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Intuitive Toxicology: Expert and Lay Judgments of Chemical Risks

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Human beings have always been intuitive toxicologists, relying on their senses of sight, taste, and smell to detect harmful or unsafe food, water, and air. As we have come to recognize that our senses are not adequate to assess the dangers inherent in exposure to a chemical substance, we have created the sciences of toxicology and risk assessment to perform this function. Yet despite this great effort to Overcome the limitations of intuitive toxicology, it has become evident that even our best scientific methods still depend heavily on extrapolations and judgments in order to infer human health risks from animal data. Many observers have acknowledged the inherent subjectivity in the assessment of chemical risks and have indicated a need to examine the subjective or intuitive elements of expert and lay risk judgments. We have begun such an examination by surveying members of the Society of Toxicology and the lay public about basic toxicological concepts, assumptions, and interpretations. Our results demonstrate large differences between toxicologists and laypeople, as well as differences between toxicologists working in industry, academia, and government. In addition, we find that toxicologists are sharply divided in their opinions about the ability to predict a chemical's effect on human health on the basis of animal studies. We argue that these results place the problems of risk communication in a new light. Although the survey identifies misconceptions that experts should clarify for the public, it also suggests that controversies over chemical risks may be fueled as much by limitations of the science of risk assessment and disagreements among experts as by public misconceptions.

KEY WORDS: Intuitive toxicology; risk perception; risk assessment; chemical risks; expert judgment.

1. INTRODUCTION

Human beings have always been "intuitive toxicologists," relying on their senses of sight, taste, and smell to detect harmful or unsafe food, water, and air. During the past several years, we have been studying the perception of risks from chemicals, based on this concept of intuitive toxicology.

As we have come to recognize that our senses and intuitions are not adequate to assess the dangers inherent in exposure to a chemical substance, we have created the sciences of toxicology and risk assessment to perform this function. Massive regulatory establishments have been formed to oversee the use of these sciences for standard-setting and policy-making in the interests of protecting public health.

Yet despite this enormous effort, people in many industrialized nations feel increasingly vulnerable to the risks from technology and believe that the worst is yet to come.[1] Regulatory agencies have become embroiled in rancorous conflicts, caught between angry environmentalists on one side and frustrated technologists and industrialists on the other. The lay public is anxious and confused. Nuclear power has long been a focus of public concerns. Today, there is great concern and dissatisfaction with the production, use, transport, and disposal of

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chemicals. The lay public has clearly not been satisfied with, or persuaded by, scientific assessments of risk for either nuclear power or chemical hazards.

Industrialists and scientists are equally dissatisfied with the public, whose concerns they equate with ignorance or worse, irrationality. Industry leaders see an urgent need to educate and inform the public in order to erase the "fear and sensationalism" that has tarnished the image of chemicals and the chemical industry.[2,3] Many have turned to the young field of risk communication in search of guidance that might make conflicts over technological decisions easier to resolve.[4,5] Much of the public unease and social conflict may be traceable to the inherent limitations of the science itself, which is short on knowledge of the mechanisms by which chemicals harm living organisms. In the absence of mechanistic knowledge, risk assessment must rely upon indirect methods, which infer human health effects from bacterial and animal responses to chemical exposures. These indirect methods have become the primary bases for government regulation and policy. Although the limitations and uncertainties underlying these methods are readily acknowledged, it is assumed that, used conservatively, they can identify chemical threats and estimate the upper bounds on risk with enough accuracy to adequately protect public health. Behind this orderly facade of what Efron[6] has labeled "regulatory" science, in the trenches of "basic" science, the field of risk assessment has been in a state of intense controversy for more than a decade.[6–11] A number of investigators have argued that the ambiguities and uncertainties of risk assessment are fertile grounds for influence from political and ideological considerations.[9,12–19] For example, Lynn[16] found that attitudes of occupational health specialists toward fundamental issues in risk assessment were strongly related to whether they worked in industry, government, or academia and whether they had voted Democratic or Republican in the previous presidential election. Graham *et al.*[9] have illustrated these kinds of biases in their detailed description of the controversies surrounding the regulation of benzene and formaldehyde.

A committee of the National Academy of Sciences has responded to this problem by calling for procedural changes designed to improve the scientific basis of risk assessment and insulate scientific analyses and interpretations from political influence.[4] It is significant that this committee highlighted the inherent subjectivity in toxicological risk assessment, noting (p. 36) that the procedures scientists follow and the interpretations they make ". . . rest, to various degrees, on a mixture of scientific fact and consensus, on informed scientific judgment, and on policy determinations (e.g., the appropriate degree of conservatism)." The Academy report further indicated the need to examine the subjective and intuitive elements of expert and lay risk assessments—both to shore up the foundations of scientific analyses and to improve communication between scientists and the lay public.

1.1. Objectives of this Research

The National Academy of Sciences report acknowledged the subjective nature of risk assessment, but did not fully come to grips with its implications. One such implication is that different assumptions, conceptions, and values, in addition to (or instead of) disagreements about facts, might underlie much of the discrepancy between expert and lay views of chemical risks.

The objective of the present study is to address this issue by exploring the cognitive models, assumptions, and inference methods that comprise laypeoples' "intuitive toxicological theories" and by comparing these theories with cognitive models, assumptions, and inference methods of scientific toxicology and risk assessment. Such comparisons should expose the specific similarities and differences within the expert community as well as the similarities and differences between lay perceptions and expert views. We hope that the knowledge gained from these comparisons will provide a valuable starting point around which to structure discussion, education, and communication about the assessment of risks from chemicals and the management of those risks.

1.2. Questionnaire Development

We began by identifying several fundamental principles and judgmental components within the science of risk assessment. Questions were developed based on these fundamentals in order to determine the extent to which laypeople and experts share the same beliefs and conceptual framework. Our questions addressed the following four topics:

Category 1: Dose–response sensitivity
Categoly 2: Trust in animal and bacterial studies
Category 3: Attitudes toward chemicals
Categoly 4: Attitudes toward reducing chemical risks

Questions on these topics were incorporated into a single questionnaire, designed for both experts and the public. Respondents were instructed to think of the term "chemicals" as including ". . . all chemical elements and compounds, including pesticides, food additives, industrial chemicals, household cleaning agents, prescription and nonprescription drugs, etc." Tables I through V present the specific questions used, categorized according to four major topic areas and a miscellaneous set of items (Category 5).[5] All but one of the questions were posed as statements to be evaluated by an agree/disagree response.[6]

Each question was designed, whenever possible, according to a guiding hypothesis about how experts and "lay toxicologists" might respond. For example, perhaps the most important principle in toxicology is the fact that "the dose makes the poison."[7] Any substance can cause a toxic effect if the dose is great enough. Thus, we expected experts to be quite sensitive to considerations of exposure and dose when responding to the five items in Category 1. In contrast, the often observed concerns of the public regarding very small exposures or doses of chemicals led us to hypothesize that the public would have more of an "all or none" view of toxicity and would be rather insensitive to concentration, dose, and exposure (thus, equating exposure with harm) when responding to items in Category 1. We also expected laypersons to view natural substances as less toxic than synthetic substances (question 5a), and experts to recognize the potential toxicity of natural substances as well as synthetic ones.[21]

With regard to Category 2, we hypothesized that, because the science of toxicology and the discipline of risk assessment rely so heavily upon animal studies, experts would have a more favorable view than laypersons regarding the value of such studies. The prediction that laypersons lack sensitivity to dose–response considerations and thus fear even small exposures to toxic or carcinogenic substances led us to expect that they would exhibit far more negative attitudes toward chemicals than experts when responding to the questions in Category 3. Similarly, we expected that laypersons' concerns about small exposures would cause them, more than experts, to want reduction and even elimination of chemical risks, regardless of cost (Category 4).

Turning to Category 5, we expected that laypersons would perceive chemicals in prescription drugs as less toxic than chemicals used in pesticides (question 5b). Further, we expected that laypersons' direct experiences with medicines and their knowledge of the risk of overdose would make them more likely to recognize that the dose makes the poison for prescription drugs than for chemicals in general (see the two forms of question 5e). Similarly, for question 5f, we expected that a 1 in 10,000,000 lifetime risk would be less worrisome if it came from taking a prescription drug than if it came from exposure to a chemical.

Question 5h examined the interpretation of evidence pertaining to the cause of birth defects observed in a region where pesticides had been used. We hypoth-

[5] The actual survey contained several additional questions not discussed in this paper because they were essentially redundant with questions in Table I.

[6] This one question, not shown in Tables I–V, was as follows: "In general, humans are (more, equally, less) vulnerable to adverse effects of chemicals than are laboratory animals" (question 5i).

[7] In reference to the observation by Paracelsus that "All substances are poisons; there is none that is not a poison. The risk dose differentiates a poison and a remedy" (as quoted in Ref. 20).

Table I. Responses of Toxicologists and Laypersons to Questions About Dose–Response Relationships (Category 1)[a]

Questions		Strongly disagree	Disagree	Agree	Strongly agree	Don't know/ no opinion
1a. If you are exposed to a toxic chemical substance, then you are likely to suffer adverse health effects	T[b]	14.0	53.7	24.4	4.3	3.1
	P[c]	3.1	9.3	51.2	34.3	1.9
1b. If you are exposed to a carcinogen, then you are likely to get cancer	T	25.7	62.3	7.8	0.6	3.6
	P	5.1	42.6	25.4	9.0	17.2
1c. 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	T	61.5	33.1	1.8	2.4	1.2
	P	11.9	47.3	29.2	6.9	4.6
1d. A chemical was found in a city's supply of drinking water in a concentration of 30 parts per million. . . . The water was filtered by a process that was able to reduce, but not eliminate, the chemical concentration in the water. Under most circumstances, this means that the danger associated with drinking the water has also been reduced	T	1.2	6.5	56.8	31.4	4.1
	P	3.8	18.8	63.2	7.3	7.1
1e. There is no safe level of exposure to a cancer-causing agent	T	27.7	47.0	13.9	4.8	6.6
	P	6.6	28.1	35.5	18.4	11.3

[a] Cell entries are percentages. Unless otherwise noted, differences between groups in this and all subsequent tables were significant at $p < .01$.
[b] T = Toxicologists.
[c] P = Public.

Table II. Responses of Toxicologists and Laypersons to Questions about Trust in Animal Studies (Category 2)

	Questions		Strongly disagree	Disagree	Agree	Strongly agree	Don't know/ no opinion
2a.	The way that an animal reacts to a chemical is a reliable predictor of how a human would react to the same chemical	T[a]	1.9	38.9	50.3	5.1	3.8
		P[b]	5.5	40.2	40.2	3.5	10.6
2b.	Laboratory studies of a chemical's harmful effects on animals will, if properly done, identify all possible harmful effects of that chemical	T	26.8	56.1	15.2	1.2	0.6
		P	17.1	60.7	11.3	2.3	8.6
2c.	Laboratory studies of a chemical's harmful effects on animals allow scientists to accurately determine how much of the chemical it takes to cause similar harm in humans	T	12.2	55.5	29.3	1.2	1.8
		P	11.7	50.0	28.9	0.8	8.6
2d.	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	T	10.3	41.3	39.4	1.2	1.8
		P	1.9	22.9	64.0	5.4	5.8

[a] T = Toxicologists.
[b] P = Public.

esized that experts would believe that the evidence presented was not sufficient to indict pesticides as the cause of the observed malformations, whereas laypersons would be more inclined to view the association between pesticides and birth defects as causal (see Jenkins and Ward,[22] who demonstrated the difficulty people have in dissociating covariation from causality). We had no strong prior hypothesis about how either experts or laypersons would judge the relative vulnerability of animals and humans to adverse chemical effects. Differing views can be found in the scientific literature. Some argue that humans are less vulnerable than the particularly sensitive strains of animals used in many bioassays. Humans are also exposed to far smaller amounts of chemicals than the test animals. Others argue that humans are more vulnerable, because of their slower metabolic processes, their great genetic diversity, and their exposure to a greater number of carcinogenic substances than laboratory animals. Regulatory policies typically assume that humans are more sensitive to adverse effects than animals.

1.3. Administration of the Survey

1.3.1. Expert Sample

The sample of experts was selected from the 1988 membership directory of the Society of Toxicology (SOT). Only full members of the Society residing in the United States were considered for inclusion in the study. The names of these full SOT members were categorized into three subgroups based on the type of organization with which they were affiliated: academic, industrial, or regulatory. Random numbers were used to select 120 names from each of the three affiliational subgroups. The survey was mailed to each of these persons, along with a cover letter from the past president of the SOT.

In all, 360 questionnaires were mailed in October 1988, and 170 completed questionnaires were returned, for an overall response rate of 47%. Subgroup response rates were consistent with this overall rate; 44% of those from the academic subgroup returned their questionnaires, along with 49% of those affiliated with industry, and 48% of those affiliated with regulatory agencies. Those who responded were highly educated (91% had a Ph.D. degree and 2.4% an M.D. degree); 84.6% of the respondents were male; 58.9% were between the ages of 33 and 48; 37.5% were ages 49-64; and 3.6% were younger than 32 or older than 64 years.

1.4. Public Sample

A sample of the general public was selected from the Portland, Oregon metropolitan area. A professional listing organization provided a sampling frame organized by zip code. This population listing was screened for a minimum annual household income of $20,000, and 1100 households were randomly selected for the mailing, which took place on October 25, 1988. Those who had not replied by November 15, 1988 were sent another copy of the survey instrument.

Of the approximately 975 deliverable questionnaires, 262 usable questionnaires were returned, for a response rate of about 27%. These individuals were nonrepresentative of the Portland general population in several ways. Specifically, respondents were more likely to be male (58.0% vs. 48.6% in the population); well educated (95.7% high school graduates in the sample and

23.1% with graduate-school training vs. 78.7% and 9.9%, respectively, in the population); and high income [24.6% of the sample had household incomes greater than $50,000 vs. 5.0% of the population in 1980 (corrected for 42.9% cumulative inflation between 1980 and 1988). Most (96.5%) of the respondents were white (vs. 92.8% of the population); 24.1% were between the ages of 16–32; 46.4% were ages 33-48; 14.9% were ages 48-64; and 14.6% were older than 64 years.

2. RESULTS

2.1. Expert vs. Layperson Comparisons

We expected that the toxicologists would differ greatly from the laypersons in their responses to most questions. However, there was striking agreement on question 5g, which asked respondents whether or not they agreed with the statement: "I think I should know as much as I can about the chemicals around me. The more I know, the more I can control the risks that these chemicals pose to my health and to the environment." The percentage of respondents who agreed or strongly agreed with this statement was 94.6% among the toxicologists and 93.4% among the public. Thus, though their perceptions and attitudes may differ, the stated motivations of experts and laypersons to understand and control chemical risks appear to be remarkably similar.

2.1.1. Category 1: Dose–Response Sensitivity

Table I presents the responses for the five questions that were designed to assess sensitivity to the view that "the dose makes the poison." For each question, members of the public exhibited much less appreciation of this view than did the toxicologists. Specifically, the public respondents were more likely than the toxicologists to agree that[8]

- exposure to a toxic chemical makes one likely to Suffer adverse health effects
- exposure to a carcinogen makes one likely to get cancer
- the fact of exposure to a pesticide is the critical concern, rather than the amount of exposure
- reducing the concentration of a possibly harmful chemical in a city's drinking water would not reduce the danger associated with drinking that water
- there is no safe level of exposure to a cancer-causing agent

Note that these views, though much more common in the public sample, were not always held by a majority of the public. Note also the high percentage (17.2%) of the public who marked "don't know" or "no opinion" regarding whether exposure to a carcinogen implies that one is likely to contract cancer (question 1b).

2.1.2. Categoly 2: Trust in Animal Studies

Comparisons with regard to *trust* in animal studies are shown in Table II. There was relatively little difference in responses of the public and toxicologists to questions 2a, 2b, and 2c (see Table II). Both groups of respondents were greatly divided in their opinions about whether animal reactions to a chemical are reliable predictors of human reactions to the same chemical (question 2a). About 41% of the experts and 46% of the public disagreed with that assertion. There was very little agreement, in either group, with the propositions that proper animal studies could identify all possible harmful effects of a chemical (2b) and that laboratory studies could allow scientists to make accurate predictions about the amount of chemical exposure needed to cause human harm (2c).

The contrast between questions 2a and 2d is instructive. The confidence of toxicologists in predicting human harm from animal studies decreased when a chemical was found to be a carcinogen in animals (agreement decreased from 55.4% in 2a to 40.6% in 2d). However, the public respondents became much more confident in the prediction of human harm from an animal test when the test was said to produce evidence of carcinogenicity in animals (agreement rose from 43.7–69.4%). As a result, the two groups differed considerably on question 2d.

2.1.3. Categories 3 and 4: Attitudes Toward Chemicals and Risk Reduction

Many of the public respondents in this study appeared to believe that if large exposures to a chemical are harmful, then small exposures are also harmful, and

[8] Unless otherwise noted in the tables, all of the reported differences between toxicologists and laypersons or between subgroups within either sample of respondents are statistically significant at $p < .01$ or $p < .001$ as determined by a chi-square test that included the don't know/no opinion responses. Significance levels are not given in the text.

that animal tests can give little guidance about risk—except when they imply harm. Given these views, we would expect these individuals to be consistently negative in their general attitudes toward chemical risks (Category **3)** and to be strongly in favor of extreme measures to reduce such risks, regardless of cost. The data in Tables III and IV support this expectation. The majority of the public respondents

- agreed that we have perceived only the tip of the chemical risk iceberg **(83.9%** agree or strongly agree)
- agreed that contamination is greater now than ever before **(88.4%)**
- disagreed that people are unnecessarily frightened about small amounts of pesticides in groundwater and food **(68.7%)**
- disagreed that people worry unnecessarily about chemicals **(87.1%)**
- agreed that chemical risks are too scary and they don't like to think about them **(84.0%)**
- agreed that it can never be too expensive to reduce the risks associated with chemicals **(61.6%)**

Although not a majority view, a surprisingly high percentage of the public sample agreed that they do everything they *can* to avoid contact with chemicals and chemical products (40.0%) and agreed that all use of prescription drugs **(17.2%)** and chemicals **(29.3%)** must be risk-free.

In comparison with the public sample, the toxicologists conveyed more favorable attitudes toward chemicals on every question in Category **3.** In most cases these differences were substantial. The story was similar with respect to questions in Category **4,** with toxicologists showing much less agreement with the assertions that use of chemicals must be risk-free regardless of cost.

2.1.4. Category 5: Additional Comparisons

The results for question 5a in Table **5** confirm the commonly held belief that the public has much more confidence in the safety of natural (as opposed to synthetic) chemicals than do the experts. Answers to questions 5b, 5e, and 5f show that the public respondents had a much more favorable view of chemicals and were more tolerant of chemical risks if the chemicals were in the form of prescription drugs. Similarly, people were more likely to recognize that the risk from a prescription drug is dependent on dose than they were to recognize dose dependence of chemicals in general (question 5e). Question 4c, shown in Table IV, also found a more tolerant public attitude toward risks from prescription drugs than for risks from chemicals in general. The toxicologists' versions of these questions used *only* the term prescription drugs, due to an error in printing the questionnaire. Compared to the public, toxicologists were not as likely to see prescription drugs as less toxic than pesticides (question 5b), more likely to

Table III. Responses of Toxicologists and Laypersons to Questions about Attitudes Toward Chemicals (Category 3)

Questions		Strongly disagree	Disagree	Agree	Strongly agree	Don't know/ no opinion
3a. Our society has perceived only the tip of the iceberg with regard to the risks associated with chemicals	T[a]	10.9	36.4	37.6	8.5	6.7
	P[b]	1.6	9.0	50.2	33.7	5.5
3b. The land, air, and water around us are, in general, more contaminated now than ever before	T	3.6	24.8	53.3	13.9	4.2
	P	1.5	8.1	45.2	43.2	1.9
3c. Use of chemicals has improved our health more than it has harmed it	T	0.0	3.0	59.4	33.3	4.2
	P	7.9	26.0	41.7	5.5	18.9
3d. People are unnecessarily frightened about very small amounts of pesticides found in groundwater and on fresh food	T	1.8	26.8	53.0	14.0	4.3
	P	13.1	55.6	20.1	3.9	7.3
3e. People wony unnecessarily about what chemicals can do to their health	T	3.6	53.3	33.9	4.2	4.8
	P	27.1	60.1	8.1	1.6	3.1
3f. Chemicals are a major force behind technological advancement	T	0.0	1.8	61.1	35.9	1.2
	P	1.9	12.4	55.4	13.2	17.1
3g. Chemical risks are too scary. I don't even like to think about them	T	74.6	24.9	0.6	0.0	0.0
	P	37.5	46.5	11.7	3.6	0.8
3h. I do everything I can to avoid contact with chemicals and chemical products in my daily life	T	44.0	46.4	6.0	3.6	0.0
	P	11.7	47.5	31.1	8.9	0.8

[a] T = Toxicologists.
[b] P = Public.

Table IV. Responses of Toxicologists and Laypersons to Questions about Attitudes Toward Risk Reduction (Category 4)

Questions		Strongly disagree	Disagree	Agree	Strongly agree	Don't know/ no opinion
4a. While we should always try to minimize the risks we take by using chemicals, it is unrealistic to expect that we can completely eliminate those risks	T[a]	0.6	1.2	45.8	52.4	0.0
	P[b]	2.8	14.2	65.8	15.0	2.3
4b. It can never be too expensive to reduce the risks associated with chemicals	T	27.7	54.2	12.7	3.0	2.4
	P	2.7	28.7	43.4	18.2	7.0
4c. All use of prescription drugs must be risk free. (Alternative form: All use of chemicals must be risk free)	Td[c]	54.8	39.9	3.6	0.6	1.2
	Pd[d]	13.4	64.2	12.7	4.5	5.2
	Pc[e]	8.9	52.8	22.8	6.5	8.9

[a] T = Toxicologists.
[b] P = Public.
[c] Td = Toxicologists, prescription drugs.
[d] Pd = Public, prescription drugs.
[e] Pc = Public, chemicals.

Table V. Responses of Toxicologists and Laypersons to the Miscellaneous Questions in Category 5

Questions		Strongly disagree	Disagree	Agree	Strongly agree	Don't know/ no opinion
5a. Natural chemicals, as a rule, are not as harmful as man-made chemicals	T[a]	45.6	40.2	11.2	2.4	0.6
	P[b]	10.8	34.0	37.8	7.3	10.0
5b. In general, chemicals used in prescription drugs are less toxic than chemicals used in pesticides	T	22.8	41.9	21.6	6.6	1.2
	P	11.5	32.1	31.1	6.9	11.2
5c. In general, chemicals used as pesticides are potentially more harmful than are chemicals used as fertilizers	T	6.0	30.5	52.1	6.6	4.8
	P	5.4	30.9	32.8	3.5	27.4
5d. How microorganisms (e.g., bacteria) react to a chemical is a reliable indicator of how humans would react to the same chemical	T	38.4	51.2	5.5	1.2	3.7
	P	12.4	43.4	7.8	1.6	34.9
5e. Some prescription drugs are harmful if they are taken in large doses, but are not harmful if taken in small doses. (Alternate form: Some chemicals are harmful if people are exposed to them in large amounts, but are not harmful if people are exposed to them in small amounts)	Td[c]	1.2	11.4	50.0	34.9	2.4
	Pd[d]	2.2	12.7	65.7	14.2	5.2
	Pc[e]	2.4	28.0	50.4	7.2	12.0
5f. A 1 in 10,000,000 lifetime risk of cancer from taking a particular prescription drug is too small a risk to worry about. (For perspective the lifetime risk of dying in a car accident in 1 in 100.) [Alternate form: A 1 in 10,000,000 lifetime risk of cancer from exposure to a particular chemical is too small a risk to worry about. (For perspective, the lifetime risk of dying in a car accident is 1 in 100)]	Td[c]	1.8	4.2	53.0	40.0	1.2
	Pd[d]	1.5	14.3	65.4	14.3	4.5
	Pc[e]	3.3	26.8	52.8	6.5	10.6
5g. I think that I should know as much as I can about the chemicals around me. The more I know, the more I can control the risks that those chemicals pose to my health and to the environment	T	0.6	4.1	47.9	46.7	0.6
	P	0.8	4.7	53.9	39.5	1.2
5h. Residents of a small community (30,000 people) observed that several malformed children had been born there during each of the past few years. The town is in a region where agricultural pesticides have been used during the past decade. It is very likely that these pesticides were the cause of the malformations	T	22.2	59.3	4.3	1.2	13.0
	P	3.9	23.4	39.5	9.0	24.2

[a] T = Toxicologists.
[b] P = Public.
[c] Td = Toxicologists, prescription drugs.
[d] Pd = Public, prescription drugs.
[e] Pc = Public, chemicals.

recognize the dependence of drug risk on dose (5e), and more likely to agree that a 1 in 10,000,000 risk of cancer from taking a prescription drug is too small a risk to wony about (5f).

There was considerable disagreement among both toxicologists and members of the public about whether pesticides are generally more harmful than fertilizers (question 5c). The toxicologists agreed with this statement more than the public did, the latter producing many more "don't know or no opinion" responses (27.4%).

Question 5d is similar to the questions about trust in animal studies (Category 2; Table 11). Toxicologists almost unanimously disagreed (89.6%) that microorganisms are reliable indicators of human reactions to a chemical. Members of the public sample also tended to disagree with this statement but exhibited an extremely high percentage of "don't knowlno opinion" responses (34.9%).

Results for question 5h confirmed the hypothesis that the public would be much more likely than the toxicologists to view an association between pesticide use and birth defects as a causal relationship (48.5% agreement among the public vs. 5.5% among the toxicologists). The percentage of "don't know/no opinion" responses to this question was high in both groups. Results from question 5i (not shown in Table V) indicated that toxicologists were about equally split between the views that humans are more, equally, or less vulnerable to adverse effects of chemicals than animals. The dominant response in the public sample was equal vulnerability (35.0%). More than 20% in both samples marked the "don't knowlno opinion" response.

2.2. Predicting Perceptions and Attitudes

Comparisons between toxicologists and the public sample showed that these two groups differed greatly with regard to appreciation of dose–response relationships and attitudes toward chemical risks and risk reduction, but did not differ much regarding trust in animal testing. From these data, it appears that dose–response views and attitudes may be closely related but that neither type of response is related to trust in animal testing.

A separate analysis was done to test these relationships at the level of the individual respondent in the public sample. The items within each of the first four categories (Tables I-IV) were assigned scores on a four-point scale of agreement corresponding to the four responses (strongly disagree = 1, disagree = 2, agree = 3, strongly agree = 4). Responses of each person in the public sample were scored, and the scores were summed across all items in the category to produce four scale scores per person:

- dose–response sensitivity (high score indicates high sensitivity to dose)
- trust in animal studies (high score indicates high trust)
- attitude toward chemicals and their risks (high score indicates a pro-chemical view)
- attitude toward risk-reduction (high score indicates acceptance of some degree of risk from chemicals)

The correlations between scales were computed across members of the public sample. The pattern of correlations indicated that laypersons who believed that exposure and dose mediate chemical risks were likely to be more favorable toward chemicals and relatively less concerned about their risks ($r = .68$) and less concerned about the necessity of reducing chemical risks ($r = .47$). Attitudes toward chemical risks and attitudes toward risk reduction were also positively correlated ($r = .55$). Trust in animal studies did not correlate significantly with any of the other scales.

Multiple regression analyses were performed to predict scale scores from demographic characteristics of the public sample. Examination of variables making a statistically significant contribution to the regression equation showed that scores on the attitude toward chemical risks scale could be predicted moderately well ($R = .49$) on the basis of education, gender, and scientific training. Scientific training, more education, better health, and male gender were all predictive of more favorable attitudes. Dose–response sensitivity was predictable ($R = .40$) on the basis of health status, education, and age. Being older, well-educated, and in good health was predictive of greater dose–response sensitivity. Trust in animal testing was not very predictable ($R = .22$) on the basis of demographic variables.

2.2.1. *Education*

It is instructive to assess the influence of the important demographic variables by examining data from specific questions. Table VI presents items on which the college educated and noncollege educated respondents showed statistically significant differences. In general, respondents with a college degree had more favorable attitudes toward chemicals, greater appreciation of the mediating role of dose and exposure, and less concern

Table **VI.** Comparisons Between Responses of College-Educated and Non-College Educated Persons in the Public Sample[a]

Questions		Strongly disagree	Disagree	Agree	Strongly agree	Don't know/ no opinion
1b. If you are exposed to a carcinogen, then you are likely to get cancer	NC[b]	3.3	38.5	23.0	9.0	26.2
	C[c]	7.0	46.9	28.1	9.4	8.6
1c. 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	NC	8.9	40.3	39.5	5.6	5.6
	C	15.4	53.8	19.2	7.7	3.8
1d. A chemical was found in a city's supply of drinking water in a concentration of 30 parts per million. . . . the water was filtered by a process that was able to reduce, but not eliminate, the chemical concentration in the water. Under most circumstances this means that the danger associated with drinking the water has also been reduced	NC	4.8	23.2	60.8	0.8	10.4
	C	3.1	13.8	65.4	13.8	3.8
1e. There is no safe level of exposure to a cancer-causing agent	NC	2.5	23.8	38.5	22.1	13.1
	C	10.2	31.3	32.8	15.6	10.2
3c. Use of chemicals has improved our health more than it has harmed it	NC	9.2	34.2	32.5	3.3	20.8
	C	7.0	18.8	49.2	7.8	17.2
3f. Chemicals are a major force behind technological advancement	NC	3.3	15.4	51.2	5.7	24.4
	C	0.8	10.1	58.9	20.2	10.1
4b. It can never be too expensive to reduce the risks associated with chemicals	NC	0.0	23.6	52.0	16.3	8.1
	C	5.4	33.3	34.9	20.2	6.2

[a] The differences between college and non-college educated respondents on question 1e were significant at $p < .05$. All other comparisons were significant at $p < .01$.
[b] NC = Non-College
[c] C = College

about risks. In these respects, the college-educated respondents appeared to be somewhat more similar to the toxicologists than were the noncollege educated persons. Examination of Table VI indicates that college-educated respondents were

- less likely to agree that worries about pesticides should depend only on whether or not one was exposed at all (1c)
- more likely to see reduction in the concentration of a possibly harmful chemical in water as reducing risk (1d)
- less likely to agree that there is no safe level of exposure to a cancer-causing agent (2e)
- more likely to agree that use of chemicals has improved our health more than it has harmed it (3c)
- more likely to agree that chemicals are a major force behind technological advancement (3f)
- less likely to agree that it can never be too expensive to decrease the risk associated with chemicals (4b)

Table VI also illustrates that respondents who did not have a college degree were far more likely to answer "don't know/no opinion" on certain of these items (1b, 1d, 3f).

2.2.2. *Gender*

Within the public sample, women were consistently more concerned about chemical risks than men, and they had less favorable attitudes regarding the benefits of chemicals. Questions for which gender differences were largest are shown in Table **VII.** Note that differences were particularly large for the attitudinal questions—3c, 3f, and 4b. Women were much less likely to agree that use of chemicals has improved our health more than it has harmed it (3c) and less likely to agree that chemicals are a major force behind technological advancement (3f). Note also the high percentage of "don't know/no opinion" responses among women for these questions. On question 4b, women were more likely than men to agree that it can never be too expensive to reduce chemical risks. On the other questions, women were more likely than men to:

- agree that, for pesticides, one should worry about whether or not they were exposed at all (1c)
- agree that they do everything they can to avoid contact with chemicals and chemical products in their daily life (3h)
- agree that pesticides caused the malformations in the children (5h)

Table VII. Responses of Men and Women in the Public Sample to Selected Questions[a]

Questions		Strongly disagree	Disagree	Agree	Strongly agree	Don't know/ no opinion
1c. 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	M[b]	14.4	54.1	20.5	7.5	3.4
	W[c]	9.3	37.4	41.1	6.5	5.6
3c. Use of chemicals has improved our health more than it has harmed it	M	6.9	21.4	51.7	8.3	11.7
	W	8.8	33.3	27.5	1.0	29.4
3f. Chemicals are a major force behind technological advancement	M	1.4	8.2	61.6	19.2	9.6
	W	2.9	19.0	46.7	3.8	27.6
3h. I do everything I can to avoid contact with chemicals and chemical products in my daily life	M	15.8	50.7	27.4	6.2	0.0
	W	6.7	44.8	34.3	12.4	1.9
4b. It can never be too expensive to reduce the risks associated with chemicals	M	4.1	34.7	40.8	14.3	6.1
	W	1.0	19.2	46.2	25.0	8.7
5h. Residents of a small community (30,000 people) observed that several malformed children had been born there during each of the past few years. The town is in a region where agricultural pesticides have been used during the past decade. It is very likely that these pesticides were the cause of the malformations	M	4.9	29.9	36.1	5.6	23.6
	W	2.9	14.3	43.8	14.3	24.8

[a] Gender differences were significant at $p < .05$ for questions 3h and 4b, and at $p < .01$ for questions 1c, 3c, 3f, and 5h.
[b] M = Men
[c] W = Women

Gender differences were less evident in the sample of toxicologists, perhaps because the number of women was too small ($n = 26$) to measure them reliably. However, female toxicologists appeared to be more concerned about chemical risks and less favorably impressed with the benefits of chemicals than were male toxicologists, though the differences between men and women toxicologists were smaller than the differences between men and women in the public sample. In other words, men and women exhibited different response patterns in both samples, although women toxicologists were far more similar to men toxicologists than they were to women members of the public.

2.3. Affiliation Effects

The three subgroups of toxicologists responded similarly on many of the questions. However, there were also important differences between the groups on a number of questions, as shown in Table VIII. Question 1e demonstrates that toxicologists from industry were much less likely than others to agree with the assertion that there is no safe level of exposure to a cancer-causing agent. With regard to the reliability and accuracy of animal tests, industrial toxicologists were somewhat more favorably inclined toward the tests (questions 2b and 2c) than other toxicologists, though the differences were not statistically significant and are not shown in the table. However, if a study produced evidence that a chemical caused cancer in animals (question 2d), the industrial toxicologists were much less confident than academic and regulatory scientists in the ability to extrapolate to humans (22.0% agreement vs. 48.9% and 52.7% in the other two groups). Similarly, industrial toxicologists were much more likely than others to see humans as less vulnerable than animals to adverse effects of chemicals (question 5i).

Industrial toxicologists also had the most favorable attitudes toward chemicals and their risks (questions 3a and 3d), and they were the group of toxicologists who most often disagreed with the statement that pesticides were the likely cause of the observed malformations in question 5h.

2.4. Are Public/Toxicologist Differences Merely Demographic?

The toxicologists in our survey tended, for the most part, to be highly educated, white males. We have seen that, within the general public, attitudes toward chemical risks are influenced by education and gender. Is it possible that these factors, and not expertise in toxicology, account for the observed differences between toxicologists and the public? Two kinds of analyses were performed to address these questions. First, multiple regression analyses were conducted to predict answers

Table VIII. Responses of Toxicologists According to Affiliation[a]

Questions		Strongly disagree	Disagree	Agree	Strongly agree	Don't know/ no opinion
1e. There is no safe level of exposure to a cancer-causing agent	A[b]	18.0	46.0	22.0	12.0	2.0
	I[c]	45.8	42.4	5.1	0.0	6.8
	R[d]	17.5	52.6	15.8	3.5	10.5
2d. 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	A	4.1	44.9	46.9	2.0	2.0
	I	18.6	57.6	22.0	0.0	1.7
	R	7.0	38.6	50.9	1.8	1.8
3a. Our society has perceived only the tip of the iceberg with regard to the risks associated with chemicals	A	8.0	26.0	46.0	12.0	8.0
	I	19.0	44.8	24.1	8.6	3.4
	R	5.3	36.8	43.9	5.3	8.8
3d. People are unnecessarily frightened about very small amounts of pesticides found in groundwater and on fresh food	A	2.1	35.4	45.8	14.6	2.1
	I	0.0	16.9	61.0	20.3	1.7
	R	3.5	29.8	50.9	7.0	8.8
5h. Residents of a small community (30,000 people) observed that several malformed children had been born there during each of the past few years. The town is in a region where agricultural pesticides have been used during the past decade. It is very likely that these pesticides were the cause of the malformations	A	20.8	58.3	2.1	4.2	14.6
	I	29.3	63.8	1.7	0.0	5.2
	R	16.1	55.4	8.9	0.0	19.6
		More vulnerable	Equally vulnerable	Less vulnerable	Don't know/ no opinion	
5i. In general humans are (more, equally, less) vulnerable to adverse effects of chemicals than are laboratory animals	A	15.2	21.7	23.9	39.1	
	I	19.6	21.4	44.6	14.3	
	R	26.3	33.3	17.5	22.8	

[a] Differences among groups were significant at $p < .05$ for questions 2d, 3a, 3d, and 5h, and at $p < .01$ for questions 1e and 5i.
[b] A = Academic.
[c] I = Industry.
[d] R = Regulatory.

to questions on which the two groups disagreed, using gender, race, education, and group status (member of the public vs. toxicologist) as predictors. These regressions showed that group status was by far the most important predictor, with education, race, and gender accounting for significant but small amounts of the variance in responses to the questions. This result can be illustrated concretely by comparing white male toxicologists with college-educated white male laypersons on two typical questions—1b and 2d. The results, presented in Table IX, show that the public sample still responds quite differently from each of the three groups of toxicologists, even when education, race, and gender differences are minimized. Results from other questions were similar.

2.5. Toxicologists' Attitudes Toward Public Concerns

We examined relationships between toxicologists' beliefs about the reliability of animal tests (question 2a) and their beliefs about whether people worry unnecessarily about chemicals (questions 3d and 3e). Comparing questions 2a and 3d, the proportion of toxicologists who agreed that people are unnecessarily frightened about small pesticide residues was about the same (70.0%) within the subsample who agreed that animal tests are reliable predictors as among those who disagreed with the assertion that animal tests are reliable (69.3% of whom agreed that people are unnecessarily frightened). Comparing questions 2a and 3e, those who distrusted animal tests were somewhat more likely (45.3%) to agree that people worry unnecessarily about what chemicals can do to their health than were those who trusted animal studies (33.3% of whom agreed that people worry unnecessarily).

These results raise a question. If distrust in animal studies is independent of or even positively related to toxicologists' beliefs that people wony unnecessarily about chemicals, what is the evidence, experience, or belief on which such views are based?

At least a partial answer to this question can be found by examining responses to the questions about

Table IX. Responses of College-Educated White Males

Questions		Strongly disagree	Disagree	Agree	Strongly agree	Don't know/ no opinion
1b. If you are exposed to a carcinogen, then you are likely to get cancer	P[a]	9.2	44.7	28.9	7.9	9.2
	A[b]	27.3	59.1	9.1	0.0	4.5
	I[c]	33.3	57.8	4.4	0.0	4.4
	R[d]	28.2	66.7	2.6	0.0	2.6
2d. 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	P	0.0	28.6	63.6	3.9	3.9
	A	4.8	45.2	45.2	2.4	2.4
	I	20.0	55.6	22.2	0.0	2.2
	R	10.0	47.5	37.5	2.5	2.5

[a] P = Public.
[b] A = Academic toxicologists.
[c] I = Industry toxicologists.
[d] R = Regulatory toxicologists.

reliability (2a) and unnecessary fear (3e) in light of responses to a third question (5i) asking about the relative vulnerability of humans and laboratory animals. The results of this three-way comparison implicated perceptions about vulnerability as a key factor in mediating attitudes toward public fears and distrust in animal tests. Toxicologists who disagreed with the statement that animal tests are reliable predictors of human reactions and who also believed that humans are less vulnerable to adverse effects of chemicals than are laboratory animals were the persons most likely to believe that people are unnecessarily frightened about very small amounts of pesticides.

2.6. Additional Data: The EPA Baseline Survey

Concern about the low response rate (27%) and the limited geographic representation of our public sample caused us to collect additional data. We were fortunate to be able to add four questions to a telephone survey conducted by McCallum et *al.*[23] for the Environmental Protection Agency (EPA) in six communities across the United States: Albuquerque, New Mexico; Cincinnati, Ohio; Durham, North Carolina; Middlesex County, New Jersey; Racine, Wisconsin; and Richmond, Virginia. Several criteria guided the selection of these communities: the presence of major industries using, storing, processing, or releasing chemicals; location of a superfund or other hazardous waste site nearby; existence of an active local emergency planning or environmental group; and previous experience with chemical-emissions problems. A total of 3129 completed interviews were obtained from the six communities (sample sizes in each community ranged from a low of 503 to a high of 604). The overall response rate was 59.1%, ranging from a high in Racine of 62.9% to a low in Middlesex County of 52.1%. Men and women were equally represented, by design. Comparison of the sample with community demographics indicated that the respondents were somewhat younger, better educated, and more affluent than the general public as a whole.

We selected two questions pertaining to dose–response sensitivity (questions 1b and 1c), one attitude question (3c), and one from Category 5 (5f). The wording was changed slightly in each case to improve clarity (e.g., the term "carcinogen" was replaced by the phrase "chemical that can cause cancer") or to increase generality (e.g., "pesticide" was replaced by "chemicals" in question 1c).

The results from these new samples, shown in Table X, differed even more from the responses of toxicologists than did the responses of the Portland public sample. For example, 73.3% either agreed somewhat or agreed strongly that "if a person is exposed to a chemical that can cause cancer, then the person is likely to get cancer later in life," in contrast to 34.4% of the Portland sample and 8.4% of the toxicologists. The new version of question 1c also produced a much higher rate of agreement with an all-or-none view of toxicity ("It's not how much of a chemical you are exposed to that matters to your health . . ."). Almost 63% agreed with this statement compared to 36.1% in the Portland sample and 4.2% of the toxicologists (on a version of the question that substituted pesticide for chemical). About 56% disagreed that some chemical risks are too small to worry about (compared to 30.1% in the Portland sample who responded to a 1 in 10,000,000 risk). There was about an even split in the percentage of persons who agreed

Table X. Responses from the EPA Baseline Survey[a]

	Community							Gender		Education		Age		
	Total	Richmond	Durham	Albuquerque	Cincinnati	Middlesex County	Racine County	Male	Female	H.S. or less	Some college or more	<30 yr	30-50 yr	>50 yr
1b. If a person is exposed to a chemical that can cause cancer, then that person is likely to get cancer later in life														
Strongly disagree	6.5	6.7	5.7	8.1	6.9	5.0	6.3	7.9	5.0	5.7	7.0	4.6	5.9	8.8
Somewhat disagree	18.3	19.0	20.0	21.1	17.4	15.3	17.2	20.4	16.2	11.7	22.8	17.7	19.0	17.6
Somewhat agree	35.8	34.8	38.4	34.6	34.1	35.6	37.3	35.2	36.5	31.3	39.0	43.5	37.0	27.6
Strongly agree	37.5	36.4	33.3	34.0	39.8	42.9	38.4	34.2	40.8	50.2	28.8	33.7	36.0	43.2
Don't know/no opinion	1.6	2.8	2.2	2.0	1.4	0.8	0.8	1.8	1.4	1.1	2.0	0.4	1.6	2.6
1c. it's not how much of a chemical you are *exposed* to that matters to your health, it's whether or not you're exposed at all														
Strongly disagree	18.6	16.6	22.0	17.4	20.6	19.7	16.1	18.7	18.5	19.8	17.8	19.2	18.7	17.7
Somewhat disagree	17.0	15.0	17.8	19.4	17.0	14.7	18.0	19.4	14.7	13.3	19.6	21.6	17.7	12.4
Somewhat agree	23.5	25.1	20.6	21.9	24.2	23.1	25.0	24.9	22.0	22.0	24.4	22.6	24.1	23.3
Strongly agree	39.2	40.9	38.2	39.7	36.8	40.2	39.6	35.7	42.8	43.3	36.5	36.2	38.2	43.3
Don't know/no opinion	1.7	2.4	1.4	1.6	1.4	1.7	1.3	1.3	2.0	1.6	1.7	0.4	1.3	3.3
3c. Chemicals have improved our health more than they have harmed it														
Strongly disagree	24.3	22.5	25.1	25.7	24.8	27.6	20.7	20.2	28.4	32.8	18.6	22.6	24.9	24.4
Somewhat disagree	22.9	23.5	23.6	19.4	20.0	25.6	24.8	19.9	25.9	22.9	22.9	26.9	24.0	18.0
Somewhat agree	34.4	36.2	31.7	35.0	35.0	30.0	37.7	37.3	31.5	28.3	38.5	37.2	34.0	32.8
Strongly agree	15.5	15.0	15.6	17.2	17.2	13.1	14.9	20.5	10.4	13.1	17.1	12.0	14.9	19.2
Don't know/no opinion	2.6	2.6	3.2	2.8	2.8	3.0	1.7	1.7	3.5	2.8	2.5	1.4	1.7	5.2
5f. There are some chemical risks that are too small to worry about														
Strongly disagree	35.3	36.0	36.2	31.6	33.5	38.6	35.8	30.7	39.9	41.0	31.5	37.0	34.5	34.9
Somewhat disagree	21.1	19.6	19.6	20.9	23.0	23.7	20.0	20.0	22.2	20.6	21.4	24.8	21.1	18.2
Somewhat agree	26.4	28.3	26.1	28.9	25.0	22.3	27.6	28.0	24.8	22.1	29.4	25.2	28.4	24.1
Strongly agree	16.8	16.2	16.6	18.0	18.2	15.5	16.6	21.1	12.5	15.6	17.6	13.0	15.6	22.0
Don't know/no opinion	0.4	0.0	1.5	0.6	0.3	0.0	0.0	0.2	0.6	0.7	0.1	0.0	0.4	0.8
Sample size	3129	506	505	506	505	503	604	1574	1555	1283	1846	720	1502	907

[a] *Source*: McCallum *et al.*[22]

and the percentage who disagreed that "chemicals have improved our health more than they have harmed it." About 47% disagreed, compared with 33.9% in the Portland sample and 3.0% of the toxicologists.

The "don't know/no opinion" response category was prominently displayed as an option in the written survey administered to the Portland survey but was not Specifically mentioned as a response option in the EPA telephone survey. As a result, the frequency of "don't know" responses was smaller in the EPA survey than in the Portland survey.

Further analysis of Table X shows that the overall response patterns for these questions varied rather little across communities, gender, education, and age. As in the Portland sample, women's attitudes were somewhat less favorable toward chemicals than were men's and respondents with more formal education were more favorable toward chemicals than were less educated persons. Older respondents were more likely than younger persons to agree that it's not how much of a chemical that matters and to agree that some risks are too small to worry about. However, they were slightly less likely than younger persons to agree that exposure to a cancer-causing chemical will cause cancer later in life.

3. DISCUSSION

3.1. Expert vs. Public Views

Our primary objectives were to describe and compare responses of laypeople and toxicologists and to test a number of hypotheses about the differences between the public's views as "intuitive toxicologists" and the views of experts. In general, we believe that this aspect of the study was successful. Toxicologists and laypeople were found to differ greatly, documenting some common assumptions (e.g., that the public believes natural chemicals to be safer than synthetic ones) and verifying many of the other hypotheses that motivated the questionnaire.

Of particular importance is the pattern of responses to questions in Category 1, which indicates that the public is much less sensitive than the experts to fundamental considerations of dose and exposure. Although the public recognizes the importance of these factors in some domains (e.g., prescription drugs), they generally tend to view chemicals as either safe or dangerous and they appear to equate even small exposures to toxic or carcinogenic chemicals with almost certain harm. This orientation was found to be associated with high levels of concern regarding chemicals, including very small residues of chemicals on food, and a desire to reduce chemical risks at any cost. It is sobering to find that 40% of our public respondents said that they do everything they can to avoid contact with chemicals and chemical products in their daily lives. It is also remarkable to find that fewer than 50% of the public respondents in the Portland sample and fewer than 25% in the EPA sample recognized that exposure to a chemical that is carcinogenic does not make one likely to get cancer later in life.

Several other findings were noteworthy: (a) the public's tendency to attribute causality to a temporal association between pesticide use and birth defects; @) the strong negative attitudes of the public toward chemicals and their risks; (c) the relatively favorable perceptions of prescription drugs[9]; (d) the finding that 30% of the public respondents did not agree that a 1 in 10,000,000 lifetime risk of cancer from exposure to a chemical was too small to worry about[10]; and (e) the finding that men and more highly educated persons were somewhat less concerned about chemical risks—in general, responses of college-educated persons were slightly more similar to responses of toxicologists than were responses of persons with less education.

One of the major surprises in the data was the lack of difference between the public and toxicologists with regard to their confidence in extrapolation from animal studies. Both groups were divided in their opinions, and the high percentage of experts who lacked confidence in animal studies is particularly noteworthy in light of the extensive reliance on such studies in risk management. The public's trust in extrapolation from animal studies increased greatly when these studies were said to produce evidence of carcinogenicity. It is well known that people (scientists included) trust information more when it is congruent with their *a priori* expectations or theories.[26,27] The reaction of our lay respondents to evidence of carcinogenicity is consistent with this view if we can assume that laypeople expect most chemicals to be carcinogenic in humans. The credibility that our public respondents gave to evidence of carcinogenicity is also consistent with a basic tenet of "regulatory" science which gives much greater weight to positive results than to negative findings.[28] The confidence of our toxicologists in extrapolation from animal studies did not appear to be influenced by a positive finding (of carcinogenicity).

3.2. Additional Data: The New Jersey Study

Further evidence that the public perceptions and attitudes observed in the present *study* are widespread comes from a telephone survey of 500 residents in 31 New Jersey communities conducted in November 1987 by Weinstein.[29] This survey produced strong evidence for dose–response insensitivity and an "all-or-none" conception of toxicity. Specifically, 78.4% of the respondents agreed strongly (and 6.6% agreed moderately) with the statement: "If even a tiny amount of a cancer-producing substance were found in my water, I wouldn't drink it." The statement: "When some chemical is discovered in food, I don't want to hear statistics, I just want to know if its dangerous or not" elicited strong agreement from *62.0%* and moderate agreement from 21.6% of the respondents. The New Jersey respondents

[9] We attribute this to the fact that prescription drugs are familiar, high in perceived benefit, and administered by highly trusted professionals. The more favorable view of prescription drugs relative to industrial and other chemicals is analogous to the more favorable perceptions of medical x-rays in comparison to industrial radiation technologies such as nuclear power and food irradiation (see Ref. 24)

[10] Many policy-makers have argued that lifetime risks equal to or less than 1 in 1 million are de *minimus—too* small to worry about or to regulate[25] The present results suggest that many laypersons would object to this view.

also recognized limitations in the knowledge of experts. The statement, "Although experts are willing to make estimates of the risk from hazardous waste, no one really knows how big the risks really are," elicited 84.9% agreement. About 78% agreed with the statement: "For a lot of chemicals, we don't know enough to make decisions." As in the other studies described earlier, women held more negative attitudes than men about chemical risks and more highly educated individuals were less likely to see chemical risks as "all-or-none" phenomena.

3.3. Understanding the Origins of Public Attitudes and Concerns

What accounts for the public's insensitivity to dose and strong concerns about even minute exposures to toxic or carcinogenic chemicals? Psychological and anthropological research on the concept of "contagion" may provide one possible explanation. Frazer[30] and Mauss[31] described a belief, widespread in many cultures, that things that have been in contact with each other may influence each other through transfer of some of their properties via an "essence." Thus, "once in contact, always in contact," even if that contact (exposure) is brief. Rozin *et al.*[32] show that this belief system, which they refer to as a "law of contagion," is common in our present culture. The implication of this work is that even a minute amount of a toxic substance in one's food will be seen as imparting toxicity to the food; any amount of a carcinogenic substance will impart carcinogenicity, etc. The "essence of harm" that is contagious is typically referred to as contamination. Being contaminated clearly has an all-or-none quality to it—like being alive, or pregnant. When a young child drops a sucker on the floor, the brief contact with "dirt" may be seen as contaminating the candy, causing the parent to throw it away rather than washing it off and returning it to the child's mouth. This all-or-none quality irrespective of the degree of exposure is evident in the observation by Erikson[33] that "To be exposed to radiation or other toxins . . . is to be contaminated in some deep and lasting way, to feel dirtied, tainted, corrupted" (p. 122). A contagion or contamination model is obviously very different from the scientist's model of how contact with a chemical induces carcinogenesis or other adverse effects. Further examination of the concepts of contagion and contamination may help us better understand the origins of the public's concerns about very small exposures to chemicals. .

Alternatively, the intuitive toxicologist may conceive of a toxic chemical as equivalent to a highly dangerous virus or bacteria such as botulism, salmonella, or hepatitis. Early and influential writers such as Rachel Carson[34] may have spawned this perception by drawing analogies between carcinogens and infectious diseases and referring to epidemics of cancer." Exposure to the regulatory philosophy that there is no safe dose of a carcinogen may also have contributed to the public attitudes we observed here. In any event, it is clear that we need to probe further to understand the determiners of public attitudes and the mechanisms by which laypeople believe chemicals induce various kinds of harm.

3.4. Disagreement Among Toxicologists

Among the most important findings in this study was the great divergence of opinion among the toxicologists themselves about fundamental issues in risk assessment and, in particular, the high percentage of toxicologists who doubted the validity of the animal and bacterial studies that form the backbone of their science. These results provide a quantitative description of the criticisms and disagreements that are clearly evident in statements of individual scientists[8,11] and in detailed case studies of specific chemical controversies.[9] These results also clash with the messages given the public. For example, the American Chemical Society's carefully written public information pamphlet on "Chemical Risk: Personal Decisions" informs people that "toxic effects found in rodents usually occur in humans exposed to the same chemical." Although acknowledging the fact that prediction to humans is not certain, the pamphlet concludes that "they are the best predictors we have."[12] The impression given the public by this authoritative source is, we submit, quite different from the impression gleaned from questions in Category 2 of our survey or from the many strong criticisms of animal testing in the scientific literature.

The affiliation bias we observed is particularly noteworthy, indicating that toxicologists working for industry see chemicals as more benign than do their counterparts in academia and government. Industrial toxicologists were somewhat more confident than other experts in the gen-

[11] Carson may have been a major influence behind another popular view of our public respondents—that natural chemicals are not as harmful as synthetic chemicals. In *Silent Spring,* she observed that although ". . . natural cancer-causing agents are still a factor in producing malignancy, . . ., they are few in number and they belong to that ancient array of forces to which life has become accustomed from the beginning" (p. *195).* She contrasts these natural chemicals with synthetic agents of the industrial era against which "man had no protection" (p. 196).

[12] A survey of other presentations of toxicology designed to educate the public shows that this relatively favorable view of the validity of animal tests is typical.

eral validity of animal tests—except when those tests provided evidence for carcinogenicity—in which case many of the industrial experts changed their opinions.

An earlier study of 136 occupational health specialists by Lynn[16] obtained remarkably similar data demonstrating the effect of affiliation on opinions about the value of animal data and the existence of thresholds for carcinogens. She found that only 27% of respondents working for industry agreed that "a substance which is shown conclusively to cause tumors in animals should be considered a carcinogen, thereby posing a risk to humans," whereas 69% and 52% of government and university employees agreed. Eighty percent of the industry respondents agreed that thresholds exist, in contrast to 61% of the academics and 37% of the government employees. She also found that these responses were correlated with political orientation (liberal/conservative) and with voting in the 1980 presidential election. Finally, Lynn showed that these differences were congruent with the public stances of industrial and regulatory representatives in a number of major risk-management controversies. Data from the present study, and the data presented by Lynn, contribute to a substantial literature documenting the strong influence of the social and political context on risk assessment.[9,12–15,18–19,35]

Some reviewers of this manuscript have argued that the affiliation differences we and others have observed reflect the fact that toxicologists in industry tend to work with less harmful chemicals than toxicologists in regulatory or academic settings and thus have a lower base-rate expectancy for chemical risks. We cannot rule this interpretation out, although, in response to the statement "Most chemicals cause cancer," industrial toxicologists in our study did not disagree more than other toxicologists (96.4% of all toxicologists disagreed or strongly disagreed with this statement). The weight of evidence seems to us to favor a sociopolitical interpretation of the affiliation effect.

3.5. Limitations of Risk Assessment

One of the major motivations behind this study was to develop an understanding of the differences between the ways that professional toxicologists and laypersons assess chemical risks, in order to facilitate communication and perhaps reduce the "gap" between expert and lay views. To a certain extent, some of the present results do point toward concepts that experts should clarify for the public. It is obvious that the words "toxic" and "carcinogenic" mean very different things to experts and laypersons. If scientists could impart a better understanding of these concepts, and their relationship to exposure, significant progress most certainly will have been achieved.

However, the present results also suggest that the controversies over chemical risks in our society may be fueled as much by weaknesses in the science of risk assessment as by misconceptions of the public. Our data (and those of Lynn) indicate that scientists cannot agree whether or not their main method of testing is reliable or accurate in predicting human health effects and that scientists who work for industry see fundamental issues quite differently from their colleagues in academia and government.

These results place the problems of risk communication in a new light. Our risk management processes are open and adversarial—we battle in courtrooms and community halls, in view of the media, with experts on each side of the issue attacking the other's credibility, models, and data. The young science of risk assessment is too fragile, too indirect, to prevail in an adversarial atmosphere. As shown in surveys by Weinstein[29] and Mitchell,[36] the public is well aware of the limitations of expertise in risk assessment. Risk assessment, though invaluable to regulators in the design of management strategies, is not at all convincing to the public. Perhaps this should not surprise us, given the many criticisms of risk assessment in the literature. Our survey indicates that these criticisms are not a minority view. The affiliation bias we and others have observed is a natural outgrowth of the scientific ambiguity—but a disturbing one nonetheless. It feeds the public sense of distrust.

Risk communication cannot take place without appropriate messages to communicate. The messages emanating from the risk-assessment community are contradictory and confusing. Do animal studies overestimate cancer risks to humans because of the use of particularly sensitive strains of animals or because of the effects of cell proliferation caused by extreme doses? Or do they underestimate the risks because of the greater genetic diversity in the human population, the slower rate of metabolism in humans, or the exposure of humans to a greater number of carcinogenic substances than laboratory animals are exposed to? Are there, or are there not thresholds for carcinogens? Regulators have sought to justify their actions through reliance on scientific consensus, insulated from considerations of policy and politics. Said William Ruckelshaus, at the beginning of his second term as EPA administrator: ". . . risk assessment at EPA must be based only on scientific evidence and scientific consensus. Nothing will erode public confidence faster than the suspicion that policy considerations have been allowed to influence the assessment of risk" (Ref. 37, pp. 1027–1028). Outside of the regulatory arena, many of the scientific foundations and findings of risk assessment are under dispute and appear to be shaped by political factors. What, then, is the message that should be communicated?

Risk assessment has been oversold because of the need to rationalize decisions about chemicals. Even Ruckelshaus came to admit this toward the end of his second term. The attempt to quantify risks to human health and the environment from industrial chemicals is, he said, "Essentially . . . a kind of pretense; to avoid the paralysis that would result from waiting for 'definitive' data, we assume that we have greater knowledge than scientists actually possess and make decisions based on those assumptions" (Ref. 38, p. 26).

The challenge to toxicologists and risk assessors is clear. These scientists must look anew at the strengths and limitations of their craft. They should work to develop stronger, more definitive ways to assess chemical risks. They should play a greater role in interpreting the health implications of their data for the public. In doing so, they should acknowledge the subjective elements, judgments, and assumptions inherent in their analyses, as well as the degree of uncertainty in their conclusions. Above all, they must protect the young science of risk assessment from being misrepresented, misused, and abused in the regulatory process. We concur with Graham *et al.*[9] in the conclusions they drew from their analysis of the intense controversies surrounding efforts to regulate benzene and formaldehyde:

> We believe that a precise and honest view about the role of science in chemical regulation will strengthen both science and democracy. Modest expectations . . . can be realized, and that means strengthened public confidence in science in the long run. Modest expectations for science also foster and legitimize explicit political discussion in our democracy about how to cope with chemical hazards. (p. 218)

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REFERENCES

1. L. Harris, *Risk in a Complex Society* (public opinion survey, Marsh & McLennan, Inc., New York, 1983).
2. C. F. Callis, "Improving the Public Understanding of Science," *Environmental Science and Technology* 24, 410-411 (1990).
3. G. C. Pimentel, "Chemistry at a Crossroad," *Chemical and Engineering News* 67(18), 53–55 (1989).
4. National Academy of Sciences. *Risk Assessment in the Federal Government: Managing the Process* (National Academy Press, Washington, D.C., 1983).
5. W. D. Ruckelshaus, "Risk in a Free Society," *Risk Analysis* 4, 157–162 (1984).
6. E. Efron, *The Apocalyptics* (Simon & Schuster, New York, 1984).
7. B. N. Ames and L. S. Gold "Too Many Rodent Carcinogens: Mitogenesis Increases Mutagenesis," *Science* 249,970–971 (1990).
8. D. A. Freedman and H. Zeisel, "From Mouse-to-Man: The Quantitative Assessment of Cancer Risks," *Statistical Science* 3, 3–56 (1988).
9. J. D. Graham, L. C. Green, and M. J. Roberts, *In Search of Safety: Chemicals and Cancer Risk* (Harvard University Press, Cambridge, Massachusetts, 1988).
10. T. Malmfors, "Toxicology as a Science," *Trends in Pharmacological Sciences 2* (1), I–IV (1981).
11. J. Marx, "Animal Testing Challenged," *Science 250*, 743–745 (1990).
12. L. Clarke, "Politics and Bias in Risk Assessment," *The Social Science Journal 25*, 155–165 (1988).
13. T. M. Dietz and R. W. Rycroft, *The Risk Professionals* (Russell Sage Foundation, New York, 1987).
14. W. T. Gormley, *Professionalism within Environmental Bureaucracies: The Policy Implications of Personnel Choices* (Occasional Paper No. 1, University of Wisconsin, Robert M. Lafollette Institute of Public Affairs, Madison, Wisconsin, 1986).
15. B. B. Johnson and V. T. Covello, *The Social and Cultural Construction of Risk* (Reidel, Dordrecht, The Netherlands, 1987).
16. F. M. Lynn, "OSHA'S Carcinogens Standard: Round One on Risk Assessment Models and Assumptions," in B. B. Johnson and V. T. Covello (eds.), *The Social and Cultural Construction of Risk* (Reidel, Dordrecht, The Netherlands, 1987), pp. 345–358.
17. A. Mazur, *The Dynamics of Technical Controversy* (Communications Press, Washington, D.C., 1981).
18. G. M. H. Swaen and J. M. M. Meijers, "Influence of Design Characteristics on the Outcome of Retrospective Cohort Studies," *British Journal of Industrial Medicine* 45, 624-629 (1988).
19. A. S. Whittemore, "Facts and Values for Environmental Toxicants," *Risk Analysis* 3, 23–33 (1983).

20. L. J. Casarett and J. Doull, *Toxicology: The Basic Science of Poisons* (MacMillan, New York. 1975).
21. B. Ames, "Dietary Carcinogens and Anticarcinogens," *Science* **221**, 1256-1264 (1983).
22. H. M. Jenkins and W. C. Ward, "Judgment of Contingency Between Responses and Outcomes," *Psychological Monographs* **79** (I, Whole No. 594) (1965).
23. D. B. McCallum, S. L. Hammond, L. A. Morris, and V. T. Covello, *Public Knowledge and Perceptions of Chemical Risks in Six Communities* (Report No. 230-01-90-074, U. S. Environmental Protection Agency, Washington, D.C., 1990).
24. P. Slovic, "Perception of Risk from Radiation," in W. K. Sinclair (ed.), *Proceedings of the Twenty-Fifth Annual Meeting of the National Council on Radiation Protection and Measurements, Vol 11: Radiation Protection Today: The NCRP at Sixty Years,* (NCRP, Bethesda, Maryland, 1990), pp. 73-97.
25. C. Whipple, *De Minimus Risk* (Plenum, New York, 1987).
26. J. J. Koehler, *Judgments of Evidence Quality Among Scientists as a Function of Prior Beliefs and Commitments* (unpublished doctoral dissertation, University of Chicago, Chicago, Illinois, 1989).
27. L. Ross and M. R. Lepper, "The Perserverance of Beliefs: Empirical and Nonnative Considerations," *New Directions for Methodology of Social and Behavwml Science* **4**, 17-36 (1980).
28. U. S. Environmental Protection Agency, "Guidelines for Carcinogen Risk Assessment," *Federal Register* **51**, 33,992–34,005 (1986).
29. N. D. Weinstein, *Attitudes of the Public and the Department of Environmental Protection Toward Environmental Hazards* (Final Report, New Jersey Department of Environmental Protection, 1988).
30. J. G. Frazer, *The New Golden Bough: A Study in Magic and Religion* (MacMillan, New York, 1959; original work published in 1890).
31. M. Mauss, *A General Theory of Magic* (Norton, New York, 1972; original work published in 1902).
32. P. Rozin, L. Millman, and L. Nemeroff, "Operation of the Laws of Sympathetic Magic in Disgust and Other Domains," *Journal of Personality and Social Psychology* **50**, 703-712 (1986).
33. K. Erikson, "Toxic Reckoning: Business Faces A New Kind of Fear." *Harvard Business Review* 118-126 (1990).
34. R. Carson, *Silent Spring* (Houghton Mifflin, New York, 1962; quotations herein taken from the paperback version, Fawcett, 1969).
35. S. Jasanoff, *Risk Mangement and Political Culture* (New York, Russell Sage Foundation, 1987).
36. J. V. Mitchell, "Perception of Risk and Credibility at Toxic Sites," *Risk Analysis* **12**, 19–26 (1992).
37. W. D. Ruckelshaus, "Science, Risk, and Public Policy," *Science* **221**, 1026–1028 (1983).
38. W. D. Ruckelshaus, "Risk, Science, and Democracy," *Issues in Science and Technology* **1** (3), 19-38 (1985).