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Characterizing Mental Models of Hazardous Processes: A Methodology and an Application to Radon

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Lay people's ability to respond to an environmental hazard is determined, in part, by their understanding of the physical, chemical, and biological processes that govern its creation and control. A general methodology is offered here for studying that understanding. It attempts to characterize people's mental models of a hazard—i.e., the sets of principles from which they generate predictions about its behavior. The organizing device for this methodology is a network representation of expert knowledge about the hazard, emphasizing concepts relevant to risk management. This methodology is illustrated here with a set of interviews about the risks of radon. The results have implications for measuring, predicting, and aiding the public's understanding of environmental hazards.

People today face a steady stream of decisions about environmental hazards. Some of those decisions might involve immediate personal behavior, such as whether to throw out apple juice after hearing that it might be contaminated with Alar (which might be a carcinogen), what to do when the emergency siren sounds at a local chemical plant, and how to dispose of used motor oil. Other decisions might involve long-term public actions, such as whether to oppose a

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hazardous waste incinerator, whether to vote for a candidate who proposes a carbon emissions tax, and what to tell children about the environment that they will inherit.

In some cases, people may have translated these choices into well-formulated decision problems, of the form favored by decision analysts, with explicit options, outcomes, and uncertainties about the chances of experiencing those outcomes (von Winterfeldt & Edwards, 1986; Watson & Buede, 1987; Yates, 1990). When that happens, people need quantitative estimates of the critical parameters in their decision-making models. Typically, these estimates will include measures of how big the hazard is and how much it can be reduced at various prices. For example, a homeowner deciding whether to test for radon needs to know how much testing costs, how accurate tests are, and how much remediation will cost if a radon problem is discovered (Fischhoff, Svenson, & Slovic, 1987).

In such cases, the first task of risk communicators is to determine what lay people currently believe about these parameters. It should then be conceptually straightforward to identify those bits of potentially available information whose provision would have the greatest impact on recipients' ability to make decisions in their own best interest (Fischhoff, 1985; Raiffa, 1968). To that end, many studies have examined the gaps in people's knowledge, even though the question of which gaps are worth filling seldom seems to have been approached analytically. These studies have elicited lay estimates of the size of a wide variety of risks, from nuclear power to communicable diseases, to pregnancy, to natural hazards (Burton, Kates, & White, 1978; Environmental Protection Agency, 1990; Freudenburg & Rosa, 1984; Kunreuther et al., 1978; Lichtenstein et al., 1978; Magat, Viscusi, & Huber, 1988; National Center for Health Statistics, 1987; National Research Council, 1989; Paikoff & Brooks-Gunn, in press). The present study focuses on the problems of conveying information. Three sources of commentary on the social context of risk communication are Fischhoff (1990), Krimsky and Plough (1988), and National Research Council (1989).

In many cases, however, what people need to know most is not summary estimates, but substantive knowledge of what a hazard is and how it works. Such knowledge is essential for following public discussions about a hazard, for assessing one's competence to deal with it, and indeed, for formulating the options that might serve as the focus for decision making. Furthermore, people often have no access to scientific estimates of risk, meaning that they must generate their own estimates on the basis of whatever they know about the nature of a hazard.

Determining what people know—and need to know—about these substantive processes requires quite different research strategies than studying their summary estimates. A straightforward approach is to make a list of "first things that one needs to know" about the risk. Risk communications could then focus on those first facts that people do not know already.

Some of the problems with this strategy are suggested by a mildly despairing comment made in the Institute of Medicine's (1986) important report, *Confronting AIDS*. It noted that, despite the extensive publicity given to the disease, only 41% of the respondents to a national survey agreed with the (correct) statement that AIDS was caused by a virus. Such ignorance shows a clear gap between expert and lay beliefs. Yet, one must ask, is it an important gap? That is, are there any decisions or substantive inferences that hinge on this knowledge? If not, then alarm over this display of ignorance could be doubly damaging. On the one hand, it would unnecessarily erode experts' respect for lay people (why fault them for ignorance of things that do not matter in the decisions that they face?). On the other hand, it would waste the public's valuable attention by focusing communications on irrelevancies, perhaps eroding public respect for experts (why are they telling us this?).

It is hard to think of a practical decision that would be directly influenced by the fact that "AIDS is caused by a virus." Yet that need not mean that this fact is irrelevant to understanding AIDS as a phenomenon. A more systematic approach is needed for circumscribing the set of relevant information.

An Approach Using Influence Diagrams

Figure 1 presents one possible approach, illustrated with the risks of radon. It is an *influence diagram*. In it, each node-link-node combination portrays an "influence," in the sense that the value of the concept at the beginning of an arrow affects the value of the concept at the arrow's point. For example, "wind velocity and direction" influences the value of "indoor–outdoor pressure difference." When completely specified, an influence would be defined in terms of conditional probabilities, where *a influences b* if the probability distribution of *b* conditioned on *a* is different than the unconditioned distribution of *b* (Howard & Matheson, 1984).

As can be seen, this influence diagram has a hierarchical structure. In places, there are up to five levels of detail in the concepts whose values could influence the state of some higher level concept. Those higher level concepts are the primary influences on the risks of radon. In principle, each influence could represent an opportunity to reduce (or increase) those risks—although, of course, there may be no known or feasible way of doing so. Thus, an influence diagram should capture the relationships needed to structure a decision, as well as to estimate its parameters.

As mentioned, a fully specified decision would contain complete conditional probability distributions for all influences. Obviously, this is a considerable challenge even for the technical experts most knowledgeable about an environmental hazard. One could hardly expect lay people to be so well informed. A more modest expectation would be that they understand the directions (and, perhaps, rough magnitudes) of the influences in the diagram. More modest

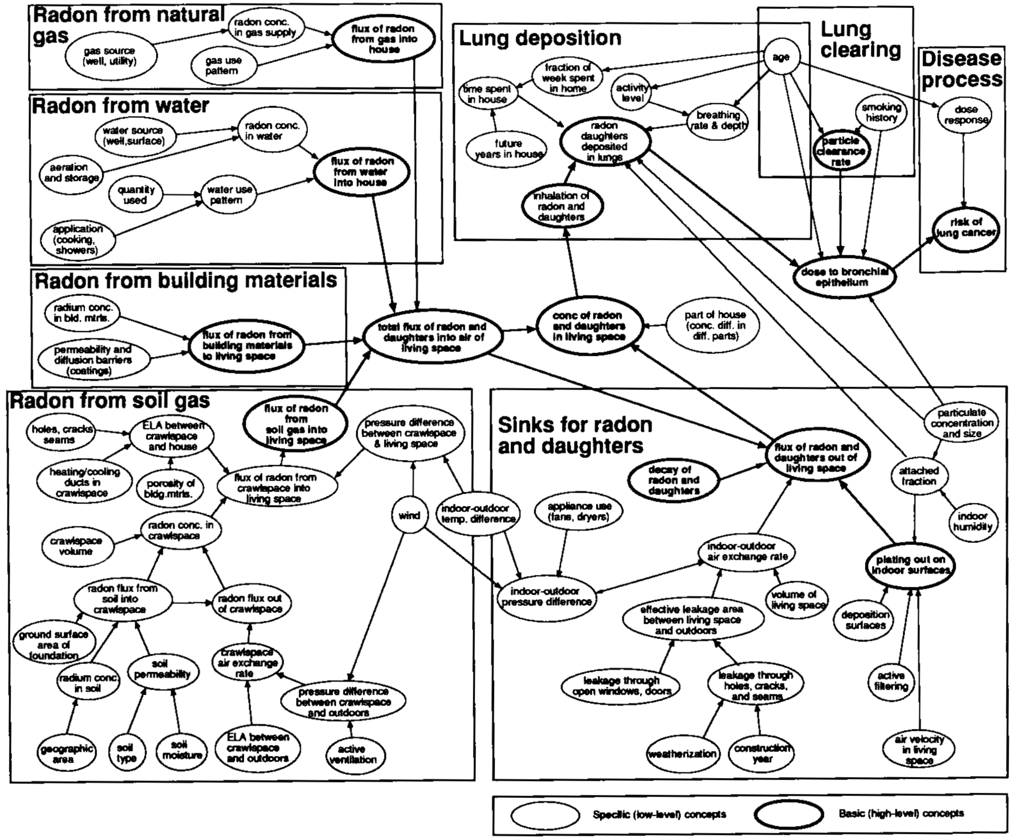

Fig. 1. Expert influence diagram for radon risk in house with crawlspace.

still would be their knowing just the important concepts. Even more modest would be their having no beliefs that are not in the diagram; that is, neither misunderstanding the influences that are there nor having erroneous beliefs not even suggested in the diagram.

If people's beliefs could be characterized in terms of deviations from this model, that could provide an orderly basis for determining the content of risk communications. Such messages could try to fill in the gaps and correct the misconceptions. The problems of making such additional information comprehensible would remain. However, those efforts would at least focus on transmitting the relevant information—and correcting misunderstandings that might cause that information to be misinterpreted. If lay people's mental models were organized along the lines of the expert model (or could be structured along those lines through instruction), then communications embodying the structure of the influence diagram might be relatively easy to understand (Atman, 1990).

Pursuing this strategy requires the following steps: (*a*) create an expert influence diagram, (*b*) elicit lay people's relevant beliefs, (*c*) map those beliefs into the diagram, and (*d*) identify gaps and misconceptions. Once risk communications have been composed to address these lacunae, their impact should be evaluated empirically by repeating Steps *b* through *d*. The remainder of the article demonstrates a set of procedures implementing this approach.

Figure 1 represents Step *a*. It was developed by Dr. Keith Florig, an applied physicist, through successive iterations with our research group, drawing on scientific sources such as National Council for Radiation Protection (1985) and National Research Council (1988), and beginning with descriptions of radon decisions such as those offered by Evans, Hawkins, and Graham (1988) and Svenson and Fischhoff (1985). Further research about the development of expert influence diagrams can be found in Howard (1989). (In our own work, we have developed analogous diagrams for a variety of hazards, including Lyme disease, skin cancer from exposure to the sun, lead, and nuclear reactors on space vehicles. They are available on request. Responses to most have been studied empirically.)

The procedure used in Step *b* begins with a very open-ended interview, so as to minimize the imposition of the scientific perspective on respondents' conceptualizations. Respondents are asked to elaborate on all comments that they had made initially as well as to say something about each major aspect of risk: exposure processes (how people come in contact with the hazard), effects processes (how the hazard affects people), and risk management (how the risk can be controlled or reduced). The intent of this procedure is to provide more directive prompts, but without suggesting any unfamiliar concepts. The interview concludes by asking respondents what, if anything, each of a set of diverse photographs has to do with radon. This step was intended to increase the chances of evoking as-yet-untapped beliefs, but with a greater risk of reactivity. In subsequent work, more easily administered closed-ended questionnaires have been developed, based on these initial results (Bostrom, 1990).

Steps *c* and *d* follow fairly directly from these initial steps, although the details of transcription, coding, reliability checking, and data analysis are moderately arduous. We believe they complete a generally applicable and revealing set of procedures.

Method

Respondents

Twenty-four interviews were conducted in the Pittsburgh area by a single interviewer, a registered nurse with experience in communicating occupational hazards. Respondents were recruited from several civic groups, which received a monetary contribution in return for their members' participation, or through signs posted at local libraries, in which case payment was direct. Respondents were divided equally between males and females. Two thirds were employed; about half of these were professional and half in service/sales/clerical jobs. Three (13%) were students. Fifteen were between 20 and 40 years old, with the remainder divided between the 40–60 and over-60 age brackets. Three quarters were homeowners. Thus, they were a diverse set of adults, although no claim is made about their representativeness.

Procedure

Respondents were interviewed individually, with the typical interview lasting 45 minutes. The first, *nondirective* stage of the interview began by asking respondents to describe everything that they knew about radon and its risks, in what was intended to be a nonevaluative tone (i.e., "we want to know what people know so that we can design helpful communications"). Once their spontaneous responses appeared exhausted, respondents were asked to elaborate on each comment that they had made. They were then asked what they knew about each major aspect of radon risk. These follow-up requests were constructed to avoid introducing new physical concepts or problem framings. In the second, *directive* stage of the interview, respondents sorted 36 black-and-white photographs according to whether each had something to do with radon. As respondents worked, they were asked to describe each photograph (to be sure that they saw in it what we had seen) and the reasons for their choice. The photos covered various topics such as a diagram of a lung, a person dusting a bookshelf, and a frozen food section at a grocery store. As we interpreted them, about one half dealt with radon-related topics, covering the major nodes in the influence diagram.

Coding

All interviews were taped and transcribed. After being checked for accuracy by the interviewer, the transcripts were coded into the expert influence diagram (see Figure 1). Concepts that did not fit into the diagram were listed separately, sorted into five types: (a) *misconceptions;* (b) *peripheral beliefs,* correct, but not particularly relevant; (c) *indiscriminate beliefs,* correct as far as they went but imprecise (e.g., "radon makes people ill," without specifying the illness); (d) *background beliefs,* such as "radon is a gas" and "radon is radioactive"; (e) *valuations,* such as "radon is dangerous." Even with only 24 interviews, the final few interviews that were coded added very few new concepts. When respondents mentioned a mitigation procedure explicitly, it was coded according to the underlying concept.

The coding scheme was developed by a pair of researchers, both familiar with the expert diagram but with limited technical knowledge of radon. Coders were given the expert vocabulary and added the lay topics. After reaching agreement on two initial interviews, they, along with a third researcher, coded two additional interviews independently. All three coders agreed about 75% of the time, depending on the interview and concept category. This seems like reasonably good agreement for such a fine-grained coding scheme. The influence diagram contained 14 first-level concepts (i.e., more important or influential ones—10 exposure, 4 effects) and 48 more specific concepts (42 exposure, 6 effects). In addition, respondents contributed 6 background concepts, 6 peripheral concepts, 20 indiscriminate concepts, 16 erroneous concepts, and 4 valuation concepts, for a total of 114 different concepts. (See Table 3 for a complete list of these concepts.)

Results

Statistical Summaries

On average, respondents produced 14.0 concepts in the nondirective portion of the interview and 15.0 concepts in the directive portion. Of the second group, 37% were restatements of concepts mentioned in the first half. The mean number of misconceptions was, however, larger in the second portion of the interview (.67 vs. 2.52; $p < .001$; Wilcoxon test), as was the average number of mitigation measures mentioned (.96 vs. 1.52; $p < .10$).

Three statistical measures of the extent of respondents' knowledge about radon were defined: completeness, accuracy, and specificity. They measured, respectively, how much respondents knew, what proportion of their beliefs were correct, and how detailed (or general) those beliefs were. See Table 1 for results on these measures.

Table 1. Mean Proportions Obtained by Respondents on Various Measures of Performance

	Nondirective phase			Directive phase		
Measures	All concepts	Exposure concepts	Effects concepts	All concepts	Exposure concepts	Effects concepts
Completeness[a]						
All levels	.11	.12	.05	.11	.12	.10
Level 1	.18	.21	.08	.22	.24	.17
Accuracy[b]						
All levels	.06	.09	.03	.06	.09	.04
Level 1	.03	.16	.05	.05	.16	.06

[a] Average proportion of expert concepts that were mentioned by a respondent.
[b] Product of completeness and concurrence (the proportion of a respondent's concepts appearing in the expert influence diagram).

Completeness was computed as the percentage of the concepts in the expert model that a given lay model included. On average, respondents produced 11% of the total expert model in each portion of the interview. As might be expected, the level of completeness was much higher for the (more important) first-level concepts (18% and 22%, for the two halves of the interview, respectively). Perhaps less predictable was the higher level of completeness for exposure concepts than for effects concepts, even though there were many more of the former than the latter. This disparity was considerably larger in the first half (12% vs. 5%) than in the second half (12% vs. 10%), suggesting that the (more directive) photos managed to elicit some latent knowledge of effects.

There are several possible ways to measure the accuracy of those concepts that respondents did mention. One, called *concurrence,* is the percentage of the concepts in a respondent's model that appeared in the expert influence diagram. This measure was 45% and 44% for the two halves, respectively. Thus, a majority of respondents' concepts were wrong, peripheral, etc. A somewhat more comprehensive measure, called *accuracy,* appears in Table 1. It multiplies concurrence by completeness, in order to give credit to respondents who not only said primarily right things, but also said many of them. It turned out that completeness and concurrence were strongly correlated in both halves (r = .89, .77, respectively, using Spearman rank-order correlations). For a sample of this size (N = 24), the following significance levels hold: r = 0.45 ($p < .05$), 0.55 ($p < .01$), and 0.65 ($p < .001$). Respondents were equally accurate in both halves, more accurate about the important, first-level concepts, and more accurate about exposure concepts than effects concepts.

There was only a modest positive correlation between respondents' concurrence scores and the number of concepts that they produced (r = .51, .32, for the two halves). Thus, respondents who said more were somewhat more likely to give a higher percentage of correct information.

Specificity was calculated as the ratio of specific (lower level, levels 2 and below) concepts to more important, general concepts (level 1) in each respondent's data, divided by the comparable ratio for the expert model. Thus, a ratio larger than 1 meant that the respondent had a higher proportion of specific concepts than did the expert diagram. This calculation considered only concepts that were in the expert model, because others did not necessarily fit in the expert hierarchy. The mean ratios were .51 and .40 for the two halves of the interview. Thus, respondents were much more general than the experts (consistent with their higher completeness scores for level 1 than overall). Respondents who provided more concepts were only slightly more specific (r = .29), meaning that saying more was nearly as likely to increase the breadth of coverage as its depth or specificity. Providing more concepts was associated with providing somewhat more wrong concepts in the second half of the interview but not in the first half (r = −.17, .43), suggesting that the photos encouraged some counterproductive groping for concepts.

Substantive Beliefs

Table 2 shows the frequency with which each concept in the expert influence diagram was mentioned by respondents. Consistent with the greater completeness at the more general level, respondents mentioned individual general concepts more frequently. Indeed, every general concept (except "radon from gas supply") was mentioned by at least one of these 24 respondents, whereas many specific concepts were never mentioned at all.

Most respondents mentioned that radon flows into living spaces and concentrates there, two exposure concepts that typically arose in both sections of the interview. Fewer respondents (11) mentioned that radon also flows out of living spaces, and most of these respondents did so only in response to one of the photos. Relatively few respondents mentioned the basic sources of radon: water (7), soil gas (6), and building materials (3). Almost none (2) mentioned the fact that radon decays (reducing exposure, as long as no additional radon is added). Radon has a half life of 3.8 days, so that once influx stops, the risk quickly vanishes.

Although most specific exposure concepts were never mentioned at all, a few seemed to be common knowledge. Specifically, most respondents mentioned the influence of the part of the house (17), the geographic area (17), the influx of radon into basements or crawl spaces (14), and the role of pipes and ducts (16) and of holes, cracks, and seams (14) in that influx—although they needed the prompts provided by the pictures to think of the latter comments. Smaller num-

Table 2. Frequency of Mention of Expert Concepts by 24 Respondents

Concept	Number of respondents mentioning concept: Nondirective phase only	Directive phase only	Both	Proportion of respondents mentioning at least once
Exposure level 1				
Concentration of radon in living space	1	0	21	.92
Total flux of radon into living space	4	2	12	.75
Efflux of radon from living space	2	9	0	.46
Radon from water	0	5	2	.29
Radon from soil gas	2	1	3	.25
Exposure level 2				
Part of house (concentration differs in different parts of house)	11	0	6	.71
Geographic area	15	1	1	.71
Pipes/ducts going into house from the ground/foundation	2	10	4	.67
Holes, cracks, and seams (in foundation, basement floor)	1	7	6	.58
Radon influx to basement/crawlspace	4	2	8	.58
Leakage through open windows/doors	2	7	2	.46
Indoor–outdoor air exchange rate	1	0	6	.29
Appliance use (fans, dryers)	0	5	1	.25
Construction of building	3	2	1	.25
Effects level 1				
Inhalation of radon	1	9	3	.54
Lung cancer	1	1	3	.21
Effects level 2				
Smoking history	1	3	1	.21

Note: Concepts mentioned by fewer than 5 subjects:

Exposure level 1: Building materials contain radon; decay of radon over time.

Exposure level 2: Weatherization; flux of radon from crawlspace/basement to living space; effective leakage area between foundation and living space; radon concentration next to foundation/barrier (in basement); radium concentration in soil; radon efflux from basement/crawlspace to outdoors; leakage through holes, cracks, seams; soil type; active ventilation of crawlspace/basement; radon concentration in water; soil permeability; effective leakage area between living space and outdoors; surface area of foundation/barrier.

Effects level 1: None.

Effects level 2: Time spent in house; age; dose response; breathing depth and rate; habits.

bers of respondents mentioned various methods of air exchange, consistent with the smaller number mentioning the general concept of radon outflow.

As previously seen in the summary statistics, respondents showed much less awareness of effects concepts. The most frequently cited expert concept (the inhalation of radon) was mentioned by only 13 respondents, most of them only after seeing the photographs (which included a diagram of a lung). Although 15 respondents mentioned cancer, only 5 noted that it was lung cancer, leaving them with (in our terms) indiscriminate beliefs, which are reported in Table 3. Indeed, the tables show that expert effects concepts were far outnumbered by incorrect or imprecise ones. There were few mentions of factors that enhance the effects of radon, like smoking and breathing deeply.

Table 3 shows the frequency with which the different kinds of nonexpert concepts were mentioned. For instance, most respondents reported the back-

Table 3. Frequency of Mention of Nonexpert Concepts by 24 Respondents

Concept	Number of respondents mentioning concept: Nondirective phase only	Directive phase only	Both	Proportion of respondents mentioning at least once
Background				
Radon is detectable with a test kit	19	0	4	.96
Radon is a gas	4	3	14	.88
Radon is radioactive	1	0	7	.33
Peripheral				
Mining/radon from mines	3	6	1	.42
Affects animals	0	8	0	.33
Indiscriminate				
Radon from underground	4	1	15	.83
Radon attaches to dust	0	7	0	.29
Radon in environment	2	3	0	.21
Fans (ventilation)	0	7	3	.42
More lower in house (correct, but reasons often incorrect)	7	0	3	.42
Cancer	6	3	6	.63
Lung problems	0	10	1	.46
Illness and death	4	2	0	.25
Radon contaminates	0	6	0	.25
Erroneous				
Affects plants	1	13	0	.58
Breast cancer	0	7	0	.29
Contaminates water	0	5	0	.21
Contaminates blood	0	9	0	.38
Radon from garbage	1	4	0	.21
Valuation				
Radon is risky, dangerous	4	3	6	.54

Note: Concepts mentioned by fewer than 5 subjects:

Background: Radon occurs naturally; radon is undetectable with senses; radon comes from uranium.

Peripheral: Radon in industrial waste; radon in radioactive waste; absorption through skin; radon comes from fossilized materials.

Indiscriminate: Porosity of building materials; health problems; genetic mutation; physiology; health; radon is poisonous; radon is an element; radon is extracted from soil; radon is a form of energy; radon is heavy (a heavy gas); radon is not volatile.

Erroneous: Radon from tank leaks; more higher in house; elevation of land; lead or concrete foundation/barrier (impermeable to radioactivity); leukemia; contaminates food; corrosion; inhibits growth (in children); skin lesions; radon is manufactured; radon has an odor.

Valuation: Radon is harmful; radon is scary; radon is costly to society.

ground facts that radon is a gas (21) and is detectable with a test kit (23). In addition to "radon causes cancer," the set of indiscriminate concepts included the facts that radon comes from underground (20), that fans affect radon exposure (10), and that radon causes lung problems (11), illness and death (6), and contamination (6). There is, obviously, some degree of discretion in deciding whether respondents' concepts are sufficiently precise to show that they really know what they are talking about. If one decided, for example, that the 15 respondents who said that "radon causes cancer" knew what kind of cancer it was (or that such general knowledge was adequate), then there would be an increase in completeness and accuracy scores, along with a decrease in specificity. However, because some respondents explicitly mentioned types of cancer not caused by radon, this inference seemed overly generous to us.

The most common misconception about exposure processes (offered by 5 respondents) was that radon comes from garbage. This idea might represent confusion between radioactive decay and organic decay. Such a misconception should be easy to correct, and it might merit attention if 20% of a general population shared it. Quite a few respondents mentioned the peripheral facts that radon comes from mining (10) and from industrial waste (3). If respondents believed these were the primary sources of radon, then these responses might better have been treated as misconceptions. If left unchallenged, such beliefs could blunt the effectiveness of risk communications.

The situation with effects processes was quite different. Very few were mentioned in the nondirective segment (except "radon causes cancer"). The photos, however, evoked a variety of peripheral and erroneous concepts. These include the beliefs that radon affects plants (14) and animals (8), that it causes breast cancer (7) and contaminates blood (9), water (5), and food (4). Quite a few respondents described radon as dangerous (13), harmful (4), etc. Thus, people seem to know that radon is bad for them, but not to have much idea why.

Discussion

This study offered a general method for studying risk perceptions, as a precursor to developing risk communications. The method's usefulness depends on completing several procedures, each with its own criteria for success. The first such procedure is producing an accurate, coherent, and encompassing influence diagram. As an example, Figure 1 has been reviewed by various individuals and is offered here for readers' scrutiny.

The second procedure is a way to elicit people's beliefs that neither puts new concepts in their minds nor leaves existing ones unstated. The method attempts to balance these somewhat conflicting goals by segmenting the interview into two parts, nondirective and directive. The nondirective approach is able to reveal much more diverse perspectives than the directive interview, which is designed to tap only ignorance and knowledge of expert facts. The risks of omission in the nondirective approach can be seen in the many concepts that appeared only in the second segment. The risks of commission in the directive approach can be seen in the many misconceptions that it evoked. The photographs that were used might be viewed as a sort of cognitive entrapment, suggesting "relevant" topics that might not have occurred to people otherwise (although that could not have happened if the respondents had understood radon well).

The third procedure is to analyze people's responses. With an open-ended procedure, that means coding responses into a common set of categories. Here, the categories were provided by the influence diagram, supplemented by respondents' nonexpert concepts. Despite the large number of categories, coding proved fairly reliable.

This coding scheme produced statistical summaries not only for the frequency of specific beliefs, but also for several aggregate properties of responses, namely their completeness, accuracy, and specificity. These statistics showed that respondents here knew relatively few of the facts in the influence diagram, with the known facts concentrated at the highest level of generality and combined with a substantial admixture of nonexpert concepts (some wrong, some imprecise, and some irrelevant). These results suggest that people like these respondents have a good deal to learn (and to unlearn) before they would understand the basic structure of the radon problem (at the level defined in Fig. 1).

If overall performance statistics such as these seem to warrant a communication program, then the belief-specific results could direct its substantive contents. For example, people need to know about the short half-lives of radon's critical decay products. Thinking that all radioactive materials, including radon, will contaminate a home indefinitely might vitiate people's accurate beliefs (e.g., why test if nothing can be done?). As it happens, this fact was so basic to understanding radon that we did not even include it explicitly in the expert influence diagram (just as we omitted some background facts that respondents did know, such as "radon is a gas"). This one vital gap notwithstanding, respondents seemed much better informed about exposure processes than about effects processes.

Thus, this set of methods seems to have produced results that are potentially useful for deciding whether to produce risk messages and, if so, what to include in them. As next steps, in addition to replication with broader samples, these results require testing through converging operations. For example, in other studies, we are examining (a) the applicability of these methods to other hazards, (b) the knowledge (and ignorance) shown in responses to closed-ended questionnaires tapping the same domain, and (c) the impact of risk messages designed to fill the gaps identified here (and structured around the influence diagram).

Our choice of method was determined, in part, by our applied focus. Thus, we have emphasized the match between respondents' beliefs and expert knowledge, because deviations indicate opportunities for providing information. We focused on individual pieces of qualitative knowledge because one cannot expect laypeople to intuit how much radon their house holds or how various interventions would affect that level. If we were interested in people's quantitative inferences, then a problem-solving task would have been appropriate, such as asking respondents how radon concentrations would change, say, when windows are opened or when ambient temperatures increase. Choosing problem-specific procedures for eliciting and representing beliefs seems an accepted practice in studies of thinking in complex domains (e.g., Gentner & Stevens, 1983; Johnson-Laird, 1983; Jungermann, Schutz, & Thuring, 1988; Rouse & Morris, 1986).

Judging by the results obtained here, people's understanding of the radon problem seems not only incomplete but also incoherent, in the sense of containing scattered and inconsistent items. If they were required to solve particular problems, such people might be expected to access and combine these beliefs quite unreliably. Thus, the process-tracing procedures that have been so useful in describing thinking in better structured domains (Ericsson & Simon, 1984; Montgomery & Svenson, 1989) might reveal a fairly messy situation here. They might also show people's inferences to be quite sensitive to the precise way in which problems are posed (Hogarth, 1982; Poulton, 1989).

Open-ended procedures such as those used here are very labor intensive. Moreover, they take one into the theoretically challenging domain of how people choose and apply propositions at different levels of specificity to rich, life-like situations (Collins & Gentner, 1987). However, they seem the only way to discover pertinent misconceptions (such as "radon is radioactive indefinitely"). As mentioned above, these misconceptions can blunt the effect of accurate beliefs. However, they will go unchecked if risk messages, as typically happens, are focused solely on the facts that some experts think are worth knowing (Bonneville Power Administration, 1987; Environmental Protection Agency, 1986; University of Maine, 1983; Yuhnke, Silbergeld, & Caswell, 1987).

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