COMPARATIVE RISK ANALYSIS: AN INFORMAL SURVEY OF EXPERTS

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Comparative Risk Analysis (CRA) was developed by the U.S. Environmental Protection Agency (EPA) to help set priorities in environmental policy and to evaluate the correspondence between current resource allocation and threats to environmental quality and human health. A primary conclusion of the first CRA was that EPA budget and staff allocations corresponded more closely with public perceptions of risks than with the risk-ranking developed by agency staff.[1] A second national CRA, conducted by the EPA's Science Advisory Board, broadly supported the initial study and reached a similar conclusion.[2] Subsequently, each of the ten EPA regions and several dozen states, municipalities, and other jurisdictions have conducted CRAs addressing varying risks relevant to their jurisdictions.[3]

The two federal EPA reports[4] were conducted by agency staff and outside experts in risk assessment, environmental science, and economics. In contrast, the state and local CRAs have tended to rely more heavily on input from representatives of a broader range of government agencies, industry, environmental and other interest groups, and interested citizens (Minard, 1996)[5]. The purposes of including such broad representation vary among projects, but in general include a desire to provide expression of the variety of attributes of environmental risks that influence social concern about them.

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1. *See* OFFICE OF POLICY ANALYSIS, U.S. ENVTL. PROTECTION AGENCY, UNFINISHED BUSINESS: A COMPARATIVE ASSESSMENT OF ENVIRONMENTAL PROBLEMS 96-97 (1987).

2. SCIENCE ADVISORY BOARD, U.S. ENVTL. PROTECTION AGENCY, REDUCING RISK: SETTING PRIORITIES AND STRATEGIES FOR ENVIRONMENTAL PROTECTION (1987).

3. *See* Richard A. Minard, *CRA and the States: History, Politics, and Results*, *in* COMPARING ENVIRONMENTAL RISKS: TOOLS FOR SETTING GOVERNMENT PRIORITIES 23 (J.C. Davis ed., 1996).

4. OFFICE OF POLICY ANALYSIS, *supra* note 1, at 2-3; SCIENCE ADVISORY BOARD, *supra* note 2, at 8.

5. *See* MINARD, *supra* note 3.

Some of these CRAs have also been directed, at least in part, toward developing a legislative agenda in Washington, [6] improving communication between political interest groups in Louisiana,[7] and to developing a broadly shared perspective on environmental and related issues in Vermont.[8]

From the start, it has been recognized that CRA requires significant value judgments in order to compare diverse endpoints, including human cancer, reproductive, and other adverse health effects, changes in ecosystem composition and function, and changes in environmental amenities such as visibility.[9] Indeed, neither national CRA presented a single ranking of the risks under review, but instead indicated which risks ranked high and low on each of several criteria including human health, ecosystem, and overall welfare considerations. The importance of value judgments suggests that the results of a CRA may be sensitive to the participants, because different groups may place more or less weight on the incremental probability of mortality or other health effects, the number of people at risk, the perceived voluntariness or controllability of the risk, the likely effects on ecosystems, and other factors.

The federal, state, and local CRAs have addressed a varied set of risks and used differing criteria for evaluating them. Nevertheless, a general finding from these studies is that judgments about the relative importance of risks arrived at through review of the relevant scientific evidence and discussion about the multiple attributes of concern differs substantially from the ranking derived by public opinion polling.[10]

This paper reports the results of a brief CRA exercise conducted by participants in the 1996 Cummings Colloquium on Environmental Law, a two-day conference on CRA hosted by the Duke University Law School and Nicholas School of the Environment.[11] In contrast to the practice in most CRAs, participants in this exercise responded

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6. *See id*. at 35-39.

7. *See id*. at 42-43.

8. *See id*. at 41-42.

9. *See* OFFICE OF POLICY ANALYSIS, *supra* note 1, at 2-3; SCIENCE ADVISORY BOARD, *supra* note 2, at 8.

10. *See* MINARD, *supra* note 3, at 30.

11. James K. Hammitt, Risk in the Republic: Comparative Risk Analysis and Public Policy, Presentation before the Second Annual Cummings Colloquium on Environmental Law, sponsored by the Duke University Law School and Nicholas School of the Environment, and the Research Triangle Chapter of the Society for Risk Analysis, Durham, North Carolina (Nov. 15-16, 1996) (unpublished).

individually to a written survey without the opportunity to discuss issues with each other. Moreover, no background information on the characteristics of the risks was provided to participants. These restrictions were required by the limited time available for the exercise. The objectives of this exercise were to familiarize participants with some of the difficult value tradeoffs inherent in CRA, to provide material for discussion at the conference, and to compare the results in this population with results obtained in surveys of general samples of United States residents. Results of the exercise are reported here. Overall, the results suggest that conference participants, who were much more knowledgeable about health and environmental risk regulation than the general public, gave relatively higher weight than do members of the general public to quantitative measures of risk such as the number of lives lost than to non-quantitative factors such as the extent to which the risk is dreaded, voluntary and controllable.

I. SAMPLE AND METHOD

The CRA exercise consisted of a survey completed by participants during the first half-day of the conference (the survey is appended). The survey was distributed at the beginning of the conference and participants were asked to complete it during the introductory welcoming and keynote addresses or during lunch. Survey forms were completed before specific risk issues were discussed the first afternoon and results of the exercise were presented to the conference the following day.

The first part of the survey asked participants to rank 24 risks according to three categories of importance (high, medium, and low), ensuring that eight risks were allocated to each category. This three-category allocation was intended as a substitute for a more refined ranking in order to reduce the amount of time participants would need to devote to making fine distinctions. The purpose of the ranking was explicitly stated to be for guiding government priorities (implicitly including state and local, as well as federal, government).

Subsequent sections included questions about which of two or three risks, or risk-reduction options, were more important. These sections included questions that evaluated rates of substitution between numbers of lives saved and other attributes of the risks. If two risks are judged equally important when the expected number of lives lost is unequal, the difference in expected lives lost provides a measure of the importance of other attributes that distinguish the risks.

This difference can be described as the Willingness to Sacrifice (WTS) to make the risks equally important.[12]

The final section of the survey requested information on participants' demographic and socio-economic characteristics. Participants in the exercise were professionals and students concerned with risk analysis, and consequently were a highly selected subset of the general population. Because of their expertise in risk analysis, participants' rankings of these risks might be expected to systematically differ from the rankings that would be provided by more diverse groups. To the extent possible, such comparisons are made below. Participants were drawn from universities (both faculty and students), government (all levels), for-profit and non-profit organizations. Many were members of the international Society for Risk Analysis (the leading professional organization in its field). The conference also served as the annual workshop of the Research Triangle Chapter of this society. In addition, about 10% of participants resided outside the United States.

As summarized in Table 1, almost all participants in the exercise held an advanced degree or were enrolled in an advanced-degree program, predominantly in environmental science and policy, biological sciences, or law (six of the 13 lawyers and law students held or were working toward a masters degree in environmental science). Three-quarters of the participants were male and household income was higher than that of the general public with 35% having incomes exceeding $100,000 (many of the participants with low incomes were students who are likely to attain above-average incomes soon after completing their studies). More than half the participants were between 35 and 54 years old with none older than 65; almost 40% have children currently living in their households.

12. Jonathan Wiener is, to my knowledge, the first to suggest this term.

Table 1: Demographic and Socioeconomic Characteristics of Participants (%) (N=56)

Age (years)	**Number of Participants**
18-24	14
25-34	16
35-44	36
45-54	21
55-64	13
65+	0
Highest Degree (completed or in progress)	
Ph.d., Sc.D.	4
M.D.	9
J.D. (46% have M.S.)	23
M.S., M.B.A.	25
B.S., B.A.	4
Educational Field (highest degree)	
Env. Science & Policy	23
Biological Science	22
Law	18
Engineering	12
Social Science	8
Medicine	6
Physical Science	5
Humanities	2
Business	2
Other	3
Annual Household Income	
<$30,000	21
$30,000 - $60,000	15
$60,000 - $100,000	29
>$100,000	35
Children in Household	
Yes	38
No	62

II. COMPARATIVE RISK RANKING

Results of the risk-ranking exercise are presented in Table 2. The number of risks included in the exercise was somewhat smaller than in the national EPA CRAs, but more diverse. In addition to many of the environmental risks included in previous CRAs, the exercise included other large health risks (e.g., accidents, infectious disease), natural disasters (e.g., hurricanes), conditions that threaten health but substantially involve other issues as well (e.g., poverty, firearms, terrorism), and a potentially catastrophic risk that has received little attention (asteroid impact). The risks were poorly defined, a characteristic inherent in this type of exercise but exacerbated here by the limited time available for administering the survey. Because the set of risks included in this survey differ somewhat from those used in previous CRAs, it is not possible to directly compare the ranking with results of other CRAs although comparisons for selected risks are discussed below.

The degree of consensus varied widely across risks. Six of the 24 risks were ranked in the highest importance category by at least 50% of participants, seven were ranked in the low-importance category by at least 50% of participants, and five risks were ranked by at least 20% of participants in each of the three categories.

The five risks for which individual rankings were most diverse are acid precipitation, hazardous waste, second-hand smoke from cigarettes, high-fat/low-fruit and vegetable diet, and firearms. For two of these risks—second-hand smoke and firearms—the balance between individual freedom and imposition of risks on others seem to be particularly salient and may have led to more diversity in ranking. The diversity with respect to diet is surprising, since diet is widely perceived as one of the largest controllable risk factors,[13] although perhaps the high level of individual control of diet accounts for the diversity of ranking. Hazardous waste is the exemplar that is ranked high by the public but low by EPA CRAs.[14] Acid precipitation has received a great degree of attention over the last 20 years, including a large-scale integrated science and assessment effort (the National Acid Precipitation Assessment Program). This extensive research was popularly interpreted as suggesting that acid precipita-

13. *See* CATHERINE E. WOTEKI & PAUL R. THOMAS, EAT FOR LIFE: THE FOOD AND NUTRITION BOARD'S GUIDE TO REDUCING YOUR RISK OF CHRONIC DISEASE 9 (1992).

14. *See* SCIENCE ADVISORY BOARD, *supra* note 2, at 95-97.

tion is not as serious a problem as originally feared since it seems unlikely to lead to widespread catastrophic damages to forests and lakes.[15] Acid precipitation is a risk for which the primary direct effects fall on the environment and on wildlife rather than on human health, although indirect human-health risks (and health risks from airborne pollution before it precipitates) may also result. There was likely to be more diversity among participants in evaluating risks to ecosystems compared with risks to humans, potentially leading to greater diversity in ranking. Global warming, for which non-health consequences may predominate, also showed considerable diversity in ranking, although loss of wildlife habitat did not.

Table 2: Risk Ranking: Allocation of Risk to Three Categories of Concern (Percentage of Respondents)

RISK	HIGH	MEDIUM	LOW
Global Warming	50	33	17
Statospheric-ozone depletion	44	52	4
Asteroids and comets hitting Earth	2	5	93
Acid precipitation	20	54	26
Loss of wildlife habitat	55	38	7
Hazardous waste	31	45	24
Electromagnetic Fields	0	7	93
Pesticide residues on food	15	35	24
Pesticide exposure to farmworkers	26	63	11
Pollution to surface waters	64	33	4
Particulate air pollution	44	54	2
Cigarette smoking (risk to smokers)	67	20	13
Second-hand smoke (cigarettes)	20	40	40
Poverty	67	25	7
High fat / low fruit and vegetable diet	44	35	22
Firearms	30	41	30
Infectious disease (excluding AIDS)	48	40	12
AIDS	31	51	18
Automobile accidents	62	27	11
Airline accidents	4	15	81
Hurricanes	6	24	70
Earthquakes	4	19	78
Terrorism	9	22	69
Violent Crime (excluding terrorism)	39	48	13

15. *See* NAPAP, INTEGRATED ASSESSMENT REPORT TO CONGRESS (1996).

The six risks that were ranked in the highest importance category by at least 50% of participants were, in decreasing order of support: surface-water pollution, poverty, cigarette smoking (risks to smokers), automobile accidents, loss of wildlife habitat, and global warming. The high ranking of surface-water pollution was unanticipated: in contrast, all six types of surface-water pollution considered in the original EPA CRA—industrial pollution of waterways, water pollution from farm runoff, coastal water contamination, sewage-plant water pollution, oil spills, and water pollution from urban runoff—ranked either low or medium.[16] The difference may reflect aggregation: while none of the five sub-categories of surface-water pollution ranked high in the EPA study, their combination ranked high in this exercise. This aggregation problem is inherent in ranking risks rather than risk-reduction opportunities: there appears to be no principled basis for choosing the appropriate aggregation of risks, and the aggregation selected may influence the ranking[17].

The other risks that were often ranked in the "high" category are unsurprising. Poverty and cigarette smoking affect very large numbers of people. Poverty is not traditionally included in CRA studies but there is substantial evidence linking it to increases in a wide range of health risks. Moreover, a substantial literature has developed around the issue of when the costs of health and safety regulations induce more fatalities, through diminishing citizens' wealth, than they save.[18] Automobile accidents are the largest cause of fatal injury in the United States resulting in about 40,000 deaths annually.[19] The magnitude and significance of destruction of wildlife habitat and of global warming are much less certain, but both are of global scale and potentially of great impact.

The seven risks ranked in the low-importance category by at least 50% of participants were, in decreasing order: electromagnetic fields (EMFs), asteroids and comets hitting Earth, airline accidents,

16. *See* STEPHEN BREYER, BREAKING THE VICIOUS CIRCLE: TOWARD EFFECTIVE RISK REGULATION 21 (1993).

17. *See* John D. Graham and James K. Hammitt, *Refining the CRA Framework*, *in* COMPARING ENVIRONMENTAL RISKS: TOOLS FOR SETTING GOVERNMENT PRIORITIES, RESOURCES FOR THE FUTURE 98 (J.C. Davis ed.1987); James K. Hammitt, *Improving Comparative Risk Analysis* (November 1996) (in this issue).

18. *See* Ralph Kenney, *Mortality Risks Induced by Economic Expenditures*, 10 RISK ANALYSIS 147 (1990); Ralph Keeney, *Estimating Fatalities Induced by the Economic Costs of Regulations*, 14 J. RISK & UNCERTAINTY 5 (1997); Aaron Wildavesky, *No Risk is the Highest of All*, 67 AM. SCIENTIST 32 (1979).

19. *See* NATIONAL CENTER FOR HEALTH STATISTICS, HEALTH, UNITED STATES, 1994 129 (1995).

earthquakes, hurricanes, terrorism, and pesticides on food. The low ranking of EMFs seems consistent with current scientific opinion, which finds little evidence of a strong causal link between exposure to EMFs and cancer or other health effects.[20] The low ranking of the risk of an asteroid or comet colliding with Earth is consistent with the limited attention this risk has received. This lack of attention, however, may be inappropriate when one considers the probability and potential impact. Chapman and Morrison (1994)[21] estimate that the probability of collision with an asteroid or comet of roughly 2 km or greater diameter is one per million years, 70 times higher than the one-per-million lifetimes criterion often invoked with respect to chemical.[22] Collision with a body of this size constitutes an ultimate catastrophe. Releasing energy equivalent to 100,000 megatons TNT or more, such an impact would affect everyone on Earth through direct effects and disruption of the global ecosystem. The impact of an approximately 10 km object at the Cretaceous/Tertiary boundary (65 million years ago) is widely believed to be responsible for mass extinction of dinosaurs and other animals.[23] Although extraterrestrial risks may appear to be uncontrollable, there have been proposals to develop monitoring processes to detect incipient collisions and to develop methods of using nuclear explosions to divert asteroids and comets from a collision course.[24]

Other natural disasters (hurricanes, earthquakes) also ranked low. These events produce few deaths in the United States although they are often catastrophic in less wealthy countries. Terrorism has, fortunately, accounted for relatively few American deaths to date.

Comparison of several pairs of risks suggests participants' rankings were influenced primarily by the expected number of fatalities and that other risk attributes received little weight. In many cases, results of these paired comparisons conflict with common wisdom about which risks are of greatest concern to the general public. As noted above, pesticide residues on food ranked low. This risk also

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20. *See* NATIONAL RESEARCH COUNCIL, POSSIBLE HEALTH EFFECTS FROM EXPOSURE TO RESIDENTIAL ELECTRIC AND MAGNETIC FIELDS 197 (1996).

21. Clark R. Chapman & David Morrison, *Impacts on the Earth by Asteroids and Comets: Assessing the Hazard*, 367 NATURE 33 (1994).

22. *See* Kathryn E. Kelley, *In Search of Zero Risk*, WALL ST. J., Feb. 24, 1995, at A-10; Alon Rosenthal et al., *Legislating Acceptable Cancer Risk from Exposure to Toxic Chemicals*, 19 ECOLOGY L.Q. 269, 276, 323-26, 328 (1992).

23. *See* Chapman and Morrison, *supra* note 21.

24. *See* William Tedeschi and Edward Teller, *A Plan for Worldwide Protection Against Asteroid Impacts*, 10 SPACE POL'Y 183 (1994).

ranked below worker exposure to pesticides and consumption of a high-fat, low-fruit and vegetable diet. Both worker exposure and poor diet are likely to account for more mortality and morbidity than residual pesticides on food. [25] The difference in quantitative risk appears to have outweighed considerations about voluntariness and controllability, which would have been expected to elevate the ranking of residual pesticide contamination, as such contamination is not detectable by the consumer. Risks of smoking to smokers ranked far ahead of the risks to non-smokers, again consistent with the participants having given greater weight to quantitative risk than to other attributes such as voluntariness and benefits to the risk-taker.

Infectious disease excluding AIDS ranked well above AIDS, despite the likelihood that AIDS is a more dreaded affliction. For example, in a general population, willingness to pay to reduce the risk of infection by HIV exceeded that to reduce the risk of infection by hepatitis when receiving transfused blood, even when the risk of hepatitis was 75 times larger than the risk of HIV—300 per million and 4 per million, respectively.[26] The ranking of other infectious disease above AIDS is consistent with the much smaller incidence of AIDS than of other infectious disease in the United States— about 27 and 475 new cases per 100,000 population in 1995. [27]

Automobile accidents ranked considerably above airline accidents, despite apparently greater public fear and attention to airline accidents. The annual death toll is perhaps 100 times larger for automobiles than for airlines. At the level of individual choice, airlines are estimated to be safer than automobiles for travel in excess of a few hundred.[28]

Hurricanes and earthquakes both ranked low, with little difference between them. Both risks account for a small number of deaths in the United States but they differ significantly in the possibility of providing and reacting to warnings. Hurricanes are observed days before making landfall and there is opportunity for people facing a

25. *See* NATIONAL RESEARCH COUNCIL, CARCINOGENS AND ANTICARCINOGENS IN THE HUMAN DIET 309 (1996).

26. *See* James K. Hammitt & John D. Graham, Willingness to Pay for Health: Are Stated Values Responsive to Scope? 14 (July 1996) (unpublished presentation given at The National Bureau of Economic Research, Summer Institute Workshop on Public Policy and the Environment, Cambridge, Massachusetts) (on file with author).

27. *See* Centers for Disease Control and Prevention, *Summary of Notifiable Diseases, United States, 1995*, 44 MORBIDITY AND MORTALITY WKLY. REP. 3 (1996).

28. *See* Leonard Evans et al., *Is It Safer to Fly or Drive*, 10 RISK ANALYSIS 239 (1990); Arnold Barnett, *It's Safer to Fly*, 11 RISK ANALYSIS 13 (1991).

high probability that the storm will strike their location to evacuate. In contrast, earthquakes strike without warning. (Both risks can be mitigated by actions taken well before the event, of course.)

III. COMPARING CANCER, HEART DISEASE AND INJURY

The second section of the CRA exercise concerned three of the major health risks to Americans—cancer, heart disease, and injury. These questions address some of the psychological attributes of the risks, allocation of government resources among them, and WTS as a measure of the importance of differences in risk attributes. Some of the questions were previously asked of a nationwide random telephone sample of 1,000 Americans in a study by the Harvard Center for Risk Analysis, which provides a means of comparing the conference participants' and general public's responses.

Perceptions of which risk is most likely to strike the respondent in the next decade were similar to those of the general sample, except the CRA participants think injury is somewhat more likely than did the general sample (Table 3). Appropriate data to test the accuracy of these perceptions are not available. Table 3 shows the lifetime mortality risk from each cause, but this grossly under-estimates the probability of injury, because most injuries are not fatal. (Responses to this question are especially difficult to interpret because the terms were not further defined—injury in particular may have been interpreted very differently by different respondents.)

A majority of conference participants reported that injury is the most neglected of the three risks by the federal government, with cancer the least neglected. In contrast, a small plurality of the general public reported cancer to be most neglected, with injury following closely behind. Judgments of "neglect" presumably incorporate beliefs about the efficacy and appropriateness of additional government efforts. One indicator of federal attention is NIH research funding. Of the total spent on these conditions, about 68% is for cancer, 25% is for heart disease, and 6% is for injury.[29] Research funding is an incomplete measure of government attention, of course, as additional amounts are spent on developing and implementing measures to reduce the incidence of these conditions and non-government resources are directed toward these problems voluntarily

29. *See* OFFICE OF THE DIRECTOR, DEPARTMENT OF HEALTH AND HUMAN SERVICES, DISEASE-SPECIFIC ESTIMATES OF DIRECT AND INDIRECT COSTS OF ILLNESS AND NIH SUPPORT (1995).

and by regulation. In a similar survey of about 1,000 Chicago-area residents, Savage asked respondents to allocate a hypothetical $100 contribution to research among four risks: stomach cancer and three causes of injury (automobile, aviation, and fires in the home).[30] He found that stomach cancer was allocated the largest amount (almost $50, on average) and concluded that willingness to fund research was greater when the risk was dreaded and unfamiliar.

Table 3: Comparing Cancer, Heart Disease and Injury

	Cancer	Heart Disease	Injury	
Which risk is most likely to strike within the next 10 yrs?				
General population (%)	21	28	50	
Conference participants (%)	15	24	62	
Lifetime fatality risk	0.25	0.30	0.06	
Which risk is most neglected by the federal government?				
General population (%)	40	23	36	
Conference participants (%)	14	34	52	
NIH research funding, $billions[a]	2.12	0.79	0.20	
From which risk would you save 100 lives?				
General population (%)	62	14	23	
Conference participants (%)	41	13	46	
Life years lost before age 65	6	4	30	
Number of lives saved from risk that would be as important as 100 lives saved from cancer				
Percentile:	25th	50th	75th	Mean
Heart Disease (lives)	100	100	110	105
Injury (lives)	60	100	135	110
How much do you feel people are in control of the risk?				
General population[b]	3.9	5.5	5.3	
Conference participants[b]	4.3	6.3	6.1	
Ratings on other attributes (conference participants only)				
Dread[b]	9.0	6.3	4.0	
Risky activities benefit risk-bearer[b]	4.7	5.0	6.8	

Notes:
[a] FY94 (NIH, 1995)
[b] Mean of 1-10 scale, 10 high.

30. *See* Ian Savage, *An Empirical Investigation into the Effect of Psychological Perception on the Willingness-to-Pay to Reduce Risk*, 6 JOURNAL OF RISK AND UNCERTAINTY 75 (1993).

The public sample expressed a strong preference for reducing risks from cancer; 62% chose to save 100 lives from cancer rather than 100 lives from heart disease or injury. In contrast, slightly more of the conference participants chose to save lives from injury (46%) than from cancer (41%). In both samples, heart disease received the least support. Conference participants may have given greater weight than the public sample to the average age of death from the different causes and hence life-years saved, although analysis of reported WTS reveals considerable diversity in how the conference participants evaluated cancer and injury. For example, one quarter of participants chose to save only 60 lives from injury rather than 100 from cancer, but another quarter of participants chose to save 100 lives from cancer over as many as 135 lives from injury. In contrast, willingness to sacrifice lives to heart disease rather than cancer suggests other attributes are of little importance in distinguishing these risks; few participants would have been willing to sacrifice many lives to alter the mode of death. (Comparable WTS questions were not included in the public survey.)

Judgments about differences in controllability of the three risks were comparable in the two samples, although the conference participants rated all three slightly more controllable than did the public respondents. Conference participants were also asked to rate the risks in terms of two other attributes—dread and the extent to which the risk-bearer benefits from activities that impose the risk. Cancer and injury were rated most differently, with cancer associated with most dread and injury most associated with providing benefits. Both differences are associated in the literature with less tolerance for cancer.

IV. WTS AND DIFFERENCES IN RISK ATTRIBUTES

The following sections of the CRA exercise involved choosing between risks or abatement programs and attempted to quantify the importance of risk and program attributes by adjusting the numbers of lives lost to each risk such that, all things considered, the risks (or programs) would be judged equally important.[31] Across a variety of contexts, conference participants expressed a strong preference for whichever risk or program had the largest benefit in terms of lives saved; other attributes had much less influence on preferences.

31. Other literature examining tradeoffs between lives saved and other risk attributes includes Cropper and Subramanian (1995), McDaniels (1988), McDaniels et al. (1992), Savage (1993), and Viscusi et al. (1991).

Allocation of government resources involves choosing not among risks but among programs designed to mitigate them. Attributes of the program, as well as the risk, may be important. Cropper and Subramanian[32] conducted a telephone survey of approximately 1,000 randomly selected individuals to evaluate WTS between a variety of environmental and public health programs. The third section of the CRA exercise replicated one of the choices they posed, between alternative programs to reduce deaths from heart and lung disease: a school education program to discourage children from becoming smokers and a program to reduce industrial air pollution. As shown in Table 4, when each program was stated to save the same number of lives per year, conference participants preferred the air-pollution control program to the smoking-education program, as did the public sample (Cropper and Subramanian did not offer their respondents a no-preference option). The magnitude and dispersion of WTS were much smaller for the conference participants than for the public sample, however. The median number of lives saved by the smoking program such that it would be as important as saving 100 lives via the pollution program was 99 for the conference participants compared with 159 for the public sample; the quartiles were 72 and 125 for the conference sample compared with about 40 and 300 for the public sample.

A similar section asked about the choice between coal combustion and nuclear fission as sources of electricity. The risks associated with these power sources differ in many dimensions, including ambiguity (confidence in risk estimates), the potential for catastrophic accidents, persistence of consequences, and others. In the initial question, the expected numbers of lives lost per unit electricity was stated to be twice as large for coal as for nuclear power (although the ambiguity or uncertainty about the risk level is larger for nuclear power). At this two-to-one ratio, nearly three-quarters of the conference participants preferred nuclear power. More than half the participants were unwilling to sacrifice any lives to rely on coal rather than nuclear power. Only one quarter chose coal if the expected number of lives lost were twice the expected number for nuclear power. One suspects that a sample of the general public confronted with this question would be much less tolerant of nuclear power.

32. MAUREEN L. CROPPER & UMA SUBRAMANIAN, PUBLIC CHOICES BETWEEN LIFESAVING PROGRAMS: HOW IMPORTANT ARE LIVES SAVED? (The World Bank, Policy Research Working Paper No. 1497, August 1995).

Table 4: Tradeoffs Between Lives Saved and Other Risk and Program Attributes

Which program is best for society?	Smoking education	Air pollution control	No preference	
General populations (%)[a]	45	55	na	
Conference participants (%)	31	48	20	
Number of lives saved by smoking education as important as lives saved by air pollution control				
Percentile:	25th	50th	75th	Mean
General population[a]	40	159	300	
Conference participants	72	99	125	139
Which energy source is preferred if the expected number of deaths from coal is twice the expected number from nuclear power?				
	Coal	Nuclear	No preference	
Conference participants (%)	20	73	7	
Number of expected deaths from coal that are as serious as 100 expected deaths from nuclear power				
Percentile:	25th	50th	75th	Mean
Conference participants	100	100	200	228
If airbags kill 10 children for every 300 adults saved, should children be prohibited from riding in the front seat?				
	Yes	No		
Conference participants (%)	55	45		
If not, should airbags be required?				
Conference participants (%)	62	38		
What is the smallest number of children killed by airbags, for every 300 adults saved, such that air-bags should not be required?				
Percentile:	25th	50th	75th	Mean
Conference participants	10	25	100	59
If fatality risks of treated and untreated water are the same, should water be chlorinated?				
	Yes	No	No preference	
Conference participants (%)	62	25	13	
For every death from cancer, how many deaths from microbial contamination would make the risks of treatment and lack of treatment equally serious?				
Percentile:	25th	50th	75th	Mean
Conference participants	50	100	101	123

Note: [a] Cropper and Subramanian (1995)

The subsequent section addressed a recently publicized competing risk of passenger-side automobile airbags—fatalities to children in low-speed crashes that they would have otherwise survived. Because the risk to children can be sharply reduced if they do not ride in the front seat, this risk highlights issues of paternalism and freedom of action. Indeed, conference participants were about evenly split on the question whether children should be legally prohibited from riding in the front seat of vehicles equipped with passenger-side airbags, if 10 children were killed for every 300 adults saved by such airbags. Almost two-thirds of the participants reported that passenger-side airbags should continue to be required even if children were not legally prohibited from riding in front. The willingness to sacrifice children by airbag for every 300 adults saved was variable: the quartiles of the distribution were 10 and 100. About 10% of respondents reported values of 200 or larger; the highest values were 275 and 250. (Data released soon after the survey was conducted suggest the tradeoff may be much worse than posed here. As of November 1, 1996, 32 children and one adult woman had been killed and 164 people had been saved by passenger-side airbags, a ratio of about five to one. Driver-side airbags have a much better record, having killed 19 and saved about 1,500 individuals.[33]

The final risk comparison involved disinfecting drinking water. The most common technology is chlorination, which is effective but produces byproduct trihalomethanes (e.g., chloroform) that may cause cancer in those consuming the water. Untreated water may have microbial contamination which can cause gastrointestinal illness. When asked whether they would prefer that their town's water supply be disinfected with chlorine or left untreated if the fatality risks of the two alternatives were equal, 62% expressed a preference for disinfection. A preference for not treating the water (selected by 25% of participants) appears to require that the morbidity consequences of cancer be viewed as substantially worse than those of gastro-intestinal illness, since the probability of non-fatal illness is likely to be much larger for untreated than for chlorinated water. Estimates of WTS suggest that most participants would have rejected chlorination if the expected number of cancer fatalities exceeded the expected number from untreated water: the 75th percentile of the

33. *See Hearings on the Effectiveness of Airbags Before the Transportation Subcommittee of the House Committee on Appropriations regarding the Effectiveness of Air Bags*, 104th Cong., 2d Sess. (1997) (statement of Ricardo Martinez, M.D., Administrator, National Highway Traffic Safety Administration).

number of microbial-illness deaths that were judged as important as 100 cancer deaths was 101 and the 25th percentile was only 50, consistent with the notion that morbidity from microbial illness was perceived to be a more important risk than cancer morbidity (due to its higher frequency). Somewhat paradoxically, the mean number of deaths from microbial illness judged as important as 100 cancer deaths was larger than 100, reflecting the sensitivity of the mean to two outlying values, 915 and 1000.

V. CONCLUSION

Comparative Risk Analysis requires integrating information about the probabilities of diverse consequences together with preferences over these consequences and over other risk attributes. The CRA exercise described here provided an opportunity for participants at the 1996 Cummings Colloquium on Environmental Law to grapple with some of the issues involved in comparing risks.

Preferences and the values that inform them differ among people. Consequently, the output of a CRA is likely to depend on the participants selected. Part of this difference is systematically related to education, professional experience, and other factors.[34] Participants in the exercise reported here are "experts" in risk assessment. Risk comparisons by this group appear to be more sensitive to differences in first-order quantitative differences in risk—mortality probability, population affected, life-years lost, and morbidity incidence—than do comparisons by samples of the general public. Such differences are plausibly related to the education, professional activities, socialization, and self-selection of participants in the conference at which this exercise was conducted.

34. *See* Hank Jenkins-Smith & Gilbert W. Bassett Jr., *Perceived Risk and Uncertainty of Nuclear Waste: Differences Among Science, Business, and Environmental Group Members,* 14 RISK ANALYSIS 851 (1994).