

Designing Risk Communications: Completing and Correcting Mental Models of Hazardous Processes, Part I

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Many risk communications are intended to help the lay public make complex decisions about risk. To guide risk communicators with this objective, a mental models approach to the design and characterization of risk communications is proposed. Building on text comprehension and mental models research, this approach offers an integrated set of methods to help the risk communication designer choose and analyze risk communication content, structure, and organization. An applied example shows that two radon brochures designed with this approach present roughly the same expert facts as a radon brochure widely distributed by the U.S. EPA but meet higher standards on other content, structure, and organization criteria.

KEY WORDS: Risk communication; risk communication design; mental models; decision analysis; evaluation.

1. INTRODUCTION

Some risk communications are content with informing recipients' decisions. Others attempt to influence the direction of those decisions; perhaps to reassure a worried public, perhaps to motivate action.⁽¹⁾ Whatever the goal of a communication, its designers need to address the mental models that recipients bring to it, that is, the pattern of knowledge gaps, overly general understandings, and outright misconceptions that can frustrate learning.⁽²⁻⁵⁾ Furthermore, these information needs should be determined through a combination of formal analysis and empirical study. One cannot rely on the intuitions of technical experts regarding either what laypeople currently believe or what they need to know.^(6,7) This article presents a systematic approach for accom-

plishing these goals in designing communications. The following paper⁽⁸⁾ presents a method for evaluating those communications. Both are illustrated with examples concerning domestic radon, which the U.S. Environmental Protection Agency (EPA) is congressionally mandated to address.^(9,10) Table I outlines this "mental models" framework for risk communication design.

The three main tenets of this approach are that (1) the recipient of a communication needs a basic understanding of the exposure, effects, and mitigation processes relevant to making decisions about the hazardous process, (2) recipients' existing beliefs affect how they interpret and use any new information,⁽¹¹⁻¹³⁾ and (3) the information should be presented with appropriate text structure and reinforced with textual aids (e.g., section headings), as established in the general research on text comprehension.⁽¹⁴⁻²⁰⁾ In effect, a risk communication should complete a recipient's mental model of the relevant risk processes,⁽²⁾ which means both adding critical missing information and dispelling misconceptions that might affect decisions. Moreover, its contents should be specific enough to aid decision making: not so general

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Table I. A Mental Models Approach to Written Risk Communication Design

	Text content ("what to say")	Text organization ("how to say it")
Objectives	Content should make recipients' mental model(s) more complete, more accurate, and specific enough for decision-making about the risk by (1) covering basic expert model (2) addressing major misconceptions	Organization should facilitate comprehension and inference by (1) utilizing structure to highlight key components of contents (2) reinforcing structure with text comprehension aids
Text-based design/evaluation methods	Content analysis Map to expert model (cover important information) Map to lay misconceptions (address major misconceptions)	Structure analysis Map to analytical framework (stress important information) Text comprehension aids Check for summaries, section headings, advanced organizers

that it cannot address the concrete decisions that recipients face, and not so detailed that it obfuscates the message with needless technical information.

2. A MENTAL MODELS PROCESS FOR DETERMINING COMMUNICATION CONTENT

2.1. Guiding Principle

A risk communication should cover the basic facts that are relevant to the recipient's decisions. Therefore, the first step in risk communication design is to create (or select) an expert model of the decisions that recipients can make. Discrepancies between this model and recipients' existing mental models then indicate the content of the communications. Thus, the relevance of information depends on the decisions that must be made. Even within a given domain, different actors may need different information because they face different decisions, (e.g., for radon, homeowners deciding whether to test, public health officials deciding what safety limits to set).⁽²¹⁾

2.2. Radon Decisions

Radon is a colorless, odorless gas that seeps into homes from the soil. It can also come from private well

water containing radon and, rarely, from radium-rich building materials. EPA estimates that between 7000 and 30,000 lung cancer deaths per year in the United States may be attributed to radon exposure.⁽¹⁰⁾ Although experts can identify areas where high concentrations of radon are likely to be found,⁽²²⁾ they cannot predict accurately which individual houses will have high concentrations. For this reason, EPA recommends that all homeowners test their homes for radon and remediate if they find a concentration higher than 4 pCi/L. About 9 million U.S. homes have been tested.⁽²³⁾

2.3. Expert Model

Figure 1 shows an influence diagram of the decision-relevant information regarding radon, for a typical homeowner. An influence diagram is a directed network that represents the dependencies and events in a process.^(24,25) On the left and across the bottom are the factors that influence radon exposure processes. Health effects processes, in the upper right-hand corner, include the end point of this directed network—the risk of lung cancer from indoor radon. Each node represents an event in this probabilistic process; each link represents a directed influence, showing the dependency of an event at the head of an arrow on that at its tail. The diagram is hierarchical in structure, with the bold nodes representing the basic events (concepts), which the risk communication should include. In principle, each link offers an

Table II. Brochure Coverage of Expert Concepts

	CMU directed network	CMU decision tree	1986 EPA <i>Citizen's Guide</i>	<i>Environ- mental diseases</i>	Expert model
Basic concepts					
Exposure	9	8	7	4	9
Effects	4	4	4	1	5
Identification	4	4	4	2	4
Specific concepts					
Exposure	23	14	15	7	42
Effects	1	1	3	0	8
Identification	2	2	2	1	2
Number of words	~2350	~2750	~3170	281	

opportunity for mitigation (although in practice many are not currently feasible).

2.4. Lay Mental Models

Data from open-ended mental models interviews were used to characterize lay perceptions.⁽²⁾ Some of the misconceptions and gaps in understanding identified in those interviews could have impeded people from responding appropriately to a radon problem. For example, some subjects thought that radon could cause other adverse health effects besides lung cancer—which could lead them to look for nonexistent symptoms or to exaggerate the value of remediation. Few subjects mentioned any mitigation techniques. Few knew that radon and its decay products are relatively short-lived, leading some to conclude that once a home is contaminated, nothing can be done to clean it up.⁽⁶⁾ These examples suggest that a communication should, at a minimum, explain (a) that there is no way to tell if one has a radon problem without testing, (b) how to test, (c) how remediation is accomplished, and (d) that radon decays in a few days.

Two brochures about indoor radon were designed: CMUN (Carnegie Mellon University Directed Network brochure)⁽²⁶⁾ and CMUD (CMU Decision Tree brochure).^(8,27) Each brochure was created by a single author, and reviewed iteratively by other researchers.

2.5. Content—Expert Concepts

Table II compares these two texts with the first edition of EPA's *A Citizen's Guide to Radon*⁽²⁸⁾ and the

radon section of a junior high school text on *Environmental Diseases*⁽²⁹⁾ in terms of the concepts in the expert model.^(30,31) The reliability of two independent coders was between 92 and 98% for the different communications. All differences were resolved and are reflected in the counts reported in Table II. Concepts were classified by level (basic versus specific) and by knowledge category: exposure concepts (e.g., radon from soil gas) and effects concepts (e.g., lung cancer). Identification concepts refer to background information so basic that it was not included in the expert model (e.g., radon is a gas).

Expert concept coverage is roughly equivalent for the two CMU brochures and EPA's *A Citizen's Guide*. Each of the three brochures covers almost all of the basic-level concepts and approximately half of the specific-level concepts. The *Environmental Diseases* text conveys only about a third of the basic-level expert concepts and 14% of the specific-level concepts, not surprising given its much reduced length. The content analysis shows not only how complete the brochures are, but also what they skip. Graphical presentation of the same analysis highlights their content and omissions (Fig. 2). Basic-level concepts covered in a text are indicated by filled ovals. Specific-level concepts are indicated by cross-hatched ovals.

Visual inspection of Fig. 2 shows the following. (1) Each of the four communications conveys different specific concepts. (2) All three full-length brochures present most specific concepts from the most likely exposure route—the "radon from soil gas" box on the lower left. (3) CMUN is most complete in its coverage of expert concepts. (4) Not only does the *Environmental Diseases* text cover far fewer concepts, but some critical concepts are missing. For example, the only effects concept is that radon can lodge in the lungs, with no mention of the fact that the exposure can lead to lung cancer.

2.6. Content—Nonexpert Concepts

To characterize the nonexpert concepts in these brochures, we pooled all that arose in our open-ended interviews (2) with those in several (partially inaccurate) newspaper articles about radon. They were categorized as (a) *wrong concepts* (e.g., radon causes skin lesions); (b) *indiscriminate concepts*—which are correct concepts, but at a level too general to help with decision making (e.g., radon is in the environment); (c) *peripheral concepts*—which are correct but are not central to the problem (e.g., radon from industrial waste, which can be true,

but is not a major source); and (d) *overly specific concepts*—which are correct, but at too specific a level (e.g., the alpha decays of ^{218}Po and ^{214}Po produce the most significant radiation dose from the radon series⁽³²⁾).

Forty-six nonexpert concepts are mentioned by CMUN, 51 by CMUD, and 40 by EPA. Although the numbers are similar, the concepts are not. Both CMU brochures aim to correct explicitly some of the misconceptions revealed in mental models interviews. The CMUN brochure contains statements directly contradicting the notions that radon comes from garbage, chemical tank leaks, or toxic waste dumps; radon affects plants; radon can build up on surfaces in the home and contaminate them; and radon causes leukemia, breast cancer, skin problems, or birth defects. The CMUD brochure contradicts the ideas that radon affects plants, that radon can build up on surfaces in the home and contaminate them, and that radon can cause health problems other than lung cancer. The EPA brochure does not directly address any of these misconceptions, although it does state that the only known health effect is lung cancer.

To summarize, the CMU and EPA brochures cover similar numbers of expert concepts and nonexpert concepts. But guided by the mental models study, the CMU brochures directly refute some wrong concepts and qualify peripheral concepts (to indicate that they are not central). Giving equal footing to marginally relevant and central facts can mislead readers by making them seem equally important.⁽⁸⁾

3. A COGNITIVE PROCESS FOR COMMUNICATION ORGANIZATION

3.1. Structure—Theory

Readers interpret what they read in terms of their existing mental representations. Information acquisition is enhanced when the surface form of the text matches these representations.⁽³³⁻³⁵⁾ Therefore, readers attempting to make decisions should be helped by text structures according to a decision model.^(36,37) People are also more likely to remember information presented at the highest level of a hierarchy.^(14-20,38) As a result, text structure should make it clear what matters most. Devices such as insets can help to adapt a nonlinear underlying structure into the inherently linear nature of sequentially read text.⁽³⁷⁾

3.2. Structure in Radon Communications

The structure of CMUN was based on the influence diagram shown at the top of Fig. 3. The section headings in CMUN follow the nodes in the influence diagram from exposure to effects processes, then cover risk control options (e.g., test to find out what the risk is; remediate if it is high). This structure ensures that the basic physical processes and contingent decisions appear at the highest level in the hierarchy, hence should have the greatest chance of being remembered. The CMUN brochure consistently presents information about radon processes at the top of the text structure hierarchy and has an organization that is consistent with the tasks readers face.

The EPA brochure also presents information in the same general order: It defines radon, then discusses in turn exposure processes, effects processes, detection procedures, and control techniques. Nonetheless, the bars to the left of the headings in Fig. 3 show that this order is not followed strictly. The flow of information is strictly exposure to effects to control in CMUN. In contrast to CMUN's hierarchical organization, in which specific concepts are presented under more basic concepts, the EPA brochure has a flat, linear structure.

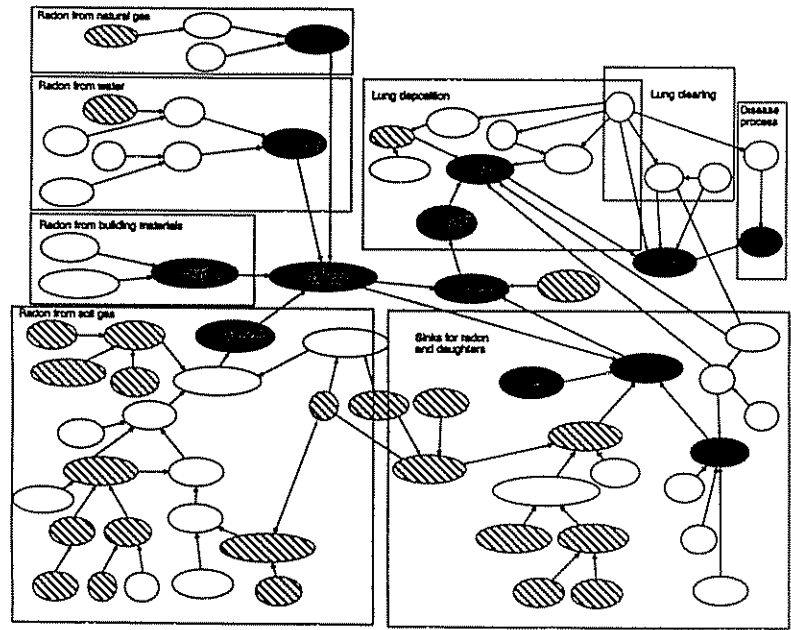
This analysis could be supplemented by a more detailed text-structure mapping at the sentence level; methods are discussed, for example, by Meyer.⁽³⁹⁾

3.3. Adjunct Aids—Theory

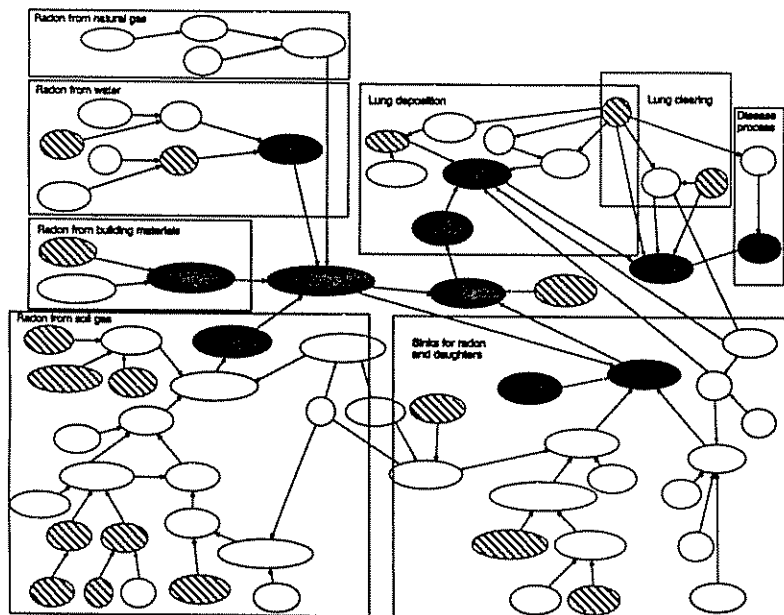
As mentioned, organizational features of a text also affect readers' comprehension and memory. (a) Headings for segments of text help readers to recall information more easily⁽⁴⁰⁾ and find information more rapidly.⁽⁴¹⁾ (b) Receiving an outline of the material that one is about to read (an "advanced organizer") also increases recall.^(18,42) (c) Readers may recall more from summaries of information than from elaborated text.^(18,43-45)

3.4. Adjunct Aids in Radon Communications

Table III compares nine radon brochures in terms of their use of text comprehension aids. The decision analytic structures of the CMU brochures are augmented with all three of the aids discussed above: Sections are reinforced by titles separating each section; advanced organizers are provided through a table of contents, a summary, and a short paragraph at the beginning of the



CMU Directed Network Brochure (CMUN)



EPA 1986 Citizen's Guide to Radon (EPA)

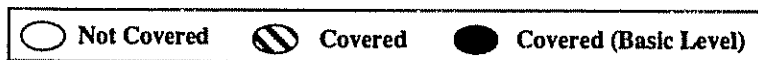
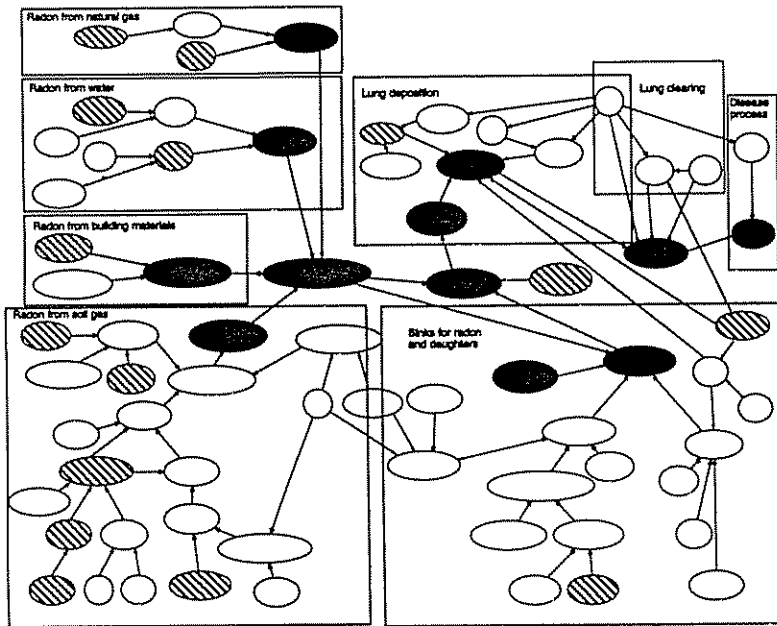
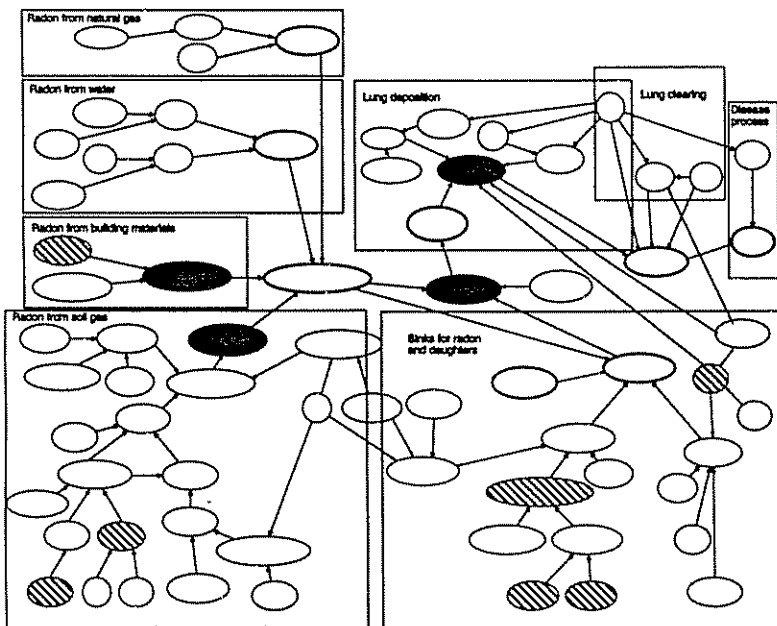


Fig. 2. Concepts covered in four communications about indoor radon displayed in reduced versions of Figure 1.



CMU Decision Tree Brochure (CMUD)



Environmental Diseases Text



Fig. 2. Continued

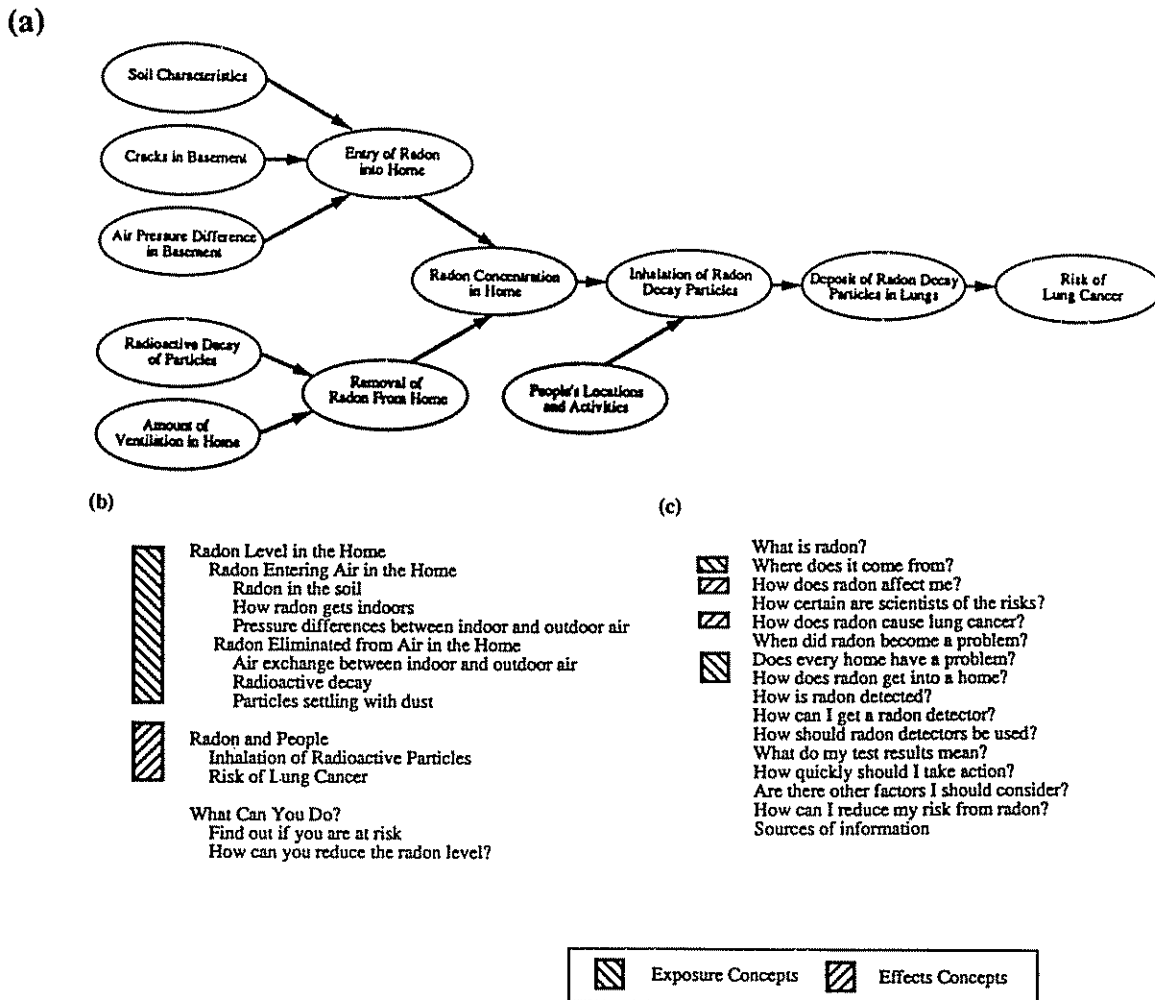


Fig. 3. (a) Influence diagram underlying CMU directed network (CMUN) brochure structure. (b) Section headings in order of appearance for CMUN brochure. (c) Section headings in order of appearance for 1986 EPA *A Citizen's Guide to Radon*.

brochure describing what to expect; and a concluding summary reinforces the most important points.

The information in the EPA brochure is also segmented, by section headings stated as questions that the text answers. However, neither advanced organizers nor summaries of the content are provided. The updated 1992 version of EPA *A Citizen's Guide* includes a summary. Section headings are the only aids in the other brochures.

4. OTHER EVALUATION TOOLS

Our research procedure also took advantage of the familiar strategies of subject matter expert review (to ensure the accuracy of our material) and iterative editing (to polish the English). Although these processes can

catch mistakes, they provide no guarantee of achieving the appropriate content or structure. Moreover, they can introduce problems by creating text better suited to people like the writers than people like the readers. We did not rely on readability measures, which purport to assess the education levels that readers need.⁽⁴⁶⁻⁴⁸⁾ While sometimes useful, such scores cannot indicate whether a text conveys the right information or whether the information actually makes sense (even if it uses short sentences and simple words). Schriver⁽⁴⁸⁾ offers a comprehensive review of text evaluation tools.

5. CONCLUSION

In this paper we ask what content and organization are most likely to help a risk communication recipient

Table III. Inclusion of Text Comprehension Aids for Various Radon Communications

Brochure	Text comprehension aids			
	Summary at end	Summary at beginning	Advanced organizer	Section headings
This study				
CMU directed network	+	+	+	+
CMU decision tree	+	+	+	+
1986 EPA <i>Citizen's Guide</i>				+
1992 EPA <i>Citizen's Guide</i>		+		+
Other radon brochures				
NYSERDA/EPA study				+
NJ/EPA study				+
NY State Health Dept.				+
NJ Dept. of Environ.				+
Bonneville Power				+

make decisions about that risk. Based on findings from mental models research and text comprehension studies, we show that inappropriate content and poor structure are likely to confuse communication recipients. The design approach presented here helps risk communicators avoid these failures. This approach offers a theoretically integrated and empirically testable set of easily used risk communication design and evaluation methods. It allows researchers to characterize risk communications explicitly, using a yardstick chosen to reflect risk communication goals. According to this yardstick, CMU brochures are superior to the U.S. EPA's first *A Citizen's Guide* in terms of both content and organization.

The following article⁽⁶⁾ asks whether readers of the CMU brochures remember and integrate more about radon processes than do readers of the EPA brochure and shows that a mental models approach also provides a way to evaluate these communications—or those derived from other perspectives.

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