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Lay Views on Uncertainty in Health Risk Assessment: A Report on Phase II Research

Branden B. Johnson

New Jersey Department of Environmental Protection

Paul Slovic

Decision Research

Eugene, Oregon

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Lynn Desautels, EPA Project Officer

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Executive Summary

It will be a challenge to present uncertainty in environmental health risk estimates to the public in ways that inform, rather than outrage, this important audience. Although such presentations may increase citizens' risk knowledge and trust in the honesty and competence of institutions providing risk estimates, careless communication could have undesirable results.

In Phase I of this research, people had no response to certain experimental presentations of a range of risk estimates; in other experiments, two-thirds of the sample saw the range estimates as a signal of government honesty and competence. We needed more study of how laypeople thought about uncertainty in risk assessment, and its implications for risk management, to untangle these mixed findings.

Phase II research included intensive interviews and open-ended questionnaires in New Jersey and Pennsylvania, focus groups in Oregon, and a long closed-ended questionnaire given to 280 Eugene, Oregon, residents (largely college students). We presented uncertainty in the form of a range of risk estimates, primarily in a hypothetical case of a chemical in drinking water.

The following responses appeared among our participants (Eugene sample, unless otherwise specified):

- About 45% doubted the honesty of the government in presenting ranges of risk estimates, a higher proportion than in the earlier research.
- About a third disagreed that government was less competent for discussing ranges of risk estimates.
- On average, people supported presentation of uncertainty information. A third of our sample strongly desired certainty, rejecting risk ranges or quantitative risk estimates of any kind.
- Zero as a lower bound for a range of risk estimates was seen on average as an indicator of either incompetence or dishonesty, whereas a very small positive lower bound (e.g., 1 in 10 million) had much less effect, even though a majority saw no difference between zero and a 1 in 10 million lower bound. Those who did see a difference seemed to doubt that the government would discuss risks if they were truly zero.

- On average, people tended to see the high end of a risk range as being more likely, even with a lower risk being labeled as "most likely."
- Some, but not all, interviewees and focus group members volunteered reasons for uncertainty, such as differences in exposure and personal susceptibility. However, explanations of uncertainty as due to extrapolation from high-dose data (e.g., from workers, or due to an accident) or from animal experiments confused, irritated, or disturbed them. Eugene responses to animal and high-dose extrapolation explanations were no different; an overwhelming majority agreed with scientist-offered reasons for uncertainty, but this seemed to be a rationalization of distrust rather than true agreement.
- People said they would doubt a lower risk estimate from a second study more than they would a higher risk estimate, but most felt more confident about the safety of drinking water after reading a scenario about a lower risk estimate.
- When faced with hypothetically overlapping risk estimates from government and environmentalists, people did not observe the overlap or interpret it as meaning anything; however, in the abstract they said agreement among these two groups (or of academics with government) would make them suspect that the environmentalists and academics had been corrupted.
- People in interviews and focus groups did not see environmental health uncertainties as having any relationship to financial, recreational, or transportation (mortality) uncertainties.
- Trust in officials was the most common predictor of people's reactions to government risk ranges.
- Although a substantial minority of our sample had difficulties with numbers, mathematical literacy played a very small role in their reaction to risk uncertainties.

Background

Several government, industry, and academic commentators have urged communication of uncertainties in environmental health risk estimates to public and other lay audiences, as we noted in our final report for Phase I (Johnson & Slovic, 1994a) and a subsequent published article (Johnson & Slovic, 1995). Such arguments continue to be made. Communication of uncertainties is needed, it is said, to avoid conveying information that "is incomplete and may be misleading" (Carpenter, 1995, p. 127). Narrative statements of "statistical reliability" should be made even if it "is not easy for scientists to make" them (Carpenter, 1995, p. 132). A recent National Research Council report (1994) advised U.S. Environmental Protection Agency (EPA) to communicate exposure or variability information in a three-part format: the estimated risk, the level of confidence that the risk is no greater than this estimate, and the subpopulation to which the estimate applies. Administrator Browner's memorandum on EPA's Risk Characterization Program (1995) said that "a balanced discussion of reasonable conclusions and related uncertainties enhances, rather than detracts, from the overall credibility of each assessment."

Since our earlier report, we have found a few dissenting voices on the benefits of conveying uncertainty. Arguing that discussing uncertainty in risk estimates would give homeowners an excuse to avoid testing for natural radon in their homes, academic researchers, state and federal officials, and nonprofit groups have urged that radon communications present "an unambiguous 'united front'" (Garrison, 1991; USEPA, 1992, ch. 6, p. 6; Weinstein, Sandman, & Roberts, 1989, p. 18). We cannot definitively refute the argument that communicating uncertainty about radon risks would have made the testing rate worse. However, with about 5% of U.S. homes having been tested, the unambiguous and forceful U.S. media campaign does not appear to have had much better results than lower-key campaigns in Sweden (4%) and Finland (2%) (Cole, 1993, pp. 72, 179, 181–182). Further, we used a radon analogue ("zydin") in a Phase I experiment on uncertainty. Zydin elicited significantly lower ratings of risk and worry than a Superfund site chemical at equal levels of estimated cancer risk. Yet intentions to get the problem solved did not vary, by either hazard or the level of uncertainty in the risk estimate. If these results can be generalized, they imply that communicating uncertainty in radon risk estimates would not have depressed radon testing frequency any further.

Various other criticisms of communicating uncertainty have been made. The President's Commission on Risk Assessment and Risk Management sent a letter to House leaders December 14, 1994, that raised concerns about H.R. 9, the Job Creation and Wage Enhancement Act. Among these concerns was that "providing for 'best estimates' of risk along with plausible upper- and lower-bounds on those estimates may not be much improvement on current methods" (*Risk policy report,* 1995, pp. 12–13). A prominent risk assessor (and member of the President's Commission) independently assailed mandated communication of risk uncertainty, arguing that a range of risk estimates might be misinterpreted as implying equal likelihood of all estimates, calculating such ranges in a consensual way would be very difficult and time-consuming, and no other policy-related numbers—including cost-benefit analyses being considered for a mandate under the same legislation mandating risk characterization, as well as other economic estimates (e.g., of gross domestic product or health care reform costs)—are expected to come with uncertainty estimates (Goldstein, 1995, pp. 1602–1603, 1609). In less explicit language, MacGregor, Slovic, and Morgan (1994, p. 827) suggested that "even careful presentation of the current 'complicated' ... state of affairs [concerning scientific knowledge about electromagnetic fields] will increase people's concerns."

This continuing debate triggered our initial studies, and led us to conclude that more research on public response to uncertainty should be conducted. The findings of our earlier research (Johnson & Slovic, 1994a, 1995) were that:

- People are unfamiliar with the notion of uncertainty in risk assessment, and with uncertainty in science generally.
- People may recognize uncertainty (i.e., a range of risk estimates) when it is presented simply.
- Graphical presentation produced mixed results in communicating uncertainty, making a range of estimates more obvious, but causing the information to seem less trustworthy.
- People's views on the environmental cases presented in our experimental stories may have been influenced less by variations in uncertainty than by personal attitudes toward risk, government and authority.
- Agency discussion of uncertainty in risk estimates appears to signal agency honesty.

- Agency discussion of uncertainty in risk estimates may be a signal for some people that the agency is incompetent.
- Low risk levels were deemed to be "preliminary" estimates by laypeople, possibly implying distrust.

Our Phase I studies used several experiments to see how people would respond to uncertainty in the form of a range of risk estimates: two hazards (natural radiation and a chemical in drinking water from a hazardous waste site), various upper- and lower-bounds, and graphics. Two focus groups also directly compared their reactions to point and range estimates. In our conclusions, we pointed out that other presentations of uncertainty may have stronger, or different, effects on perceived risk, honesty, and competence. For example, only one source of uncertainty (the difficulty of extrapolating from animal data) was described in one of our experiments; more focus on explanation might affect lay responses.

However, we concluded that it would be premature to test such variations without a better understanding of how citizens conceive of uncertainty in environmental health risk assessment. Rather than employing experiments, where one infers thoughts from behaviors, our present goal was to begin with qualitative methods (interviews, open-ended questionnaires, focus groups) to see the world from the lay participant's viewpoint. Once we can describe how citizens might interpret a description of uncertainty, we might be able to suggest useful contextual and focal information for use by organizations wishing to convey uncertainty in health risk assessment to their audiences.

Method

Our earlier findings suggested that uncertainty in risk assessment was a novel concept for laypeople. This implied that the approach to revealing "mental models" of risk-related topics pursued by Bostrom, Fischhoff, and Morgan (1992) would not work. In that approach one asks people to "tell me" about the topic (e.g., radon) and uses follow-up questions to elicit details of the person's cognitions that aren't volunteered initially. Asking people to tell us about "uncertainty in risk assessment" did not seem likely to be fruitful.

We, therefore, provided stimulus items that people could read and react to (see Appendix I for 14 examples). These items used one to six sentences to briefly introduce a range of risk estimates, or to explain how risk assessors identify a "safe" level for human exposure to a noncarcinogen. In contrast to the simulated news stories of our earlier work,[1] these items included only information that identified the hazard and described or explained uncertainty as a range of risk estimates. Once a stimulus was read, we began by asking "what thoughts, questions, and so forth, come to mind when you read this?" Only after allowing this open-ended response, and asking (in interviews) for more details about this response, were more focused questions asked. The intent was to minimize biasing responses through interviewer behavior or survey construction.

We collected information through interviews, focus groups, open-ended questionnaires, and two versions of a closed-ended questionnaire. All stimulus items used in focus groups and questionnaires dealt with a government announcement about a chemical in the person's drinking water (whether tap or bottled water). Another seven items used only in interviews probed reactions when the same risk information concerned contaminated soil or air in people's neighborhood, or automobile, or airplane crashes.

[1] Experiments in Phase I research (Johnson & Slovic, 1994a, 1995—Appendix has copy of latter) used simulated news stories about environmental problems, with headlines, quotations from government spokespersons and local citizens, and so forth. The content of these stories varied. The problem might be chemicals from an abandoned waste site or natural radiation; a point estimate or a range of estimates of risk might appear; and so on. Each participant read one of these stories. By comparing their responses across different stories, we could see whether hazard type, mention of uncertainty, and so forth, made a difference.

Interviews

Thirteen people were interviewed in twelve interviews (one interview included both members of a couple, at their request) in January 1995. The median interview took 45 minutes (range 30–120 minutes) and involved responses to seven items (range 4–11). Nine interviewees were women; four interviewees were in their 20s, five in their 30s, and the rest up to age 79. Two interviewees were black, with the rest white; five were single, two widowed, and the rest married. Four interviews were conducted with nonscientist employees of the New Jersey Department of Environmental Protection in Trenton, the rest with residents of an apartment complex in a Philadelphia suburb. Interviewees' occupations included personnel administrator, secretary, paralegal, florist, nurse, university administrator, home health care administrator, dentist, entertainer, and risk communication specialist; two retirees had been in business and engineering.

A brief introduction included a request to read and answer each stimulus item as if it concerned the water that people actually drank, including bottled water for the two people who relied on it exclusively (see Exhibit 1 for examples; others appear in Appendix I). Each interviewee was then handed a sheet of paper on which the initial item was printed and asked to read it and respond with any thoughts, questions, or comments that occurred. Probes were used to elicit further comments, or to clarify earlier comments. When the interviewee indicated that he or she had no more thoughts to offer on an item, that sheet of paper was retrieved and the next one proffered. At the end of 30 minutes—the time span promised when people were first contacted—the interviewer asked interviewees whether they wished to continue. That only two people chose to stop at this point, and that four took an hour or more, suggests that the topic—despite repetitiveness in the stimuli—captured people's attention.

No interviewee read every stimulus item. The reasons for this were that there were too many items to be covered in even the longest interview, and there was no need to ask the same questions if, after several interviews, no new responses were being heard. Thus each item was presented to a median of five interviewees (the range was 1–7, out of 12 interviews). Overall, there was no attempt to present items in the same order, because this (given time constraints) would have prevented some items from ever being presented.

EXHIBIT 1. Examples of Interview Stimulus Items

Item 2a
The government announces that the water you drink contains a level of chemical X that poses an extra health risk of getting nonfatal kidney damage of 1 in 1,000,000 (one in a million) over a lifetime of drinking that water.

Item 11a
The government has found a chemical in your drinking water that can cause nonfatal kidney damage in laboratory rats. The level of the chemical which the government considers safe for humans to be exposed to is 1 part per 100 million. The level of the chemical in your drinking water is smaller than 1 part per 100 million.

Focus Groups

Two focus groups—each comprised of three women and one man—were conducted on February 21 and March 7, 1995, in Eugene, Oregon. The first group included employees and volunteers of United Way of Lane County, while the second comprised clients and staffers of a job retraining program jointly run by the county and private industry. The aim was to reduce the educational level of members, relative to those in our earlier focus group research. Interview results were used to design the focus group protocol.

Each member of the focus groups read three items on risk uncertainty (see Exhibit 2), and answered a questionnaire about them, before coming to the focus group session. This approach allowed us to tap their individual views as well as those they would express in a group environment; overall these views did not differ from those in interviews or (for Item 3 only) open-ended questionnaires. Besides reviewing these responses, issues raised by the focus group facilitator included (a) the effect of zero versus positive lower bounds; (b) use of similar or different denominators in the probabilities presented; (c) extrapolation from animal data; (d) extrapolation from high-dose human data; (e) exposure to average concentrations below-standard versus slightly above-standard; (f) explanation of Reference Concentration calculations; (g) reaction to a graphic (see Figure 1) on confidence bounds in excess risk relative to varying exposure; and (h) how reaction to uncertainty in environmental risks compares to uncertainty in financial or safety risks.

EXHIBIT 2. Focus Group Questionnaire Items

Item 3
The government announces that the water you drink contains a level of chemical X that poses an extra health risk of getting cancer in 1 in 1,000,000 (one in one million) over a lifetime of drinking that water. The government says that is the most likely risk, but it says the true risk could be as low as zero or as high as 1 in 100,000.

Item 5
The government announces that there is a 5% chance that the extra level of risk from drinking chemical X in the water you drink for your entire lifetime is above 1 in 100,000 (one in one hundred thousand), and a 5% chance that the risk is zero. The government says this means there is a 90% chance that the true risk is between zero and 1 in 100,000.

Item 8
The government announces that its scientists have calculated the risk of getting cancer from drinking the water you drink, which has a small amount of chemical X in it, for an entire lifetime. It is 95% certain that at least 90% of the population has an extra risk of no more than 1 in 1,000,000 (one in one million). A small proportion of people who are more likely than others, when exposed to a cause of cancer, to get cancer may have a risk as high as 10 in 1,000,000 (ten in one million) if they drink this water for their entire lives.

Open-Ended Questionnaires

A wider variety of items (12, rather than 3), but similar to those given to focus group members, were distributed to volunteers from the jury pool for Essex County, New Jersey. Four versions of the questionnaire, each including three unique questions, were created; 20 copies of each version were distributed. Of the 80 questionnaires distributed, only 29 were returned, and only 18 included substantive responses. The "nonsubstantive" responses included answering only the sociodemographic questions, providing one or two answers and then apparently losing interest, and providing answers whose content (e.g., "none," "good thing") seemed to indicate a superficial or irrelevant response to the questions.

Most respondents (24 of 29) gave enough sociodemographic information to compare those who gave substantive responses to those who did not. Overall, men and women were equally numerous (11 to 13), although women dominated in the substantive group (10 to 6). Median age was nearly identical (45 and 44) and ranged from 20 to 67. The sample of 17 whites, 4 blacks, and 1 Hispanic was equally divided among substantive and peripheral responses (79% vs. 75% white). The main difference between the two groups was education: 75% of substantive respondents had a college degree or better, while five of the peripheral respondents had a high

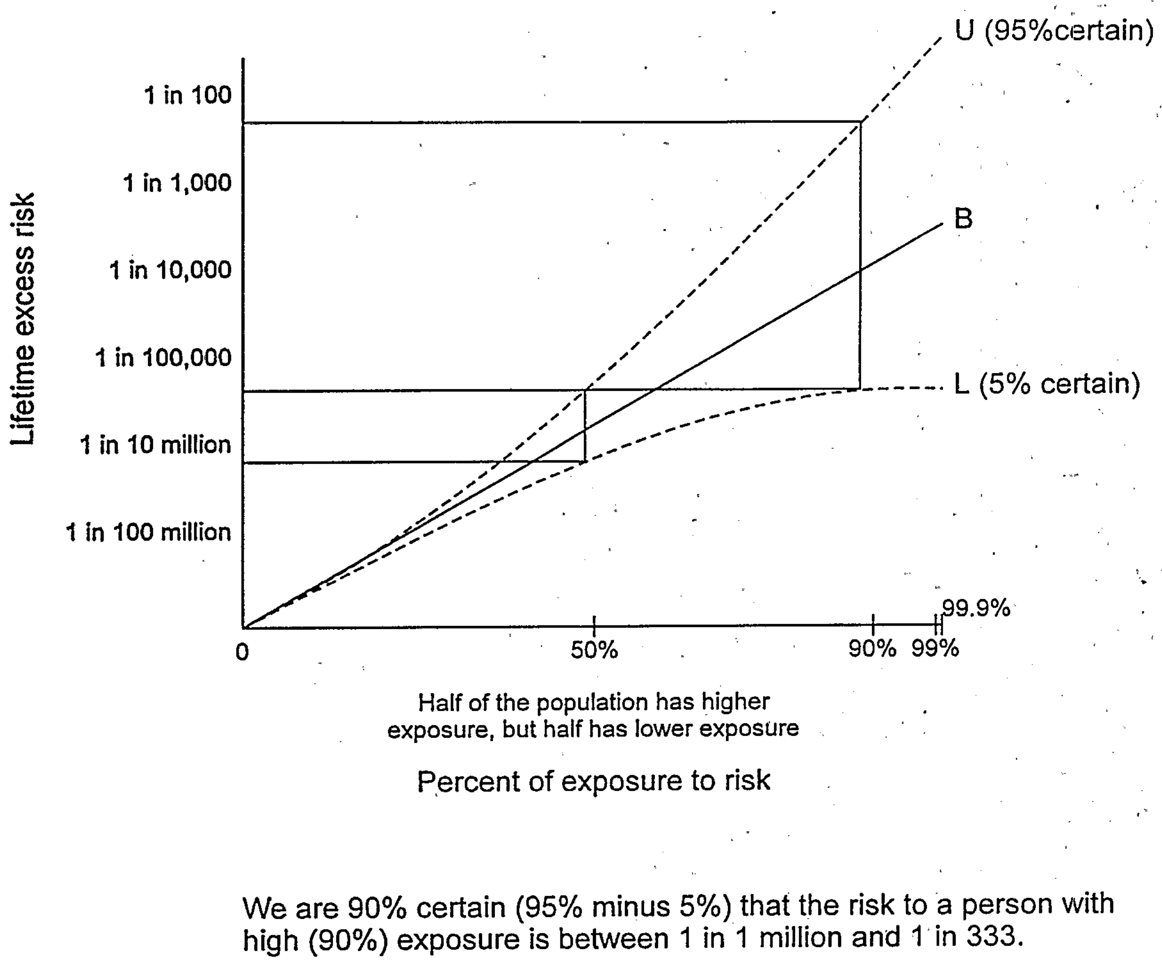

Figure 1. Graphic presenting variability in exposure, shown to focus groups; adapted from NRC (1994, pp. 10 – 25).

school diploma or less, and the other two members in this category reported their educational background as "some college."

Closed-Ended Questionnaire

Results from the preceding data collection were used to develop a questionnaire that could give us a broad view of lay beliefs and attitudes about uncertainty in environmental health risk estimates. Material was added from focus groups in our earlier research, scientific literature on uncertainty, and hypotheses stimulated by our earlier research. Statements were also drawn from the literature and elsewhere that might measure some potentially mediating variables (e.g., attitudes to uncertainty in daily life, ideology, behavior regarding drinking water). No attempt was made to be comprehensive or rigorous with such mediating variables, because our primary goal was to understand lay concepts about uncertainty in environmental health risk assessment, not to explain differences in these concepts. Most statements were designed with a four-step, strongly disagree–strongly agree Likert response format. The sequence of items in the closed-ended questionnaire included the following:

- mediating factors
- questions about their drinking water
- a scenario on a range of drinking water risk estimates and an explanation for the range (extrapolation from either animal or high-dose data)
- responses to the scenario
- attitudes toward receiving no risk estimate (e.g., being told they are safe or unsafe), a point estimate, or a range of estimates
- miscellaneous uncertainty statements
- a scenario on two estimates of risk over time, and responses to it
- sociodemographic information

After pretesting, the questionnaire was answered in late November of 1995 by 280 respondents to an advertisement in the University of Oregon newspaper. This group was 50.7% male, with a median age of 20 (range 17–36). Three-quarters (74.6%) had some college, with 14.7% having a bachelor's degree or better. Most (79.3%) were white, with 8.6% labeling themselves as Asians or Pacific Islanders, 2.9% as Native American, and 1.4% as black. Only 2.5% were of Hispanic origin, although 5.4% did not answer this question. About 14% had one or more children living at home, and 13% were affiliated with an environmental group. Split samples read animal (49.6%) or high-dose (50.4%) extrapolation explanations of the scenarios' range of health risk estimates. For 127 questions these two groups (readers of animal or high-dose scenarios) had only three significant differences ($p < .05$). Given that this small proportion of across-scenario differences could have arisen by chance, and occurred only once for each of three different topics, these differences are probably not reliable. Thus we combined all 280 responses for analysis.

Reviewers of our earlier research suggested that use of mostly student respondents in Eugene, Oregon, limited generalization of our results. Phase II interviews and open-ended questionnaires used a more diverse, New Jersey/Pennsylvania population, and focus group members who were less educated than in earlier research, but these were few in number. Non-Eugene, nonstudent responses did not differ qualitatively from those of Eugene students. It is unlikely a less educated audience would grapple more easily with the concept of uncertainty in risk estimates or science, or have a more positive reaction to it, although generalization from responses to the closed-ended questionnaire should be done cautiously. People with less than a college education were very unlikely to answer our open-ended questionnaire; whether due to incomprehension or disinterest in the topic, or less socialization to answer questionnaires, this may imply that we would fail to get adequate answers from a more diverse group. However, a much shorter instrument based on our closed-ended questionnaire might be used with a more diverse population (like our New Jersey jury pool members) to test these hypotheses.

Results

In the discussion below we group qualitative and quantitative (closed-ended questionnaire) results by topic. Lay-proffered concepts are distinguished from those derived from the literature on uncertainty and earlier hypotheses of ours. In contrast to sketchy evidence (from this study and others) that citizens have a clear (if incomplete) concept of environmental problems and government management of those problems, they seem to lack a structured view of uncertainty about risk estimates. We thus will not offer a detailed lay "mental model" of uncertainty like that suggested for radon (Bostrom et al., 1992).

Results are discussed in the following order, to facilitate understanding: general responses to environmental health risk uncertainty; responses to range bounds; reasons for uncertainty; uncertainty and risk management; understanding of science and risk assessment; potentially mediating factors; and multivariate analysis.

General Responses to Environmental Health Risk Uncertainty

Here we discuss responses to the relation of health risk uncertainty to other kinds of risk; willingness to see risk ranges; and reactions to a drinking water scenario involving a range of risk estimates.

Uncertainties in Environmental Health Risks Seen as Dissimilar to Uncertainties for Other Risks

It has been suggested that the value for improved decision making of assessing risk uncertainty can be demonstrated with the example of investment uncertainties (Finkel, 1994). The author's goal seemed as much to educate risk policymakers as citizens, and he did not make explicit the implication that investment and health risks (and thus their uncertainties) are similar, at least in their value for decision making. We thought a brief (because this was not our central goal) exploration in interviews and focus groups of whether citizens see such analogies as valid might show whether they could be used to educate people about uncertainty in health risk assessment.

First, we examined in interviews whether reaction to uncertainty was common across environmental health risks. Some interviewees were asked whether their reactions to the risk estimate ranges would change if the hazard was not a chemical in drinking water, but instead a chemical in neighborhood soil or in the local air from a nearby factory. Some people felt water offered more personal control, and thus less personal worry, because there were more feasible protective actions (e.g., switch to bottled water vs. move out of the neighborhood). Others said that one could move away from polluted soil, while water was needed for survival. The air-factory scenario elicited particular outrage, as implying immoral behavior on the part of business. These immediate reactions seemed to be based on factors unrelated to uncertainty, suggesting that such variations might occur across environmental hazards regardless of whether point or range estimates of risk were used.

Second, parallels between responses to uncertainty in environmental and nonenvironmental risks were rejected by both interviewees and focus group members. A comparison of the drinking water scenario with the same range of risk estimates for airplane crashes was dismissed by interviewees. Their grounds were that air travel was occasional, familiar, and (if frequent) a probable requirement of one's job, while drinking contaminated water was unfamiliar and a matter of daily exposure; similar responses occurred for uncertainty in automobile risks. Focus group members said recreational risks were chosen (on the basis of joy garnered from the activity), and financial risks (in investing or job security) were not irrevocable, whereas environmental health risks were imposed by others and death permanent. Thus uncertain recreational and financial risks were acceptable, usually without formal or (allegedly) conscious weighing of risks and benefits; uncertainty in environmental health was not. These reactions suggest, but do not prove, that using a stock market investment example to show the superiority of choices made with understanding of uncertainty (Finkel, 1994) may not work with lay audiences facing uncertain environmental risks and estimates.

Some Willingness to Receive Risk Estimate Ranges

Interviews yielded several statements that people would prefer only a single risk estimate rather than a range. For example, two people offered diametrically opposed views: "Government should announce its preliminary calculations for an environmental health risk, no matter how uncertain these numbers are" and "Government should never announce a risk number about anything until they know for sure exactly how risky it is." We included 13 such statements (six from interviews, the rest from the literature) about preferences for single risk numbers or for no numbers at all in our closed-ended questionnaire. Table 1 shows those questionnaire statements that loaded high on a single dimension in factor analysis, and thus were used to produce a scale for multivariate analysis ($\alpha = .80$). As can be seen, our hypothesis that aversion to numbers (of any kind) and aversion to ranges of risk estimates would be distinct concepts was rejected. Further, a "desire for certainty" was not dominant in this sample (Weinstein, 1987); about 35% rated at or above the middle score on this index. Strong desire for certainty in this minority may explain the slightly positive net response to statement 1d, because otherwise this sample seemed distrustful of experts and officials (see below).

TABLE 1. Desire for Certainty

	Disagree	Agree	Don't know
1a I prefer being told that a situation is safe or unsafe, rather than hearing risk numbers, such as "a health risk of getting cancer of 1 in 1,000,000."	53.2%	42.1%	4.6%
1b If the government is having difficulty in determining how much of a risk an environmental condition poses to me, I prefer they give me a range of numbers rather than give me a single risk number. (R)	18.9	74.3	6.8
1c When a chemical is discovered in my drinking water, I don't want to hear statistics, I just want to know if my water is safe.	47.1	48.9	3.9
1d I am more comfortable with an expert's opinion about whether or not my water is safe than with a range of risk numbers from which I must draw my own conclusions.*	42.9	53.2	3.9
1e I would prefer that government tell me that they're just not sure about the size of an environmental health risk, if that's the case, rather than giving me a range of risk numbers.*	51.4	43.9	4.6
1f I'd prefer a single, concrete risk number rather than a range of numbers for the environmental health risks I face.	61.4	30.7	7.9

Note. * Item (quotation or paraphrase) derived from Phase II interview; data from Eugene, Oregon, questionnaire. (R) Reversed scoring for construction of CERTAIN index. Cronbach's alpha = .80.

Mixed Reactions to the Uncertain Risks Scenario

Respondents to the closed-ended questionnaire were asked several questions after reading one of the initial scenarios (see figures 2 and 3), with a caution to assume that "the term 'water' refers to the water you drink, whether it is bottled or tap water" (during interviews bottled water drinkers tended to assume "pollution" scenarios only concerned tap water). Table 2 shows the answers, including indices created from statements loading high on the same dimensions. Responses to items in the NOWORRY index (items 2h, 2i, and 2j) indicates that people felt the risk was low and they would continue to drink the water. However, the CONCERN index (items 2c and 2d) showed that they were concerned about the effects of drinking this water and committed to getting it cleaned up.

Table 2 also suggests mixed reaction to the government agency in the scenario (GOVHONEST index, items 2e, 2f, and 2g). Nearly a third of the respondents could not decide whether the government was honest, and a plurality doubted it was "telling the truth." In Phase I research, about two-thirds of our Study 2 sample felt discussion of a range of risk estimates signaled government honesty. In the study reported here, equal numbers agreed and disagreed with this proposition. However, as in the earlier research, only about a third felt such discussion made the government seem less competent and 45.7% disagreed that the discussion made the agency seem more honest.

FIGURE 2. Initial Scenario, Version 1

Assessing the Risks of Water Quality

Next consider risks from the water you drink, whether it is bottled or tap water. Suppose that a government study found that the water you drink in your home contains a level of a particular chemical that poses a health risk of getting cancer of 1 in 1,000,000 (one in a million) over a lifetime of drinking that water.

Most likely risk
1 in 1,000,000
Lifetime extra cancer risk

The government study indicates that this is the most likely level of risk, but the study also finds that the true risk could be as low as zero or as high as 10 in 1,000,000.

Lowest risk		Highest risk
0	↔	**10 in 1,000,000**

The government says that the reason for this range of risk numbers is that the only scientific studies of risks from this chemical involved laboratory tests with animals. Scientists disagree about whether the way an animal reacts to a chemical will reliably predict how a human would react to the same chemical. This is because different assumptions about how to predict human risks from animal reactions to the chemical result in the range of risk numbers shown above.

Read each of the items below and respond by circling the appropriate number or checking the appropriate box. Assume that the term "water" refers to the water you drink, whether it is bottled or tap water.

FIGURE 3. Initial scenario, Version 2, New Last Paragraph

The government says that the reason for this range of risk numbers is that the only scientific studies of risks from this chemical involved cases where people were exposed to much larger amounts of the chemical in their drinking water than appear in your drinking water (at the time they were exposed, no one knew this chemical could affect health). It is not clear that the cancer-causing effects in these people of high levels of the chemical reliably predict how a human would react to the much lower levels of the same chemical in your water. This is because different assumptions about how to predict risks from low levels of the chemical, when only information about risks from high levels is available, result in different risk numbers.

TABLE 2. Scenario Responses Statement

	Disagree	Agree	Don't know
2a The information in the scenario above is not understandable.	73.6%	20.4%	6.1%
2b Government knows exactly what the level of risk is.*	62.5	26.8	10.7
CONCERN index ($\alpha = .63$)			
2c I would actively work to get my water supply cleaned up.	31.4	61.8	6.8
2d I would be concerned about the effects of drinking this water.	26.8	70.7	2.5
GOVHONEST index ($\alpha = .74$)			
2e The government is telling the truth.	40.4	29.3	30.4
2f The government's discussion of the range of possible risk levels makes the government seem less competent. (R)	56.8	32.5	10.7
2g The government's discussion of the range of possible risk levels makes the government seem more honest.	45.7	44.6	9.6
NOWORRY index ($\alpha = .74$)			
2h This water poses a serious health risk. (R)	68.2	26.8	5.0
2i I would continue drinking this water.	21.4	73.9	4.6

	Somewhat or considerably higher	About the same as other health risks	Somewhat or considerably lower	Don't know
2j Compared to other health risks in my life, the risk from drinking the water discussed in the scenario on the previous page is...	8.6%	19.6%	71.4%	0.4%

Note. * Item (quotation or paraphrase) derived from Phase II interview; R = item reversed in index; Cronbach's alpha for indices in parentheses; data from Eugene, Oregon, questionnaire.

Responses to Range Bounds

Presenting uncertainty through ranges of risk estimates by definition requires upper and lower bounds to the range. This raises questions about how people might react to these bounds (e.g., by anchoring to one or the other extreme, and basing their response on that number rather than on the range). We present results here suggesting an upward bias among some people and a seemingly distrustful view of zero as the lower bound of a range of risk estimates.

Upward Bias in Assessing Ranges of Estimates

Earlier experiments had people pick a level of known risk that left them indifferent between living in the area subject to that risk and in another area of ambiguous risks. Some respondents showed a strong bias toward anchoring on the upper bound of a range of risk numbers (Viscusi, Magat, & Huber, 1991). We tested this bias hypothesis in two ways.

First, we asked about agreement with the statement "If a range of environmental health risk numbers is given, I would believe that the highest risk number is the correct one," which had been volunteered by a Phase II interviewee. Half (46.4%) of our respondents said they agreed with it, although nearly as many (43.2%) disagreed (10.4% did not know). If we take agreement with this statement as a valid measure of "upward bias," Viscusi et al. (1991, p. 163) found a much smaller bias than we did. For a range of disease risk between 110 and 240 cases per million, 13 of 58 (22.4%) picked the highest number of the range. We do not know whether the wider spread in their range (130 in 1,000,000) than in ours (10 in 1,000,000) affected the relative upward bias. We should note that an even larger upward bias occurred in response to scientific conflict (see "Disagreement Among Groups and Scientists").

Our second means of testing the Viscusi et al. result produced less dramatic results. We asked readers of our initial scenario about cancer risk from drinking water to judge the size of this risk in two ways, for the community and for themselves. The scenario (presented in figures 2 and 3) said that the "most likely risk" was 1 in 1,000,000, but that "the true risk could be as low as zero or as high as 10 in 1,000,000." Table 3 shows the proportion of sample members who estimated the community and personal risks from our scenario at various levels of risk. When we add the proportion who assessed the risk as equal to the upper bound in the scenario (10 in 1,000,000) and the proportion who assessed the risk as higher than this level, we see that 14.3% (7.5% plus 6.8%) judged the community risk at or above the upper bound of the government risk estimate. Similarly, 10% (4.3% plus 5.7%) judged the personal risk at or above the government's upper bound estimate. We would expect only 5% (rather than 10–15%) of our respondents to estimate risks as this high if the government's upper bound is a 95% confidence limit, and there was the same distribution of estimates among citizens as in the government analysis. These results also suggest a tendency among our respondents to see larger risk estimates as more likely. However, the discrepancy between this finding and the proportion who claimed they assumed higher risk numbers were more correct prevents us from estimating the prevalence of this upward bias in the population.

TABLE 3. Respondent-Estimated Risks of Initial Scenario

Risk Estimate	Community	Personal
Zero [lower bound of scenario]	1.1%	6.8%
Between zero and 1 in 1,000,000	11.1	15.4
1 in 1,000,000 ["most likely risk" in scenario]	12.5	17.5
Between 1 in 1,000,000 and 10 in 1,000,000	52.5	40.7
10 in 1,000,000 [upper bound of scenario]	7.5	4.3
Higher than 10 in 1,000,000	6.8	5.7
Don't know	8.6	9.6

Note. Respectively, questions were "The risk to the community from the scenario on the previous page is..." and "My personal risk from the scenario...is most likely to be...." These formed ESTRISK index, α =.73, with data from Eugene sample.

These results raise questions about the hypothesis that "those not familiar with quantitative methodology" would misconstrue each number within a range of risk estimates as "equally probable" (Goldstein, 1995, p. 1602). Some 89% of the Eugene sample whose answers appear in Table 3 have at least some college education. Although some are less comfortable with mathematics than this level of education might imply (see later discussion), these results do not seem to reflect a widespread equal-probability view. Because the questions were phrased as "The risk to the community from the scenario ... is" and "My personal risk from the scenario ... is most likely to be," we were encouraging participants to pick only one of the options listed in Table 3. If they expected each risk number to be equally likely, we would expect them to have selected "I don't know," because we did not offer an "equally probable" choice. Clearly, most people did not make this selection. Our results may have differed if we had had access to a less educated sample, but at this point we would lean toward rejecting the equal-probability hypothesis.

Zero as a Lower Bound Risk Estimate Created Problems

A National Research Council (NRC) committee noted (1994, pp. 9–23) that USEPA has typically used the standard phrase that a risk "could be as low as zero." The committee said this might be misleading in a given case, and current information allowed for more accurate (in many cases nonzero) lower bound estimates. A reviewer of our previous article on public responses to uncertainty felt our findings might have been affected by use of the same terminology in our scenarios. People might think "zero" indicated risk assessors' ignorance, and he felt a small but positive lower bound might yield different results. On the other hand, experiments with college students suggest that people treat small incidence numbers (e.g., less than .000003) as essentially zero (Stone, Yates, & Parker, 1994). One of our earlier studies did include positive (one in ten thousand and one in one million, bracketing the Stone et al. figure) *and* zero lower bounds, without prompting significant differences in response.

We presented interviewees, focus group members, and jury pool members with alternative lower bounds. Among their open-ended responses were the following:

- government never announces an environmental issue if there truly could be zero risk involved, even if they *say* the risk could be zero
- when government says about environmental issues that "the true risk could be as low as zero," they are really saying "we could be wrong"
- if the risk of getting an environmental health problem *could* be zero, one doesn't worry about it
- if one is told that an environmental risk *could* be zero or *could* be higher, one tends to assume that the risk is zero
- the fact that government says the risk *could* be zero means to me that it's probably not zero.

Clearly different people offered different, and therefore sometimes contradictory, comments. They agreed that it would make no difference whether the lower bound of a range of risk estimates was zero or 1 in 10,000,000, but disagreed on the reasoning. Some saw the two numbers as essentially the same, others saw the latter as a risk that should be eliminated.

To understand the scope of these contradictions and disagreements, we turned four of these volunteered phrases (shown in Table 4) into statements for our closed-ended questionnaire. Each statement occurred with two different numbers—zero and 1 in 10,000,000—with otherwise identical language. Depending on the statement, 56–72% of participants gave the same response to both items in each pair, thus apparently treating these alternate lower bounds as identical. The majority, treating very low risks as effectively equal to zero, confirmed the findings of Stone et al. (1994).

TABLE 4. Responses to Lower Bounds

	Risk	Disagree	Agree	Don't know
4a The fact that government says the risk could be _____ means to me that it's probably not __. * ($p < .0001$)	Z	29.3%	55.7%	15.0%
	T	50.7	34.6	14.6
4b When government says about environmental problems that "the true risk could be as low as __," they are really saying "we could be wrong." * ($p < .0002$)	Z	28.6	58.9	12.5
	T	36.4	53.6	10.0
4c If the risk for humans of getting an environmental health problem could be __, I don't worry about it. * ($p < .0001$)	Z	53.2	41.4	5.4
	T	37.9	58.9	3.2
4d If I'm told that an environmental health risk could be __ or could be higher, I tend to assume that the risk is higher than __. * ($p < .0001$)	Z	9.3	87.5	3.2
	T	26.1	62.5	11.4

Note. Risk: Z = zero; T = 1 in 10 million. * Item (quotation or paraphrase) derived from Phase II interview; data from Eugene, Oregon, questionnaire.

However, close examination of Table 4 shows that not everyone reacted to the two numbers in the same way. More people agreed that zero, versus 1 in 10 million, as a lower bound meant that government could be wrong (item 4b), the true risk was not at that level (item 4a), and the true risk must be higher (item 4d). Thus use of zero as a lower bound seemed to evoke doubt about the risk estimate, and an upward bias in perception of the risks.

Statement 4c (Table 4) presents an apparent exception. Respondents were less likely to worry if the lower bound was 1 in 10 million than if it was zero. Because a zero risk is objectively lower than a 1 in 10 million risk, there should be less worry about zero risk. These results are thus consistent with those discussed above, concerning doubt about the government's risk estimates if they include a lower bound of zero. Given this doubt, the higher risk number may seem more trustworthy, and thus less worrying. Phase I research (Johnson & Slovic, 1994a, 1995) found people rating lower risk estimates (1 in 1,000,000) as "preliminary" information significantly more often than higher risk estimates (1 in 1,000). Together these findings suggest that, everything else being equal, the public assumes that higher risk numbers are either more honest or more competent (e.g., have been based on a more thorough, less "preliminary," analysis).

Overall, these results show that use of the term "zero" as a lower bound had a significant impact on the Eugene sample's responses to a range of risk estimates. The National Research Council (1994) recommended that government agencies avoid the default language of "as low as zero" in reporting ranges of risk estimates, unless the data did not allow alternatives. The NRC committee making this recommendation felt that agencies making full use of available information would rarely have to resort to zero as a lower bound.[2] We believe our results suggest that communication, as well as risk analysis, would benefit from avoiding zero as a lower bound on risk estimate ranges.

Reasons for Uncertainty

General unfamiliarity with the concept of uncertainty in health risk assessment makes laypeople's understanding of reasons for such uncertainty difficult to plumb. However, because anyone wishing to communicate about uncertainty would want to take audiences' understanding of these reasons into account, we did some exploration of this topic. First, we review some evidence on people's reaction to explanations of uncertainty that concerned extrapolation from

[2] Other technical reasons exist for avoiding ranges of risk estimates that include zero. For example, suppose there is uncertainty about whether an animal carcinogen is also a human carcinogen. Two risk estimates for human health are then possible: zero if the chemical is not a human carcinogen, or a range of risk estimates whose lower bound is a small positive number. According to this analysis, which was provided to us by Dr. Alan Stern of the New Jersey Department of Environmental Protection, it is improper to have a range of risk estimates that includes zero.

either animal data or human data involving high doses of a chemical. Then we discuss how they respond to shifting risk estimates over time, disagreement over risk estimates among groups (e.g., government vs. environmentalists) or scientists, and expert-proffered reasons for scientific uncertainty about environmental conditions (e.g., in measurement, due to complexity, or about past or future risks).

Little Impact of Explanations of Uncertainty

If ranges of risk estimates are offered by institutions, as many risk assessors suggest, explanations of why there are ranges (i.e., uncertainty) would seem necessary for lay understanding and acceptance. Except in Study 4 (where explanation of extrapolation from animal data had no observable impact), such explanations were largely absent from Phase I experiments. We decided to explore the impact of several different explanations on people's response to uncertainty in this phase of research.

The bulk of our effort focused on explanations concerning extrapolation from animal and high-dose data. The versions used in interviews, focus groups, and open-ended questionnaires appear in Exhibit 3. Reading these items did not seem to help people either understand or accept the reasons for having a range of risk estimates. Most who read them rated the explanations as irrelevant to the main issues of risk management (e.g., cleaning up the pollution), confusing, and too wordy. The few people who reacted positively seemed to be more satisfied with the extrapolation-from-animal-data explanation than by the extrapolation-from-high-dose explanation.

The interviewees who were less appreciative of the high-dose than the animal extrapolation explanation could not explain their feelings. However, anecdotes from sources outside this study raised the possibility that people might believe that risks to workers, the population which often provides the high-dose data from which risk assessors extrapolate to lower doses, are not properly related to risks to the general public. We asked our Eugene sample to indicate their level of agreement with the following statement: "Suppose the government uses the effects on humans of high levels of a chemical (for example, among factory workers) to predict the effects of lower levels of the chemical on members of the public. The government is competent when it uses this method to determine the size of an environmental chemical risk for humans." Although

EXHIBIT 3. Examples of Interview Stimulus Items

Item 6
The government announces that the water you drink contains a level of chemical X that poses an extra health risk of getting cancer of 1 in 1,000,000 (one in one million) over a lifetime of drinking that water. The government says that is the most likely risk, but the true risk could be as low as zero or as high as 1 in 100,000. The government says that the reason for this range of risk estimates is that the only scientific studies of this chemical's effects on cancer risks involved laboratory tests with animals. It is not clear that the way an animal reacts to a chemical will reliably predict how a human would react to the same chemical. Different assumptions about how to predict human risks from animal reactions to the chemical result in different risk estimates.

Item 7
The government announces that the water you drink contains a level of chemical X that poses an extra health risk of getting cancer of 1 in 1,000,000 (one in one million) over a lifetime of drinking that water. The government says that is the most likely risk, but the true risk could be as low as 0.01 in 1,000,000, or as high as 10 in 1,000,000. The government says that the reason for this range of risk estimates is that the only scientific studies of this chemical's effects on cancer risks involved cases where people were exposed to much larger amounts of the chemical in their drinking water than appear in your drinking water (at the time they were exposed, no one knew this chemical could affect health). It is not clear that the cancer-causing effects in these people of high levels of the chemical reliably predict how a human would react to the much lower levels of the same chemical in your water. Different assumptions about how to predict risks from low levels of the chemical, when only information about risks from high levels is available, result in different risk estimates.

this phrasing does not directly ask people about the propriety of high-dose extrapolation from workers, it provides an indirect measure of this concern. Slightly more people disagreed (41.4%) than agreed (33.9%) with this statement; many (24.6%) said they did not know. Given these answers, we can only conclude that the impropriety of extrapolation from high doses to workers to low doses to members of the general public *may* be a factor in the qualitative negative reception for our high-dose explanation.

During early interviews, requests were made for an explanation of the high doses "elsewhere" from which scenario risk estimates were supposedly extrapolated. Item 7 (see Exhibit 3) about high-dose extrapolation was thus modified to say that "an accident" had caused the high doses. It was assumed that an accident would have less moral taint than legal (i.e., permitted) emissions, and thus would not distract people from the explanation of the range of risk estimates. However, the few interviewees who had a chance to comment upon this explanation after the "accident" modification seemed to take it as a reason to be more, rather than less, afraid of the consequences of their own exposure to lower concentrations. This reaction may reflect a long-hypothesized (and debated) aversion to "chance" as a reason for troubles that people like oneself suffer, since that seems to make one more vulnerable: how can I guard against chance making me a future victim (Shaver, 1970)? Interesting in this regard is the response to the following statement in the Eugene questionnaire: "Suppose scientists use the health effects of a high dose of a chemical on people exposed elsewhere by chance to predict the effects of a much lower dose of the same chemical found in my water. That would make me feel more at risk than if they got the same numbers for predicted health effects from just studying the chemical's effect on animals." Somewhat more people agreed (40.4%) than disagreed (32.5%) with this statement, which had been volunteered by an interviewee, and a substantial number (27.1%) could not answer it either way. This is not proof that "chance" is an upsetting explanation of risk alone, much less of uncertainty, but it raises questions for future practice and research.

Explanations about extrapolation from animal and high-dose data also appeared in the closed-ended questionnaire; half of our Eugene sample read one explanation, half read the other (see Figures 2 and 3). We did not provide a "control" scenario (that is, one without any explanatory paragraph). Our focus here was on seeing whether these two explanations had different effects on responses to the scenario. Out of 127 comparisons of the answers given by our split sample, only three significant differences were found (the questions on which these differences appeared are in Exhibit 4).

EXHIBIT 4. Items Eliciting Significantly Different Responses From Readers of "Animal" and "High-Dose" Extrapolation Explanations (from the close-ended questionnaire)

- I prefer being told that a situation is safe or unsafe, rather than hearing risk numbers, such as "a health risk of getting cancer of 1 in 1,000,000."
- Government risk estimates tend to indicate the risk that an environmental pollutant poses for the average person.
- The second study came up with a lower risk number because better scientific knowledge was available.

If the proportion of comparisons finding a difference that is statistically significant does not exceed the criterion of significance ($p < .05$ in this study), a rule of thumb is that these differences might have arisen by chance and should be treated as suspect. Because three significant differences out of 127 comparisons is less than the criterion of 5%, we do not believe the animal and high-dose explanations for uncertainty evoked substantively different responses. Our confidence in this conclusion is heightened by the fact that the significant differences were found for three different topics, and each of these topics also appeared in one or more other statements for which significant differences in the two split samples were not found. If a substantive difference in response to the explanations was occurring, but not meeting statistical significance, we would expect it to be concentrated in one topic (if only three differences occur).

A final explanation of uncertainty was offered during qualitative data collection, concerning concentrations of a noncarcinogen in drinking water (the stimulus items concerned appear in Exhibit 5). Each person read them in the same sequence: first the item with concentrations slightly below the government-calculated "safe" level, then the item with concentrations slightly above this level, and then the lengthy explanation. As can be seen, the latter concerns calculation of the "reference concentration" for the noncarcinogen, extrapolated from animal data. The drinking water in this item also contained concentrations above "safe" concentrations, to see if the explanation would offset the discomfort we expected respondents to have with these above standard concentrations. With one exception, every person who read this explanation deemed it irrelevant, confusing, overly complex, or arbitrary ("why divide by 10?," as one interviewee put it). The one exception was a woman who was very distrustful and upset over the above safe concentration; this explanation changed her attitude to one of feeling very safe and informed.

EXHIBIT 5. Exploring the Impact of an Uncertainty Explanation in the Qualitative Study.

Item 11a
The government has found a chemical in your drinking water that can cause a nonfatal kidney damage in laboratory rats. The level of the chemical which the government considers safe for humans to be exposed to is 1 part per 100 million. The level of the chemical in your drinking water is smaller than 1 part per 100 million.

Item 11b
The government has found a chemical in your drinking water that can cause nonfatal kidney damage in laboratory rats. The level of the chemical which the government considers safe for humans to be exposed to is 1 part per 100 million. The level of the chemical in your drinking water is 1.2 parts per 100 million.

Item 11c
The government has found a chemical in your drinking water that can cause nonfatal kidney damage in laboratory rats. However, this chemical did *not* cause kidney damage when fed to laboratory rats in doses of 1,000 parts per 100 million or less. Government scientists took a cautious approach to calculating a safe dose for humans, although it is possible 1,000 parts per 100 million would be safe for them too. They divided this number by 10 to account for the fact that the rats were only fed the chemical for a short time, and humans (at worst) might be exposed for an entire lifetime; divided by 10 again to account for the possibility that humans might be more sensitive to the chemical than are rats; and divided by 10 again to account for humans who may be more sensitive to the chemical than the average human. Thus, the level of the chemical which the government considers safe for humans to be exposed to is 1 part per 100 million. The level of the chemical in your drinking water is 1.2 parts per million.

Shifting Risk Estimates Over Time

Item 4 in the qualitative study (see Exhibit 6) dealt with changing estimates over time as new scientific information became available. In general, temporal changes did not seem to alter interviewees' concerns that there was any risk at all, although there seemed more distrust of government reducing its estimates than increasing them over time. This reaction is consistent with Weinstein's (1987) finding that government is more credible when it says that a situation is unsafe than when it reassures people.

EXHIBIT 6. Example of Shifting Risk Item in the Qualitative Study

<u>Item 4</u>
A government study was done of the water you drink a few years ago, which contained (and still contains) small amounts of chemical X. It found that the most likely extra level of risk of getting cancer from drinking this water for your entire lifetime was 1 in 100,000 (one in one hundred thousand). This was below the drinking water standard for this chemical at the time, so no action was taken and the amount of the chemical in the water has stayed the same. The government did another study recently, using new scientific information about the chemical's effects, and concluded that the most likely level of risk was 1 in 1,000,000 (one in a million).

The closed-ended questionnaire included a scenario (Figure 4) of a follow-up study to the "original" risk estimate for health risk of cancer from drinking water (most likely 1 in 1,000,000; range of zero to 10 in 1,000,000). The scenario said that the government was trying "to obtain a more accurate number." The result was a most likely estimate of one in a billion, with a range from zero to 10 in a billion. The fact that the second study produced a lower risk estimate was specified in the scenario, to avoid any mathematical confusion. Answers to questions about this scenario appear in Table 5.

FIGURE 4. Second Study Scenario

You will recall that the government study described earlier in this survey found that the water you drink in your home contains a particular chemical that poses a health risk of getting cancer of 1 in 1,000,000 (one in a *million*) over a lifetime of drinking that water. Though this is the most likely level of risk, the study also found that the true risk could be as low as zero or as high as 10 in 1,000,000.

Imagine that the government has now conducted a second study to try to obtain a more accurate number for the actual health risk you face. This second study finds that the health risk of getting cancer is most likely 1 in 1,000,000,000 (one in a *billion*), though the study says it could be as low as zero or as high as 10 in 1,000,000,000 (ten in a *billion*). Thus the second study finds a lower risk than the first study.

Risk Study One:

Most likely risk
1 in 1,000,000
Lifetime extra cancer risk

Lowest risk **0** ↔ Highest risk **10 in 1,000,000**

Risk Study Two:

Most likely risk
1 in 1,000,000,000
Lifetime extra cancer risk

Lowest risk **0** ↔ Highest risk **10 in 1,000,000,000**

TABLE 5. Responses to Lower Risk Estimate From Follow-Up Study

	Disagree	Agree	Don't know
5a The second study was more competently done than the first.	29.3%	20.0%	50.7%
5b I am more confident about the safety of my water after seeing the results of the second study.	35.4	54.6	10.0
5c The two studies are essentially in agreement about the level of cancer risk from the chemical in the water.	60.0	31.8	8.2
5d Study One, with the higher risk number, was less competently done.	41.8	12.9	45.4
5e The difference in level of risk between the two studies is probably due to chance.	40.4	25.4	34.3
5f If the government did a third study it would find a risk level even closer to zero than the second study.	31.8	15.7	52.5
5g Taken together, the results of the two studies provide a more accurate assessment of the level of risk than either study by itself.*	23.9	59.6	16.4
5h The second study came up with a lower risk number because better scientific knowledge was available.	27.5	20.7	51.8

Note. These statements followed the scenario in Figure 3. * Item (quotation or paraphrase) derived from Phase II interview; data from Eugene, Oregon, questionnaire.

A majority felt more confident of their water's safety after the second study (5b), presumably because it found a lower risk. But in the context of the above-mentioned findings of greater government credibility with *higher* risk estimates, this is surprising. However, a full third did not feel better even with a maximum risk of 10^{-8}, perhaps due to distrust. About half of the sample refused to rate the relative competence of the two studies (5a), to predict what risk level a third study might find (5f), or to judge that the second (lower) estimate was based on better knowledge (5h). Perhaps this was due to respondents feeling such opinions were not supportable by the available information.

Several interviewees indicated that conducting more studies of environmental problems is a signal that officials respond to public concerns. An alternate hypothesis is that multiple studies reduce uncertainty. The fact that a majority agreed with an earlier interviewee that the studies together gave a more accurate assessment of the risk than either one alone (5g) could be interpreted as confirming the second hypothesis. This judgment would be due to the two estimates confirming roughly the same risk level, with the second range of risk entirely subsumed within the first, and both levels being quite small. Yet, contrary to the uncertainty-reduction hypothesis, most people disagreed that the two studies had found the same level of risk (5c), and only a quarter thought the difference was probably due to chance (5e). This suggests, though it does not prove, that the response-to-public-concerns hypothesis is a better explanation of the positive response to having more than one risk study.

Disagreement Among Groups and Scientists

We expected to find that people had differing views of the credibility of risk estimates from various types of organizations, and this was so. Environmentalists and university scientists were seen by interviewees and open-ended questionnaire respondents as somewhat more trustworthy in their risk estimates than government or business. However, there was surprisingly little unconditional trust even in the first two groups. People volunteered the possibility of academic bias due to funding sources for research and were as likely to be suspicious if environmentalists agreed with institutional risk assessments as to see this as a signal of the latter's accuracy. Item 18 offered in interviews (see Exhibit 7) had government estimates lower than, but overlapping with, environmentalists' estimates (both in ranges). Environmentalists were universally favored over government in risk assessment, and it was very difficult in either interviews or the open-ended questionnaire to get people to recognize that the two groups' ranges overlapped.

EXHIBIT 7. Overlapping Estimates of Government and an Environmental Group

Item 18

The government announces that the water you drink contains a level of chemical X that poses an extra health risk of getting cancer of 1 in 1,000,000 (one in one million) over a lifetime of drinking water. The government says that is the most likely risk, but it says the true risk could be as low as 0.01 in a million or as high as 10 in 1,000,000 (ten in one million). An environmentalist group responds by saying that the most likely risk is probably 10 in 1,000,000, and it says the true risk could be as high as 100 in 1,000,000 (one hundred in one million).

Disagreement among scientists is a form of uncertainty (as well as a reflection of uncertainty) probably more familiar to most people than arguments about dose-response curves. Item 10 (see Exhibit 8) had a majority of scientists disagreeing with a minority. The fact that "most" scientists agreed with the government estimate was not persuasive to interviewees and jury pool members; distrust of government seemed to carry over to scientists, who might be on its payroll. Our qualitative respondents were prone to attribute conflict among scientists to self-interest or incompetence. One interviewee suggested that she would trust the view of whoever had been right in the past, rather than by how many scientists shared that view, but was unable to articulate criteria for such predictive success. Two-thirds (65.4%) of our Eugene sample agreed with the interviewee-volunteered statement: "When scientists disagree over the size of an environmental health risk, I assume the worst case is true, just in case." This reaction also appears to mirror the Viscusi et al. (1991) finding of an upward bias in people's response to a range of risk estimates. However, it may represent a prudent rule of thumb as well as a personal bias in response to risk ranges. In our earlier discussion of upward bias findings, people had no external guidance for their answers when we asked them, for example, what the community and personal risks were of drinking the chemical-contaminated water. The fact that, given only the numbers in the risk scenario, as a group they produced numbers somewhat higher on average seems fairly direct evidence of an upward bias. Similarly, nearly half agreed—without external signals—with the statement that they would tend to take the highest number in a range of risk estimates to be correct. In the case of the statement quoted above, however, they have external guidance on the risks: the scientists' opinions. And even the scientists cannot agree on the size of the risk! Why should laypeople attempt to judge which scientist is correct? In this case it would seem prudent, even without a personal bias toward higher risk numbers, to assume the worst is true. This may explain why the proportion assuming the worst rises from 46.4% without scientists being mentioned to 65.4% when scientists disagree. One of our interviewees had said that, "When scientists disagree over the size of an environmental health risk, it must not be a serious problem." However, most Eugene respondents (84.3%) rejected this proposition. This response may mean that they presume one side must be right, and—given an upward bias (see "Upward Bias" discussion)—would assume that danger is more likely than no danger.

EXHIBIT 8. Disagreement Among Scientists' Estimates

Item 10
The government announces that the water you drink contains a level of chemical X that poses an extra health risk of getting cancer of 1 in 1,000,000 (one in one million) over a lifetime of drinking that water. Most scientists agree with this number, and many think that the true risk could be as low as zero. However, a few scientists believe that the true risk could be as high as 100 in 1,000,000. Both groups have reputations as being competent scientists.

Reasons for Scientific Uncertainty About Environmental Conditions

Given the clear ignorance of, and doubt about, risk estimate uncertainty among our participants, we did not seek to explore whether people had their own explanations for such uncertainty. However, a few spontaneous responses (e.g., in interviews) suggested some such ideas among the public. For example, in interviews and open-ended questionnaires a few people volunteered that point estimates of risk did not account for varying exposure (e.g., amount of water drunk or food eaten) or susceptibility (e.g., children or elderly vs. healthy adults), or that scientists might be biased by who paid them. We used statements developed from Rowe (1994), on various potential reasons for scientific uncertainty, in our closed-ended questionnaire, to see how this sample ($N = 280$) would react to general reasons for scientific uncertainty. These statements appear in tables 6 to 9, with the responses of our Eugene respondents.

People agreed with all of these reasons for scientific uncertainty in the areas of measurement, complexity, past risks and future risks; two-thirds of the reasons (16 of 24) garnered 80% or more agreement. (These topics formed coherent dimensions in factor analysis, and created scales for use as dependent variables in multivariate analysis.) The most consensus (81% – 91% agreement) occurred for reasons concerning complexity in the processes producing environmental health risks, with the least agreement (55% – 88%) on measurement problems. Such consensus may be due to agreement with positively framed statements on topics unfamiliar or not salient to respondents, or to a fair understanding of the challenges that risk assessors face, perhaps due more to inference from daily experience or distrust of experts than to education or experience with risk assessment. Only further study can test these hypotheses, although this group of people could have signaled lack of salience or lack of a firm position by answering

TABLE 6. Measurement Reasons for Uncertainty

Each question began: "Scientists can be uncertain about their measurements of environmental and health conditions because"	Disagree	Agree	Don't know
6a ...of the inherent randomness of nature.	14.6%	79.6%	5.7%
6b ...experts can have biases, conscious or unconscious, in how they make measurements.	11.1	83.9	5.0
6c ...experts can have biases, conscious or unconscious, in their interpretation of the results.	8.2	87.5	4.3
6d ...they can't get enough measurements to be sure that they've measured accurately.	34.3	55.0	10.7
6e ...it can be difficult to decide which facts to include and which can be safely ignored.	18.2	75.4	6.4
6f ...the act of measuring itself can change the conditions being measured.	11.8	77.9	10.4
6g ...the available instruments may not use units of measurement small enough to tell one condition from another.	21.4	60.4	18.2

Note. Statements were abstracted from the discussion in Rowe (1994).

TABLE 7. Complexity Reasons for Uncertainty

Each question began: "Scientists can be uncertain about environmental health risks because..."	Disagree	Agree	Don't know
7a ...they can't be sure they have identified all factors that affect such risks.	5.4%	91.1%	3.6%
7b ...the factors that affect risks may interact with each other in unknown ways.	3.9	91.1	5.0
7c ...their models of how the environment works may be oversimplified.	10.0	80.7	9.3
7d ...there may be more than one believable model of how the environment works, with no evidence to tell which one is more correct.	6.8	85.4	7.9

Note. Statements were abstracted from the discussion in Rowe (1994).

TABLE 8. Reasons for Uncertainty About Past Risks

Each question began: "Scientists can be uncertain about past environmental health risks because..."	Disagree	Agree	Don't know
...they don't have complete historical information.	16.4%	77.1%	6.4%
...conditions now are different from what they used to be.	5.0	90.0	5.0
...there are conflicting reports about what happened in the past.	10.0	82.9	7.1
...the conditions measured in the past may not provide information suitable for identifying past risks.	8.2	82.9	8.9
...historical information may be biased.	5.0	87.5	7.5
...they can't do experiments to check that past measurements were accurate.	18.9	70.4	10.9
...they can't be sure today's interpretations of past information are correct, even if hindsight seems 20/20.	8.6	80.7	10.7

Note. Statements were abstracted from the discussion in Rowe (1994).

TABLE 9. Reasons for Uncertainty About Future Risks

Each question began: "Scientists can be uncertain about future environmental health risks because..."	Disagree	Agree	Don't know
...of the inherent randomness of nature.	11.4%	83.6%	5.0%
...unusual combinations of outcomes can occur.	6.4	89.3	4.3
...humans often do the unexpected.	11.1	81.4	7.5
...they haven't studied the environment long enough to separate long-term trends from short-term changes.	21.4	66.1	12.5
...rare events could occur that would make a big difference.	11.8	82.5	5.7
...the same health problem can have nonenvironmental causes, too, and it's hard to tell which cause is responsible for a particular person's (or group of people's) health problems.	8.2	80.7	11.1

Note. Statements were abstracted from the discussion in Rowe (1994).

"don't know/no opinion." They used this choice often elsewhere (above 10%, up to more than 50%, for 47 of 103 other nondemographic statements), but much less here (7 of 24 reasons evoked "don't know" answers from 10% or more, to a maximum of 18.2% "don't know" responses).

Lack of understanding of environmental science may underlie some of the stronger disagreements with these statements. For example, a full third (34.3%) disagreed (6d) that measurement uncertainty is due to scientists being unable to "get enough measurements" implying ignorance of resource constraints on field collection of data or an assumption that reliable risk estimates require very few measurements. Other major disagreements suggest belief in the obviousness of environmental problems and data (6e), unfamiliarity with the concept of limits to measurement precision (6g), confusion over the nature of experimentation or "past data" (8f), and belief that *any* change in the environment would be long-term, making discrimination of short-term changes unnecessary (9d). The impact of level of formal education on these misconceptions may be small. A survey of Americans (Miller, 1993) found poor conceptions of science: 2% saw it as involving the development and testing of theory, 13% as experimentation, 25% as rigorous comparison or precise measurement, and 60% volunteered no idea about the nature of science. Those with graduate and professional degrees were not much more accurate: 9% saw science as dealing with theory and 38% with experimentation.

Uncertainty and Risk Management

Although uncertainty is usually viewed as a technical issue in risk assessment, it may also have implications for risk management. Here we report the only two such implications raised in Phase II research: the relative perceived value of uncertainty and risk estimates in risk management, and the signals uncertainty might give to citizens about agency honesty and competence.

Neither Uncertainty Nor Risk Estimates Were Very Important

Questions asked about stimulus scenarios by nearly every interviewee, focus group member, and respondent to the open-ended questionnaire were:

- Why did this chemical get into the water, and why wasn't this prevented?
- What is the government doing to get the chemical out of the water, and why hasn't it done so already?
- What can I do to protect myself?

Other questions were raised as well (e.g., about the source, effects, and naturalness of the chemical), but qualitative respondents returned again and again to these three issues. They seemed to be driven by two assumptions: that any exposure and any risk was too large, and that government had a responsibility to ensure that no *environmental health* risk was present in their water, soil, or air. However, we do not believe that this expectation of government responsibility can be easily equated with a desire for, or expectation of, "zero" risk in their lives. As noted earlier, interviewees and focus group members were willing to accept recreational, financial, and even airplane risks, but not environmental health risks. Furthermore, the Eugene sample's reactions to the initial scenario were not solely concern about effects of drinking the contaminated water and commitment to getting it cleaned up. Simultaneously, they disagreed that this was "a serious health risk" and said they intended to "continue drinking this water." If they really wanted zero risk, these would not be their answers. After all, they could switch water supplies (e.g., by moving from tap water to bottled water, or from one brand of bottled water to another).

Doubts About Government Honesty and Competence

In Phase I we found evidence that providing ranges of risk estimates might, at least for a minority, undermine perceptions of government honesty and competence. Our Phase I measures for these responses were few, and our understanding of the reasoning of respondents on this point limited. For example, Phase I (Study 2) focus group members said that government never offers any information about environmental problems unless it is forced to, releases information about environmental problems only so that people can't say that they were never told about them, will tell you there is a big risk if it wants credit for cleaning up an environmental problem, and will tell you the risk is zero if it can't or won't clean up an environmental problem. These responses did not clarify what people thought in detail (if anything) about government honesty and competence with regard to risk assessment, much less whether disclosures of uncertainty or more general judgments about government drove their answers, so we chose to study this further in Phase II.

We found in qualitative work that people would often explicitly point to the range of risk estimates (or to related issues, such as statistical "confidence"—see discussion below) as a *rationale* for their conclusions that government was dishonest or incompetent. For example, one comment was that a government that was honest about the size of an environmental health risk would give only one estimate. Another was that government is just guessing if it gives a range of risk estimates for an environmental problem. Someone who said that the government calculates environmental risks without taking into account the inevitability of unexpected events was clearly using her awareness of uncertainty to judge government competence as low. Some people said that judgments of honesty depend on explanations of how the research was done on which government's risk number is based, or whether government is willing to show how they calculated a "safe" risk number.

Questions about whether a given item's risk estimate was honest or competent seemed to be the most challenging ones for interviewees and focus group members to answer. Although many people seemed to answer these based on their prior views of government, many others said that they couldn't answer them, didn't have enough information, or had no idea how to evaluate honesty or competence in risk assessment. Although we gained some insights on the cues people used (or would like to use) to make such decisions—the Agent Orange controversy, background research studies' design or number, whether environmentalists agreed with the government—it is clear that we do not fully understand how people judge honesty and competence in risk assessment. We have no evidence that people have explicit, *a priori* criteria for such judgments; if this is true, it would make future research on this issue particularly challenging and valuable.

Despite this caveat, it seemed worthwhile to identify the distribution of opinion about government honesty and competence in risk assessment in our Eugene, Oregon, sample. As noted in Table 2 earlier, there were mixed feelings about government honesty and competence regarding the scenario of drinking water contamination they read. More generally (see Table 10), three-quarters disagreed that government provision of a range of risk numbers was less honest, and a slight majority said it was more competent, than providing a single risk number. (Items 10b and 10c were deliberately phrased to mirror each other, to test the reliability of competence judgments; these were clearly reliable.) These responses clash somewhat with the response to statement 10d, a view expressed by one interviewee. Roughly half of our sample said that government talks about environmental issues only when they pose a high risk. This opinion may explain why the reaction to lower bounds of zero (see above) is apparently so distrustful, and people split over whether government discussion of ranges is honest. Risk estimate ranges in general may be welcomed as honest and possibly competent, but particular ranges may seem dishonest if they can include zero when "obviously" the problem must be high-risk for government even to discuss it publicly. By contrast, the disagreement with statement 10e may reflect skepticism over the validity of extrapolation from animal data (see below) rather than a judgment of government itself.

TABLE 10. General Views of Government Risk Assessment

		Disagree	Agree	Don't know
10a	If government was being honest about the size of an environmental health risk it would give only one number, rather than a range of numbers.	75.0%	15.4%	9.6%
10b	I would feel more confident that government knows how to determine the size of environmental health risks if they give a single risk number for an environmental problem.	59.6	26.1	14.3
10c	I would feel more confident that government knows how to determine the size of environmental health risks if they give a range of risk numbers for an environmental problem.	29.3	53.6	17.1
10d	Government only makes an announcement about an environmental issue when there is a high risk involved.	39.3	48.6	12.1
10e	The government is competent in estimating the size of an environmental chemical risk for humans when it takes into account the chemical's effects on animals.	50.4	35.4	14.3

Understanding of Science and Risk Assessment

Whether people are familiar with how science and risk assessment operate may have an impact on their responses to uncertainty in risk estimates. We discuss here awareness of uncertainty in science and risk assessment, and beliefs about risk assessment concepts (e.g., animal data extrapolation) and government practice.

Familiarity With Uncertainty in Risk Assessment and Science

Qualitative data supported our earlier conclusion that uncertainty in risk assessment was unfamiliar. Occasionally people noted that they "had heard" statements like the ones we offered, but usually in reaction to such items (see Exhibit 9), which to our knowledge have not been publicized in any form. We suspect this sense of familiarity was due more to an overall impression of numbers and phrases (e.g., "risk of getting cancer") likely to accompany environment-related information, rather than an actual recognition of uncertainty. This does not mean that interviewees and others were entirely unable to recognize uncertainty as an issue in risk assessment. For example, some people mentioned differences in apparent vulnerability (e.g., children, elderly, the sick) or exposure (e.g., "How much water are we supposed to drink to get this risk?"). Focus group members felt there were "too many numbers" and not enough "personalized information" about risk factors or information on what protective measures were being or could be taken. The comments about "personalized" information also imply an awareness of variability.

EXHIBIT 9. Uncertainty Scenario: Qualitative Study

Item 8
The government announces that its scientists have calculated the risk of getting cancer from drinking the water you drink, which as a small amount of chemical X in it, for an entire lifetime. It is 95% certain that at least 90% of the population has an extra risk of no more than 1 in 1,000,000 (one in one million). A small proportion of people who are more likely than others, when exposed to a cause of cancer, to get cancer may have a risk as high as 10 in 1,000,000 (ten in one million) if they drink this water for their entire lives.

The closed-ended questionnaire had only one direct measure of whether people expect risk assessment to be certain (Table 11). Most disagreed with statement 11a that a single number could describe an environmental health risk. This may be why they felt (above) that presentation of ranges of risk estimates was *potentially* honest. The difference between the qualitative and quantitative results may be due to different samples. The quantitative group had more education, and were largely still in college, where they might have been recently exposed to similar concepts. There was no correlation between education and answers to this question, although education did not vary much in the Eugene sample. Statements 11b and 11c discuss the abstract fact that "different scientific ideas" about how to extrapolate from high human doses or animal data "can be equally valid" in estimating human risks at low doses. About half of our sample agreed with these indirect measures of familiarity with uncertainty in risk assessment. Similarly, the interviewee-volunteered idea that scientific certainty must accompany a "real" environmental concern (11d) was rejected by a scant majority.

TABLE 11. Expectations of Uncertainty in Risk Assessment and Science

		Disagree	Agree	Don't know
11a	No environmental health risk can be described by a single number.*	17.1%	69.6%	13.2%
11b	When experts only have information on the effects of much higher levels of the chemical, different scientific ideas of how to determine human health risks from lower levels of that chemical can be equally valid.	28.6	50.0	21.4
11c	When there is only information on animal reactions to a chemical, different scientific ideas of how to determine human health risks from that chemical can be equally valid.	38.2	51.8	10.0
11d	If an environmental problem was a real concern, scientists wouldn't say that there "could be" health risks.*	54.3	35.0	10.7
11e	A competent scientist gives a single, definitive answer to a question.	80.4	12.5	7.1
11f	It is typical of good science that the most likely value for what is being measured has a range of uncertainty around it.	11.1	77.9	11.1

Note. * Item (quotation or paraphrase) derived from Phase II interview; data from Eugene, Oregon questionnaire.

As for uncertainty in science, few agreed that scientific competence requires definitive answers (statements 11e and 11f), or even said that they did not know. Most members of this highly educated group (most of whom had at least some college education) thus seem somewhat familiar with the concept. While education did not correlate with "competent scientist" answers—note that variability in education was low in this sample—better educated respondents were more likely ($r = .21, p < .0007$) to agree that good science could be uncertain. Thus the substantial minority of this sample who doubted science's uncertainty may better represent the view of the general, less educated public. Statements 11e (reversed) and 11f formed an index ($\alpha = .41$) on "Science Uncertainty" for multivariate analysis.

Knowledge of Risk Assessment

Differential knowledge has been hypothesized as a cause of different responses to risk in general and is worth exploring as a factor in reactions to uncertainty. One of many ways to measure the elusive concept of "knowledge" is to see whether experts and laypeople agree on propositions about concepts relevant for risk assessment. Table 12 compares agreement with items on dose-response relationships and animal data among three groups: our Eugene sample, and samples from the Portland, Oregon, public, and the Society of Toxicology in earlier research (Kraus, Malmfors, & Slovic, 1992). For about half of the items, people in our study were even farther from expert views than the earlier public sample, while for the other half they were closer to the expert views. Overall, however, experts and both public samples are farther apart—with citizens more likely to see any exposure as harmful. As noted in the table, we used two of these items to create an "Animal Studies" variable for multivariate analysis ($\alpha = .48$); about a third of our respondents believed in the extrapolation value of such studies.

TABLE 12. Concepts of Risk Exposure

		Sample*	Disagree	Agree	Don't know
12a	There is no safe level of exposure to a cancer-causing agent.	E P T	38.6% 34.7 74.7	52.5% 53.9 18.7	8.9% 11.3 6.6
12b	For pesticides, it's not how much of the chemical you are exposed to that should worry you, but whether or not you are exposed to it at all.	E P T	47.9 59.2 94.6	43.6 36.1 4.2	8.6 4.6 1.2
12c	The way that an animal reacts to a chemical is a reliable predictor of how a human would react to the same chemical.	E P T	52.9 45.7 40.8	34.3 43.7 55.4	12.9 10.6 3.8
12d	If a scientific study produces evidence that a chemical causes cancer in animals, then we can be reasonably sure that the chemical will cause cancer in humans.	E P T	29.6 24.8 57.6	55.4 69.4 40.6	15.0 5.8 1.8
12e	If a person is exposed to a chemical that can cause cancer, then that person will probably get cancer some day.	E	62.1	20.0	17.9
	If you are exposed to a carcinogen, then you are likely to get cancer.	P T	47.7 88.0	34.4 8.4	17.2 3.6

Note. * E = Eugene, Oregon, sample in this study; P and T are the samples of the Portland, Oregon, public and Society of Toxicology members, respectively, in Kraus et al. (1992). Statements 12c and 12d formed the index ANIMAL, = .48.

Another way to assess knowledge is to examine notions of standard practice in government risk assessment (see Table 13), although experts could dispute what that is. The many "don't knows" indicate that people feel they don't know much about this topic. Statements 13e and 13f, asked at different points of the questionnaire, imply the belief that average exposures are used in government risk estimates, but contradict statement 13a (maxima). Both are contradicted by statement 13b on actual measures. Whatever government risk assessors do, our sample clearly has no firm concept of that practice; these statements did not load together on any dimension when data were factor analyzed.

TABLE 13. Beliefs About Government Risk Assessment

		Disagree	Agree	Don't know
13a	Government risk numbers tend to be based in part on the maximum amount of a pollutant that any person could be exposed to.	20.0%	47.5%	32.5%
13b	Government risk numbers are based on actual measurements of how much of a pollutant people are exposed to, not just on assumptions about human exposures.	39.3	32.5	28.2
13c	Government tends to take a cautious approach in calculating the size of environmental health risks, and assumes the worst case about how people might be exposed or react to a pollutant.	45.4	33.6	21.1
13d	Government risk numbers tend to indicate the risk that an environmental pollutant poses for the person at greatest risk.	38.6	32.5	28.9
13e	Government risk numbers tend to be based in part on the amount of a pollutant that the average person is exposed to.	17.1	60.4	22.5
13f	Government risk numbers tend to indicate the risk that an environmental pollutant poses for the average person.	19.6	59.3	21.1

Potentially Mediating Factors

Beliefs and stances unrelated to the environment or risk or risk assessment may affect how people react to the issue of uncertainty in human health risk estimates. It is thus important for us to account for at least some of these potentially mediating factors in this study, particularly in multivariate analysis. Here we discuss our findings with regard to mathematical prowess, personal vulnerability, uncertainty in daily life, and worldviews.

Numbers, Uncertain or Not, Are Hard to Grasp

Difficulty with numbers may be related to education, mathematical or statistical knowledge, and/or personal comfort with numeration. Education varied little in our closed-ended questionnaire sample (75% with some college, 4% with a high school degree or less), although we used it as an independent variable in multivariate analysis. As noted under "Methods," most people with a high school degree or less failed to give substantive responses to the open-ended questionnaire. Perhaps education makes it easier to cope with risk numbers, including uncertain ones; perhaps people with more education were more accustomed to answering questionnaires.

Several interviewees had problems comparing different risk numbers (e.g., two "most likely" estimates, or "lowest" vs. "highest" risk numbers). For example, one person expected to "feel safer about drinking water" if estimated risks changed from 1 in 1,000,000 to 1 in 100,000. A retired engineer had trouble with Item 11c (see Appendix I), because it required a confusing triple-division by 10, in the process of applying "uncertainty factors" to a NOAEL to derive a Reference Concentration for a noncarcinogen. (Another reaction to that item—"there was no justification for dividing by 10 rather than 20 or 5"—was a policy or communication conflict rather than a signal of difficulty with numbers.)

Because of these earlier reactions, we decided to put some crude measures of mathematical skill into the closed-ended questionnaire. We asked for the degree of agreement with two statements that compared two risk numbers: "You are less likely to get a disease if the risk of getting it is 10 in 1,000,000 than if the risk is 1 in 1,000,000" and "You are more likely to get a disease if the risk of getting it is 7 in 1,000,000 than if the risk is 1 in 100,000." The first statement used a common denominator and numerators one magnitude apart; the second statement used different denominators and an odd difference (7-fold) in numerators. Their difficulty varied as one might expect: only 13.6% of our respondents agreed (incorrectly) with the first statement, while 31.4% agreed (also incorrectly) with the second statement.

Some focus group members in Phase I research had suggested that using a common denominator to compare numbers (e.g., 0.1 in 1,000,000, 1 in 1,000,000 and 10 in 1,000,000) would make this task easier than the usual common-numerator format (1 in 10,000,000, 1 in 1,000,000, and 1 in 100,000). Most people shown these variants in Phase II qualitative research felt the first format was more confusing than helpful; some people given items in this format actually translated them into the common-numerator format to answer the open-ended questionnaire, implying the latter is more familiar. However, in our closed-ended questionnaire there was very little error with the common-denominator format. We also used this common-denominator format in our scenarios for the closed-ended questionnaire (e.g., a most likely risk of 1 in 1,000,000, with a range extending up to 10 in 1,000,000). About a fifth (20.4%) of the sample agreed that the information in the initial scenario was "not understandable," but this could have been due as much to the presence of numbers alone, or to the other information in the scenario, as to the use of this numerical format.

A third measure of mathematical skill was self-reported: agreement with the statement "I feel very comfortable dealing with numbers and calculations." About a third (32.9%) of our Oregon questionnaire respondents—equal to the proportion erring on the more challenging numerical comparison cited above—disagreed with this statement.

Responses to the two comparisons and one self-report were poorly correlated (e.g., $r = .03$ among the comparisons; highest correlation was $r = .15$ [$p > .01$] between self-reported comfort with numbers and the common-denominator statement), and Cronbach's alpha was extremely low ($\alpha = .19$). We thus used these three items as separate independent variables in subsequent multivariate analyses.

Statistical wording created other problems for respondents. For example, use of the phrase "95% confidence" in some early interviews evoked outrage about the government's "lack of confidence" and lack of explanation as to why it wasn't surer; explanations of what was meant by statistical confidence were not persuasive. Changing this term to "95% certain" did not reduce confusion and anger much either; people seemed to interpret this primarily as government not knowing what the risk was, or "there is too much of a risk," although one or two said this was about the same as being certain. Item 5 (see Exhibit 10) said there was a 5% chance of risk above 1 in 100,000, and a 5% chance that the risk was zero, and thus a 90% chance of the true risk being between zero and 1 in 100,000. It failed to help interviewees understand the concept of confidence limits.

EXHIBIT 10. Confidence Limits: Qualitative Study

<u>Item 5</u>
The government announces that there is a 5% chance that the extra level of risk from drinking chemical X in the water you drink for your entire lifetime is above 1 in 100,000 (one in one hundred thousand), and a 5% chance that the risk is zero. The government says this means there is a 90% chance that the true risk is between zero and 1 in 100,000.

Confusion became even worse in response to a phrase recommended by the National Research Council (1994, pp. 10–24) for communicating about variability in susceptibility. Our version (item 8; see Exhibit 9) said that "It is 95% certain that at least 90% of the population has an extra risk of no more than 1 in 1,000,000." Focus group members (in questionnaires answered before the group met) said, among other responses, that this meant:

- "They are not 100% sure. They need to be 100% sure of what's going to happen."
- "What are they really saying.... This info is truly frustrating."
- "These numbers are self-explanatory and give people the information they need."
- "A guess ... could be a fair guess."
- "Most confusing to me is: how do they get these numbers?"

The focus groups also saw a graphic proposed by a National Research Council committee (1994, pp. 10–25), slightly modified for readability, for communicating variability in exposure and confidence limits on the resulting risk estimate (see Figure 1). This was also greeted with confusion by focus group members, despite an explanation by the focus group facilitator, who teaches statistics professionally. For example, they could not by themselves find on the graphic the risk of median exposure.

Personal Vulnerability

We seemed to confirm earlier conclusions about an "optimism" bias, in which people see their own risks as being less than those of society or other people (Weinstein, 1980). In response to the initial scenario (Figure 2), as many as 39.7% saw their personal risk as at or below the "most likely" (1 in 1,000,000) level calculated by government, while only 24.7% saw the same level of risk as likely for the community (see Table 3). These two answers formed an index of ESTRISK ($\alpha = .73$) used in later multivariate analysis. Over two-thirds (71.4%) rated the risk from drinking the water discussed in the scenario as "somewhat" or "considerably" lower than "other health risks in my life." Others saw equal (19.6%) or higher (8.6%) risks from drinking this water than from other health risks they faced.

More generally, most respondents felt their chances of being exposed to an environmental pollutant were "about the same as" (78.2%) or "less likely than" (14.3%) chances of exposure for the average person. Similar responses (78.9% and 15.0%, respectively) were obtained on judgments of their chances of getting sick from environmental pollution, compared to the average person. About 13 agreed with an interviewee who said she assumes she is likely to be the person who suffers a 1-in-1,000,000 environmental health risk. These findings together suggest that a conscious (or at least admissible) sense of personal vulnerability to environmental problems is not common; we formed an index from these statements ($\alpha = .57$) to use in multivariate analysis.

However, we also found nearly half our sample (43.2%) agreeing that "There are serious environmental health problems where I live" (45% disagreed). They saw moderate to high risk from drinking tap water in their homes as more likely (35.4%) than for bottled water (7.1%), although only 4.3% drank bottled water every day. The distinction between those who saw tap water risks as zero or low (62.5%) and those who saw these risks as high might have affected responses to uncertainty in a scenario about drinking water contamination. Each of these questions (except the question on perceived risks of bottled water, which had too little variance) was an independent variable in subsequent multivariate analyses.

Life Uncertainty

We also expected that personal stances to uncertainty in general might affect reactions to uncertainty in health risk assessment. Over half of our Eugene sample (56.1%) agreed that "I try to avoid uncertainty in my life as much as possible," but disagreed (62.9%) that "To a great extent my life is controlled by accidental happenings." These items did not form a viable index, so they were entered as separate independent variables in the multivariate analyses.

Worldviews

As mentioned in our Phase I report and article (Johnson & Slovic, 1994a, 1995), we had found evidence that general worldviews might affect response to uncertainty. Because of analytical constraints on the earlier data set, however, our findings were not conclusive, and we believed that some further analysis was warranted. Thus several questions that appeared to elicit salient worldviews were asked in our Eugene questionnaire. Table 14 shows those that formed reasonably coherent indices, which were entered in multivariate analyses. (Cronbach's alpha is listed in parentheses next to each index title.)

One apparent dimension we labeled "antiegalitarian," because most of its component statements concerned support for inequality (e.g., beliefs that the "equal rights" movement has gone too far, or more pay should go to those with greater ability). Measures of egalitarianism seemed to be associated with beliefs about dishonesty or incompetence in ranges of risk estimates in our Phase I research. They also have been associated with risk beliefs in some other studies (e.g., Dake, 1991; Peters & Slovic, in press; Rayner & Cantor, 1987). Earle and Cvetkovich (1995) have argued that values such as those that appear to underlie our ANTIEGAL index drive trust, and thus in turn affect perceptions of risk, and so forth. The fact that our factor analysis found TRUST to be separate from ANTIEGAL raises questions about this hypothesis. Statements that together seemed to represent support for "environmentalism" formed another index. This viewpoint has been associated with egalitarianism in some of the research cited above, but it formed a separate dimension here. A "trust in authority" index, although weaker (see the low Cronbach's alpha of .54), also emerged from factor analysis. Phase I research found trust linked to judgments of honesty and competence in government discussion of risk uncertainty. Finally, a very weak "fatalism" index appeared as well, exemplifying a perceived lack of control over one's life.

Multivariate Analyses

Although our sample was not randomly selected, we felt it would be useful to compare the impact of some potential influences on responses to the risk uncertainty scenarios (figures 1 to 3) through multiple regression analyses. Tables 15 and 16 show the dependent and independent variables, respectively, indicating (where appropriate) Cronbach's alpha for indices and the text location of the statements making up these indices (table number and/or statement number within a table are provided), as well as the number of respondents providing each item.

TABLE 14. Worldview Statements and Indices

	Disagree	Agree	Don't know
Antiegalitarian Index (α = .69)			
We have gone too far in pushing equal rights in this country.	83.2%	15.4%	1.4%
In a fair system people with more ability should earn more.	23.9	65.0	11.1
If people in this country were treated equally, we would have fewer problems. (R)	18.9	74.6	6.4
What this world needs is a more equal distribution of wealth. (R)	21.1	75.0	3.9
When the risk is very small, it is OK for society to impose that risk on individuals without their consent.	81.8	12.1	6.1
I am in favor of capital punishment.	37.5	52.1	10.4
Environmentalism Index (α = .70)			
All species, including humans, have an equal right to co-exist on the planet.	12.1	85.0	2.9
I would be willing to sacrifice much of my current standard of living to insure that nature is not harmed.	35.0	56.1	8.9
I am attracted to the spiritual qualities inherent in the natural world.	19.6	71.1	9.3
I know a lot about environmental health issues.	45.0	48.9	6.1
Trust in Authority Index (α = .54)			
Decisions about health risks should be left to the experts.	71.8	20.4	7.9
The police should have the right to listen to private phone calls to investigate a crime.	76.4	17.9	5.7
When there is a really serious health problem, then public health officials will take care of it. Until they alert me about a specific problem, I don't really have to worry.	78.2	16.4	5.4
Those in power often withhold information about things that are harmful to us. (R)	17.1	69.6	13.2
Government has no right to regulate people's personal risk-taking activities such as smoking, mountain climbing, hang gliding, etc. (R)	24.6	68.9	6.4
Fatalism Index (α = .43)			
I have very little control over risks to my health.	70.7	23.6	5.7
It's no use worrying about public affairs; I can't do anything about them anyway.	84.6	13.6	1.8

Note. R = reversed scoring for construction of indices; Cronbach's alpha indices in parentheses.

TABLE 15. Multiple Regression Dependent Variables

Variable name	Variable description	Cronbach's alpha	Text location	*N*
CERTAINTY	desire for certainty	.80	Table 1	273
WRONG	government could be wrong	.74	Table 4b	229
WORST	assumes worst given risk range	.38	Table 4d	244
NOWORRY	not worried by drinking water scenario	.74	Table 2	256
CONCERN	concerned about water in drinking water scenario	.63	Table 2	254
ESTRISK	estimated risk of drinking water scenario	.73	Table 3	245
GOVHONEST	government honest in drinking water scenario	.74	Table 2	247
GOVKNOWS	government knows exactly what risk is in drinking water scenario	—	Table 2b	280
2NDEST	second study more competent in two-study scenario	.74	Table 5a,d,h	146
2BETTER	two studies better than one in two-study scenario	.49	Table 5b,g	222
MEASURE	measurement reasons for uncertainty	.73	Table 6	259
COMPLEX	complexity reasons for uncertainty	.80	Table 7	266
PAST	past risk reasons for uncertainty	.84	Table 8	261
FUTURE	future risk reasons for uncertainty	.83	Table 9	265
TAPWATER	perceived risks of home tapwater	—	Page 47	274
SERIOUS	serious environmental health problem where I live	—	Page 47	247

Note. Shading separates variable types; respectively, reaction to uncertainty in general; initial scenario; government risk estimates; the second study scenario; reasons for scientific uncertainty; local risks.

The shading in Table 15 separates dependent variables that cover reaction to: uncertainty in general, the initial scenario and government risk estimates, a second study with lower risk ranges, reasons for scientific uncertainty, and local risks. Table 16 is shaded to distinguish various categories of independent variables, dealing in turn with worldviews, personal stances toward uncertainty, knowledge, and sociodemographic characteristics (three dependent variables—CERTAINTY, WRONG and WORST—also became independent variables for some multiple regressions).

TABLE 16. Multiple Regression Independent Variables

Variable name	Variable description	Cronbach's alpha	Text location	N
ANTIEGAL	antiegalitarian	.69		277
ENVIRON	environmentalism	.70		267
TRUST	trust in authority	.54		273
FATAL	fatalism	.43		260
AVOIDUNC	avoids uncertainty in one's life	—		256
LIFEACC	life controlled by accidental happenings	—		253
P_VULNER	feels personally vulnerable	.57		260
TAPWATER	high health risks from drinking tap water in own home	—		274
BOTTLED	frequency of drinking bottled water	—		279
SERIOUS	serious environmental health problem where I live	—		247
MATHCOMF	comfortable with numbers and calculations	—		275
EASYODDS	10 in 1,000,000 risk less than 1 in 1,000,000 risk	—		263
HARDODDS	7 in 1,000,000 risk less than 1 in 100,000 risk	—		261
SCIUNCER	science is uncertain	.41	11	235
ANIMAL	belief in extrapolation from animal studies	.48	12	214
SEX	sex	—	—	278
AGE	age in years	—	—	277
BAEDUC	education of bachelor's degree or higher	—	—	276
WHITE	race	—	—	270
CHILDREN	children living in household	—	—	280
ENVGRP	affiliated with environmental group	—	—	280
CERTAINTY	desire for certainty	.80		273
WRONG	government could be wrong	.74		229
WORST	assumes worst given risk range	.38		244

Note. Shading separates variable types; respectively, worldviews; personal stances toward uncertainty (personal vulnerability, life uncertainty); knowledge, sociodemographic; reactions to uncertainty in general.

'To increase sample sizes, we included respondents who had only one missing response for indices consisting of three to four items, and two missing responses for indices of five to six items. No missing responses were allowed for two-item indices, or where indices mixed statements with differing numbers of response options. This resulted in *N*s of 128–145 for various regression analyses, except that for the dependent variable of considering the second study to be more competent ($N = 88$).

Note that Cronbach's alpha for most index variables were modest to weak, although far better for dependent than independent variables. (Ten of 13 dependent variable indices had alphas above .70; only one exclusively independent variable reached that level, and three of the seven independent indices had alphas under .50.) Although this means that generalizing the results of multivariate analysis must be done cautiously, we think it is appropriate in an exploratory study like this one to relax statistical constraints. Our primary aim for Phase II research was to understand the concepts, if any, that laypeople have of uncertainty in human health risk assessment, which the univariate analyses discussed earlier portray. The purpose of the multiple regression analyses discussed below is not to describe uncertainty concepts, but instead to provide *preliminary* examination of reasons for these concepts. For such a purpose the current data are sufficient.

Reactions to Uncertainty

The multiple regressions are divided into two groups. Table 17 concerns three generic reactions to uncertainty—desire for certainty (CERTAINTY), belief that risk ranges mean the government could be wrong (WRONG), and tendency to assume the worst if a range is given (WORST)—and several reactions to the initial scenario (NOWORRY, CONCERN, ESTRISK, GOVHONEST, GOVKNOWS). Table 18 includes regressions concerning reactions to the scenario of a second risk estimate (2NDEST, 2BETTER), reasons for scientific uncertainty (MEASURE, COMPLEX; PAST, FUTURE), and risk beliefs (TAPWATER, SERIOUS).

As shown in Table 17, six of the eight regressions conducted to predict reactions to uncertainty were statistically significant (with a p of at least .05 or greater). The two regressions that were not significant were those predicting the belief that risk ranges mean government could be wrong (WRONG) and the tendency to assume the worst if a range is given (WORST). For five the six significant models the variance explained ranged from 22% to 35%. The variance explained in the regression predicting belief in government's honesty was only 11% and none of the regression coefficients were significant.

TABLE 17. Multiple Regressions: Reactions to Uncertainty and Initial Scenario

Variables	certainty	wrong	worst	noworry	concern	estrisk	govhonest	govknows
antiegal	–.03	.26*	–.08	–.01	–.32**	–.11	.09	.01
environ	.01	.16	.17	.10	.02	.14	–.05	.10
trust	–.09	–.24	–.07	.04	–.23**	–.10	.35****	.22*
fatal	.18	–.17	–.14	–.05	–.07	–.16	.01	.10
avoidunc	.08	.05	.02	.08	.06	.14	–.03	.15
lifeacc	.04	–.07	–.05	–.06	–.04	–.04	.07	.04
p_vulner	.04	–.07	.12	–.24*	.05	.03	–.03	.11
tapwater	–.01	.02	–.01	–.28**	.19*	.15	–.09	.05
bottled	.04	.00	.17	.02	.05	–.10	–.04	.14
serious	–.25*	–.00	.08	–.11	–.08	.10	.06	–.13
mathcomf	–.10	–.07	.04	–.05	–.06	.08	.07	–.10
easyodds	.06	.17	–.16	–.11	.10	–.13	–.27**	–.05
hardodds	–.07	–.03	–.03	–.09	–.01	.04	–.06	.02
sciuncer	–.37***	–.16	–.10	.25*	.18	.05	.07	–.17
animal	.09	.09	.06	–.14	.22*	.10	–.07	.19*
sex	–.02	.07	–.02	–.14	.06	–.08	.09	.10
age	.06	.11	–.09	–.05	–.01	–.02	–.02	–.10
baeduc	–.09	.01	.14	–.19*	.06	.08	.09	.06
white	–.03	–.09	.05	–.00	–.02	.14	.11	.04
children	.18	.05	–.02	–.16	.10	–.02	–.04	–.04
envgrp	.01	.00	.04	–.04	.02	–.16	–.01	.06
wrong	.11	—	—	—	—	—	—	—
worst	.05	—	—	—	—	—	—	—
certainty	—	.20	.07	–.06	.05	.03	–.33***	.20
adjusted r^2	.29	.10	.05	.27	.27	.11	.35	.22
f value	3.00	1.60	1.30	3.10	3.20	1.70	4.10	2.50
f value probability.	.0001	.06	.21	.0001	.0001	.04	.0001	.001
N	117	122	124	125	129	122	124	119

* $p < .05$
** $p < .01$
*** $p < .001$
**** $p < .0001$

Note. Cell entries are standardized regression coefficients (β weights).

TABLE 18. Multiple Regressions: Reactions to Second Study, Reasons for Uncertainty and Risk Beliefs

Variables	2ndest	2better	measure	complex	past	future	tapwater	serious
antiegal	–.06	.11	.04	–.07	–.05	.09	.02	.01
environ	–.17	.02	–.12	–.12	–.19	–.17	.10	.20*
trust	–.28*	–.06	–.13	–.32***	–.19*	–.27**	–.04	–.15
fatal	.39**	–.00	–.08	–.00	–.21	–.03	.07	–.06
avoidunc	–.00	.08	.05	.02	.01	.08	.02	–.06
lifeacc	–.10	.01	.34***	.13	.18*	.17	–.07	.06
p_vulner	.01	.06	–.01	.05	–.04	–.09	.06	.20*
tapwater	.01	.07	–.06	–.09	–.10	–.07	—	.36****
bottled	.01	–.08	–.00	–.12	.04	–.06	—	–.04
serious	.01	–.10	.11	–.05	–.12	–.07	.41****	—
mathcomf	.16	.10	.03	.11	.17	.12	–.04	–.14
easyodds	–.02	–.11	.06	–.12	.00	–.09	.11	–.06
hardodds	–.11	–.03	–.18	–.08	–.11	.17	–.04	–.03
sciuncer	–.05	–.05	.06	.09	.07	.10	.08	–.06
animal	.00	.07	–.00	.12	.06	–.04	.10	–.01
sex	.02	–.11	.25*	.27**	.24*	.23*	.12	–.12
age	.04	–.00	.04	.17	.16	.08	.23*	–.12
baeduc	–.01	.05	.06	.08	.03	–.01	–.07	.16
white	.05	.13	–.02	–.01	–.12	.01	–.21*	.09
children	.30*	–.06	.13	.03	.15	.03	.17*	.00
envgrp	–.02	–.13	–.04	.05	–.10	–.02	–.05	.06
certainty	.36*	.13	–.07	–.10	–.12	.05	–.02	–.24**
adjusted r^2	.20	–.03	.07	.21	.14	.13	.21	.32
f value	1.90	0.90	1.40	2.50	2.00	1.90	2.80	4.00
f value probability	.03	.64	.11	.0009	.01	.02	.0004	.0001
N.	77	116	127	127	128	127	131	131

* $p < .05$
**$p < .01$
***$p < .001$
**** $p < .0001$

Note. Cell entries are standardized regression coefficients (β weights).

CERTAINTY. Two independent variables were significant predictors (SCIUNCER and SERIOUS) of desire for certainty (CERTAINTY). Respondents who *disagreed* that good science has a range of uncertainty (SCIUNCER) expressed a greater desire for certainty. Those who *disagreed* that there were serious environmental health problems where they live (SERIOUS) were more likely to have a greater desire for certainty.

NOWORRY. Four variables were significant predictors of worry (TAPWATER, SCIUNCER, P_VULNER, and BAEDUC). Respondents with higher perceived risks of home tapwater were more likely to worry about the water risks presented in scenario one. The belief that good science has a range of uncertainty was positively correlated with not worrying. Respondents who feel greater personal vulnerability were more likely to worry about the water risks in the initial scenario. Respondents with a bachelors degree were more likely to worry about the water risks.

CONCERN. Four of the independent variables significantly predicted concern about the water in the drinking water scenario (ANTIEGAL, TRUST, ANIMAL, and TAPWATER). Respondents holding egalitarian worldviews and having less trust in authority were more likely to be concerned about the water. Those with a greater belief in the reliability of animal studies were more likely to be concerned about the water. Higher risk perceptions of home tapwater was positively correlated with greater concern about the water.

GOVHONEST. Three variables were significant predictors of the belief that the government is honest in drinking water scenario (TRUST, CERTAINTY, and EASYODDS). Greater trust in authority was positively correlated with the belief that the government is honest. Respondents with a greater desire more certainty were less likely to believe that the government was honest in the drinking water scenario. Those who understood that "you are less likely to get a disease if the risk of getting it is 10 in 1,000,000 than if the risk is 1 in 1,000,000" (EASYODDS) were more likely to believe in the government's honesty.

GOVKNOWS. Two variables were significant predictors of the belief that the government knows exactly what the risk is in the drinking water scenario (TRUST and ANIMAL). Respondents with higher levels of trust in government/authority were more likely to believe that the government knows what the risk is in the scenario. People with a greater belief in the reliability of animal studies were also more likely to think that the government knows what the risk is in the scenario.

Regressions To Predict Reactions to the Second Risk Estimate, Reasons for Uncertainty, and Risk Beliefs

Eight regressions were conducted to predict reactions to second study (and second risk estimate), reasons for uncertainty and risk beliefs. Overall regressions predicting six of the dependent variables were statistically significant ($p<.05$).

2NDEST. Three variables were significant in predicting the belief that the second study was more competent in the two-study scenario (FATAL, CERTAINTY, and CHILDREN). Respondents holding fatalistic worldviews, with a greater desire for certainty, and with children living in the household were more likely to believe that the second study (with the lower risk estimate) was more competent.

COMPLEX. The two variables significant in predicting complexity as reasons for scientific uncertainty were trust in authority (TRUST) and gender (SEX). Women and people with less trust in authority were more likely to see complexity as reasons for scientific uncertainty.

PAST. Three variables were significant in predicting the belief that problems with past information about risks were reasons for scientific uncertainty (TRUST, LIFEACC, and SEX). Respondents lacking trust in authority, women, and those with a belief that "my life is controlled by accidental happenings" are more likely to view these problems from the past as reasons for scientific uncertainty.

FUTURE. Only two variables were significant in predicting the belief that problems with forecasting the future were reasons for scientific uncertainty (TRUST and SEX). Women and respondents with less trust in authority were more likely to see these problems as reasons for scientific uncertainty.

TAPWATER. Three variables were significant in predicting perceived risks of home tapwater (SERIOUS, AGE, and WHITE). Respondents who agreed that there were serious environmental health problems where they live were more likely to have higher risk perceptions of home tapwater as were older and non-white respondents.

SERIOUS. Two variables were significant predictors of the belief that there are serious environmental health risks were one lives (TAPWATER and CERTAINTY). Respondents with higher perceived risks of home tapwater, environmentalists, and those with less desire for certainty were more likely to believe that there were serious environmental problems where they live.

Importance of the Independent Variables

TRUST (i.e., trust in officials) was the most common predictor of the various dependent variables, reaching statistical significance in 6 of the 17 multiple regressions run. Those who trusted officials were much more likely to see government's discussion of a range of risk estimates as implying honesty and competence (GOVHONEST). This finding confirms our Phase I regression findings. To a lesser degree, TRUST also predicted the belief that government knew exactly what the risk was for the initial drinking water scenario. Earlier we had hypothesized that this belief might indicate distrust, in the sense that government had a correct point estimate of the risk, but only announced a range of risk estimates. But if it is the trusting ones who are more likely to hold this belief, this hypothesis seems less tenable. Possibly the belief that government knows the risk is another signal of a belief in its honesty and competence, but if so this statement should have loaded on the same dimension under factor analysis.

By contrast, those who trusted (TRUST) were *less* likely than others to agree with three of the four sets of reasons for uncertainty (COMPLEX, PAST, and FUTURE). This may mean that people who tended to distrust government on principle seized upon these reasons to justify their suspicions, on the grounds that all these things that could "go wrong" showed that government risk estimates could not be trusted. Earlier we had wondered whether the overwhelming agreement with these sets of reasons for uncertainty truly represented the Eugene sample's beliefs about uncertainty. This regression result suggests that that doubt may be justified.

TRUST was inversely related to CONCERN. Those who trusted were less concerned about the drinking water contamination than others. This is consistent with other findings (e.g., Bord &

O'Connor, 1992) that trust seems to reduce perceived risk. However, no significant relation between TRUST and two other measures of perceived risk—NOWORRY and ESTRISK—appeared, undermining our confidence in a general relationship between trust and perceived risk.

The three worldview variables other than TRUST had less of an impact on the dependent variables in our regressions than expected, having among them significant effects in only four of the 17 regressions. As noted earlier, beliefs like those included in our ANTIEGAL (antiegalitarianism) have been associated with risk beliefs in some other studies. It was the strongest predictor of CONCERN, but—as also happened with TRUST (above)—it had no significant impact on NOWORRY and ESTRISK. ENVIRON (environmentalism) had a significant impact only on the belief that there are serious environmental health risks in one's community (SERIOUS).

The final worldview variable, FATAL (fatalism), was the strongest predictor of 2NDEST, the belief that the second risk study—which produced a lower risk estimate—was more competently done and based on better scientific knowledge. It is not clear what this means, given the much more common view that lower risk estimates are less trustworthy, and majority disagreement (or inability to decide) about the second study's competence. Possibly fatalists were more likely to see competence in the second, lower-risk estimate because this allowed them to deny a risk that made them feel vulnerable (i.e., they might be "fated" to suffer health consequences of the contamination). The fact that FATAL did not combine with seemingly related indices of vulnerability (e.g., AVOIDUNC, LIFEACC, P_VULNER) raises doubts about this hypothesis. On the other hand, the other significant predictors of 2NDEST—CHILDREN (having children in the household) and CERTAINTY (desire for certainty)—are certainly potential motives for denial of risk, in the sense of accepting the lower risk estimate as more competent rather than continuing to doubt its validity.

Conclusions

As a consequence of Phase II research on public responses to uncertainty in environmental health risk assessment, we have a much better grasp of the content and limits of lay conceptions of risk uncertainty and its implications for hazard management. Certainly there are gaps remaining in our understanding, which will be outlined in detail under "Research Implications," but these have more to do with generalizing our results to other populations, risk types, and so forth, than with introducing entirely new concepts. Our findings are as follows.

People Support Ranges of Risk Estimates in General

For the above-average-education sample in our Eugene study, the presentation of uncertainty in the form of a range of risk estimates was deemed honest and competent in general, although (as in Phase I studies) we continued to find a substantial minority who questioned the presentation of uncertainty on both grounds. This support for receiving a range of risk estimates seemed to have been enhanced by a college-derived familiarity with the concept that uncertainty is common in good science (regression analysis found an inverse relation between desire for certainty and belief that science is inherently uncertain). However, they were not any more familiar with concepts of dose-response relationships than earlier public samples, and had no coherent idea of standard practice in government risk assessment. To the extent that such support is knowledge-based, we would not expect it to be more common among populations with average education (i.e., less than in our sample).

Yet Uncertainty Makes Many People Uneasy

About a third of our Eugene sample rejected ranges and even risk estimates, saying they preferred to be told simply that an environmental condition was safe or unsafe. As we noted above, others doubt risk information that does not incorporate ranges; together these beliefs potentially put purveyors of risk estimates in a quandary, chancing alienation of some individuals whatever they do. Multiple regression analysis suggested that desire for certainty was associated with beliefs that good science is certain and that there are serious local environmental health problems.

Uncertainty in Government Risk Estimates Is Particularly Suspect

While a majority of our respondents, as in Phase I, found government discussion of a range of risk estimates to be competent, they were more dubious about whether this indicated honesty. We have suggested that this reaction is partly related to two other findings: that *zero as a lower bound on a range of risk estimates*, rather than a small positive bound, seems to raise doubts about honesty and competence all by itself, and that people believe *government discusses publicly only high risk items*. The presence of zero led people on average to feel that the risk was probably higher, to believe that the government could be wrong, and to worry significantly more often than when a small positive lower bound was used. Citizens who see zero risk as unlikely or impossible, and high-risk information as both technically more complete (see Phase I results) and politically more likely to appear in public discussion, would be suspicious of a government risk estimate ranging from zero to some higher number, even if they supported risk ranges in general. If a risk exists at all—and by this definition it must, because government announces it—then it must be a high risk, and the range should include only risks higher than zero. On this interpretation our scenarios stimulated general distrust of government risk ranges because they included the lower bound of zero, which the National Research Council has characterized as EPA "boilerplate." Distrust for some people also seemed to be ideologically-based, or derived from beliefs about how government risk estimates were developed (in technical or political terms). Belief in government honesty and competence was related to low desire for certainty, high trust in officials (a combination of expectations of honesty and deference to authority), and one of our measures of difficulty with arithmetic.

Environmental Health Risk Uncertainties Are Seen as Special

The exact same range of risk estimates that elicited concern when it applied to environmental health elicited little or no concern when applied to transportation (mortality), financial or recreation risks. People offered contextual information (work requirements, familiarity, offsetting joys) for their differing reactions to the latter uncertainties. Because the transportation risks (airplane and automobile crashes) involved death, we cannot explain this reaction solely on the grounds that the stakes with environmental health are different (although that was the reasoning offered by focus group members about the financial and recreation cases). Varying reactions *within* the environmental health category (drinking water vs. soil vs. air contamination) seemed driven more by criteria of morality or protective opportunities than by uncertainty considerations (as our comparison of "natural" to "human" sources of risk in Study 1, Phase I, suggested as well).

All Range Numbers Are Not Interpreted Equally

People do not seem to treat every number within a range as equally probable, despite the only signal of varying probabilities across risk estimates being a brief statement that one risk level is "most likely." Instead, on average they appear to treat higher risk numbers as more probable (compare to the Phase I finding that lower risk numbers were seen as "preliminary" estimates), confirming an earlier hypothesis (Viscusi et al., 1991) of an "upward bias" in response to ranges. By contrast, use of zero as a lower bound seemed to be particularly disturbing (see above), although a majority responded to questions using this bound no differently than they responded to a lower bound of 1 in 10 million.

Explanations of Uncertainties Are Confusing, Irrelevant, or Troubling

Explanations of extrapolation from animal or high-dose human data did not differ in their impact, and qualitative reactions suggest people largely found them confusing or irrelevant. Earlier research (Kraus et al., 1992), confirmed by this study, found laypeople and experts divided over the validity of using animal data. This may partly explain why explaining uncertainty in risk estimates as due to extrapolation from animal data was seemingly without effect ("seemingly" because we attempted no experimental test in this study, although a Phase I experiment found no evidence of impact). Poor responses to explanation of high-dose extrapolation in interviews seemed partly due to use of the word "chance" to describe how the high dose was received by the other population, perhaps stimulating aversion to a risk that thus seemed more likely to affect the interviewee (on the grounds that chance cannot be avoided). Extrapolation from factory workers to members of the general population also seemed troubling for a plurality of our Eugene sample. Explanation of how a safe reference concentration is calculated for a noncarcinogen also confused or upset almost all interviewees and respondents to open-ended questionnaires. By contrast, the Eugene sample overwhelmingly agreed with reasons for risk uncertainty stemming from measurement or complexity, or problems associated with past or future risks, derived from the risk literature (Rowe, 1994). On methodological grounds alone we raised the question of whether these are their own views; the regressions showing distrust significantly related to agreement suggest that people were finding these reasons justifying prior distrust.

These findings do not necessarily mean explanations of uncertainty are useless. A minority of our qualitative respondents found them enlightening, even enthralling; some respondents volunteered reasons (varying exposures or susceptibility across subpopulations) why they found ranges of risk estimates preferable to point estimates, or said they would distrust risk estimates without explanations of how they were derived. However, any effort at explanation must deal with the challenges of salience, trust and scientific understanding. Some of the lack of impact among our respondents may be due to our using hypothetical cases of drinking water contamination that did not motivate people to seek and process information; yet people who believe they face a real life-and-death situation may put a low priority on understanding uncertainty as opposed to protecting themselves. As our regression results imply, people who are disposed to distrust officials anyway may seize explanations of uncertainty as reasons for such distrust. Finally, many citizens do not understand how science works or have difficulties with mathematical information. Despite the general poor role of measures of mathematical competence in this study, successful explanations of uncertainty will probably require a basis in lay cognitive models of both science in general and what scientists are doing (and why) when they, for example, extrapolate from animal data to human risks.

Shifting or Disputed Risk Estimates Do Not Reassure

Changes in risk estimates do not seem to affect public beliefs about risks strongly, except possibly to make them more suspicious if the estimates decrease. Although a majority in our Eugene sample did feel more confident in their drinking water's safety after such a decrease, our scenario concerned a deliberately unlikely change from a "most likely" risk of 10^{-6} to 10^{-9}, and even then a full third of respondents were not reassured. The basis for the latter reaction is unclear: the only variables predicting a belief that a lower follow-up risk estimate was more competent were fatalism, desire for certainty, and having children living in the home. Qualitative answers suggested that an increase in government risk estimates may slightly reassure people about government honesty (Weinstein, 1987), but of course higher risks are likely to be disturbing in themselves. Half our sample were even unwilling to hazard a guess as to whether a lower risk number was produced because of better scientific knowledge, and slightly more disagreed than agreed with this statement. We suspect that this is due less to doubt that scientific knowledge can improve than to suspicion that government is trying to calm the public or bow to industry pressure. Similarly, the general reaction to conflicting risk estimates seems to be to distrust everyone (but distrust government and business somewhat more than environmentalists and academics), attribute conflict as much to scientists' self-interest or incompetence as to the nature of the evidence, reject majority scientific opinion in favor of good "track records" for being right, and assume the worst is true if scientists disagree. People were largely unable to see the overlap in hypothetical ranges of risk estimates from government and environmentalists, or believe that this overlap signaled anything about the groups' consensus or "objective" risk levels.

Mathematical Literacy, Vulnerability and General Worldviews Are Only Partial Explanations

Much attention has been paid by elites to the deplorable level of scientific illiteracy among Americans (Miller, 1993), and mathematical incompetence has been one explanation for conflicts between officials and citizens over environmental issues. Although we found a substantial minority even in a college-educated sample who struggled with one or another arithmetic operation, this difficulty was only one of several factors in public response to health risk uncertainties, and a relatively minor one in our multiple regression analyses. Although not unimportant (see "Practical Implications"), it should not be an excuse to disenfranchise citizens from participation in hazard management (a strong majority in our college-educated sample was able to answer these arithmetic questions satisfactorily). Similarly, felt vulnerability and worldviews (e.g., antiegalitarianism, environmentalism, trust in authority, fatalism) were factors in some responses to uncertainty by our respondents, but neither personality nor cultural forces (except for "trust in officials") were dominant explanations of these responses among those we were able to test.

Risk Estimates and Their Uncertainties Are Not Critical to Most People's Views of Environmental Problems

Willing though they were, by and large, to answer our questions about uncertainty in environmental health risk assessment, interviewees and other qualitative respondents made quite clear that the central issue for them was prevention and cleanup of environmental pollution. They made it clear that for them risk numbers were generally beside the point. Although we did not give Eugene respondents to the closed-ended questionnaire a chance to express this view directly, the third of the sample who did not want to see ranges of risk estimates plausibly fall into the same category. Nor can we assume that the rest of the sample welcome such ranges as much more than yet another piece of information to be weighed for its credibility.

We think this is the key message to be taken from our study. Risk assessment will clearly remain an important component of environmental problems; making risk estimates available to the public will not only continue, but is part of their right to be informed and participate in decision making (Johnson and Slovic, 1994b). However the debate over the role of uncertainty in risk assessment and risk management is resolved, at some point it is likely (even if only qualitatively) that such uncertainty will be discussed publicly. Such discussion will undermine the credibility and effectiveness of government if it is made the centerpiece of attention, rather than prevention and cleanup of pollution. Uncertainty is a fact of life, but life goes on; similarly, citizens expect government action on pollution in spite of uncertainty, and may suspect uncertainty is being raised merely to justify inaction. Attention to uncertainty can be critical to deciding *which* action to take, but this public discussion must take due account of the wider context to ensure a successful and informed outcome.

Practical Implications

As we have noted several times, generalization of our results should be done cautiously. However, it is unlikely that any substantial knowledge-based differences in response to uncertainty will be found from applying our methods to populations less educated than our college sample. If a group relatively knowledgeable about uncertainty in science is troubled by uncertainty in risk assessment, there seems little hope of finding a less concerned public audience. Ideologically-based differences may vary more widely among the general public than in our Eugene sample, of which 67% was "environmentalist," 79% "egalitarian," 88% distrustful of authority, and 92% not fatalist, as measured by worldview statements in the questionnaire. Nevertheless, we believe there are reasonably strong grounds for making recommendations to government (and other institutions) about practical implications of our findings.

Our interviewees and focus groups in particular stressed their interest in having environmental problems prevented, and cleaned up swiftly if not prevented; getting risk estimates was of far less interest, even for those who preferred a range of risk estimates to simply being told that conditions are safe. As noted earlier, we conclude from this that *communication of risk estimates, whether uncertainty is included or not, should be secondary to dealing with the risk management issues* posed by our respondents. This may seem like stating the obvious, but official emphasis on communicating "the risk numbers" is still common enough to make repeating this argument worthwhile. This does not mean that communication of risk estimates is useless or unnecessary, but it conveys our feeling that an emphasis solely or primarily on such communication will be interpreted by most citizens as an attempt to hide incompetence or the "true" risks. This interpretation would help neither agencies nor the public.

Some of our recommendations apply to *forms* of communicating uncertainty:

- Use of "zero" as a lower bound in a range of risk estimates should be used only when the available data clearly show this is a likely "true" level of risk. The doubts that this term raised among our respondents about government honesty and competence, plus the technical arguments about its validity referred to earlier (NRC, 1994), do not justify its use as boilerplate. Very small positive lower bounds may be much more acceptable: a majority of our respondents saw no difference between zero and 1 in 10 million as a lower bound, and yet those greatly disturbed by zero were far less affected by use of the latter figure as a lower bound. If there is no alternative to using the term "zero" in a risk estimate, clear explanation of the reasons for its presence should be included. Although (as mentioned below) the explanations for uncertainty we provided rarely "worked" for our respondents, in this case omitting an explanation only means that audiences will substitute their own explanations (of dishonesty or incompetence or both).

- About two-thirds of our respondents "assumed the worst" (thought the high end of a range of risk estimates to be more likely); to the extent that this contradicts the beliefs of officials and risk assessors, the discrepancy should be pointed out. On average people's estimates of risk to themselves or to their community based on our scenario were not greatly skewed upwards; on the other hand, simply saying that one intermediate estimate was "the most likely risk" did not prevent an upward bias, even if it seemed to avoid projections that every risk level within the range was equally probable. This suggests that a more explicit specification of the reasons for the (presumably) low probability of a range's upper bound might help some members of public audiences put the range into perspective. However, as with many of our other recommendations, these explanations should be brief (with fuller details for those who wish them available separately) and undue faith in their effectiveness should be avoided.
- Phrases like "95% confidence" or "95% certain" aroused suspicion among our respondents, and we suggest they be used very cautiously if at all. One option is to simply announce upper and lower bounds to risk ranges, without specifying their link to confidence limits except in the more detailed information available to those who request it. What that more detailed explanation should be, however, we cannot say on the basis of our current findings.
- Our Phase II research added little to what we had learned from Phase I about the helpfulness of graphics: just as the earlier research suggested a simple line graphic made the presence of uncertainty itself more obvious (but raised doubts about the truth of the risk information), the graphics appearing in figures 1 to 3 apparently conveyed

uncertainty without implying equal probability of all risk levels within the range. However, a more complex (and more accurate and potentially informative) graphic recommended by a National Research Council body (1994) was quite confusing. We suggest that simpler graphics be used, if at all, until further research can specify what kinds, if any, graphics would be most helpful to citizens.

Some recommendations relate to use of *explanations* of uncertainty:

- Attempts to explain in detail why a range of risk estimates has been presented should be directed primarily at audiences that express an interest in understanding the reasons. Otherwise, explanations will be seen as irrelevant or distracting from central issues (e.g., risk management). A simple statement may be enough in most cases, such as: "We are providing a range of risk estimates because [for example] we want to account for the fact that different people may have different levels of exposure to the problem; if you have a special interest in information on this uncertainty, we have a handout." Some cases (e.g., those where zero is a lower bound) may require explanation anyway, to avoid even more serious communication problems, but these explanations should be few and brief.
- Responses to our explanations of uncertainties based on extrapolation from animal data or high-dose human data did not vary significantly. Combined with our Phase I finding that adding such an explanation to a hypothetical news story did not produce different responses than a story without explanation of uncertainty, this might imply that explanations are useless and should not be attempted. *We do not recommend offering no explanation of uncertainty.* Our Phase II finding only suggests that animal and high-dose explanations are equally good or poor; the Phase I finding may have been due to information overload (the "explanation" story included much other information) rather than irrelevance of the explanation; other phrasings than the ones we used might work better.
- We do not at this time recommend using analogies to uncertainty in financial or other nonhazard areas to explain environmental health uncertainties. The aim of such explanation might be to clarify how uncertainty works, or how it can help one make better decisions. We are concerned that the public may interpret this instead as an

argument that they should accept risk and uncertainty for environmental health if they accept it in investments or recreation or transportation. Our Phase II study suggests they are likely to strongly resent such an argument. Because explaining the difference between their inference and the intention will be challenging, using the analogy does not seem worth the dangers.

- Extrapolation from animal data faces skepticism from both citizens and experts (Kraus et al., 1992; Slovic, in press; Slovic et al., 1995), and so will explanations of its role in risk uncertainty. Direct acknowledgment of this skepticism, that such data are the only ones available for this pollutant, and that having some rough idea of the risk is better than having no idea at all (the only alternative in this case), may be the best options for explaining this kind of uncertainty. We do not guarantee that this explanation will satisfy all or even most audiences.
- Extrapolation from high-dose data resulting from occupational exposure or accidents seems to evoke doubt as well, perhaps due to concern that occupational data are not relevant (or, in the example we offered in interviews, that others' exposure to a pollutant by accident or "chance" may make people feel more vulnerable than otherwise). The recommendations (and caveats) for explaining animal data apply here as well.

Administrator Browner, in her memorandum on EPA's Risk Characterization Program (1995), said that while "the final risk assessment document ... is available to the public, the risk communication process may be better served by separate risk information documents designed for particular audiences." We endorse this statement whole heartedly, in the sense that details should be reserved for "backup" documents whose existence would be publicized.

Research Implications

Our study raised many questions for future research. Those that concern communication about uncertainty in risk assessment include:

- Our research examined lay response only to uncertainties in risk assessments based upon toxicological studies. Although we have no reason to believe that the general reaction to epidemiological uncertainties would be much different, research on this topic would allow testing of reaction to particular kinds of such uncertainties and to alternative explanations of them.
- Phase II research focused on drinking water scenarios. In a few interviews reactions to other environmental health scenarios (e.g., air pollution from a local factory; soil contamination in the neighborhood) varied from those given by the same person to the drinking water scenario. These variations, however, were not the same across interviewees, and did not seem to be based on uncertainty as much as other factors (e.g., perceived immorality of the factory's emissions; perceived availability of protective options). But we did not test more widely for the presence of similarities or differences in reactions to uncertainty across hazards (one study in Phase I found differing reactions, unrelated to uncertainty, between natural radiation and a hazardous-waste-site chemical). Although we are confident that reactions of uncertainty will not vary widely across hazard types, research testing this hypothesis would be valuable.
- The potential role of graphics in communicating risk uncertainty has been little explored (Ibrekk & Morgan, 1987), and our results make the issue seem even more complex. We wonder whether the graphic proposed by Ibrekk and Morgan (a cumulative distribution function above its equivalent probability distribution) can be explained simply and briefly. Certainly the graphic proposed by the National Research Council that we showed focus groups elicited nothing but confusion. Our simpler graphics, although they did not seem to make people think that risk estimates within the range were equally probable, may not be as helpful to the public as agency officials might like. Research focusing on these and alternatives seems valuable.
- More extensive testing of reactions to various explanations of uncertainty is needed. Our explanations of animal-data extrapolation, high-dose extrapolation (including citing

chance or workers as the source of the data), and construction of a reference concentration were largely taken to be confusing, irrelevant, or upsetting. Because we expect that some such explanations will be used when agencies and others present uncertainty, more study (including development of alternate versions, in language and for different audiences) is necessary to provide agencies some confidence that they will not make matters worse with explanations. As part of this research, we need to understand how widely explanations might be treated as reasons for distrust, rather than as enlightening.

- Our findings that zero as a lower bound of a range elicited strong negative reactions are striking, but further experimental work is needed to generalize these results (which, after all, did not appear in Phase I, Study 1). Among other things, we need to test whether the alternative suggested earlier makes a difference. This concerned having uncertainty about whether a chemical is a human carcinogen represented as "a risk of zero, if it is not a carcinogen, or a risk ranging from [a low positive lower bound] to [a higher upper bound]," rather than as "could be as low as zero or as high as…," which is misleading.

Several other research topics are less directly focused on uncertainty, but are important:

- Understanding of lay cognitive models of science and risk assessment-including, but not stressing, uncertainty—would help us design communications that better explain these critical factors in hazard management.
- Trust in officials was the most powerful, although by no means universal, predictor of responses to government risk ranges; although "trust" has elicited much attention from researchers in the last several years, little is yet known about its antecedents. Further research, perhaps using think-aloud protocols while respondents read a risk estimate announcement (with or without uncertainty), would be valuable.
- Similarly, we were unable to clarify how people judge the honesty and competence of officials with regard to risk estimates (much less on other risk management tasks). Some trust researchers suggest such judgments stem from the perception that officials share the observer's values, but others believe these judgments reflect other factors.

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Appendix I

Fourteen Items Used in Qualitative Data Collection

NOTE: Item numbers are those identifying items developed during interviews, which were retained in focus groups and the open-ended questionnaire (some with slight wording changes) to aid comparing responses across the various data collection methods.

ITEM 2a

The government announces that the water you drink contains a level of chemical X that poses an extra health risk of getting non-fatal kidney damage of 1 in 1,000,000 (one in one million) over a lifetime of drinking that water.

ITEM 3 [focus group]

The government announces that the water you drink contains a level of chemical X that poses an extra health risk of getting cancer of 1 in 1,000,000 (one in one million) over a lifetime of drinking that water. The government says that is the most likely risk, but it says the true risk could be as low as zero or as high as 1 in 100,000.

ITEM 4

A government study was done of the water you drink a few years ago, which contained (and still contains) small amounts of chemical X. It found that the most likely extra level of risk of getting cancer from drinking this water for your entire lifetime was 1 in 100,000 (one in one hundred thousand). This was below the drinking water standard for this chemical at the time, so no action was taken and the amount of the chemical in the water has stayed the same. The government did another study recently, using new scientific information about the chemical's effects, and concluded that the most likely level of risk was 1 in 1,000,000 (one in a million).

ITEM 5 [both focus group and questionnaire]

The government announces that there is a 5% chance that the extra level of risk from drinking chemical X in the water you drink for your entire lifetime is above 1 in 100,000 (one in one hundred thousand), and a 5% chance that the risk is zero. The government says this means there is a 90% chance that the true risk is between zero and 1 in 100,000.

ITEM 6

The government announces that the water you drink contains a level of chemical X that poses an extra health risk of getting cancer of 1 in 1,000,000 (one in one million) over a lifetime of drinking that water. The government says that is the most likely risk, but the true risk could be as low as zero or as high as 1 in 100,000. The government says that the reason for this range of risk estimates is that the only scientific studies of this chemical's effects on cancer risks involved laboratory tests with animals. It is not clear that the way an animal reacts to a chemical will reliably predict how a human would react to the same chemical. Different assumptions about how to predict human risks from animal reactions to the chemical result in different risk estimates.

ITEM 7

The government announces that the water you drink contains a level of chemical X that poses an extra health risk of getting cancer of 1 in 1,000,000 (one in one million) over a lifetime of drinking that water. The government says that is the most likely risk, but the true risk could be as low as 0.01 in 1,000,000, or as high as 10 in 1,000,000. The government says that the reason for this range of risk estimates is that the only scientific studies of this chemical's effects on cancer risks involved cases where people were exposed to much larger amounts of the chemical in their drinking water than appear in your drinking water (at the time they were exposed, no one knew this chemical could affect health). It is not clear that the cancer-causing effects in these people of high levels of the chemical reliably predict how a human would react to the much lower levels of the same chemical in your water. Different assumptions about how to predict risks from low levels of the chemical, when only information about risks from high levels is available, result in different risk estimates.

ITEM 8 [focus group]

The government announces that its scientists have calculated the risk of getting cancer from drinking the water you drink, which has a small amount of chemical X in it, for an entire lifetime. It is 95% certain that at least 90% of the population has an extra risk of no more than 1 in 1,000,000 (one in one million). A small proportion of people who are more likely than others, when exposed to a cause of cancer, to get cancer may have a risk as high as 10 in 1,000,000 (ten in one million) if they drink this water for their entire lives.

ITEM 10

The government announces that the water you drink contains a level of chemical X that poses an extra health risk of getting cancer of 1 in 1,000,000 (one in one million) over a lifetime of drinking that water. Most scientists agree with this number, and many think that the true risk could be as low as zero. However, a few scientists believe that the true risk could be as high as 100 in 1,000,000. Both groups have reputations as being competent scientists.

ITEM 11a

The government has found a chemical in your drinking water that can cause non-fatal kidney damage in laboratory rats. The level of the chemical which the government considers safe for humans to be exposed to is 1 part per 100 million. The level of the chemical in your drinking water is smaller than 1 part per 100 million.

ITEM 11b

The government has found a chemical in your drinking water that can cause non-fatal kidney damage in laboratory rats. The level of the chemical which the government considers safe for humans to be exposed to is 1 part per 100 million. The level of the chemical in your drinking water is 1.2 parts per 100 million.

ITEM 11c

The government has found a chemical in your drinking water that can cause non-fatal kidney damage in laboratory rats. However, this chemical did not cause kidney damage when fed to laboratory rats in doses of 1000 parts per 100 million or less. Government scientists took a cautious approach to calculating a safe dose for humans, although it is possible 1000 parts per 100 million would be safe for them too. They divided this number by 10 to account for the fact that the rats were only fed the chemical for a short time, and humans (at worst) might be exposed for an entire lifetime; divided by 10 again to account for the possibility that humans might be more sensitive to the chemical than are rats; and divided by 10 again to account for humans who may be more sensitive to the chemical than the average human. Thus the level of the chemical which the government considers safe for humans to be exposed to is 1 part per 100 million. The level of the chemical in your drinking water is 1.2 parts per 100 million.

ITEM 13

Chemical X occurs naturally in drinking water in this part of the country. The government standard for a safe level of this chemical, assuming that a person drinks this level for an entire lifetime, is 1 part per 100 million. The government has found that the level in your drinking water system averages 0.9 parts per 100 million. Due to random changes in the natural level of the chemical in the water source, the government says the level of chemical X in the water you drink at any particular time and place can range from undetectable amounts to 1.2 parts per 100 million.

ITEM 17

The government announces that the water you drink contains a level of chemical X that poses an extra health risk of getting non-fatal kidney damage of 1 in 1,000,000 (one in one million) over a lifetime of drinking that water. The government says that is the most likely risk, but it says the true risk could be as low as zero or as high as 1 in 100,000 (one in one hundred thousand).

ITEM 18

The government announces that the water you drink contains a level of chemical X that poses an extra health risk of getting cancer of 1 in 1,000,000 (one in one million) over a lifetime of drinking that water. The government says that is the most likely risk, but it says the true risk could be as low as 0.01 in a million or as high as 10 in 1,000,000 (ten in one million). An environmentalist group responds by saying that the most likely risk is probably 10 in 1,000,000, and it says the true risk could be as high as 100 in 1,000,000 (one hundred in one million).

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Appendix II

Presenting Uncertainty in Health Risk Assessment: Initial Studies of Its Effects on Risk Perception and Trust

Branden B. Johnson[1,3] and Paul Slovic[2]

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Some analysts suggest that discussing uncertainties in health risk assessments might reduce citizens' perceptions of risk and increase their respect for the risk-assessing agency. We tested this assumption with simulated news stories varying simple displays of uncertainty (e.g., a range of risk estimates, with and without graphics). Subjects from Eugene, Oregon, read one story each, and then answered a questionnaire. Three studies tested between 180 and 272 subjects each. Two focus groups obtained more detailed responses to these stories. The results suggested that (1) people are unfamiliar with uncertainty in risk assessments and in science; (2) people may recognize uncertainty when it is presented simply; (3) graphics may help people recognize uncertainty; (4) reactions to the environmental problems in the stories seemed affected less by presentation of uncertainty than by general risk attitudes and perceptions; (5) agency discussion of uncertainty in risk estimates may signal agency honesty and agency incompetence for some people; and (6) people seem to see lower risk estimates (10^{-6}, as opposed to 10^{-3}) as less credible. These findings, if confirmed, would have important implications for risk communication.

KEY WORDS: Risk perception; risk communication; risk assessment; uncertainty.

1. INTRODUCTION

An abiding issue in risk communication is how best to convey risk information from scientists and officials to citizens. A key element of such technical information is uncertainty, yet neither for this topic nor for risk characterization materials in general has there been "systematic study of . . . their comprehensibility and usefulness to various types of users"[1] (p. 14). In particular, no one knows how presentations of uncertainty in risk estimates affect public risk perceptions or citizens' trust in risk managers.

We report here the results of four preliminary studies of this topic, funded by the U.S. Environmental Protection Agency.[2] Defining and calculating uncertainty itself has been the subject of entire books,[3] and was not addressed in the present studies. Here we use "uncertainty" to mean a risk assessment presented in terms of a range of risk estimates, rather than as a point estimate.

2. BACKGROUND

There have been numerous claims that explicit discussion of uncertainties in risk estimates would, among other benefits, improve the public's views of environmental hazard management. One alleged effect is that being open about uncertainty will enhance credibility and trustworthiness;[4] presenting important uncertainties in a risk assessment will improve "*public confidence* in the quality of our scientific output . . ."[5] (p. 1, emphasis added). Another argument is that citizens will make "more informed choices when the range of risks [from a given hazard] to which one is exposed is considered"[6] (p. 87).

Few studies of public response to risk uncertainty have been done. Risk perceptions of a hypothetical haz-

[1] Risk Communication Unit, Division of Science and Research, New Jersey Department of Environmental Protection, CN409, Trenton, New Jersey 08625.
[2] Decision Research, 1201 Oak Street, Eugene, Oregon 97401.
[3] To whom all correspondence should be addressed.

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ardous waste case were unaffected by a caution about the uncertainty of risk estimates in general.[7] Views on global warming effects were unaltered by large variations in the timing and magnitude of scientific predictions about such warming.[8] Another study asked people to name the certain risk magnitude in one area that would make them indifferent to living there or in an area with uncertain risk. The wider the range of risk for the second area, the more risk averse people became; a risk figure received more weight if it came from a "later study." Risk aversion was attenuated if the lowest risk estimate was well below average, and intensified if the highest estimate was well above average.[9] In another study, people's desire to reduce catastrophic risks increased with uncertainty: risk aversion was greater for an accident with an equal chance of yielding zero or 100 deaths than for an accident that would certainly yield 50 fatalities.[10] Only one case study cited an uncertainty-trust relation, implying that *lack of* discussion of uncertainty may be a problem. British sheep farmers distrusted official statements on post-Chernobyl radiation because these ignored uncertainty, while their farming experience exemplified uncertainty.[11] Thus most previous studies did not test hypotheses about uncertainty effects on public trust or manipulate uncertainty directly.

It is unclear that explaining uncertainty (at least by itself, and in the one-shot state of most environmental communication) will increase trust and public confidence. First, uncertainty may disturb people; they want assurances of their safety and may prefer being told that a situation is safe or unsafe to receiving formal risk estimates.[12-13] Descriptions of uncertainty in risk estimates may undercut any illusion of safety. Second, technical risk information, including information on uncertainty, may affect public response to risk and government less than other factors; stressing uncertainty might confuse people, or even cause outrage.[14] One study found that government actions to address public concerns and share information early sharply reduced perceived risk and improved judgments of agency performance for a hypothetical chemical spill. By contrast, details on health effects and exposure pathways had no apparent effect.[15-16] In another study, concern for a hypothetical hazardous waste site was significantly affected by trust in industry and government, perceived health threats to oneself and family, and the sense that hazardous waste risks were controllable. However, knowledge about chemical risks and a generic warning about the uncertainty of risk estimates were not related to concern.[7]

In short, presenting uncertainty in risk estimates may create, rather than remove, public confusion or conflict. Yet uncertainty, inherent in risk assessment, must be part of accurate communication about risk. Research is needed to help us determine how best to communicate uncertainty to the public. The studies reported here represent initial steps toward that goal.

3. RESEARCH DESIGN

Our subjects read simulated newspaper stories about a hypothetical USEPA risk estimate for a potentially hazardous case. Stimuli were varied to identify the separate effect each of several design variables made on risk and other judgments. Use of a mock newspaper story reflects the press's role as a major channel for citizens' receipt of risk information. Use of an official or simulated agency fact sheet instead might restrict experimental variation due to limits on what the agency can say about risks.

Table I shows the major manipulations deployed in the four studies reported here; Table II shows excerpts of three stories. Study 1 used four levels of uncertainty, described as percentages of the (highest) point estimate; Studies 2 and 4 used only two treatments, a point estimate and a range of estimates. Risk estimate ranges in Studies 2 and 4 extended from zero to an order of magnitude above the point estimate of risk; Study 1's range extended only downward from the point estimate. Study 3 (two focus groups with Eugene, Oregon, residents) used three Study 2 stories without alteration. In Study 4, information about the range of probabilities was supplemented by translating these probabilities to additional cases of cancer that would be expected in a city the size of Eugene, Oregon, over 70 years. Study 4 also added, due to comments from the focus group participants, a statement about the typicality of uncertainty in science, and an explanation of the uncertainty (only animal toxicity data were available, and extrapolation from animals to humans is inevitably uncertain). This issue of animal-to-human extrapolation is one of the most debated issues in toxicology for both citizens and experts.[17]

We used fake names for the hazard stimuli: "butydin" for a chemical from an abandoned hazardous waste site (used in all four studies) and "zydin" for radioactive gas entering homes from a natural source (Study 1 only). These names reduced biases (e.g., dread of dioxin or apathy about radon) from prior beliefs about real chemicals or radioactivity.[18] Two risk magnitudes (point estimates)—one in a thousand and one in a million—were used as stimuli in all four studies. Graphics were added in Study 2 (see examples in Figure 1) to see whether respondents would take more notice of a visual-

Table I. Research Design: Variables Used in Four Studies[a]

Study	No. of stories, (no. of subjects)	Story designs	Uncertainty variations (examples)[b]
1	16 (272)	2 Hazards * 2 Risk Magnitudes * 4 Uncertainty Conditions	1) No mention of uncertainty, e.g.: "EPA scientists estimate that the additional risk of getting cancer over a lifetime of living in a home that might be contaminated by zydin at the levels seen in local houses is one in a thousand." 2) "EPA announced the highest risk estimate produced by their risk model; the true risk could be as low as 10% of the current EPA estimate, or one in ten thousand." 3) "... as low as 0.1% of the current EPA estimate, or one in one million." 4) "... as low as zero."
2	8 (180)	2 Risk Magnitudes * 2 Uncertainty Conditions * 2 Graphic Conditions	1) No mention of uncertainty: "EPA scientists stated that the additional risk of getting cancer over a lifetime of drinking water that might be contaminated by butydin at the levels seen at the Lancaster site is one in a thousand." 2) "EPA announced the most likely risk estimate. However, the true risk could be as low as zero, or as high as one in a hundred."
3	3 (13, in two focus groups)	1:1,000 stories from Study 2: Certainty without Graphic, Certainty with Graphic, Uncertainty with Graphic	as in Study 2
4	4 (217)	2 Risk Magnitudes * 2 Uncertainty-plus-Graphic Conditions	1) No mention of uncertainty: "If butydin gets into the water supply, EPA scientists calculate a person who drinks this butydin-contaminated water for 70 years would have one additional chance in a thousand of getting cancer.... The one-in-a-thousand calculation is the equivalent, in Eugene's population of about 100,000, of 100 extra cases of cancer if all city residents drank water with this level of butydin in it for their entire lives. This compares to the average American's one chance in four of getting cancer from any cause (or an average of 25,000 cases of cancer over 70 years in a city like Eugene)." 2) "The EPA spokesperson said that one additional chance of cancer in a thousand is the most likely risk level, but added that the true risk could be as low as zero, or as high as one in a hundred (1,000 extra cases of cancer if all city residents drank water with this level of butydin in it for their entire lives)."

[a] Hazards: Imaginary names were used for the chemical ("butydin") and radiation ("zydin"). Risk magnitudes: One in a thousand (1:1,000) and one in a million (1:1,000,000). Graphic conditions: Study 2 stories appeared with or without a graphic, for both certainty and uncertainty conditions; all Study 4 stories included a graphic, for both certainty and uncertainty conditions (see Fig. 1 for examples).

[b] All examples are based upon a point risk estimate of 1:1,000; stories using a point estimate of 1:1,000,000 were altered accordingly (e.g., for Study 1, "as low as 0.1% of the current EPA estimate, or one in one billion").

plus-written, than of a written only, presentation of uncertainty. Each story in Study 4 had a graphic.

Simulated news stories included a headline, dateline, and a column format, as in real news stories. All stories in each study cited (1) the risk estimate source (USEPA); (2) the weight of evidence (*possible* cause of cancer); (3) the effect of estimate uncertainty (more study needed); and (4) a risk comparison ("For comparison, the risk of getting cancer from exposure to all possible causes of cancer is about one in four for an American"). Study 4's risk comparison (and graphic) also listed the cases of cancer the estimated risk would entail in a city the size of Eugene, Oregon.

All four studies took place during 1993. Subjects for Studies 1, 2, and 4, mostly college students, were recruited through an advertisement in the University of Oregon newspaper and were paid a nominal fee.

Subjects in Studies 1, 2, and 4 answered a questionnaire after reading one story. They could refer to the story when answering the questions. Some questions measured how well the manipulation worked (e.g., did people reading stories with ranges of estimates see more uncertainty than those reading stories with point estimates?). Other questions assessed dependent or confounding variables, such as perceived risk, agency honesty and technical competence, and general attitudes toward risk, government, and authority.[19] The questionnaire also asked respondents to indicate their sex and to rate how well adjectives from a scale devised by Bem[20] to measure masculinity and femininity described them-

Table II. Excerpts from Simulated News Stories

Study 1. EPA scientists estimate that the additional risk of getting cancer over a lifetime of drinking water that might be contaminated by butydin at the levels seen at the Lancaster site is about one in a thousand.

For comparison, the risk of getting cancer from exposure to all possible causes of cancer is about one in four for an American. . . .

EPA announced the highest risk estimate produced by their risk model; the true risk could be as low as 10% of the current EPA estimate, or one in ten thousand.

Study 2. EPA scientists estimate that the additional risk of getting cancer over a lifetime of drinking water that might be contaminated by butydin at the levels seen at the Lancaster site is one in a thousand.

For comparison, the risk of getting cancer from exposure to all possible causes of cancer is about one in four for an American.

EPA announced the most likely risk estimate. However, the true risk could be as low as zero, or as high as one in a hundred.

Study 4. If butydin gets into the water supply, EPA scientists estimate a person who drinks this butydin-contaminated water for 70 years would have one additional chance in a thousand of getting cancer. . . .

The one-in-a-thousand estimate is the equivalent, in Eugene's population of about 100,000, of 100 extra cases of cancer if all city residents drank water with this level of butydin in it for their entire lives. This compares to the average American's one chance in four of getting cancer from any cause (or an average of 25,000 cases of cancer over 70 years in a city like Eugene).

The EPA spokesperson said that one additional chance of cancer in a thousand is the most likely risk level, but added that the true risk could be as low as zero, or as high as one in a hundred (1,000 extra cases of cancer if all city residents drank water with this level of butydin in it for their entire lives).

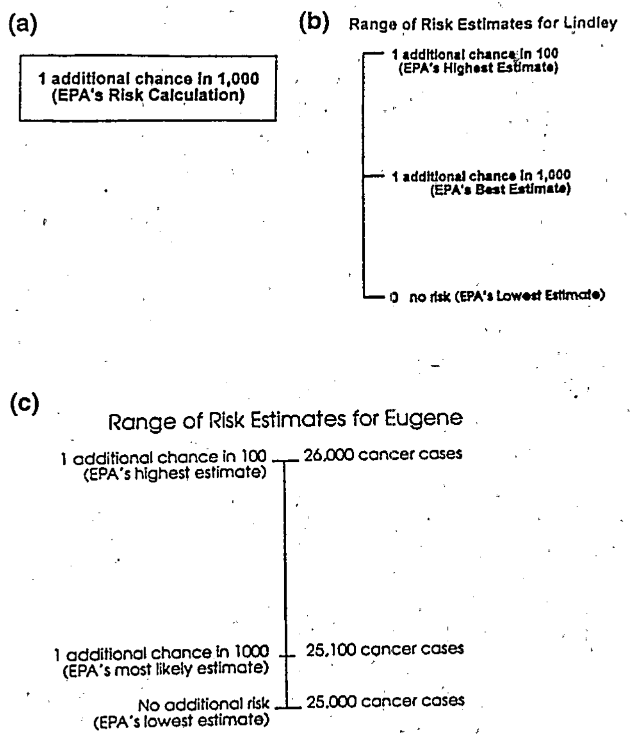

Fig. 1. Examples of graphics used in Study 2, certainty condition (a), Study 2, uncertainty condition (b), and Study 4, uncertainty condition (c).

selves. Numerous studies suggest men and women see risks differently.[21]

The first focus group in Study 3 included seven volunteers (four women and three men) in a local social change and political action group, all with undergraduate degrees and an average age in the late twenties. The second focus group included six members and friends of a women's community volleyball team (four women and two men). All had attended some college, four held undergraduate degrees, and two were in graduate school; their average age was in the mid-twenties. After reading each of three stories from Study 2—both point and range variants (see Table I)—focus-group members answered a few questions from Study 2 and discussed their reactions to the stories and to uncertainty. This study provided a more in-depth analysis of reactions to uncertainty than a questionnaire could provide.

These four studies focused on simple, direct effects of presenting uncertainty: Do lay people notice ranges of risk estimates in simulated news stories? Do these ranges affect perceived risk or trust?

RESULTS

We discuss our results below by topic; Tables III and IV summarize observed uncertainty effects for each experimental study.

Recognition of Risk in the Story. The first question asked whether people had read about a risk in the story. We expected that nearly all subjects would say "yes," because they were well-educated and could refer to the story while answering questions. Yet 16% of the respondents in Study 1 and 22% in Study 2 denied that a risk was mentioned in the story. This lack of recognition was not significantly affected by a shift in the question's wording between Study 1 ("Did the government agency say what the risk of this problem was?") and Study 2 ("Did the government agency say what the risk was of getting cancer from drinking water contaminated with butydin?"). This question was changed again for Study 4 to address potentially confounding factors in respondents' answers ("Did the story report an EPA calculation of the risk of getting cancer from drinking water contaminated with butydin? This question concerns

Table III. Effects of Experimental Manipulations

Findings	Study 1	Study 2	Study 4
Range story readers saw more range in story	No	Yes	No
Percent of subjects who saw risk mentioned in story	84%	78%	91%
Percent of subjects who correctly recognized range of risk estimates in range-story	71-83% (across the three range stories read)	80%	83%
Percent of subjects who correctly recognized single risk estimate in point-story	41.5%	52%	46.5%
Effect of graphic	Not applicable	Raised perceived range of risk in story; lowered trustworthiness of story information; did not raise fraction seeing risk number in story	Not applicable

Table IV. Findings of Experimental Studies

Experimental questions	Study 1	Study 2	Study 4
Change in risk perceptions	No effect	Range—more risk, worry (but not with attitudes constant)	Range—more risk (with attitudes constant)
Effect of agency discussion of how much risk might vary on views of agency honesty and competence	No effect	Agree agency is more honest, disagree that it's less competent	No effect
Effect of attitudes toward risk, government, and authority	No effect	Attitudes predict ratings of risk, worry, experts' knowledge of hazardous waste risks	Attitudes predict ratings of risk, worry, experts' knowledge of hazardous waste risks, EPA honesty on size of risks, EPA competence at risk estimation, EPA competence dealing with environmental problems

whether a risk number appears in the story, not whether the agency or the reporter gave an accurate number.''). This last wording change reduced to 9.7% the percentage who saw no risk mention in the story. Perhaps there was too much information, even in the briefest experimental stories, for these respondents to notice a risk number written as a word, as in ''one in a thousand.'' Study 1 and 2 questions also did not ask about a ''risk number.'' However, the same risk estimate appearing as a number in an accompanying graphic did not increase the proportion in Study 2 who said risk was mentioned in the story, compared to those who read stories lacking the graphic.

Recognition of Ranges. Those who said a risk *was* mentioned in the story were then asked whether the government gave ''a single number for the risk or . . . a range within which the risk might lie.'' In all three experiments (Studies 1, 2, and 4) those who read a story in which no intended uncertainty appeared were significantly more likely to answer ''a single number'' than were readers of stories mentioning uncertainty. However, many readers of point-estimate stories said a range of risks was mentioned (58.5% in Study 1, 48% in Study 2, 53.5% in Study 4). A lower but still striking fraction of range-story readers (from 17% to 29% for the three uncertainty conditions in Study 1; 20% in Study 2 and 16.7% in Study 4) reported that only one number appeared in the story.

These results may be due to a combination of confusion and lack of comprehension. All stories, including the single-number stories, also contained a risk comparison (see earlier language). Readers of single-number stories may have inferred from remembering *two* numbers—for example, the 1:1,000 point estimate of risk and the 1:4 general cancer risk—that these comprised a range. The rarer error of classifying range-stories as containing a single number is more likely due to incomprehension, because both the text and the graphic portrayed a range. The consistency of these error rates across three studies (1, 2, and 4) suggests that, except for removal of the risk comparison, further revision of the stories and questionnaire would not greatly reduce the error rate for well-educated respondents for whom the issue is not immediately salient.

These results do not mean people could not recognize the experimental manipulations of uncertainty. Study 2 (although not Studies 1 or 4) found that readers of stories with ranges of risk estimates were more likely than those reading single-estimate stories (86% vs. 42%; $p < .001$) to say that a "very great" or "moderate" range of risk was reported in the story. The "range" groups were also more likely to rate the story's risk information as uncertain (5-7 on a seven-point scale), by 54% to 28% ($p < .02$).

Uncertainty Effects on Perceived Risk. Study 1 found no statistically significant differences in perceived risk across the four uncertainty levels (whether point estimate, or a range of—for example—1:1,000,000 to 1:1,000). Readers of Study 2 range-stories were more likely than point-story readers (34% vs. 14%) to rate the butydin risk as high (5-7 on a seven-point scale; $p < .05$). We think this was due to a higher top risk in range-stories: a maximum of 1:100 for the point estimate of 1:1,000, and of 1:100,000 for the other point estimate of 1:1,000,000. If one focuses only on the range maxima it is reasonable to see the range-story risk estimates as higher than in the point stories.[9] This idea was confirmed by the reasoning of one participant in Study 3:

> I ignored the fact that there was zero risk because they wouldn't have reported it if there was zero risk ... for some reason this graph looked more government-like, and so I immediately went to worst case scenario....

Another participant said, "if it is zero, they are just really saying, 'We could be wrong.' " (Note that Study 1 found similar risk perceptions with a lower-bound estimate of zero and one that is a small positive number; Table 1 has examples of these variations.)

Uncertainty was also more worrisome in Study 2: 73% of the "range" readers, versus 58% of the "point" readers, were "somewhat" or "very worried" ($p < .01$). About 71% of the "range" group in Study 2 agreed that the agency's discussion of uncertainties would have made them more concerned about the risk had they lived in this imaginary town. Somewhat more than half of all Study 3 members, who read both stories, were more concerned about the risks described in the range-story than those in the point-story. (However, because the range included zero risk, one person noted that "people who don't want to worry about this are going to find plenty of support for not worrying about it.") Studies 1 and 4 found no differences in worry by uncertainty condition.

In Study 4, whether one received uncertainty information significantly predicted responses only to a question about the perceived risk to Eugene residents. On a scale from 1 (very low risk) to 7 (very high risk), those reading range-stories had a mean rating of 3.14, to 2.58 for readers of point-stories ($p <.01$).

Effect of Uncertainty on Perceptions of the Agency That Provided the Risk Assessment. Participants who read Study 1 and Study 4 stories with varied levels of uncertainty did not differ in their views of USEPA. Within the Study 2 group that read a range-story and recognized that it contained a range of estimates ($N = 56$), 66% agreed that the agency's discussion of how much the risk might vary made it seem more honest; 29% disagreed. Some 34% agreed that this discussion made the agency seem less competent; 59% disagreed with the statement. However, these findings need not contradict the findings of Studies 1 and 4: Study 2 judgments of agency honesty and competence correlated with attitudes about risk, government and authority, implying that people were not reacting to uncertainty information (see discussion of regression analyses, below).

In Study 3, most participants felt that providing a range was more honest. For example,

- [The range approach] tends to see the public as competent, educated citizens, who are going to have more information, who are going to have to make up their own minds, which I think is a good first step for the government to do. It hasn't done it in the past most of the time.
- I assumed vast uncertainty even when it was presented as an absolute fact, so ... I guess it is more encouraging to see it [in a range].
- I think it's a little more honest when there might not be any risk and there might be a high risk or a higher risk.... I feel more comfortable with something like this than I do with ... a number like a risk 1 in 1,000, or whatever. Just like a definitive number where ... I can't even imagine how they come up with something like that.

Yet several people in Study 3 said they would not be upset by agency silence about a range if they did not know such a range existed (most were unaware of uncertainty in risk estimates). For some, however, the range evoked doubt about agency trustworthiness:

- They may give you the idea that there is zero risk, if they don't have any way to clean it up.... If ... they got the money, and they are going to clean it up, and they want to look good, and they want to do PR and stuff, they are going to tell you there was this huge risk and we're going to take care of it. And I just think it's all so politically motivated that it doesn't really mean anything anyway.

Despite the general sense of honesty evoked by ranges of risk estimates, several Study 3 members felt that USEPA's report of a range meant that "they don't have a clue." Among other comments:

- It bothers me when there are a lot of maybes and who knows.
- I didn't think much of their ability to be precise....
- Their preliminary results were too preliminary.

Even if reporting uncertainty seemed to convey agency honesty, this did not seem to offset concerns about the agency's competence:

- I kind of assume that the government doesn't know what they are doing most of the time.... At least they are finally admitting that they don't know what is up.
- [Person 1:] How would you feel if the government ... told you that they have no idea whether this is going to pose a risk of cancer to you or not. And they really just are having a hard time with studies determining it. [Person 2:] Yeah, thank you for being honest.
- [about the story's line that "the true risk could be as low as zero":] How come you can't even figure out if there is a risk or not? You say it causes cancer. Well, is there a risk or is there not a risk? I don't know, it just bothered me.
- The honest imbeciles: The EPA.

In Study 4, exposure to uncertainty information predicted (in multiple regression analyses) *lower* perceived competence of USEPA at risk assessment and environmental management, and *more* apparent truthfulness in news stories, than for those reading point-stories. Despite their very weak statistical significance ($p < .10$ or $p < .20$), these findings' direction fits with the "honest but ignorant" theme of the focus group discussions. Nor is this inconsistent: Honesty and competence are logically independent attributes.

Uncertainty in Science. Study 4 subjects were asked whether they agreed that "It is typical of good science that the most likely estimate of what is being measured has a range of uncertainty around it." Item intercorrelations were analyzed for the 56 subjects who read the range stories and correctly reported the story as containing a range of agency risk numbers. These correlations showed that those agreeing with this statement were more likely to find the risk information in the story understandable ($r = .36$, $p < .01$), certain ($r = .27$, $p < .05$), and scientifically valid ($r = .39$, $p < .001$). They were less likely to think that the agency's discussion of uncertainty indicated incompetence ($r = -.25$, $p < .05$), and less likely to be concerned because of that discussion ($r = -.34$, $p < .01$).

Some focus group members (Study 3) thought that reminding people about science's imprecision would make ranges of risk estimates more credible:

> Sometimes a little disclaimer that reminds people that no matter how many tests you do you can never be positively sure will remind people that ... they are doing the best they can. And I would think that that would help me assess that at least they are being honest about the fact that they are really not sure what risk this poses.

However, the presence of such a caveat (with other "clarifying" information) in Study 4's uncertainty stories did not evoke significantly higher ratings of EPA's honesty than in the same study's point estimate stories.

Graphics. For all conditions in Study 2, use of a graphic significantly increased the perceived range of risk—perceived uncertainty—described in the stories (3.06 for graphic, 2.8 without, on four-point scale from "no" to "very great range," $p < .04$). It also decreased the perceived trustworthiness of story information (mean of 3.31 for graphic, 3.84 without, on seven-point scale from "not trustworthy" to "trustworthy," $p < .01$). Yet reaction to graphics in the Study 3 focus groups was generally positive: For example, the graphic with the certainty story (see Figure 1a) was said to make the story clearer and more salient.

Natural vs. Technological Hazards. Study 1 stories about zydin (natural radiation) elicited significant rankings of lower risk, less worry, more understandable and honest information, and a more honest agency than were elicited by stories about butydin, the imaginary chemical from an abandoned hazardous waste site, despite identical risk estimates for the two hazards. This finding is consistent with previous studies that have found lower perceived risk from natural hazards than for technological hazards.[22]

Risk Magnitude. Significantly different reactions occurred to differing risk estimates. In Study 1, risk estimates of 1:1,000 drew higher ratings of honesty, for both the news story information and the agency, than did 1:1,000,000 estimates. This parallels an earlier finding that people would believe a government agency more if it said there was an environmental problem than if it said there was no problem.[13] Study 2 did not replicate this finding about perceived honesty. However, the higher probability (1:1,000) in the story did evoke more perceived risk and more worry, and (while not quite significant at $p < .05$) greater expressed intention of getting the site cleaned up. Lower probability (i.e., 1:1,000,000) was seen as preliminary rather than complete information. Study 4 subjects who read the 1:1,000 range story were significantly more likely than those reading the 1:1,000,000 range story to say that the agency's discussion of uncertainty made them more concerned. They also rated the risks as better known to the government than did readers of the lower risk range story. These results, with earlier research,[13] suggest that citizens see lower risk numbers as either less accurate or less honest. However, Study 4 found no significant differences across risk magnitude conditions in ratings of agency honesty, agency competence in risk estimation, or agency competence in managing environmental problems.

Attitudes. The results reported so far were based on direct manipulation of the presentation of uncertainty in Studies 1, 2 and 4, and qualitative analysis of focus group discussions in Study 3. We also conducted stepwise regression analyses to examine effects of the uncertainty manipulations relative to the effects of attitudes about risk and agency honesty and competence. These analyses used responses from the 100 (Study 2) and 135 (Study 4) respondents who correctly answered questions 1 and 2, thus indicating they recognized the experimental conditions (single risk estimate vs. range of risk estimates). After respondents with missing data were deleted, effective sample sizes were 37-38 for Study 2 and 62-67 for Study 4. These samples were small; each of nine regression analyses found different independent variables to be significant; and these analyses combined experimental (uncertainty) with nonexperimental (attitude) data. For these reasons, we will not discuss these results in detail, but we believe they carry important implications worth further study.

Six dependent variables were used: perceived risk, worry, experts' ability to correctly estimate risk, EPA's honesty about the size of risks, and EPA's competence at estimating risk magnitudes and managing environmental problems (the last three for Study 4 only). Independent variables were (a) the respondent's uncertainty condition (0 = single number; 1 = range); (b) various attitudes toward risk, government, and authority; (c) sex; (d) gender-related adjectives respondents used to describe themselves[20]; and (e) being active in various environmental activities.

Within the context of the regression analyses, exposure to uncertainty stories significantly predicted only one variable: In Study 4 it increased perceived risk to Eugene residents. Responses to other dependent variables were predictable from attitudes toward risk, government, and authority, and gender-related adjectives (sex itself was not a significant predictor). For example, those prone to judge EPA as honest in reporting the size of environmental risks did not see risks as serious in their home community, trusted the government, disagreed that more equality would solve social problems, and described themselves as gentle. Respondents who judged the EPA competent to deal with environmental problems were less likely to see local environmental problems as serious, more likely to trust the government to manage risks, and more likely to describe themselves as gentle leaders without strong personalities who were not active in environmental groups. The best predictor, entering first in five of the nine regressions, was the belief that "There are serious environmental health problems where I live."

If supported by further research (one study found similar trust, equality, and risk attitudes linked to low risk ratings among white men, compared to others),[21] these findings would indicate that uncertainty is less important than general attitudes about risk and authority in shaping views of risk and agency performance.

4. DISCUSSION

Results of these initial studies of public response to uncertainty in risk assessments raise more questions than they answer. However, some tentative conclusions can be reached:

- **People are unfamiliar with uncertainty in risk assessment, and with uncertainty in science generally.** Responses by respondents in Studies 3 and 4 point to unfamiliarity with uncertainty in science. Up to 20% of respondents in Studies 1, 2, and 4 had difficulty even recognizing the presentation of uncertainty in the form of a range of risk estimates.
- **People may recognize uncertainty (i.e., a range of risk estimates) when it is presented simply.** Moving from Study 1's percentage-based, one-tailed presentation of uncertainty to Study 2's probability-based, two-tailed presentation did produce some responses to uncertainty manipulations. Yet many participants in both studies could not correctly categorize risk estimates (as a single number or a range). Moreover, Study 4, intended to enhance Study 2's uncertainty effects, failed to show any statistically significant effects of uncertainty except in a regression analysis for perceived risk to people in Eugene, Oregon. Because our exploratory regressions implied a greater impact of attitudes about risk and government on views of risk and agency performance, the univariate analyses for Study 2 *may* overstate the effects of uncertainty.
- **Graphics had mixed results in communicating uncertainty.** Those used in Study 2 made the range of estimates more obvious, but made the story information seem less trustworthy. Because the latter finding was experimental—people reading a story with a graphic rated its trustworthiness lower than did people reading the same story without a graphic—we cannot say whether people *consciously* saw the graphic as being (or as a sign of the story being) untrustworthy.

Focus group members found the same graphics useful, but their comments indicated that crafting clear, helpful graphics would not be easy (Ibrekk and Morgan[23] argued that no graphical display of uncertainty will be clear to everyone). Visual displays of the relative probabilities of various risk estimates being correct may have different impacts than our graphics, which merely stressed that there was a range of estimates.

- **People's views on the environmental cases presented in the stories may have been influenced less by uncertainty manipulations than by attitudes toward risk, government, and authority.** Trust in government and attitudes toward authority have been identified in the research literature as important, if not dominant, factors in perceived risk. With the methodological caveats noted earlier, this view seems to be supported by findings from exploratory regression analyses using data from Studies 2 and 4. Such attitudes as personal risk aversion, trust in government risk management, and support for equality strongly affected reactions to the stories, while uncertainty had a significant effect in only one of the nine regressions.
- **Agency discussion of uncertainty in risk estimates appears to signal agency honesty.** Effects of the experimental manipulations (not regressions) in Studies 2 and 4, and comments in Study 3, support this finding. The focus groups' reactions combined surprise that government would offer *any* unsought information, belief that all information is desirable, and suspicion (among a few, anyway) that precise risk estimates cannot be believed. Yet several comments about possible cover-ups suggest some people may find declarations about uncertainty a signal of dishonesty. Past experience (direct or through the mass media) with agencies actually or seemingly using risk assessment to delay pollution cleanups may fuel this suspicion. Or reactions to uncertainty may be shaped more by prior views of agency honesty.
- **Agency discussion of uncertainty in risk estimates may be a signal of incompetence for some people.** One-third of Study 2 range-story readers said the agency seemed less competent when discussing uncertainty. This may be due to unfamiliarity with science: If science is deemed certain, uncertain risk estimates must come from incompetent scientists. Comments in Study 3 about uncertainty being expected (and acceptable) only for "preliminary" risk estimates also suggest citizens find it hard to fathom that competence and uncertainty can co-exist. Again, prior trust or distrust of agency competence may shape reactions to uncertainty rather than the reverse.
- **Estimated risk levels may affect views of expert knowledge.** That "low" estimates were deemed more "preliminary," whether uncertainty was mentioned or not, implies that risk assessors may have difficulty communicating their estimates even if citizens deem these to be honest. This response may be due to distrust (no government estimate that low could be true). Or it may stem from feeling that a 1:1,000 risk estimate must be based on high, and thus tangible, inputs (e.g., for exposure), while a 1:1,000,000 risk estimate is based more on guesswork.

Our studies used words and graphics to present a range of risk estimates, in simulated news stories, to communicate uncertainty about two hazards (natural radiation and a chemical in drinking water from a hazardous waste site). Study 1 used an upper-bound point estimate, and both zero and positive lower-bounds; the other studies' ranges went from zero to an order of magnitude above the point estimate. Experimental respondents read only one story, while Study 3 participants directly compared point and range stories. Although they preferred the latter, this may not have been a good measure of point- and range-estimates' respective ability to meet public needs and skills. Only one source of uncertainty (extrapolating from animal data) was described, in Study 4.

Despite the various tests we used, other presentations may have stronger, or different, effects on perceived risk, honesty, and competence. A short list might include other descriptions or sources of uncertainty; graphics conveying the relative probabilities of a given risk estimate (e.g., a probability density function plotted directly below its cumulative distribution function, with the mean clearly marked on each curve[23]);[4] the source of the risk estimate; the source of the hazard; who is threatened; presentations of variability; interactions of uncertainty with agency actions affecting trust, or conflict among environmental policy actors over risk estimates and uncertainties. We expect to address some of these issues in future research.

Communicating about uncertainty is necessary, because it is a reality of risk assessment and risk management, and all parties—including citizens—deserve access to full information. Our results should *not* be taken as proof that laypeople do not grasp uncertainty. They may not understand it in the way scientists do; they may also not have understood our specific presentations of uncer-

[4] The value of testing the hypothesis that these graphics provide useful risk communication information would depend in part on the likelihood that risk assessors could routinely provide the information needed to generate these graphics.

tainty. These hypotheses do not mean they lack experience with uncertainty, in their own lives or in environmental matters. Yet no one should assume that "educating" citizens on scientific uncertainty will be simple; given the above-average education of our samples, their members may have given the most sophisticated responses to our simulated news stories that one could expect.

Given our initial results, we advise caution in assuming that explaining uncertainties will improve public trust or knowledge. In the long run, such explanations *may* make citizens' expectations of government, risk assessors, and scientists more realistic.[5] Yet overall public trust and knowledge on risk issues may have to be built with methods more direct and difficult than uncertainty explanations.

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[5] Among options suggested by anonymous reviewers: agency reporting of uncertainty may force reporters to be more probing and balanced even if they do not report risk estimates; citizen outrage and alienation over reporting of risk ranges may ultimately yield more respect for science's limits and reduce undue expectations of risk assessment and government; uncertainty analysis may replace single point estimates with a variety of point estimates chosen to illustrate (when taken together) the underlying distribution, so that only experts need deal with ranges, probability distributions, and the like; and a more extended discussion of uncertainty with citizens—unlike the "snapshot" of lay reactions in these studies—may correct their assumptions that science is certain. These proposals are thoughtful, perhaps even right. Yet they imply that positive effects will come only from discussing uncertainty publicly—in general and for specific cases—for prolonged periods (years?). Because uncertainty is hardly mentioned now in government announcements about risk, and long-term dialogues on scientific uncertainty are infeasible in the way that government and citizens currently interact (e.g., in one-time public hearings), it is unclear how these outcomes will occur without societal reforms that go far beyond simply discussing uncertainty.