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The Nature of Technological Hazard

C. Hohenemser, R. W. Kates, P. Slovic

Summary. Technological hazards are evaluated in terms of quantitatively expressed physical, biological, and social descriptors. For each hazard a profile is constructed that considerably extends the conventional definition of risk. The profile, which is termed hazardousness, was understood in pilot experiments on perception and appeared to capture a large fraction of lay people's concern with hazard. It also suggests an orderly method for establishing priorities for the management of hazards.

Each year the hazards associated with technology lead to illness and death, as well as varying environmental, social, and economic impacts; these effects correspond to a significant fraction of the gross national product (*1, 2*). Despite the burden imposed by technological hazards and the broad regulatory effort devoted to their control, there have been few studies comparing the nature of technological hazards in terms of generic characteristics. Most investigators have produced case studies (*3*), comparative risk assessments of alternative technologies (*4, 5*), comparative lists of hazard consequences (*6, 7*), or comparative costs of reducing loss (*8–10*).

A first step in ordering the domain of hazards should be classification. Today technological hazards are classified by the source (automotive emissions), use (medical x-rays), potential for harm (explosions), population exposed (asbestos workers), environmental pathways (air pollution), or varied consequences (cancer, property loss). One scheme is chosen, usually as a function of historical or professional choice and the relevant regulatory organizations, even though most technological hazards fall into several categories. For example, a specific chemical may be a toxic substance, a consumer product, an air or land pollutant, a threat to worker health, or a prescription drug. Indeed, a major achievement has been the cross-listing of several of these domains of hazardous substances by their environmental pathways (*11*).

We have sought to identify common differentiating characteristics of technological hazards in order to simplify analysis and management of them. Techno logical hazards may be thought of a involving potentially harmful releases (energy and materials. We characterize the stages of hazard causation by !

physical, biological, and social descriptors that can be measured quantitatively; we then scored 93 technological hazards and analyzed the structure of correlations among them. In this article we present a highly condensed account of our analysis (*12*).

Measures of Hazardousness

We should first distinguish between the terms hazard and risk. Hazards are threats to humans and what they value, whereas risks are quantitative measures of hazard consequences that can be expressed as conditional probabilities of experiencing harm. Thus, we think of automobile usage as a hazard but say that the lifetime risk of dying in an auto accident is 2 to 3 percent of all ways of dying.

We conceive of technological hazards as a sequence of causally connected events leading from human needs and wants to the selection of a technology, to the possible release of materials and energy, to human exposure, and eventually to harmful consequences (Fig. 1). To differentiate among types of hazards, we defined 12 measures for individual hazards and applied them to the appropriate stage in this chain. We selected descriptors (Fig. 1 and Table 1) that would be applicable to all technological hazards, comprehensible to ordinary people, and could be expressed by common units or distinctions.

One variable describes the degree to which hazards are intentional, four characterize the release of energy and materials, two deal with exposure, and five apply to consequences (Fig. 1). Only one descriptor, annual human mortality, is closely related to the traditional idea of risk as the probability of dying; the others considerably expand and delineate the quality of hazardousness. Four descriptors require categorical distinctions and eight use logarithmic scales (Table 1). Logarithmic scales are practical for cases where successive occurrences range over a factor of 10 or more in magnitude and where estimated errors easily differ by the same amount. Logarithmic scales may also match human perception better than linear scales, as seen by the success of the decibel scale for sound intensity and the Richter scale for earthquake intensity.

Hazards were selected from a variety of sources (*3, 8, 13*) and, after scoring, were found to be well distributed on the 12 scales (Fig. 2). Where appropriate, hazards were scored by reference to the scientific literature. Many cases were discussed by two or more individuals, or referred to specialists for clarification. When the results of this scoring were checked for consistency, changes of 1 or 2 points were made in 8 percent of the scores and 3 points or more in a few scores (< 1 percent). We therefore believe replicability to be within ± 1 scale point in most cases.

C. Hohenemser is in the Department of Physics and R. W. Kates in the School of Geography and the Center for Technology, Environment, and Development at Clark University, Worcester, Massachusetts 01610. P. Slovic is at Decision Research, a branch of Perceptronics, Eugene, Oregon 97401.

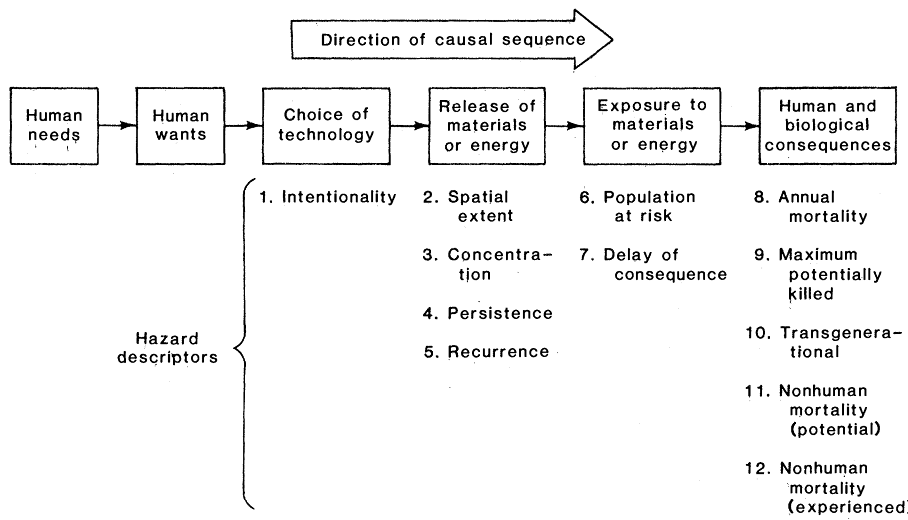


Fig. 1. Causal structure of technological hazards illustrated by a simplified causal sequence. Hazard descriptors used for classifying hazards are shown below the stage to which they apply.

Table 1. Hazard descriptor scales.

Technology descriptor

1. Intentionality. Measures the degree to which technology is intended to harm by a categorical scale: 3, not intended to harm living organisms; 6, intended to harm nonhuman living organisms; 9, intended to harm humans.

Release descriptors

2. Spatial extent. Measures the maximum distance over which a single event has significant impact on a logarithmic scale, $1 < s < 9$, where $s = \log_{10} d + 1$ rounded to the nearest positive integer, and d is the distance in meters.

3. Concentration. Measures the concentration of released energy or materials relative to natural background on a logarithmic scale, $1 < s < 8$. For materials and nonthermal radiation $s = \log_{10} R + 2$ rounded to the nearest positive integer where R is the average concentration of release divided by the background concentration. For mechanical energy, $s = \log_2 a + 0.68$ rounded to the nearest positive integer where a is the acceleration to which individuals are exposed measured in units of the acceleration of gravity. For thermal energy, $s = \log_2 f + 0.68$ rounded to the nearest positive integer where f is the thermal flux expressed in units of the solar flux.

4. Persistence. Measures the time over which a release remains a significant threat to humans on a logarithmic scale, $1 < s < 9$, with $s = \log_{10} t + 1$ rounded to the nearest positive integer where t is the time measured in minutes.

5. Recurrence. Measures the mean time interval between releases above a minimum significant level on a logarithmic scale identical to that used for persistence.

Exposure descriptors

6. Population at risk. Measures the number of people in the United States potentially exposed to the hazard on a logarithmic scale, $1 < s < 9$, with $s = \log_{10} P$ rounded to the nearest integer where P is the population.

7. Delay. Measures the delay time between exposure to the hazard release and the occurrence of consequences on the logarithmic scale defined for persistence.

Consequence descriptors

8. Human mortality (annual). Measures average annual deaths in the United States due to the hazard on the logarithmic scale defined for population at risk.

9. Human mortality (maximum). Measures the maximum credible number of deaths in a single event on the logarithmic scale defined for population at risk.

10. Transgenerational. Measures the number of future generations at risk from the hazard on a categorical scale: 3, hazard affects the exposed generation only; 6, hazard affects children of the exposed generation and no others; 9, hazard affects more than one future generation.

11. Nonhuman mortality (potential). Measures the maximum potential nonhuman mortality on a categorical scale: 3, no potential nonhuman mortality; 6, significant potential nonhuman mortality; 9, potential or experienced species extinction.

12. Nonhuman mortality (experienced). Measures nonhuman mortality that has actually been experienced on a categorical scale: 3, no experienced nonhuman mortality; 6, significant experienced nonhuman mortality; 9, experienced species extinction.

Hazard Classification

Many investigators have developed descriptive classifications of technological hazards (*14–19*). Though mindful of this work, we based our classification entirely on the causal structure descriptors defined in Table 1.

Energy versus materials hazards. A simple, but significant, distinction is the division of hazards into those resulting from energy releases and those from materials releases. Comparison of 33 energy hazards and 60 materials hazards reveals four striking differences (*12*). (i) Energy releases persist for short periods, averaging less than a minute; materials releases persist on the average for a week or more. (ii) Energy hazards have immediate consequences, with exposure-consequence delays of less than a minute; materials hazards have exposure-consequence delays averaging 1 month. (iii) Energy hazards have only minor transgenerational effects; materials hazards affect on the average one future generation. (iv) Energy hazards have little potential nonhuman mortality; materials hazards significantly affect potential nonhuman mortality.

Reducing the number of dimensions. In addition to simple division of hazards by release class, we explored the extent to which hazards may be grouped according to causal structure. Using principal component factors analysis (*20*), we derived five orthogonal composite dimensions (factors) that account for 81 percent of the variance of the sample. This means that the causal structure of each of the 93 hazards, and probably others to be scored in the future, can be described by five variables, rather than by 12.

The relation of the derived factors to the original set of descriptors is summarized in Table 2. The names given to the factors—biocidal, delay, catastrophic, mortality, and global—are intended to aid the intuition and are related to the descriptors that define each factor. The first four factors use descriptors whose scores increase as the factor increases (positive factor loadings), but the factor global is different. Because of negative loading of concentration, hazards scoring highest on global are high in population at risk and low in concentration (that is, diffuse) (Table 2). The factor global thus defines a special combination of hazardousness with widespread exposure and a concentration of release that is modest with respect to background.

Several tests indicate that the factor structure does not change significantly when hazards are added and deleted from the sample, or when scoring changes comparable to the estimated scoring errors are made. Thus an initially chosen set of 66 hazards yielded the same factor structure as the final 93; changing 10 percent of the scores by 1 to 3 scale points had no significant effect. Furthermore, removal of 24 hazards with the most extreme factor scores produced only minor changes in factor structure, an unexpected finding since extreme scores often dominate the analysis.

Scores of the 93 hazards and the derived factor structure are summarized in Table 3. Individual descriptor scores have been grouped by factor into a 12-digit descriptor code, and extreme scores on each factor have been identified through a five digit factor code, with the use of truncated factor scores (*12*).

Inspection of Table 3 permits quick identification of dimensions that dominate hazardousness in specific cases. For example, commercial aviation (crashes) is high in the catastrophic factor and nondistinctive in the other four; power mower accidents are extreme in none of the five factors; nuclear war (radiation effects) is extreme in four.

The results of the coding in Table 3 led naturally to a seven-class taxonomy with three major groupings (Table 4). The first major group, multiple extreme hazards, includes cases with extreme scores in

Table 2. Factor structure. Factor loadings are the result of varimax rotation (*20*).

Factor	Variance explained	Hazard descriptors: Name	Hazard descriptors: Factor loading
Biocidal	0.21	Nonhuman mortality (experienced)	0.87
		Nonhuman mortality (potential)	0.79
		Intentionality	0.81
Delay	0.21	Persistence	0.81
		Delay	0.85
		Transgenerational effects	0.84
Catastrophic	0.18	Recurrence	0.91
		Human mortality (maximum)	0.89
Mortality	0.11	Human mortality (annual)	0.85
Global	0.11	Population at risk	0.73
		Concentration	−0.73
Residual		Spatial extent	

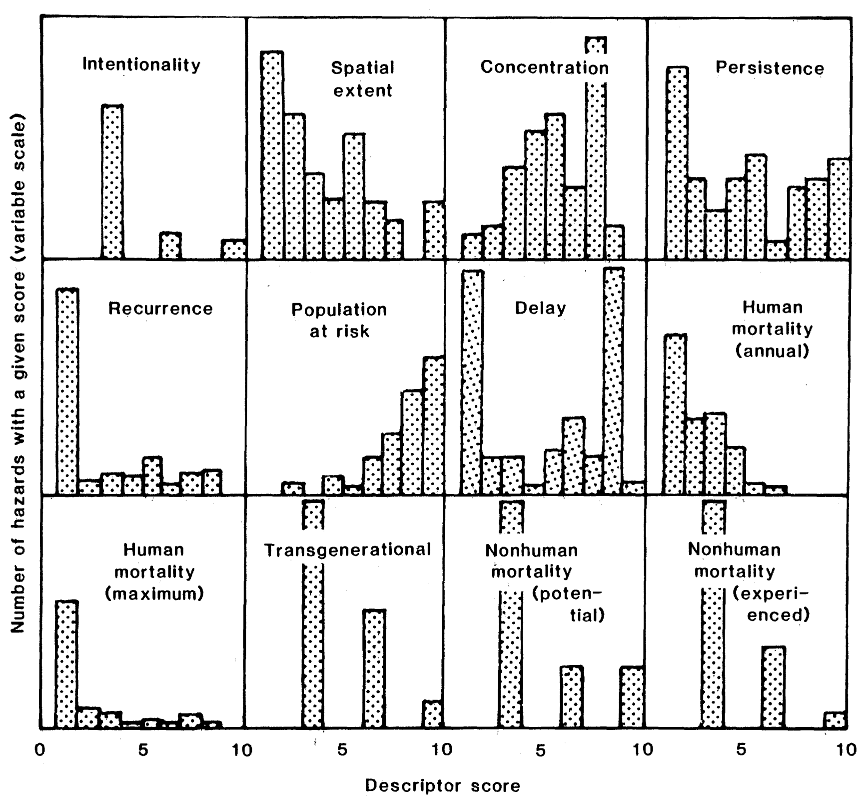


Fig. 2. Descriptor frequency distributions for 93 hazards.

two or more factors; the second, extreme hazards, has cases with extreme scores on one factor; the third group, hazards, contains all the other cases. The group into which a hazard falls depends, of course, on the cutoff for the designation extreme. Although the location of the cutoff is ultimately a policy question, our preliminary definition is arbitrary (*21*).

How appropriate and useful is our approach to hazard classification? To succeed it must describe the essential elements that make specific hazards threatening to humans and what they value, reflect the concerns of society, and offer new tools for managing hazards. On the first point, we invite the review and evaluation of specialists; on the second and third points, we have additional evidence that we discuss below.

Comparing Perceptions

Although the scores for 93 hazards are the result of judgments, we relied on explicit methods, a scientific framework, and deliberate efforts to control bias. These attributes are not necessarily part of the judgments made by the general public. Indeed many scientists believe that lay judgments about hazards vary widely from scientifically derived judgments (*22*).

Because policies governing various types of hazards are determined to a large extent by people who are not scientists or hazard assessment experts, it is important to know whether lay people are able to understand and judge our hazard descriptors and whether these descriptors capture their concerns. The results of a pilot study that we conducted with 34 college-educated people (24 men and 10 women, mean age 24) living in Eugene, Oregon, are interesting.

To test the perceptions of these people we created nontechnical definitions and simple scoring instructions for the causal descriptors of hazards and asked the subjects to score our sample of 93 hazards (*12*). After an initial trial, concentration was judged to be too difficult for our respondents to score. For similar reasons, 12 of the less familiar hazards were omitted. The subjects then scored 81 hazards on 11 measures from our instructions and their general knowledge, reasoning, and intuition.

The results indicate reasonably high correlations between the scores derived from the scientific literature and the mean judgments of our lay sample (r = .65 to .96) (*12*). But despite these high correlation coefficients (Fig. 3), deviations of a factor of 1000 between

Table 3. Descriptor and factor codes for 93 hazards. The descriptor code for each hazard consists of a digit for each descriptor, and represents scores on the scales defined in Table 1. To help visualize the factor structure, descriptors have been grouped by factor in the order defined in Table 2. The factor code consists of a single digit for each factor, and identifies extreme scores by "1" and non-extreme scores by "0", and also follows the order defined in Table 2. Hazards with two or more extreme factors are identified with *.

HAZARD	DESCRIPTOR CODE	FACTOR CODE
ENERGY HAZARDS		
1. Appliances - fire	333-333-42-3-95-2	00000
2. Appliances - shock	333-113-21-3-95-1	00000
3. Auto - crashes	333-113-11-5-96-2	00010
4. Aviation - commercial - crashes	333-113-63-3-97-4	00100
5. Aviation - commercial - noise	333-213-11-1-85-5	00000
6. Aviation - private - crashes	333-113-32-4-97-4	00010
7. Aviation - SST noise	333-313-41-1-76-5	00000
8. Bicycles - crashes	333-113-11-3-84-2	00000
9. Bridges - collapse	333-113-53-1-95-3	00000
10. Chainsaws - accidents	666-113-11-1-74-2	10000
11. Coal mining - accidents	333-233-53-3-64-3	00000
12. Dams - failure	693-423-74-2-85-5	10100*
13. Downhill skiing - falls	333-113-21-2-63-1	00000
14. Dynamite blasts - accidents	333-113-32-2-65-3	00000
15. Elevators - falls	333-113-52-2-96-2	00000
16. Fireworks - accidents	333-113-31-1-83-2	00000
17. Handguns - shootings	369-113-41-4-96-1	10010*
18. High construction - falls	333-113-71-1-28-2	00000
19. High voltage wires - electric fields	333-173-11-1-74-3	00000
20. LNG - explosions	363-213-85-1-86-5	00100
21. Medical x-rays - radiation	333-189-11-4-92-2	00011*
22. Microwave ovens - radiation	333-173-11-1-84-2	00000
23. Motorcycles - accidents	333-113-11-4-76-2	00010
24. Motor vehicles - noise	333-213-11-1-83-3	00000
25. Motor vehicles - racing crashes	333-113-52-2-67-2	00000
26. Nuclear war - blast	699-213-87-4-98-6	10110*
27. Power mowers - accidents	333-113-21-2-73-2	00000
28. Skateboards - falls	333-113-11-3-73-1	00000
29. Skydiving - accidents	333-113-51-2-48-1	00000
30. Skyscrapers - fire	333-423-53-3-85-4	00000
31. Smoking - fires	333-433-32-3-85-1	00000
32. Snowmobiles - collisions	333-113-41-2-73-2	00000
33. Space vehicles - crashes	333-313-84-1-98-5	00100
34. Tractors - accidents	333-113-41-2-74-2	00000
35. Trains - crashes	333-213-53-3-84-3	00000
36. Trampolines - falls	333-113-51-1-74-2	00000
MATERIALS HAZARDS		
37. Alcohol - accidents	333-313-11-4-95-2	00010
38. Alcohol - chronic effects	333-486-11-5-85-1	00010
39. Antibiotics - bacterial resistance	666-563-11-3-97-1	10000
40. Asbestos insulation - toxic effects	333-583-11-3-56-3	00000
41. Asbestos spray - toxic effects	333-583-11-1-83-3	00000
42. Aspirin - overdose	333-456-11-3-97-1	00000
43. Auto - CO pollution	333-346-11-2-94-4	00000
44. Auto - lead pollution	663-976-11-2-95-5	01000
45. Cadmium - toxic effects	663-986-11-2-74-6	01000
46. Caffeine - chronic effects	333-566-11-1-95-1	00000
47. Coal burning - NO_x pollution	693-566-11-3-95-7	10000
48. Coal burning - SO_2 pollution	693-563-11-4-94-7	10010*
49. Coal mining - black lung	333-483-11-4-64-3	00010
50. Contraceptive IUD's - side eff.	333-763-11-2-67-1	00000
51. Contraceptive pills - side eff.	333-586-11-3-74-1	00000
52. Darvon - overdose	333-556-11-4-77-1	00010
53. DDT - toxic effects	996-886-32-1-87-5	11000*
54. Deforestation - CO_2 release	696-993-11-1-91-9	10001*
55. DES - animal feed - human toxicity	333-586-11-1-93-1	00001
56. Fertilizer - NO_x pollution	393-686-11-1-93-9	00001
57. Fluorocarbons - ozone depletion	393-883-11-1-97-9	00000
58. Fossil fuels - CO_2 release	393-993-11-1-92-9	00001
59. Hair dyes - coal tar exposure	333-286-11-1-87-1	00000
60. Hexachlorophene - toxic effects	666-363-11-2-87-1	10000
61. Home pools - drowning	333-223-41-3-83-1	00000
62. Laetrile - toxic effects	333-553-11-1-55-1	00000
63. Lead paint - human toxicity	333-773-11-3-75-2	00000
64. Mercury - toxic effects	663-986-13-2-85-5	01000
65. Mirex pesticide - toxic effects	696-886-22-1-67-5	11000*
66. Nerve gas - accidents	669-836-73-1-77-5	10100*
67. Nerve gas - war use	699-836-87-3-97-7	10100*
68. Nitrite preservative - toxic eff.	336-786-11-1-91-1	00001
69. Nuclear reactor - radiation release	363-969-86-1-96-7	01100*
70. Nuclear tests - fallout	663-989-73-3-91-9	01101*
71. Nuclear war - radiation effects	699-989-88-4-97-9	11110*
72. Nuclear waste - radiation effects	363-989-15-1-82-6	01001*
73. Oil tankers - spills	663-763-61-1-15-6	00000
74. PCB's - toxic effects	663-976-13-1-97-6	01000
75. Pesticides - human toxicity	996-886-12-2-97-5	11000*
76. PVC - human toxicity	333-486-11-2-77-4	00000
77. Recombinant DNA - harmful release	393-869-97-1-97-9	01100*
78. Recreational boating - drowning	333-223-51-4-83-2	00010
79. Rubber manufacture - toxic exp.	333-986-11-3-57-4	01000
80. Saccharin - cancer	333-486-11-1-87-1	00000
81. Smoking - chronic effects	333-486-11-6-85-1	00010
82. SST - ozone depletion	393-893-11-1-93-9	00001
83. Taconite mining-water pollution	663-983-11-1-67-6	00000
84. Thalidomide - side effects	333-456-51-1-17-1	00000
85. Trichloroethylene-toxic effects	333-983-11-1-87-4	00000
86. Two,4,5-T herbicide - toxic eff.	696-886-22-1-77-5	11000*
87. Underwater construction - accidents	333-223-61-1-44-3	00000
88. Uranium mining-radiation	333-989-12-2-64-5	01000
89. Vaccines - side effects	696-556-11-2-84-1	10000
90. Valium - misuse	333-566-11-3-87-1	00000
91. Warfarin - human toxicity	666-653-11-1-87-1	10000
92. Water chlorination-toxic eff.	666-583-11-1-97-5	10000
93. Water fluoridation-toxic eff.	333-786-11-1-82-5	00001

Table 4. A seven-class taxonomy.

Class	Examples
Multiple extreme hazards	Nuclear war (radiation), recombinant DNA, pesticides
Extreme hazards	
Intentional biocides	Chain saws, antibiotics, vaccines
Persistent teratogens	Uranium mining, rubber manufacture
Rare catastrophes	LNG explosions, commercial aviation (crashes)
Common killers	Auto crashes, coal mining (black lung)
Diffuse global threats	Fossil fuel (CO_2 release), SST (ozone depletion)
Hazards	Saccharin, aspirin, appliances, skateboards, bicycles

scientific and lay estimates were encountered, suggesting that there were strong biases among our subjects for some descriptors and some hazards. The subjects also tended to compress the hazard scale, systematically overvaluing low scoring hazards and undervaluing high scoring hazards. Because this effect appeared in the scores of individual subjects, it was not an artifact of regression toward the mean. Similar effects were reported by Lichtenstein *et al.* (*23*) in comparisons of perceived risk with scientific estimates of annual mortality.

To test whether our descriptors by causes of hazards would capture our subjects' overall concern with risk, we collected judgments of perceived risk, a global risk measure whose determinants have been explored in other psychometric studies (*13, 19*). Subjects were asked to consider "the risk of dying across all of U.S. society," as a consequence of the hazard in question, and to express their judgment on a relative scale of 1 to 100. Modest positive correlations between perceived risk and our descriptor scores were obtained in 9 of 12 cases (Table 5). Each hazard descriptor thus explains only a small portion of the variance in perceived risk.

The five factors from Table 2 also showed modest positive correlations with perceived risk. Because the factors are linearly independent, the summed variance of the factors may be used to determine the total variance explained. With the sample of 34 Oregonians we find that our descriptors account for about 50 percent of the variance in perceived risk.

Perhaps the most striking aspect of these results is that perceived risk shows no significant correlation with the factor mortality. Thus, the variable most frequently chosen by scientists to represent risk appears not to be a strong factor in the judgment of our subjects.

When average ratings from the 34 subjects were used instead of descriptor scores, correlations with perceived risk increased substantially, and factor scores derived from the subjects' descriptor ratings explained 85 percent (not 50 percent) of the variance in perceived risk. It appears, therefore, that the hazard descriptors were well understood by our nonexpert subjects and that they captured most of the global concern with risk that is expressed in the variable perceived risk. Larger and more representative groups must be tested before the results can be generalized.

Applications to Managing Hazards

In addition to improving our understanding of hazards, our conceptualization of hazardousness may help society select social and technical controls to ease the burden of hazards. Though detailed discussion of hazard management is beyond the scope of this article, we can suggest three ways of improving this process.

Comparing technologies. Basic to hazard management are comparisons and choices among competing technologies. For example, for electricity generation, coal and nuclear power are frequently compared, and the hazards of each are invariably couched in terms of mortality estimates. Inhaber (*4*) has estimated that mortality rates associated with coal technology are 50 times those for nuclear power technology (Fig. 4A). Such one-dimensional comparisons have created considerable dissatisfaction because they ignore other important differences, including other aspects of hazardousness, between the two technologies (*24*).

Table 5. Correlation of causal structure descriptors with psychometrically determined values of perceived risk for 81 hazards. Only values of r at greater than 95 percent confidence level are given.

Descriptor	r
Technology descriptor	
Intentionality	.28
Release descriptors	
Spatial extent	.57
Concentration	—
Persistence	.42
Recurrence	—
Exposure descriptors	
Population at risk	.42
Delay	.30
Consequence descriptors	
Human mortality (annual)	—
Human mortality (maximum)	.53
Transgenerational	.43
Nonhuman mortality (potential)	.53
Nonhuman mortality (experienced)	.30
Factors	
Biocidal	.32
Delay	.41
Catastrophic	.32
Mortality	—
Global	.30
Variance explained (Σr^2)	.50

Our factors and descriptors for hazardousness offer a partial solution by allowing a multidimensional hazard profile to be applied to coal and nuclear power (Fig. 4B). This profile was obtained from combined descriptor scores for each of several hazard chains that make up the total hazard of coal and nuclear power (*12*). Coal still exceeds nuclear in human mortality, as expected from Inhaber's analysis, and it also exceeds nuclear in nonhuman mortality, that is, environmental effects. Nuclear power, on the other hand, dominates in possible transgenerational effects and the catastrophic factor. The two technologies show little difference in persistence, delay, population at risk, and diffuseness.

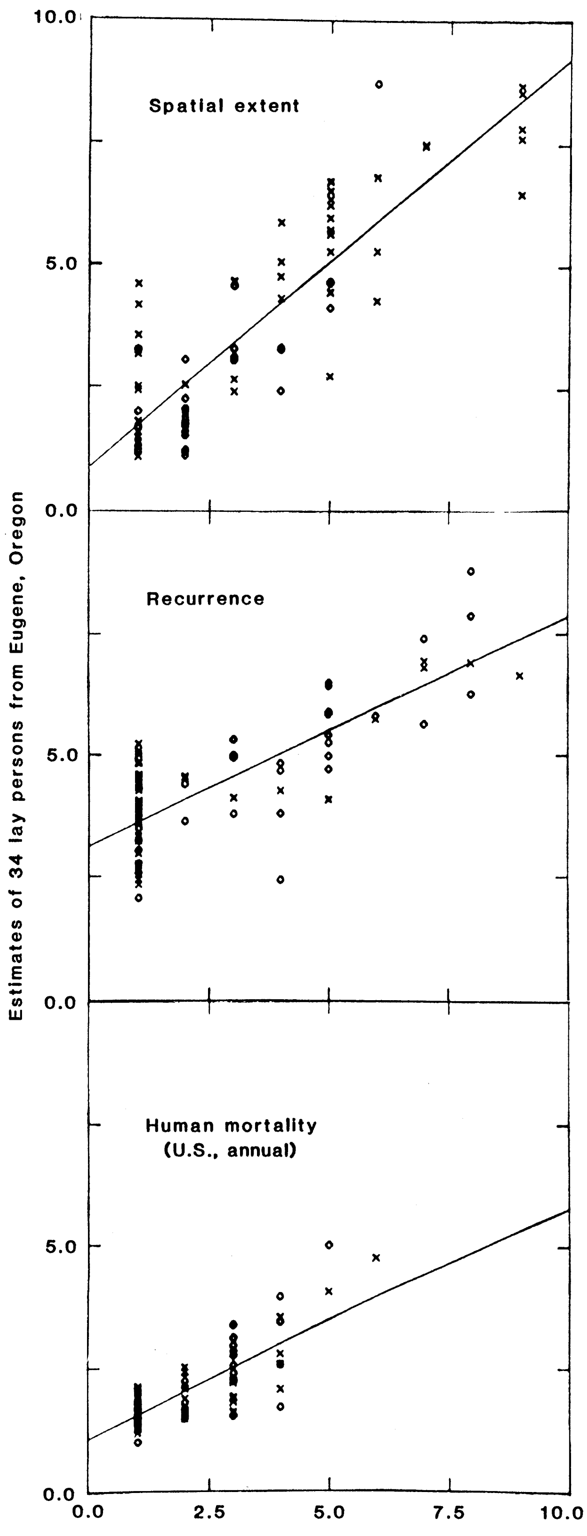
The profile of hazardousness developed from the 12 hazard descriptors seems to capture the complexity of choice in energy risk assessment and management better than the common mortality index. The problem of choice remains, as does the question of how should society weight the different dimensions of hazardousness.

Hazard of the week. Analysis of national news media shows that 40 to 50 hazards receive widespread attention each year (*25*). In theory, each new hazard goes through a sequence that includes problem recognition, assessment, and managerial action. Often there is need for early managerial response of some kind. Our descriptors of hazardousness provide a quick profile that allows new hazards to be grouped and compared with others that have similar profiles. Such comparisons may provide industrial or governmental managers some immediate precedents, as well as a warning of unexpected problems, a range of suggested managerial options, and, at the very least, a measure of consistency in public policy.

We tested this use of the profile by scoring a new hazard, tampons—toxic shock syndrome. The profile of this hazard was most similar in structure to that of the profiles of contraceptive intrauterine devices (IUD's)—side effects; and then to aspirin—overdose; Valium—misuse; and Darvon—overdose. Indeed, subsequent regulatory response to the hazard associated with tampons has paralleled that to IUD's, the hazard in our inventory closest in structure to tampons.

Triage. As a society we cannot make extraordinary efforts on each of the 100,000 chemicals or 20,000 consumer products in commerce. If our causal structure and descriptors reflect key aspects of hazards—threats to humans and what they value—then our taxonomy provides a way of identifying those hazards worthy of special attention. Cases with multiple extreme scores (Table 3) lead naturally to a proposal for triage: extraordinary attention for multiple extreme hazards, distinctive effort for each of the groups of extreme hazards, and an ordered, routine response for the remainder.

Although we regard the suggestion of triage as an important outcome of our analysis, it is well to remember that many of the extreme hazards, such as



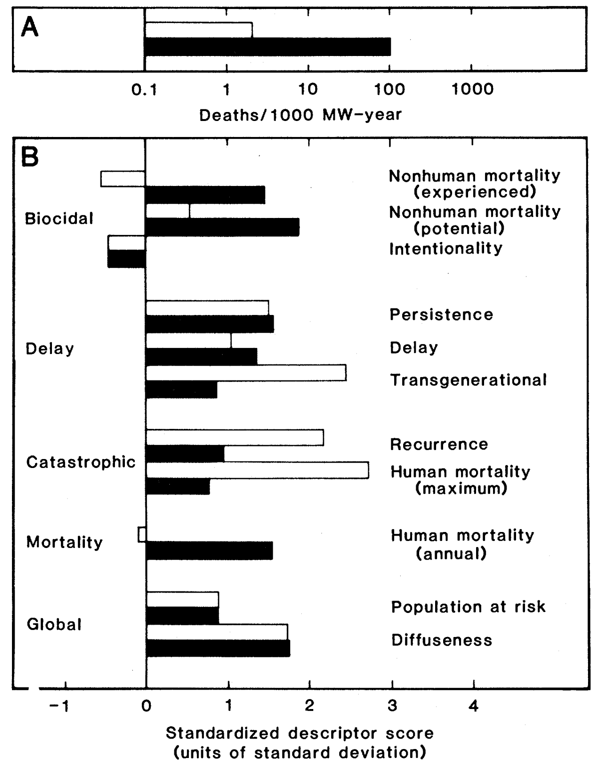


Fig. 3 (left). Scatter plots with linear regression lines indicating the correlation between mean lay judgments and our estimates of hazard descriptors. The three cases illustrate the generally high degree of correspondence between the two types of judgment, occasional deviations by as much as a factor of 1000, and except in the case of spatial extent, a significant compression of the scale of lay judgments. (x) Materials hazards; (O) energy hazards. Fig. 4 (above). Comparison of nuclear (light bars) and coal-fired (black bars) electric power by using Inhaber's analysis (A) and our hazardousness factors and descriptors (B).

nuclear weapons, are among a group that has defied solution for a long time and that special efforts expended on them may produce few concrete results. This leads some to argue that society should focus its effort on cases of proven cost-effectiveness—cases with the maximum reduction in hazardousness per unit expenditure.

We regard neither triage nor adherence to cost-effectiveness criteria as adequate foundations for managing hazards; rather, we see them as the horns of a familiar dilemma—whether to work on the big questions where success is limited, or to work on the normal, where success is expected.

Summary and Conclusions

All taxonomies are based on explicit or implicit assumptions, and ours is no different. We assume that technological hazards form a single domain, that they are defined by causal sequences, and that these are usefully measured by a few physical, biological, and social descriptors. Our picture leads us to distinguish between energy and materials releases and provides a method for constructing profiles of hazardousness that considerably extend the conventional concept of risk as annual human mortality. Our profiles of hazardousness appear to be comprehensible to lay people and to capture a significant fraction of our subjects' concern with hazardousness. This suggests that some conflict between experts and lay people may be resolved by clarifying the definition of hazardousness.

We expect that our approach can improve the quality and effectiveness of hazard management. In particular, it may help in comparing the hazards expected from competing technologies as well as provide a quicker, more orderly response to new hazards and offer society a rational approach to triage. Yet to be resolved is the assignment of weights to the different descriptors of hazard.

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