area disasters are increasing, suggesting an increase in the catastrophic potential of major disasters (Dworkin, 1974).

as either less than, greater than, or inappropriate to the true hazard potential. And each draws upon and is reinforced by the paradox between societal perception and statistical trend.

4.3.1 The Hazard is Greater than the Risks Assessed

If the everyday appears more secure, the appearance may be illusory. Particularly in developed countries, the statistics of well-being conceal certain long-range

and threatening trends posed by the rapid and recent increase in technological threat (Commoner, 1971). Ford describes the consequences as:

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

An extension of this view holds that even if the everyday is more secure, the exceptional is less so. Medical advances, improvements in safety, engineering devices to protect against natural hazard, while they prove effective in eliminating much of the day-to-day environmental threats of life, nonetheless serve to increase the magnitude and frequency of the catastrophic.

A global study of natural disaster (Dworkin, 1974, Figure 4.2) shows that death rates have risen dramatically over the past 25 years, despite the relative constancy of 30 global disasters per year over the past 25 years. Using a different definition of catastrophe (accidents with five or more deaths), statisticians at the Metropolitan Life Insurance Company in the United States have measured the annual number of such events for many years (*Statistical Indicators*, 1967-). The recent trend is downward, paralleling increased safety of transport and buildings. But despite the trend, the number of larger catastrophes (deaths of 25 and over) is staying high or is on the increase.

Some years ago, Rapoport speculated on the cultural nature of accidents and wondered, if society succeeds in making certain accidents culturally unacceptable, will all others increase slightly to maintain the same overall risk? (Rapoport, 1961.) A corollary speculation may be that even if the short-term hazard can be measurably reduced for an entire class of events, such reduction may be partly illusionary. Society may have only postponed the average loss to some future catastrophic encounter. Carried to the extreme, the speculation posits a law for the conservation of variance: To the extent that technology succeeds in reducing the variation in nature, making life more secure, such variation is not eliminated but rather shifted forward in time or space, leading to fewer but more catastrophic events.

4.3.2 The Hazard is Less than the Risks Assessed

Such a view holds that the everyday and the exceptional are indeed more secure and are so because of scientific and technical advance, administrative oversight, and the long-term increase in societal ability to cope with threat. If the environment

TABLE 4.1 Case Studies of Public Alarm over Technology

Case	Scale ¹	Magnitude	
		No. of People Threatened ²	Age of Technology in Years
1. Human Artificial Insemination	S	<10 ⁴	>100
2. Oral Contraceptive Safety Hearings	M	>10 ⁶	15
3. Southern Corn Leaf Blight	L	10 ⁴ -10 ⁶	15
4. The Great Cranberry Scare	M	10 ⁴ -10 ⁶	10
5. The Diethylstilbestrol Ban	L	>10 ⁶	20
6. The Cyclamate Affair	M	>10 ⁶	30
7. MSG and the Chinese Restaurant Syndrome	S	10 ⁴ -10 ⁶	60
8. Botulism and Bon Vivant	M	>10 ⁶	>100
9. The Fish Protein Concentrate Issue	S	<10 ⁴	10
10. The Fluoridation Controversy	M	<10 ⁴	5
11. Salk Polio Vaccine Hazard Episode	L	>10 ⁶	2
12. The Thalidomide Tragedy	M	<10 ⁴	12
13. Hexa, Hexa, Hexachlorophene	M	10 ⁴ -10 ⁶	30
14. Krebiozen - Cancer Cure?	S	—	8
15. DMSO - Suppressed Wonder Drug?	S	—	5
16. X-Ray Shoe Fitting Machine	M	>10 ⁶	20
17. Abuse of Medical and Dental X-Rays	L	>10 ⁶	35
18. X-Radiation from Color TV	M	>10 ⁶	15
19. Introduction of the Lampreys	S	<10 ⁴	>100
20. The Donora Air Pollution Episode	M	<10 ⁴	30
21. The Torrey Canyon Disaster	S	—	20
22. The Santa Barbara Oil Leak	M	<10 ⁴	70
23. Mercury Discharges by Industry	M	10 ⁴ -10 ⁶	70
24. The Mercury-In-Tuna Scare	M	10 ⁴ -10 ⁶	>100
25. The Rise and Fall of DDT	L	10 ⁴ -10 ⁶	25
26. Asbestos Health Threat	M	>10 ⁶	100
27. Taconite Pollution of Lake Superior	S	10 ⁴ -10 ⁶	12
28. Foaming Detergents	M	10 ⁴ -10 ⁶	10
29. Enzyme Detergents	S	10 ⁴ -10 ⁶	3
30. Nitrilotriacetic Acid (NTA) in Detergents	S	<10 ⁴	1
31. Saltville - An Ecological Bankruptcy?	S	10 ⁴ -10 ⁶	75
32. Truman Reservoir Controversy	S	<10 ⁴	15
33. Plutonium Plant Safety at Rock Flats	S	<10 ⁴	20
34. Storage of Radioactive Wastes in Kansas	S	<10 ⁴	15
35. Amchitka Underground Nuclear Test	M	<10 ⁴	20
36. The Dugway Sheep Kill Incident	S	<10 ⁴	25
37. The Nerve Gas Disposal Controversy	M	10 ⁴ -10 ⁶	20
38. Project West Ford	S	—	2
39. Project Sanguine	M	<10 ⁴	10
40. Project Able	S	—	1
41. The Chemical Mace	M	10 ⁴ -10 ⁶	50
42. The Bronze Horse	S	—	—
43. Synthetic Turf and Football Injuries	M	10 ⁴ -10 ⁶	15
44. Disqualification of Dancer's Image	S	<10 ⁴	15
45. The AD-X2 Battery Additive Debate	S	<10 ⁴	20

¹ S = small; M = medium; L = large.² Directly threatened.

After Lawless, 1974.

Information				Societal Action				
Sufficient and/or In Time	Credibil- ity Un- disputed	Critical to Decision	Public Information Dramatized	Problem Allowed to Grow	Threat Overem- phasized	Threat Underem- phasized	Government Action Taken	
Yes	Yes	No	No	No	--	Yes	Yes	
No	No	Yes	Yes	Yes	Yes	Yes	Yes	
No	No	Yes	No	Yes	No	Yes	?	
No	No	Yes	Yes	Yes	Yes	--	Yes	
No	No	Yes	Yes	Yes	Yes	Yes	Yes	
Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	
No	No	Yes	Yes	No	--	Yes	Yes	
Yes	Yes	Yes	No	No	--	No	Yes	
Yes	Yes	No	No	No	--	No	Yes	
No	No	No	No	No	Yes	Yes	Yes	
No	Yes	Yes	Yes	No	No	--	Yes	
No	Yes	Yes	Yes	No	No	No	Yes	
No	No	Yes	Yes	Yes	No	Yes	Yes	
No	No	No	Yes	No	No	Yes	Yes	
No	No	Yes	Yes	No	Yes	No	Yes	
No	No	Yes	No	Yes	No	Yes	Yes	
No	No	Yes	Yes	Yes	Yes?	Yes	Yes	
No	No	Yes	Yes	No	Yes?	Yes	Yes	
No	Yes	Yes	No	No	--	--	Yes	
No	No	No	No	Yes	No	Yes	Yes	
No	No	No	No	No	No	No	Yes	
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No	Yes	Yes	Yes	Yes	No	Yes	Yes	
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Yes	Yes	Yes	No	Yes	No	No?	Yes	
No	No	Yes	Yes	No	Yes	Yes	Yes	
No	No	Yes	Yes	Yes	No?	Yes	No	
No	No	Yes	Yes	No	No?	Yes	No	
Yes	No	Yes	Yes	No	Yes	No?	No	
Yes	No	Yes	No	Yes	No	Yes	Yes	
Yes	Yes	Yes	No	Yes	Yes	Yes?	Yes	
No	No	No	No	Yes	No?	Yes?	No	
No	No	Yes	No	No	No?	Yes	No	
Yes	No	Yes	Yes	No	No	Yes?	No	
Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	
No	No	No	Yes	No	--	No	No	
No	No	No	No	Yes	No	Yes	No	
No	No	Yes	No	No	Yes?	--	Yes	
No	No	No	No	No	No	Yes	No	

appears less secure to many, it is because of changes in social expectations, dramatic increase in communication, and recurrent waves of public fad or mood.

Expectations of security and the values underlying these expectations have changed, becoming more demanding over time. Movements for improved health care, environmental and consumer protection, and occupational safety are all manifestations of this tendency. For the scientists concerned with cases of *spina bifida* or the mother worried about toys that can injure or maim, it provides little consolation to point to the conquest of infectious disease. And in the developing world, studies have shown that there are few expectations that rise faster than an expectation of assistance from central governments in time of disaster. While well intended, such anticipation of higher orders of humane care and secure existence bias risk assessments toward the excessive.

Such bias is exacerbated by public processes that focus on the novel and dramatic. In this view, scientists appear to compete in the discovery of new threats, no matter how remote, and to use mass media to communicate to the public rather than to colleagues or authorities in ways that inevitably distort their findings.

Lundqvist's study of the mercury controversy in Sweden found such distortion inevitable — even with high scientific and journalistic accuracy — simply as a result of the nature of the media, the role of headlines and the like. Such distortion led to a public overreaction — a boycott of all fish regardless of origin — and paradoxically rendered harm to the blameless fisherman who had long sought to curb pollution (Lundqvist, 1974).

Lawless's careful review of major case histories of public media concern over technology in the U.S. concludes:

On the whole, the news media have not done a particularly creditable job of reporting scientific and technological events to the public over the last 30 years. They tend to overdo the bizarre or the scare aspects at the beginning of a case and seldom follow through to summarize adequately the resolution of an issue. They tend to over-focus on the catchy phrase (e.g., at congressional hearings) and the spectacular event (e.g., the moon voyages) while neglecting the general trends that may be changing our lives. Some needed fundamental changes appear to be occurring slowly in the media's attitudes on reporting scientific and technological news. The printed media's coverage appears to be far more extensive and possibly more responsible today than it was 30 years ago. The roles of the media and the public opinion polls in assessing our technology are almost sure to grow. (Lawless, 1974, p. 453).

Finally, the dramatic increase in scale of communication media leads to exaggerated assessment. Improved reporting of many events previously unreported creates an illusion of their increase, and simultaneous reports from many parts of the world create the illusion of global threat for what may be highly localized problems.

Added to these trends of rising expectation and overdramatic communication are the many and different explanations that attribute perceived environmental threat or concern to long-term secular or cyclical changes in popular or elite attitudes. Recurrent waves of pessimism are thought to alternate with periods of optimism, especially among intellectuals and elites. The populace, and especially

youth, is seen as suspicious of authority, hostile to science, and attracted by irrationality. The public is viewed as ill-informed, depersonalized and frustrated by the bigness, complexity and remoteness of phenomena that have an impact on its life.

4.3.3 The Hazard is Different from the Risk Assessed

The everyday and the exceptional are both more and less secure. The alarmed scientists, journalists and publics sense that the visible risks assessed may be but the tip of the iceberg; the sceptical statistician, technologist or social commentator knows that many perceived threats will on hindsight appear exaggerated. In this view, the societal ability to assess risk is seen as limited, expandable but not infinite, in danger of being squandered on the unimportant and failing to identify the truly perilous.

Stated as the 'worry bead' hypothesis, individuals and societies have a small, relatively fixed stock of worry beads to dispense on the myriad threats of the world. They are not irrational but are constrained in their rationality either by human limitations of cognition and judgement; by cultural, ideological or personal aversions toward certain risks and the discounting of others; by ignorance, misunderstanding or limited experience; or by the sheer number and complexity of threats to cope with. The societal capacity to worry intelligently exceeds that of individuals; it is possible to divide the labour and the anxiety. But even this expanded capacity, in this view, is less than the threats perceived, and to both individuals and societies, where and when to rub one's worry beads is baffling and difficult to rationalize even if desired.

Each year, perhaps 10^4 to 10^5 new chemical compounds are formulated; their contents are hardly recorded, much less tested for toxicity. To determine low threshold dosages for many toxic substances would transcend scientific capacity. As Alvin Weinberg notes, all global person-power could be engaged in the care and feeding of laboratory rats (Weinberg, 1972).

The review of Lawless of 45 major public alarms over technology found that in over 25 percent of the 45 study cases, the threat was not as great as originally described by opponents of the technology, but in over half of the cases, the threat was probably greater than admitted by the proponents. Still the problem was allowed to grow. Early warning signs were available but mostly ignored in 40 percent of the cases, and technology assessments (which usually include a risk assessment), had they been done, were judged by the study team as probably having been surely helpful in only 40 percent of the cases (Lawless, 1974). (See Table 4.1) This record is a troubling one, speaking poorly of societal risk assessment abilities and greatly to the need. It is even more troubling when one asks, 'And what were the number of missing alarms not yet considered?'

4.4 CASE STUDY: RISK ASSESSMENT OF NUCLEAR REACTORS: THREE VIEWS OF THE REACTOR SAFETY STUDY

One of the most elaborate risk assessments done to date is the reactor safety study, entitled *An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*. It is informally known as the Rasmussen Report after its director, Professor

Norman C. Rasmussen of the Massachusetts Institute of Technology. The study, using 50 person-years of professional effort, cost \$3,000,000 and has undergone considerable review and scrutiny. It has rapidly become a standard-setter in the field of risk assessment.

This case study uses the draft study and the critical responses to it. It begins with a summary outline of the methodology employed in terms of the risk assessment elements. This is followed by excerpts from the report and its critiques as concrete illustrations of the typology of the three overriding risk assessment attitudes.

4.4.1 Risk Assessment Elements in the Reactor Safety Study

The hazard identified in the Reactor Safety Study (United States Atomic Energy Commission, 1974) is the 'risk to the public from potential accidents in nuclear plants of the type being built in the U.S. today.' Not included are intentional acts, e.g., sabotage, as well as external events such as earthquakes or airplane crashes, although they are mentioned and somewhat discounted.

Risk estimation The events considered are accidents that release large amounts of radioactivity to the environment from commercial nuclear plants. These events are specifically considered for a typical specific pressurized water reactor (PWR) and boiling water reactor (BWR). All possible (imaginable) accidental event sequences leading to a core melt with release of radioactive isotopes to the environment through containment failure (or other means) are considered by the assessor.

Beginning with classes of initiating loss-of-coolant accidents (LOCA) or transient events, logical accident sequences are traced for each reactor section leading to the failure of protective systems, core meltdown, and containment failure or other means of releasing large amounts of radioactivity to the environment.

The likelihood of such events occurring is calculated as follows:

The probability of occurrence of an accident sequence is composed of the initiating event probability, the failure probabilities of systems included in the sequence, and the containment failure probability. The probabilities for LOCA initiating events such as pipe breaks, vessel ruptures, transients, etc., were determined by deriving appropriate failure rates from applicable failure rate data. The large majority of the system failure probabilities were determined with the aid of the fault tree technique... To account for probable dependencies in failures of components and systems involved in the fault trees and event tree accident sequences, many special analyses were performed for the purpose of determining significant common mode failures... The applicable containment failure modes are largely determined by the accident sequences and the various physical processes that can result from the accident sequences. (P. 93)

The consequences to the public of accidental releases of radioactive material considered in the report are effects on health and damage to property. The health effects are acute fatalities (deaths are assumed to occur shortly after the accident to all persons receiving whole-body exposure of 400 rem or higher and varying linearly down to 133 rem), acute illness (for those receiving doses between 100 and

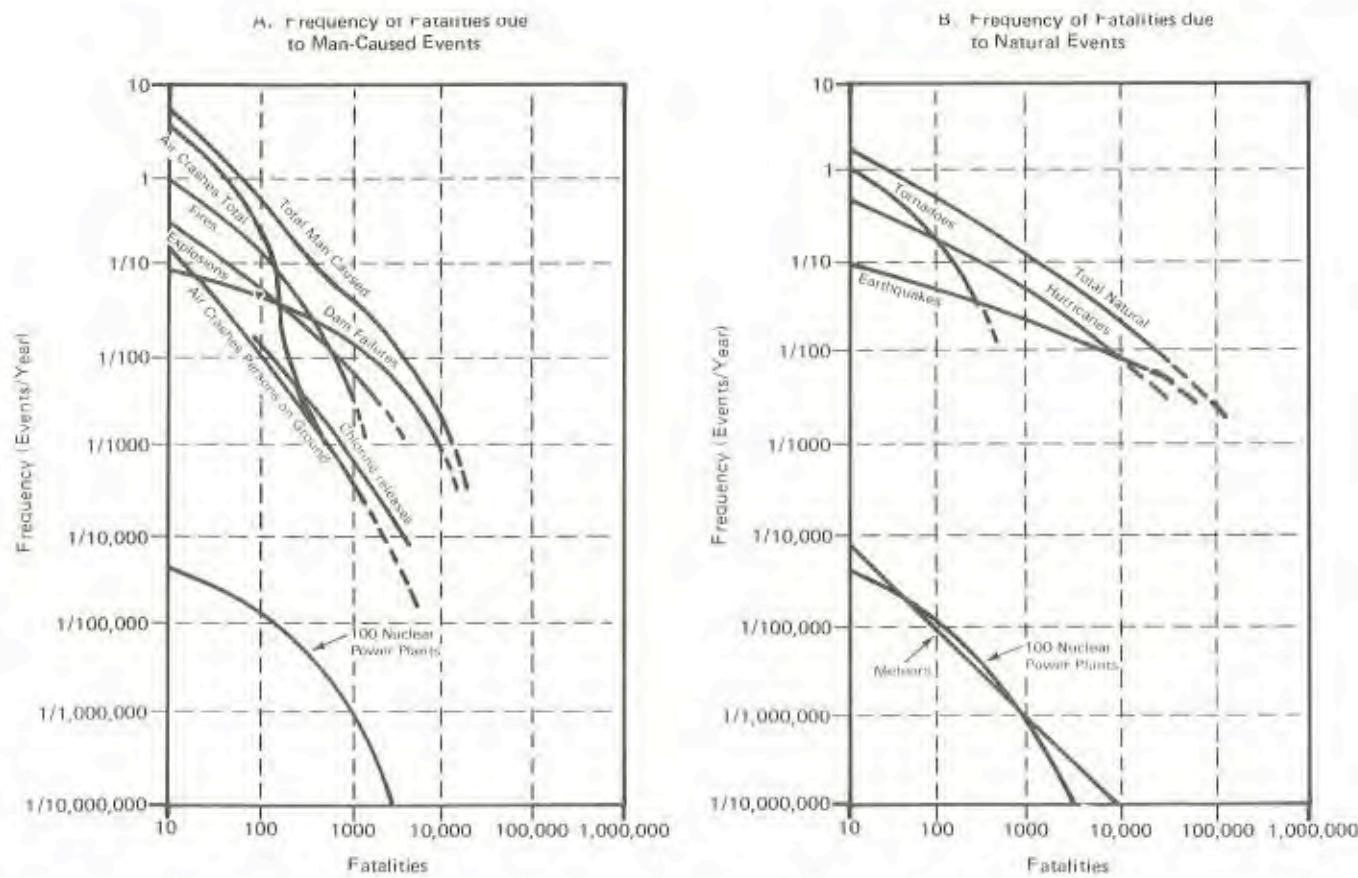


Figure 4.3 Comparative risks of a major nuclear reactor accident. Source: *Reactor Safety Study* (Executive Summary), 1975, p. 2.

- Notes:
1. Fatalities due to auto accidents are not shown because data are not available. Auto accidents cause about 50,000 fatalities per year.
 2. Approximate uncertainties for nuclear events are estimated to be represented by factors of 1/4 and 4 on consequence magnitudes and by factors of 1/5 and 5 on probabilities.
 3. For natural and man-caused occurrences the uncertainty in probability of largest recorded consequence magnitude is estimated to be represented by factors of 1/20 and 5. Smaller magnitudes have less uncertainty.

200 rem); and long-term health effects of cancer, thyroid nodules, and genetic change (to all those exposed to 100 rem or over). Property damage consists of costs of evacuating population (up to 90 percent), with loss of their productive earnings, and the use of their reproducible assets and land also considered.

Health consequences are then calculated by the whole-body exposure and doses to the lung, thyroid and gastrointestinal tract received from a possible nine types of release from PWR's and six types of release from BWR's. The probability of each release is multiplied by the probability of 25 average weather patterns and 15 million people in 13 average population densities (developed from the 66 sites of 100 reactors) to yield a dose/population likelihood. This is then converted into the three major health effects, using conservative no-threshold dose descriptions. Evacuation of up to 90 percent of population is assumed with a half-rate each of two hours after warning. Property damage is based on simplified values of \$2,000 per acre for land value, about \$5 per person for reproducible assets and \$15 per person per day for evacuation and income loss.

The risks from accidental releases from U.S. nuclear plants are summarized as rates for each of the four consequences for individual plants and extrapolated to the 100 plants to be built by 1985. They are described as overall rates of fatalities, illness, long-term health effects and property damage per year both to society and to the individual at risk.

Risk evaluation These rates are then compared to those of other natural hazards (tornadoes, hurricane, earthquake and meteor) and man-made accident (dam failure, chlorine gas, aircraft, explosion and fire), to indicate nuclear accident rates 100 to 10,000 times lower than other large-consequence events, with long-run expected fatalities at .04 per person per year or .3 per year if long-run health effects are included (see Figure 4.3).

In the sections that follow, excerpts from the *Reactor Safety Study* and its critics exemplify the three types of assessment attitudes. *The Reactor Safety Study* is itself an example of the second type of risk assessment (hazards less than the risks assessed), its major finding showing that the 'consequences are smaller than people had been led to believe by previous studies.' The Kendall-Moglewer critique of the study is only one of several such critiques (Environmental Protection Agency, 1975; American Physical Society, 1975), but is the most critical and specific in its faulting both the methodology for its built-in underassessment of risk, and the results in its underassessment of consequences. In contrast, the Hohenemser extract focusses beyond the *Reactor Safety Study* to the range of nuclear hazard. In turn, this comparison could be further extended to the hazard of other forms of energy production.

4.4.2 The Hazard is Less than the Risk Assessed: Excerpt from Draft Summary, WASH-1400, Reactor Safety Study (U.S. Atomic Energy Commission, Washington, D.C., 1974)

Introduction and Results

The Reactor Safety Study was sponsored by the U.S. Atomic Energy Commission to estimate the public risks that could be involved in potential accidents in commercial nuclear power plants of the type now in use. It was

performed under the independent direction of Professor Norman C. Rasmussen of the Massachusetts Institute of Technology. The risks had to be estimated, rather than measured, because although there are about 50 such plants now operating, there have been no nuclear accidents to date. The methods used to develop these estimates are based on those developed by the Department of Defense and the National Aeronautics and Space Administration in the last 10 years.

The objective of the study was to make a realistic estimate of these risks and to compare them with non-nuclear risks to which our society and its individuals are already exposed. This information will be of help in determining the future use of nuclear power as a source of electricity.

The basic conclusion of this study is that the risks to the public from potential accidents in nuclear power plants are very small. This is based on the following considerations:

- (a) The consequences of potential reactor accidents are no larger, and in many cases, are much smaller than those of non-nuclear accidents. These consequences are smaller than people have been led to believe by previous studies which deliberately maximized risk estimates.
- (b) The likelihood of reactor accidents is much smaller than many non-nuclear accidents having similar consequences. All non-nuclear accidents examined in this study, including fires, explosions, toxic chemical releases, dam failures, airplane crashes, earthquakes, hurricanes and tornadoes, are much more likely to occur and can have consequences comparable to or larger than nuclear accidents.

How do we know that the study has included all accidents in the analysis?

The study devoted a large amount of its effort to ensuring that it covered all potential accidents important in determining the public risk. It relied heavily on over 20 years of experience that exists in the identification and analysis of potential reactor accidents. It also went considerably beyond earlier analyses that have been performed by considering a large number of potential failures that had never before been analyzed. For example, failure of reactor systems that can lead to core melt and the failure of systems that affect the consequences of core melt have been analyzed. The consequences of the failure of the massive steel reactor vessel were considered for the first time. The likelihood that various external forces such as earthquakes, floods and tornadoes could cause accidents were also analyzed.

In addition there are further factors that give a high degree of confidence that all significant accidents have been included. These are: 1) the identification of all significant sources of radioactivity located at nuclear power plants, 2) the fact that a large release of radioactivity can occur only if reactor fuel melts, and 3) knowledge of the factors that can cause fuel to melt. This type of approach led to the screening of thousands of potential accident paths to identify those that would determine the public risk.

While there is no way of proving that all possible accident sequences which contribute to public risk have been considered in the Study, the systematic approach used in identifying possible accident sequences makes it very unlikely that an accident which would contribute to the overall risk was overlooked.

How do your calculations of reactor accidents compare with those of earlier studies that predicted much larger consequences?

The principal earlier study of reactor accidents (WASH-740) was published by the AEC in 1957, before any commercial nuclear power plants were

operating. Thus, this study was necessarily vague about the engineering details of reactor accidents. The purpose of that study was to essentially maximize the consequences that could occur in an accident. This was done because it was to serve as a basis for the Congress to use in establishing adequate indemnification of the public in the event that an accident occurred. Thus, WASH-740 served as the basis for the Price-Anderson Act which provides such indemnification.

The reactor used for the WASH-740 study was one that generated 500 million watts (megawatts) of thermal energy as opposed to today's reactor of about 3200 megawatts. To compare the earlier estimates with the more realistic approach used in this study, calculations were made for a 500 megawatt reactor using the Reactor Safety Study model. The results are presented in the table below.

TABLE 4.2 Comparison of Consequences from Accidents in a 500 MWt Reactor as Calculated in WASH-740 and as Predicted by WASH-1400

Parameter	WASH-1400		
	WASH-740	Peak	Average
Acute Deaths	3,400	92	0.05
Acute Illness	43,000	200	0.01
Total Dollar Damage (billions)	7 ¹	1.7 ²	0.51 ²
Approximate Chance per Reactor Year		One in a billion	One in ten thousand

¹This is the value predicted in 1957 dollars.

²The values shown are in 1973 dollars. In 1957 dollars, these values should be about two-thirds of that shown.

The differences between these two sets of results can in large part be explained as follows:

1. This study used actual population data from the census bureau for the areas in the vicinity of actual reactor sites. WASH-740 used an estimated population that was much higher.
2. WASH-740 assumed that 50% of all the core radioactivity would be released to the environment. This study, using available experimental data, finds it physically impossible to attain total core releases as large as those used in WASH-740.
3. The WASH-740 calculation made no provisions for the evacuation of people. Experience shows that evacuation is highly likely and would significantly reduce the consequences of an accident should it occur.
4. The radioactivity released in a potential reactor accident would be in the form of a plume such as can be seen from smoke stacks. The radioactivity has sufficient heat associated with it to cause the plume to rise, thus reducing the concentration of radioactivity near the ground. This has some effect in reducing consequences. WASH-740's calculations did not include this effect.

4.4.3 The Hazard is Greater than the Risk Assessed: Excerpt from Preliminary Review of AEC Reactor Safety Study (Sierra Club-Union of Concerned Scientists, San Francisco-Cambridge, 1974)

The release by the AEC of its massive Reactor Safety Study signals an important contribution to the now vigorous controversy over hazards in the civilian nuclear power program. It is the first time the AEC had addressed this thorny problem at the level of thoroughness and completeness that characterizes the Reactor Safety Study. The question of whether the level that the Reactor Safety Study achieved is adequate to the task or not is another matter. Methodologies developed in the space program in the U.S. Air Force's ballistic missile program were adopted for the first time by the AEC to attempt to identify *all* of the important accident modes and to evaluate their probabilities. The Reactor Safety Study moved to determine first the consequences of these events, then the attendant risks were compared to the panoply of the other risk that we are all exposed to.

The weaknesses we have identified in the Reactor Safety Study use of event tree/fault tree methodology are several:

1. We regard it as unlikely to the point of impossibility that RSS was able to identify all of the important accident sequences. There are far too many damaging examples of failure to recognize and understand rare and potentially serious accident chains in complex technologies — including in the nuclear experience — to support the RSS view of success in this area.
2. The analysis methodology does not judge the design adequacy of equipment and must largely take it on faith. This can introduce serious errors in the event that design mistakes go unnoticed, as they occasionally do.
3. Human error can make imponderable and frequently damaging contributions to accidents. It is the least tractable source of failure in a fault tree analysis.
4. Structural failures are normally so infrequent that good data are just not available to establish the failure rates and no widely accepted testing procedure has been found to simulate such failure. This, too, may introduce significant error.
5. Fault tree analysis can reflect the dependency of one component failure on another if the dependency is known. However, in the vast majority of cases studied in RSS, components are assumed to fail independently. Subtle but crucially important dependencies can arise from physical proximity, unexpected component response to the abnormal circumstance of an accident or design error. Experiences with reactor accidents show this to be an important consideration as such dependencies have badly aggravated otherwise innocuous events.
6. Secondary failure is failure of a component because it is stressed beyond its specified range of performance. It is stated in RSS Appendix 2 that except in restricted cases secondary failures were not considered owing to the multitudes of possible secondary failures, the absence of failure

data, and previous experience that such failures are less likely than other failure modes. Although this practice may be necessary to make the analysis tractable, it unavoidably introduces possibly significant error.

7. Common mode failures are relatively uncommon unscheduled events in which redundant and presumably independent systems are nevertheless simultaneously disabled through some common cause. Such events do occur. For example, multiple redundant reactor shutdown mechanisms have been found to be wholly inoperative. This is a very critical issue and RSS has made an apparently sincere effort to assess it by adopting certain analytical assumptions, concluding that such failures do not contribute importantly to reactor risk. However, the same assumptions applied to combinations of common mode failures that have actually occurred assess them to be virtually impossible, indicating that this is a more important source of risk than recognized by RSS. We doubt that it is, in principle, possible to locate all such potential failures.
8. The use of failure rate data is suspect. Especially, RSS neglects the possibility of catastrophic pressure vessel rupture, assuming it to present a negligible risk. Conclusions limiting the number of deaths in their assessments of accidents are crucially dependent on this assumption. Based on the best available evidence, we conclude that such rupture represents a very real risk. Other improper use by RSS of failure rate data appears possible if not likely.

We have concluded that the event tree/fault tree methodology if properly utilized can be very helpful in making comparisons between diverse system designs, assessing relative improvements from system component changes, or identifying design weak points. We do not believe, however that the methods can be employed as RSS has done to determine absolute probability values for accident probabilities and to use these predictions as proof of the safety of nuclear plants. The many and important residual uncertainties introduced by use of the methodology make this RSS application technically unsound and unjustified. Experience with manned and unmanned space mission applications of these methods fully supports our conclusions.

* * *

The RSS treatment of the consequences to public health and property also include a number of weaknesses. These are:

1. The amount of radioactivity released in a given core melting accident appears to have been understated by as much as a factor of 2.
2. The damages to human health from radioactive exposure, including prompt and delayed lethal damage, have been seriously understated. The factors of discrepancy that we have conservatively identified are:

Fatalities and acute illness	3-4
Latent cancers	4-6
Genetic effects	1-2
Thyroid illness	4

The factors may prove larger on more detailed examination, but even as stated have very important consequences.

3. RSS relies on prompt and effective evacuation and on shielding of exposed persons to achieve a significant reduction of health effects. We have found RSS assumptions in this area to be inadequately supported and the extent of the reductions overstated. Indeed, the evacuation model and shielding assumptions contradict one another.
4. Expected population growth in the vicinity of nuclear plants was not incorporated in RSS evaluations. The consequences, while modest, are important.

We have concluded that the aggregate consequences to human health of major accidents evaluated by RSS are seriously understated. We can conservatively account for a factor of 16 in regard to fatalities and acute illness. The value may well be higher. Reevaluation of RSS results, correcting only for this error, using RSS methods, establishes that the probability of killing 2300 persons and injuring 5600 more in an accident is increased over the RSS value by a factor of 400. The accident probability assigned by RSS to an accident of that size is, on reevaluation of the consequences, found to be the probability of an accident in which 37,000 people are killed and 90,000 made acutely ill. Similar results occur for cancers, genetic damage, thyroid illnesses, and for property damage.

4.4.4 The Hazard is Different from the Risk Assessed: Excerpt from paper by C. Hohenemser entitled: Assessing the Risks of the Nuclear Fuel Cycle (Department of Physics, Clark University, Worcester, Mass., 1975)

A. Routine and Catastrophic Hazards

A large number of hazards have been identified within the nuclear fuel cycle. These may be conveniently divided into two classes, which we denote by 'routine' and 'catastrophic,' and which are describably as follows.

1. *Routine hazards.* Generally characterized by well defined risks and consequences, these hazards are akin to the hazards of automobile driving or cigarette smoking. Examples of routine hazards are low-level normal radioactive dust from nuclear installations, or radioactive dust encountered in uranium mining.

2. *Catastrophic hazards.* Characterized by poorly defined or undefined risks common to all rare events, these hazards are akin to hazards from meteors and earthquakes. Because quantitative statements about such hazards have proven difficult to make, much of the literature is concerned with conceivable consequences alone, as distinct from the probability that such consequences will be experienced.

During most of the 1960's, the dominant public discussion of nuclear safety concerned routine hazards. Despite a heated debate on the proper level of radiation standards, the routine hazards of the nuclear fuel cycle can be shown to be small compared to many other hazards that we tolerate, including the burning of fossil fuels. Most occur as occupational hazards, and the largest part of them are not related to radiation at all. It is therefore possible to dismiss them as insignificant for the present purposes. They simply do not carry any weight in arguments dealing with the proliferation of nuclear power.

In the 1970's, an increasing concern with catastrophic hazard has 'surfaced' in public discussion. One root of the new concern has been the safety of the reactors themselves, particularly the effectiveness of emergency core cooling systems (ECCS). This discussion was largely initiated through the publications of the Union of Concerned Scientists. Another root of concern has been the wide availability of separated plutonium in the maturing fuel cycles of advanced countries. This concern was stimulated from independent directions. Taylor worried about theft of weapons grade material. Geesaman, and later Tamplin and Cochran, saw potential disaster in the toxicity of plutonium.

Stimulated by critics, and pressed by environmentalists in the courts, the Atomic Energy Commission has begun to make more serious studies of reactor safety in the past few years, as illustrated by the recent publication of the Reactor Safety Study.

B. Typology of Catastrophic Nuclear Events

After some reflection and discussion among colleagues, it has been possible to arrive at what is hopefully an exhaustive typology of possible catastrophic events in the nuclear fuel cycle. The object of this exercise is to see to what extent the recent discussion of reactor safety has in fact been inclusive in all significant problems.

To begin with, some event types are identified as follows:

(1) *Theft of weapons grade material.* Plutonium and highly enriched uranium are both weapons grade material. As has been shown by Taylor and Willrich, both may be easily stolen in significant quantities from the mature fuel cycle, national and international safeguards notwithstanding. Taylor and others have in addition pointed out that denaturing by ^{240}Pu does not prevent manufacture of crude nuclear explosives, albeit with somewhat degraded yield. Taylor has also argued that the problems of detonation are if anything easier than they were thought to be 14 years ago by outsiders to the U.S. weapons program. Thus, the theft of weapons grade material from a mature nuclear power program is a catastrophic event that reintroduces fears that were earlier related to the nth country problem — but with a new and different twist. Today, a would-be nuclear terrorist need only steal the right shipping container and learn the detonation game, where formerly it was thought he would have to embark on at least a miniature Manhattan project.

(2) *Massive release of fission products.* As the equivalent of 'combustion products,' fission products occur everywhere in the fuel cycle beyond the reactor. The fission product inventory of a large reactor in equilibrium operation is ~ 1500 times the amount of fission products released in a Hiroshima sized nuclear explosion. Because of their intense radioactivity, release of fission products in large quantities from any nuclear facility is undeniably a catastrophic event.

To represent the occurrence of catastrophic hazard in a manner that is *prima facie* exhaustive, we have constructed a matrix as shown in Table 4.3. In this matrix, the types of risk are listed horizontally, and the stages of the fuel cycle are given vertically. The symbols entered in each matrix element indicate separate conceivable events. Some elements, left unmarked, are devoid of catastrophic events. Others, as can be seen, include as many as six distinct events.

Independent of the particular outcome in the debate centered on WASH-1400, it is clear that even this most comprehensive reactor study does not get close to describing all the terms that contribute to nuclear fuel cycle hazard. To see what is missing, we can refer to the matrix in Table 4.3.

In terms of Table 4.3, WASH-1400 covers exactly one event, i.e., a massive fission product release in the light water reactor following core

meltdown. This may well be the most important, but is surely not the only one!

Besides WASH-1400 and its relatives, there are, of course, other studies that will help fill the existing gap. A preliminary conclusion in this regard is that most of these studies are in the WASH-740 era (an early effort to define the maximum conceivable event); i.e., the discussion deals with conceivable primary events and conceivable losses, but no estimates are made of primary event probabilities and physical consequences probabilities. An example of such a study is the excellent work by Taylor and Wilrich on nuclear theft, and its consequences.

Finally, there are studies that should exist, but do not. For example, nuclear reactor sabotage is an important primary event. Physical consequences and losses have been journalistically treated, but to my knowledge, not even the WASH-740 stage has been reached, to say nothing of probability estimates. Another significant example is the study of fuel reprocessing. Because of its very large fission product and plutonium inventory, it certainly represents a hazard. Yet there appear to be no significant risk estimates for these.

TABLE 4.3 Typology of Catastrophic Nuclear Events (LWR Fuel Cycle)

Fuel Cycle Stage	Hazard Type		
	Nuclear Explosion	Plutonium and/or Actinide Release	Massive Fission Product Release
<i>Mining, etc.</i>			
Enrichment, fuel fabrication	F'	FF'	
Reactor operation		XX'	XX'
Fuel reprocessing	X'	XX'	XX'FF'
Plutonium storage	X'F'	XX'FF'	
Waste disposal		FF'	FF'

Key: X - conceivable accidental events occur
 X' - conceivable deliberate events occur
 F - conceivable future accidental events occur
 F' - conceivable future deliberate events occur

The final version of the Reactor Safety Study addressed itself to many but not all of the critiques made. It revised upward the consequences but revised downward some other assumptions, leaving its conclusions little changed. Major new efforts to assess other risks in the fuel cycle have also been initiated. Nonetheless the nuclear debate persists stronger than ever, giving further evidence of what is yet to be learned in improving the practice of risk assessment and its use by society.

4.5 IMPROVING METHOD, THEORY AND PRACTICE

Some risks are underassessed; their hazard continues to imperil humankind. Some risks are overassessed, and resources are squandered in their abatement or opportunities are foregone in their avoidance. And many hazards remain unidentified; society is hostage to the chance of discovery. Yet the state-of-the-art of risk assessment is such that much more is known than is currently employed; much more could be learned than is currently studied. The best understood element of risk assessment is risk estimation; currently the most studied is social evaluation; the least studied and understood is hazard identification.

Risk Estimation Enough is now known about concepts of risk estimation to share widely. That risk from environmental hazard is a joint probability of events and consequences, that events and consequences are unevenly distributed in space, time and among populations, that some consequences are more easily identified than others — these are limitations well understood by assessors but not by those who ask for or use risk assessments.

Enough is also known about more subtle problems of risk estimation — the limits of experience, distorted assumptions and cognitive constraints — that guidelines for assessors in dealing with uncertainty and other problems could be readily prepared (Munn, 1975b). Methods of modeling hazard events and consequences are at the textbook stage, but good judgement in matching models to problems needs to be more widely diffused. More reliable methods of eliciting expert judgement are also readily at hand.

There are of course many technical difficulties. A few notable ones are the adequate quantification of very small probabilities, the combination and compounding of uncertainty, the modeling of secondary and higher order consequences, the modeling of processes poorly understood scientifically, and the dangers of 'numbers' manipulation and pseudo-science in assessments of large, complex systems. But none of these research needs should deter the wider utilization of the fairly advanced art of risk estimation. More pressing are research needs in hazard identification, social evaluation, and communication and decision-making.

Hazard Identification The most important missing element in hazard identification is theoretical; the absence of obvious mechanisms or generic principles that explain the hazardousness of more than a limited subset of the sources, materials, media and processes that threaten us and the environments we value. The development of such theory can be assisted by the compilation of taxonomies of structural characteristics of hazard.

The creation of taxonomies or classifications of hazard events and consequences should be approached with caution (see, for example, Russell and Landsberg, 1971). Classification schemes are the end-product rather than the prologue of research effort and may be meaningless out of the context of specific applications. Nevertheless, there are needs other than theoretical ones which would encourage priority effort to taxonomy consideration.

As societal resources become taxed with the burdens of hazard identification — screening, monitoring, diagnosis — and with risk estimation and social evaluation, an ordering to enable a more rational match between resource and risk assessment need becomes obvious. It is necessary to develop typologies which can systematize

hazard events and consequences and group appropriate coping strategies by structural similarities, rather than by intellectual origin or professional discipline. Such an ordering is also required in order to appraise the relative success of hazard identification. Are some hazards overstudied while in the domains of others there is little or no effort? To sample the effort requires an ordering of the domains.

A second major area for the improvement of hazard identification is information management. There is a veritable explosion in proposed, partially implemented and underutilized information systems for hazard identification. One recent U.S. compilation lists 39 operational systems related to the identification and assessment of toxic chemicals (Environmental Protection Agency, Office of Toxic Substances, 1974). Global systems multiply these several times over. What is needed is not additional systems but improved information management programmes which would emphasize creative bridges between *existing* information systems, including proprietary ones, and would pose better questions to them. A comparative assessment of information systems in an international context is needed to develop standards and tests for the utility of data.

Social Evaluation Risk estimation and evaluation – the making and comparing of estimates of risk with other risks, benefits and costs – are but a few of many processes of social evaluation. Three general classes of evaluation processes are found: in the market, in the striking of consensus, or in the judgement of adversarial process. None are cost-free and some are unsuitable for some social settings. Conditions under which risk evaluation takes place seem to vary and one emergent theme of research is to look for the comparative advantage of market, consensus, and adversarial processes. For what kinds of hazards, for what kinds of events and consequences, for what kinds of judgements, in what societal contexts, do each of the three processes operate well or poorly? Do some processes create higher social costs simply by their practice, regardless of the judgements they provide? Is there choice for other processes within the social, organizational, or political framework of most countries?

A related question is that of the needs of developing countries. They face particular dilemmas of risk assessment. On the one hand, they lack the statistical base and special expertise to carry out many independent risk assessments of the type described in this report. On the other hand, the transfer of assessments, evaluations, and standards of industrialized countries to their special settings is often inappropriate and may exacerbate rather than diminish overall risk. Too often in the past, so-called 'international' standards have also proved inappropriate. There would seem to be need for a specialized effort to distill the state-of-the-art for its applicability to the particular needs of developing nations.

Regardless of the chosen process, a major obstacle in social evaluation relates to the balancing of multiple risks, costs and benefits expressed in different quanta. The comparison of uncertain risks or benefits with more certain ones, diffuse risks or benefits with more concentrated ones, and latent or postponed risks and benefits with more immediate ones are the norm rather than the exception in risk assessment. Existing theory and methods appear inadequate to first describe fairly these diverse prospects and then to balance them in a judicious way. There are new evaluation techniques emerging from laboratory and field studies, techniques related to multiple attribute utility preference and to the making of judgements and decisions. These require critical review as to their range, promise, and – most

important — their performance. New modes of mass public evaluation are also being experimented with and experiences in France, Hungary, Sweden and the United States are described in the Report of a Workshop on Comparative Risk Assessment of Environmental Hazards in an International Context (1975). These raise further issues whether mass public participation in social evaluation, especially that dealing with highly technical issues, is possible and desirable.

Communication and Decision-Making Risk assessment methodology needs to be linked to the channels and processes of communicating both to institutions and to publics and to understanding the ways in which such assessments can be used in societal decision-making.

Risk exists because all is not known. The hazards are unidentified — the likelihood of events, the nature of consequences, or both, are uncertain. But not all that is known is communicated, and the way in which what is known is communicated often conditions how it will be evaluated. There is evidence that careful risk assessment may be distorted by an executive summary, a covering letter, or a press release. A quantitative estimate, written description, or chance selection of graphic display can change the perceived meaning of information. Great variety is found in channels of communication and those who have access to them. Thus risk assessments, like all potential societal issues, are in constant competition for public attention and action. Content is clearly important, as are the ways of communication, but so is an understanding of the intended decision process.

A very significant body of case study material relating to the communication of risk assessment and societal response is accumulating. Some have been cited in this report. As with many case studies, they suffer from the lack of a conceptual frame. A first effort, then, should be addressed toward drawing from these disparate studies an inventory of central findings, ordering them, interpreting for potential users what is known, and identifying further research needs.

Laboratory and field experiments are needed as well in the fair presentation of information. It is well known that differences in presentation distort information content, but the obverse, how to fairly present information on risks, particularly low probability-high consequence events, is not known with confidence.

Finally, there is need to move from a societal response to individual risks to an overall risk policy. The range of options for a coherent, consistent risk policy across the spectrum of hazards has not been defined anywhere. Until that is done, societal response is likely to be haphazard, incoherent, and inconsistent.

The ultimate response to environmental threat, however, lies neither with improved assessment nor communication but with the reduction of threat itself. It is possible to argue, for example, as Commoner (1971) has, that it is unnecessarily hazardous to input into the environment large amounts of synthetic materials not found in nature if natural substitutes, marginally equivalent or different, exist. Or that it may be excessively hazardous to undertake all possible technical experiments simply because they are feasible and interesting. We need, in short, some global abominations — some avoidances, some risks to be averted — not because it is impossible to cope successfully with any of these potential hazards, but because it may be impossible to cope successfully with all of them.