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4

A Causal Taxonomy[1]

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Despite the burden imposed by technological hazards and the broad regulatory effort devoted to their control, few studies have compared the nature of technological hazards in terms of generic characteristics. Existing studies are limited to case studies (Lawless 1977), comparative risk assessments of alternative technologies (Inhaber 1979;National Research Council 1980), lists of comparable hazards (Wilson 1979;Cohen and Lee 1979), and comparative costs of reducing loss (U.S. Dept. of Transportation 1976;Schwing 1979;Lave 1981).

A first step in ordering the domain of hazards should be classification. Today technological hazards are classified by the technology source (automotive emissions), use (medical x-rays), potentially harmful events (explosions), exposed populations (asbestos workers), environmental pathways (air pollution), or varied consequences (cancer, property damage). A single scheme is chosen, often as a function of historical or professional choice and regulatory organizations, although a given technology usually falls 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 recent achievement has been the cross-listing of several of these domains of hazardous substances by their environmental pathways (Greenwood, Kingsbury, and Cleland 1979).

In this chapter, we identify common differentiating characteristics of the domain of technological hazards in order to simplify hazard analysis and management. We conceptualize technological hazards as involving potentially harmful releases of energy or materials; characterize the stages of hazard causation via 12 physical biological, and social descriptors expressed on quantitative scales; score 93 technological hazards on these scales and analyze their correlative structure; and consider the implications of hazard structure for understanding hazards, their perception, and their management. The following is a highly condensed account of our detailed analysis (Hohenemser et al. 1983).

Measures of Hazardousness

We distinguish between **hazard** and **risk.** We define hazards as threats to humans and what they value and we define **risks** as quantitative measures of hazard consequences expressed as conditional probabilities of experiencing harm. Thus, we think of automobile driving as a hazard but say that the average American's lifetime risk of dying in an automobile crash is 2-3 percent of all ways of dying.

As already explained in chapter 2, we describe hazards as a sequence of causally connected events that lead from human needs and wants, to choice of technology, to initiating events, to possible release of materials and energy, to human exposure, and eventually to harmful consequences. To differentiate among types of hazards, we define 12 appropriate measures for describing individual hazards at each stage of this causal chain. We chose descriptors, which are identified in Figure 1 and explained in Table 1, that would be universally applicable to all technological hazards, comprehensible to ordinary people, and capable of being expressed by common units and distinctions.

As Figure 1 indicates, 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. Only one descriptor, human mortality (annual), is closely related to the traditional concept of risk as the probability of dying; the others considerably expand and delineate the idea of hazardousness.

As Table 1 indicates, four of 12 scales involve categorical distinctions, and eight are logarithmic. The latter are practical where successive occurrences range over a factor of 10 or more in magnitude and where estimated errors easily differ by the same amount. Compared to linear scales, logarithmic scales may also better match human perception, 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 (Lawless 1977; Slovic, Fischhoff, and Lichtenstein 1980;chapter 5) and, after scoring, were found to be well distributed on the 12 scales (Figure 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 of available information. After completion of scoring, a series of consistency checks led to alteration of 8 percent of the scores by 1-2 sclae points and less than 1 percent by 3 or more scale points. We therefore believe replicability to be within ±1 scale point in most cases.

Hazard Classification

Many authors have developed descriptive classifications of technological hazards. These include distinctions between voluntary and involuntary exposure (Starr 1969) and between natural and technological hazards (Burton, Kates, and White 1968). They also include lists of "considerations" (Lowrance 1976), risk factors (Rowe 1977;Litai, Lanning, and Rasmussen 1983) and psychometric qualities (chapter 5). Though mindful of this work, we based our classification on the causal structure descriptors defined in Table 1.

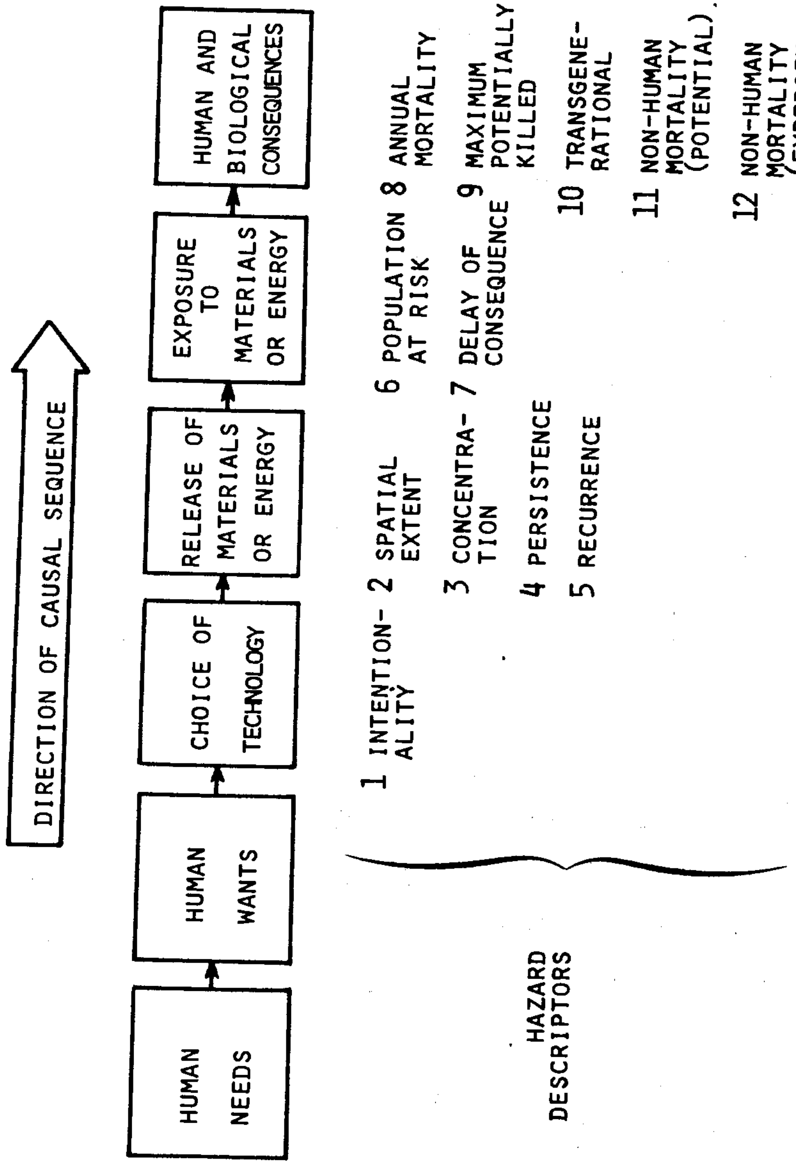

Figure 1. Causal structure of technological hazards illustrated via a simplified causal sequence. Hazard descriptors used in our classification of hazards are shown below the stage of causal evolution to which they apply.

TABLE 1
Hazard descriptor scales

TECHNOLOGY DESCRIPTOR

1. Intentionality

Measures the degree to which technology is intended to harm.

Score	Categorical Definition
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 spatial extent over which a single release exerts a significant impact. The quantitative scale is based on lineal dimensions, the categorical scale on common geographical units.

Score	Distance Scale	Categorical Definition
1	1 m	Individual
2	1-10 m	Small Group
3	10-100 m	Large Group
4	100-1000 m	Neighborhood
5	1-10 m	Small Region
6	10-100 km	Region
7	100-1000 km	Subcontinental
8	10^3-10^4 km	Continental
9	$>10^4$ km	Global

3. Concentration

Measures the degree to which concentration of released energy or materials is above natural background.

Materials and nonthermal radiation: the scale is based on the ratio, R, defined as the concentration averaged over the release scale divided by the natural background.

Score	Concentration Scale
1	$R < 1$
2	$R \simeq 1$
3	$1 < R < 10$
4	$10 < R < 100$
5	$100 < R < 1000$
6	$10^3 < R < 10^4$
7	$10^4 < R < 10^5$
8	$10^5 < R$

TABLE 1
Hazard descriptor scales (continued)

RELEASE DESCRIPTORS

Mechanical energy: the quantitative scale is based on the acceleration, a, to which humans are subjected, expressed in units of the acceleration of gravity, $g = 9.8 \text{ m/s}^2$.

Score	Acceleration Scale	Categorical Equivalent
1	$a < 1$ g	Protected ordinary life
2	$a \simeq 1$ g	Ordinary life, small falls
3	$2 < a < 5$ g	Very few fatalities
4	$5 < a < 10$ g	A few unlucky fatalities
5	$10 < a < 20$ g	Significant fatalities
6	$20 < a < 40$ g	Protected individuals survive
7	$40 < a < 80$ g	Some protected individuals survive
8	$80 < a$ g	Rare survivors

Thermal energy: the quantitative scale is based on the thermal flux, f, to which a human is subjected, expressed in units of the solar flux, $s = 2 \text{ cal/cm}^2\text{/min}$.

Score	Thermal Flux Scale	Categorical Equivalent
1	$f < 1$ s	Protected ordinary life
2	$f \simeq 1$ s	Ordinary life: 1st degree burn possible
3	$2 < f < 5$ s	1st-degree burn in minutes
4	$5 < f < 10$ s	2nd-degree burn possible; few deaths
5	$10 < f < 20$ s	2nd-degree burn in minutes; some deaths
6	$20 < f < 40$ s	3rd-degree burns possible
7	$40 < f < 80$ s	3rd-degree burns in minutes; many deaths
8	$80 < f$ s	Rare survivors

4. Persistence

Measures the time period over which the release remains a significant threat to humans.

Score	Time Scale
1	1 min.
2	1-10 min.
3	10-100 min.
....	....
8	10^6-10^7 min.
9	$>10^7$ min.

5. Recurrence

Measures the time period over which the minimum significant release recurs within the U.S. Use the scale for Persistence.

TABLE 1
Hazard descriptor scales (continued)

EXPOSURE DESCRIPTORS

6. Population at risk

Measures the number of people in the U.S. exposed or potentially exposed to the hazard.

Score	Number of People
1	0-10
2	10-100
....	....
8	10^8
9	$> 10^8$

7. Delay

Measures the delay time between exposure to the hazard release and the occurrence of consequences. Use the scale for Persistence.

CONSEQUENCE DESCRIPTORS

8. Human mortality (annual)

Measures the average annual number of deaths in the U.S. due to the hazard in question. Use the scale for population at risk.

9. Human mortality (maximum)

Measures the maximum credible number of people that could be killed in a single event. Use the scale for population at risk.

10. Transgenerational

Measures the number of future generations that are at risk for the hazard in question.

Score	Categorical Definition
3	Hazard affects the exposed generation only.
6	Hazard affects children of the exposed, no others.
9	Hazard affects more than one future generation.

11. Nonhuman mortality (potential)

Score	Categorical Definition
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.

Score	Categorical Definition
3	No experienced nonhuman mortality.
6	Significant experienced nonhuman mortality.
9	Experienced species extinction.

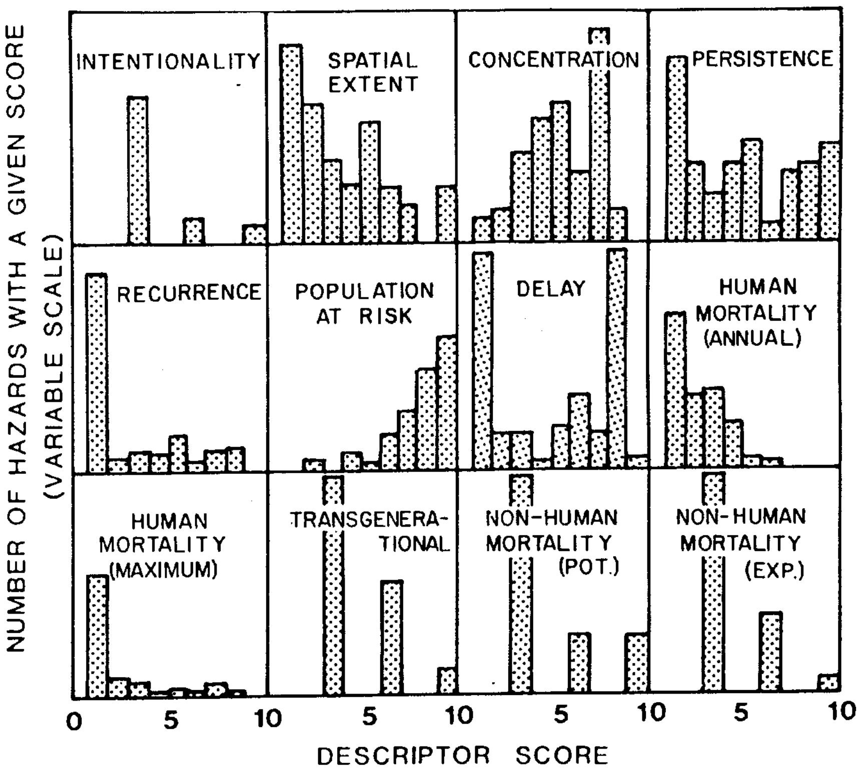

Figure 2. Descriptor frequency distribution for 93 hazards. The vertical scales are chosen to fit the space available and are different for the various descriptors.

Energy versus Materials Hazards

One of the simplest, yet significant, distinctions is the division of hazards into those that involve energy and materials releases, respectively. As illustrated in Figure 3, comparison of 33 energy hazards and 60 materials hazards leads to four striking differences: (1) Energy releases have short persistence times, averaging less than a minute; materials releases have long persistence times, averaging a week or more. (2) Energy hazards have immediate consequences, with exposure-consequence delays of less than a minute; materials hazards have exposure-consequence delays averaging one month. (3) Energy hazards have only minor transgenerational effects; materials hazards affect on the average one future generation. (4) Energy hazards have little potential nonhuman mortality; materials hazards have significant potential effects on nonhuman mortality.

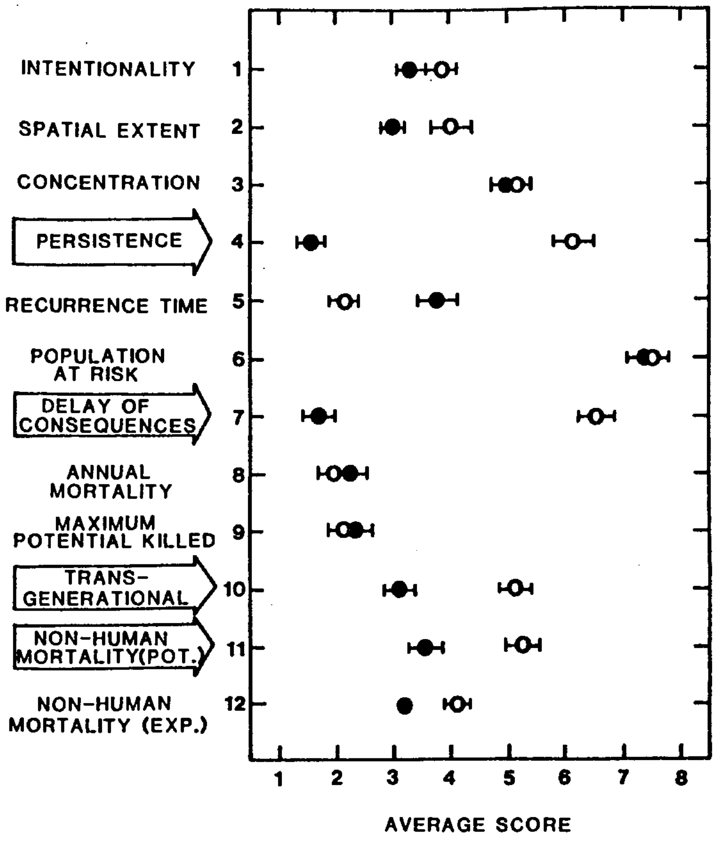

Figure 3. Average scores for energy hazards (solid circles) and materials hazards (open circles) on 12 descriptor scales. Significant differences (more than three standard deviations) are indicated by arrows on the vertical axis. Error bars indicate the standard deviation of the mean.

Reducing the Number of Dimensions

Beyond simple division of hazards by release class, we explored the extent to which hazards may be grouped according to causal structure. To this end we used principal component factor analysis^2 to derive five orthogonal composite dimensions (factors) that "explain" 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 twelve.

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. It is noteworthy that whereas the first four factors involve descriptors whose scores increase as the factor increases (positive factor loadings), the factor **global** is different. Here, because of negative loading of **concentration**, hazards scoring highest on **global** are high in **population at risk** and low in **concentration** (i.e., diffuse). The factor **global** thus picks out a special combination of hazardousness involving widespread exposure and a concentration of release that is modest with respect to background.

TABLE 2
Factor structure

FACTOR No.	FACTOR Name	Variance Explained[a] (%)	HAZARD DESCRIPTOR Name	Factor Loading[b]
1.	BIOCIDAL	33	nonhuman mortality (experienced)	0.87
			nonhuman mortality (potential)	0.79
			intentionality	0.81
2.	DELAY	19	persistence	0.81
			delay	0.85
			transgenerational effects	0.84
3.	CATASTROPHIC	11	recurrence	0.91
			human mortality (maximum)	0.89
4.	MORTALITY	11	human mortality (annual)	0.85
5.	GLOBAL	9	population at risk	0.73
			concentration	-0.73
	RESIDUAL		spatial extent	

[a] The percentages given for "variance explained" differ somewhat from those in previous work (Hohenemser, Kates, and Slovic 1983, 380), which was subject to erroneous reading of the computer output.

[b] Factor loadings are the result of varimax rotation.

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 20 percent of the scores by 1-2 scale points had no significant effect; and removing 24 hazards with the most extreme factor scores produced only minor changes in factor structure. Particularly the last finding is remarkable and quite unexpected, since extreme scores often dominate a factor solution.

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, the descriptors have been grouped by factor in the order defined in Table 2. The factor code consists of a single digit for each factor, identifies extreme scores by "1" and nonextreme 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 IUDs - side effects	333-763-11-2-67-1	00000
51.	Contraceptive pills - side effects	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 effects	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.	PCBs - 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 exposure	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 effects	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 effects	666-583-11-1-97-5	10000
93.	Water fluoridation - toxic effects	333-786-11-1-82-5	00001

Hazard scoring and 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**, using truncated factor scores.[3] The code sequence is defined in Table 3.

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 distinctions offered in Table 3 led naturally to a seven-class taxonomy with three major groupings (Table 4). The first group, **multiple extreme hazards**, includes cases with extreme scores in two or more factors; the second, **extreme hazards** comprises cases with extreme scores on one factor; and the third, **hazards**, contains all other hazards. 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.[4]

How appropriate and useful is our approach to hazard classification? To succeed it must approximate 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 next.

Comparing Perceptions

The scores for 93 hazards are products of judgments relying on explicit methods, a scientific framework, and deliberate efforts to control bias. None of these are necessarily attributes of public perception. Indeed, many scientists believe that lay judgments of hazards vary widely from scientifically derived judgments (Kasper 1980). Since hazard policy in our society is determined to a large extent by people inside and outside government 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. Although we cannot offer a definitive answer to these questions, we can report on the results of a pilot study of a group of 34 college-educated people (24 men, 10 women, mean age 24) living in Eugene, Oregon. (The study employed methods similar to those described further in chapter 5.)

To test the perception of these subjects we created nontechnical definitions and simple scoring instructions for the causal descriptors of hazards and asked our subjects to score our sample of 93 hazards.[5] After an initial trial, **concentration** was judged too difficult for our respondents to score. For similar reasons, 12 of the less familiar hazards were omitted. The subjects, using only our instructions and their general knowledge, reasoning, and intuition, then scored 81 hazards on 11 measures.

TABLE 4
A seven-class taxonomy

CLASSES	EXAMPLES
1. MULTIPLE EXTREME HAZARDS (extreme in more than one factor)	nuclear war - radiation, recombinant DNA, pesticides, nerve gas - war use, dam failure.
2. EXTREME HAZARDS (extreme in one factor)	
a. intentional biocides	chain saws, antibiotics, vaccines.
b. persistent teratogens	uranium mining, rubber manufacture.
c. rare catastrophes	LNG explosions, commercial aviation crashes.
d. common killers	auto crashes, coal mining - black lung.
e. diffuse global threats	fossil fuel - CO_2, SST - ozone depletion.
3. HAZARDS (extreme in no factor)	saccharin, appliances, aspirin, skateboards, power mowers, bicycles.

The results indicate reasonably high correlations between the scores derived from the scientific literature and the mean judgments of our lay sample, with correlation coefficients ranging from 0.65 to 0.96 (Table 5). As illustrated in three sample scatter plots (Figure 4), despite high correlation coefficients, deviations of a factor of 1000 between scientific and lay estimates were encountered. This suggests that there were significant biases in lay perceptions for some descriptors and some hazards. Also, the subjects tended to compress the scale of their judgment; in effect, lay judgments exhibited systematic overvaluation of low scoring hazards and systematic undervaluation of high scoring hazards. This effect was not an artifact of regression toward the mean, for it appears in the scores of individual subjects as well. Similar effects were found by Lichtenstein et al. (1978) in comparisons of **perceived risk** with scientific estimates of annual mortality.

To test whether our causal structure descriptors capture our subjects' overall concern with risk, we collected judgments of **perceived risk**, a global risk measure whose determinants have been explored in psychometric studies (chapter 5). 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 6, top). Each hazard descriptor thus explains only a small portion of the variance in perceived risk.

In Table 6, bottom, we show the modest positive correlations of the five factors with perceived risk. Because the factors are

TABLE 5
Correlation of lay and scientific judgments of hazard descriptors

HAZARD DESCRIPTOR	CORRELATION COEFFICIENTS ENERGY HAZARDS	MATERIALS HAZARDS	ALL HAZARDS
TECHNOLOGY DESCRIPTOR			
1. Intentionality	0.95	0.84	0.89
RELEASE DESCRIPTORS			
2. Spatial Extent	0.83	0.89	0.87
3. Concentration	N/A	N/A	N/A
4. Persistence	0.33	0.62	0.79
5. Recurrence	0.85	0.73	0.80
EXPOSURE DESCRIPTOR			
6. Population at risk	0.77	0.73	0.74
7. Delay	0.88	0.92	0.96
CONSEQUENCE DESCRIPTORS			
8. Human mortality (annual)	0.79	0.77	0.76
9. Human mortality (maximum)	0.89	0.75	0.79
10. Transgenerational	0.34	0.56	0.65
11. Nonhuman mortality (potential)	0.82	0.75	0.78
12. Nonhuman mortality (experienced)	0.63	0.73	0.71

linearly independent, the summed variance of the factors may be used to determine the total variance explained. From the sample of 34 young 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 the analysis of Table 6 is carried out using not our descriptor scores but average ratings obtained from our 34 subjects, correlations with perceived risk increase substantially, and factor scores derived from the subjects' descriptor ratings explain 85 percent (not 50 percent) of the variance in perceived risk. We conclude, therefore, that our hazard descriptors were well understood

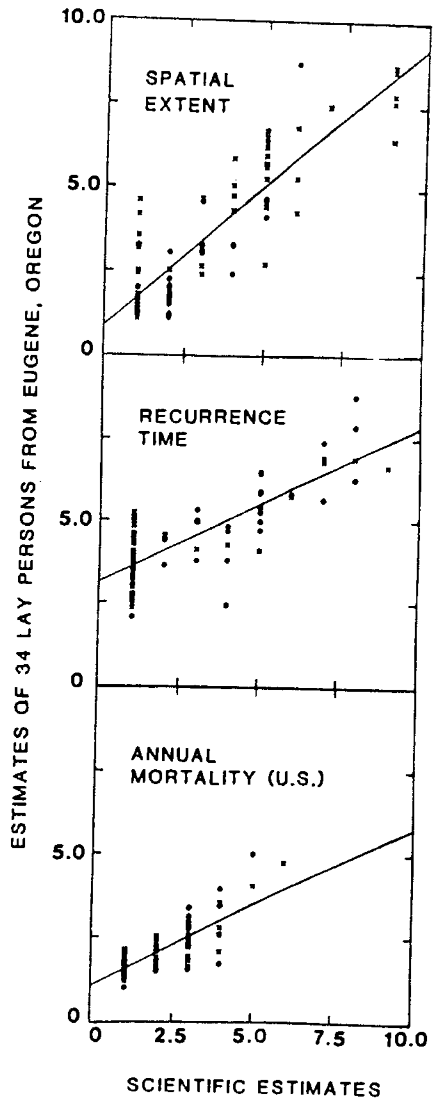

Figure 4. Scatter plots with linear regression lines indicating correlations between mean lay judgments and our estimates of hazard descriptors. The three cases are illustrative of the principal features of these correlations: (1) a generally high degree of correspondence between the two types of judgments; (2) some deviations corresponding to a factor of as high as 1000 (three scale points) on quantitatively defined logarithmic scales; (3) except for the case of spatial extent (top graph), a significant compression of scale for lay judgments, indicated by a slope of less than unity.

TABLE 6
Correlation of causal structure descriptors with psychometrically determined values of "perceived risk" across 81 hazards

HAZARD DESCRIPTOR	CORRELATION COEFFICIENTS (only r-values at greater than 0.95 confidence level are given.)
TECHNOLOGY DESCRIPTOR	
1. Intentionality	0.28
RELEASE DESCRIPTORS	
2. Spatial Extent	0.57
3. Concentration	-
4. Persistence	0.42
5. Recurrence	-
EXPOSURE DESCRIPTORS	
6. Population at risk	0.42
7. Delay	0.30
CONSEQUENCE DESCRIPTORS	
8. Human mortality (annual)	-
9. Human mortality (maximum)	0.53
10. Transgenerational	0.43
11. Nonhuman mortality (potential)	0.53
12. Nonhuman mortality (experienced)	0.30
FACTORS	
1. Biocidal	0.32
2. Delay	0.41
3. Catastrophic	0.32
4. Mortality	-
5. Global	0.30
Variance explained = Σr^2	0.50

by our pilot sample of nonexperts and that they captured most of the global concern with risk that is expressed in the variable perceived risk. Nonetheless, before these conclusions can be cast in a more general form, much additional work is needed with larger, more representative samples.

Applications to Hazard Management

In addition to improving our understanding of hazards, our conceptualization of hazardousness may assist in selecting the social and technical controls that society employs to ease the burden of hazards. Though detailed discussion of hazard management is not intended here (See chapter 3), we envision three ways of improving the management process.

Comparing Technologies

Basic to hazard management are comparisons and choices among competing technologies. For example, in debates on electricity generation, comparisons between coal and nuclear power are common. Insofar as such comparisons involve hazards, they are invariably couched in terms of mortality estimates. A controversial example is the estimate by Inhaber (1979) that coal has a mortality rate 50 times that of nuclear power (Figure 5, top). Quite aside from the validity of Inhaber's methods, which have been questioned (Holdren et al. 1979;Herbert, Swanson, and Reddy 1979), such one-dimensional comparisons create considerable controversy and dissatisfaction because they ignore other important differences, including other apsects of hazardousness, between the two technologies (Holdren 1982).

Our broader conceptualization of hazardousness offers a partial solution. To illustrate, we apply our multidimensional hazard profile for coal and nuclear power (Figure 5, bottom). This profile was obtained by combining descriptor scores for each of several hazard chains that make up the total hazard of coal and nuclear power.[6] Coal exceeds nuclear in human mortality, as would be 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 transgenerational effects and the catastrophic factor. The two technologies show little difference in persistence, delay, population at risk, and diffuseness.

We believe that our 12-descriptor profile captures the complexity of choice in energy risk assessment and management better than the common mortality index. At the same time it in no way settles the problem of choice but raises an interesting new and largely normative question: how should society weight the different dimensions of hazardousness?

Dealing with the Hazard of the Week

Analysis of national news media shows that 40 to 50 hazards receive widespread attention each year (Kates 1977). Each new hazard goes through a sequence of problem recognition, hazard assessment, and managerial action. Often there is need for early managerial response of some kind. To this end, our descriptors of hazardousness provide a quick profile that allows new hazards to be grouped with other hazards that have similar profiles.

To illustrate this possibility we used available information to score the new hazard **tampons—toxic shock syndrome.** Profile comparisons enabled us to determine that this hazard was most similar in structure to the previously scored hazards **contraceptive**

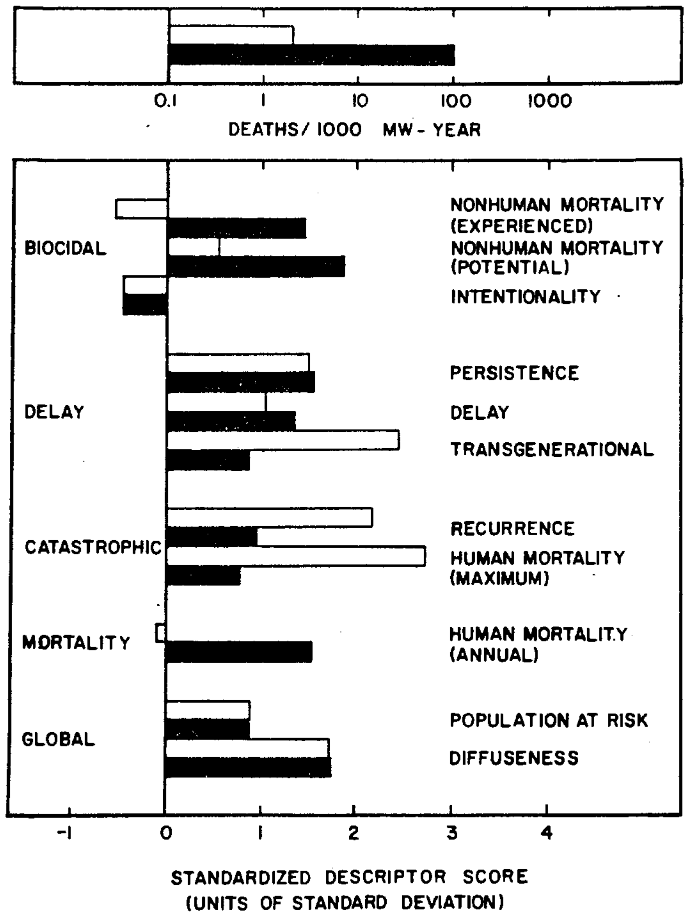

Figure 5. Comparison of nuclear and coal-fired electric power, shown by light and dark shading, respectively, using Inhaber's analysis (top) and our hazardousness concept (bottom). Labels on the left are factor names, labels on the right are names of descriptors belonging to each factor. For the method of computing the combined descriptor scores plotted here, see note 5.

IUDs—side effects, aspirin—overdose, Valium—misuse, and **Darvon—overdose.** Such comparisons may provide industrial or governmental hazard managers immediate access to relevant, albeit incomplete, precedents, as well as warning of unexpected problems, a range of suggested managerial options, and, at the very least, a measure of consistency in public policy. Indeed, subsequent societal response on tampons has paralleled that of IUDs, the hazard in our inventory closest in structure to tampons.[7]

A Case for 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 its 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 extreme scores in each of the five composite dimensions of hazard have already been identified in Table 3, and these lend themselves 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 an important outcome of our analysis, it is well to remember that many of the extreme hazards, such as 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 sequences 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.

A pilot study has shown that our profiles of hazardousness appear comprehensible to lay people and that they 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 of competing technologies, provide a quicker, more orderly response to new hazards, and offer society a rational approach to triage.

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NOTES

1. Except for editorial changes appropriate for this volume, the contents of this chapter appeared previously under the title "The nature of technological hazard," Science 220 (1983):378-384. Copyright 1983 by the American Association for the Advancement of Science. Reproduced by permission.

2. Factor analysis was done using the package Biomedical Computer Program, Program BMDP:P4M, developed by the Health Sciences Computing Facility, U.C.L.A., available in BMDP, P-series, 1979, ed. W. J. Dixon and M. B. Brown (Los Angeles: University of California Press, 1979). Orthogonal rotation was performed according to the varimax criterion, which maximizes the variance of the squared factor loadings.

3. In identifying extreme scores on each factor, we might have used exact factor scores generated by the factor analysis. These, however, include significant off-diagonal contributions, so that two hazards with identical descriptors may have significantly different factor scores. Because we believe that the significance of factor analysis lies in descriptor grouping, and not in the mathematical abstraction called a "factor," we have used truncated factor scores (consisting of sums of descriptors belonging to a given factor) to generate the extreme scoring hazards designated in Table 3. Our truncation procedure and its validity may be described as follows. By using the raw descriptor scores D_{ik} for the ith descriptor and the kth hazard, we obtained truncated factor scores

$$F^{t}_{jk} = \sum_{i} D_{ik},$$

where i runs over just the salient descriptors belonging to the jth factor. This suppresses contributions from descriptors that load weakly on the jth factor. In contrast, the factor analysis program obtains exact standardized factor scores through the 12-term sum

$$F_{jk} = \sum_{i} d_{ik} f_{ij},$$

where the d_{ik} are standardized descriptor scores belonging to the ith descriptor and the kth hazard, and f_{ij} is the 12x5 factor score coefficient matrix, given in the following table. In a statistical sense, there is little difference between the two methods: the correlation coefficients between F^{t}_{jk} and F_{jk} are (0.94, 0.96, 0.97, 0.85, and 0.96) for j = (1,2,3,4,5), respectively.

VARIABLE			FACTOR SCORE COEFFICIENTS FOR FACTORS				
No.	Mean	Stdev.	1	2	3	4	5
12	3.9	1.5	.42	-.07	-.15	-.03	-.08
11	4.6	2.4	.31	-.05	-.00	-.14	.15
1	3.7	1.6	.41	-1.2	-.04	.18	.09
4	4.4	3.0	.01	.32	-.02	-.10	-.08
7	4.8	3.1	-.03	.38	-.18	.01	-.07
10	4.4	1.9	-.21	.47	.15	.25	-.10
5	2.7	2.4	-.09	-.08	.47	-.10	-.08
9	1.8	1.6	-.06	.09	.44	.10	.03
8	2.1	1.2	.02	.08	-.00	.67	.03
6	7.6	1.7	.11	-.06	.02	.30	.57
3	5.1	1.8	.14	.07	.05	.17	-.59
2	3.5	2.5	.02	.06	.19	-.29	.27

4. We define **extreme** hazards as those with truncated factor scores of 1.2-1.5 standard deviations above the mean.

5. Instructions to subjects sought to follow as closely as possible the scale definitions described in Table 1. For example lay instructions for the descriptor **persistence** are as follows:

> Rate the persistence over time of the damage-producing activity or substance. For example, collisions or explosions usually last one minute or less. For environmental pollutants, persistence time is the length of time they remain active in the environment. For prescription drugs, rate the time they remain active in the body. Use the following scale.
>
> 1: Less than 1 minute
> 2: 1-10 minutes
> 3: 10-100 minutes
> 4: 2 hours-17 hours
> 5: 17 hours-1 week
> 6: 1 week-2 1/2 months
> 7: 2 1/2 months-2 years
> 8: 2 years-20 years
> 9: More than 20 years

6. To obtain "combined" hazard profiles, the hazards of coal-fired electric power were taken to be numbers 11, 47, 48, 49, and 58 in Table 3, and those of nuclear electric power numbers 69, 72, and 88. Consistent with the logarithmic character of most of the descriptor scales, corresponding descriptor scores from different hazard chains were combined through the addition

algorithm: score (a + b + c...) = maximum (a,b,c, ...). In effect, combined hazardousness on a given descriptor is determined by the highest scoring component hazard. Because of the negative loading of concentration on the global factor, "minimum" was substituted for "maximum" in applying the above algorithm to the descriptor concentration.

7. Management for both IUDs and tampons included three responses: (1) removal of specific products most associated with health effects; (2) stricter classification and scrutiny by the regulatory agency; and (3) warnings and recommendations for use packaged with all other products in the generic class. For details on IUDs, see chapter 17.

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