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Science versus educated guessing - risk assessment, nuclear waste, and public policy.

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The antiscience view prevalent among the public stems from scientists' presentation of their opinions as facts even when these are mere educated guesses. Two examples of subjectivity in the National Research Council study on standards for the proposed Yucca Mountain radioactive site are cited.

Many writers have bemoaned contemporary attacks on the objectivity and importance of science. Harvard physicist Gerald Holton (1994) tried to silence these detractors with a book about the dangers of "anti-science." John Maddox (1994), in a subsequent issue of Nature, criticized the public's benign tolerance of "mumbo jumbo" such as astrology and called for polemicists to take up the fight against the enemies of science.

Who are the enemies of science? Paul Gross and Norman Levitt (1994) blame feminists, leftists, and environmentalists. Alvin Weinberg (1988) of Oak Ridge National Laboratories says that antiscientific "environmental hypochondria" today has caused numerous "witch hunts" against science and industry, even though there is no proof that various "environmental insults" cause "real health problems." He says someone needs to bring the public to its senses. Risk assessors Chauncey Starr and Christopher Whipple (1989) say that the public is irrational and ignorant in fearing risks such as permanent disposal of radioactive waste. In recent congressional debate over quantitative risk assessment, politicians have criticized laypersons' views of environmental risk as antiscientific and irrational.

Rather than being antiscientific or irrational, members of the public may reject scientists' policy-related opinions if they are presented as facts when they are really just educated guesses. Even the reports of the respected National Academy of Sciences sometimes present scientists' subjective judgments about environmental risks as if they were confirmed science. Last August, the Board on Radioactive Waste Management of the National Research Council of the National Academy of Sciences (NRC 1995) released a landmark study on standards for the proposed Yucca Mountain permanent repository for high-level radioactive waste. Although the report significantly advanced the science and policy relevant to disposal, it made several questionable judgments - educated guesses about the likelihood of safe, million-year disposal of nuclear waste.

On the scientific side, the report affirmed that Yucca Mountain geological processes are sufficiently boundable to allow million-year performance assessment, but it wisely warned that estimating the frequency of repository intrusion is impossible. The report noted that, over the long term, no system can prevent breaching the engineered barriers of a waste system.

On the policy side, the NRC study made several groundbreaking recommendations. It urged that repository compliance with waste standards be measured, not merely up to 10,000 years, but at the time of peak risk, whenever it occurs. Arguing that risk acceptability is a policy judgment, the committee called for rule making, with full public participation, to decide levels of acceptable risk and repository exposure scenarios. The report also encouraged the United States to adopt a risk standard (based on calculated probability of harm) rather than to rely on the current dose limit for radiation exposure. The committee recommended moving from a dose to a risk standard on the practical grounds that the risk standard could remain the same, in perpetuity, even if scientists' knowledge of the dose-response relationship for radiation changed.

Although the NRC report deserves praise for affirming intergenerational equity, for recognizing the impossibility of predicting repository intrusion, and for emphasizing the value dimensions of disposal choices, two of its opinions are questionable. Its affirming the reliability of million-year repository performance assessment, and its recommendation to move from a dose to a risk standard for radiation protection, are both examples of controversial and subjective opinions posing as scientific conclusions.

Recommending a uniform annual risk limit - that is, a standard based on the expected value of the probabilistic distribution of health effects of radiation - could weaken current protection against radioactive pollution. I concur fully with the recommendation of the International Commission on Radiological Protection for standards based on both dose and risk because assessing risk is more difficult than assessing dose and because dose standards often can provide greater safety (ICRP 1991). Determining risk requires estimating the probability and distribution of exposures, neither of which can be directly determined, especially over a million-year period. The

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dose standard frequently is more direct and more protective because, at any point in time, it applies "controls on each individual's accumulation of dose" (ICRP 1991).

Because the dose standard is more direct and more protective, people can count on the combination of dose and risk standards in a way that they cannot count on risk standards alone. Risk standards alone are subject to potential manipulation, arbitrary models, and assumptions about the future. Also, how would repository operators adhere to a risk standard if they had to perform calculations to determine exactly what exposure levels the standard required? Besides, what is the practical benefit of an unchanging risk standard if it is difficult to define and if newer technologies enable us to reduce the risk standard in the future? Even if it needs to be revised periodically, at least the dose standard is clear and dependable. Measurable dose often may be more protective than calculable risk. The devil you know may be better than the devil you do not know.

The NRC committee's confidence in long-term geological estimation, as adequate for million-year performance assessment and nuclear repository compliance, is likewise questionable. This confidence seems at odds with the consensus conclusions of the 14 peer reviewers for the US Department of Energy (DOE) Yucca Mountain site-suitability report (Albrecht et al. 1992). After discussing difficulties with the "subjective judgments" in the DOE Yucca Mountain studies, these reviewers (primarily geologists) concluded, in a "Consensus Position" (signed by 9 of the 14 peer reviewers):

It is the opinion of the panel that 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. (Albrecht et al. 1992, p. B-2)

Despite the peer reviewers' warnings about the inapplicability of long-term quantitative risk assessments and the unreliability of precise estimates of volcanic and seismic activities at Yucca Mountain, the NRC report affirms both. It claims, for example:

We conclude 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.sup.6] years.... (NRC 1995, p. 91)

Established procedures of risk analysis should enable the combination of the results of all repository system simulations into a single estimated risk to be compared with the standard. (Human intrusion is excluded from such a combination.) (NRC 1995, p. 69)

Unlike our conclusion about the earth science and geological engineering factors..., we believe that it is not possible to predict on the basis of scientific analyses the societal factors that must be specified in a far-future exposure scenario. (NRC 1995, p. 96)

Contrary to the NRC report's conclusion, and consistent with the DOE peer reviewers' position, million-year "earth science and geological engineering" predictions - adequate for repository performance assessment - also may rely on educated guesses and opinions, just as million-year societal predictions do.

Even if the DOE peer reviewers are wrong in questioning the reliability of using quantitative risk assessment for million-year performance assessment of the repository, it would have been good for the NRC report to explain why its judgments differed from those of the DOE reviewers. Instead, the NRC report suggests that its opinions about performance assessment are scientific, and it affirms that million-year geological assessments of repository performance are reliable. Such assessments appear particularly problematic if human activities can affect repository performance over the next million years, and if the committee admits that human activities are not predictable over this time period.

Although no single committee can do everything, discussion of the DOE peer reviewers' document might have enabled the NRC report both to address some important questions about the limits of science and to distinguish science from educated guesses and subjective opinions. The DOE peer reviewers' volume neither is in the NRC document's bibliography nor appears to have been part of the committee's deliberations. This study is significant both because it is the product of 14 of the most distinguished geologists and earth scientists in the nation and because the peer reviewers' consensus statement appears to challenge several conclusions in the NRC report.

When scientists do not sort out contradictory opinions on science-related issues, and when they present their own educated (but controversial) guesses as science, they can jeopardize the credibility of science. The result can be the

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antiscience sentiment that is widespread today.

Saying that risk standards may not protect the public as much as both dose and risk standards - or questioning the possibility of repository performance assessment, 1 million years into the future - is neither antiscience nor irrational. Recognizing the limits of scientific prediction, and distinguishing between empirical science and educated guesses, is essential to maintaining the credibility of science.

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