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COMMENTARY

NUCLEAR WASTE: THE ACADEMY AND MILLION-YEAR ESTIMATES

KRISTIN SHRADER-FRECHETTE

Environmental Sciences and Policy Program, University of South Florida
Tampa, Florida 33620-5550 USA

PREPARING TO BUILD the world's first permanent repository for high-level nuclear waste at Yucca Mountain, Nevada, the U.S. government has spent nearly $5 billion on site studies. In its 1992 Energy Policy Act, Congress directed the Environmental Protection Agency (EPA) to develop standards for the proposed Yucca Mountain Repository. Congress also asked the U.S. National Academy of Sciences to advise the agency on the technical bases for such standards. In a report published last August, the Academy's Board on Radioactive Waste Management gave its advice to the EPA. This advice is supposed to assist the government in achieving what no one has ever accomplished: to secure nuclear waste in perpetuity, so that it presents no threat to the biosphere.

The Academy report, *Technical Bases for Yucca Mountain Standards* (NRC 1995), is a landmark document that significantly advances our understandings of both the science and the policy that are relevant to radioactive waste disposal. It has many positive features, notably its recommendation that compliance with the risk standard for radioactive waste be measured at the time of peak risk, whenever it occurs (NRC 1995:2, 55–56, 67); its conclusion that there is no scientific basis for limiting safety concerns to merely 10,000 years (NRC 1995: 56); and its important stance in favor of intergenerational equity.

The study also does an excellent job of emphasizing the fact that it is not possible to assess the frequency of intrusion into a permanent repository for a million years into the future (NRC 1995:2, 73). It explains that there is no system (based on active institutional controls) for postclosure oversight of the repository that is able to prevent an unreasonable risk of breaching the engineered barriers (NRC 1995:11).

The document is straightforward about many important uncertainties in its recommendations about radioactive waste disposal, site modeling, and performance assessment generally (NRC 1995:19–20). It also stresses that there is no sharp dividing line between science and policy (NRC 1995:viii); that there is a limited scientific basis for choosing one waste policy option over another (NRC 1995: viii); and that the committee ought not recommend what levels of risk are acceptable because this is a policy decision (NRC 1995:20, 49). Perhaps, most importantly, the Academy report wisely recommends choosing future Yucca Mountain exposure scenarios on the basis of rulemaking with full public participation (NRC 1995:99, 127). Such conclusions are both balanced and defensible.

Despite its strengths, the Academy report has at least three controversial aspects that

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should concern all scientists and policymakers: (1) It affirms the scientific feasibility and reliability of million-year performance assessments for a permanent geological repository; (2) It approaches standard-setting for nuclear waste disposal by overemphasizing the physical sciences and underemphasizing the biological and health sciences; (3) It rejects current standards that require keeping radiation exposures as low as reasonably achievable (ALARA), and thus appears to be less protective of public and environmental health than current national and international guidelines recommend.

MILLION-YEAR KNOWLEDGE OF REPOSITORY SAFETY

Biologists are well aware of the great difficulty of making long-term predictions about living systems. One of the most questionable aspects of the Academy report is its affirming the adequacy of million-year estimates of repository safety that will affect living systems. The Academy committee's confidence in precise, long-term geological estimation, adequate for performance assessment and compliance, seems at odds with the consensus conclusions of the fourteen U.S. Department of Energy (DOE) peer reviewers for the proposed Yucca Mountain site.

The massive 1992 document of the DOE peer reviewers on the Early Site Suitability Evaluation (ESSE) for Yucca Mountain neither is in the report's bibliography nor appears to have been part of the committee's deliberations. This document is significant both because it is the product of fourteen of the most distinguished geologists and earth scientists in the nation and because the consensus statement of the peer reviewers appears to challenge the feasibility of many long-term geological estimates at Yucca Mountain.

After discussing difficulties with the "subjective judgments" in the DOE Yucca Mountain ESSE (see Shrader-Frechette 1993:123–124, 152–153, 164–168, 175), the DOE reviewers (primarily geologists) unanimously concluded, in a "Consensus Position," that many aspects of site suitability were not well suited for quantitative risk assessment, including predictions involving future geological activity, future value of mineral deposits, and mineral occurrence models. They said that any projections of the rates of tectonic activity and volcanism, as well as natural resource occurrence and value, would be fraught with substantial uncertainties that could not be quantified using standard statistical methods (Younker et al. 1992:B2).

Despite the peer reviewers' misgivings about long-term risk assessments and future estimates of volcanic and seismic activities at Yucca Mountain, the Academy report affirms the adequacy of both million-year risk assessments and geological estimates of repository safety. It says that the probabilities and consequences of modifications generated by climate change, seismic activity, and volcanic eruptions at Yucca Mountain are sufficiently boundable so that these factors can be included in performance assessments that extend over periods on the order of about 10^6 years (NRC 1995:91). It concluded that established procedures of risk analysis would enable the combination of the results of all repository system simulations into a single estimated risk to be compared with the standard (NRC 1995:69). The report affirmed that geological processes were sufficiently boundable to be included in performance assessments that extended over time frames on the order of 10^6 years (NRC 1995:85). The document stated that, through careful examination of the geologic record, scientists could establish a chronological history of the activity over millions of years and use it to extrapolate over similar periods into the future (NRC 1995:93).

The apparent disagreement between the DOE peer reviewers and the Academy committee members about million-year geological estimates of repository safety raises a number of questions: (1) If the committee believes that future societal events cannot be predicted (NRC 1995:96), could societal events influence "geological engineering factors" and render repository geology not susceptible to realistic estimation as well? (2) Given problems with the verification and validation of computer models of future geological events (Oreskes et al. 1994), why are million-year performance assessments of geological events reliable? (3) Are claims about repository compliance and million-year geological estimates

matters of expert opinion or science? (4) If the committee believes that there are serious uncertainties about $^{14}CO_2$ exposures (NRC 1995:87–88); nonuniform radionuclide distributions (NRC 1995:88–89); fracture flow, especially in the unsaturated zone (NRC 1995: 88–90); and several glacial periods during the million years of the repository (NRC 1995:97), then how can it be confident about million-year geological estimates guaranteeing repository safety?

Although no single committee can do everything, nevertheless the inclusion and discussion of the DOE peer reviewers' document might have enabled the Academy committee to address some important questions of scientific controversy. It might have enabled the committee to avoid claiming too much for science and to recognize the limitations of precise, long-term scientific estimates.

UNDEREMPHASIZING THE BIOLOGICAL COMPONENTS OF NUCLEAR SAFETY

Because the U.S. Congress asked the Academy to advise the EPA on standards that would ensure the safety of the proposed Yucca Mountain Repository, another concern raised by the Academy report is its apparent overemphasis on engineering aspects of waste-related safety and its underemphasis on concerns of biology, earth science, and health science.

Of the fifteen committee members, most have degrees in physics or engineering. There appears to have been only one person on the committee with an advanced degree in geology or hydrogeology, one with an advanced degree in hydrology, one in public health, one physician, and no one in biology. More geologists—particularly specialists in long-term seismic and volcanic prediction and in long-term prediction of rock distress under natural circumstances—might have been useful on the committee. Especially in the light of the DOE peer report, volcanologists and seismologists might have given a more precise focus to the concerns of DOE reviewers about million-year geological estimates and use of long-term quantitative risk assessment.

Because the committee's charge was to conduct a study to provide findings and recommendations on reasonable standards for protection of the public health and safety (NRC 1995:142), it seems important to have had biologists, as well as more than one medical doctor and one public health expert, on a committee of fifteen members. While it is true that a committee may seek expert advice from outside, its day-to-day deliberations need to be accomplished by a group that adequately represents most relevant areas of the committee's charge. As well as a balance of expertise, committees need a balance of approach. Biologists and public health experts often approach health and safety issues differently than do physicists or engineers.

The concern about sufficient committee representation in biology, medicine, and public health is crucial because one member of the committee, Thomas Pigford, who is also a member of the National Academy of Engineering, criticized the committee's recommended exposure scenario as more permissive than current national and international practice and said that its adoption would undermine confidence in the adequacy of public health protection (NRC 1995:161). Whether Pigford is correct or not, more representation in the areas of biology, medicine, and public health might have alleviated such concerns. If life is at risk because of nuclear waste, more experts in the life sciences should be advising the EPA.

WEAKENING PUBLIC AND ENVIRONMENTAL HEALTH PROTECTION

A third concern about the Academy recommendations for nuclear waste disposal is that the report rejects several protective guidelines from the International Commission on Radiological Protection (ICRP), the most influential body recommending radiation standards today (NRC 1995:4). It rejects the ICRP dose-based standard (in favor of a risk-based radiation standard). The report also rejects the ICRP ALARA (as low as reasonably achievable) standard that requires optimizing radiation protection and limiting inequity in exposures (ICRP 1991:28, 71).

The Academy committee reasoned that, in situations in which the relevant probabilities and consequences can be known precisely, risk is a more desirable radiation standard than dose because risk standards would not need to be changed whenever knowledge of dose-

response relationships for radiation changed. As a result, for permanent nuclear repositories, the committee rejected the ICRP view, and recommended using a risk standard (rather than a dose standard) where risk is defined as the expected value of the probabilistic distribution of health effects.

Paradoxically, the committee's choice of risk rather than dose appears least practical in the very situation (million-year repository standards) in which the committee proposes it, because probabilities and consequences cannot be known precisely into the distant future. Long-term estimates of risk are much less reliable than short-term estimates. Actual doses often can be measured, whereas risks always must be calculated, usually on the basis of subjective judgments. The longer the time period of calculation, the more subjective are the judgments used. Also, as technology improves, inexpensive ways of avoiding needless risks are likely to force some risk standards to change, perhaps to become more protective. If both dose and risk standards seem likely to change, there is little benefit in moving to a risk standard, as the committee recommends. Ideally, the ICRP says, both a dose and a risk standard are required, even for potential exposures (ICRP 1991:31), not merely the risk standard proposed by the Academy committee.

Although risk-based standards are useful in including potential health effects of radionuclides (NRC 1995:30, 63), nevertheless members of the public can "count on" particular dose standards. They are less able to count on risk standards because they are subject to manipulation, potentially arbitrary risk models, and questionable assumptions about the future. The ICRP opposes using only a risk standard and warns that, in assessing risk, it is necessary to depend on an examination of the procedures for estimating the probability of the exposures. The probabilities (necessary for calculating risk) cannot be directly determined (ICRP 1991:32).

Citizens likewise cannot count on a risk standard that relies on experts (in the DOE or elsewhere) to accomplish objective risk calculations. Trust in such experts is in short supply today: The current climate surrounding waste disposal is one of lack of trust in the DOE (NRC 1994a:1; Dunlap et al. 1993). This lack of trust argues for both dose and risk standards.

The public can count on a dose standard, knowing that exposures are not allowed to exceed it (ICRP 1991:31). Regulators cannot adhere to a risk standard if they must make calculations to determine exactly what the standard requires. At least the dose standard is clear, an important advantage of health and environmental regulations. A recent committee of the U.S. National Research Council advised regulators to give the public clear-cut, noncontroversial statements of regulatory philosophy (NRC 1994a:284). For risks a million years in the future, the devil you know (measurable dose) seems better than the devil you don't know (calculable risk).

In failing to follow the ICRP standards that require radiation exposure to be as low as reasonably achievable (ICRP 1991:28, 71), the Academy committee also leaves itself open to question. Its grounds for rejecting ALARA are that such a technology-based standard is not useful in discussing nuclear waste disposal because technological alternatives for repository design are quite limited (NRC 1995:13, 125). Actually, repository planners have many technological options, such as whether to use double-walled or single-walled canisters, or to use copper or stainless steel ones. At least some of these technological options appear to pose choices that ALARA might require. Moreover, the ICRP adopted ALARA in large part to promote a culture of safety, to encourage people to optimize safety, to pursue maximum vigilance, and not merely to adhere blindly to dose/risk limits. Indeed, the protective ALARA principle constitutes one of the three main foundations of ICRP radiation-safety norms (ICRP 1990).

Although the Academy committee is correct to point out that demonstrating compliance with ALARA sometimes is difficult (NRC 1995:13), courts in the UK have successfully shown that British Nuclear Fuels violated ALARA in disposing of radioactive waste. Courts in France have successfully shown that industries have violated regulations by failing to keep exposures ALARA. Given this legal and regulatory background, the rejection of ALARA (and its goal of optimizing protection and equity), places the committee in the ques-

tionable position of recommending radiation standards that appear less protective than those of the ICRP. Besides, the ICRP explicitly warns against blindly following a dose or risk limit when the optimization of protection (ALARA) is the more appropriate course of action (ICRP 1991:31).

In a society where radioactive waste has been called the "Achilles heel" of the nuclear industry, and where nearly every community has rejected repositories for radioactive waste in their vicinity, the Academy recommendations may not do enough to allay public concerns. Citizens may ask how anyone can estimate what will happen to a repository a million years hence. Citizens may ask why more biologists and public health experts do not contribute to policymaking about nuclear waste, or why the Academy committee appears to have recommended less stringent radiation standards than those currently in force. Most Nevadans (eighty percent) say they do not want the long-lived, high-level nuclear waste, even though government compensation programs for the state amount to millions of dollars (Slovic et al. 1991:1604). Despite the many strengths of the Academy's advice about nuclear waste, several aspects of its report may reduce neither the worries of Nevadans nor those of all other Americans.

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