Expert Decisionmaking in Risk Analysis: The Case of the Yucca Mountain Facility

Kristin Shrader-Frechette
University of Notre Dame
346 O'Shaughnessy Hall
NOTRE DAME, INDIANA 46556
UNITED STATES OF AMERICA

1. Introduction

Thirty-five or forty centuries ago, there were probably Egyptian experts who argued that they could safeguard the tombs of the pharaohs for 10,000 or a million years. Six centuries ago, there were probably Italian experts who believed that they could secure their Renaissance art treasures. Neither the Egyptians nor the Italians succeeded completely in their efforts. Today's experts, working on permanent nuclear waste disposal, face no easier a task. To understand some of the most difficult problems of expert judgment regarding nuclear repositories, these remarks (1) address 10 problematic judgments of scientists about the proposed Yucca Mountain permanent nuclear repository for spent fuel and high-level nuclear waste; (2) argue that legal constraints imposed by the US government exacerbate these problems of expert scientific judgment; and (3) conclude that, for any permanent repository program to succeed, nations ought to avoid problems (in expert scientific judgment and in the law) that have dogged US repository efforts.

2. Ten Questionable Expert Judgments

In their investigations of the proposed Yucca Mountain high-level nuclear waste repository, scientific experts have made a number of problematic judgments. First, government experts' framing questions (of repository site suitability) in question-begging ways is a fundamental problem at Yucca Mountain. Because those who frame the questions control the answers, it is arguable that the US Department of Energy (DOE) is covertly controlling conclusions about site acceptability. Eager to pursue the waste facility, the DOE defined site acceptability by placing the burden of proof on those who are potential victims of its waste migration. The DOE required scientists assessing the location to conclude that it was acceptable if no one could prove it unacceptable [1].

The two-value frame of this DOE requirement presents a number of problems. For one thing, the DOE forced scientists to conclude that the site was either acceptable or unacceptable; it disallowed the choice that the data were uncertain or that the proposal needed more study. Yet, in any laboratory, often the results are uncertain. By forcing scientists to choose between only two options, site suitability or unsuitability, the DOE forced scientists to beg the question of whether the site-suitability question even ought to be asked in such a frame. Moreover, by forcing scientists to use a two-valued decision frame, rather than the normal three-valued frame of hypothesis testing, the DOE forced scientists not only to give policy opinions, rather than scientific choices, but it put the burden of proof on those least able to perform the science, the potential victims of the proposed facility. As one of the least populous states in the nation, Nevada has few monies available for site studies and less scientific expertise than most states. The site promoter (DOE), however, is a deep pocket. All things being equal, when two groups of scientists seek, respectively, to prove or disprove some hypothesis, the group having more funds at its disposal will have the easier task. Also, because the government used the Nevada region for nuclear weapons testing for many years, high radioactivity prevented scientists from collecting long-term, comprehensive data on site characteristics. In the absence of adequate data, it is almost impossible to prove the site unsuitable. Therefore, by the default (two-value) decision rules of the DOE, scientists are more likely to judge the site suitable.

A second troubling expert judgment in the Yucca Mountain studies is the use of subjective probabilities and the failure or inability to check these ex ante probabilities by means of ex post observations. Although the Yucca Mountain site decision was framed in terms of expert scientific opinion, basic conclusions about the scientific acceptability of the site rely ultimately on subjective probabilities – about future flooding, seismic activity, groundwater velocity, and so on. Virtually every probability proposed for some site characteristic is questionable because of the numerous methodological value judgments that scientists must make in the face of uncertainty about site data and methods [2]. More generally, conclusions about site acceptability are highly sensitive to predicted probabilities of events such as radionuclide migration through groundwater. Because of this sensitivity, it is doubly questionable to rely on subjective probabilities. Non-Bayesian decision theorists also question subjective probabilities, especially in situations where the practical consequences of being wrong are so dangerous [3].

If Yucca Mountain scientists were able to employ both ex ante and ex post probabilities in analyzing problems such as those associated with radioactive waste disposal, then the subjective nature of the Yucca Mountain numbers would not be so problematic. One could simply test the ex ante probabilities. However even in nuclear-related cases in which government assessors were able to obtain ex post probabilities, often they have not used them. For example, in the case of the Maxey Flats (Kentucky) radioactive-waste facility, government assessors assured local residents that it would take 24,000 years for the radionuclides to migrate one-half inch onsite. Yet, only 10 years after the

facility was opened, the waste had migrated two miles offsite [2]. Similarly, when scientists working under US government contract calculated the ex ante probabilities for various nuclear accidents, no government-funded researchers later compared them to the ex post probabilities. Instead Dutch researchers obtained the accident frequency data from Oak Ridge National Labs and compared them to the ex ante probabilities. They discovered that the US government scientists exhibited a consistent overconfidence bias and that they underestimated accident probabilities for all seven types of failures in reactor subsystems [4]. Citizens and scientists would be more likely to accept government ex ante accident or waste-migration probabilities if they knew that oversight scientists would both calculate the ex post probabilities, when possible, as well as modify risk assessment and management procedures on the basis of the new ex post data.

A third problematic judgment made by the DOE scientists at Yucca Mountain is that even poor numbers are better than no numbers at all, when trying to predict site characteristics. At Yucca Mountain, government scientists used groundwater migration models that are contraindicated for site characteristics. They employed porous-media models -- specified for use only in homogeneous, uniform, nonfractured media -- in the nonhomogeneous, nonuniform, fractured volcanic tuff at the Nevada site. Their models gave them numbers for groundwater velocity, but they are almost meaningless. As a consequence, the models fail to take account of site phenomena and likely underestimate the potential for groundwater flow at the site [2].

Even practical considerations suggest that such misused models are wrong because fallout from above-ground weapons testing has migrated far underground, even to the water table in some Nevada areas, in less than 50 years. Nevertheless, DOE scientists use their contraindicated porous-media models to argue that the proposed waste will not migrate, at the same location, in less than 1000 years [2]. By arriving at some number, rather than no number, when they use contraindicated models for prediction, the DOE experts are not reasonable, especially because they typically do not note the contraindicated conditions and the limits on certainty. A better alternative would be to say that it is not possible, within appropriate confidence limits, to arrive at a reasonable prediction about groundwater migration. Indeed, this is precisely what the DOE's own peer reviewers concluded:

> Many aspects of site suitability are not well suited for quantitative risk assessment. In particular are predictions involving future geological activity, future value of mineral deposits and mineral occurrence models. Any projections of the rates of tectonic activity and volcanism, as well as natural resource occurrence and value, will be fraught with substantial uncertainties that cannot be quantified using standard statistical methods [5].

If government (DOE) scientists provide precise predictions of site safety, contrary to what the best nongovernment experts ([5] above) affirm – then controversy is sure to

follow. If members of the public are put at risk by a proposed facility, and if government reassurances contradict nongovernmental expert opinion, then no one should be surprised when members of the public oppose the facility.

Fourth, government assessors at Yucca Mountain repeatedly relied on computer "verification" and "validation" of site predictions when, in reality, no reliable data check was even possible for their predictions. Using computer models of site characteristics, models in which data were inadequate and incomplete, Yucca Mountain (government) researchers concluded repeatedly that their assessments were "validated" and "verified." In the jargon of computer modelers, however, such claims amount merely to affirming that benchmarking has been successful. Benchmarking is using one computer model to generate specific predictions and then comparing those results with the predictions generated by another computer model. If the two sets of results are comparable, then the computer scientist is able to affirm that one model has "validated" or "verified" the other. Despite the misleading language, however, the modeler has really only confirmed that one set of results is consistent with another, not that either set of results reflects reality [2].

Fifth, ordinary citizens might be reassured when a committee of scientists affirms the reasonable choice of a site for radioactive waste management, but in the case of Yucca Mountain, such reassurance has been difficult, in part because of problematic committee composition. Risk assessors need to get the science right and they need to get the right scientists. The committee charged by the US National Research Council (NRC)/ National Academy of Sciences (to develop technical and safety standards for Yucca Mountain) did not have as desirable a disciplinary representation as it ought to have had [6] [7]. Most of the members of the committee were physicists and nuclear engineers, and yet the charge to the committee was to determine appropriate standards for a repository that could generate potential public-health threats [6]. Only one medical doctor was on the 15-person committee, only one public-health expert, and only one hydrogeologist, even though the mechanism for radwaste migration is hydrogeological, and even though the main potential threat is to public health. Reasonable citizens might believe that the recommendations of such a committee were not adequately protective because the majority of committee members were in the business of promoting nuclear activities rather than public health.

Sixth, experts analyzing permanent repositories need not only to get the science right, and to get the right scientists, but also to have access to the right data. A fundamental problem with the Yucca Mountain repository is DOE's ignoring relevant research. The DOE essentially funded hydrogeological and engineering studies, and it largely ignored the site research most relevant to Nevadans: ecological and economic analyses and social-science studies of the effects of the repository on tourism [2]. Hence, even if the committee composition were reasonable, the DOE could not have had the data it needed to make a reliable decision about the site.

In the case of the national academy report on technical bases for Yucca Mountain waste-disposal standards, key references were missing from the bibliography [6]. For example, the committee did not consider the most important peer review of the Yucca Mountain program, an evaluation that was critical of many DOE efforts. This lengthy and detailed document was authored by 14 of the top scientists in the nation, people not in the employ of the DOE, although the DOE itself selected them to do the evaluation. This peer review committee determined, as mentioned earlier, that quantitative risk analysis was not possible for most site characteristics and that it was not possible even to set limits of uncertainty on conclusions about alleged site characteristics [5]. When the National Academy staff person assigned to the committee was asked why this document was not examined and included in the bibliography, he did not even know about it. He said that the committee had relied on the DOE, the very agency whose results the academy was evaluating, to provide all the necessary documents. Even the academy's own peer review system also is questionable, since none of the academy's document reviewers had mentioned the incomplete bibliography. Given such flaws, citizens have grounds for questioning both the DOE and the academy reports. Good science dictates no relevant evidence be ignored.

Given experts' ignoring relevant research, it is not surprising that the academy committee explicitly affirmed a seventh problematic judgment about the repository. It confirmed "the feasibility of using quantitative performance assessment at Yucca Mountain" for a period up to a million years in the future [6]. Specifically the committee said:

> We conclude that these physical and geologic processes are sufficiently quantifiable and the related uncertainties sufficiently boundable that the performance can be assessed over time frames during which the geologic system is relatively stable or varies in a boundable manner.... This time frame is on the order of 10^6 years [6].

If the academy committee had been privy to the earlier document [5], or had peer reviewers who had brought it to their attention, presumably it would have been able to provide a scientific defense of its belief that million-year performance assessments were possible for Yucca Mountain. Presumably it would have been able to explain its contradicting the consensus statement of the 14 distinguished peer reviewers – hydrologists and geologists -- who denied the feasibility of such a quantitative assessment of the site [5]. In the absence of academy consideration of all the relevant findings, the outsider scientist or citizen has reasonable grounds for believing that million-year repository performance assessment is not possible. A reasonable outsider scientist or citizen might claim that, because the last ice age was only about 30,000 years ago and that, because human intrusion into the repository is not able to be evaluated [6], therefore million-year repository performance assessment also is not able to be assessed in a reliable way. In fact, one could not assess the security of the tombs of the pharaohs, several dozen centuries ago, just as one could not assess the security

of Italian Renaissance art treasures, only several centuries ago. And if not, it is not clear that government scientists can assess repositories for more than 1000 centuries.

Another questionable expert judgment, eighth, is that radiation regulations ought to move from a dose and risk standard merely to a risk standard [6]. This judgment is questionable, in large part, because it recommends a standard that is extremely subject to manipulation and thus is less protective of public health than it could be. The NRC group proposed moving from the current dose + risk (DR) standards for radiation protection to risk (R) standards alone. The committee also rejected the ALARA standards of all official international and national radiation-protection bodies. ALARA articulates an ideal of radiation protection: "as low as reasonably achievable" [6]. It mandates that, once nuclear operators have met the government-required dose standards, they should attempt to keep all radioactive emissions and effluents ALARA, because all ionizing radiation is harmful [8].

The NRC committee dropped the ALARA clause of international and national radiation recommendations and instead recommended only that nuclear facility operators stay below a risk-exposure level, to be set by the federal government. By rejecting the ALARA, however, despite the fact that all ionizing radiation is harmful and has cumulative effects, the committee has arguably encouraged nuclear-facility operators not to contain as much radiation as possible. Dropping ALARA also encourages a more relaxed attitude toward radiation exposure. Because it is important to protect the health of radiation workers and the public, both British and French courts have prosecuted those who do not adhere to ALARA [9], [10], and the US Nuclear Regulatory Commission has made ALARA mandatory in all regulatory settings [11]. Under the NRC Yucca Mountain recommendations, however, neither workers nor the public would have this protection. Likewise, instead of ensuring the public that no dose of ionizing radiation would exceed a particular level, the NRC said that the public should be protected by a risk standard, that is, a standard specifying probability of adverse health effects.

In theory, the dose and risk standards should be equivalent, since risk (given a particular population distribution, environmental circumstances, and so on) is a function of dose. In practice, however, an assessor could show a reduction of the alleged risk associated with a particular dose merely by changing the environmental, personal, or spatial characteristics associated with the exposure. For example, if those within a 5-mile radius of a waste facility received a particular dose of radiation, then an assessor could reduce the calculated risk by averaging it over a larger set of people, perhaps those within a 10-mile radius, even though a person living within 5 miles would have no change in dose. Increasing the spatial frame over which the risk was averaged, or failing to aggregate data (that include age at exposure) typically would lower it. In short, instead of retaining the dose plus risk standard endorsed by the International Committee on Radiation Protection, the UN and virtually all other national and international agencies [8], the academy committee endorsed only a risk standard.

Besides being subject to manipulation, the risk standard is also more difficult to operationalize than a dose standard because it would be impossible to specify, ahead of time, what dose limits would be necessary to meet particular risk constraints. Meeting risk constraints would be impossible without knowing how many people were exposed, whether small children were in the vicinity, and so on. Also, once exposure occurred, scientists would be more likely to disagree about risk, rather than dose, because the former would have to take into account various controversial circumstances. Because of this disagreement, high exposures could be "justified" by some ex post facto scenario dependent on questionable exposure assumptions. Dose standards, however, would protect every individual, everywhere, every time.

A ninth questionable expert judgment in the academy recommendations about Yucca Mountain is that, contrary to international consensus in favor of the subsistence-farmer critical group, government should use the probabilistic critical group and develop an "exposure scenario," a set of societal factors on the basis of which to calculate risk to exposed individuals [6]. Thomas Pigford, Professor of Nuclear Engineering at the University of California, Berkeley, and a member of the academy committee, pointed out (1) that the probabilistic critical group does not include the individuals with the highest exposures from the repository, even though the academy report proposes using it for risk calculations, and (2) that the exposure scenarios are subject to manipulation because the assessor can dictate various societal factors that constrain the exposure. As with the academy's recommended risk standards, the exposure scenario also is difficult to operationalize and hard to enforce. For both risks and exposure scenarios, the devil is in the details.

A tenth questionable expert judgment, made by the US Nuclear Regulatory Commission, is that because Yucca Mountain will be unable to meet the radiation standards currently enforced, therefore the US should make the standards more lenient. The commission amendments to the Code of Federal Regulations -- to make specific, more relaxed standards for Yucca Mountain -- specify a 25 mrem limit, 20 km from the site. After the deadline (May 10, 1999) for proposed comments on the new rules, the Nuclear Regulatory Commission will decide whether to implement them. The proposal is disturbing since the repository assessment is predicated on finding the site suitable or unsuitable. Now that it has been found unsuitable, government wants to change the rules. It has undercut its own two-value frame.

3. The Law Exacerbates Questionable Judgments

Questionable scientific opinions, used to justify nuclear repository siting, might not be a serious problem, at least at Yucca Mountain, if the government were willing to protect the public against the practical consequences of errors in those opinions. Often, however, the opposite appears to be the case. First, although the US government has

repeatedly reassured the public that any nuclear repository it builds will be safe, it will not give full liability protection to citizens who might be harmed by the repository. It makes no sense to say that repository operators, not citizens, need protection against accidents or leaks that could bankrupt them. Government's refusal to provide such protection suggests that it is talking out of both sides of its mouth [2].

Second, it makes no sense for government to tell Nevada residents that they have no reason to fear the proposed Yucca Mountain repository, but then to pass laws that give Yucca Mountain contractors freedom from prosecution for all safety violations, including deliberate safety violations. If the government is serious about safety, then its holding contractors and subcontractors accountable is reasonable [2].

Third, faced with citizen damages in the past, the US government routinely has claimed "sovereign immunity" (immunity of government to citizen lawsuits) to avoid compensating citizens for their government-caused losses. This occurred with the 500,000 atomic veterans, most downwinders, victims of the Fernald nuclear feed materials plant, and so on [2].

Fourth, even if compensation for nuclear harms were forthcoming, history shows that the transaction costs (bearing the burden of proof, using the courts to obtain justice) are very great, in terms of both time and money [2].

Fifth, the DOE told citizens of Nevada they could have funds to study the repository site, provided they gave up their veto power. Catch-22 [2].

Sixth, although US workers have a guaranteed right to know, citizens of the state of Nevada have no such right. The state had to sue the federal government in order to obtain copies of site studies that were funded with taxpayer money [2].

Seventh, before the Nevada location was even studied for its alleged scientific merits, the US Congress dictated that it would be the only site considered for permanent nuclear waste disposal [2].

4. Lessons Learned from US Difficulties

Everyone makes mistakes. The preceding problems with expert judgments about Yucca Mountain do not mean that decisions about radioactive waste are easy. On the contrary, they are difficult, and reasonable people can disagree about them. Reasonable people may disagree about how to handle nuclear waste but, presumably, reasonable people do not disagree that experts ought to be representative of the requisite scientific disciplines; ought not ignore crucial studies; ought not change regulations when sites fail to meet them; ought not tell citizens that a facility is safe when they will not give them full insurance; and ought not tell citizens that government will take care of accident

damages when, in the past, government has denied responsibility and claimed sovereign immunity. Nations that make the same mistakes of scientific opinion as the US, and then exacerbate these mistakes by withdrawing legal protections, will not be able to site a permanent repository.

References

1. Younker, J.L. et al. Report of the Peer Review Panel on the Early Site Suitability Evaluation of the Potential Repository Site at Yucca Mountain, Nevada, Washington, DC: US DOE; SAIC-91/8001; 1992.

2. Shrader-Frechette, K. Burying Uncertainty: Risk and the Case Against Geological Disposal of Nuclear Waste, Berkeley: University of California Press, 1993.

3. Resnik, M.D. Choices: An Introduction to Decision Theory, Minneapolis: University of Minnesota Press, 1987.

4. Cooke, M. Risk Assessment and Rational Decision Theory, Dialectica 36(4): 334, 1982.

5. Younker, J. L. et al. Report of the Peer Review Panel on the Early Site Suitability Evaluation of the Potential Repository Site at Yucca Mountain, Nevada. Washington, DC: US DOE; SAIC-91/8001, 1992.

6. National Research Council. Technical Bases for Yucca Mountain Standards, Washington, DC: National Academy Press, 1995.

7. Shrader-Frechette, K. Science Versus Educated Guessing, BioScience 46(7): 488-489, July/August 1996.

8. International Commission on Radiological Protection. 1990 Recommendations of the International Commission on Radiological Protection: Adopted by the Commission in November 1990, Oxford: Pergamon Press; ICRP Publication 60; Ann. ICRP 21(1-3), 1991.

9. Charlesworth, F.R. A Case of ALARA: An Incident at Sellafield, November 1983, Journal of the Society of Radiological Protection 7(1): 5-13, 1987.

10. Lochard, J. Grenary-Boehler, M.C. Optimizing Radiation Protection: The Ethical and Legal Bases, Nuclear Law Bulletin No. 52:9-27, 1993.

11. Hiam, J. NRC and ICRP Lower Radiation Exposure Limits, Journal of Nuclear Medicine 32(5): 29N, 1991.