Modeling the Societal Impact of Fatal Accidents*

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Abstract

A number of proposals have been put forth regarding the proper way to model the societal impact of fatal accidents. Most of these proposals are based on some form of utility function asserting that the social cost (or disutility) of N lives lost in a single accident is a function of N^{α}. A common view is that a single large accident is more serious than many small accidents producing the same number of fatalities, hence $\alpha > 1$. Drawing upon a number of empirical studies, we argue that there is insufficient justification for using any function of N fatalities to model societal impacts. The inadequacy of such models is attributed, in part, to the fact that accidents are signals of future trouble. The societal impact of an accident is determined to an important degree by what it signifies or portends. An accident that causes little direct harm may have immense consequences if it increases the judged probability and seriousness of future accidents. We propose that models based solely on functions of N be abandoned in favor of models that elaborate in detail the significant events and consequences likely to result from an accident.

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Although the world has become safer on the average, it has remained quite dangerous at the extreme. Thus as technology has increased life expectancy, it has also created the potential for catastrophic losses such as those due to dam failures, radiation releases, and airline crashes. Not surprisingly, the control of hazards has become a major concern of society and a growing responsibility of government. The need to cope with these risks has led to the development of formal analytical methods such as risk assessment and decision analysis, designed to assist policy makers in making decisions about safety.

This paper addresses a frequently asked question pertaining to the application of formal analysis to safety decisions: "How should a single accident that takes N lives be weighted relative to N accidents, each of which takes a single life?" The answer to this question can have a substantial influence on the resources allocated towards preventing accidents of varying degrees of severity. Assigning disproportionate weight or seriousness to multiple-fatality accidents would tend to prevent such accidents at the cost of increasing the risk from smaller accidents.

Following Keeney [11], we distinguish the personal impacts of a fatal accident (such as the pain, suffering, and economic hardship of the victims and their friends and relatives) from its societal impacts (such as the public distress and the political, social, and economic turmoil that may result from such an accident). Our focus here is on the societal impacts. We begin by surveying various proposals from the literature regarding the relative weighting of multiple-fatality accidents. The most common view found there is that: (a) the societal impact of the fatalities arising from an accident can be modeled adequately as a function of N, the number of lives lost and (b) this function should treat a single large accident as more serious than many small accidents producing the same total number of fatalities. We shall present evidence counter to this view, arguing that such a model is a doubtful basis for social policy.

Proposals

Most of the proposals for modeling the impacts of multiple-fatality accidents have been based upon some form of utility function asserting that the societal cost (or disutility) of N lives lost in a single accident is a function of N^{α}. We shall refer to this as the α model. Three general forms of the α model have been discussed. As shown in Figure 1, these are distinguished by whether $\alpha=1$ (risk neutrality), $\alpha>1$ (risk aversion), or $\alpha<1$ (risk proneness).

Insert Figure 1 about here

Many different arguments have been brought forth regarding the proper value for α. Casual observation of society's apparent acceptance of major chronic hazards (such as those from motor vehicles), contrasted with its seemingly greater concern for potentially catastrophic hazards (e.g., nuclear reactors) has led some to conclude that society is risk averse:

> The public appears to accept more readily a much greater social impact from many small accidents than it does from the more severe, less frequent occurrences that have a smaller societal impact. [20; p.12].

Wilson [22] attempted to quantify the degree of risk aversion, proposing that an accident involving N people simultaneously be treated as N^2 (not N) times as serious as an accident involving one person. More systematic observation of accident statistics led Ferreira and Slesin [9] to a similar conclusion, namely, "the value of each additional life lost in a single accident is greater than the one before" (p. 35). The analysis leading to this conclusion was based on the assumption that existence of a consistent relationship between severity (N) and frequency of occurrence (f) of deaths would reflect, and thus reveal, the workings of a deliberate social attitude towards disasters. Plotting data on deaths due to fires, natural hazards, mining disasters, and transportation accidents, Ferreira and Slesin observed that $f \cdot N^3$ was approximately constant. This result, they argued, revealed an aggregate social consensus that the relative impact of a disaster taking N lives is approximately equal to N^3.

Griesmeyer, Simpson, and Okrent [9] disputed Ferreira and Slesin's methodology and interpretations, pointing out that the steep decline in frequency with increase in magnitude need not reflect the controlling influence of any social value system. Griesmeyer et al. noted that the observed frequency-magnitude relationship could be due to many other factors, such as the cost of accident prevention and physical limitations on the number of situations that could lead to large consequence events. Further, they argued that α values of 2 or 3 are clearly inconsistent with the level of risk tolerated from many current technologies. For example, many dams or chemical storage facilities located near large population centers pose extremely small (but non-zero) probabilities of accidents killing thousands of persons. The benefits of such facilities would never be able to outweigh the expected social costs if the potential fatalities were raised to the second or third power prior to being weighted by their probabilities of occurrence. Yet such facilities exist.

A more fundamental weakness of analyses like that of Ferreira and Slesin's is the assumption that current levels of risk are socially acceptable and constitute appropriate guides for future decisions. If one doubts these assumptions, then little can be concluded from historical risk statistics [7].

Although skeptical of Ferreira and Slesin's analysis, Griesmeyer and Okrent [8] did not abandon the notion of risk aversion. Arguing that the trauma and other secondary impacts of large accidents reduce society's resilience, they recommended incorporating a modest degree of risk aversion in safety criteria for nuclear reactors. To provide an incentive to reduce the magnitude and frequency of large accidents, they tentatively proposed using α=1.2 to evaluate the severity of early deaths due to reactor accidents. Other proposals for reactor safety criteria have also incorporated risk aversion [4, 13, 19, 23].

Risk aversion is a popular, but by no means universal, view. Keeney [11, 12] has presented three assumptions, each of which leads to risk proneness. The first assumption asserts that a sure loss of N fatalities is less desirable than a 50-50 chance of either 2N fatalities or 0 fatalities. This assumption has received some empirical support. When people were asked to imagine themselves in the role of civil defense officials forced to choose between such policies, fewer than 25% selected the policy leading to the sure loss [6]. Keeney's second assumption asserts that as N gets increasingly large, each incremental life lost has less marginal societal impact. The intuitive justification for this second assumption is Keeney's impression that the societal impacts of, say, 50,000 and 100,000 fatalities would be fairly similar. Keeney's third assumption is that people would prefer "risk equity" defined as uniform risk of death across individuals. He has shown that risk proneness logically follows from such a preference [12].

The linear, or risk-neutral, impact function of Figure 1 also has its advocates. As Keeney [11] observed, only this type of function is compatible with the desire to minimize the expected number of lives lost. Also, it is the function underlying the use of monetary amounts to value lives lost in risk analysis [10, 14, 24].

Are People Really Risk Averse?

Our own view, to which we now turn, is that social response to multiple-fatality accidents does not reflect risk aversion and that the use of the α model in risk analysis is inappropriate. As a case in point, we will consider the limitations of models with $\alpha>1$ for guiding social policy regarding nuclear power.

For some observers, the clearest evidence that society places disproportionate emphasis on avoiding multiple-fatality accidents is its treatment of nuclear power. There is no question that society reacts strongly to the threat of nuclear accidents by requiring reactors to satisfy a great number of strict and costly regulations. We believe, however, that this reaction occurs because many people see the risks from nuclear reactors as uniquely unknown and unbounded. It's not that $\alpha>1$ for nuclear power risks but that the potential N is believed to be very large.

One source of evidence for this view comes from studies in which various groups of laypeople were asked to characterize the risks from nuclear power and other risky technologies and activities on various qualitative dimensions

[15, 16, 17, 21]. The "risk profiles" derived from these ratings showed that nuclear power had the distinction of scoring at or near the extreme on a number of undesirable characteristics. Its risks were seen as particularly involuntary, unknown, uncontrollable, unfamiliar, dread, and fatal. Further analysis indicated that these various risk characteristics could be collapsed into two more general dimensions or factors, unknown risk and dread (uncontrollable, catastrophic) risk. The unique position of nuclear power, in the extreme unknown and dread quadrant of this space, is shown in Figure 2.

Insert Figure 2 about here

Further research has provided additional insights into the nature of people's perceptions of nuclear risks. In one study [15] people were asked to "estimate how many people are likely to die in the U.S. next year (if next year is an average year)" as a consequence of each of 30 activities and technologies. In addition, respondents were asked to give a multiplier indicating how many times more deaths would occur if next year were "particularly disastrous," rather than average. The results indicated that nuclear power was recognized as having relatively few fatalities in an average year. However, nuclear power was in a class by itself as far as its perceived potential for catastrophic losses of life. The geometric mean of these multipliers was about 100. More than 40% of the respondents had multipliers in excess of 1,000. Each respondent's expected number of fatalities from an activity in a disastrous year was estimated by applying the disaster multiplier to his or her average-year fatality estimate. When this was done for nuclear power, almost 40% of the respondents had estimates greater than 10,000 fatalities and more than 25% had estimates exceeding 100,000 fatalities. Another study [18], in which people were asked to write scenarios describing their image of a maximum credible nuclear power disaster, further demonstrated the belief that nuclear power can lead to hundreds of thousands, even millions, of immediate deaths. Given such images of disaster, there is no need to raise the number of expected fatalities to a power greater than 1 to explain people's strong concerns about nuclear power and their desire to see it regulated strictly.

An Experimental Test of Risk Aversion

The research cited above suggests that what appears to be a special aversion to nuclear reactor accidents may result from people's perceptions of these risks as extreme, unbounded, and catastrophic. Because people view these risks as unknown and possibly immense, they react strongly to actual and potential accidents.

However, our ability to draw general conclusions from these results is limited because nuclear power risks confound two important characteristics, catastrophic potential and imprecision. A clearer understanding of people's risk attitudes might be obtained if these two qualities could be unconfounded. Would people be averse to multiple-fatality accidents if their risks were known with precision? Would the introduction of imprecision into the risk estimates lead to greater risk aversion?

We addressed these questions by designing an experiment in which we asked several hundred college students to play the role of a regulator who had to choose between two proposed safety rules that expressed different attitudes towards risk aversion. Rule A would save lives by preventing individual-fatality accidents. Rule B would save somewhat fewer lives by reducing the probabiblity (or in some cases the magnitude) of multiple-fatality accidents (see Table 1). The risks associated with each action were precisely described. Thus a choice indicating risk aversion could not be attributed to the greater imprecision that usually characterizes catastrophic risks.

Insert Table 1 about here

In this study, more than 70% of the respondents selected Rule A, thus choosing to minimize average lives lost rather than reduce the risk of a catastrophic accident. In order to assess the robustness of this result, we tried two variations on this task. In one case, Rule B was said to reduce the number of lives lost in a single accident from 300 to 30, leaving the probability unchanged at 1/10. In the second, paragraph-length arguments were given in support of each rule. Neither variation made a difference in the results. Thus, for these precisely defined fatality estimates, we found no evidence of risk aversion.

In order to investigate the effects of uncertainty, we designed a variation of the regulatory choice task in which respondents were told:

> One complication is that even the best technical experts express uncertainty about the number of lives that might be lost if a multiple-fatality accident occurs. Although 300 is indeed the best estimate, it is possible that many fewer or many more lives might be lost. Having considered the rather large range of the number of fatalities that might occur, the staff feels strongly that 30 fatalities is a realistic average per year for multiple-fatality accidents.

This description was intended to simulate the sort of imprecise knowledge that might be found in the assessments of risk from nuclear reactors.

Introduction of imprecision into the risk estimate made our respondents somewhat more concerned about reducing the multiple-fatality accident. Although the majority still chose to minimize average fatalities by means of Rule A, selection of Rule B increased from below 30% to about 43% of the respondents.

The effect of imprecision, although small in this study, further suggests that people's strong concerns about reactor accidents are due, not to risk aversion, but to their belief that N is large and not precisely bounded.

Accidents as Signals

In addition to being skeptical about the appropriateness of modeling societal impacts by some risk-averse function of N fatalities, we have doubts about the ability of any function of N, risk averse or not, to capture the societal importance of fatal accidents. The most dramatic demonstration of the inadequacies of such models comes from examining the consequences of the accident at the Three Mile Island (TMI) nuclear reactor in 1979 [2,3]. Few accidents in our history have had such enormous societal impact. As one industry source observed with a mixture of frustration and puzzlement:

> The irrevocable loss of nuclear generating capacity for the rest of the century [due to the TMI accident] is already equivalent to 2 million barrels of oil per day during that time, regardless of conservation efforts. This represents an additional fuel bill of as much as $500 billion...and is one measure of the price being paid as a consequence of fear arising out of an accident that according to the most thorough estimates may

not have physiologically hurt even one member of the public. [1; p. 30]

The extreme impact of the TMI accident on the structure and viability of the entire nuclear power industry would never have been predicted by the α model or any other model based solely on number of fatalities. We believe that at least one missing ingredient in these simple models is recognition of the role that accidents play as signals of future trouble [22]. Thus, the social impact of an accident will be large, regardless of its death toll, if the accident greatly increases the estimated risk of the activity or technology. The accident at TMI was seen as such an extremely informative and ominous signal, raising fears that this technology was not adequately under control. As a result, it led to a strong sociopolitical reaction whose consequences (stricter regulation of the nuclear industry, reduced operation of reactors worldwide, increased costs of reactor construction and operation) dwarfed the more direct costs (possible latent cancers, property damage, repairs, cleanup, etc.), significant as these were.

The potential importance of viewing accidents as signals goes beyond the domain of nuclear power. The generality of this concept is demonstrated by a study in which we asked 21 women (median age = 37) to rate the seriousness of 10 hypothetical accidents. Several aspects of seriousness were rated, including:

(a) The total amount of suffering and grief caused by the loss of life in each mishap;

(b) the number of people who need to be made aware of the mishap via the media;

(c) the amount of effort (and money) that should be put into investigating the cause of the mishap and preventing its recurrence; and

(d) the degree to which hearing about the mishap would cause one to be worried and upset during the next few days.

Our respondents also rated the informativeness of these incidents, defined as the degree to which the mishap told them (and society) something that may not have been known about the hazardousness of the specific activity.

The accidents were constructed so as to vary with respect to total fatalities and informativeness (see Table 2). The five less informative accidents represented incidents that were generated by reasonably familiar and understood processes. The more informative mishaps were designed to signal a change in riskiness, some potential for the proliferation of similar mishaps, or some breakdown in the system controlling the hazard. For example, a bus skidding on ice represented a low-information mishap because its occurrence did not signal a change in motor-vehicle risks (except for a limited time at that site), whereas an accident caused by a poorly designed steering system in a new model automobile would be informative about all such vehicles.

Insert Table 2 about here

All ratings were on a seven-point scale. The mean ratings are shown in Table 2. Note that the five mishaps designed to be high in signal value were all judged more informative than any mishap in the low-information category. In general, the amount of suffering and grief attributed to an accident was closely related to the number of people killed. All other aspects of perceived seriousness were, however, more closely related to the accident's information content. Accidents signaling a possible breakdown in safety control systems or the possibility that the mishap might proliferate were judged more worrisome and in need of greater awareness and greater public effort to prevent reoccurrences. The number of people killed was not related to these aspects of seriousness.

To gain a more systematic understanding of the concept of accidents as signals, we attempted to determine whether signal potential was related to the factor structure of perceived risk shown in Figure 2. We selected a set of 30 hazards, known on the basis of a previous study [17] to be distributed across the four quadrants of the factor space. From the high dread, high unknown quadrant, we selected hazards such as DNA technology, nuclear reactors, orbiting space satellites, and radioactive wastes. Highly unknown but not dread hazards included microwave ovens, contraceptives, water chlorination, and antibiotics. Known and dread hazards included coal mining, nerve gas, dams, and commercial aviation. Known but not dread hazards included skateboards, power mowers, tractors, bicycles, automobiles, and recreational boating.

The participants in this study were 78 university students who rated each of these 30 hazardous activities and technologies according to the degree to which an accident taking 1 or 2 lives "serves as a warning signal for society, providing new information about the probability that similar or even more destructive mishaps may occur within this type of activity." The participants were also asked to rate the overall seriousness of an accident involving each of those hazards (holding fatalities and other damages constant).

The size of each point in Figure 3 reflects the mean rating of signal potential for each hazard. It is apparent that the judged signal potential of a hazard is closely related to location within the two dimensional space. Signal potential correlated with the "dread" factor (r=.58), the "unknown" factor (r=.71), and their linear combination (r=.92). Signal potential also correlated .94 with mean ratings of the overall seriousness of an accident.

Insert Figure 3 about here

In sum, the signal potential of an accident is closely related to its perceived seriousness and is highly predictable from knowledge of where the hazard stands with regard to dread risk, unknown risk, and the component characteristics that comprise these general factors (these components are shown at the bottom of Figure 2).

Conclusions

The societal impact of fatal accidents cannot be modeled solely by a function of N, the number of fatalities, including the oft-proposed function N^{α}. Therefore, models based on such functions should not be used to guide decisions about hazardous activities or technologies.

One reason for the inadequacy of models based solely on the number of fatalities is that accidents are signals, providing information about the nature and controllability of the risks involved. An accident will have relatively little societal impact beyond that of its direct casualties if it occurs as a result of a familiar, well understood process with little potential for proliferation or catastrophe. In contrast, an accident that causes little direct harm may have immense consequences if it increases the judged probability or seriousness of future accidents.

The concept of accidents as signals helps explain society's strong response to some nuclear power mishaps. Because reactor risks are perceived as poorly understood and catastrophic, accidents with few direct casualties may be seen as omens of disaster, thus producing indirect or "ripple" effects resulting in immense costs to industry and society. One implication of signal value is that great effort and expense might be warranted to minimize the possibility of small but frightening reactor accidents.

The systematic relationship between signal potential, accident seriousness, and the characteristics of a hazard (Figure 3) may provide some guidance for modeling societal impacts. For familiar hazards, whose risks are seen as well understood and neither dread nor catastrophic, accidents may carry little new information and their social impact may be determined adequately by the direct costs of N lives lost. For hazards that are less well understood, more dread, or both, accidents will be more potent signals and a simple function of N will not be adequate to represent their import.

Although signal potential may be a useful indicator of the need for more complex modeling, it alone is an incomplete model of impact. For example, the rupture of a pipe in the steam generator of the Ginna Nuclear Power Plant in January 1982 and the subsequent radiation release, had some characteristics of the accident at TMI. However, the Ginna mishap was controlled quickly and effectively and led to none of the broader societal consequences that followed TMI. The physical, managerial, and social contingencies that differentiated this accident from the one at TMI need to be discovered and included in models designed to represent the societal impacts of a reactor mishap.

In sum, when attempting to model the societal impacts of accidents, we see no alternative but to elaborate the various events and consequences that may result from such accidents, the consequences of these consequences, the probabilities of all these direct and higher order effects, and some measures of their costs. Such modeling may appear unmanageably complex. However, we believe that even a rough or crude attempt to anticipate possible higher order consequences of an accident is preferable to the use of simpler models with known inadequacies.

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Table 1

Descriptions of Safety Rules Posing a Choice Between Minimizing Fatalities or Reducing the Risk of Multiple-Fatality Accidents

Summary of Current Situation

Type of accident	No. of deaths per accident		Average frequency of accidents per year		Average No. of deaths per year
Single-fatality accidents	1	x	200	=	200
Multiple-fatality accidents	300	x	1/10	=	30
	Total Average Number of Deaths			=	230

Summary of Safety Rule A

Type of accident	No. of deaths per accident		Average frequency of accidents per year		Average No. of deaths per year	Average No. lives saved
Single-fatality accidents	1	x	170	=	170	30
Multiple-fatality accidents	300	x	1/10	=	30	0
	Total Average Number of Deaths			=	200	30

Safety Rule A is a rule requiring the installation of a different set of new and expensive equipment that would reduce the frequency of single-fatality accidents per year from its present average of 200 down to a new average of 170. The new equipment would not change the likelihood or severity of multiple-fatality accidents. Thus Safety Rule A would, on average, save 30 lives per year.

Summary of Safety Rule B

Type of accident	No. of deaths per accident		Average frequency of accidents per year		Average No. of deaths per year	Average No. lives saved
Single-fatality accidents	1	x	200	=	200	0
Multiple-fatality accidents	300	x	1/100	=	3	27
	Total Average Number of Deaths			=	203	27

Safety Rule B is a rule requiring the installation of new and expensive equipment that would reduce the frequency of a mutliple-fatality accident from its present 1-in-10 chance per year to a 1-in-100 chance per year. It would not affect the number of workers dying if the accident occurs. Nor would it in any way affect the frequency of single-fatality accidents. Under Safety Rule B, the average number of lives lost per year from a mutlple-fatality accident would go from its present 1/10 x 300 = 30 down to 1/100 x 300 = 3. Thus Safety Rule A would, on average, save 27 lives per year.

TABLE 2

Effect of Informativeness on the Impact of Catastrophic Mishaps

	Informativness	Suffering and Grief	Need for Awareness	Effort to Prevent Recurrence	Worry
Less Informative Mishaps					
Bus skids on ice and runs off road (27 killed)	1.8	4.4	2.5	3.1	1.8
Dam collapse (40 killed)	4.7	4.9	4.7	5.9	3.8
Two jumbo jets collide on runway (600 killed)	4.8	6.1	5.8	6.5	4.5
Hundred year flood (2,700 killed)	2.8	6.1	5.3	3.5	2.7
Meteorite hits stadium (4,000 killed)	2.2	6.2	5.7	2.1	2.5
More Informative Mishaps					
Nuclear reactor accident: Partial core meltdown releases radiation inside plant but not to outside (1 killed)	6.5	4.5	6.5	7.0	6.1
Botulism in well-known brand of food (2 killed)	5.7	3.7	5.2	6.1	4.6
New model auto steering fails (3 killed)	5.2	3.8	5.2	6.3	4.6
Recombinant DNA workers contract mysterious illness (10 killed)	6.1	4.6	5.9	6.3	5.1
Jet engine falls off on takeoff (300 killed)	5.7	6.0	6.1	6.9	5.5

Source: Slovic, Fischhoff & Lichtenstein [16]

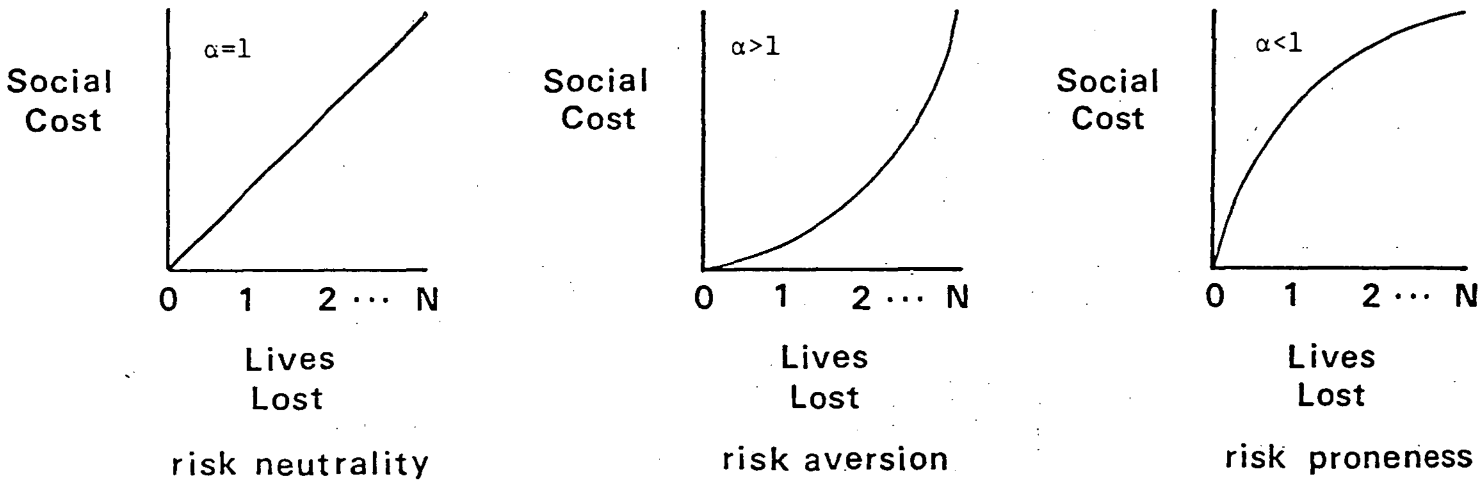

Figure 1. Three proposals regarding the impact of multiple-fatality accidents.

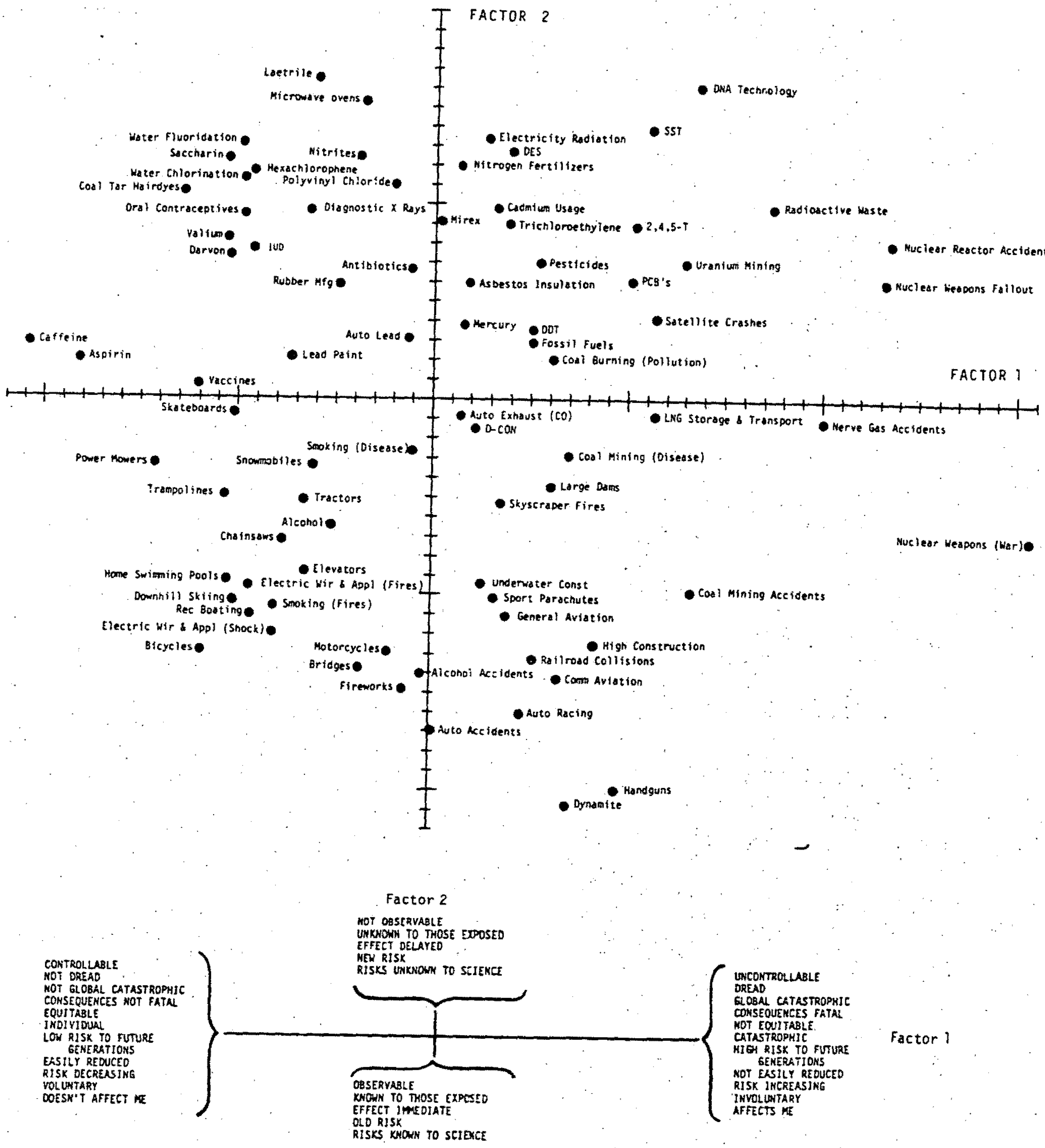

Figure 2. Hazard locations on Factors 1 and 2 derived from the interrelationships among 18 risk characteristics. Each factor is made up of a combination of characteristics, as indicated by the lower diagram.

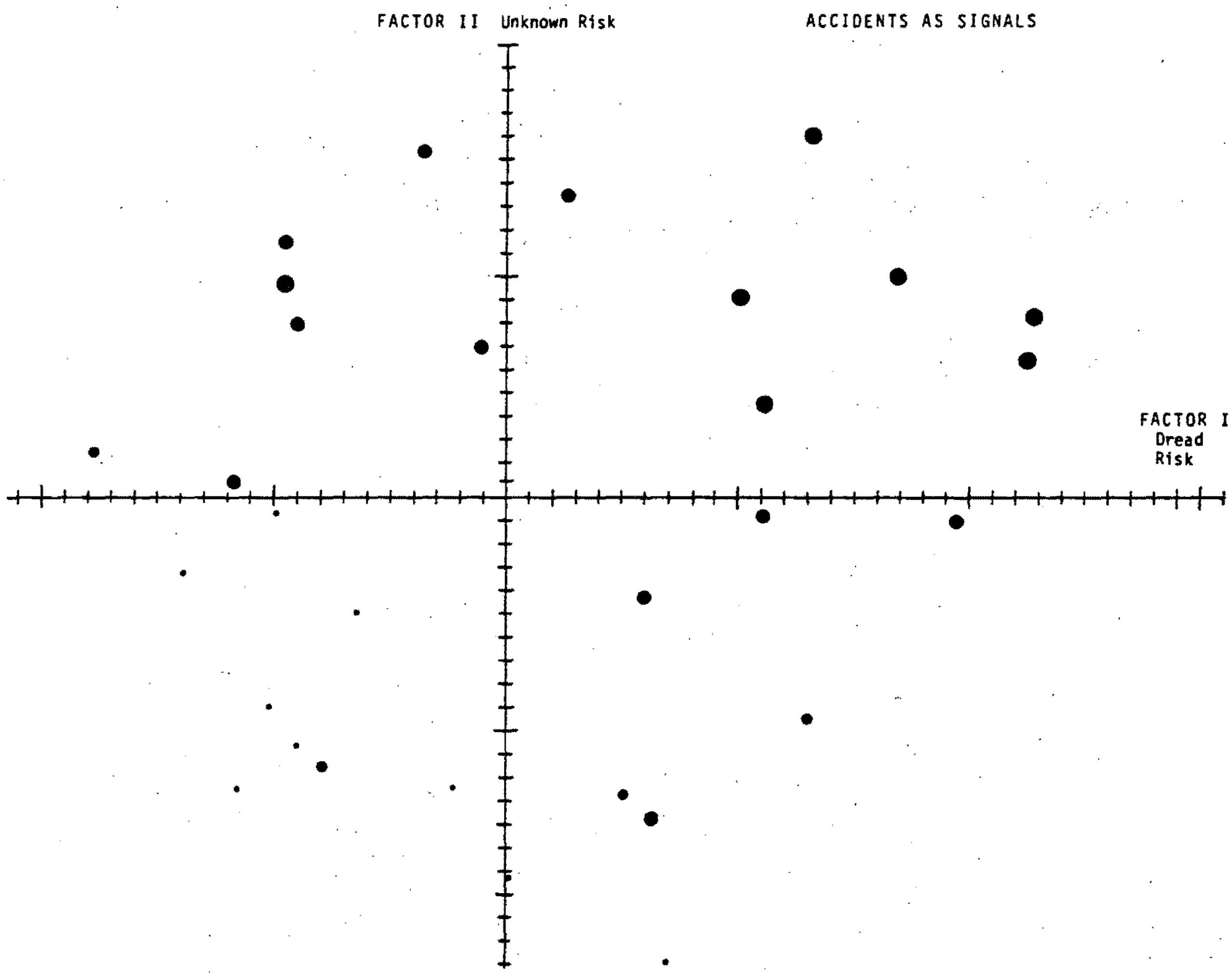

Figure 3. Relation between signal potential and risk characterization for 30 hazards. Each point represents a hazardous activity. The larger the size of the point, the greater the degree to which an accident involving that hazard was judged to "serve as a warning signal for society, providing new information about the probability that similar or even more destructive mishaps might occur within this type of activity."