POLICY FORUM: NUCLEAR WASTE

Yucca Mountain

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President George W. Bush has recommended Yucca Mountain in Nevada as the U.S. site for the disposal of 70,000 metric tons of high-level nuclear waste, mainly the used fuel from commercial nuclear power plants. This will be the world's first geologic repository for high-level nuclear waste.

The President's recommendation to Congress initiates an automatic series of events. Nevada has already submitted a Notice of Disapproval to Congress. On receipt of this notice, the Congress, within the first 90 days of continuous session, can overrule Nevada's disapproval by a simple majority. With congressional approval, the Department of Energy (DOE) has 90 days to submit a construction license to the Nuclear Regulatory Commission (NRC). The NRC then has up to 4 years to decide on the license application. With NRC approval, DOE can begin construction of the repository and apply for a license to receive waste. In the event that Congress does not overrule Nevada's Notice of Disapproval, there is no alternative site or strategy.

The Secretary of Energy, in his recommendation to the President, maintained that "sound science" supports the decision (*1*). However, during the past 8 months three government agencies have reviewed the suitability of a Yucca Mountain repository and have issued a series of revealing reports. In September of last year, the Advisory Committee on Nuclear Waste of the NRC issued a letter report (*2*) that, among other points, concluded that the total system performance assessment in support of the site recommendation (TSPA-SR) "relies on modeling assumptions that mask a realistic assessment of risk" and that "computations and analyses are assumption-based, not evidence-supported." Last December, the General Accounting Office (*3*) concluded that, "DOE will not be able to submit an acceptable application to NRC within the express statutory time frames for several years because it will take that long to resolve many technical issues." This past January, the Nuclear Waste Technical Review Board issued its report (*4*). The NWTRB expressed "limited confidence in current performance estimates" and found the technical bases for the repository performance estimates to be "weak to moderate."

The President's decision should be based on a compelling and transparent analysis of the safety of the site. This analysis requires a strong scientific basis. Although the Secretary of Energy has detailed the activities over the past 15 years [e.g., the collection of over 75,000 feet of core and 18,000 geologic and water samples (*1*)], such figures alone do not establish the scientific basis for the recommendation. The necessary science to support this decision requires an analysis that couples atomic-scale processes, such as spent fuel and waste package corrosion, to crustal-scale processes, such as volcanic activity and climate change, that extend over temporal scales of thousands, if not tens of thousands, of years.

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This is an unprecedented, first-time effort. Geologic disposal of high-level nuclear waste is not a short-term science and engineering effort like the Manhattan Project, for which near-term success was evident. The construction of a repository does not demonstrate its safety. The safety case can only be based on a scientific understanding of the processes that control the release of radionuclides and a design strategy that uses a series of independent barriers to reduce the uncertainty in the safety analysis. The current understanding of the performance of the engineered barriers (e.g., the waste form and waste package) and the geologic processes of the mountain (e.g., transport though the unsaturated and saturated zones) falls far short of that required to make a substantive evaluation of the safety of the repository. We can never know whether the repository "worked" as designed. Even with an operating period lasting for hundreds of years and the possibility of an engineered "fix" for problems, we cannot know whether the predicted behavior of the repository matches its actual performance. This would be an unreasonable expectation; however, the law requires that there be a "reasonable assurance" that the repository meets regulatory requirements.

How do we develop a reasonable assurance? For most technologies, operating experience is the basis for predicted reliability. Nuclear reactors are safer today than when originally designed and built. This is because we have the benefit of actual operating experience with over 400 nuclear reactors around the world. In the absence of relevant operating experience, we are left in an unusually demanding position in which we must rely on our understanding of natural processes that operate on geologic time scales in order to predict the future behavior of a nuclear waste repository. This task requires extensive knowledge and a strategy that minimizes the uncertainty in the safety analysis.

The DOE has based its positive recommendation to the President on a comprehensive performance assessment of the repository in its *Preliminary Site Suitability Evaluation,* with thousands of pages of supporting documents. The DOE's conclusion is that the Yucca Mountain repository will meet the Environmental Protection Agency's (EPA's) final radiation protection standard in the Code of Federal Regulations, 40 CFR 197, and the NRC's repository licensing criteria, 10 CFR 63.

Both the EPA standard and the NRC regulations have taken nearly 20 years to develop and have only recently been available for public comment. The site-specific standard and the implementing regulation are based on the calculation of a dose to individuals at a distance of approximately 20 km from the repository over a 10,000-year period. The determination of compliance depends almost exclusively on the results of the total system performance assessment. At the same time, the disposal strategy has moved away from the use of geologic barriers and now relies heavily on the role of engineered barriers, mainly a highly durable, metal waste package protected from water

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by umbrella-like "drip" shields. By lessening the importance of the geologic barriers, the properties of the site become less important. Indeed, the original concept of geologic disposal has been turned on its ear.

In the face of the scientific uncertainties about the site, there is a surprising sense of urgency to move forward with a positive decision on Yucca Mountain as a nuclear waste repository. In the coming months, utilities that own nuclear power plants and states that have spent nuclear fuel stored at the reactors will press hard for action to approve the Yucca Mountain site, their concern heightened by fears of terrorist attacks on the storage facilities. Some have argued that the future of nuclear power is at risk in the absence of a positive decision. The Secretary of Energy has said that a permanent geologic repository "will promote our energy security by removing a roadblock to expanding nuclear power" (*5*). Thus, the present sense of urgency is driven not by an understanding of the properties of the Yucca Mountain site, but rather by larger-scale policy decisions concerning nuclear power and national security.

Decades of effort costing billions of dollars, and, in fact, our entire site-specific regulatory framework are now at risk if we do not accept Yucca Mountain as a repository. As a public, we are presented with a major policy decision for which there is no alternative strategy or site. In fact, the Nuclear Waste Policy Act Amendments of 1987 eliminated alternative sites. The present decision to make Yucca Mountain a repository for high-level nuclear waste is a political decision that was presaged by the 1987 NWPAA. The scientific basis for the selection of the Yucca Mountain site continues to be only a marginal consideration.

What of the science? Are there essential scientific and technical issues that can potentially affect the performance of the repository? Does the method of analysis provide a substantive basis for evaluating the safety of the repository? Are there deficiencies in the disposal and containment strategy, either as proposed by DOE or as allowed by the standards and regulations?

In our view, the disposal of high-level nuclear waste at Yucca Mountain is based on an unsound engineering strategy and poor use of present understanding of the properties of spent nuclear fuel.

The repository has been placed at a depth of 300 meters below the surface in the unsaturated zone, some 300 meters above the water table. The United States is the only country in the world that has pursued the concept of placing a repository in the unsaturated zone. The original rationale for selecting the unsaturated zone at Yucca Mountain was based on having a "dry" repository, as water would be the main agent for release and transport of radionuclides. A dry repository has been elusive, as the percolation flux of water through the repository has been difficult to estimate (*6*). Initial predictions of 4 mm/year were reduced to less than 0.5 mm/year during the early years of the project, and the low value seemed to validate the original concept. However, in 1996, scientists at Los Alamos National Laboratory discovered elevated levels of ^{36}Cl at the repository horizon (*7*). If this ^{36}Cl is the result of atmospheric testing of nuclear weapons, which ended in 1963, the "bomb pulse" ^{36}Cl provides evidence for rapid transport of some water through the unsaturated zone. Although this issue, the role of fast path transport in the unsaturated zone, remains unresolved, these results have changed the basic picture of how the repository works. As described by Daniel Metlay, a staff member for the Nuclear Waste Technical Review Board, instead of being a "tin roof," Yucca Mountain is "more akin to a torn wet blanket" (*5*). The efforts to keep the repository dry have resulted in a variety of engineered "fixes." For example, the "hot" repository design would drive water away from the repository horizon. Only after cooling would water seep back through the formations. Another fix has been the drip shield that would protect the waste packages from water that finds its way to the repository horizon. Regardless of the results of future scientific studies or the efficacy of the engineering fixes, the uncertainty in the estimated percolation flux will ultimately be tied to climate change. It is a poor design strategy that relies on assumed boundary conditions, rather than the properties of the repository itself.

The Yucca Mountain repository is essentially a repository for the disposal of used nuclear fuel that consists mainly of reduced uranium in the form of UO_2. More than 95% of the total radioactivity will originate from this spent nuclear fuel. After the engineered barriers have failed, the release of radionuclides will depend on the chemical durability of the fuel. In the presence of even minor amounts of moisture and under oxidizing conditions, UO_2 is not stable. The process of degradation, initiated by oxidation of U^{4+} to U^{6+}, is rapid and pervasive (*8*). Orders of magnitude of durability for the spent fuel would be gained by maintaining reducing conditions at the repository horizon (*9*). This is well established by many experimental studies using UO_2 or actual spent nuclear fuel and is confirmed by numerous studies of uranium deposits (*10*). At Yucca Mountain, the passive properties of the repository site do not provide a long-term barrier to radionuclide release.

The concept of placing spent nuclear fuel in the unsaturated zone where it will experience oxidizing conditions is simply a poor strategy. This is a strategy that finally relies on an optimistic assessment of the long-term durability of metallic waste packages, such as the presently proposed Ni-Cr-Mo alloy, C-22, an alloy for which there are only limited data. The Secretary of Energy has pointed to studies of "over 13,000 engineered material samples to determine their corrosion resistance in a variety of environments" (*1*), but there are few data on the C-22 alloy, and the uncertainty in its extrapolated behavior is high (*11*).

In addition to these fundamental issues of strategy, there are other unresolved technical issues (*4*): the continuing controversy over the frequency and impact of volcanic activity (*12*), the role of sorption in the unsaturated zone in reducing radionuclide mobility (*13*), and the role of colloids in enhancing transport (*14*).

With further study, Yucca Mountain may be judged to be an adequate site for the disposal of nuclear waste, but a project of this importance, which has gone on for 20 years, should not go forward until the relevant scientific issues have been thoughtfully addressed. Some have suggested a "staged" approach that would allow an opportunity for such studies, but of course, "staged" can have two meanings. To move ahead without first addressing the outstanding scientific issues will only continue to marginalize the role of science and detract from the credibility of the DOE effort. As Thomas Jefferson cautioned George Washington,

"Delay is preferable to error."

References and Notes

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