

## CONTRASTING PERCEPTIONS OF THE RISKS OF USING NUCLEAR ENERGY SOURCES IN SPACE

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### Abstract

An open-ended interview procedure was used to elicit beliefs regarding the risks created by the use of nuclear energy sources in space. Respondents selected from two organizations of peace and environmental activists and from several engineering associations were found to have generally similar levels of knowledge, despite having very different attitudes toward the technology. A third group, drawn from the general public, performed more poorly in most respects. The details of each group's beliefs provide clues regarding the factors shaping their attitudes and the ways to formulate effective risk communications.

### Introduction

Many environmental controversies boil down to furious debates between protagonists identified with either pro-development or pro-environment groups, while members of the general public look on as bewildered spectators. A common diagnosis of these disputes is that they reflect disagreements over the magnitude of the risks posed (or avoided) by environmental actions. Because the people favoring development often have technical backgrounds, a convenient variant of this diagnosis is that their opponents simply do not understand the issues. The convenient rejoinder is that the technical analysts are captives of the technology's developers or at least of their own enthusiasm; as a result, the risk numbers that they produce are not to be trusted (National Research Council, 1989).

These conflicting interpretations are unsatisfying for many reasons. Aside from being self-serving and unsubstantiated by systematic empirical evidence, such claims typically ignore all the other possible reasons for disagreeing about environmental actions. Two parties can agree about the size of the risks and still disagree about how aversive those risks are, about how much benefit is provided in compensation for bearing the risks, and about what else is at stake (e.g. the distribution of power in society). A full understanding of these controversies requires exploration of all these potential sources of disagreement (Fischhoff *et al.*, 1983; Weller, 1987;

Krimsky & Plough, 1988; Kasperson & Stallen, 1991).

Even when disputes actually do focus on the size of the risks, many different issues may be involved. Estimates of the size of a technology's risks may reflect (any combination of) its annual death toll, its potential for catastrophic accidents, the uncertainty surrounding it, and the future extent of its effects—among other dimensions.<sup>2</sup> Thus people may disagree about the size of a risk simply because they define 'risk' differently (Crouch & Wilson, 1981; Kuklinski *et al.*, 1982; Fischhoff *et al.*, 1984; Slovic, 1987; Fischhoff *et al.*, 1993).

The size of a risk is most relevant when one is poised to make a decision in which the quantity of risk can be compared with the quantity of the attendant benefits, or else to some absolute standard of acceptability. In many cases, though, risk debates are predecisional, focusing on qualitative issues such as how the environmental intervention works, how it causes its good and bad effects, and what can be done to amplify or attenuate them. Such issues can be the center of attention, for example, when people are trying to achieve cognitive competence on a topic, or to articulate possible responses, or just to follow the debate. Even when quantitative estimates are needed, risk-estimation procedure may be so controversial that they cannot be trusted without some substantive knowledge of how the technology works, against which the realism of the estimates can be judged.

One obvious way to measure qualitative understanding is by administering a structured (e.g. True-False, multiple choice) knowledge test. The performance of different groups can then be expressed in terms of their scores, perhaps broken down by topics, or even by individual items. There are, however, well-known threats to the validity of such tests: inadvertent hints, unfamiliar terminology, misleading distractors, and failure to explore misconceptions that test compliers never considered. These threats may be particularly large when studying environmental issues, where experts and lay-people often have very different cultural, educational, and socioeconomic backgrounds (e.g. Fischhoff *et al.*, 1987; Vaughn, 1993; Wandersman & Halman, 1993). In principle, one would prefer an open-ended procedure that allows people to express their beliefs in their own terms.

Over the past 5 years, we have developed such a procedure, which we have used to study perceptions of varied risks, including those posed by radon, Lyme disease, climate change, electromagnetic fields, and river flooding. With it, we have had some success in identifying misconceptions, examining the coherence of beliefs, developing convergent structured tests, and creating communications that improve understanding (Bostrom *et al.*, 1992; Morgan *et al.*, 1992; see also Jungermann *et al.*, 1991).

In an earlier study (Maharik & Fischhoff, 1992), we applied this procedure in a fine-grained analysis of the perceptions of citizens drawn from two peace and environmental groups, regarding the processes capable of creating risks in one particular context: the use of nuclear energy sources in space. Their responses revealed a complex pattern of strengths and weaknesses. The details of these results provide guidance on how to design communications that will help such citizens participate in decisions about these technologies. Viewed in isolation, though, the results convey no clear message regarding such citizens' current level of competence to make those decisions. Since they know some things and not others, it is possible to view their beliefs as a glass half empty or a glass half full. In such situations, it may be tempting to accentuate the negative or the positive, in keeping with one's prejudices regarding how much society should listen to such activists (Fischhoff, 1990). The results of these studies also say nothing directly regarding how similar their beliefs are to those held by individuals who favor technological development or by members of the general public. As mentioned, such individuals could agree about the facts of a risk, while still disagreeing about its acceptability.

The present study provides such comparisons by applying the same open-ended interview procedure to individuals drawn from pro-technology groups and members of the general public. Their responses allow an assessment of where the groups disagree, how essential those disagreements are, and where to focus communications and discussions in order to bridge the informational gaps between the groups.

In the period preceding this study, these particular risks had been the topic of considerable media attention, especially around the Galileo and Ulysses space missions, both of which use nuclear energy sources. This might be seen as a case (a) where a generally favored technology (space flight) and a highly disfavored one (nuclear energy) come together, (b) where people draw on beliefs about more familiar technologies (e.g. nuclear power, nuclear weapons, space flight) to make inferences about an unfamiliar one, and (c) where a common industrial practice suddenly comes into public view (Davis 1989; Dye, 1989; Foley, 1989; Sawyer, 1989). The space community's concern over adverse publicity can be seen in its stream of risk communications (Jet Propulsion Laboratory, 1989, 1990; NASA, 1990a,b,c).

Nuclear energy sources have been used for space missions since the late 1950s (Angelo & Buden, 1985). They are the only way to provide the power needed for missions far from the sun or requiring very large or concentrated amounts of power. They also represent a convenient way to address other engineering needs. To date, the U.S. and the (former) U.S.S.R. have each used nuclear energy sources on about 60 missions. There have been nine reported accidents (Jet Propulsion Laboratory, 1990; Aftergood, 1991). The best-known of these is probably Cosmos-954, which scattered debris over a large area near Canada's Great Slave Lake (Angelo & Buden, 1985).

There are two kinds of nuclear energy sources: fission reactors and radioisotope thermoelectric generators (RTGs), which rely on the heat produced by radioactive decay. Neither source can explode like an atomic bomb (although fission reactors can produce an explosion-like process, called excursion). They use plutonium or uranium, both highly toxic chemicals.

## Method

### Procedure

Respondents' beliefs were elicited in a two-stage process, fuller details of which can be found in

Bostrom *et al.* (1992). The first stage described the topic in very general terms, then asked respondents to say as much as they could about it, speaking for a tape recorder. As in client-centered therapy, respondents were asked to elaborate on each concept that they had mentioned. At the end of the first stage, they were explicitly asked to comment on (a) exposure processes, (b) health and environmental effects, and (c) mitigation processes—in cases where those topics had not arisen spontaneously. These seemed to be such basic concepts that their omission was treated as representing an oversight, rather than ignorance.

In the second stage, respondents characterized each of 45 varied black-and-white photographs as being either relevant or irrelevant to the topic, explaining their rationale. About two-thirds of the photos were intended to be relevant to the topic, spanning its domain. Some of the others were clearly irrelevant (e.g. Mickey Mouse), in order to reduce any implicit pressure on respondents to find some relevance in each photo.

From membership lists, we randomly selected members of two environmental and peace activist groups and members of professional engineering associations, continuing until 30 from each population agreed to participate. We also randomly selected 19 individuals from Pittsburgh residents appearing in the local white pages. The activist groups were the Pittsburgh Peace Institute and the Thomas Merton Center, which describe themselves as being dedicated to minority rights and environmental problems, as well as to alternatives to racism and violence at all levels of society. The engineering groups included the Pennsylvania Society of Professional Engineers, Society of Mining Engineers, American Ceramics Society, Hospital Engineers of Southern Pennsylvania, and Engineering Society of Western Pennsylvania.

Table 1 summarizes responses to several demographic questions. The engineers were generally similar to the activists in educational level and employment status. They were, however, somewhat older and preponderantly male (whereas the activists were divided equally between the genders). In all these ways, they are reflective of the populations from which they were drawn. The general public group was younger and less educated than the other two groups.

#### *Standard of comparison*

Respondents' beliefs were evaluated in terms of an *expert model* of the processes creating and con-

trolling the risks of using nuclear energy sources in space. It was created through an iterative process, pooling the knowledge of a diverse group of experts. In its final form, it consisted of 113 concepts, organized into five sequential modules: (a) aerospace system failures (14 concepts, such as launch pad failure, fragment impact, and fireball), (b) release processes (27 concepts, such as corrosion, cladding failure, and excursions), (c) transport processes (22 concepts, such as wind conditions, wet and dry redeposition, and root uptake), (d) personal exposure (11 concepts, such as inhalation, decontamination, and shielding), and (e) health effects (34 concepts, such as body injury, pulmonary injury, and mental retardation). Categories a–d were treated as exposure processes, in the sense of potentially leading to personal environmental exposures to the risk outcomes appearing in the effects category (e). The concepts were divided into two levels of detail, where level 1 concepts referred to general processes (e.g. the release of nuclear material, the risk of cancer), while level 2 concepts were more specific (e.g. failure of the fuel cladding—as a specific way to release nuclear material, lung cancer—as a special case of cancer).

Although not relevant to the data analyses reported here, these concepts were organized further into an influence diagram, a directed network in which concepts are linked if beliefs about the status

TABLE 1  
*Respondents' demographic data (percentages of samples)*

	Activists	Engineers	General public
<i>Gender</i>			
Males	50	90	63
Females	50	10	37
<i>Age (years)</i>			
20–40	33	27	53
40–60	54	33	42
60+	13	40	5
<i>Education</i>			
High school	7	0	11
Some college	10	0	22
Bachelor's degree	33	67	28
Master's or doctoral degree	50	33	39
<i>Employment status</i>			
Employed	80	80	84
Unemployed	0	3	11
Student	7	0	0
Retired	13	17	5
<i>Occupation type (employed subjects only)</i>			
'White collar'	62	100	93
'Blue collar'	0	0	7
Service sales/secretarial	38	0	0

of one concept (e.g. the probability of an explosion) affect beliefs about another concept (e.g. the probability of a fireball). A fully specified influence diagram would characterize each such influence by a conditional probability distribution (Howard, 1989). Such precision would be needed to compute the risk of various risky outcomes. Our influence diagram (or expert model) captured qualitative relations alone (i.e. saying 'a influences b' without saying by how much). Such relationships capture the sort of information that can be conveyed in non-technical communications, as well as being relatively uncontroversial scientifically. Maharik and Fischhoff (1992) present the diagram in full.

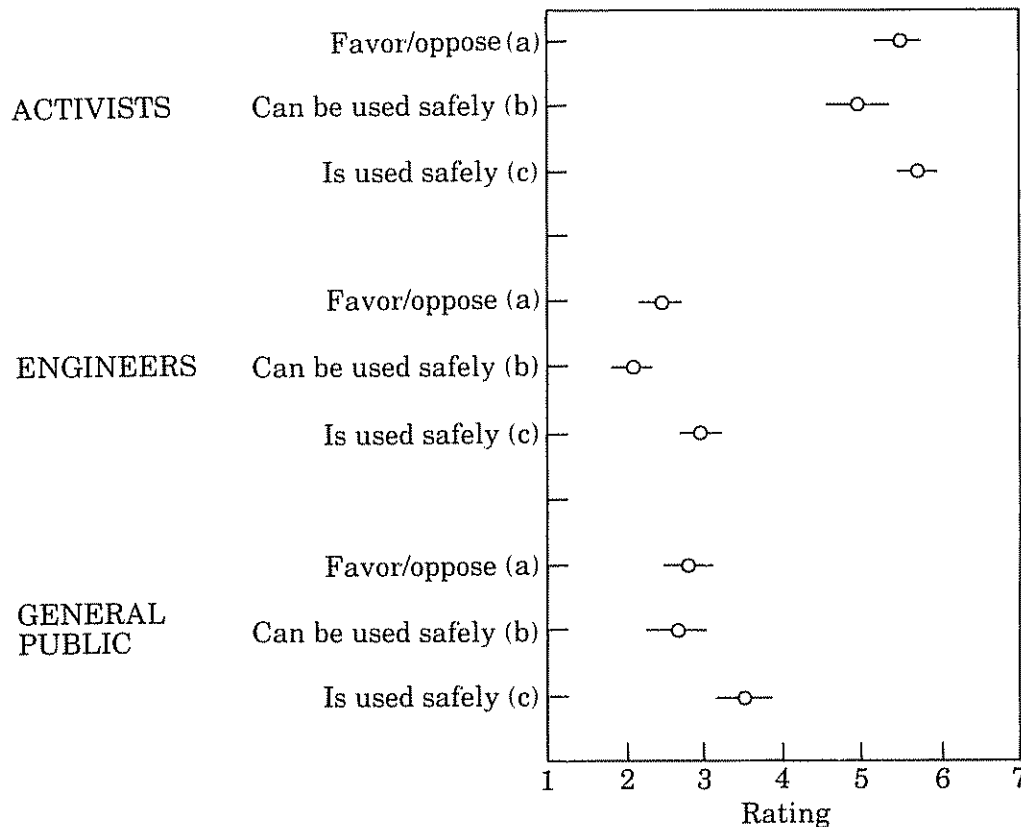
In the analyses that follow, we treat the expert model as a definitive representation of the risk processes. One might challenge the privileged status that this affords to the expert model. In that case, the following analyses of the quality of lay understanding would have to be reinterpreted as reflecting the correspondence between two sets of beliefs,

one belonging to laypeople and the other to experts (Fischhoff *et al.*, 1983; Fischhoff, 1989, 1991). For simplicity's sake, and because the qualitative relationships in the expert model seem uncontroversial, it is treated as factual.

*Risk attitudes*

At the end of each interview, respondents answered three attitude questions: (a) whether they favored or opposed the use of this technology, (b) whether they felt that this technology can be made safe enough to the public (as opposed to its being inherently too risky), and (c) whether the nuclear energy sources in space today are safe enough (or whether their operation should be cut back until stricter regulations are put into practice). The answers were marked by 7-point scales, labeled at the anchors (see Figure 1 for wording).

Figure 1 summarizes these attitudes: For the activists, the mean of each attitude was significantly



- a 1: Completely favor; 7: completely oppose
- b 1: Definitely can be made safe enough; 7: definitely cannot be made safe enough
- c 1: Definitely is safe enough; 7: definitely is not safe enough

FIGURE 1. Attitudes towards using nuclear energy sources in space. Lines indicate  $\pm 1$  standard error.

above the scale midpoint, indicating opposition to the technology (*t*-tests for difference from midpoint,  $p < 0.0001$ ,  $p = 0.05$  and  $p < 0.0001$ , respectively). All three of the engineers' attitudes were significantly below the midpoints ( $p < 0.0001$ ,  $p < 0.0001$  and  $p < 0.005$ ). For the general public group, the first two attitudes were also significantly below the midpoint ( $p < 0.0005$ ,  $p < 0.005$ ). In each group, answers to the second equation ('can be made safe enough') were significantly below answers to the third question ('is safe enough today'), suggesting that improvement seemed possible ( $p < 0.01$ ,  $p < 0.001$  and  $p < 0.005$ , respectively).

## Results

### Repertoire of concepts

Despite their less technical background, the group of 30 activists produced 84 of the 113 concepts in the expert model, compared with just 69 for the group of 30 engineers. The 19 members of the general public mentioned 64. The ratio of exposure to effects concept was higher in each group (activists, 60 : 24 = 2.50; engineers, 51 : 18 = 2.83; public, 43 : 21 = 2.05) than in the expert model (71 : 42 = 1.69). Thus, compared with the model, respondents tended to focus on how the risks are created more than on what impacts they can have.

The average engineer mentioned *fewer* expert concepts than did the average respondent in either of the other two groups; this difference was statistically significant, both overall ( $p < 0.05$ ) and for effects processes ( $p < 0.005$ ). One possible source of this surprising difference seems to have been a greater willingness on the part of the engineers to admit ignorance (and greater reluctance to risk offering concepts that might be wrong). A second possible source seems to have been a greater tendency for the other respondents to offer non-specific concepts in order to tie the portions of their descriptions together. However, all groups mentioned about the same number of exposure-process concepts. Many of these concepts lay within these engineers' general areas of expertise (unlike the effects processes, which focused on health issues).

Respondents also mentioned 82 concepts not in the expert model. These were coded in terms of both where they fit into the expert model (i.e. which of the five modules, whether they referred to exposure or effects processes, whether they were general or specific) and why we had not included them in that model. The latter classification had five categories:

*background knowledge and beliefs* (correct concepts that might clarify the expert model, but are not needed in it), *general concepts* (correct, but too broadly defined to clarify the process), *peripheral concepts* (correct but only conditionally or marginally relevant), *wrong concepts* (misconceptions), and *concepts outside the model boundaries*. For each group, most of the wrong concepts involved release processes, while most of the peripheral concepts were specific (i.e. level-2) references to health effects. Respondents in the general public group produced more wrong concepts, on average, than did the activists ( $p < 0.05$ ) or engineers ( $p < 0.001$ ).

Before considering the specific entries in these repertoires of concepts, we consider several additional measures of performance.

### Performance measures

Table 2 reports four measures comparing the concepts mentioned by respondents with those appearing in the expert model: *Completeness* measured how much people knew about the topic. It was defined as the percentage of the concepts in the expert model that a subject mentioned. The correctness of people's beliefs was characterized in two ways: *concurrency*, defined as the percentage of their concepts that appeared in the expert model, and *accuracy*, defined as the product of concurrency and completeness (thus 'rewarding' respondents who not only said right things, but also said many of them). *Specificity* measured how detailed respondents' beliefs were. It was defined as each respondent's ratio of specific (level-2) concepts to general (level-1) concepts, divided by the comparable ratio for the expert model. Thus, a ratio greater than 1 had a higher proportion of specific concepts that did the expert model.

Consistent with the previous section, the engineers had lower completeness scores than the activists ( $p < 0.05$ ). However, they also had somewhat higher concurrency scores ( $p = 0.06$ ), indicating that a higher proportion of what they did say appeared in the expert model. Given these countervailing advantages, there was no difference in accuracy scores (= completeness  $\times$  concurrency). The two groups were equally specific.

Members of the general public had lower completeness, concurrency, and accuracy scores than either of the two other groups, with five of the six comparisons being statistically significant ( $p < 0.05$ ). These inferior performance statistics are consistent with the higher rate of misconceptions among the general public. Their beliefs were also significantly less specific.

TABLE 2  
Mean performance measures

Specificity level	Level 1			All levels		
	Exposure processes	Effect processes	All	Exposure process	Effect processes	All
<i>Completeness*</i>						
Activists	0.59	0.30	0.51	0.31	0.19	0.28
Engineers	0.55	0.26	0.46	0.29	0.15	0.25
Public	0.53	0.22	0.44	0.26	0.14	0.22
<i>Concurrence†</i>						
Activists	0.75	0.63	0.73	0.71	0.54	0.67
Engineers	0.75	0.77	0.75	0.72	0.66	0.69
Public	0.69	0.62	0.68	0.68	0.49	0.64
<i>Accuracy‡</i>						
Activists	0.45	0.20	0.38	0.23	0.11	0.19
Engineers	0.42	0.21	0.35	0.21	0.09	0.17
Public	0.38	0.14	0.31	0.18	0.08	0.14
<i>Specificity§</i>						
Activists				0.23	0.44	0.25
Engineers				0.24	0.46	0.26
Public				0.18	0.50	0.21

\* Average proportion of expert concepts mentioned by subject

† Average proportion of subject concepts appearing in expert model.

‡ Product of completeness and concurrence.

§ Average ratio of respondent's specific (level 2) to general (level 1) concepts, divided by the comparable ratio for expert model.

None of the five measures of performance (completeness, concurrence, accuracy, specificity, number of concepts) was related to any of the three attitude measures, for either the engineer or activist groups. However, 13 of these 15 correlations were in the 0.4–0.6 range for the public group. Three follow-up studies tended to support the intriguing notion that the attitudes of more ideologically committed individuals (of either persuasion) are unrelated to how much they know, whereas members of the (uncommitted) general public become more favorable as they learn more—at least for this particular technology (Maharik & Fischhoff, 1993a,b).

#### Specific beliefs

Our initial study (Maharik & Fischhoff, 1992) describes the complete set of beliefs reported by the activists. We consider here the most notable differences between the groups:

(a) The activists mentioned plutonium more often than uranium as a fuel source (23 vs 14), whereas for the engineers the ratio was reversed (15 vs 23). Possibly, the engineers drew upon textbook knowledge of energy production, while the activists were influenced by newspaper reports of the Galileo and Ulysses missions (both of which use plutonium). Or, the activists might just have heard more concern

over plutonium. Differential media influence might also account for thyroid cancer (discussed heavily after Chernobyl) being mentioned by nine activists, but only one engineer; it was never mentioned in the general public group.

(b) Members of both groups were much more likely to mention several key technical concepts than were the general public respondents. For example, the notion of a dose–response relationship was mentioned by 40% of the activists and 43% of the engineers, but by only 17% of the general public subjects. Radiation decay was mentioned by 33% of the activists and 47% of the engineers, but by only 21% of the general public subjects.

(c) Many subjects referred to specific events. Some of these were obviously related to the topic (e.g. Cosmos-954, Challenger, TMI), whereas others seem to reflect general concern over nuclear technologies (e.g. Chernobyl—mentioned by 49 of 79 respondents, Hanford, Skylab). Such indirect references were particularly common among the activists.

(d) The activists were much more likely to mention the possibility of human error than were the engineers (40% vs 3%), perhaps reflecting skepticism in the one case, complacency in the other.

(e) More than a third of the total sample believed that an accident would release only radiation (or

'rays' or 'radioactive energy') and not radioactive material—which is, in fact, the main source of risk. In order to ensure that this was a conceptual, and not just a terminological mistake, respondents were pressed to clarify their beliefs. They typically produced a 'family' of related confusions, focused around notions of contamination. Nine of the 19 general public respondents (and five of the engineers) described how radiation makes matter radioactive (to a far greater degree than any actual physical process).

(f) The activists mentioned more concepts outside the model than did the engineers (65 vs 23), as well as more misconceptions (47 vs 33). Many of these concepts involved environmental effects, such as the (erroneous) beliefs that acid rain carries radioactive material or that radiation depletes the ozone layer or affects weather patterns (also found by Kempton, 1991).

### Discussion

Overall, respondents had quite a large body of knowledge about the risks of using nuclear energy sources in space, with each group's pooled repertoire of concepts covering large portions of the expert model. The activists had more complete knowledge than the engineers regarding possible health effects, while engineers were more accurate on the process as a whole. The members of the general public knew less, were less accurate, and were less specific in their knowledge, than were the two other groups. They also offered, on average, a larger number of misconceptions than either the activists or the engineers. Thus, although they were almost as favorable towards the technology as were the engineers, their attitudes were based on much poorer information. Within this group (but not the others), greater knowledge was associated with more favorable attitudes. Thus, this may be a case where providing the public with more information might make them as positive as the engineers.

Although differences in knowledge could not account for differences in attitude within the activist and engineer groups, could they account for the differences between the groups? Their overall performance statistics were quite similar (Table 2). There were, however, possibly important differences in the kinds of concepts that they mentioned. The activists said more about the (aversive) health effects. The engineers said more about the exposure processes, describing a mixture of potential problems and strategies for managing them.

Another potential source of these attitude differ-

ences is the activists' much broader definition of the problem. They mentioned many more concepts outside of the expert model. Those extensions include such troubling issues as human error, Chernobyl, and thyroid cancer. The appropriateness of considering these issues is a moot point, the resolution of which depends on how skeptical one is regarding designers' assurances that they have bounded a system, that they have learned the lessons of earlier incidents, and that all possible effects have been enumerated.

A further contribution to fears may have been the confusion between radiation and radioactive material (Keren & Eijkelhof, 1991). The belief in permanently contaminating 'rays', active at long distance could also frustrate responses to accidents if it made mitigation techniques (e.g. handwashing) seem ineffective.

Although necessarily speculative, these potential accounts of attitude differences could only be developed because of the open-ended procedure used here, and the detailed expression of respondents' beliefs that it allows. The data it produces reflect how people talk as well as how they think. As a result, we have been able to look at the data from several perspectives. For example, the engineers' lower completeness scores seemed to reflect a higher threshold for expressing uncertain or potentially peripheral beliefs. That possibility was partially confirmed by their somewhat higher concurrence scores. We believe that the richer informational yield of this procedure justifies the somewhat reduced sample size that is necessary with such labor-intensive methods of elicitation and data analysis. Such studies are also useful, and perhaps essential, inputs to more structured (and traditional) approaches (Bostrom *et al.*, 1992; Morgan *et al.*, 1992). Questionnaires and experiments could be developed and administered to larger samples, in order to pursue hypotheses raised here, using the lay terms and conceptualizations evoked by this format. These results could also allow communications about these risks to begin with a better understanding of the contents and gaps in recipients' belief systems. Providing such targeted communications would also provide a clearer test of the effect of knowledge on attitudes.

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### Notes

- (1) Address correspondence to: B. Fischhoff, Department of Engineering & Public Policy, Carnegie Mellon University, Pittsburgh, PA 15213, U.S.A.
- (2) How the dimensions are weighted in order to produce a summary measure of 'risk' represents a political decision, reflecting the importance of different consequences (Crouch & Wilson, 1981; Fischhoff *et al.*, 1984)

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