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From Experts' Beliefs to Safety Standards: Explaining Preferred Radiation Protection Standards in Polarized Technical Communities

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From Experts' Beliefs to Safety Standards: Explaining Preferred Radiation Protection Standards in Polarized Technical Communities

I. INTRODUCTION

Public policy debates often involve complex, high-stakes issues in which the views of experts within scientific and technical communities play a prominent role. Disputes over appropriate governmental actions concerning global climate change, genetically modified organisms, nuclear waste disposal, cloning, and stem cell research highlight the political importance that can be attached to debates within scientific communities. Not only do these debates influence the kinds of assumed causal relationships that underlie policy alternatives (e.g., the link between CO_2 concentrations in the atmosphere and global temperatures, or the dispersal patterns of pollens from genetically modified corn), but also those appointed to advisory and technical policy making positions are often chosen from the participating scientific communities. The appointment to such positions has become an increasingly contentious process; some critics contend that experts' policy positions have trumped their scientific standing in determining appointments to important science policy boards (Revkin 2004; Mooney 2005).

The relationship between debates within technical communities and policy-making can become particularly complicated when scientists are called upon to inform decisions for managing technological risk in the face of incomplete or ambiguous scientific data. The most significant challenge for scientists is likely to stem from the need to take the step from beliefs founded on less-than-certain theory and empirical evidence to normative advice on appropriate regulation. In these situations scientific consensus may be difficult to achieve. Uncertainty and complexity may result in competing scientific claims in support of alternative policy positions, as has been evident in such cases as fluoridation and nuclear power (Mazur 1981: 13-32). Scientists can be quite self-conscious about their need to rely on extra-scientific bases for providing expert advice. Jasanoff (1990: 229) argues that "the experts themselves seem at times painfully aware that what they are doing is not 'science' in any ordinary sense, but a hybrid activity that combines elements of scientific evidence and reasoning with large doses of social and political judgment" (Also see Salter, 1988; McGarity, 1979).

If experts sometimes have no choice but to draw upon extra-scientific bases in the provision of policy advice, what are these bases? Of particular interest for this study is the manner in which values and attitudes about society, politics, and risk may serve to guide judgments about risk standards in the absence of scientific consensus concerning the central underlying causal relationships that generate a hazard. One might expect that norms of science would lead scientists to ground policy recommendations firmly on their beliefs about those causal relationships. But it is also possible that recommendations will require experts to invoke value judgments, or what Weinberg dubbed “trans-scientific” considerations (Weinberg 1972). Yet little systematic evidence is available to shed light on how members of technical communities make the step from what they believe they know – or do not know – about the sources of hazards to making policy advice to address the hazard.

A wide range of studies, grounded in various disciplines, has confirmed that scientific and technical experts participate as policy advocates in technical disputes (c.f. Mazur 1981; Sabatier and Zafonte 1999; Weible and Sabatier 2005). Broad evidence also indicates that scientists, like lay people, tend to associate perceived technological risks with political and social values (Barke and Jenkins-Smith 1993; Slovic et al 1995; Plutzer, Maney and O’Connor 1998; but see Rothman and Lichter 1987). But little systematic research has focused on the roles social and political values play in mediating between experts’ scientific and technical beliefs and their public policy recommendations. One might surmise that, once a trained scientist has identified what she believes to be the “most likely” causal relationship underlying a hazard, she will be reluctant to recommend a different basis for setting public policy. But it is equally plausible that scientists will seek to minimize salient hazards (or “err on the side of caution”) in translating beliefs about causal relationships into policy advice concerning safety standards, particularly in the face of ambiguity. Indeed, this is the basis for much of the support for the “precautionary principle” in regulatory standard setting (Tickner, Raffensperger and Myers 1999; Tickner 2002; but see Sunstein 2005).

Our inquiry focuses on a specific case in which scientific communities have been asked to provide advice on an uncertain empirical question: what is the form of the relationship between low doses of ionizing radiation and human cancer incidence? Data from a unique survey of scientists from two distinct subpopulations – those working in the federal nuclear energy and weapons laboratories and those who are members of the Action Network of the Union of Concerned Scientists (UCS) – allow us to gain insight into how members of technical communities reach conclusions about risk and risk standards. This case is of particular relevance for several reasons. First, despite the fact that the relationship between ionizing radiation and cancer has been the focus of an enormous scientific effort, uncertainty remains about that relationship at very low doses. Second, controversy over radiation standards has spilled over from contentious policy debates such as those concerning nuclear energy, nuclear waste disposal, and clean-up of the nuclear weapons complex. This combination of uncertainty and controversy makes this case potentially quite revealing. Third, this case is of substantial relevance to current policy debates. Radiation protection standards are at the core of current questions about the effort to dispose of spent nuclear fuel, promote safe utilization of nuclear energy, and transport spent nuclear fuel from reactors to storage and disposal sites. As such, the radiation dose-response case can provide both theoretical insights and improved understanding of the way technical experts reach policy positions on pressing current issues. Finally, this is one of very few cases for which systematic data are available with which to empirically observe the shift from beliefs about technical relationships to policy standards.

The attributes that make our case useful and instructive also dictate caution when making inference to other technical issues. The health effects of ionizing radiation have been characterized by contention for decades. While the level of controversy in some scientific debates may rise to similar levels (e.g., global climate change and genetically modified organisms), we expect that such high levels of publicly salient contention are the exception rather than the rule. As such, we would urge caution in inferring from this case to less controversial technical issues.

1.a. Uncertain Science and Risk: The Radiation Dose-Response Controversy

The complex role of science in contentious policy debates is well illustrated by the question of "how much exposure to radiation should be permitted by public safety standards?" Radiation is pervasive in the natural environment from cosmic sources, soil, and rocks, so there exists a background level of radiation exposure that presumably poses little or no threat to human health. Because artificial radiation is by definition subject to some human control, the policy issue of "how much exposure is safe?" is of substantial importance. Until quite recently, however, there appeared to be no scientific consensus on the health effects of small doses of ionizing radiation (US General Accounting Office 2000).

Since 1972 the U.S. National Academy of Science's Committees on the Biological Effects of Ionizing Radiation (BEIR), under the auspices of the National Research Council, have conducted a series of reviews of the state of knowledge about radiation epidemiology, bioeffects, and risk analysis in order to provide estimates of the risks associated with low levels of ionizing radiation (for background see Hendee, 1992; Kocher, 1991). One of the most important questions considered in the BEIR committees is the nature of the dose-response relationship for ionizing radiation. There are several models for describing this relationship. To oversimplify a very complex topic, some evidence indicates that there are threshold levels of radiation exposure below which health effects are not likely, and that at some point above this threshold the carcinogenic response becomes linear. This model is generally referred to as the "Threshold Model".[i] On the other hand, some studies suggest that there is no safe level of exposure and that small doses of radiation can induce disproportionate carcinogenic responses (a "Low-dose/High-response" or "supralinear" model). Between these extremes lies the conventional "Linear-No Threshold" model, in which cancer incidence is assumed to be roughly proportional to the absorbed dose over the full range of exposures. These models are depicted in Figure 1.

(Figure 1 About Here)

A scientific consensus on which model is correct has proven to be elusive (Mettler and Moseley 1985; U.S. General Accounting Office 1994, 2000; Moore 2002). While the linear model has long been the predominant choice in standard setting in both the U.S. and international regulatory bodies, as recently as 2000 the GAO found that there was no consensus on the scientific basis for that model – or any other. This lack of consensus has reflected the complexity of the radiation dose/response phenomenon (these complexities are summarized in Chapter 2 of National Academy of Sciences 2005), compounded by the lack of data on a wide range of doses on humans. As a result, different regulatory agencies (the U.S. Environmental Protection Agency and the Nuclear Regulatory Commission) continue to employ different radiation exposure standards (U.S. Government Accounting Office 1994; 2000).

The technical debate over the effects of low-level radiation has come to reflect the fault-line between proponents of nuclear programs and their critics. Many nuclear program proponents have argued that the Linear-No Threshold model overestimates risks, while critics counter that it underestimates risks.[ii] High stakes trade-offs between protection levels and public expenditures have pushed the debate onto the U.S. Congressional agenda. The cost of a deep-geologic repository in Nevada for disposal of spent fuel and high-level nuclear waste has been driven in part by the EPA regulatory requirement that doses of radiation migrating from the repository meet exposure safety standards for thousands of years. Similarly, the cost of site remediation at federal nuclear weapons facilities contaminated with plutonium and other isotopes is based, in part, on the exposure standards set by federal regulators (Schwartz 1998; Jacobson 2002). The costs of these programs are sensitive to the radiation exposure standards that are to be met, which in turn are justified by the assumed radiation dose/response relationship. The budgetary implications are enormous, potentially amounting to a net difference of over a trillion dollars depending on which standard is employed.[iii] Therefore the assumed form of the radiation dose-response relationship has huge implications for both human health and government expenditures.

Not surprisingly, the safety and budgetary implications of radiation protection standards served to focus political attention on the scientific bases for those standards. In 1997 the U.S. Congress called upon the National Academy of Science to reassess the radiation low dose/response function utilizing the most recent data available. This effort was the seventh in a sequence of committees evaluating the biological effects of ionizing radiation, referred to as the BEIR VII Committee. The composition of the Academy's Committee led to disputes over the potential bias of the members, with nuclear critics arguing that the nominees were stacked with proponents of relaxing nuclear safety standards, public comment on the nominations had been inadequate, and that conflicts of interest by nominees had not been disclosed (Moore 2002:35). After several modest changes in the composition of the BEIR VII Committee, the task was initiated, and the committee report was released in 2005 (National Academy of Sciences 2005).[iv]

The BEIR VII report surveyed the available studies on low-doses of radiation, and concluded that – despite remaining uncertainties – the accumulated evidence has strengthened the case for the Linear-No Threshold model. The report urges further research to reduce uncertainty and fill in gaps in the data for various mechanisms by which low-level radiation may induce cell damage. Whether the report generates broader scientific consensus remains to be seen. Members of technical communities will need to make the step from the dose-response models inferred from the body of current research, with its remaining uncertainties and limitations, to preferences for models to be employed in radiation protection standards. How will they go about making that step?

1.b. Values, Beliefs and Judgments about Caution

The low-level radiation dose/response issue combines scientific uncertainty, high stakes and political controversy. Like many other on-going scientific debates on environmental and health issues, the question raises clear theoretical questions that, in principle, could be answered with appropriate data collection and hypothesis testing. Moreover, again in principle, the scientific evidence on the issue of the functional *form* of the dose/response relationship would seem to be separable from judgments about managing risks in setting health and safety standards. But scholars of the role of science in policy-making argue that the “hybrid activity” of regulatory science necessarily invokes the social values and beliefs of experts in reaching scientific conclusions. The question we pose is *what kinds of values and beliefs matter, and in what ways,* as scientists make the step from beliefs about dose-response functions to appropriate assumptions for regulatory standard setting?

We conjecture that the kinds of values and beliefs most likely to enter into scientific and safety assessments concerning low-level radiation exposure fall into three major groupings.

The first concerns fundamental dispositions held by scientists concerning the ways in which society and politics should be oriented. These values play a central role in theories of belief system hierarchies (Hurwitz, Peffley, and Seligson 1993, Fiske and Taylor, 1992). Recent scholarship suggests several kinds of "dispositions"[v] that would be directly relevant to the issue of radiation protection. Douglas and Wildavsky (1980) argue that beliefs about the appropriate structure of social relationships in society underlie decisions about which kinds of threats (e.g., social disorder, loss of personal liberties, or threats to the environment) should have priority. By this argument, those who adhere to an egalitarian world-view would perceive risks imposed upon people by corporations or government agencies as grave threats because these entities represent hierarchical concentrations of wealth and power (Dake 1992; Ellis, Wildavsky and Thompson 1990; Wildavsky 1991; Kahan et al 2006). Measures of egalitarianism have been shown to be predictive of attitudes concerning environmental risks in a number of studies (Dake and Wildavsky 1990; Dake 1991; Jenkins-Smith and Smith 1994; Slovic and Peters 1998). In line with this research, we conjecture that egalitarian values will be associated with a greater tendency toward "precaution" in radiation protection standards. Another general disposition that has been linked to environmental concerns among Americans is political ideology. Like many scholars before us, we employ a measure of political ideology based on a liberal-conservative continuum (Kuklinski, Metlay and Kay 1982; Rothman and Lichter, 1987; Plutzer, Maney and O'Connor 1998). Political ideology has been found to be associated with attitudes toward nuclear power, such that politically conservative individuals were more likely to support continued reliance on nuclear energy. Following these findings, we conjecture that political conservatism will be associated with a tendency to support less restrictive radiation protection standards.

A second set of beliefs and values concerns how society ought to make decisions about technology, risk and environmental preservation. We distinguish among three societal decision components; who should make decisions about potentially risky technologies? How should the risks generated by society be allocated? And how should tradeoffs between preserving the environment and material gains be weighed? Judgments about who is to make decisions regarding potentially risky technologies (such as those that produce ionizing radiation) can range from preferences for strong top-down systems dominated by experts to those grounded in direct participatory democracy (Press 1994). We conjecture that a preference for reliance on technical experts, coupled with a belief that mass publics are generally ill equipped to make reasoned choices about complex technologies, will be associated with a belief that technology and the technological elite can be relied upon to effectively manage risks. We refer to this as a "technocratic disposition"[vi] and conjecture that it will be associated with a less precautionary approach to standard setting. The second kind of societal decision concerns preferences for managing and allocating risks in society. Here the consideration is whether society can or should avoid imposing risks on individuals, whether individuals ought to be consulted before risks are imposed, and whether societal benefits can justify imposing risks on individuals (Beck 1992; Franklin 1998; Piller 1991). We conjecture that those who are societally "risk acceptant" – meaning that they believe it is acceptable for society to impose risks on individuals in return for social gains – will see less need for precautionary safety standards than those who are societally "risk averse". The third societal decision component concerns tradeoffs between environmental preservation and economic or material gain. Inglehart (1989; 1997) has argued that the evolution of mass beliefs toward a "post-materialist" culture has led to an emphasis on environmental preservation and "quality of life" issues, in contrast to the earlier "materialist" emphasis on security and material wealth. Preferences for environmental preservation over material wealth are likely to carry with them a dislike for technologies that appear to be harmful to the environment and human health. Moreover, those who see important environmental values to be in jeopardy from human activity will place greater urgency on avoiding or restraining environmentally threatening activities. Thus, we conjecture that those most concerned with environmental preservation will be more likely to take a precautionary stance in health standard setting than those who are more sanguine about the state of the environment.

A third grouping of values and beliefs likely to enter into scientific and safety assessments concerning low-level radiation exposure focuses on scientists' perceptions of the nature of science itself. Does the scientist believe that the scientific enterprise is a cumulative, progressive development of bodies of knowledge, or is the scientific enterprise subject to radical "paradigm shifts" in which prior knowledge must be apprehended in light of new fundamental understandings? (Popper 1980; Kuhn 1970; Lakatos 1978). Is knowledge grounded in the scientific process accorded special, superior status, or is scientific understanding merely one among many ways of knowing alongside intuition, revelation, and other sources of knowledge? And how much is expected of science –ultimately, can it fully explain everything, or is its scope more limited? While these points only skim the surface of a rich philosophical debate, we suggest that they provide indications of broader beliefs about how progress in science is understood, and how scientific knowledge can be expected to contribute to resolving social problems. For purposes of this analysis, we dub those who see science as the preeminent method of knowing, and as capable of explaining just about everything as "scientific optimists." We conjecture that those with the least optimistic views of science will be more skeptical of extant scientific findings, and therefore will be more likely to embrace the precautionary principle in setting radiation protection standards.

Along with the kinds of values and beliefs addressed above, we also expect that beliefs about the appropriate degree of precaution in standard setting will be associated with an array of demographic and educational attributes of the scientist. There is a substantial body of work that relates demographic factors such as gender, age, education, and race to risk perceptions (Sjöberg and Drottz-Sjöberg, 1991; Steger and Witt, 1989; Smith and Watzke, 1990; Svenson and Karlsson, 1989; Flynn, Slovic, and Mertz, 1994). This research has found women, non-whites, the young, and the less well educated to perceive greater risks. Some of this research has examined scientists in particular and found patterns similar to the general public to apply to those well trained in science and technology (Barke, Jenkins-Smith, and Slovic, 1993). Given this previous work, in testing for the role of beliefs and values we control for age, gender, and field of specialization.[vii]

Along with beliefs and the individual-level characteristics of scientists, we expect that the kinds of professional organizations to which scientists belong can have a substantial association with the kinds of policy-relevant beliefs and values of scientists. As noted above, some observers claim that scientists' perspectives in the BEIR debate are linked to membership in professional associations as well as advocacy policy positions (Moore 2002). Such associations are likely to result from a combination of selection effects (as when scientists choose to affiliate with organizations that take scientific and policy positions compatible with their own), peer influence, and perhaps organizational interests. In the case of the BEIR debate, we would expect the effects of organizational affiliation to be strongest when the organizations themselves are positioned within the radiation protection policy subsystem (Sabatier and Jenkins-Smith, 1993). For that reason we compare scientists from two distinct populations: the Action Network of the Union of Concerned Scientists (UCS) and the scientific and technical staffs of several of the Department of Energy's national laboratories.

The UCS was selected because the organization has, since its creation in 1969, remained at the center of policy debates concerning nuclear issues.[viii] The UCS has taken frequent positions expressing concern that "the government that we see today is in many respects no longer democratic because the vast bulk of its constituency cannot begin to scrutinize some of the gravest issues," (Balogh, 1991) and arguing that only the scientific community is capable of penetrating the "shroud of secrecy" that covers advanced military technologies, environmental impacts of industrialization, and the applications of biological research. The UCS has recruited scientists to address health and safety issues regarding nuclear power, and it has publicized divisions among the scientific experts responsible for development and monitoring of large-scale risky technologies (Balogh, 1991).[ix] The scientific and technical staffs from four of the national laboratories of the U.S. Department of Energy were also selected, including Sandia and Los Alamos National Laboratories (which include nuclear weapons technologies in their research agendas), as well as the Lawrence Berkeley and Pacific Northwest Laboratories (which normally do not conduct nuclear weapons research). These organizations were chosen because we expect that the values of scientists in the UCS and National Lab groups will have systematically different impacts on their interpretation of scientifically ambiguous evidence and on the application of scientific understanding to policy recommendations. We also wish to examine whether value differences within these groups are explained by factors that have been found to affect risk perceptions of scientists in other arenas (e.g., Barke and Jenkins-Smith, 1993; Barke, Jenkins-Smith, and Slovic, 1997).

II. DATA AND METHODOLOGY

The data used in this study are taken from a mail survey that was designed to investigate attitudes regarding a range of issues related to nuclear technologies. One part of the survey focused on judgments about the scientific process, the interpretation of scientific evidence, and the relationship between scientific knowledge and the policy process. Study design and question wording were sharpened by the results of three focus groups that included lay citizens, nuclear and other types of engineers, physicists, sociologists, and science policy makers.

The survey was administered to randomly selected samples of two groups. The first was a random sample of the 80,000 members of the UCS Action Network. A total of 1,155 usable responses were received for a response rate of 55 percent. Of these, 865 had Ph.D. or Masters degrees and are included in this analysis. The second sample was drawn from lists of eligible members of the scientific and technical staffs were obtained from each Lab, including 2229 individuals.[x] The overall response rate for the Lab sample was 53 percent, producing 1,226 valid returns. Among the Lab respondents, 872 had Ph.D. or Masters degrees and were included for analysis.

Table 1 shows the educational and demographic characteristics of the respondents included in the study. In order to narrow the focus to scientists, we included only those who reported that they had achieved a Masters or Ph.D. degree. Among the National Lab respondents, the modal field was engineering (47%), followed by the physical sciences (39%). Among the UCS respondents, the most frequent field was the physical sciences (39%) followed by the life sciences (29%). UCS respondents were more likely than Lab respondents to have earned a Ph.D., and were on average about 5 years older. Both groups were predominantly male.

(Table 1 about here)

2b. Variables

The dependent variables in this study are measures of what scientists believe to be the correct (or most likely) dose/response relationship for low-level radiation, and which relationship scientists believe should be used for safety standard setting. Of particular interest is the difference, if any, between these beliefs. Survey respondents were asked the following question:

> Studies of the relationship between radiation dose and incidence of cancer have had to rely on incomplete data. In particular, data on the low dose effects are statistically inconclusive. Several possible kinds of relationships have been

hypothesized:

(1) a LINEAR RELATIONSHIP, in which the low-dose effects of radiation have been assumed to be proportionate to high-dose effects (hereafter referred to as the "linear-no threshold" or LNT model)

(2) a QUADRATIC RELATIONSHIP, in which the effects of radiation at low doses are minimal below some threshold (hereafter referred to as the threshold model)

(3) a LOW-DOSE, HIGH RESPONSE RELATIONSHIP in which the effects of radiation are assumed to be proportionately higher at the low dose ranges (hereafter referred to as the supralinear model)

The possible relationships were then illustrated for the respondents as shown in Figure 1. Respondents were then asked two questions:

> Given your own knowledge of radiation effects on humans and other organisms, which of the above hypothesized relationships do you think is most likely to be correct? ("Dose-Response").
>
> Which of the hypothesized relationships do you think should be assumed for purposes of setting public safety standards for management of radioactive materials? ("Policy Standard").

The responses to these questions, broken out by the two scientist samples, are shown in Table 2.

(Table 2 about here)

A substantial majority of the Lab respondents (70.2%), and a plurality of the UCS respondents (47.7%), chose the threshold model as the one "most likely to be correct". When asked which function should be assumed for purposes of safety standard setting, a plurality of the Lab scientists (43.2%) picked the LNT model. The UCS scientists were nearly evenly split between the LNT (36.2%) and supralinear (35.7%) models. For both groups, scientists make a cautionary shift when moving from a "most likely" model to the one preferred for safety standard setting. Given that the USC and Lab scientists occupy such disparate positions in the nuclear policy domain, the similarity of this pattern across the two groups is quite remarkable. Such broad similarities provide some support for the proposition that scientists within policy domains can act as an "epistemic community" that finds common ground despite the apparent prevalence of institutional and political controversy (Haas 1989; Haas 2006). Nevertheless there is significant variance both within and between samples, and explaining that variation is the focus of our analysis.

The shift from most likely relationships to those preferred for setting safety standards provides a measure of the extent of risk acceptance or aversion in radiation protection. The three response functions can be ordinally ranked from those in which (all else being equal) low-doses of radiation pose least risk (threshold) to greatest risk (supralinear). Thus a “risk neutral” scientist would be consistent – the relationship assumed for safety standards would be the same as the one believed most likely to be correct. A “risk averse” scientist, as might be called for by the precautionary principle, would chose a dose-response function for safety standards that implies greater risk than is judged as likely to be correct. Finally, in the unlikely case of a “risk acceptant” scientist, safety standards would be set on the basis of a dose-response relationship that implies less risk than is likely to be correct. Table 3 shows the pattern of shifts from the choice of “most likely” functions to those that respondents to the scientist survey would assume for purposes of safety standard setting.

(Table 3 about here)

Of the respondents who chose the threshold model as the most likely to be correct, more than 60 percent were inconsistent, and in the risk-averse direction. As expected, less than 1 percent of either Lab Scientists or UCS Scientists were "risk-acceptant" -- endorsing the threshold for policy while choosing either the LNT or supralinear model as scientifically correct. Thirty-six percent of the respondents were risk neutral, and a plurality (40%) were risk averse. Thus, as is evident from the results in Table 3, the largest fraction of the scientists we surveyed gave responses that were consistent with the precautionary principle.[xi]

Independent Variables

As discussed above, we hypothesize that scientists’ judgments about risk may be associated with three major categories of beliefs and values. The first set concerns broad social and political dispositions, including egalitarianism and political ideology. The survey items used to measure these dispositions are shown in Table 4, and the full question wording is provided in the appendix. Mean values are shown for the Lab and UCS sub-samples, with difference of means tests shown in the right-hand column. The measures of egalitarianism, similar to those employed elsewhere (Dake and Wildavsky 1990; Jenkins-Smith and Smith 1994), indicate that the UCS respondents tended to be more egalitarian than the respondents from the national laboratories. Similarly, the UCS respondents placed themselves closer to the liberal end of the political ideology scale, while the Lab respondents tended toward the conservative side. The shaded rows in the table indicate which variables will be employed as independent variables in our models explaining the respondents' choice of radiation dose/response functions.

(Table 4 about here)

The second set of beliefs and values concern scientists' views about how society should make decisions about technology, risk and environmental preservation. These measures are shown in Table 5, and full question wording is included in the appendix. One set of measures concerns how risks should be allocated in society: is it necessary or proper for society to impose risks on people without consent? Can risks be imposed if the benefits to society are large, or if compensation is provided to those who are harmed? As seen in Table 5, while the risk perspectives differed consistently across the UCS and Lab survey respondents, both groups tended (on average) to disagree with imposing risks on individuals without consent, regardless of whether benefits are large or compensation is provided. Interestingly, both groups also agreed that it is necessary for risks and sacrifices to be accepted in order for society to prosper. These measures were collapsed onto a "risk allocation index" (scale alpha 0.715).

(Table 5 about here)

Table 5 also includes measures of scientists' perspectives on how decisions about technology and risk should be made. Scientists from both groups tended to prefer that the technical elite make such decisions, though the Lab respondents were more emphatic in this regard. These measures were combined into a “technocratic index” (scale alpha=0.611), with higher values indicating a greater preference for elite influence in technical and risk decisions.

Table 5 also includes measures of scientists’ preferences in the trade-off between environmental preservation and economic development. While the central tendencies for both samples were on the same side of the scale midpoints, the UCS respondents were less likely to agree that no environmental regulation should be imposed unless it is proven that benefits exceed the costs, or that one’s right to a job was more important than another’s right to a clean environment. These items were combined into an environment/economy scale (scale alpha = 0.606). The full question wording is included in the appendix.

The third set of measures concerns beliefs concerning scientific optimism, as shown in Table 6. On these matters differences between the UCS and Lab respondents are quite modest, with both tending to agree that the scientific process is the only valid way to understand nature, tending to disagree with the propositions that “scientific evidence can be interpreted to fit opposing points of view,” and that scientific research results are always affected by the values of the researcher. At the same time, both tended to agree that intuition can provide an understanding of nature as valid as that of science. These items were collapsed into a “scientific optimism index” (scale alpha = 0.677). In addition, respondents indicated whether they believed change in scientific knowledge tended to occur incrementally and gradually, or in an abrupt and revolutionary manner.[xii] The UCS respondents were somewhat more likely to believe that the process was abrupt and revolutionary. The full question wording is included in the appendix.

(Table 6 about here)

III. ANALYSIS

Our primary interest in this study is to ascertain whether the kinds of values and beliefs discussed above have a significant bearing on the ways in which scientists make the shift from “most likely” dose-response relationships to those that they believe should be used as the basis for setting safety standards. For this purpose, we employ nominal logistic regression models designed to measure the influence of covariates on categorical dependent variables.[xiii] The models allow us to test our conjectures about the effects of our array of independent variables on the ways in which scientists reach judgments about appropriate safety standards.

As shown in Table 3, more than half of those scientists who picked the threshold model as most likely to be correct would also reject it for standard setting. Roughly a third of those who picked the LNT as correct would also reject it for standard setting. The shift was overwhelmingly in the direction of a more stringent standard – or a "precautionary shift."

To model this precautionary shift, differences between the choice of the "most likely" and "preferred standard" dose-response functions were coded as a nominal dependent variable. Those who were consistent made no precautionary shift; these respondents opted for standards that reflected the relationship judged most likely between low-level radiation exposure and human cancer incidence. Those who changed from the threshold to the LNT, or LNT to the supralinear, were making a single-step precautionary shift. Those who shifted from the threshold as "most likely" to the supralinear function as the preferred basis for standard setting were making a two-step precautionary shift.[xiv]

We first model the precautionary shift among those respondents who believed the threshold dose-response function was most likely to be correct.[xv] Those who made no precautionary shift provide the base of comparison, and coefficients are estimated for shifts to the LNT and the supralinear functions. The results are shown in Table 8. The pseudo R^2 for this model is 0.167, indicating that the independent variables account for roughly 17% of the variation in the precautionary shift.

(Table 8 about here)

The estimated coefficients for the shift from the threshold function as "most likely to be correct" to supralinear function as the preferred basis for standard setting (a two step precautionary shift) are shown in the top panel of Table 8. A higher score on the egalitarian index increased the odds of this shift (p=0.006). By contrast, a higher score on the risk allocation (p=0.001), technocracy (p=0.032) and economic/environment tradeoff (p=0.012) indices all reduced the odds of such a shift. Interestingly, those respondents who believed that changes in scientific knowledge happen in a revolutionary (rather than cumulative and incremental) manner had significantly greater odds of making this two step precautionary shift ($p=0.009$). Among the control variables, only age and field of expertise had a discernible effect. The older the respondent the lower the odds of the two-step shift, while life science experts had slightly higher odds.

The bottom panel of Table 8 provides the estimated coefficients for the one-step shift from the threshold model as most likely to be correct to the LNT form as the preferred safety standard. Neither of the broad disposition variables is significantly associated with the shift. Among the policy variables, only the technocracy index has a discernible relationship ($p<0.001$). Those who scored higher on this index had lower odds of making the one-step precautionary shift. Responses on the scientific optimism index were also related ($p=0.039$), such that those with a more "optimistic" disposition were *more* likely to make the one-step precautionary shift.

The final step in our analysis focused on the precautionary shift among those respondents who believe the LNT dose-response function was most likely to be correct. We used a logistic regression model to test for relationships among our independent variables and the respondents' preference for the LNT or supralinear function as the basis for the preferred safety standard. The model again was modestly predictive of the precautionary shift, with a pseudo R^2 of 0.168. The results are shown in Table 9.

(Table 9 about here)

Respondents who scored higher on the egalitarian index had greater odds of shifting from the LNT to the supralinear function as the preferred basis for radiation protection safety standards ($p=0.026$). In addition, both the measures of perceptions of science proved to be statistically significant. The higher the score on the scientific optimism index, the lower the odds of the precautionary shift from the LNT to the supralinear function ($p=0.001$). At the same time, those who believed scientific knowledge changes in a revolutionary manner were more likely to make this shift (p=0.025). None of the control variables were statistically significant in this model.

IV. DISCUSSION

This analysis has focused on the way an array of beliefs and values are associated with scientist and expert choices of preferred radiation exposure safety standards. Our findings should be considered with two caveats in mind. First, the selection of our samples was designed to capture divergent perspectives in the radiation protection policy domain, and therefore it may not be directly generalized to the propensities of the entire scientific community. Second, the analysis is based on a set of structured questions in a survey interview format. It is possible, therefore, that we would observe more self-conscious adherence to scientific evidence when scientists are in actual advisory positions. Yet there is a clear pattern in our analyses, across scientists from quite different kinds of positions, that justifies a degree of confidence in these relationships. The results indicate a strong presence of extra-scientific considerations in the judgments that scientists make about the characterization of risk and their tendency toward caution in setting safety standards.

We emphasize our first-order finding that a substantial fraction of both the UCS and the Lab scientists took the precautionary step. Among the UCS, excluding “don’t know” responses, 50.2% opted for a precautionary shift. The comparable number for the Lab scientists is 53.1%. Less than 1% of *either* group opted for a standard that assumed a riskier model than the one perceived to be “most likely”. The propensity to precaution in policy advice appears to be substantial and to hold across scientists from quite different corners of the radiation risk policy domain, as might be expected based on the epistemic community argument of Haas and others (Haas 2006). The question we raise is *why* scientists make these precautionary shifts.

This overall pattern of value and belief relationships that underlies the precautionary shift is largely, though not entirely, consistent with our initial conjectures. When considering the most general disposition, the egalitarian index was consistently related to the choice of the most risk averse of the dose-response options: the low dose, high-response function. The egalitarian respondents were the most likely to shift to the supralinear function as their preferred basis for radiation protection safety standards. The egalitarian disposition did not differentiate between the choice of the threshold and LNT models. As such, the egalitarian perspective enters the dose-response judgment concerning standard setting, and militates toward the choice of the function that is associated with the greatest risk from low doses of radiation. Given the clarity of the effects of the egalitarian disposition, it is interesting to note that the measure of political ideology was statistically insignificant in all of our models.[xvi] This finding extends the important work of Slovic and Peters (1998) and Kahan et al (2006) on the role of cultural dispositions to the more specific domain of precautionary decision-making among scientists.

Among the policy measures, all three were related to the choice of dose-response functions in the hypothesized directions. Our risk index, which taps respondents' perspectives on whether and under which circumstances risks can be imposed on others without their consent, was consistently related to precautionary tendencies. Those who were most permissive of imposing societal risks were significantly less likely to shift to the supralinear model as the basis for safety standard setting. The technocracy index, concerning who should make policy choices concerning scientific and technical issues, had a similar relationship to the choice of dose-response functions. The more "technocratic" scientists – i.e., those who believed that technical choices should be left up to knowledgeable experts rather than the lay public – were less likely to make a precautionary shift. And scientists who placed greater emphasis on economic values and rights than on environmental preservation, as captured by the economic-environment tradeoff index, were less likely to shift to the supralinear function as the basis for safety standard setting. Thus, like the egalitarian disposition, scientists' norms concerning the ways in which society goes about managing risks, making technical choices, and making environmental tradeoffs appear to enter judgments concerning the radiation dose-response to be assumed for setting standards.

The most interesting set of findings concerned the relationship between the scientists' perceptions of the scientific process and the choice of dose-response functions. Recall that we used two measures here: an index of leanings concerning validity, certainty, and the exclusivity of science as a way of knowing about nature (scientific optimism), and a measure of whether scientific knowledge was seen to change in a cumulative and continuous fashion or a discontinuous, revolutionary one. A high score on the scientific optimism index had the effect of increasing the odds of choosing the LNT dose-response response relationship as the appropriate one for standard setting.[xvii] The optimistic perspective on science thus appears to veer scientists toward the model traditionally used in regulating radiation exposure. Perspectives on how science changes had quite a different effect. Regardless of which function was believed to best characterize the dose-response relationship, those who viewed changes in scientific knowledge to be revolutionary in nature were the most likely to pick the supralinear function for safety standard setting. Thus, scientific optimism (as we operationalize it here) seems to induce a "migration to the middle" for standard setting, while a discontinuous or revolutionary view of scientific change militates toward the strongest form of risk aversion.

V. CONCLUSION

The scientific debate concerning the effect of low doses of radiation on human health provides a revealing case study of the kind of "hybrid activity" in which scientists engage when grappling with uncertain scientific problems. Faced with less than precise empirical evidence and competing theoretical claims, scientists within technical communities with a significant stake in the policy debate appeared to draw from an array of social, political and even epistemological predispositions in reaching conclusions about how to make the transition from what is true (in a scientific sense) to what is right (in a regulatory context). While we urge caution in making general inference from a singe case, our evidence leads us to hypothesize that similar predispositions are involved when policy makers call upon scientists to inform the policy debates in forums ranging from government sponsored scientific advisory boards or committees of the National Academy of Sciences. At the same time, our evidence suggests that experts' reliance on extra-scientific considerations in the provision of scientific advice is not without limit. Recent critics of critics of the use of scientific boards and committees (e.g., Mooney 2005) have argued that policy advice may be biased, and may exclude consideration of important perspectives, precisely because political or value dispositions play an overwhelming role in shaping the advice given to decision makers. Our data show that, even in a highly contentious policy domain, a wide array of beliefs including political ideology "explain" less than a fifth of the overall variation in policy recommendations. One might further expect that the relative role of these dispositions will diminish as the available evidence accumulates, and alternative theories are either validated or dismissed on the basis of that evidence.[xviii]

The widespread preference for precautionary judgments in the face of ambiguous or incomplete scientific evidence provides insight into the interplay of extra-scientific values and beliefs in policy advice. Our analysis demonstrates that a large fraction of scientists from within a contentious policy domain implicitly or explicitly apply some variation of the principle of precaution to radiation health protection, and that the expression of precaution itself is related to any array of societal values and policy dispositions. Given the critical role of scientific experts across the spectrum of pressing policy issues, systematic investigation of the extra-scientific bases for scientific judgments in other policy domains, across other scientific groups and other nations would seem warranted.

REFERENCES

Balogh, Brian. 1991. *Chain Reaction: Expert Debate and Public Participation in American Commercial Nuclear Power*, 1945-1975 (Cambridge University Press).

Barke, Richard P. 2005. "Balancing Uncertain Risks and Benefits in Human Subjects Research ," presented at annual meeting of the American Association for the Advancement of Science, Washington.

Barke, Richard P. Barke and Hank C. Jenkins-Smith. 1993. "Politics and Scientific Expertise: Scientists, Risk Perception, and Nuclear Waste Policy," *Risk Analysis*, Vol. 13 (August): 425-439.

Barke, Richard P., Hank C. Jenkins-Smith, and Paul Slovic. 1997. "Risk Perceptions of Men and Women Scientists," *Social Science Quarterly* 78 (March):167-176.

Beck, Ulrich. 1992. *Risk Society: Toward a New Modernity*. Sage.

Dake, Karl. 1991. "Orienting Dispositions in the Perception of Risk: An Analysis of Contemporary Worldviews and Cultural Biases," *Journal of Cross-Cultural Psychology* 22:61-82.

Dake, Karl. 1992. "Myths of Nature: Culture and the Social Construction of Risk." *Journal of Social Issues* 48:21-37.

Dake, Karl and Aaron Wildavsky. 1990. “Theories of Risk Perception: Who Fears What and Why?” *Daedalus* (Spring 1990): 41-60.

Douglas, Mary, and Aaron Wildavsky. 1983. *Risk and Culture: An Essay on the Selection of Technical and Environmental Dangers*. Berkeley: University of California Press.

Ellis, Richard, Aaron Wildavsky and Michael Thompson. 1990. *Cultural Theory*. Westview Press.

Fiske, S. T., & Taylor, S. E. 1992. *Social Cognition*. New York: McGraw-Hill.

Flynn, J. Flynn, P. Slovic, and C. K. Mertz. 1994. "Gender, Race, and Perception of Environmental Health Risks," (Report No. 94-1). Eugene, OR: Decision Research.

Flynn, J. Flynn, P. Slovic, and C. K. Mertz. 1993. Decidedly Different: Expert and Public Views of Risks from a Radioactive Waste Repository”. *Risk Analysis* 13:643-648.

Franklin, Jane (ed.). *The Politics of Risk Society*. Cambridge, UK: Polity Press.

Haas, Peter. 1989. "Do Regimes Matter? Epistemic Communities and Mediterranean Pollution Control," *International Organization* 43(3): 377-403.

Haas, Peter. 2006. “Reconstructing Epistemic Communities.” Workshop on Science, Knowledge Communities and Environmental Governance: Global-Local Linkages Center for Global Change and Governance, May 4, 2006, Rutgers University, Newark NJ.

Health Physics Society 2001

Hendee, William R. 1992. "Estimation of Radiation Risks: BEIR V and Its Significance for Medicine," *Journal of the American Medical Association*, 268 (August 5): 620-24.

Herrmann, Richard K., Philip E. Tetlock and Penny S. Visser. 1999. “Mass Public Decisions on Going to War: A Cognitive-Interactionist Framework.” *American Political Science Review* 93 (September): 553–73.

Hively, William. 1988. "Union of Concerned Scientists," *American Scientist*, vol. 76 (Jan.-Feb.): 18.

Holden, Constance. 1992. "Scientists' Campaign to Save Earth," *Science*, 258 (Nov. 27): 1433.

Hurwitz, Jon, Mark A. Peffley, and Mitch Seligson 1993. “Foreign Policy Belief Systems in Comparative Perspective: The United States and Costa Rica," *International Studies Quarterly*, 1993, 37: 245-270

Inglehart, Ronald. 1989. *Culture Shift in Advanced Industrial Society*. Princeton University Press.

Inglehart, Ronald. 1997. *Modernization and Post-Modernization*. Princeton University Press.

Jacobson, Louis. 2002. “Rocky Flat’s Road to Recovery,” *National Journal* 25(2):116-117.

Jasanoff, Sheila. 1990. *The Fifth Branch: Science Advisers as Policymakers*, Cambridge, MA: Harvard University Press.

Jenkins-Smith, Hank and Walter Smith. 1994. “Ideology, Culture and Risk Perception” in Dennis Coyle and Richard Ellis (eds.) *Politics, Policy and Culture*. Boulder, CO: Westview Press.

Kahan, Dan M., Paul Slovic, Donald Braman, and John Gastil. 2006. “Fear of Democracy: A Cultural Evaluation of Sunstein on Risk,” *Harvard Law Review* 199: 1071-1109.

Kocher, D. C. 1991. "Perspective on the Historical Development of Radiation Standards," *Health Physics*, 61.

Kuklinski, J., D. Metlay, and W. Kay. 1982. "Citizen Knowledge and Choices in the Complex Issue of Nuclear Energy," *American Journal of Political Science*, 26: 615-642.

Kuhn, Thomas. 1970. *The Structure of Scientific Revolutions.* Chicago: University of Chicago Press.

Lakatos, Imre. 1978. *The Methodology of Scientific Research Programmes*. Cambridge UK: Cambridge University Press.

Margolis, Howard. 1996. *Dealing with Risk: Why the Public and the Experts Disagree on Environmental Issues.* Chicago: University of Chicago Press.

Mazur, Allan. 1981. *The dynamics of technical controversy*. Washington, D.C.: Communications Press.

McGarity, Thomas O. 1979. "Substantive and Procedural Discretion in Administration Resolution of Science Policy Questions: Regulating Carcinogens in EPA and OSHA," *Georgetown Law Journal* 67: 729-809.

Mettler FA, Moseley RD. 1985. *Medical Effects of Ionizing Radiation*. Orlando, FL: Grune and Stratton; 1985.

Mooney, 2005

Moore, LeRoy. 2002. "Lowering the Bar," *Bulletin of the Atomic Scientists* (May/June): 28-37.

National Academy of Sciences. 2005. *Health Risks from Exposure to Low Levels of Ionizing Radiation*. Washington: National Academies Press.

Pillar, Chalres. 1991. *The Fail-Safe Society: Community Defiance and the End of American Technological Optimism.* Berkeley, CA: University of California Press.

Plutzer, Eric, A. Maney and R. O'Connor. 1998. "Ideology and Elites' Perceptions of the Safety of New Technologies," *American Journal of Political Science,* 42 (January): 190-209.

Popper, Karl. 1992. *The Logic of Scientific Discovery*. New York, NY: Routledge Press.

Press, Daniel. 1994. *Democratic Dilemmas in the Age of Ecology: Trees and Toxics in the American West.* Duke Durham, NC: University Press.

Raffensperger, C., and J. Tichner. 1999. *Protecting Public Health and the Environment: Implementing the Precautionary Principle.* Washington DC: Island Press.

Revkin, 2004

Rothman, Stanley and S. Lichter. 1982. "Elite Ideology and Risk Perception in Nuclear Energy Policy," *American Political Science Review,* 81: 383-404.

Sabatier, Paul A. and Hank Jenkins-Smith 1993. *Policy Change and Learning: An Advocacy Coalition Approach*. Boulder: Westview Press.

Sabatier and Zafonte

Salter, Liora. 1988. *Mandated Science: Science and Scientists in the Making of Standards.* Boston: Kluwer.

Schwartz, Stephen (ed). 1998. *Atomic Audit: The Costs and Consequences of U.S. Nuclear Weapons since 1940.* Washington DC: Brookings.

Sjöberg, Lennart and Britt-Marie Drottz-Sjöberg. 1991. "Knowledge and Risk Perception Among Nuclear Power Plant Employees," *Risk Analysis*, 11 (Dec.): 607-618.

Slovic, Paul, T. Malmfors, D. Krewski, C. K. Mertz, N. Neil, and S. Bartlett. 1995. "Intuitive Toxicology II: Expert and Lay Judgments of Chemical Risks in Canada". *Risk Analysis* 15(6): 661-675.

Slovic, Paul and E. Peters. 1998. "The Importance of Worldviews in Risk Perception". *Risk Decision and Policy.* 3(2):165-170.

Smith, David B. and James R. Watzke. 1990. "Perception of safety hazards across the adult life-span." Proceedings of the Human Factors Society: 141-145, Orlando: Proceedings of the Human Factors Society 34th Annual Meeting.

Steger, Mary Ann and S. L. Witt. 1989. "Gender Differences in Environmental Orientations: A Comparison of Publics and Activists in Canada and the U. S.," *Western Political Quarterly* 42: 627-49.

Sunstein 2005

Svenson, Ola and Gunnar Karlsson. 1989. "Decision-making, Time Horizons, and Risk in the Very Long-Term Perspective," *Risk Analysis* 9 (Sept.): 385-99.

U. S. General Accounting Office. 1994. Consensus on Acceptable Radiation Risk to the Public Is Lacking, GAO/RCED-94-190, September.

U. S. General Accounting Office. 2000. Radiation Standards: Scientific Basis Inconclusive, and EPA and NRC Disagreement Continues, GAO/RCED-00-152, June.

Wager, Janet S. 1994. "Union of Concerned Scientists," *Environment*, 36 (May): 4-5+.

Watson, Traci. 1992. "Petition Warns of Pending Global Environmental Crisis," *Nature*, 360 (Nov. 19): 200.

Weible, Christopher W. and Paul A. Sabatier. 2005. “Comparing Policy Networks: Marine Protected Areas in California,” Policy Studies Journal 33: 181-201.

Weinberg, Alvin. 1972. "Science and Trans-Science," *Minerva*, 10: 209-222.

Wildavsky, A. 1991. *The Rise of Radical Egalitarianism.* University Press of America.

Figure 1: Diagram of Alternative Relationships between Radiation Dose and Cancer Incidence

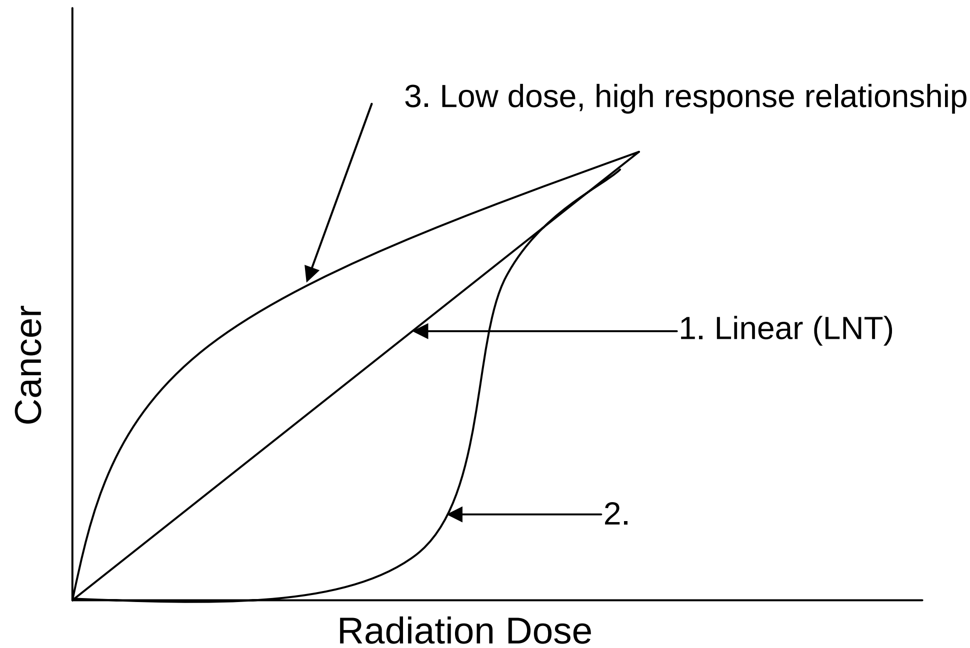

Table 1: Characteristics of Scientist Samples

Variable		National Lab Respondents (n=872)	UCS Respondents (n=865)	Total Sample
Scientific Field	Physical Sciences	39.0%	39.1%	39.0%
(Chi-Sq=446.55)	Life Sciences	3.9%	28.8%	16.3%
	Engineering	47.0%	10.8%	29.0%
	Math, Statistics, Comp Science	4.4%	2.0%	3.2%
	Social Science, Humanities	1.9%	12.8%	7.4%
	Other Field	3.8%	6.6%	5.2%
Highest Degree	Doctorate or equivalent	53.3%	72.9%	63.1%
(Chi-Sq=72.88)	Masters or Equivalent	46.7%	27.1%	36.9%
Gender	Percent Male	84%	80%	82%
Age	Average Age in Years	43.9	53.6	48.8
	Standard Deviation	10.38	14.79	13.67

Table 2: Scientists' Assessments of the "Most Likely" and "Assumed Safety Standard" Radiation Dose Response Functions

Variable		National Lab Respondents (n=872)	UCS Respondents (n=865)	Total Sample
Most Likely DR Function	Threshold	70.2%	47.7%	59.0%
(Chi-Sq=103.01, p<0.0001)	Linear – No Threshold	12.0%	21.1%	16.5%
	Supralinear	2.6%	9.8%	6.2%
	Don't Know	15.2%	21.4%	18.3%
Assumed Safety DR Function	Threshold	27.5%	15.8%	21.7%
(Chi-Sq=88.72, p<0.0001)	Linear – No Threshold	43.2%	36.2%	39.7%
	Supralinear	17.2%	35.7%	26.4%
	Don't Know	12.1%	12.3%	12.2%

Table 3: Precautionary Shift from "Most Likely" to "Assumed Safety Standard" Radiation Dose Response Functions

(Pearson Chi Square=806.322; p-value<.0001)

	Supralinear standard	LNT standard	Threshold standard	Don't Know	Total
Supralinear correct	5.7%	0.4%	0.1%	0.1%	6.2%
LNT correct	5.7%	10.0%	0.3%	0.5%	16.4%
Threshold correct	9.5%	24.7%	20.9%	4.0%	59.1%
Don't Know	5.6%	4.6%	0.4%	7.7%	18.3%
Total	26.5%	39.7%	21.7%	12.3%%	100.0%

Table 4: Measures of Scientists' Dispositions, Values and Beliefs

Variable		National Lab Respondents (n=869)	UCS Respondents (n=855)	Difference of Means (t-test)*
Egalitarian Worldview	Shift taxes so burden falls more on corporations and the rich (7=Agree Strongly)	3.96 (1.748)	5.77 (1.341)	1.81 (p<0.001)
	Society needs a fairness revolution (7=Agree Strongly)	2.45 (1.464)	4.26 (1.788)	1.81 (p<0.001)
	Most harm in society comes from big corporations the government (7=Agree Strongly)	2.63 (3.423)	3.41 (1.580)	0.78 (p<0.001)
Egalitarian scale	Index of above three items (scale alpha = 0.677)	3.013 (1.128)	4.478 (1.139)	1.465 (p<0.001)
Political Ideology	1=Strongly Liberal, 7=Strongly Conservative	4.41 (1.477)	2.47 (1.206)	1.94 (p<0.001)

* Equal variances not assumed for t-tests.

Table 5: Measures of Scientists' Risk, Technocratic and Environmental Beliefs

Variable		National Lab Respondents (n=869)	UCS Respondents (n=855)	Difference of Means (t-test)*
Societal Risk Allocation	OK to impose small risks (7=Agree strongly)	3.66 (1.897)	3.05 (1.841)	0.61 (p<0.001)
	Even if benefits are large, wrong to impose risks (7=Disagree strongly)	3.66 (1.938)	3.26 (1.966)	0.39 (p<0.001)
	OK to impose risks if those harmed are compensated (7=Agree Strongly)	2.35 (1.414)	2.20 (1.451)	0.15 (p=0.030)
	For society to prosper, it's necessary to impose risks (7=Agree strongly)	5.54 (1.345)	5.13 (1.624)	0.40 (p<0.001)
Risk Allocation Index	Index of above 4 items (scale alpha =.7148)	3.80 (1.244)	3.41 (1.240)	0.39 (p<0.001)
Technocratic Disposition	1=Public should decide about advanced technologies, 7=experts	4.94 (1.377)	4.02 (1.709)	0.92 (p<0.001)
	Better informed should have more influence (7=agree strongly)	5.45 (1.082)	5.43 (1.240)	0.03 (p=0.640)
	Even if public uninformed, rely on popular opinion (7=disagree strongly)	5.74 (1.310)	5.55 (1.475)	0.18 (p<0.006)
Technocratic Index	Index of above 3 items (scale alpha =0.6114)	5.38 (0.967)	5.01 (1.101)	0.37 (p<0.001)
Economic-Environmental Tradeoff	No environmental regulations unless benefits exceed costs (7=agree strongly)	3.61 (1.78)	2.32 (1.54)	1.29 (p<0.001)
	Right to clean environment not as important as right to jobs (7=agree strongly)	3.05 (1.35)	2.26 (1.29)	0.79 (p<0.001)
Econ/Env Index	Index of above 2 items (scale alpha=0.6062)	3.33 (2.29)	2.29 (1.18)	1.04 (p<0.001)

* Equal variances not assumed for t-tests.

Table 6: Measures of Scientists' Perspectives on Science

Variable		National Lab Respondents (n=869)	UCS Respondents (n=855)	Difference of Means (t-test)*
Perspectives on Science	Scientific process only valid way to understand nature (7=Agree Strongly)	5.28 (1.530)	5.14 (1.838)	0.14 (p=0.086)
	Scientific evidence can be interpreted to fit opposing views (7=Disagree Strongly)	3.36 (1.628)	3.26 (1.694)	0.095 (p=0.235)
	Intuition provides understanding as valid as that of science (7=Disagree Strongly)	5.11 (1.505)	5.15 (1.742)	0.041 (p=0.605)
	Scientific research always affected by values of researcher (7=Disagree Strongly)	4.25 (1.631)	4.10 (1.850)	0.152 (p=0.069)
Scientific Optimism Index	Index of above four items (scale alpha = 0.677)	4.497 (1.099)	4.405 (1.290)	0.093 (p=0.110)
Scientific Change	1=Scientific change is always continuous and incremental, or always revolutionary=7	3.85 (1.171)	4.02 (1.128)	0.170 (p=0.002)

* Equal variances not assumed for t-tests.

Table 8: Nominal Logit Model of Precautionary Shift for Scientists Who Chose the Threshold Function as "Most Likely"
(-2 Log Likelihood=1672.851; Chi-Square=138.157; Nagelkerke R^2=0.167; n=879)

		B	Std. Error	Wald	Sig.	Exp(B)
Shift to Supralinear	Intercept	1.068	1.174	.828	.363	
	Egalitarian Index	.301	.109	7.604	.006	1.351
	Ideology	.064	.095	.453	.501	1.066
	Risk Allocation Index	-.312	.092	11.370	.001	.732
	Technocracy Index	-.244	.114	4.609	.032	.783
	Econ-Environ Tradeoff	-.245	.098	6.244	.012	.783
	Sci. Optimism Index	.165	.095	3.028	.082	1.180
	Scientific Change	.240	.092	6.798	.009	1.271
	Age	-.035	.009	14.082	.000	.966
	Gender (Male=1)	-.294	.269	1.195	.274	.745
	Engineer	-.304	.279	1.187	.276	.738
	Life Sciences	.676	.309	4.787	.029	1.965
	Other Field	.168	.383	.192	.661	1.183
	Sample	.070	.296	.057	.812	1.073
Shift to LNT	Intercept	3.390	.892	14.449	.000	
	Egalitarian Index	-.038	.083	.207	.649	.963
	Ideology	-.112	.070	2.595	.107	.894
	Risk Allocation Index	-.039	.066	.349	.555	.962
	Technocracy Index	-.321	.086	13.825	.000	.725
	Econ-Environ Tradeoff	-.098	.067	2.161	.142	.907
	Sci. Optimism Index	.149	.072	4.266	.039	1.161
	Scientific Change	.069	.066	1.080	.299	1.071
	Age	-.026	.007	14.396	.000	.975
	Gender (Male=1)	-.081	.220	.136	.712	.922
	Engineer	-.192	.185	1.083	.298	.825
	Life Science	.034	.258	.017	.896	1.034
	Other Field	-.619	.336	3.385	.066	.539
	Sample	-.116	.224	.269	.604	.890

Table 9: Logit Model of Precautionary Shift for Scientists Who Chose the LNT as "Most Likely"

(-2 Log Likelihood=360.537; Chi-Square=43.190; Nagelkerke R^2=0.168; n=358)

		B	Std. Error	Wald	Sig.	Exp(B)
Shift to supralinear	Intercept	-2.579	1.388	3.452	0.063	
	Egalitarian Index	.323	.145	4.980	.026	1.381
	Ideology	.029	.118	.062	.804	1.030
	Risk Allocation Index	-.102	.117	.767	.381	.903
	Technocracy Index	.030	.131	.054	.816	1.031
	Econ-Environ Tradeoff	.156	.114	1.866	.172	1.169
	Sc. Optimism Index	-.367	.112	10.659	.001	.693
	Scientific Change	.268	.120	5.038	.025	1.308
	Age	.008	.010	.544	.461	1.008
	Gender (Male=1)	-.199	.359	.307	.579	.820
	Engineer	-.414	.453	.837	.360	.661
	Life Sciences	.389	.343	1.284	.257	1.475
	Other Field	.075	.438	.029	.864	1.078
	Sample	-.027	.375	.005	.942	.973

[i] Some studies go so far as to suggest that radiation exposure is beneficial at very low doses (US General Accounting Office 2000: 35).

[ii] The Health Physics Society, a scientific professional organization that focuses on radiation protection issues, argued in an online position paper that the use of the linear dose/response model results in “an overestimation of risks”. (Health Physics Society 2001: 1). Some proponents of more stringent radiation exposure standards dismissed the Health Physics Society as consisting of “people who have a stake in perpetuating the nuclear enterprise” or even “a labor union for the nuclear industry” (Moore 2002:31-2).

[iii] According to the GAO, the costs of these programs accelerate rapidly as the regulated radiation exposure limits to the human population fall; the estimated cost of the Yucca Mountain nuclear waste repository rises from $35 billion to over $1 trillion as the acceptable dose falls from 100 millirem per year to less than 10 millirem per year (U.S. General Accounting Office 2000: 27).

[iv] As of February 2006, the Committee’s report was available online at: http://books.nap.edu/catalog/11340.html

[v] See Herrmann, Tetlock and Visser (1999) for an excellent assessment of the role of alternative dispositions in reaching complex decisions.

[vi] Studies of the differences between experts’ and the lay public’s perceptions of risk have shown convincingly that experts tend to see risks as smaller and more manageable than does the public (Flynn et al 1993; Slovic et al 1995). Substantial differences remain in explanations for those differences (Margolis 1996).

[vii] We do not control for level of education because our respondents are overwhelmingly Ph.D.s. These attributes are discussed below, and shown in Table 1.

[viii] The UCS was formed in 1969 after student activists at MIT challenged faculty researchers to show personal involvement in policy disputes over the application of technology, particularly those which presented "a major threat to the existence of mankind" (Hively, 1988; Wager, 1994).

[ix] More recently, the UCS has taken positions such as urging caution in allowing genetically-engineered vegetables to be sold to consumers and in favor of increased development and production of wind power. In 1992 it gathered signatures from more than 1,500 prominent scientists, including 98 Nobel prize winners, on a petition calling for resource conservation, reproductive rights for women, and the shifting of government expenditures from military purposes to the elimination of poverty (Watson, 1992; Holden, 1992).

[x] The Lab sample was stratified by Laboratory, with unequal sample sizes due to differences in the number of eligible participants and variations in response rates across the four Laboratories. For that reason, we do not make inference from the univariate distributions of beliefs in our samples to those that would obtain to the populations of Laboratory scientific and technical staffs. Rather, we focus on the patterns of associations among beliefs, particularly as they bear on precautionary tendencies in standard setting.

[xi] Among the UCS respondents, who were more likely than Lab scientists to say that the LNT or supralinear (see Table 2), relationship was correct, 37.1% were risk averse. Among the Lab respondents, 42.7% were risk averse.

[xii] The relationships among the perspectives on science proved to be quite interesting. The scientific optimism index, which captures the extent to which the respondents believed the scientific process generates a complete and unambiguous understanding of nature unaffected by the researchers values, is modestly negatively correlated (r = -0.10, $p<0.0001$) with the perception that science develops in a

revolutionary, non-cumulative manner. The scientific optimism index is also negatively correlated with the measure of egalitarianism ($r = -0.16$, $p<0.0001$) and positively associated with the technocracy index ($r = 0.19$, $p<0.0001$).

[xiii] The decision to treat the dependent variable as a nominal (rather than ordinal) measure is based both on conceptual and empirical grounds. Conceptually, and as depicted in Figure 1, the three dose-response functions appear to differ chiefly in the extent to which changes in very low doses of radiation result in changes in cancer incidence in humans. However, it is quite plausible that scientists would make a different conceptual distinction among the relationships, such as the simplicity of underlying assumptions (in which case the linear model takes a polar position). Given the potential for non-ordinal properties, we modeled the choices of functions using both ordinal and nominal regression. The results were sufficiently different that we opted for the nominal approach, in that this model makes less demanding assumptions about the underlying scale structure of the dependent variable.

[xiv] Thirteen cases (0.8% of our observations) in which the shift was “risk acceptant” were omitted from this stage of the analysis.

[xv] Those who responded “don’t know” to either the “most likely” or “preferred standard” options were omitted from the analysis in this section.

[xvi] When used in isolation, the political ideology measure had a modest and significant effect in all of our models. However, this effect disappears when we control for the other dispositions, beliefs and values. The egalitarian index, on the other hand, is largely unaffected by the presence of the ideology measure in the model.

[xvii] This finding is corroborated by a simple difference of means test. Those scientists who picked the LNT model as “most likely to be correct” had the highest average score on the positivist index ($p<0.001$)

[xviii] Note that an important part of the criticism of science advice to policy makers appears to be grounded in skepticism that the scientific process itself can be counted on to reliably resolve such scientific ambiguities. For that reason, critics might expect the intensity of scientific conflict to parallel that of broader political and social controversies in spite of – and perhaps because of – efforts to reduce scientific uncertainty (Barke, 2005).