

The Risks of Using Nuclear Energy Sources in Space: Some Lay Activists' Perceptions

Michael Maharik¹ and Baruch Fischhoff^{1,2}

Received March 11, 1991; revised March 5, 1992

A combination of directive and nondirective techniques was used to study the mental models of 30 lay activists regarding the risks of nuclear energy sources in space. Respondents' perceptions were compared with an "expert model" of the processes generating and controlling these risks, in terms of both the substance of their beliefs and several statistical measures of their performance. These analyses revealed a complex pattern of strengths and weaknesses. Their details are used to derive recommendations for formulating messages about these risks.

KEY WORDS: Risk perception; risk communication; nuclear energy; space; mental models.

1. INTRODUCTION

Nuclear energy sources have been used for space research since the start of the space age.⁽¹⁾ In recent years, however, this use has been met by a series of public protests, including lawsuits and demonstrations.⁽²⁾ Despite optimistic beliefs like those of Vice President Quayle (who states that the antinuclear forces are "a distinct minority"),⁽³⁾ this conflict may be with us for quite some time. How effectively the public defines and pursues its interests on this topic depends on the quality of the information that it receives. People need clearly presented information summarizing what the ranking experts believe about a technology and how complete those experts' knowledge is. That information is, of course, only one input to deliberations about a technology.⁽⁴⁾ Even if laypeople agree with the experts regarding the magnitude of a risk, they may still disagree (with the experts and with one another) about its acceptability. Citizens might, for example, reject an admittedly small risk if they fail to see compensating benefits or if they feel disenfranchised by the decision-making

process (so that they are losing political rights, however acceptable the resulting risk-benefit tradeoffs may be). Thus, a better understanding of expert opinion need not change attitudes toward the technology.⁽⁵⁻⁸⁾

Satisfying people's informational needs requires understanding not only the technology, but also recipients' existing beliefs—in the light of which they interpret (or perhaps misinterpret) incoming information.⁽⁹⁾ The present study demonstrates a general method for achieving these goals in the specific context of designing communications regarding the risks of using nuclear energy sources in space. Its organizing concept is the *mental model*, defined as people's collection of beliefs (both true and false) about a certain topic, on the basis of which they intuit how it works.⁽¹⁰⁾ Further details about this methodology and other uses of a mental-model perspective in cognitive psychology can be found in Bostrom *et al.*⁽¹¹⁾

METHOD

2.1. General

The mental-model methodology has four steps: (a) creating an *expert model* of the risk-development process;

¹ Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213-3890.

² To whom all correspondence should be addressed.

(b) eliciting laypeople's beliefs about the process; (c) describing laypeople's mental models by mapping their beliefs into the expert model; and (d) deriving communication guidelines from the differences between the expert and lay models.

2.2. Expert Model

The expert model is a qualitative representation of the physical phenomena that may produce risk to members of the public. An expert model for nuclear energy sources in space includes topics in aerospace engineering, nuclear engineering, environmental engineering, medicine, and public health. After reviewing pertinent agency publications⁽¹²⁻¹⁵⁾ and technical handbooks,^(1,16) we summarized their contents in the *influence diagrams* appearing in Figs. 1 and 2.^(17,18) In this form of directed network, each node-link-node combination portrays an "influence," in the sense that beliefs about the concept lying at the beginning of each arrow affect beliefs about the concept lying at its point. In a completely specified diagram, each such influence would be characterized by a conditional probability distribution. Our diagram expresses qualitative relationships alone (i.e., saying "a influences b" without specifying by how much). Although such relationships are inadequate for a thorough scientific analysis, they do capture the sort of information that can be conveyed in a nontechnical communication. Moreover, they depict expert beliefs that are relatively uncontroversial. Quantifying these beliefs takes one into domains where the disagreements among experts grow, as do the grounds for lay skepticism about expert claims.⁽⁴⁾

After internal review, our model was evaluated by experts from relevant professional fields, and revised accordingly. Figure 1 shows the general layout of the model. The first four of its five modules form the exposure process, while the last one is the effects process.⁽¹⁹⁾

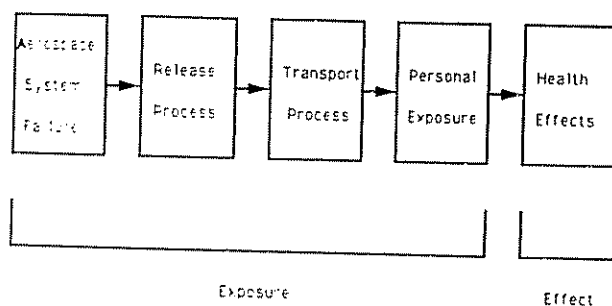


Fig. 1. Expert model—general layout.

Figure 2 shows the full diagram. It contains 113 concepts (79 exposure and 34 effects), which can be classified into two levels of detail: *level 1* refers to general concepts (e.g., release of nuclear material, risk of cancer); *level 2* refers to more specific ones (e.g., failure of the fuel cladding, lung cancer).

2.3. Respondents

Thirty interviews were conducted at Carnegie Mellon University by a single interviewer (the senior author). Respondents were members of two organizations active in peace and environmental topics, the Pittsburgh Peace Institute and the Thomas Merton Center. Activists were chosen because they are often opinion leaders on these issues. Moreover, they are the target of NASA's own risk communications on this issue.⁽²⁰⁾ Respondents were recruited by letters sent to 121 active members, whose names were provided by the two organizations. The 30 were chosen randomly from the 51 who agreed to participate in return for a small personal payment. Half of all respondents were males. One third had a bachelor's degree, while another half had higher degrees; the rest had either some college education (10%) or just high school (7%). Four fifths were employed, while the others were students (7%) or retired (13%). One third were between 20 and 40 years old, a half between 40 and 60, and the rest over 60. About half were homeowners.

After the interview, respondents evaluated the use of nuclear energy sources in space on three 7-point attitude scales. Their responses showed skepticism. They opposed the use of the technology ($\bar{x} = 5.43$, $SD = 1.52$, where 1 = "completely favor" and 7 = "completely oppose"), believed that it cannot be made sufficiently safe ($\bar{x} = 4.93$, $SD = 1.91$, where 1 = "definitely can be made safe enough" and 7 = "definitely cannot be made safe enough"), and felt that it is inadequately safe at present ($\bar{x} = 5.67$, $SD = 1.15$, where 1 = "definitely is safe enough" and 7 = "definitely is not safe enough"). All three means were significantly above the scale midpoint ($p < 0.0001$, $p = 0.012$, and $p < 0.0001$, respectively). Answers to the second question ("can be made safe") were significantly lower ($p = 0.01$) than answers to the third ("is currently safe"). Thus, these individuals might be made happier by increased safety, although even that would not leave them very satisfied. Overall, these individuals represent a diverse set of well-educated adults opposed to this technology. We believe that their beliefs and attitudes will generalize fairly well

to those of other activists with no direct involvement in the problem.

2.4. Procedure

Respondents were interviewed individually. Each interview took 60–80 min. It was tape recorded and later transcribed.

The interview procedure was designed to avoid the problems of potential *reactivity*, which are possible when respondents lack highly articulated beliefs.⁽²¹⁾ We tried to direct respondents to the topic without influencing their answers (e.g., by the words we used, or their order of presentation). Our goal was to stimulate something like the thought processes that would occur naturally (although at a slower rate) if respondents dealt with the topic in their own lives.

To this end, the interview began with an open-ended, nondirective stage, asking respondents to “tell me whatever you know about the risk of using nuclear energy sources in space.” Once spontaneous responses were exhausted, respondents were asked to elaborate on each comment that they had made. They were then asked whether they could say anything (more) about each of the five modules in Fig. 1. With this exception, the interviewer tried not to introduce new concepts. The phrasing of questions was adjusted to respondents’ natural terminology. In the second, directive stage, respondents sorted each of 45 black-and-white pictures into two piles, according to its perceived relevance to the topic. Respondents were asked to describe each photograph and the reason for their choice of category. The photos covered various topics. About two thirds were (to our minds) related to the research topic (e.g., a satellite, clouds, lungs), covering the major concepts in the expert model. The others were general (e.g., a dam, a swamp, Bugs Bunny). Finally, respondents answered the three closed-ended attitude and demographic questions, the answers to which are reported above.

2.5. Coding

The coding procedure was developed in three stages. Initially, two interviews were coded separately by three researchers, each familiar with the expert model (but only one having extensive technical knowledge). They agreed 70.3% of the time. Disagreements among their codings were resolved and the coding scheme was adjusted accordingly. The senior author coded the remaining interviews using this procedure. As a reliability check,

an independent coder applied the procedure to two interviews. They agreed 78.8% of the time, which seems reasonably good given the very detailed nature of the expert model, which included some closely related concepts.

3. RESULTS

The average respondent produced 40.5 concepts in the open-ended interview and 21.4 concepts in the photo session. Of the latter, 72% restated concepts mentioned before. The interviews were examined in several different orders, each showing that the number of concepts added with each successive interview eventually approached zero, indicating that we exhausted the set of concepts held with any frequency.

3.1 Expert Concepts

As mentioned, the expert model contained 113 concepts, classified into the five modules of the physical process and the two levels of details. Overall, the 30 interviewees mentioned 84 of these concepts, 60 referring to exposure and 24 to effects. As Table I shows, 41 of the 42 level-1 concepts³ and about 60% of the 71 level-2 concepts were mentioned by at least one respondent. Table II shows the 45 expert-model concepts mentioned by at least eight respondents. It contains 32 level-1 concepts, and 13 level-2 concepts.

Most respondents mentioned the basic elements of possible *aerospace system failures*, mentioning almost all concepts at least once, and most with some frequency. This might reflect the retrievability of past accidents (e.g., *Challenger*) or the imaginability of such events.⁽²²⁾ Less familiar and harder-to-imagine level-2 details, like the effect of mechanical and thermal stresses, were much less common.

In terms of *release* processes, only three respondents mentioned both types of nuclear energy sources presently usable in space, Radioisotope Thermoelectric Generators (RTGs) and fission reactors. The other 12 respondents who mentioned any source at all cited only reactors.⁴ Eight respondents mentioned the possibility of

³ The never-mentioned exception was “chemical toxicity of fuel particles.”

⁴ In the open-ended phase of the interview, respondents were asked explicitly whether they knew about any specific type of nuclear energy source available for use in space. Their responses were coded according to general topics, without insisting on proper scientific terminology.

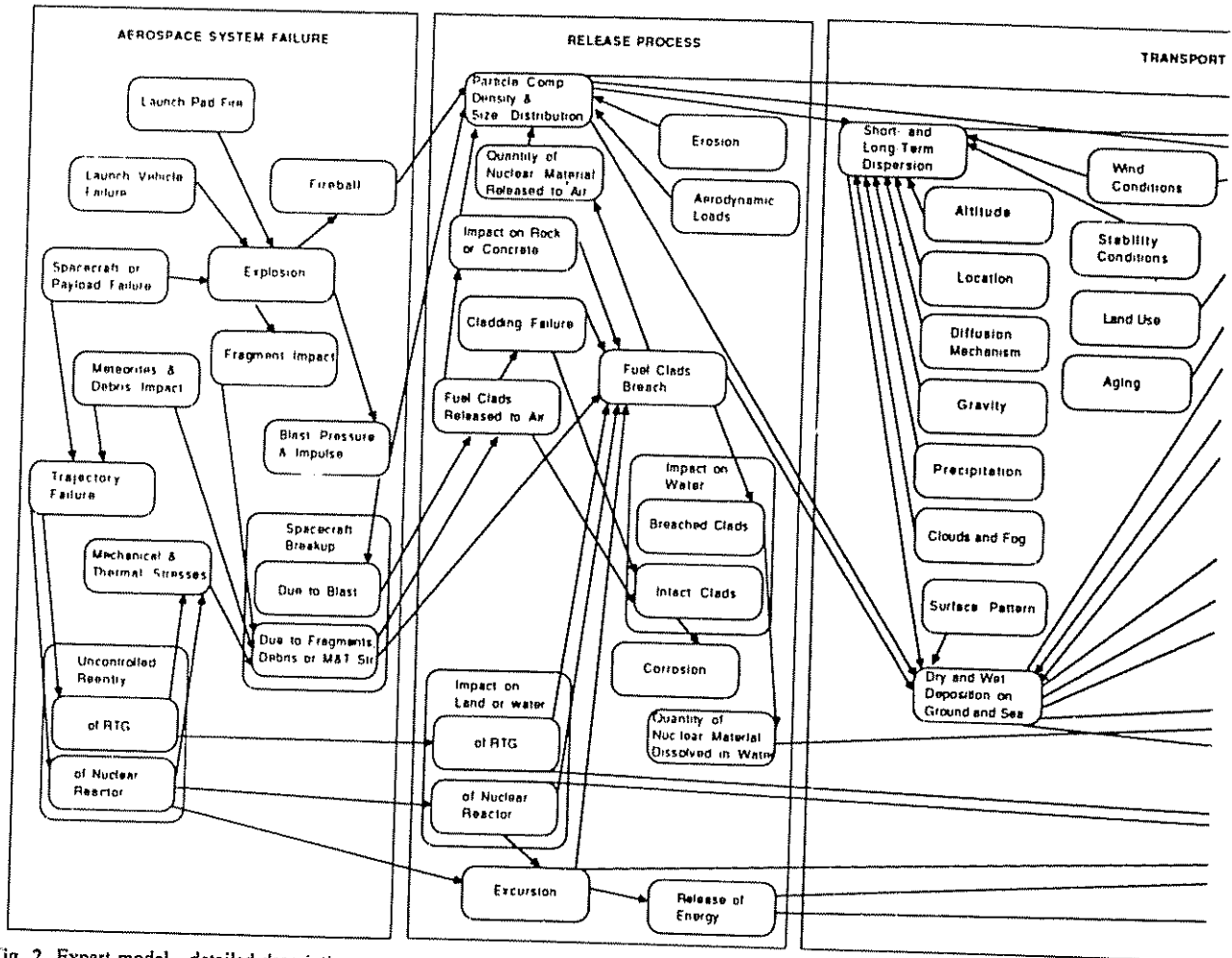


Fig. 2. Expert model—detailed description.

a nuclear explosion; only one knew that it can happen only with a fission reactor.⁵ For the others, knowing that a spacecraft uses an RTG need not eliminate the fear of a nuclear explosion. Plutonium was mentioned more frequently than uranium as an energy source, even though plutonium is used only in RTGs and uranium only in reactors. This may reflect the extensive media coverage of the previous years' launches of RTGs, or general theories about nuclear power.

The general processes of atmospheric *transport* and deposition were clearly familiar to most respondents. Here, respondents seem to have drawn successfully on

⁵ Technically speaking, the kind of "explosion" possible even with fission reactors is actually an excursion process. Without a more intrusive interview process, it is difficult to tell whether respondents meant something like this process or envisioned a full-scale thermonuclear explosion.

their knowledge of other environmental issues. Only one third mentioned radioactive decay or the half-life of released materials, both specific to nuclear energy.

Most respondents mentioned the three main paths of *personal exposure* to radioactive material—*inhalation*, *ingestion*, and *external exposure*. Appropriately for respondents far from the launch site, few cited exposure through a "direct hit," blast, or heat. Regarding ways to mitigate personal exposure, most respondents (24) mentioned sheltering, evacuation, and shielding. Fewer mentioned restricting one's food supply, while less than five cited decontamination and washing, indicating information that would need to be disseminated in the case of an accident.

Almost all respondents mentioned the focal *health effect* of cancer, with two thirds referring specifically, and correctly, to lung and bone-marrow cancers. On the

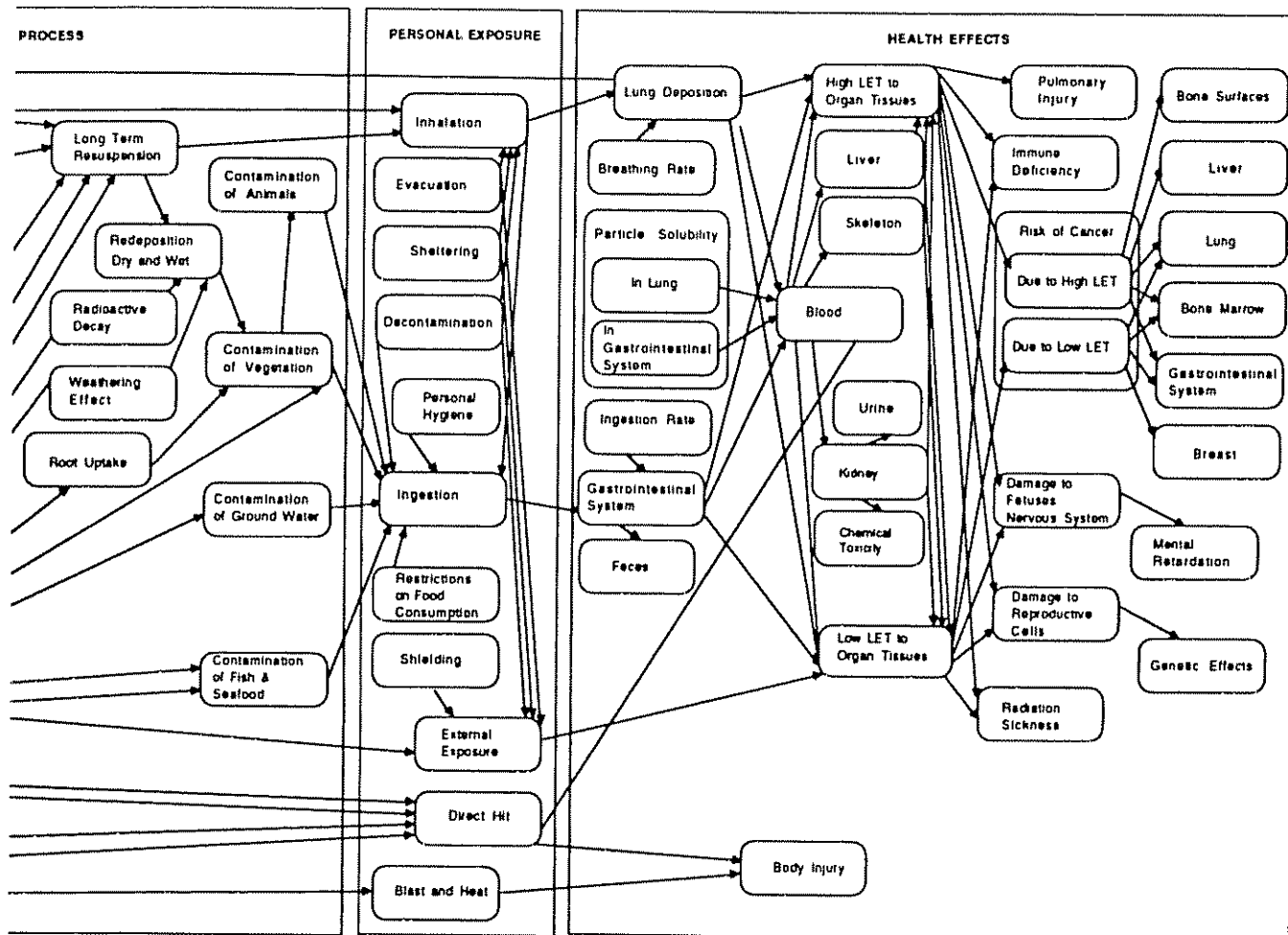


Table I. Number of Concepts Appearing in Expert Model and Mentioned at Least Once by Respondents

Level	Module	Aerospace					Health effects	All
		system failure	Release process	Transport process	Personal exposure	Total exposure		
Level 1	Expert	5	7	7	11	30	12	42
	Respondents	5	7	7	11	30	11	41
Level 2	Expert	9	20	20	—	49	22	71
	Respondents	7	13	10	—	30	13	43
Both levels	Expert	14	27	27	11	79	34	113
	Respondents	12	20	17	11	60	24	84

other hand, few mentioned liver and bone-surface cancers, two other possible effects of exposure to plutonium. Many respondents mentioned other effects as well. However, the details of these processes seemed poorly

understood, compared to respondents' relatively structured descriptions of exposure processes. No respondent mentioned how radioactive particles affect cells by releasing bursts of energy.

Table II. Expert-Model Concepts Mentioned by at Least Eight Respondents

Exposure	
Aerospace system failure	
Level 1	
Explosion blow-up	25
Launch vehicle failure/malfunction	22
Spacecraft failure/malfunction	20
Uncontrolled reentry	20
Spacecraft breakup	17
Level 2	
Impact of meteorites, debris, or other satellites	15
Trajectory failure	14
Blast pressure and impulse	11
Release process	
Level 1	
Particles of nuclear material	26
Release of nuclear material leakage	24
Nuclear reactor/fission reactor	15
Impact on land or water	12
Nuclear fuel	8
Excursion nuclear explosion	8
Level 2	
Plutonium	23
Uranium	15
Transport process	
Level 1	
Contamination of vegetation	30
Contamination of water	30
Contamination of animals	29
Deposition of released material, fallout	26
Dispersion of released material, dissemination	25
Contamination of fish and seafood	12
Radioactive decay, half-life	10
Level 2	
Effect of precipitation on dispersion, rain, snow	25
Effect of wind conditions on dispersion, air currents	22
Location of release, place of release, name of place	17
Effect of gravity on dispersion	13
Effect of clouds and/or fog on dispersion	11
Personal exposure	
Level 1	
Ingestion of material, food chain, food supply	29
Inhalation of material	26
External exposure to material	26
Sheltering	24
Evacuation	18
Shielding/protective clothing	18
Restrictions on food consumption	12
Direct hit	8

Finally, when asked whether nuclear energy sources in space provided any benefits, most respondents offered none. The few who did, described the small size and

Table II. Continued

Effects	
Health effects	
Level 1	
Risk of cancer	29
Genetic effects	24
Deposition of particles in lung	12
Radiation sickness	12
Immune deficiency	9
Particles transfer into internal organs	8
Level 2	
Lung cancer	21
Bone marrow cancer/leukemia	20
Damage to fetuses/birth defects	9

long life of those sources. No one stated explicitly that nuclear energy was the only (known) way to accomplish many missions, such as interplanetary voyages.⁽¹⁾

3.2. Nonexpert Concepts

Respondents also mentioned 65 concepts not in the expert model. These were classified into the five modules and two levels of the model, as well as in terms of their relationship to the expert model: *background knowledge and beliefs* (correct concepts that may clarify the expert model, but were 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*.⁶ Most outright errors involved release processes, while most peripheral concepts were detailed (i.e., level 2) references to health effects.

As might be expected, respondents referred frequently to such *background concepts* as radioactivity and radioactive materials (29), burn up (14), and dose-response relations (12). Perhaps more surprisingly, most (25) mentioned specific events, some directly related to the topic (*Challenger*, 16) and others more indirectly (TMI, Chernobyl, and Hanford—11, 20, and 4, respectively). Often, these references were accompanied by a general (political) statement about nuclear energy.

General concepts often seemed like attempts to link up previously mentioned concepts. It was not always clear, however, how detailed these mental models were.

⁶ Such concepts could be either right or wrong. They are sometimes linked to topics in the model, but do not form a part of them.

For example, respondents who mentioned "damage to cells" (21) or "toxicity" (9) seldom described any specific health effects. Other frequently mentioned general concepts included "air contamination" (7), "soil contamination" (14), "direct external touch" (such as on skin or going barefoot, 19), and "human error" (12).

Seven of the 22 different peripheral concepts were mentioned by at least eight respondents: children (15), hair loss (14), burns (10), orbital decay (10),⁷ skin cancer (9), thyroid cancer (9), and sterilization (9). Many of these more unlikely health effects reflected associations with background topics. For example, "skin cancer" was sometimes triggered by "external exposure," and "thyroid cancer" by reference to Chernobyl. This category also included forms of radiation sickness requiring very high doses, as well as cancers with no known association with nuclear fuels.

Only one *wrong* concept was mentioned by at least eight respondents: the belief that only radiation (or "rays" or "radioactive energy") is released following an accident and not radioactive material. This belief has been reported elsewhere.⁽²³⁾ The most common misconception about effects processes was that nuclear material or radiation depletes the ozone layer (6).⁸ Another four respondents said that radioactivity affects weather patterns. Specific misconceptions about how radioactivity causes health damages included the belief that radiation harms the body by generating heat (3), by inhibiting the transport of oxygen to cells (1), and by having radioactive particles replace atoms in the bone marrow (1).

The concepts that we coded as *outside the expert model* typically reflected political positions, such as "stop using this technology" (16), "environmental risk" (15), "political activity" (9), and "act of war" (9). Twelve respondents mentioned prelaunch events which we excluded when bounding the problem.

3.3. Performance Measures

Four summary statistics were used to characterize the degree of agreement between respondents' mental models and the composite expert model in Fig. 2. For ease of

⁷ We categorized orbital decay as peripheral because satellite trajectories are typically designed so that the radioactivity of the source will be negligible before the orbit decays.

⁸ A related confusion is the causal link that people often make between the "hole" in the ozone layer and global warming.⁽²⁴⁾ Although the two phenomena have one common cause (the use of chlorofluorocarbons), they have no direct relationship. The present confusion may owe something to the fact that the hole in the ozone layer allows in ultraviolet radiation and to the associations of "warming" and "radiation" with "energy."

exposition and because the qualitative relationships that the expert model contains seem uncontroversial, we will treat it as factual (hence, the term "performance measures"). More generally, these statistics reflect the correspondence between two sets of beliefs, one belonging to laypeople and the other to ranking experts.⁽²⁵⁻²⁷⁾ If a portion of the expert model were changed, then the measures could be readily recomputed.

Completeness is the proportion of concepts in the expert model mentioned by a respondent. As shown in Table III, by the end of the interview, the average respondent produced 28% of the total expert model and 51% of its level-1 concepts. On average, respondents knew a higher proportion of exposure concepts than effects concepts (.31 vs. .19). The similar completeness means for the open-ended phase and for both phases reflect the low rate of new concepts in the photo-sorting session.

Completeness considers only correct concepts. Two other measures incorporated lay concepts outside the expert model. *Concurrence* is the percentage of respondents' concepts that were in the expert model; *accuracy* is the product of concurrence and completeness, resulting in higher scores for respondents who not only said right things, but also said many of them. Over all respondents and both phases, mean concurrence was 0.67 and mean accuracy 0.19. As would be expected, the two measures were correlated ($r=0.60$). Both were higher for level-1, indicating better understanding of more basic concepts, and similar in the two phases of the interview, suggesting that the photos did not induce erroneous concepts. The number of concepts that respondents produced was highly correlated with their completeness scores ($r=0.98$), but not with their concurrence scores ($r=0.29$). Thus, respondents who said more covered a larger portion of the expert model, but were not necessarily more accurate. Saying more added both right and wrong concepts.

Specificity measured how detailed people's knowledge was. It was defined as a respondent's ratio of specific (level-2) concepts to general (level-1) concepts, divided by the comparable ratio for the expert model. A ratio larger than 1 means that a respondent had a higher proportion of specific concepts than did the expert model. The mean ratio was 0.25, indicating that respondents' concepts were much more general than those in the expert model (consistent with the higher completeness scores for level 1 than overall). Respondents were more specific about effects than about exposure (0.44 and 0.23, respectively). Number of concepts was strongly correlated with specificity ($r=0.78$); thus, more concepts meant deeper coverage.

Table III. Mean Performance Measures

Interview phase Process	Open-ended phase			Both phases		
	Exposure	Effect	All	Exposure	Effect	All
Completeness ^a						
All levels	.28	.16	.24	.31	.19	.28
Level 1	.52	.28	.45	.59	.30	.51
Level 2	.12	.10	.12	.14	.13	.14
Concurrence ^b						
All levels	.69	.56	.66	.71	.54	.67
Level 1	.74	.68	.73	.75	.63	.73
Level 2	.59	.43	.54	.59	.46	.55
Accuracy ^c						
All levels	.20	.09	.16	.23	.11	.19
Level 1	.39	.20	.34	.45	.20	.38
Level 2	.08	.06	.07	.09	.07	.08
Specificity ^d						
	.22	.40	.24	.23	.44	.25

^a Proportion of expert concepts mentioned by respondent.

^b Proportion of respondent concepts appearing in expert model.

^c Product of completeness and concurrence.

^d Ratio of respondent's level 2 to level 1 concepts, divided by the comparable ratio for expert model.

4. DISCUSSION

Overall, these laypeople had a large body of knowledge regarding the risks of using nuclear energy in space, with their pooled repertoire of concepts including large portions of the expert model. Their understanding was more complete and more accurate about exposure processes than about effects processes, but less specific. Respondents who said more typically covered a larger portion of the expert model and at greater depth, without, however, being much more accurate.

The coding of specific beliefs revealed a complex pattern of strengths and weaknesses, which underlie the recommendations presented below. We believe that such a detailed description of laypeople's mental models is essential to designing effective risk communications. Without it, one may waste their time telling them things they already know, miss the opportunity to build on those correct beliefs, and fail to address misconceptions that can misdirect their inferences. The impact of preexisting mental models was seen most clearly in references to specific features of events like Chernobyl, such as thyroid cancer caused by the radioactive iodine that it released, taking iodine to prevent such cancer, and contamination of elks in Lapland.

As detailed as these interviews and analyses have been, our recommendations also attempt to capture holistic observations which are harder to quantify. One of

those is the possibility of mentioning concepts without fully understanding their implications. For example, respondents who cited the possible dispersion of nuclear fuel particles following an accident and described some of the attendant physical process, might still explain that they meant subatomic rather than molecular particles (thereby referring to the release of radiation and not radioactive material). Many respondents who mentioned "radiation" seemed to include both relevant and irrelevant forms (e.g., both radioactivity and ultraviolet radiation). Some people who mentioned the release of radiation (but not radioactive materials) also discussed fallout, inhalation, or air transport. The recommendations that follow reflect the need both to complete mental models and to integrate their components:

1. Concepts should be clearly defined. For example, although most respondents mentioned "radioactivity," few knew its physical meaning or could explain it in any detail; some mixed it with misconceptions such as the depletion of the ozone layer by radioactivity. Thus, even when communicators are focused on a specific risk, they may need to present background scientific information.
2. Significant gaps in knowledge should be filled. For example, respondents knew little about how radioactive materials caused health effects or

about some related mitigation possibilities (e.g., washing). Similarly, not distinguishing between RTGs and fission reactors may mean believing that both energy sources can explode.

3. Significant misconceptions should be corrected, such as the belief that released energy, rather than dispersed nuclear material, presents the major risk to the public. People holding this belief might be confused by communications describing the dispersion and propagation of particles.
4. Communications should relate concepts to one another, describe phenomena in structured terms, and explicitly state causal relations. Doing so will help laypeople integrate the existing concepts in their mental models, as well as incorporate new ones.
5. Peripheral concepts that might confuse or misdirect mental models should be addressed. For example, it would make sense to clarify the relevant and nonrelevant features of the events at Three Mile Island, Chernobyl, and Hanford.

These recommendations are based on the responses of 30 individuals interested in peace and environmental issues and generally opposed to the use of nuclear energy in space. Further research is planned with respondents from technology-oriented groups, who might have more positive attitudes, and with a sample of the general public. We expect the same kinds of recommendations to recur, although their specifics may change.

In conclusion, we repeat the cautionary note in our introduction, regarding the role of communicating technical information in risk management. Knowing more about what experts believe should help laypeople identify courses of action in their own—and their society's—best interests. In some cases, this will reduce conflicts. In others, it will sharpen them, by clarifying the grounds for disagreement. Both outcomes could be the result of a successful risk communication process. Achieving a social consensus regarding the fate of technologies requires not only agreement over the facts, but also agreement about values and political processes.

ACKNOWLEDGMENTS

This research was supported in part by National Science Foundation grant SES-8715564. We also thank Roger Boisjoly, Ann Bostrom, Cliff I. Davidson, Benoit Morel, M. Granger Morgan, Indira Nair, Daniel J. Strom, members of the Center for Risk Perception and Communication at Carnegie Mellon University, and three

anonymous reviewers for their contributions. The opinions expressed are those of the authors.

REFERENCES

1. J. A. Angelo and D. Buden, *Space Nuclear Power* (Orbit Book Company, Malabar, Florida, 1985).
2. T. M. Foley, "NASA Prepares for Protests over Nuclear System Launch," *Aviation Week and Space Technology*, June 26 (1989), pp. 83-87.
3. K. Sawyer, "Build Nuclear-Powered Rocket for Mars Mission, Panel Urges," *Washington Post*, June 12 (1991), p. A3.
4. National Research Council, *Improving Risk Communication* (National Academy Press, Washington, D.C., 1989).
5. J. Kuklinski, D. Metlay, and W. Kay, "Citizen Knowledge and Choices in the Complex Issue of Nuclear Energy," *American Journal of Political Science* 26, 615-642 (1982).
6. A. A. Rouse, H. C. Jenkins-Smith, and R. P. Barke, "The Origins of Perceptions of Environmental Risk: A Comparative Study of Elite and Mass Beliefs" (paper presented at the Annual Meeting of the Western Political Science Association, Seattle, Washington, March 1991).
7. D. R. Hensler and C. P. Hensler, *Evaluating Nuclear Power: Voter Choice on the California Nuclear Energy Initiative* (Rand, Santa Monica, California, 1979).
8. H. Jungermann, H. Schutz, and M. Thuring, "Mental Models in Risk Assessment: Informing People about Drugs," *Risk Analysis* 8, 147-155 (1988).
9. M. H. Ashcraft, *Human Memory and Cognition* (Scott, Foresman, Glenview, Illinois, 1989).
10. B. E. Tonn, C. B. Travis, R. T. Goeltz, and R. H. Phillippi, "Knowledge-Based Representations of Risk Beliefs," *Risk Analysis* 10, 169-184 (1990).
11. A. Bostrom, B. Fischhoff, and M. G. Morgan, "Characterizing Mental Models of Hazardous Processes: A Methodology and an Application to Radon," *Journal of Social Issues* (in press).
12. GE Astrospace, *Final Safety Analysis Report for the Galileo Mission, Vol. II—Accident Model Document* (Doc. no. 87SDS4213, GE, Philadelphia, 1988).
13. NUS Corporation, *Final Safety Analysis Report for the Galileo Mission, Vol. III—Nuclear Risk Analysis Document* (Doc. no. NUS 5126, NUS, 1989).
14. Interagency Nuclear Safety Review Panel, *Safety Evaluation Report for Galileo, Vol. I-II* (Doc. no. INSRP 89-01, INSRP, 1989).
15. National Aeronautics and Space Administration, *Final Environmental Impact Statement for the Ulysses Mission (Tier 2)* (NASA, Washington, D.C., 1990).
16. C. H. Hobbs and R. O. McClellan, "Radiation and Radioactive Materials," in L. J. Casarett and J. Doull (eds.), *Toxicology* (Macmillan Publishing Co., New York, 1980).
17. R. A. Howard and J. E. Matheson, "Influence Diagrams," in R. A. Howard and J. E. Matheson (eds.), *The Principles and Applications of Decision Analysis, Vol. II* (Strategic Decisions Group, Palo Alto, California, 1984).
18. R. A. Howard, "Knowledge Maps," *Management Science* 35, 903-922 (1989).
19. M. G. Morgan, "Probing the Question of Technology-Induced Risk," *IEEE Spectrum* 18, 58-64 (1981).
20. J. McDonald (Launch Approval Planning Group, Jet Propulsion Laboratory, California Institute of Technology, personal communication, March 1991).
21. B. Fischhoff, "Value Elicitation: Is There Anything in There?" *American Psychologist* 46, 835-847 (1991).
22. A. Tversky and D. Kahneman, "Judgment under Uncertainty: Heuristics and Biases," *Science* 185, 1124-1121 (1974).
23. G. Keren and H. Eijkelhof, "Prior Knowledge and Risk Com-

- munication: The Case of Nuclear Radiation and X-Rays," in R. E. Kasperon and P. J. M. Stallen (eds.), *Communicating Risks to the Public: International Perspectives* (Kluwer, Dordrecht, The Netherlands, 1990).
24. W. Kempton, "Lay Perspectives on Global Climate Change," *Global Environmental Change* 1, 183-208 (1991).
 25. B. Fischhoff, P. Slovic, and S. Lichtenstein, "Lay Foibles and Expert Fables in Judgments about Risk," in T. O'Riordan and R. K. Turner (eds.), *Progress in Resource Management and Environmental Planning*, Vol. 3 (Wiley, Chichester, U.K., 1981).
 26. B. Fischhoff, "Risk: A Guide to Controversy," Appendix to National Research Council. *Improving Risk Communication* (National Academy Press, Washington, D.C., 1989).
 27. B. Fischhoff, "Psychology: Tool or Toolmaker?" *American Psychologist* 45, 57-63 (1990).